AMERICAN TELEPHONE PRACTICE

BY

KEMPSTER B. MILLER

FOURTH EDITION, ENLARGED AND ENTIRELY REWRITTEN

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TO THE MEMORY OF MY FATHER, JOSEPH KEMPSTER MILLER, THIS BOOK IS DEDICATED. IT WAS THROUGH HIS INFLUENCE THAT THE WORK WAS BEGUN.

KEMPSTER B. MILLER.

PREFACE TO FIRST EDITION.

THE intended scope of this book is set forth in its title. To those interested the writer has endeavored to present in as clear a manner as possible the general principles of telephony, the design and construction of commercial apparatus, the circuits connecting such apparatus into operative systems, and the methods used in the construction, operation and maintenance of these systems. No attempt whatever has been made to treat the subject from its purely mathematical standpoint, that being beyond the scope of this work. The apparatus and methods of both Bell and independent companies have been given impartial attention.

The writer sincerely thanks his friends, Mr. Wm. H. Donner and Mr. Wm. R. Mackrille, for their many suggestions and untiring labors in proof-reading, and also Mr. W. D. Weaver, editor of the *Electrical World and Engineer,* for his interest and assistance throughout the entire preparation of this book.

KEMPSTER B. MILLER.

PREFACE TO THIRD EDITION.

THAT a third edition of this work should have been called for within three months after the appearance of the first is indeed gratifying. The time since the second edition was exhausted has been utilized in making many changes in the matter already presented, and in the preparation of much new matter, all of which it is thought will make the work more valuable as a guide and general reference-book in practical telephony.

The chapter on Automatic Exchanges has been written because the book seemed incomplete without it. If it is hereafter criticised for containing no descriptions of practical apparatus, my plea will be that it is mainly the fault of the subject.

That very important factor in modern telephony, the storage battery, was certainly very inadequately handled in the first edition. Chapter XXXV. is intended to remedy this.

The last chapter on Specifications is given as a help rather than as an inflexible guide to those drawing specifications. The specifications given represent modern practice, but they are not meant to serve in the place of common sense or of engineering ability.

I desire to thank Mr. Thomas D. Lockwood for his kindly criticisms on the first editions; Mr. Franz J. Dommerque, who has read the proofs of the chapters on Storage Batteries and Specifications, and made many good suggestions; and Mr. E. R. Corwin, to whom I am indebted for information concerning lead-burning.

KEMPSTER B. MILLER.

PREFACE TO FOURTH EDITION.

THE revision for this edition has resulted in an almost complete rewriting, upon which far more labor has been expended than in the original writing of the early editions. During the past year and a half in which the work has been done, the magnitude of the intended task has steadily grown, owing to the development of the telephone field, and to the wider view of this field made possible by my own changed environment.

The work is now believed to cover telephone practice of to-day much more comprehensively and accurately than was true of any of the earlier editions with respect to the practiced art at the times of their publication. Obsolete methods and equipment are not dealt with, except where of distinct educational or historic value; and much of the historic matter of former editions has been cut out in order to make room for modern methods and things.

The classification according to chapters has been materially altered, many of the old chapters having been combined with others or subdivided, in order to afford a more logical arrangement. The chapter on The Telephone Exchange in General has been added as an introduction to the subsequent chapters, which deal with the various parts of the exchange, particularly with the switch-board systems, appliances and auxiliaries.

When former editions were written, the common battery or central energy systems were comparatively new and little information concerning them was available. The resulting lack of full information on this subject, for which the early editions might have been criticised with justice, is now thought to have been removed.

Chapters XVI. to XXXV., inclusive, are almost entirely new, although they contain some matter that was barely touched upon in previous editions. Such subjects as trunking between common battery offices, private branch exchange service, measured service, toll switch-board systems and power plants are now here treated for the first time.

There has been rapid recent development in automatic switchboards and the complete description of the modern Strowger system, contained in Chapter XXXV., is indicative of the increasing importance of this branch.

This work is intended not only as a guide to the student of practical telephony whose experience has not been sufficient to make him conversant with all branches of the subject, but also as an aid to the more experienced telephone engineer and operator, who may find it of value as a general reference work.

To my partner, Mr. Samuel G. McMeen, and to my former associate, Mr. Charles S. Winston, now Chief Engineer of the Kellogg Switchboard and Supply Company, are due my first acknowledgements for valuable assistance. I have drawn freely on their funds of knowledge, judgment and good nature, and on their much more limited funds of time.

I feel some pride in the illustrations, most of which are quite new. This is true particularly of the diagrams of complicated circuits, which are thought to be more complete than any thing heretofore attempted in this line. Much of the credit for the appearance and arrangement of these is due to the skill of Mr. Howard M. Post, who drew most of them. To Mr. R. H. Burfiend credit is given for the appearance of many of the apparatus drawings and some of the circuit work.

The various telephone manufacturing companies have co-operated by loaning photographs and half-tones illustrative of modern apparatus and work. Especially is this true of the Stromberg-Carlson Telephone Manufacturing Company, the Kellogg Switchboard and Supply Company, the Holtzer Cabot Electric Company, and the Automatic Electric Company.

In the preparation of the manuscript for a work of this nature the amanuensis may be a boon or a "calamity." I tender sincere thanks to Miss B. R. Werden and Miss Eva A. Garlock for their unusually painstaking and intelligent work in preparing all the manuscript from my dictation and notes, and in the proof-reading.

I feel that the public will, as the writer does, thank the makers of this book, the McGraw Publishing Company, for the manner in which they have done their work. Their patience is also to be commended.

The kindly reception of the earlier editions is keenly appreciated, and it is my hope that the work is now more nearly worthy.

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AMERICAN TELEPHONE PRACTICE.

CHAPTER I.

HISTORY AND PRINCIPLES OF THE MAGNETO TELEPHONE.

THE history of the telephone, from its inception to its present state of perfection, is interesting in the extreme, and affords a striking example of the fact that great inventions are almost invariably the result of long and careful study on the part of many workers, rather than the sudden inspiration of a single genius. It is of even greater interest from a scientific standpoint, for in no way can one obtain a better idea of the fundamental principles involved in telephony than by following their development, step by step, noting the contributions made by each of the many scientists and inventors whose names are closely connected with electrical progress.

These steps were made in logical order, the knowledge contributed by each investigator making possible a deeper insight into the subject on the part of his successors. It is best, therefore, to follow this order in obtaining primary ideas of the subject.

The history of the knowledge of electromagnetism begins with July 20, 1820, and with this date very properly begins the history of the electric telephone. On that day Oersted, a professor in the University of Copenhagen, discovered that a magnetic needle tends to place itself at right angles to a wire carrying a current of electricity. Ampere immediately took up the subject, and in a very short time disclosed the laws upon which present electromagnetic theory is based.

In the following year Arago and Davy discovered that if a current be caused to flow through an insulated wire wrapped about a rod of steel the latter would exhibit magnetic properties. It was William Sturgeon, however, who in 1825 made an electromagnet as we know it to-day, and called it by that name. To these three men, therefore, belongs the credit of one of the greatest discoveries in the history of science. Joseph Henry also made his classic experiments on the electromagnet, and to him must be accredited a large amount of our knowledge regarding it. Henry showed how to build a magnet capable of being operated over a great length of wire, a most important step.

In 1831 Faraday and Henry, independently, discovered the converse of these laws of electromagnetism—that if the intensity of a magnetic field inclosed by a conductor be in anywise changed, a current of electricity will flow in the conductor. This current will flow only while such change is taking place, and its strength will depend directly on the rate of the change.

These two laws concerning the transformation of electric energy into magnetic, and its converse, the transformation of magnetic energy into electric, are certainly the most important in the whole realm of electrical science; as singly or together they form the foundations not only of the telephone and telegraph, but of electric

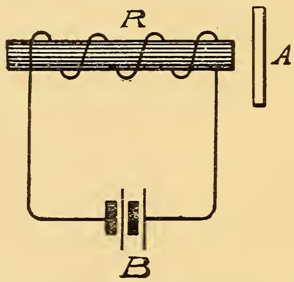


FIG. 1.—STURGEON ELECTROMAGNET.

lighting, electric power transmission, and of every other achievement by which electricity has revolutionized the methods of life throughout the whole civilized world.

As these laws form the very root of all telephone practice, a few illustrations directly in line with the principles of the telephone will not be amiss, even though they are very generally understood; for they will give a clearer understanding of the developments made by subsequent inventors.

If, as shown in Fig. 1, a coil of wire be wrapped around a rod, *R*, of iron or steel, and a battery, *B*, placed in circuit with the coil, the rod becomes a magnet upon the closure of this circuit, and will attract an iron armature, *A*, in the vicinity of either of its poles. Any variation in the strength of this current will cause corresponding variations in the attractive power of the magnet. If the rod be of steel, and permanently magnetized, it will exert an attractive force of its own on the armature, and the current will, according to its direction, increase or diminish this attractive force

About every magnet there exists a field of force; that is, a region in which any body capable of being magnetized (such as

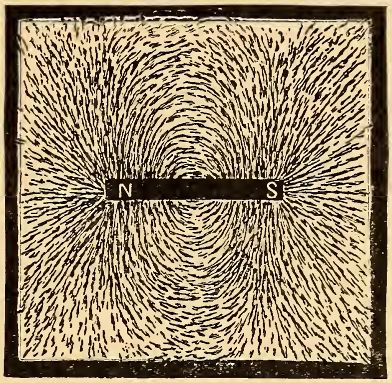


FIG. 2.—LINES OF FORCE OF BAR-MAGNET.

iron) has exerted on it, by the magnet, an influence of attraction or repulsion. This field of force is usually graphically represented by closed curves, radiating from the poles of the magnet, and the strength of the magnet is commonly measured in terms of

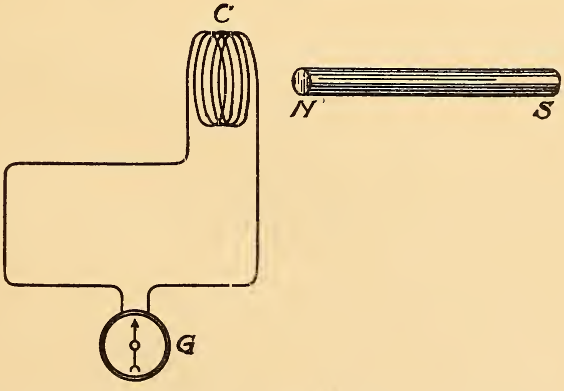


FIG. 3.—FARADAY AND HENRY MAGNETO ELECTRICITY.

the number of such lines radiating from one of its poles. A magnet may be made to map out its own field of force by placing it in a horizontal position and directly over it a sheet of paper or cardboard. If iron filings are then dropped from a height of a few feet, on the paper, they will arrange themselves in the direction of the lines of force. Fig. 2 shows such a map produced by the bar-magnet, *N S*.

If now a galvanometer, *G*, or other current-indicator (Fig. 3) be placed in circuit with a coil, *C*, and a magnet *N S*, moved in the vicinity of the coil, or the coil in the vicinity of the magnet, in such manner as to change the number of the lines of force passing through the coil, a current is generated in the coil and is indicated by the galvanometer. This current will flow only while such movement is taking place. Its direction will depend on the direction of the lines of force threading the coil and on whether their number is being increased or diminished. Its strength will depend on the rate at which their number is changing.

If a mass of iron be brought within the field of a magnet, the field becomes distorted by virtue of a larger number of lines finding their path through the space occupied by the iron than through the same space when filled with air. Therefore, if a closed coil be placed

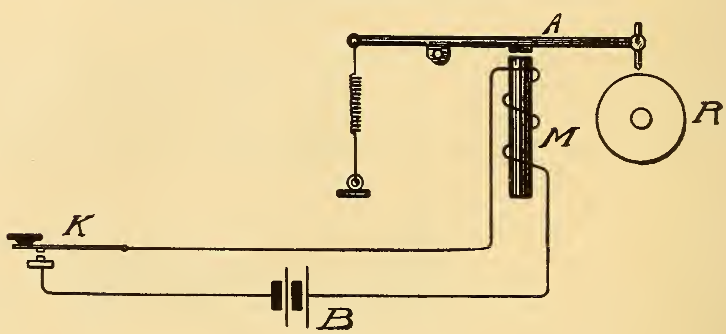


FIG. 4.—MORSE ELECTROMAGNETIC TELEGRAPH.

about a pole of the magnet and the body of iron be moved to and from the pole, the intensity of the field in which the coil lies will vary, and currents of electricity will flow in the coil.

In 1837 Professor Page of Salem, Mass., discovered that a rod of iron, suddenly magnetized or demagnetized, would emit certain sounds due to a molecular rearrangement caused by the changing magnetic conditions. This phenomenon is known as "Page's effect."

Late in the thirties Professor S. F. B. Morse placed at one end of a line Sturgeon's electromagnet, *M* (Fig. 4), with a pivoted armature, *A*, and at the other end a battery, *B*, and a key, *K*, for making and breaking the circuit. By manually closing and opening the key, the core of the magnet became magnetized and demagnetized, thus alternately attracting and releasing the armature. By this means signals were sent and recorded on a strip of paper, carried on a roller, *R*, in front of the armature, and thus intelligence was practically conveyed by electrical means between distant points.

In 1854 a Frenchman, Charles Bourseul, predicted* the transmission of speech, and outlined a method correct save in one particular, but for which error one following his directions could have produced a speaking telephone. His words at this date seem almost prophetic:

"I have asked myself, for example, if the spoken word itself could not be transmitted by electricity; in a word, if what was spoken in Vienna may not be heard in Paris? The thing is practicable in this way:

"Suppose that a man speaks near a movable disc, sufficiently flex-

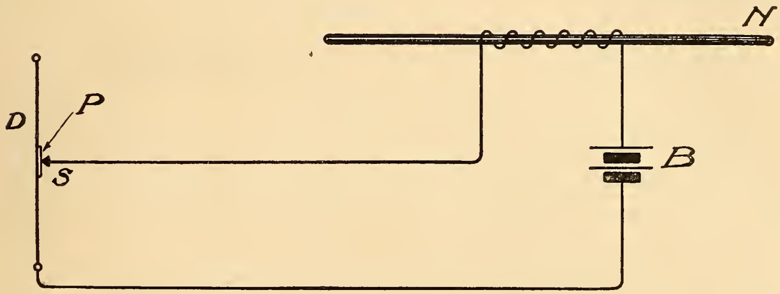


FIG. 5.—REIS' MAKE-AND-BREAK TELEPHONE.

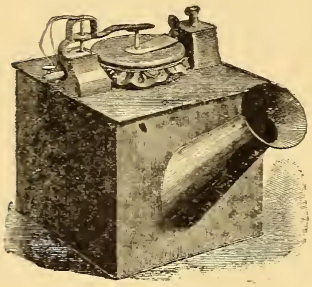
ible to lose none of the vibrations of the voice; that this disc alternately *makes and breaks the* connection from a battery: you may have at a distance another disc which will simultaneously execute the same vibrations."

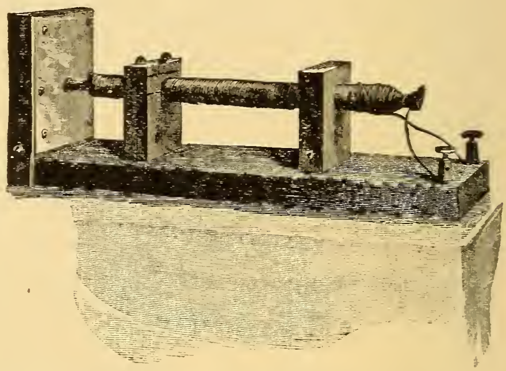
The words "makes and breaks" in Bourseul's quotation have been italicized by the present writer. They form the keynote of the failures of those who subsequently followed Bourseul's directions literally.

Philip Reis, a German inventor, constructed what he called a telephone in 1861, following implicitly the path outlined by Bourseul. He mounted a flexible diaphragm, *D* (Fig. 5), over an opening in a wooden box, and on the center of the diaphragm fastened a small

* Vol. XXIV., "L'Illustration," Paris, Aug. 26, 1854.

piece of platinum, P. Near this he mounted a heavy brass spring, s, with which the platinum alternately *made and broke* contact when the diaphragm was caused to vibrate. These contact points formed the terminals of a circuit containing a battery, B, and the receiving instrument. His receiver assumed various forms, prominent among which was a knitting needle, N, wrapped with silk-insulated copper





FIGS. 6 AND 7.—REIS' TELEPHONE TRANSMITTER AND RECEIVER.

wire and mounted on a cigar box for a sounding board. Its operation was as follows: The sound waves set up in the air struck against the diaphragm of the transmitter, causing it to vibrate in unison with them. This caused the alternate making and breaking of the circuit at the point of contact between the platinum and the spring, and allowed intermittent currents to flow through the receiver. These

FIG. 8.—SOUND WAVES OF VOICE AND SIMPLE MUSICAL NOTE.

caused a series of sounds in the knitting needle by virtue of "Page's effect." The sounding board vibrated in unison with the molecular vibrations of the needle, and the sound was thus greatly amplified. Reis' transmitter and one form of his receiver are shown in Figs. 6 and 7, respectively.

Reis' telephone could be depended upon to transmit only musical sounds. The question as to whether it actually did transmit speech has been the subject of much discussion, but if it did this at all it was very imperfectly. The cause of its failure to successfully transmit speech will be understood from the following facts:

A simple musical tone is caused by vibrations of very simple forms, while sound waves produced by the voice in speaking, are very complex in their nature. These two forms of waves may be graphically represented as in Fig. 8.

Sound possesses three qualities: pitch, depending entirely on the *frequency* of the vibrations; loudness, depending on the *amplitude* of the vibrations, and timbre or quality, depending on the *form* of the vibration. The tones of a flute and a violin may be the same as to pitch and loudness and yet be radically different. This difference is in timbre or quality.

Reis' transmitter, as he adjusted it, was able only to make and break the circuit, and a movement of the diaphragm barely sufficient

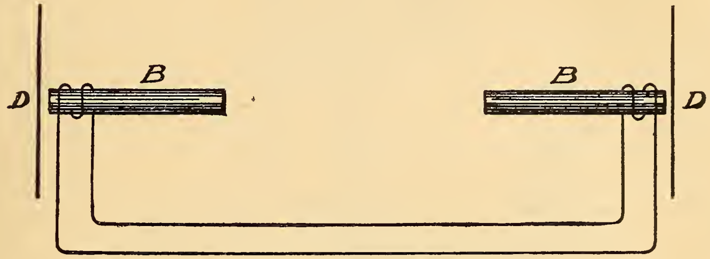


FIG. 9.—BELL MAGNETO TELEPHONE.

to break the circuit produced the same effect as a much greater movement. The current therefore flowed with full strength until the circuit was broken, when it stopped entirely. The intermediate strengths needed for reproducing the delicate modulations of the voice were entirely lacking. This apparatus could therefore exactly reproduce the pitch of a sound, but not its timbre and relative loudness.

For the next fifteen years no apparent advance was made in the art of telephony, although several inventors gave it their attention.

In 1876 Professor Alexander Graham Bell and Professor Elisha Gray almost simultaneously invented successful speaking telephones. Gray has been one of the principal claimants for the honor of being the first inventor of the telephone, but Bell has apparently established his right to it, and has also reaped the profit, for, after long litigation, the United States Patent Office and the courts have awarded the priority to him as against Gray and many others.

Bell possessed a greater knowledge of acoustics than of electrical science, and it was probably this that led him to appreciate wherein others had failed. His instrument consisted of a permanent bar-magnet, *B* (Fig. 9), having on one end a coil of fine wire. In front of the pole carrying the coil a thin diaphragm, *D,* of soft iron was so

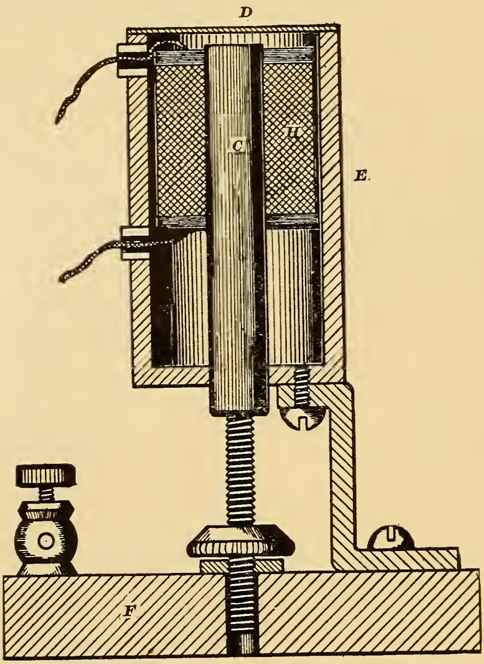


FIG. 10.—BELL'S CENTENNIAL RECEIVER.

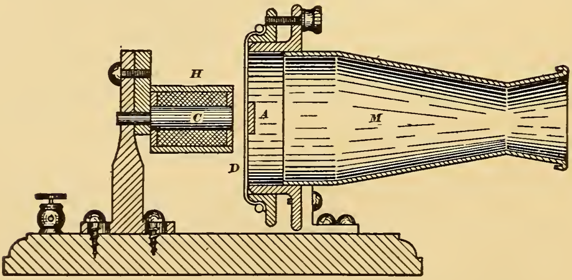


FIG. 11.—BELL'S CENTENNIAL TRANSMITTER.

mounted as to allow its free vibration close to the pole. Two of the instruments are shown connected in a circuit in Fig. 9.

Two points will be noticed which have heretofore been absent: that no battery is used in the circuit, and that the transmitting and receiving instruments are exactly alike. When the soft-iron diaphragm of the transmitting instrument is spoken to, it vibrates in exact accordance with the sound waves striking against it. The movement of the diaphragm causes changes in the magnetic field in which lies the coil, which changes, as already pointed out, cause currents to flow in the circuit. These currents flow first in one direction, and then in the other, varying in unison with the movements of the diaphragm, the waves being very complex, and represented graphically, similar to those of the voice shown in Fig. 8. Passing along the line wire, these electrical impulses, so feeble that only the most delicate instruments can detect them, alternately increase and decrease the strength of the permanent magnet of the receiving instrument, and thereby cause it to exert a varying pull on its soft-iron diaphragm, which, as a result, takes up the vibrations and reproduces the sound faithfully. Bell's earlier instruments, exhibited in 1876 at the Centennial in Philadelphia, are shown in Figs. 10 and 11, the former being his receiver, the latter his transmitter. The receiver consisted of a tubular magnet, composed of a coil of wire, *H*, surrounding a core, *C*, and inclosed in an iron tube, *E*, which was about 1¾ inches in diameter and 3 inches long. This tube was closed by a thin iron armature or diaphragm, *D*, which rested loosely on the upper face of the iron tube, the length of the core being such as not quite to touch the diaphragm when in this position. The whole was mounted on a base, *F*, as shown, arrangements being made to adjust the air gap between the pole of the core and the diaphragm by means of a thumb-screw.

The transmitter, Fig. 11, consisted of an electromagnet, *H*, in front of the core, *C*, of which was adjustably mounted a diaphragm of goldbeater's skin, *D*, carrying a small iron armature, *A*, at its center. A long mouthpiece, *M*, into which the sounds to be transmitted were spoken, served to convey the sound waves more directly to the diaphragm.

Nearly all books and articles on telephones, that treat of Bell's early receiver at all, show and describe it as having the diaphragm fastened at one edge by a single small screw to the upper face of the iron tube, and sprung away from the tube at its opposite side. This mistake occurred in the first two editions of this work, and would have been in this one but for Mr. Thomas D. Lockwood, who was kind enough to call attention to it. The origin of the error is explained in the following interesting extract from a letter written by Mr. Lockwood to the writer of this book:

"This mistake first appeared in the account given by *Engineering* of Sir William Thomson's address to the British Association in September, 1876, and has been universally copied. * * * The origin of the mistake is very odd. The screw of the instrument given to Sir William Thomson, and which he exhibited in England on his return, was put through a hole in the edge of the diaphragm, and engaged with a threaded hole in the edge of the tube, for the purpose of attaching the diaphragm while in transit, to prevent it from getting lost. No one, however, notified Sir William of this, it probably having been forgotten; and Sir William seems to have forgotten what the instrument, as he saw it in Philadelphia, looked like. Finally, in kocking about among Sir William's luggage, the free end of the diaphragm was apparently, and without doubt unintentionally, bent upward, as the picture shows. But when so bent, being at the same time rigidly fastened at the opposite edge, it would not and could not work: and when Sir William showed it in England he couldn't make it work."

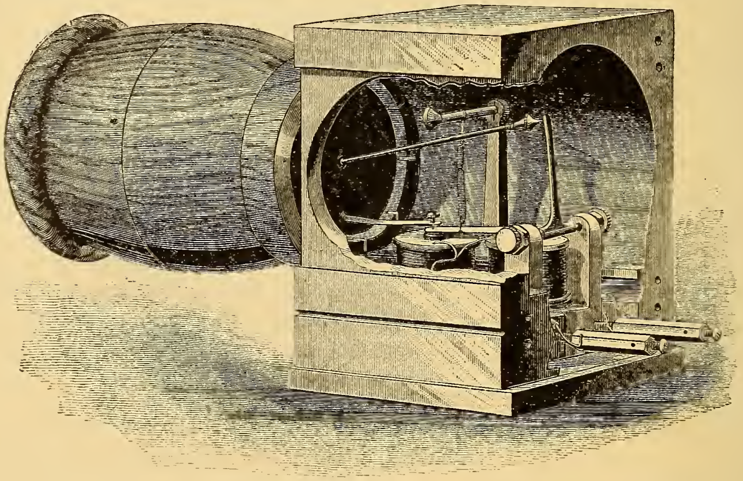


FIG. 12.—ROYAL E. HOUSE'S ELECTRO-PHONETIC TELEGRAPH.

Bell's instrument, in a modified form, is the standard of to-day. It is now used as a receiver only, a more efficient transmitter, depending upon entirely different principles, having been invented.

In speaking of Bell's invention, Sir William Thomson, now Lord Kelvin, has said: "Who can but admire the hardihood of invention which devised such very slight means to realize the mathematical conception that if electricity is to convey all the delicacies of quality which distinguish articulate speech, the strength of its current must vary continuously as nearly as may be in simple proportion to the velocity of a particle of air engaged in constituting the sound?"

Much has been said, and books have been written on the rights of Reis as the inventor of the speaking telephone. The validity of Bell's controlling patent[1] was the subject of many attacks, the litigation finally reaching the Supreme Court of the United States. In the opinion of this court (October Term 1887)[2] the following brief but comprehensive statement is found:

"We have not had our attention called to a single item of evidence which tends in any way to show that Reis or any one who wrote about him had it in his mind that anything else than the intermittent current caused by the opening and closing of the circuit could be used to do what was wanted. No one seems to have thought that there could be another way. All recognized the fact that the 'minor differences in the original vibrations' had not been satisfactorily reproduced, but they attributed it to the imperfect mechanism of the apparatus used, rather than to any fault in the principle on which the operation was to depend.

"It was left for Bell to discover that the failure was due not to workmanship, but to the principle which was adopted as the basis of what had to be done. He found that what he called the intermittent current—one caused by alternately opening and closing the circuit—could not be made under any circumstances to reproduce the delicate forms of the air vibrations caused by the human voice in articulate speech, but that the true way was to operate on an unbroken current by increasing and diminishing its intensity. * * * Such was his discovery, and it was new. Reis never thought of it, and he failed to transmit speech telegraphically. Bell did and he succeeded. Under such circumstances it is impossible to hold that what Reis did was an anticipation of the discovery of Bell. To follow Reis is to fail, but to follow Bell is to succeed. The difference between the two is just the difference between failure and success."

A very interesting fact, and one which might have changed the entire commercial status of the telephone industry is that in 1868 Royal E. House, of Binghamton, N. Y., invented and patented an "electro-phonetic telegraph," which was capable of operating as a magneto telephone, in the same manner as the instruments subse-

[1] United States Patent No. 174,465, dated March 7, 1876; application filed February 14, 1876.

[2] Supreme Court Decisions, United States reports, Volume 126.

quently devised by Bell. House knew nothing of its capabilities, however, unfortunately for him. The instrument is shown in Fig. 12, and is provided with a sounding diaphragm of pine wood stiffened with varnish, mounted in one end of a large sound amplifying chamber, so formed as to focus the sound waves at a point near its mouth, where the ear was to be placed to receive them. The electro-magnet adapted to be connected in the line circuit had its armature connected by a rod with the center of the wooden diaphragm as shown. By this means any movements imparted to the armature by fluctuating currents in the line were transmitted to the diaphragm, causing it to give out corresponding sounds; and any movements imparted to the diaphragm by sound waves were transmitted to the armature, causing its movements to induce corresponding currents in the line. Two of these instruments connected in a circuit, as shown in Fig. 9, would act alternately as transmitters and receivers in the same manner as Bell's instruments.

CHAPTER II.

HISTORY AND PRINCIPLES OF THE VARIABLE RESISTANCE TRANSMITTER.

It has been shown that in order to transmit speech by electricity it is necessary to cause an undulatory or alternating current to flow in the circuit over which the transmission is to be effected, and that the strength of this current must at all times be in exact accordance with the vibratory movements of the body producing the sound.

Bell's magneto transmitter was used as the generator of this current; as a dynamo, in fact, the energy for driving which was derived from the sound waves set up by the voice. The amount of energy so derived was, however, necessarily very small and the current correspondingly weak, and for this reason this was not a practical form of transmitter, except for comparatively short lines.

Elisha Gray devised a transmitter which, instead of generating the undulatory current itself, depended for its action on causing variation in the strength of a current generated by some separate source; this variation in current strength always being in accordance with the movements of the diaphragm.

He mounted on his horizontal vibrating diaphragm a metal needle, extending into a fluid of low conductivity, such as water. The needle formed one terminal of the circuit, the other terminal being a metal pin, extending up through the bottom of the containing vessel. The vibration of the diaphragm was supposed to cause changes in the resistance of the path through the fluid on account of the varying distance between the points of the electrodes and therefore corresponding changes in the strength of the current.

Bell also used a liquid transmitter (Fig. 13) in which a conducting liquid was held in a conducting vessel, *C*, forming one terminal of the circuit. The other terminal was a short metallic needle, *R*, carried on the diaphragm, *D*, and projecting slightly into the liquid, so that the area of contact between the liquid and the needle would be varied to better advantage by the vibration of the diaphragm than if the needle were immersed a greater distance into the fluid.

Bell's liquid transmitter depended on variation in the extent of immersion of the electrode, while Gray's instrument, owing to the great extent to which the pin was immersed, depended rather on the variation in the length of the conducting path through the liquid itself, a faulty principle for this purpose.

Bell's liquid transmitter was also exhibited at the Philadelphia

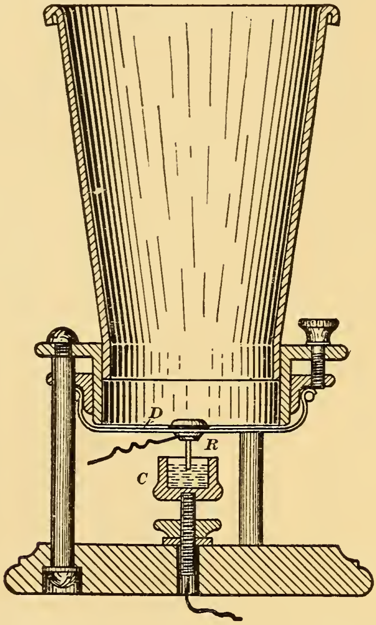


FIG. 13.—BELL'S CENTENNIAL LIQUID TRANSMITTER.

Centennial in 1876, and, unlike that of Reis, simply caused variations in the resistance of the circuit, and thereby allowed a continuous but undulatory current to pass over the line, the variations in which were able to reproduce all the delicate shades of timbre, loudness, and pitch necessary in articulate speech.

Gray and Bell embodied, or attempted to embody, in these instruments the main principle upon which all successful battery transmitters are based. A battery furnished the current, and the transmitter, actuated by the voice, served to modulate it. It was not long, however, before a much better means was devised for putting this principle into practice.

In 1877 Emile Berliner, of Washington, D. C., filed a caveat, and later in the same year applied for a patent on a transmitter, depending upon a principle pointed out in articles published in 1856, 1864 and 1874 by the French scientist, Du Moncel, that if the pressure between two conducting bodies forming part of an electric circuit be increased, the resistance of the path between them will be diminished, and conversely, if the pressure between them be decreased, a corresponding increase of resistance will result.

Berliner's transmitter is shown in principle in Fig. 14, which is a reproduction of the principal figure in his now famous patent. In this *A* is the vibratory diaphragm of metal, against the center of which rests the metal ball, *C*, carried on a thumb-screw, *B*, which is mounted in the standard, *d*. The pressure of the ball, *C*, against the plate, *A*, can be regulated by turning the thumb-screw. The diaphragm and ball form the terminals or electrodes of a circuit,

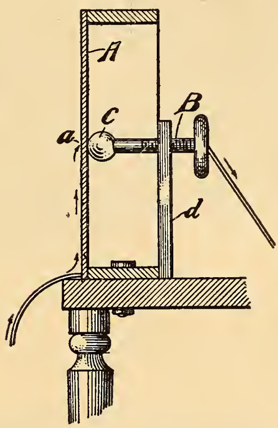
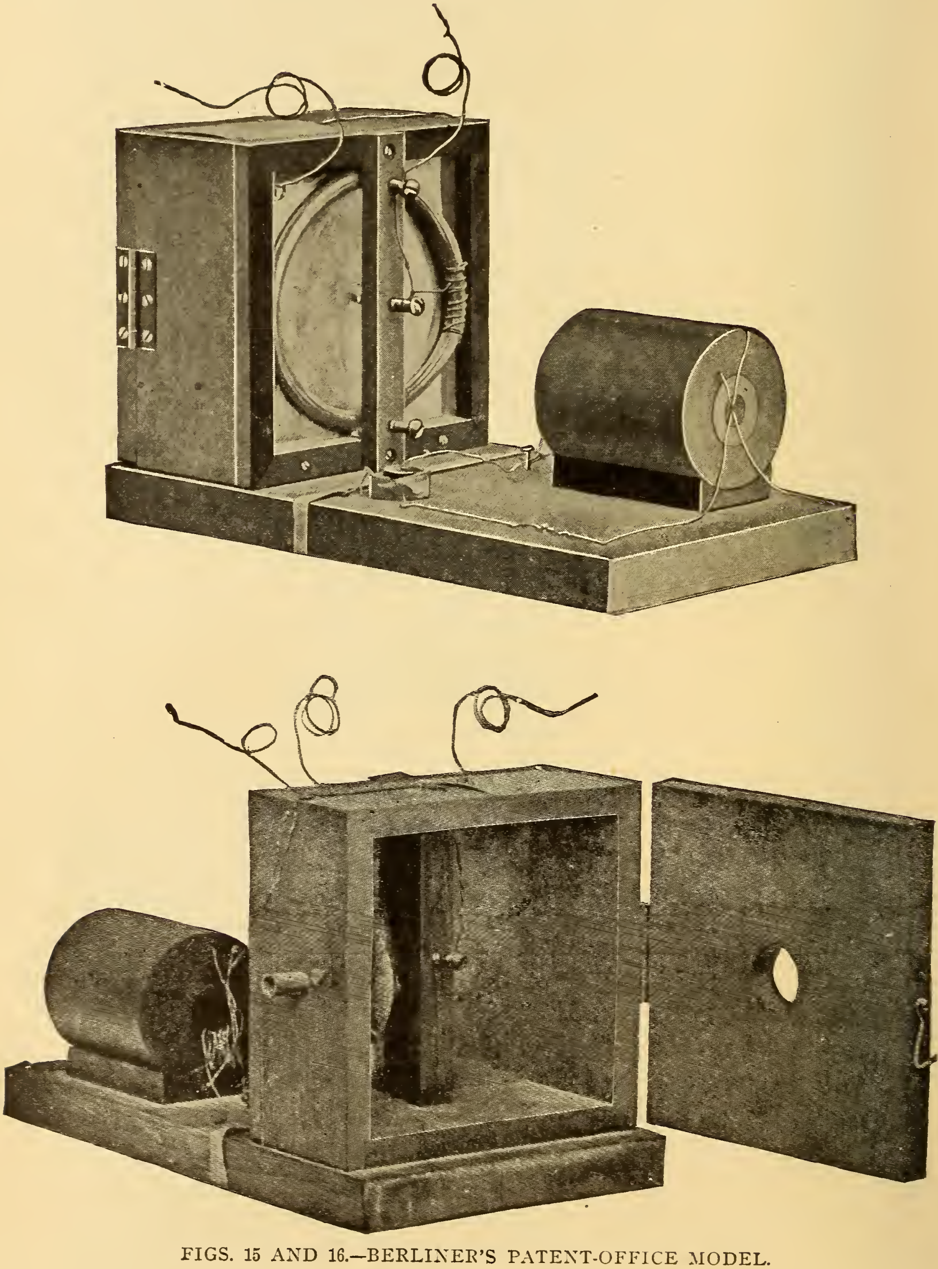


FIG. 14.—BERLINER'S TRANSMITTER.

including a battery and receiving instrument. Figs. 15 and 16 show two different views of an exact duplicate of Berliner's original model as filed in the patent office. This was very roughly constructed as shown. The diaphragm was a circular piece of ordinary tin and the contact-piece a common blued-iron wood screw. The action of this instrument (which at best has never been satisfactory or commercial) is as follows: when the diaphragm vibrates, the pressure at the point of contact, *a*, Fig. 14, becomes greater or less, thus varying the resistance of the contact and causing corresponding undulations in the current flowing.

Soon after this Edison devised an instrument using carbon as the medium for varying the resistance of the circuit with changes of pressure. Edison's first type of carbon transmitter consisted simply of a button of compressed plumbago bearing against a small plati-



FIGS. 15 AND 16.—BERLINER'S PATENT-OFFICE MODEL.

num disc secured to the diaphragm. The plumbago button was held against the diaphragm by a spring, the tension of which could be adjusted by a thumb-screw.

A form of Edison's transmitter, devised by George M. Phelps in 1878, is shown in Fig. 17. The transmitting device proper is shown

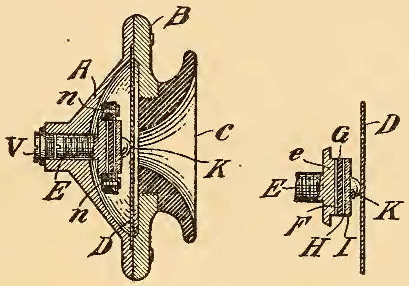


FIG. 17.—PHELPS-EDISON TRANSMITTER.

in the small cut at the right of this figure, and is inclosed in a cup-shaped case formed of the two pieces, *A* and *B*, as shown. Secured to the front of the enlarged head, *e*, of the adjustment screw, *E*, is a thin platinum disc, *F*, against which rests a cylindrical button, *G*, of compressed lampblack. A plate of glass, *I*, carrying a hemispherical button, *K*, has attached to its rear face another platinum disc, *H*. This second platinum disc rests against the front face of the lampblack disc, *G*, and the button, *K*, presses firmly against the center of the diaphragm, *D*. The plates, *F* and *H*, form the terminals of the transmitter, and as the diaphragm, *D*, vibrates, it causes variations in the pressure, and corresponding changes in the resistance of the circuit, thus producing the desired undulations of current.

Professor David B. Hughes made a most valuable contribution tending toward the perfection of the battery transmitter. By a series of interesting experiments, he demonstrated conclusively that a loose contact between the electrodes, no matter of what substance they are composed, is far preferable to a firm, strong contact. The apparatus used in one of his earlier experiments, made in 1878, is shown in Fig. 18, and consists simply of three wire nails, of which *A* and *B* form the terminals of the circuit containing a battery and a receiving instrument. The circuit was completed by a third nail, *C*, which was laid loosely across the other two. Any vibrations in the air in the vicinity caused variations in the intimacy of contact between the nails, and corresponding variations in the resistance of the circuit. This was a very inefficient form of transmitter, but it demonstrated the principle of loose contact very cleverly.

It was found that carbon was, for various reasons, by far the most desirable substance for electrodes in the loose contact transmitter, and nothing has ever been found to even approach it in efficiency and desirability.

Another form of transmitter devised by Hughes, and called by him the microphone, is shown in Fig. 19. This consists of a small pencil of gas carbon, *A*, pointed at each end, and two blocks, *B B*, of carbon fastened to a diaphragm or sounding board, *C*. These blocks are hollowed out in such a manner as to loosely hold between them the pencil, *A*. The blocks, *B B*, form the terminals of the circuit. This instrument, though crude in form, is of marvelous deli-

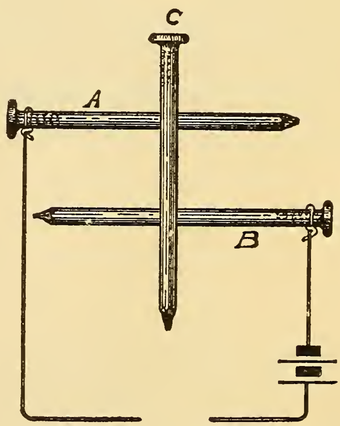


FIG. 18.—HUGHES' NAIL MICROPHONE.

cacy and is well termed microphone. The slightest noises in its vicinity, and even those incapable of being heard by the ear alone, produce surprising effects in the receiving instrument. This particular form of instrument is, in fact, too delicate for ordinary use, as any jar or loud noise will cause the electrodes to break contact and produce deafening noises in the receiver. Nearly all carbon transmitters of to-day are of the loose-contact type, this having entirely superseded the first form devised by Edison, which was then supposed to depend on the actual resistance of a carbon block being changed under varying pressure.

In speaking of Professor Hughes' work on loose contacts and the microphone, the *Telegraph Journal and Electrical Review,* an English electrical paper, says in its issue of July 1, 1878: "The microphone is a striking illustration of the truth that in science any phenomenon whatever may be turned to account. The trouble of one generation of scientists may be turned to the honor and service of the next. Electricians have long had sore reasons for regarding a 'bad contact' as an unmitigated nuisance, the instrument of the evil one, with no conceivable good in it, and no conceivable purpose except to annoy and tempt them into wickedness and an expression of hearty but ignominious emotion. Professor Hughes, however, has, with a wizard's power, transformed this electrician's bane into a professional glory and a public boon. Verily, there is a soul of virtue in things evil."

Professor Hughes, in an article in *Nature,* June 27, 1878, thus

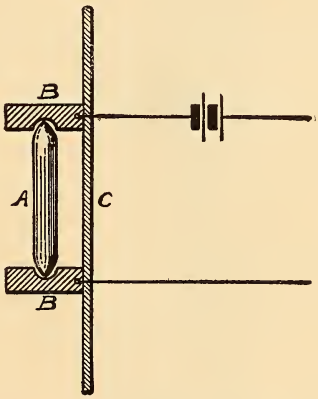


FIG. 19.—HUGHES' CARBON MICROPHONE.

describes the conditions necessary for microphonic action: "If the pressure on the materials is not sufficient, we shall have a constant succession of interruptions of contact, and the galvanometer needle will indicate the fact. If the pressure on the materials is gradually increased the tones will be loud but wanting in distinctness, the galvanometer indicating interruptions; as the pressure is still increased, the tone becomes clearer, and the galvanometer will be stationary when a maximum of loudness and clearness is attained. If the pressure be further increased, the sounds become weaker, though very clear, and, as the pressure is still further augmented, the sounds die out (as if the speaker was talking and walking away at the same time) until a point is arrived at where there is complete silence."

Only one radical improvement now remains to be recorded. In 1881 Henry Hunnings devised a transmitter wherein the variable resistance medium consisted of a mass of finely divided carbon granules held between two conducting plates. His transmitter is shown in Fig. 20. Between the metal diaphragm, *A*, and a parallel conducting plate, *B*, both of which are securely mounted in a case formed by the block, *D*, and a mouthpiece, *F*, is a chamber filled with fine granules of carbon, *C*. The diaphragm, *A*, and the plate, *B*, form the terminals of the transmitter, and the current from the battery must therefore flow through the mass of granular carbon, *C*. When the diaphragm is caused to vibrate by sound waves, it is brought into more or less intimate contact with the carbon granules and causes a varying pressure between them. The resistance offered by them to the current is thus varied, and the desired undulations in the current produced. This transmitter, instead of having one or a few points of variable contact, is seen to have a multitude of them. It can carry a larger current without heating, and at the same time produce greater changes in its resistance, than the forms previously devised, and no ordinary sound can cause a total break between the electrodes. These and other advantages have caused this type in one form or another to largely displace all others.

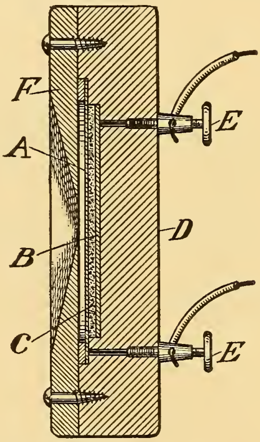


FIG. 20.—HUNNING'S GRANULAR CARBON TRANSMITTER.

At first the practice was to put the transmitter, together with the receiver and battery, directly in circuit with the line wire. With this arrangement the changes produced in the resistance by the transmitter were small in comparison with the total resistance of the circuit, especially in the case of a long line, and the changes in current were therefore small. Edison remedied this difficulty by using an induction coil in connection with the transmitter.

The induction coil used then and now is made as follows: Around a core formed of a bundle of soft iron wires is wound a few turns of comparatively heavy insulated copper wire. Outside of this, and entirely separate from it, is wound another coil consisting of a great number of turns of fine wire, also of copper, and insulated. The transmitter, together with the battery, is placed in a closed circuit with the coarse winding of a few turns, while the fine winding of many turns is included directly in circuit with the line wire and the receiving instrument. The coarse winding is usually termed the primary winding, because it is associated with the primary source of current, the battery; while the fine winding is usually termed the secondary winding, because the currents flowing in it at the transmitting station are secondary, or induced currents. In coils of this kind the coarse winding is almost invariably termed the primary for the above reason, although many conditions exist in electrical work, and in telephone work, where the high resistance winding is in reality the primary coil.

The circuit arrangement spoken of is shown in Fig. 21, in which *T* is a transmitter, *B* a battery, *P* and *S* primary and secondary

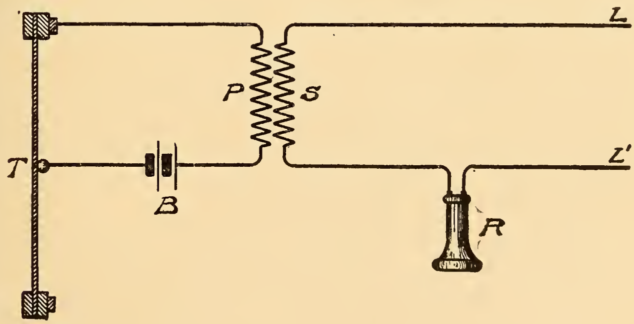


FIG. 21.—TRANSMITTER WITH INDUCTION COIL.

windings, respectively, of an induction coil, *L L'* the line wires, and *R* the receiving instrument. It is well to state here that the usual way of indicating the primary and secondary of an induction coil, in diagraphic representation of electrical circuits, is by an arrangement of two adjacent zigzag lines, as shown in Fig. 21. A current flowing in the primary winding of the induction coil produces a field of force in the surrounding space, and any changes caused by the transmitter in the strength of the current produce changes in the intensity of this field. As the secondary winding lies in this field, these changes will, by the laws of Faraday and Henry, cause currents to flow in the secondary winding and through the line wire to the receiving instrument. In good induction coils the electromotive forces set up in the secondary coil bear nearly the same ratio to the changes in electromotive force in the primary coil, as the number of turns in the secondary bears to the number of turns in the primary.

The use of the induction coil with the transmitter accomplishes two very important results: First, it enables the transmitter to operate in a circuit of very low resistance, so that the changes in the resistance produced by the transmitter bear a very large ratio to the total resistance of the circuit. This advantage is well illustrated by contrasting the two following cases:

Suppose a transmitter capable of producing a change of resistance of one ohm be placed directly in a line circuit whose total resistance is 1000 ohms; a change in the resistance of the transmitter of one ohm will then change the total resistance of the circuit one one-thousandth of its value, and the resulting change in the current flowing will be but one one-thousandth of its value. On the other hand, suppose the same transmitter to be placed in a local circuit, as above described, the total resistance of which circuit is 5 ohms; the change of one ohm in the transmitter will now produce a change of resistance of one-fifth of the total resistance of the circuit, and cause a change of one-fifth of the total current flowing. It is thus seen that fluctuations in the current can be produced by a transmitter with the aid of an induction coil which are many times greater than those produced by the same transmitter without the coil.

The second advantage is that by virtue of the small number of turns in the primary winding and the large number in the secondary winding of the induction coil, the currents generated in the secondary are of a very high voltage as compared with those in the primary, thus enabling transmission to be effected over much greater length of line, and over vastly higher resistances than would be possible if the transmitter were forced to vary the current flowing through the entire length of the line.

CHAPTER III.

ELECTROMAGNETIC AND ELECTROSTATIC INDUCTION.

INDUCTION—both electromagnetic and electrostatic—together with the allied subjects—self-induction, retardation, and capacity—play such important parts in the whole telephonic art, and seem so little understood among the rank and file of telephone workers and users, that this chapter will be devoted to an elementary and, as far as possible, non-mathematical discussion of these two phenomena, with a view to explaining their existence and effect in a simple manner, rather than to throw any new light upon the subject.

Ohm's law states that for a steady flow of electricity in a given circuit the amount of current in amperes is equal to the electromotive force expressed in volts, divided by the resistance of the circuit expressed in ohms. In algebraic form this becomes the well-known equation:

$$I = \frac{E}{R},$$

where I represents the current in amperes, E the electromotive force in volts, and R the resistance of the circuit in ohms. Knowing any two of the above quantities, the third may be determined from the equation already given, or from the following, which are derived from it:

$$E = IR,$$

$$\text{and } R = \frac{E}{I}.$$

These three equations, which are merely different ways of expressing Ohm's law, are the most useful in the entire science of electricity. It is unfortunate for an easy understanding of telephony that these equations in their simple forms hold true for a *steady flow* only, and that when currents which are rapidly changing in value or in direction are considered, we must face a more complex set of conditions.

An electric current flowing through a conductor sets up a field of force about the conductor throughout its entire length. This field of force consists of magnetic lines extending in closed curves about the conductor, and is often termed a magnetic whirl. A freely suspended magnetic needle placed within this field of force will tend to assume a direction corresponding to the direction of the lines of force, and therefore at right angles to the conductor.

If the current flowing in the conductor is maintained at a constant value and in the same direction, the field of force about the conductor will not change. On the other hand, if the current strength fluctuates, the field of force will become more intense and will expand while the current strength is increasing, and will become less intense and will therefore contract while the current strength is decreasing. If the current changes its direction, the field of force existing is entirely destroyed, and is built up in an opposite direction.

Whenever there is such a relative movement between a conductor and the lines of force of a magnetic field as to cause the conductor to cut the lines, or the lines to cut the conductor, an electromotive force is set up in the conductor which tends to cause a current to flow. This direction of the electromotive force will depend on the direction of the lines and of the movement of the conductor, and its value will depend on the rate of cutting. The field of force may be set up either by a magnet or by a conductor carrying a current, and in either case the phenomenon just described is called electromagnetic induction.

If two wires, one of them carrying a current, are formed into adjacent parallel coils, each having a number of turns, then the lines of the field of force set up by the coil carrying the current will, when the field of force contracts or expands, cut some or all of the turns of the other coil. An electromotive force will thus be induced in each turn of the latter coil, the result being that the sum of all the electromotive forces induced in the separate turns will be added, thus producing a much greater effect than if the latter coil had but a single turn. The contracting or expanding of the field due to the coil carrying the current will take place only when the current in this coil is decreasing or increasing in value, and it therefore follows that electromotive forces will be induced in the second coil, only when the current in the first coil is changing. Furthermore, if the two coils are wrapped about an iron core, the field of force due to the coil carrying the current will be greatly strengthened, because a given magnetizing force, or force which tends to set up a field of force, will produce a greater number of lines in iron than in air. The electromotive force induced in the second coil will therefore be greatly increased, owing to the greater rate of cutting of lines caused by the changes in the current.

It is evident that in a coil formed of a single wire, carrying a current, each turn of the coil is surrounded by a field of force, and that each turn must therefore lie more or less within the fields of force of all the other turns. Each turn will therefore have an inductive action upon all the other turns of the same coil when the current through the coil is varying. Whenever a diminution of the current occurs the decreasing number of lines of force set up by any one turn will act on each of the other turns to induce an electromotive force tending to cause a current to flow in the same direction. The decreasing field of force around each one of the turns will act in a like manner on all of the other turns, and as all of the electromotive forces in all of the turns will be in the same direction as the current which is already flowing in the coil, their effects will be added and will tend to prolong the flow of current. On the other hand, an increase in the current will cause an increasing number of lines to surround each turn, and this increase around any one turn will induce electromotive forces in each of the other turns in the opposite direction to that producing the current already flowing. This phenomenon of induction between the various parts of a single coil of wire each on the other is termed self-induction.

In view of the fact that a decreasing current induces an electromotive force tending to produce a current in the same direction as that already flowing, while an increasing current induces an electromotive force tending to produce current in the opposite direction, it follows that the general effect of self-induction in a circuit is to tend to prevent any changes in current from taking place in that circuit. This accounts for the fact that coils of wire, such as those forming electromagnets, tend to so greatly retard the flow of any rapidly varying currents, such as voice currents, through them.

It is quite evident that in circuits containing self-induction and subject to rapidly fluctuating electromotive forces, the tendency of self-induction to prevent changes in the current will always cause any change in current to lag slightly behind the change in electromotive force which produces it. Where the electromotive force impressed upon a circuit varies according to the law of sines, the electromotive force produced by self-induction lags a quarter of a phase or 90° behind the current flowing in the circuit. That this is so may be seen from the fact that the electromotive force of self-induction is a maximum when the current producing it is changing most rapidly, and is zero when the current producing it is not changing at all. The maximum rate of change of the current flowing in a circuit occurs when the current is passing through zero, and its minimum rate of change occurs at the crests of the wave, that is, at its maximum points. It therefore follows that the electromotive force of self-induction is a maximum when the current in the circuit is zero, and is zero when the current is a maximum. This evidently indicates a phase difference of 90°, and we have already seen that this phase difference is a lagging rather than a leading one.

In circuits containing only non-inductive resistance the electromotive force impressed upon the circuit has only to overcome the ohmic resistance, and the value of the current may be obtained at any time by a direct application of Ohm's law. Where self-induction, however, is added, the impressed electromotive force, if it be a varying one, must overcome not only the ohmic resistance, but the electromotive force of self-induction; and then the current equation becomes

$$\text{Current} = \frac{\text{Electromotive Force}}{\text{Impedance}}.$$

The word impedance in this equation may be termed the apparent resistance, and the apparent resistance in circuits having self-induction is always greater than the ohmic resistance. In fact, Z, the impedance, is equal to

$$\sqrt{R^2 + 4\pi^2 f^2 L^2};$$

where f is the frequency of alternations and L is the coefficient of self-induction—a term denoting the total number of lines of force set up in a given coil when traversed by current of unit strength. The equation of the flow of current, I, may then be written

$$I = \frac{E}{Z} = \frac{E}{\sqrt{R^2 + 4\pi^2 f^3 L^2}},$$

which is the equivalent of saying that the current flowing is equal to the electromotive force divided by the apparent resistance.

The current flowing in a circuit in which self-induction and resistance are present is the resultant of that produced by the impressed electromotive force and the electromotive force of self-induction. The greater the electromotive force of self-induction the greater will be the lag of the current behind the impressed electromotive force. Furthermore, the greater the self-induction the greater will be the apparent resistance or impedance, and consequently the smaller will be the current flowing. The above formula applies only to current varying according to the sine law; but telephone currents do not vary according to this law, or according to any other definite law, so far as we have been able to determine. This does not, however, destroy the significance of the formula as applied to telephony. Fourier's theorem states that any complex periodic wave motion may be considered as being made up of a number of simple wave motions having 1, 2, 3, 4, etc., times the rate of vibration of the complex wave motion. Telephone currents are very complex, and are composed not only of a fundamental tone, but of many overtones; it is by the various blending of these overtones, with regard to their relative loudness and their relative position in phase with respect to each other, that articulate speech is produced. A consideration of the formula for the flow of current, just given, shows that the effect of self-induction is greater upon currents of high frequency than upon those of low frequency, for as f, the frequency, increases, the value of the impedance or the apparent resistance increases, and, therefore, the value of the current decreases. In other words, self-induction tends to weed out the higher overtones in preference to the lower ones and the fundamental tone, thus rendering speech indistinct, as well as reducing its volume.

Applying these principles to the practical side of telephony, we see that the presence of an electro-magnet in the path over which voice currents must pass, will be deleterious to good speech transmission. This is true because the self-induction of the magnet tends, as we have seen, to reduce the flow of varying current, and to modify the wave form, thus not only reducing the *power* of the transmission, but actually interfering with its *quality*.

On the other hand, we may be quite free in connecting electro-magnets, having high coefficients of self-induction, in shunt or bridging paths across the two sides of a circuit over which voice currents must pass, because the very high apparent resistance or impedance offered by these magnets, prevents an undue amount of the voice currents from being shunted from the path it is desired to have them follow.

The coefficient of self-induction of a coil depends directly on the number of turns of wire on it, and also on the number of magnetic lines of force set up through the coil by a given current. This latter factor depends largely on the form of the core and the amount of iron in it, and also on the softness of the iron. To make a magnet of high impedance it is therefore necessary to use a comparatively large number of turns of wire on it, and to employ a core of soft iron of ample cross section, with a return magnetic circuit if possible.

Coming now to the phenomena of capacity: Every insulated conductor is capable of receiving a certain charge when subjected to an electromotive force; for instance, if a metallic plate insulated from all surrounding bodies is connected to one terminal of a battery the other terminal of which is grounded, a certain amount of electricity will flow into the plate until its potential is raised to that of the battery terminal. The plate is then said to be charged, and the amount of electricity held by it determines its capacity. The charge of electricity on the plate will be considered positive or negative, according to whether the positive or negative terminal of the battery, or other charging source, was connected with it.

It is well known that no charge exists by itself—there is always an equal and opposite charge induced by it upon neighboring bodies. It is also well known that like charges repel each other, while unlike charges attract; that if an uncharged body be brought near a charged body an equal and opposite charge will be induced on the side of the uncharged body which is toward the charged body, and that similarly a charge of the same sign as that on the charged body will be induced on the opposite side of the uncharged body. If now the body which was originally uncharged is connected with the ground, this latter charge—that is, the one of the same sign as the original charge—will be driven to the ground, while the charge of the opposite sign will still be attracted by the charge on the first body. The second body will therefore be charged, although it has not been in contact with the first. The action between charges of electricity taking place through an insulating medium is called electrostatic induction. It is found that where two conductors are placed side by side, but insulated from each other, the capacity of each will be greater than if the other were not present. For the purpose of holding charges in this manner the well-known Leyden jars have long been in use. They are usually made by coating a glass jar inside and out with a layer of tin-foil to within a few inches of the top. The outer coating is usually connected with the ground, while the inner coating is connected with a metallic rod approaching it through the mouth of the jar. If the inner coating is connected with a source of electromotive force, a current lasting but an instant will flow into the coating, producing a charge. This charge, which we will say is positive, will attract a nearly equal negative charge to the outer coating, repelling an equal positive charge to the earth, as already described. The amount of charge which the inner coating will receive under these circumstances is very much greater than if the outer coating were not present, and the capacity of the inner coating is therefore much higher than before. Devices consisting of two electrical conductors separated by an insulating medium for the purpose of holding two charges of electricity are called condensers. The Leyden jar is, therefore, a type of condenser.

The capacity of a condenser is increased as the area of the conducting surface is increased; is increased as the distance between the conductors is diminished, and may be increased or diminished by using different kinds of insulating material between the conductors. The medium separating the conductors is called the dielectric, and, as stated above, upon it depends to a great extent the efficiency of a condenser. Several condensers built exactly alike, so far as size of plates and the distance between them are concerned, and using different materials for dielectrics, will be found to have different capacities. This difference is due to a peculiar property possessed to different degrees by different dielectrics and called specific inductive capacity.

The specific inductive capacity of a dielectric is a measure of that quality which enables the dielectric to hold a charge between two conductors, as in a condenser. The specific inductive capacity of air is taken as a standard and is for convenience considered as unity; it is lower than that of any other known substance excepting, perhaps, hydrogen. If two condensers having plates of equal size and distance apart are constructed with dielectrics respectively of air and guttapercha, it will be found that the condenser having the dielectric of guttapercha will receive a charge nearly $2\frac{1}{2}$ times as great as the condenser having the dielectric of air. The actual ratio between the two is 2.462, and for this reason the specific inductive capacity of guttapercha is said to be 2.462. The following table gives the specific inductive capacities of some of the more important insulators:

Air	1.00
Glass	3.013
Shellac	2.74
Sulphur	2.580
Guttapercha	2.462
Ebonite	2.284
India-rubber	2.220
Paraffin	1.904
Carbonic Acid	1.00036
Hydrogen	0.99967
Vacuum	0.99941

It is probable that with very rapidly varying electromotive forces, such as are dealt with in telephony, the specific inductive capacities of the various substances would be higher in comparison with air than those indicated by this table.

Specific inductive capacity is a very important consideration in the construction of cables for telephone purposes. In the construction of these cables it is desirable, as will be shown later, to reduce the capacity of the wires of the cable to as great an extent as possible, and in order to do this the dielectric is, in the best forms of cables, made to as great an extent as possible of dry air. On the other hand, in the construction of condensers it is desired that the capacity may be as great as possible for a given area of plates, and therefore some material other than air is used. Paper saturated with paraffin is perhaps the most commonly used, paraffin having about twice as great a specific inductive capacity as air, and moreover lending itself readily to the purposes of insulation. To sum up, the capacity of a condenser varies in direct proportion as the area of its plates, inversely as the square of the distance between the plates, and directly as the specific inductive capacity of the dielectric.

Condensers used for telephonic purposes, where a comparatively high capacity is desired within a small space, are usually built up of alternate layers of tin-foil and paper, and tightly compressed so as to bring the plates as close together as possible. The paper is usually soaked in paraffin.

The effect of a condenser bridged across a circuit carrying an alternating current is to absorb a portion of the current as the electromotive force at its terminals increases, and as the electromotive force decreases, to give this current back to the line. Consider such a circuit when the electromotive force active in driving current through it begins to rise. The electromotive force at the condenser terminals will also rise, and current will therefore flow into the condenser. The strength of this current will depend directly upon the rate at which the potential at the terminals of the condenser is changing. When the electromotive force acting in the circuit reaches a maximum, the potential at the condenser terminals will also be a maximum and will for an instant cease to change. At this point the condenser is fully charged, but as the electromotive force of the line is not changing, no more current flows into the condenser; in other words, the condenser current is zero. As the electromotive force in the line decreases, current will flow out of the condenser and into the line, because the condenser is not capable of holding so much charge at the lower potential. The flow of current out of the condenser reaches a maximum when the electromotive force in the line is changing most rapidly, and this occurs when it is passing through zero. From this it will be seen that the condenser current is zero when the electromotive force in the line is a maximum, and is a maximum when the electromotive force in the line is zero. This indicates, as in the case of self-induction, a phase of difference of 90°, or a quarter of a cycle. It is not so easy to say whether this phase difference is lagging or leading, but a consideration of the direction of flow of current throughout the cycle will throw some light upon the subject.

At the instant when the current flowing in the line (which is in exact phase with the active electromotive force in the line*) is positive and at a maximum, the condenser current will be zero. As the active electromotive force decreases toward zero the condenser current increases, but in a different direction,—negative,—because current is now flowing out of the condenser back to the line. As the active electromotive force reaches zero the condenser current is at its maximum negative value, and as the active electromotive force reaches its maximum negative value the condenser current reaches zero. During the next half-cycle the condenser current increases to a positive maximum and decreases to zero, while the active electromotive force passes from a negative maximum to a positive maximum. In other words, while the active electromotive force, and therefore the line current with which it is in phase, decreases from a positive maximum value to a negative maximum value, the condenser current is negative, and while the active electromotive force increases from its negative to its positive maximum value the condenser current is positive. The condenser current therefore reaches its zero value, while decreasing, 90° in advance of the same value of the active electromotive force; its maximum negative value 90° in advance of the maximum negative value of the active electromotive force; and upon investigation it will be found that every value of the condenser current occurs 90° in advance of the corresponding value of the actual line current. The electromotive force which is in phase with the condenser current is called the condenser electromotive force, and is 90° degrees in ad-

* The active electromotive force is the resultant of the impressed electromotive force and the condenser electromotive force, and is in phase with the current actually flowing in the line.

vance of the electromotive force which is active in driving current through the line. This latter electromotive force which, as we have said, is in phase with the current flowing in the line, is the resultant of the impressed electromotive force and the condenser electromotive force, and therefore leads the impressed electromotive force by a certain angular distance.

The current equation for a circuit containing resistance and capacity is, as before,

$$\text{Current} = \frac{\text{Electromotive Force}}{\text{Impedance}}.$$

In this case the impedance depends on the ohmic resistance of the circuit and on its capacity, and is equal to the following expression:

$$\sqrt{R + \frac{1}{4\pi^2 f^2 C^2}};$$

where f is the frequency, as before, R the ohmic resistance, and C the capacity of the condenser in farads. From this the current equation becomes

$$I = \frac{E}{\sqrt{R^2 + \frac{1}{4\pi^2 f^2 C^2}}}.$$

The denominator is the apparent resistance, depending upon the ohmic resistance of the circuit, the capacity, and the frequency of alternations. An inspection of this equation will show that as the frequency, f, is increased the impedance or apparent resistance becomes smaller, and this accounts for the fact that a condenser will readily transmit rapidly fluctuating currents, such as voice currents. Evidently the effect of increasing f reduces the second member in the denominator of the equation, and if sufficiently great, this may be neglected, and the equation becomes simply

$$I = \frac{E}{R}.$$

Again, increasing the capacity of the condenser also increases the effective current by reducing the impedance.

Considering these facts and formulæ from the standpoint of telephonic practice, it may be seen that a condenser may be introduced in the path of voice currents without seriously interfering with their passage. Although introducing enormous ohmic resistance into the circuit, a good condenser will allow voice currents to pass through it by induction to such an extent that its presence cannot be detected by one listening to the transmitted sounds. Again, on account of this ability to transmit voice currents, it is very injurious to transmission to bridge a condenser of considerable size across the two sides of a circuit carrying voice currents, because of the shunting effect of the path through the condenser.

The condenser must be treated in its relation to telephonic circuits in exactly the opposite manner from an impedance coil. A condenser may be put in series without seriously reducing the voice currents, while an impedance coil may not. An impedance coil may be bridged across the telephonic circuit without evil results, while a condenser may not.

The condenser affords the designer of telephone systems a means for allowing varying currents to pass, to the exclusion of unvarying currents. An impedance coil may be made a practical bar to the passage of rapidly varying currents while allowing steady currents to pass freely.

The overcoming of the deleterious effects of self-induction and of capacity on telephonic transmission is the most difficult problem with which the telephone engineer has to deal at present. On the other hand, these two phenomena often afford the skillful worker means for accomplishing results which without their aid would be impossible. So it is throughout the whole realm of science and invention; phenomena which seem at first to put insurmountable difficulties in the way of accomplishing an end, often when better understood, finally prove the touchstone of success.

CHAPTER IV.

THE TELEPHONE RECEIVER.

To construct a receiver capable of reproducing speech is a very simple matter. In fact, nearly any small electromagnet, with a light iron armature, such as is commonly used in electric bells and telegraph instruments, may be made to reproduce, with more or less distinctness, sounds uttered in the vicinity of a transmitting apparatus with which it is in circuit. It has proved more difficult, however, to construct a receiving instrument which will reproduce speech *well,* and at the same time be practically useful in everyday use.

Aside from actual talking efficiency, many considerations of a purely mechanical nature enter into the design of a good telephone receiver. It should be durable and capable of withstanding the rough usage to which it will necessarily be subjected by careless or ignorant users. It should be of such construction that its adjustment will not be changed by mechanical shocks or by changes in temperature. Failure to provide against this latter effect is one of the chief sources of trouble in telephone work. It should be of such external configuration as to enable it to be conveniently placed to the ear. The chamber in which the diaphragm vibrates should be small and of such shape as not to muffle the sound. The binding posts should be so securely fastened in as to prevent their becoming loose and twisting off the wires inside the receiver shell; and the construction should be so simple as to render the replacing of any damaged part an easy matter.

A few years ago most of the receivers used in America were of the single-pole type; but nearly all of these have now been replaced by those of the bipolar type. The particular form shown in Fig. 22 proved effective, and was formerly almost universally used by the American Bell Telephone Company. Its chief merit lies in its simplicity.

In this figure, *M* is a compound bar-magnet, composed of two pairs of separately magnetized steel bars arranged with like poles together. Between the pairs of bars is clamped a soft-iron pole-piece, *P*, at one end, and a similarly shaped iron block, *Q*, at the other end. These parts are firmly bound together by the two screws, *S S*. On the end of the pole-piece is slipped a coil of wire, *G*. This coil is usually wound with two parallel No. 38 B. & S. silk-insulated copper wires, having a resistance in multiple of about 75 ohms.

The magnet is encased in a shell of hard rubber, composed of two pieces, *A* and *B*, which screw together and clamp between them

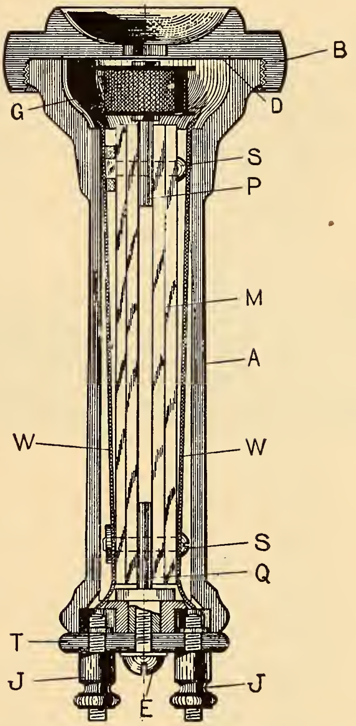


FIG. 22.—BELL SINGLE-POLE RECEIVER.

the diaphragm, *D*, of thin sheet iron. The piece, *B*, is hollowed out as shown, to form a convenient earpiece. A hard rubber tailpiece, *T*, carrying two binding posts, *J J*, fits over the end of the case opposite the earpiece, *B*, and is held in place by a screw, *E*. This screw engages a threaded hole in the block, *Q*, and serves not only to hold the tailpiece in place, but to bind the magnet securely to the shell. Soldered to the binding posts are heavy leading-in wires, *W W*, which pass along the sides of the magnet and are soldered to the respective terminals of the fine wire forming the coil.

The diaphragm of this instrument is about 1-100″ in thickness and $2\frac{1}{4}$″ in diameter. The diameter of the free portion is $1\frac{3}{4}$″.

Fig. 23 shows the external appearance of this instrument. In some single-pole receivers a magnet, consisting of a single cylindrical bar of steel was used instead of the compound magnet formed of several separately magnetized bars, but with generally inferior results, owing to its weaker and less permanent magnetic field.

In many forms of receiving instruments much trouble is experienced in keeping permanent the adjustment between the magnet and the diaphragm. This is often due to flimsy construction, but in many of the old designs to the fact that steel and hard rubber differ widely as to their amounts of expansion or contraction under changes in temperature. In instruments where the magnet is

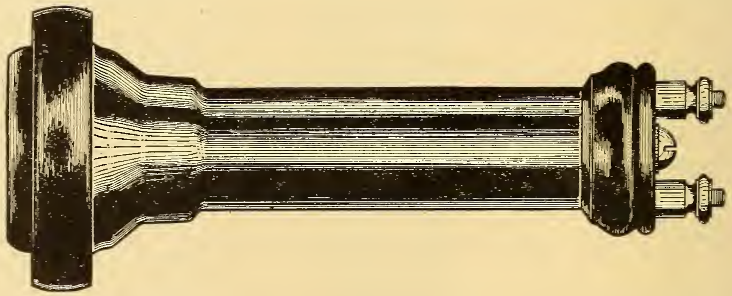


FIG. 23.—BELL SINGLE-POLE RECEIVER.

rigidly secured to the shell only at a point at considerable distance from the diaphragm, the unequal expansion or contraction of the magnet and the shell causes the distance between the pole-piece and the diaphragm to vary with every change in temperature. A sudden change will thus often render a receiver inoperative.

This defect is seen to exist without any attempt at a remedy in the receiver shown in Fig. 22. The point of support of the magnet is as far removed from the diaphragm as possible, being at the screw, *E*, and therefore the full effect of all the differences in contraction and expansion between the hard rubber and the steel is obtained.

In bipolar receivers which have now come into almost universal use, the object is to strengthen the field in which the diaphragm vibrates, by presenting both magnet poles to the diaphragm. The length of the path of the lines of force through the air is thus greatly shortened, and the field of force is concentrated at the point where it will be most effective.

It is important to have faulty construction pointed out, and the bipolar receiver shown in Fig. 24, which unfortunately came into wide use, may be cited historically as a "horrible example."

The shell, *A*, and earpiece, *B*, were of a material resembling hard rubber, and clamped between them the soft-iron diaphragm, *D*, as in the single-pole instrument described.

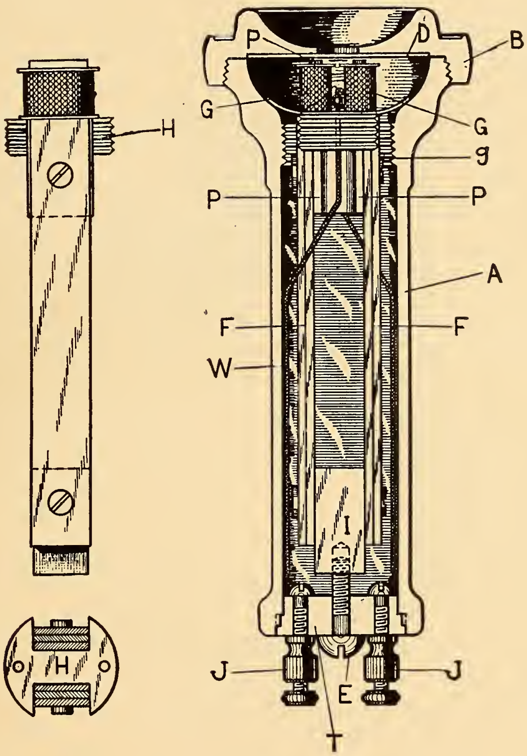


FIG. 24.—OLD TYPE BIPOLAR RECEIVER.

The magnet consisted of two pairs of separately magnetized steel bars, *F F*, the bars in each pair being laid with like poles together, thus forming two compound bar-magnets. These were so laid together that the north pole of one pair was opposite the south pole of the other. The two pairs of bars were held apart at one end by the adjustment block *H*, made of the same material as the shell, and at the other end by the soft-iron block, *I*. On each side of the block, *H*, and between it and the pairs of bar-magnets, were the soft-iron pole-pieces, *P P*, on which were wound the coils, *G G*, having a resistance of about 50 ohms each. These coils were connected in series so that the total resistance of the receiver was 100 ohms.

The block, *H*, had two segmental flanges, screw-threaded on their circumferential surfaces so as to engage a thread, *g*, on the inner surface of the shell, *A*. The magnet could thus be adjusted toward or from the diaphragm by turning it in the shell, *A*.

A tailpiece, *T*, of imitation hard rubber was shouldered to fit into the small end of the receiver shell, and a screw, *E*, extending through it into the block, *I*, served to clamp the magnet in position. To the binding posts, *J J*, were soldered heavy leading-in wires, *W W*, which passed through holes in the adjustment block, *H*, and were soldered to the terminals of the fine magnet wire.

In this receiver an attempt was made to remedy the defect caused by the unequal contraction and expansion of the parts by securing the magnet to the shell at a point close to the diaphragm, thus reducing the differences in expansion and contraction to a minimum. In this particular case, however, this introduced a defect quite as serious, because the shell was also bound to the other end of the magnet by the screw, *E*. The contraction and expansion thus tended to loosen the screw-thread on block, *H*, making frequent readjustment necessary. Moreover, a good screw-driver in the hands of an ordinary repair man, or of a subscriber, often subjected the screw-thread on block, *H*, to such a strain as to strip it, thus rendering the receiver useless.

Several important points may be learned from the behavior of the two forms of receivers shown in Figs. 22 and 24.

It indicates very faulty design to secure the magnet in the shell at the farthest end of the diaphragm. It is equally bad to fasten the magnet and shell rigidly together at both ends, unless the shell is of metal. The use of any of the old materials in imitation of hard rubber has proven attractive but disastrous. Attractive on account of its low cost and the facility with which it could be moulded. Disastrous because, until a very recent date, at least, these materials were usually subject to some or all of the following faults to a greater extent than hard rubber: They were very brittle and liable to have "cold shuts" or seams formed in moulding, which resulted in a lack of toughness and liability to cause cracks or fractures. They were often hygroscopic, tending to absorb moisture and thus reduce their insulating properties. Some of them softened under heat and gave way slowly under long continued pressure to an even greater extent than hard rubber, this resulting in permanently distorted forms when cooled or relieved from pressure. Lastly, many of these materials would discolor and roughen with use, thus spoiling their appearance and rendering them unpleasant to the touch.

Recent improvements in these materials have been made, however, which seem to justify the hope that a material as good as hard rubber may be found. Composition shells are again being used to a limited extent by reliable manufacturers, as in some of the new compositions little seems lacking in the matter of toughness, insulating qualities and ability to resist an ordinary amount of

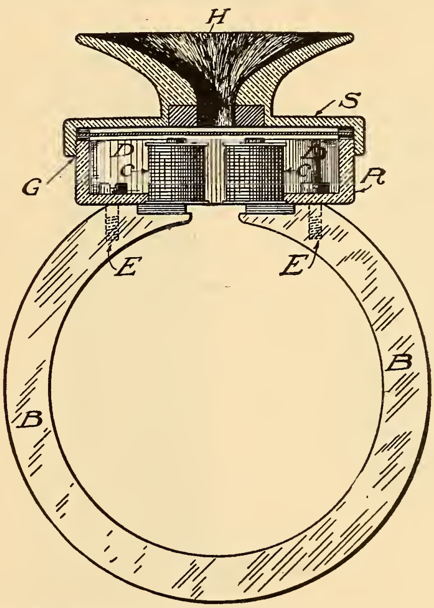


FIG. 25.—ADER BIPOLAR RECEIVER.

moisture. Moreover, the improved material does not seem to possess the objectionable softening and changing under heat and pressure to as great an extent as hard rubber.

A way of obviating the expansion and contraction difficulty used largely in European countries and to some extent in this country, is to construct the shell holding the diaphragm of some such metal as to give it nearly the same coefficient of expansion as the steel magnets.

Fig. 25 shows one of the early forms of bipolar receivers. This was devised in 1881 by Clement Ader, of Paris, France, and is with some modifications still used to a limited extent in Europe. This embodies an interesting and ingenious attempt at increasing the electrical efficiency of the telephone receiver. The magnet, *B*, is ring-shaped, and has fastened to its poles two L-shaped pole-pieces carrying coils, *C C*. The box, *R*, inclosing the pole-pieces and coils is of brass and is secured to the magnet by screws, *E E*. It is screw-threaded at *G*, so as to engage a corresponding screw-thread on the inner surface of the cap, *S*, which has a flaring portion, *H*, forming an ear-piece. The diaphragm, *D*, is clamped between the pieces, *R* and *S*, in the usual manner.

Surrounding the opening, leading from the diaphragm to the ear-

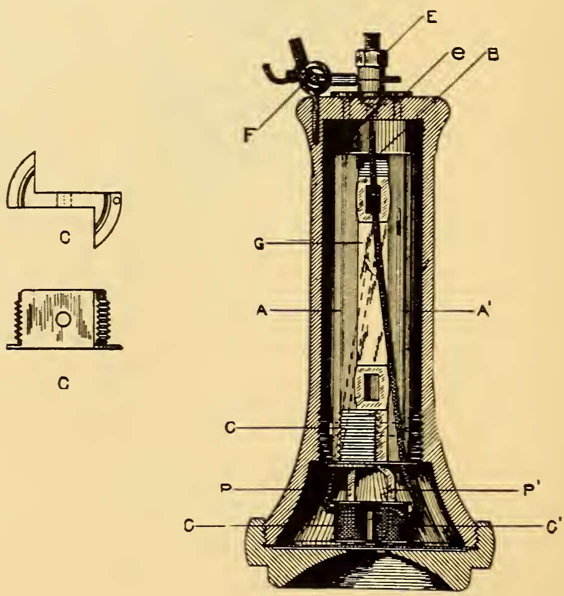


FIG. 26.—WESTERN ELECTRIC RECEIVER.

piece, is a ring, *m*, of soft iron, and in this ring lies the chief point of Ader's invention. The additional mass of iron placed near the poles of the magnet affords a more ready path for the lines of force, and their number is thus increased. The diaphragm, therefore, moves in a stronger field of force, and the power of the receiver is said to be correspondingly augmented. Practice in this country has not, however, shown any perceptible gain of efficiency by the use of this ring.

Fig. 26 shows the latest form of receiver used by the Bell licensees companies and manufactured by the Western Electric Company of Chicago.

The working parts of this receiver are composed of two magnets, *A A'*, clamped together by screws passing through an iron tail-block, *B*, at one end, and through a threaded block, *C*, of brass at the end nearest the magnet coils. The pole-pieces, *p p'*, are clamped between the pole end of the magnets and the block *C*, and carry on their outer ends the coils c c'. Threaded block *C* engages a screw-threaded portion on the interior of the body of the shell, and by turning the block in this threaded portion, adjustment of the mag-

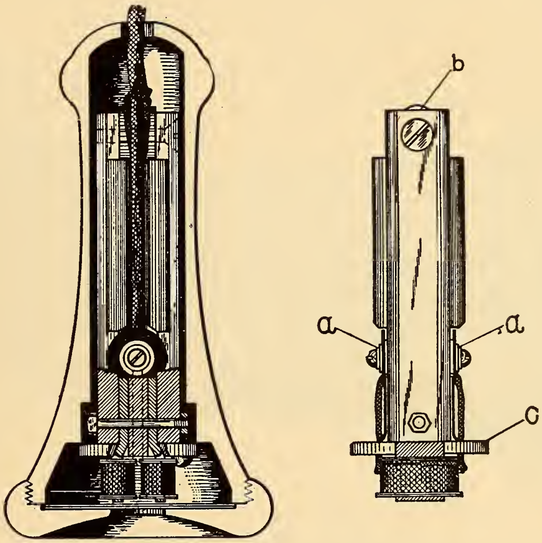


FIG. 27.—KELLOGG RECEIVER.

net poles toward or from the diaphragm may be readily accomplished. When this adjustment is once determined, however, in the factory, it is made permanent by driving a pin through a flange on the block and into the hard rubber, thus preventing accidental derangement of the parts. The diaphragm is clamped between the body of the shell and the ear-piece in the usual manner. The shell and ear-piece of this receiver are made of the best possible grade of hard rubber, carefully turned and finished. The binding posts, *E*, are of the lock-nut type and are provided with flanges, *c*, by means of which, and flat-headed machine screws, they are firmly secured to the rubber shell. An eyelet, *F*, also screws into the end of the shell, serving as a means for attaching the straining cord of the receiver cord so as to prevent any strain (such as might be caused by dropping the receiver) from coming on the cord tips themselves.

In order to give this receiver sufficient weight to have it properly operate the automatic hook switches in ordinary use, a lead weight, *g*, is clamped between the bars, *A A'*, of the magnets. The total weight of this receiver (and in nearly all others of its general type) is about fifteen (15) ounces.

In Fig. 27 the latest receiver of the Kellogg Switchboard & Supply Company is shown in section. This resembles in its main features the receiver of the Western Electric Company, just described, but in addition possesses the very desirable feature of having no exposed metallic parts on the exterior of the shell. Instead of having the binding posts on the outside of the receiver, the cord passes directly through a hole in the small end of the shell, its two strands terminating in flat cord tips which may be attached by means of screws to the clips, *a a'*, secured on an insulating block

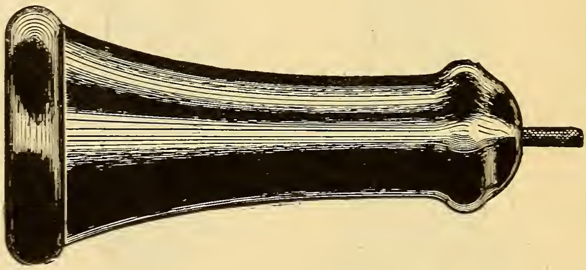


FIG. 28.—RECEIVER WITH NO EXPOSED METALLIC PARTS.

carried between the magnets. The terminals of the coils are permanently secured to these clips, thus completing the circuit of the receiver. The straining cord is tied around the iron block, *b*, between the ends of the magnets. Instead of securing the magnets within the shell by means of a screw-threaded block, as in case of the Western Electric receiver, a flanged block, *c*, is provided in the Kellogg receiver, which rests on a shoulder on the interior of the shell and is secured thereto by means of ordinary machine screws. The shell and cap of this receiver are usually made of hard rubber, turned and polished, but the Kellogg Company has recently also put out a composition shell which seems to possess merit while at the same time considerably reducing the cost of the receiver.

This receiver has been adversely criticised on account of the fact that it is necessary to remove the magnets from the shell in order to put in a new cord. This objection, however, is probably fully offset by the fact that the cord tips, which are always the weakest portion of a cord, are concealed from the user and are protected from any possible mechanical injury.

An external view of this type of receiver, with no exposed metal parts, is shown in Fig. 28.

In Fig. 29 the form of receiver originally introduced by the Western Telephone Construction Company of Chicago is shown. This was the first receiver of the type having no exposed metal surfaces, and this particular design has been widely copied. The

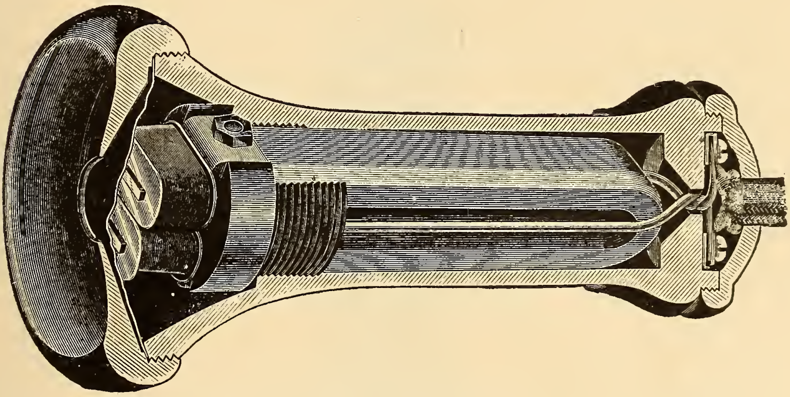


FIG. 29.—WESTERN TELEPHONE CONSTRUCTION COMPANY'S RECEIVER.

magnet is of horse-shoe form, consisting of a single bar of magnet steel bent into the form shown. On the forward ends of the magnet is carried a block of brass grooved on each side to partially enclose the magnet limbs. The rear portion of this block is screw-threaded, as shown, so as to engage the corresponding thread turned in the interior surface of the shell in a manner similar to the design shown in Fig. 26. The unique point in this receiver is in the method of attaching the receiver cord to the terminals leading from the coils. These terminals are composed of heavy, insulated wire, passing through the brass block to the coil chamber; the other ends of these wires are twisted together and passed through a central opening in the rear of the shell, where each is soldered to a connector held in place against the shell by a small machine screw. The cord is provided with similar connectors which may be slipped under the screw heads, thus completing the circuit between the cord and the coils of the receiver. After these connections are made a tail-cap composed of hard rubber or composition is screwed in place as shown, thus completely covering the cord connectors. An enlargement in the covering of the cord effectually prevents any strain coming on the cord terminals when the receiver is dropped.

The receivers shown in Figs. 26 and 27 are representative of the highest type of receiver construction in America to-day. They are extremely efficient and durable. The design shown in Fig. 29 is also good, but this particular form has suffered from poor

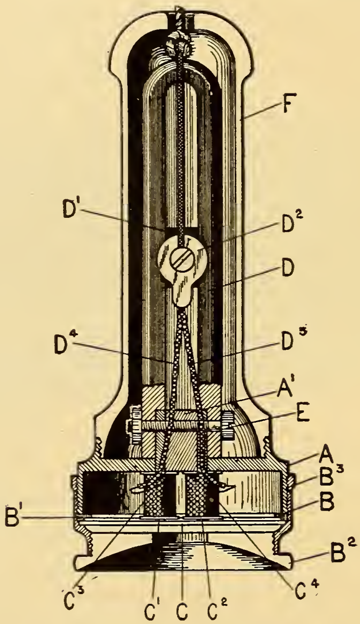


FIG. 30.—STROMBERG-CARLSON RECEIVER.

workmanship in manufacture. The tendency of American practice seems to be at present toward this general form of receiver, with binding posts concealed.

The Stromberg-Carlson receiver is a very powerful one and has stood the test of time well. It is shown in Fig. 30, in which *A* is a casing of brass forming a framework upon which all of the other parts of the instrument are supported. This is screw-threaded on its outer surface to receive the internally screw-threaded cap, *B*, and the lock ring, B^3. One unique feature of this receiver is the method of supporting the diaphragm, which is held in place in the cap B by the clamping ring B'.

Upon the cap, B, is screwed an ear-piece, B^2, of hard rubber. The lock-ring, B^3, is adapted to be screwed against the cap, to lock it in any adjusted position on the casing A. Upon the rear of the casing is provided a projection, A', against the faces of which rest the soft-iron cores, C' and C^2, which extend through the bottom of the casing and carry upon their end the coils, C^3 C^4. The ends of the permanent magnet, D D', rest upon the cores, C' and C^2, and a screw or bolt, E, passes through the ends of the magnet, the cores, and the projection, to maintain them in position. The ends of the magnet, d, are cut away as shown to permit the cores to be set flush with the inner faces of the magnet.

Between the limbs of the magnet is provided a block, D, of fiber upon which are mounted two binding posts, D^2, these being connected to the terminals of the coils by heavy insulated wires, D^4 D^5.

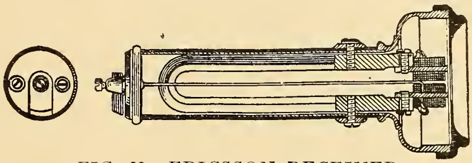


FIG. 32.—ERICSSON RECEIVER.

To the binding posts are also attached the ends of the receiver cord. Upon the rear of the casing, A, is provided a threaded flange upon which the insulated casing, or rubber shell, F, is screwed, this latter being provided with an opening at the end through which the receiver cord passes.

The magnet is mounted rigidly upon the metal casing, A, the rubber shell being entirely independent so that it may be removed by unscrewing. The diaphragm support or cap, B, may be raised or lowered to adjust the diaphragm relatively to the magnet cores, the ring, B^3, serving to lock the diaphragm in its adjusted position.

This receiver does away entirely with the troublesome effects due to expansion or contraction. The insulating casing forms a handle and serves as a protection to the cord terminals, but forms no part of the working structure itself.

Still another form of receiver, and one of the non-adjustable type, is shown in Fig. 32; this is manufactured by the Ericsson Company, of Sweden, and is being imported into this country to a considerable extent. This is of the bipolar type. The magnets are secured to the metal cup by means of two screws shown in the figure, each extending transversely through the case and into the magnets. The holes in the case through which these screws project are slotted so that a certain amount of adjustment can be obtained if it is absolutely necessary, although the idea of the manufacturers is to bind it so tightly that no adjustment will ever be needed.

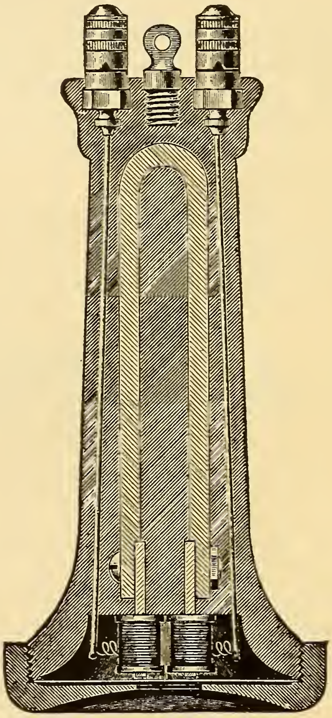


FIG. 33.—MURDOCK SOLID RECEIVER.

The inclosing tube for the magnets is of brass covered by a thin layer of insulating material, usually hard rubber, but sometimes of leather. This tube is also held in position by the screws before mentioned. A piece of hard rubber projects between the two binding posts of the instrument as shown, the object of this being to prevent the tips of the receiver cords from twisting the posts in their sockets until they touch each other, thus short-circuiting the instrument. This receiver is well made, handsome, and efficient.

The receiver shown in Fig. 33, manufactured by W. J. Murdock, Chelsea, Mass., embodies a decidedly novel feature. In this all the working parts of the receiver, including the permanent horse-shoe magnet, the pole-pieces, the binding posts and the leading-in wires, are moulded in a shell so as to form one integral part. The diaphragm is held in place by the ordinary ear-piece, which screws in place as in other receivers. The coils slip on over the pole-pieces, this being the only way of replacing a coil in case of a burn-out or injury without destroying the shell itself. It has now been on the market for over a year and is apparently giving satisfaction.

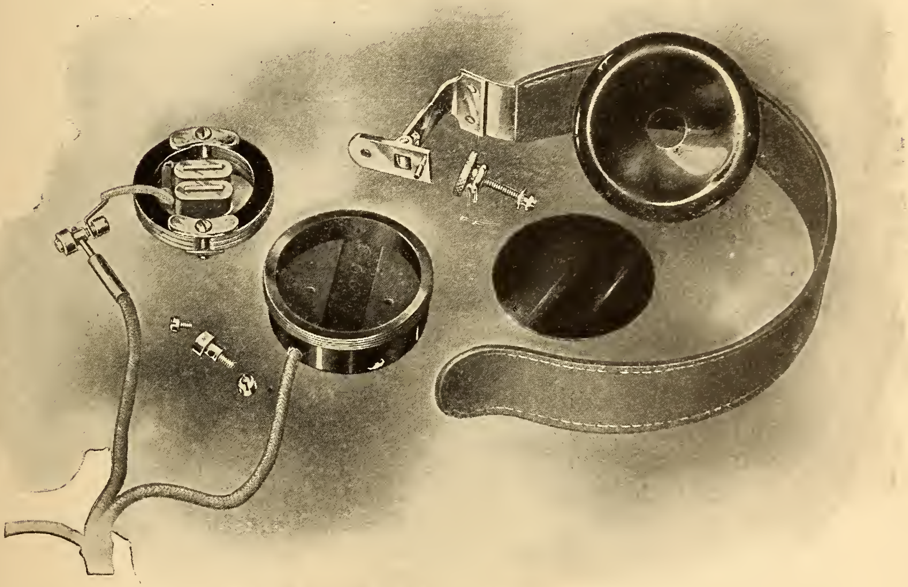


FIG. 34.—PARTS OF WATCH-CASE RECEIVER.

The diaphragms used for receivers are made of very soft thin sheet iron; the ferrotype plate formerly used for tin-types in photography being as good material as can be found for this purpose. Some companies, however, are using tinned-iron diaphragms, which give equally good results.

The diaphragms for the various receivers here described vary from 2 to $2\frac{1}{2}$ inches in diameter, the free portions—that is, the portions not clamped by the supports—ranging from $1\frac{3}{4}$ to 2 inches. The usual thickness is from .009 to .011 of an inch. The thickness of a diaphragm, to produce the best results with a given receiver, must be obtained by experiment, as it depends on the diameter of the portion free to vibrate, and also on the strength of the magnetic field, due to the permanent magnet. It has been shown that with a very thin diaphragm and a very powerful magnet the iron in the diaphragm becomes saturated, so that it is not responsive to changes in the strength of the existing field.

In certain classes of telephone work it becomes desirable or necessary to have the receiver held constantly to the ear of the user. This is true particularly in the case of the work of a switchboard operator, who must have both hands free for manipulating the switchboard. Any of the types of receiver so far described would prove too cumbersome and heavy for this use, and therefore a different type possessing small weight and volume has come into existence. These are commonly known as "watch-case" or "head" receivers.

In Fig. 34 are shown the parts of such a receiver. The permanent magnets are of the ring type, these being cross-magnetized so as to produce poles on opposite sides of their circumferences. Secured to the compound ring magnet are circular pole-pieces which carry the coils, these pole-pieces presenting their pole-faces to the diaphragm, as in the ordinary types of hand receivers. The magnet and coils are mounted in a hard rubber cup or shell, and the diaphragm is clamped between the front face of this cup and the earpiece in the usual manner. The binding posts to which the terminals of the cord are attached are usually placed within the shell, this being particularly desirable in this type of receiver because of the liability, if left outside, of entangling the operator's hair. Such receivers, if properly designed and constructed, may be made to possess almost as great an efficiency as the best hand receivers, while their weight is only a few ounces, and their form so compact as to enable them to be worn without discomfort to the operators.

In Fig. 35 is shown such a receiver assembled, with a head band for securing it to the ear of the operator. This head band is a light strip of flexible steel, covered with leather. It is attached to the receiver by a hinge joint as shown, in order to adapt itself more readily to the ear of the wearer. Many different forms of head bands have come into use, but the type shown, consisting of but a single band, is coming into most favor. A good operator's receiver and head band should, while being efficient, be light and compact, and be so constructed as to avoid catching the operator's hair. In order to prevent possible electric shocks to the operator all exposed metallic parts should be carefully insulated from the coils and other parts having electrical functions.

The question of receiver cords is one of a good deal of importance, as a faulty cord is one of the most prolific sources of trouble in any part of a telephone instrument. If the conductors in a cord are not properly insulated, so that they may come into contact with each other, or if a break occurs in one of the conductors, the instrument will be short-circuited in the one case or left open in the other. The

FIG. 35.—WATCH-CASE RECEIVER WITH HEADBAND.

conductors in the best receiver cords are usually composed of tinsel, laid up in the manner of ordinary twisted rope; a few strands of fine copper wire are frequently added to give greater strength. These tinsel conductors are then tightly wrapped with silk and given one or more braids, usually of cotton, after which the two conductors so insulated are laid together and braided over with a worsted or silk braid. Frequently a spiral wrapping of spring brass wire is put about the two insulated conductors before the outer braid is put on.

Cord tips are necessarily subject to a rather rough usage, as it frequently happens that a receiver is dropped, thus allowing a heavy strain to come on the cords which is usually most severe just where the tip joins the cord proper.

The method of fastening the tip to the cord, shown in Fig. 36, has

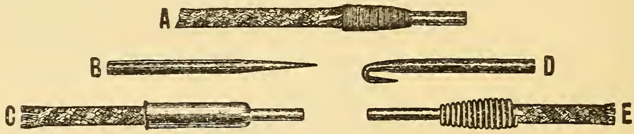


FIG. 36.—DETAILS OF RECEIVER CORD TIP.

become very popular. In this, a needle or pin *B* of No. 14 brass wire tapered to a long point, is inserted into the hollow of a braided tinsel cord for about half an inch, when the end is passed out through the conductor and covering and bent backwards, forming a hook, as shown at *D* and *A*. Before the pin is put in, the conductor is bared for a short distance, and after the pin is inserted it is wound with a fine wire and soldered. The tip is then finished with a spiral of wire, as shown at *E*, or with a shell, as shown at *C*, the latter being most common.

The cord tip used by the Kellogg Switchboard and Supply Company is shown in Fig. 37. In this the tinsel conductor is looped back on itself and wound with a linen thread, this thread extending back

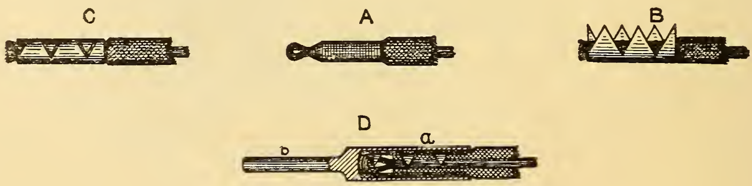


FIG. 37.—KELLOGG CORD TIP.

over the silk or worsted braiding, as shown at *A*. A collar of sheet brass is then formed around the portion thus served, this collar being shown in process of formation at *B*, and in its completed form at *C*. The cord tip proper is composed of a piece of brass rod bored out at one end, *a*, to receive the end of the cord, and turned down at the other end, *b*, to fit an ordinary binding post. The prepared end of the cord, as shown at *C*, is secured in the hollow portion of the cord tip by means of solder, the completed tip being shown at *D*. By this construction the strain of the tip is borne by the combined strength of the braid and of the conductor, and electrical contact between the tinsel and the tip proper is assured by means of the brass collar and the solder.

The cord tip of the Western Electric Company is shown in Fig.

FIG. 38.—WESTERN ELECTRIC CORD TIP.

38. In this the tinsel is first bared for a distance of about half an inch, and then the braid is passed back for about an equal distance farther, while a wrapping of brass wire is put tightly on the tinsel. The braiding is then partially returned over this wrapping of wire, and is served with linen thread, as shown at *A*, after which the end thus prepared is soldered in the hollow end of the tip proper, as shown at *B*.

In order to prevent an undue strain on the tips when a receiver is dropped, it is best to have the cord provided at each end with an

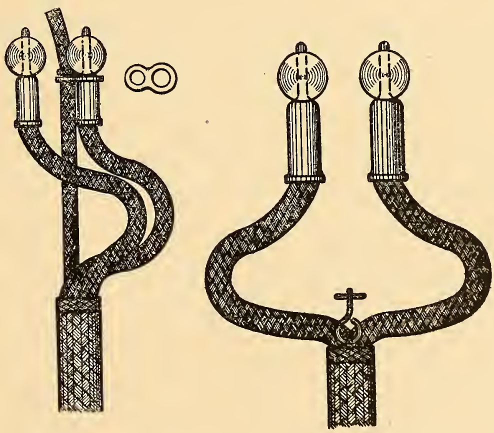


FIG. 39.—SUPPORTING LOOP AND HOOK FOR RECEIVER CORD.

auxiliary string firmly secured to the braiding or outer covering of the cord, which may be tied to the receiver at one end, and to some support on the telephone at the other, in such manner as to take up the strain due to the weight of the receiver, rather than letting this strain come upon the conductors and tips themselves. This straining string, as it is usually called, is, as a rule, a continuation of the outer braiding of the cord, and may be fastened to an eyelet in the receiver or to a small link on one of the binding posts, as shown in the left-hand portion of Fig. 39. Another way of accomplishing the same result is by means of a small wire hook sewed to the braiding, just at the fork of the cord, which hook may be closed by pliers around a screw-eye, as shown in the right-hand portion of Fig. 39.

Any receiver which is not provided with some means of taking the strain off the cord tips or cord fastenings, should be considered faulty, as the conductors and cord tips are frail at best, and should not be subjected to the strain which would otherwise be put upon them by the careless user. The receiver of the Western Electric Company, shown in Fig. 26, uses a straining string attached to an eyelet, as above described. In the receiver of the Kellogg Company (Fig. 27), with its internal binding posts, the straining cord is tied around the block at the end of the magnet, which is the better practice, because the strain is thus taken directly by the heavy part of the receiver without the intervention of the rubber shell. The receiver of the Stromberg-Carlson Company (Fig. 30) has this same feature.

CHAPTER V.

THE CARBON TRANSMITTER.

Many vain attempts have been made to discover a satisfactory substitute for carbon as the variable resistance medium in telephone transmitters, the patents on the use of carbon electrodes having, at first, formed one of the mainstays of the American Bell Telephone Company's great monopoly.

The theory of the action of carbon in the transmitter has been the subject of much discussion. As previously pointed out, any motion of the diaphragm which increases the pressure between the electrodes lowers the resistance between them, thus allowing the passage of a greater current. A decrease of pressure produces the opposite result.

Four different explanations for this action have been put forth, and are as follows:

First, that the electrical resistance of the carbon itself is caused to vary by the changes in pressure.

Second, that a film of air or gas exists between the electrodes, and that the thickness of this film is varied by the changes in pressure, thus varying the resistance. This theory is apparently still adhered to by Mr. Berliner.*

Third, that the peculiar property possessed by carbon of lowering its resistance with increased temperature is in the following way accountable for the action, in part at least: that an increase of current (due to increased pressure and diminished resistance between the electrodes) causes a slight heating at the point of contact; that this heating causes a still further diminution of resistance with an additional increase of current; and that conversely a momentary decrease of current causes a decrease of temperature with a corresponding additional increase of resistance and diminution of current.

Fourth, that change in resistance is due to the variation in the area of contact between the electrodes—that is, the variation in the number of molecules in actual contact. This change in area is perfectly apparent in the liquid transmitter of Bell, and in the case

* "Microphonic Telephonic Action," by Emile Berliner, *American Electrician*, March, 1897.

of solid electrodes may be well illustrated by the following well-known experiment:

If a billiard ball be gently pressed on a plain marble slab coated with graphite, the area of contact of the ball with the slab will be indicated by a small dot of graphite on the ball. If, now, the ball be dropped from a considerable height, it will be noticed that the spot of graphite on the ball is much larger, showing that the ball has flattened out to a considerable extent, owing to the greater pressure exerted. This demonstrates clearly the variation in area of contact between two bodies, due to variations of pressure between them. Of course, if the two bodies are conductors of electricity, the resistance between them will vary inversely and the current directly as the area of contact.

It seems most probable that of the above explanations, the fourth is the true one, and that none of the others aid in any perceptible degree in producing desirable effects in the microphone.

As to the first explanation, that the resistance of the carbon itself changes under pressure, experiments have been made with long carbon rods; and with measuring instruments of ordinary sensibility no difference whatever could be detected in the resistance of a rod when the pressure on it was varied from zero up to the crushing point, care being taken that none of the contacts in circuit were subjected to the change in pressure.

As to the layer of air theory, Professor Fessenden has thrown some light upon it,* by showing that if the layer of air were in the ordinary gaseous state, its resistance would be almost infinite, while if it existed in some peculiar condensed state of which we know little, but in which air might be conceived to be a conductor, then the law of change of resistance between the electrodes would be different from what it has actually been found to be. On the other hand, the curves plotted with resistances as ordinates and with distances as abscissæ have been found by Professor Fessenden and by Messrs. Ross and Dougherty to exactly agree with the form obtained from theoretical considerations on the basis that the change in resistance is due to area of surface contact alone.

As to the third explanation, it may be said that the very fact that the increase of current is needed to cause the rise of temperature seems to preclude the supposition that the rise of temperature should cause the diminution of resistance with its corresponding

* "Microphonic Telephonic Action," by Professor R. A. Fessenden, *American Electrician*, May, 1897.

increase of current in time to do any good. The heating effects in carbon are comparatively slow, and it would seem that the changes in temperature would lag slightly behind the changes in current producing them, in such a manner as to be detrimental to telephone transmission.

It is certainly most fortunate that in one substance—carbon—should be found all the qualifications which make it particularly desirable for microphonic work. It produces the change in re-

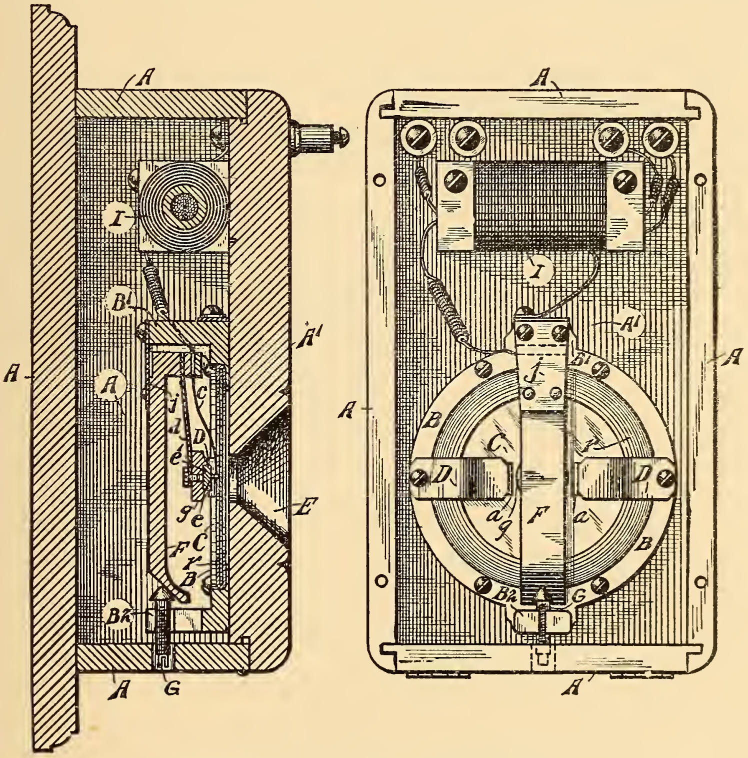


FIG. 40.—THE BLAKE TRANSMITTER.

sistance with changes in surface contact, all things considered, better than any other known substance, possesses the desirable property of lowering its resistance when heated, and is elastic, non-corrosive, non-fusible, cheap, and easily worked.

The form of transmitter almost universally used in this country up to within a few years ago, but now almost obsolete, is that devised by Francis Blake of Boston. This instrument is shown in Fig. 40, in which *B* represents a metal ring or frame for holding the mechanism of the instrument. It is screwed to the cover, *A'*, of the box *A*, and has two diametrically opposed lugs, B' B^2. On this ring is mounted the diaphragm, *C*, of rather heavy sheet-iron, supported in a rubber ring, *r*, stretched around its edge, and is held in place by two damping springs, *D D*, each bearing on a small block of soft rubber, *a*, resting on the diaphragm at a point near its center. The object of these damping springs is to prevent too great an amplitude of vibration of the diaphragm, and also to keep it from vibrating in separate parts instead of as a unit.

Opposite the center of the diaphragm is the orifice, *E*, in the cover, *A'*, so hollowed out as to form a mouthpiece. The adjusting lever, *F*, is attached to the spring, *j*, secured to the lug, *B'*, of the ring, *B*. The lower end of this lever rests upon an adjusting screw, *G*, in the lug, B^2, which is drilled and slotted as shown to prevent the screw from working loose. On the back of the diaphragm and at its center is placed the front electrode, consisting of a small bar, *e*, of platinum; one end of the bar rests against the diaphragm, while the other end is brought to a blunt point and is in contact with the back electrode, *e'*. The electrode, *e*, is supported independently upon a light spring, *c*, mounted on the lever, *F*, but insulated from it. This spring tends to press away from the diaphragm and toward the back electrode. The back electrode is formed of a block of carbon, *e'*, set into a brass block, *g*, of considerable weight, mounted on a spring, *d*, supported on the adjusting lever, *F*. This spring, *d*, has a tension in the opposite direction to that of the spring, *c*, and being stronger than the latter it keeps the electrode, *e*, in contact with the diaphragm.

It is seen that instead of having one of the electrodes held in fixed position while the other is pressed against it with greater or less force by the vibration of the diaphragm with which it is connected, both electrodes are supported in such manner as to be capable of moving with the diaphragm, but the outer electrode is so weighted that its inertia will offer enough resistance to the slight and rapid vibrations of the diaphragm to give a varying pressure between the electrodes and consequent changes of the resistance of the circuit. By this means the initial pressure between the two electrodes will not be affected by changes of temperature, and the adjustment will therefore be more nearly permanent.

This transmitter is very delicate, and transmits the quality of the voice in a manner unexcelled by others. It is, however, lacking in power, especially when compared with instruments of later design. Besides this, it has a tendency to rattle or break contact when acted on by loud noises.

Fig. 41 illustrates the Crossley transmitter, introduced into Europe early in 1879. This well illustrates the class very appropriately termed "multiple-electrode" transmitters. Transmitters devised by Johnson, Gower, Ader, D'Arsoncal, Turnbull, and many others are of this type, and differ merely in the arrangement and number of electrodes. They give, as a rule, more powerful results than the transmitters having a single pair of electrodes, but most of them are subject to the grave defect of breaking the circuit entirely when subjected to loud noises.

In this figure, *J* represents a diaphragm formed of a thin piece of pine board about $\frac{1}{8}''$ thick and mounted on a supporting ring, *K*. Fastened to this diaphragm are four carbon blocks, *F*, *G*, *H* and *I* in

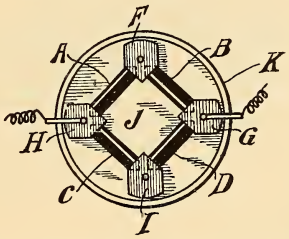


FIG. 41.—THE CROSSLEY TRANSMITTER.

the relative positions shown. These are hollowed out to receive the conical ends of the carbon pencils, *A*, *B*, *C* and *D*, which are supported loosely between them. The blocks, *H* and *G*, form the terminals of the transmitter. The current divides at the block, *H*, and passes through the pencils, *A* and *C*, in multiple to the blocks, *F* and *I*, and thence through the pencils, *B* and *D*, to the other electrode, *G*. Vibrations of the diaphragm cause variations in the intimacy of contact between the eight points of support of the four rods, and thus produce the desired fluctuations in resistance. It is seen that this is merely a modification of the Hughes microphone, the principles being the same, but the multiple contact allows a greater current to pass through the transmitter, and at the same time produce greater changes in this current than in the original form, where a single pencil was used. Moreover, the liability of "rattling" is greatly reduced.

Fig. 42 shows the Turnbull transmitter, which has been used to a limited extent in this country, even until recently. In this figure, *A* is the diaphragm of thin wood, on the back of which is mounted the bracket, *B*. Pivoted on a rod, *b*, carried by this bracket, are several carbon rods or pendants, *a*, which rest at their lower end against a carbon rod, *c*, carried on a bracket, *C*, also mounted on

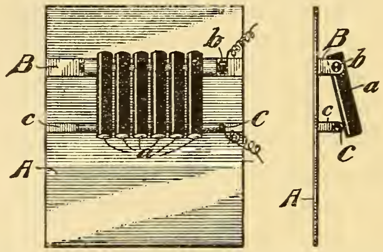


FIG. 42.—THE TURNBULL TRANSMITTER.

the diaphragm. The rods, *b* and *C*, form the terminals of the transmitter, and the current passes from one of them through the carbon pendants in multiple to the other. The variations in resistance occur principally in the contacts between the rod, *C*, and the pendants, *a*, although there is an additional effect between the pendants and the supporting rod, *b*, particularly if this rod is made of carbon.

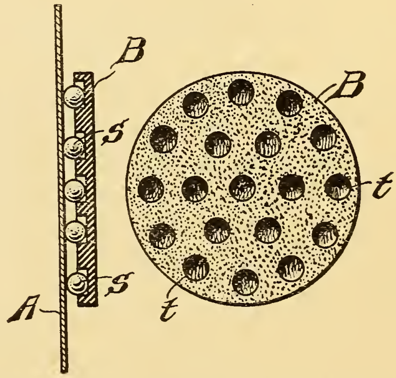


FIG. 43.—THE CLAMOND TRANSMITTER.

Fig. 43 shows still another form of the multiple-electrode transmitter, using carbon balls instead of pencils or pendants. *A* represents the vibratory diaphragm of carbon; *B* a plate of carbon having a number of cylindrical cavities, *t t*, upon one side. Fitting loosely in each cavity is a ball of carbon, *s*. The depth of the cavities is a little less than half the diameter of the balls, and the diaphragm is so placed in the front of the plate that the balls, following their tendency to roll out of the cavities, will rest against its inner surface and also upon the edges of the cavities. Many other forms of instruments have been devised using one or more balls held in various positions between carbon plates. Few are used to-day, and all the transmitters so far described are being rapidly replaced by the Hunnings form of instrument, which, as has already been stated, uses granules of carbon for the variable resistance medium.

Among the earlier forms of the granular transmitter is one designed by Émile Berliner, and called the "Berliner Universal." In

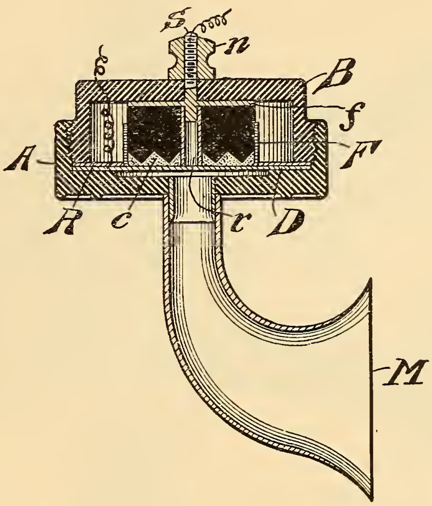


FIG. 44.—THE BERLINER UNIVERSAL TRANSMITTER.

this the diaphragm, *D* (Fig. 44), is of carbon, and is mounted horizontally in a case formed of the two pieces, *A* and *B*, of hard rubber, a brass ring, *R*, being clamped above it to insure good electrical contact. Secured to the enlarged head, *f*, of the screw, *s*, mounted on the block, *B*, is a cylindrical block of carbon, on the lower face of which are turned several concentric V-shaped grooves. The points formed between these grooves almost touch the diaphragm. The finely divided carbon, *c*, rests on the diaphragm, and is confined in the space between it and the carbon block by a felt ring, *F*, which surrounds the latter and bears lightly against the diaphragm. To the center of the back plate a soft rubber tube, *r*, is fixed which is of sufficient length to make contact with the diaphragm, its function being that of a damper to the vibrations of the diaphragm. The mouthpiece, *M*, is so curved as to conduct the sound waves against the center of the diaphragm. This transmitter was once used to some extent by the American Bell Telephone Company, but has long since been entirely replaced for long distance work by the White transmitter.

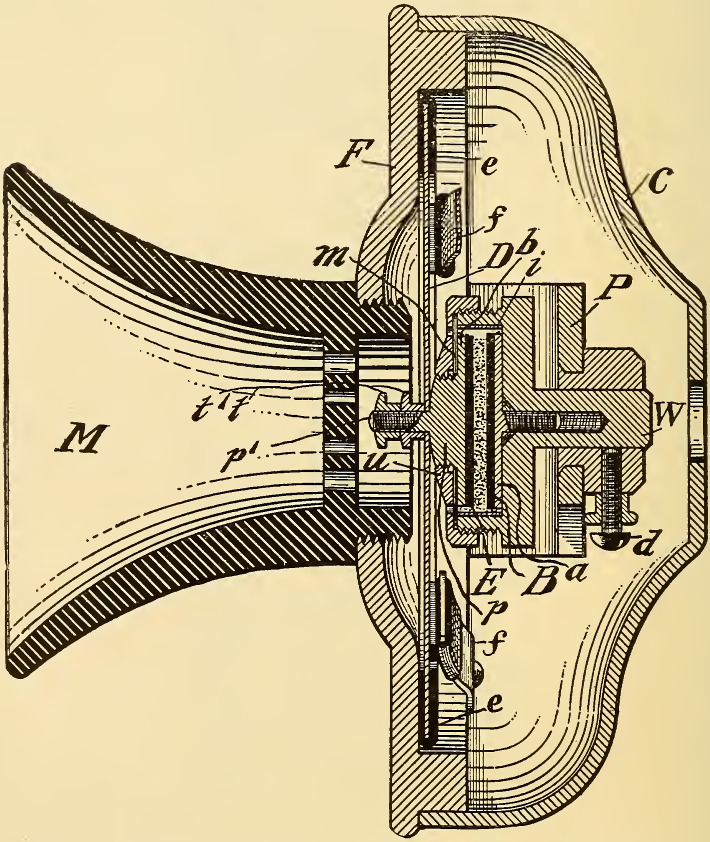


FIG. 45.—SECTIONAL VIEW OF SOLID-BACK TRANSMITTER.

The White, or "solid back," transmitter, as it is called, is shown in Figs. 45 and 46, the latter giving a clear idea of the construction of the working parts. Fig. 45 shows the section of the complete instrument. The sections of the bridge piece, *P*, shown in Figs. 45 and 46 are taken on planes at right angles to each other. This instrument has proven remarkably successful in practice, it being able to stand a very heavy current without undue heating. Besides this, the tendency of the granules to settle down in a compact mass, commonly called "packing," is greatly diminished. It is without question one of the most successful transmitters yet introduced, and for a long time was unapproached in general efficiency.

The front, *F*, is of brass, and is held, as shown, in the hollow shell, *C*, the two pieces forming a complete metallic casing for the working parts of the instrument. The sound-receiving diaphragm, *D*, of aluminum, is encased in a soft-rubber ring, *e*, held in place by two

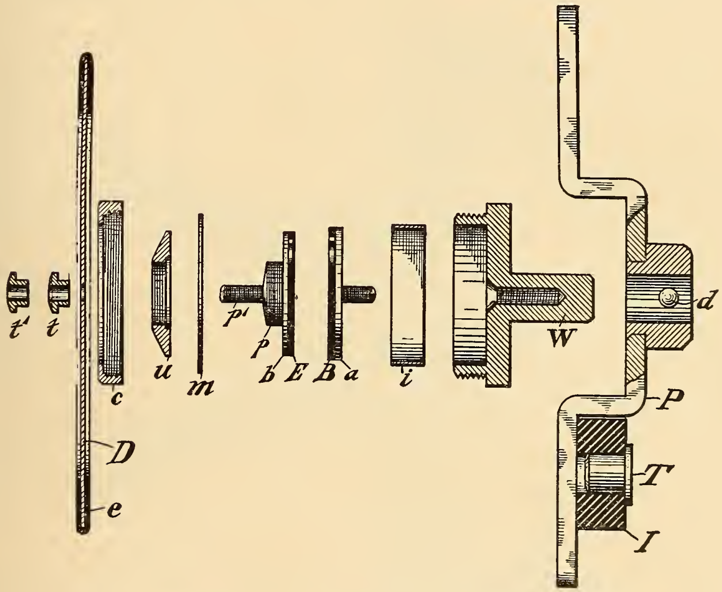


FIG. 46.—DETAILS OF SOLID-BACK TRANSMITTER.

damping springs, *f f*, as in the Blake transmitter. *W* is a heavy metallic block hollowed out, as shown, to form a casing for the electrodes. The inner circumferential walls of this block are lined with a strip of paper, *i*. This block is mounted, as shown, on a supporting bridge, *P*, secured at its ends to the front casting, *F*. The back electrode, *B*, of carbon is secured to the face of the metallic piece, *a*, which is screw-threaded into the block, *W*. *E* is the front electrode, also of carbon, carried on the face of the metallic piece, *b*. On the enlarged screw-threaded portion, *p*, of the piece, *b*, is slipped a mica washer, *m*, held in place by the nut, *u*. This washer is of sufficient diameter to completely cover the cavity in the block, *W*, when the electrode is in place. After the required amount of granular carbon has been put into the cavity, and the front electrode put in position, the cap, *c*, is screwed in its place on the block, *W*, as shown, and binds the mica washer, *m*, firmly against the face of the block, *B*, thus confining the granules in their place. The electrodes are of somewhat less diameter than the paper-lined interior of the block, *W*, so that there is a considerable space around the periphery of the former, which is filled with carbon granules. This prevents the binding of the free electrode against the edge of its containing chamber, and also allows room for the granules directly between the electrodes to expand when heated by the passage of current. The screw-threaded portion, *p'*, of the piece, *b*, passes through a hole in the center of the diaphragm, and is clamped firmly in place by the nuts, *t t'*. *M* is the mouthpiece of hard rubber, screw-threaded in an opening in the front block *F*. Any vibration of the diaphragm is transmitted directly to the front electrode, *E*, which is allowed to vibrate by the elasticity of the mica washer, *m*. The back electrode is, of course, stationary, being firmly held by the bridge, *P*.

The back electrode is in metallic connection with the frame of the instrument, which forms one terminal. The other terminal is mounted on an insulating block, *I*, and is connected by a flexible wire with the front electrode, *E*.

This transmitter is now used on all of the long-distance lines of the Bell Companies, and has given excellent service.

The following data concerning the dimensions and material used in this instrument will, it is believed, be found of interest:

Diaphragm—aluminium, 2½″ diameter and .022″ thick.

Rubber band gasket—¾″ wide, 2⅜″ double length, very soft and elastic.

Front electrode—carbon, hard and polished, 21-32″ diameter, 1-16″ thick.

Back electrode—carbon, hard and polished, 11-16″ diameter, 1-16″ thick.

Mica diaphragm—27-32″ diameter, very thin.

Back electrode chamber—inside diameter, ¾″, depth 5-32″, clearance between sides of electrode and walls of chamber 1-32″.

Distance between electrodes about .04″.

Damping spring—spring steel, 11-32″ wide, .010″ thick, 1 7-16″ long; bent at right angles when not in place. The one which rests near center of diaphragm is tipped with soft rubber and also with felt; the outer spring, with rubber only.

In Fig. 47 is shown a sectional view of the standard transmitter of the Kellogg Switchboard & Supply Company, and in Fig. 48 a detail of the working parts of this transmitter. This instrument is one of the most carefully designed and constructed, and gives excellent results in practice. The front, *A*, is of cast metal, similar to that used in the solid back transmitter shown in Figs. 45 and 46, and, as in the case of that transmitter, all of the working parts are mounted upon it. The diaphragm, *B*, is of aluminum, and differs from that of any other transmitter now on the market, in that instead of being

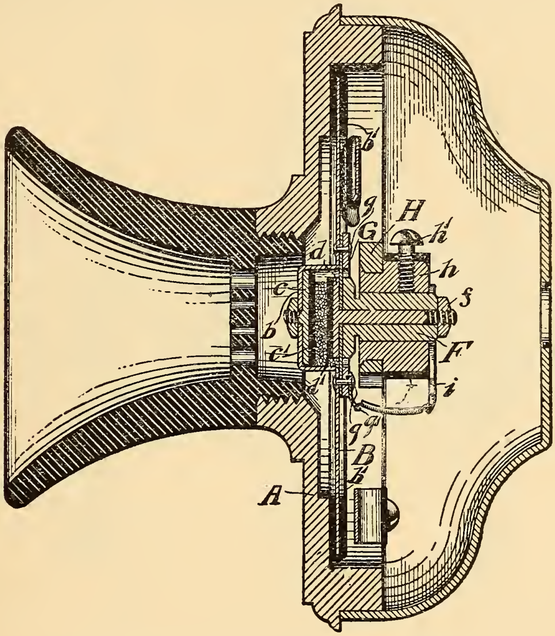


FIG. 47.—THE KELLOGG TRANSMITTER.

a plane it has formed up in its center part a cup, *b*, which contains the electrodes and the variable resistance medium. The formation of this cup from a piece of thin sheet aluminum, which, by the requirements of its service, must be hard rather than soft, has proved, as the writer knows by experience, a difficult problem in metal drawing, and is interesting on that account, if on no other. The front electrode, *C*, is composed of a brass screw, *c*, having an enlarged head to which is soldered a hard carbon disc, *c′*. This is secured by means of a nut to the front inner face of a chamber formed in the diaphragm in a manner readily understood from the assembled drawing. The rear electrode, *D*, is similarly made up of a carbon disc, *d'*, soldered to a brass disc, *d*, having a prolonged screw-threaded shank. The shank of the rear electrode, *D*, passes through a mica washer, *E*, and a heavy brass bushing, *F*, having an enlarged face to clamp the mica washer against the rear face of the electrode. These parts are tightly clamped together by means of a small nut, *f*. After assembling the parts thus far, the proper amount of granular carbon is poured into the chamber, *b*, on top of the front electrode, after which the rear electrode, with the mica washer, is put in place, and the mica washer is firmly riveted to the diaphragm by means of

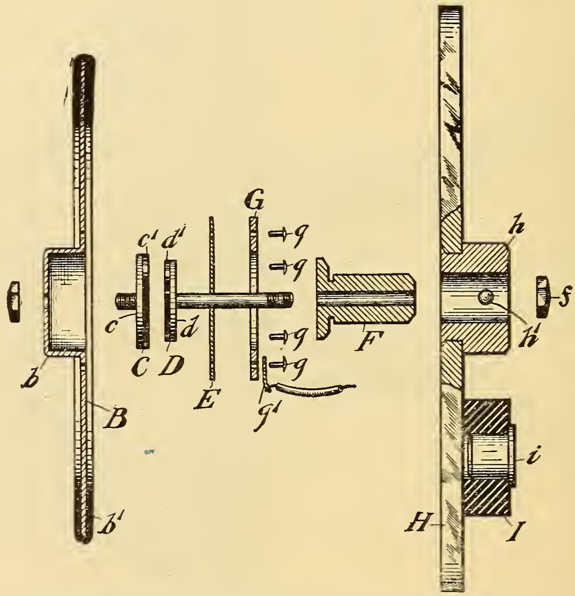


FIG. 48.—DETAILS OF KELLOGG TRANSMITER.

an aluminum ring, *G*, and the small rivets, *g*. Under the heads of one of the rings is fastened a small clip, *g'*, by which electrical connection is afterwards made with one of the terminals of the transmitter. The diaphragm of the transmitter is thus made to carry with it the chamber and both electrodes, the chamber being permanently closed by means of the mica washer riveted in place, as described. The diaphragm thus assembled is surrounded by a soft rubber ring, *b'*, held in place against the front piece by two heavy damping springs, as in the case of the solid back transmitter. The bridge, *H*, is secured at its ends to the rear face of the front, *A*. This bridge carries at its center the heavy bushing, *h*, into which the bushing, *F*, of the rear electrode fits. The screw, *h′*, serves to hold the rear electrode rigidly with respect to the bridge after it has once been adjusted.

A terminal block, *I*, of hard rubber, is secured to the rear side of the bridge upon which is mounted a terminal, *i*, to which a wire leading from the clip, *g′*, is soldered. The lug, *i*, therefore forms one terminal of the transmitter, it being in electrical contact with the front electrode. The other terminal is formed by the frame of the transmitter itself, it being in contact with the rear electrode through the bridge, *H*.

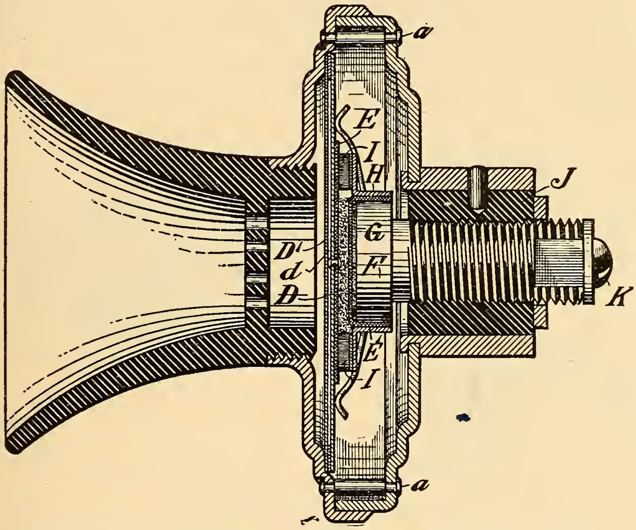


FIG. 49.—THE STROMBERG-CARLSON TRANSMITTER.

In this transmitter the piston action of the electrodes is obtained as in other forms, the rear electrode being held rigid while the front electrode vibrates with the diaphragm. The flexible mica washer serves to allow a slight relative motion between the two electrodes, this washer also serving to completely close the chamber to prevent the escape of the granules or the entrance of moisture. Besides the piston action of the electrodes, it will be seen that practically the entire mass of granules is caused to be agitated by the vibration of the diaphragm, and therefore a certain amount of microphonic action may be expected from this cause alone. Certain it is, however, that this is an exceedingly powerful form of transmitter. It was developed by Mr. W. W. Dean after a long and most careful series of experiments.

In Figs. 49 and 50 is shown the transmitter of the Stromberg-Carlson Telephone Manufacturing Company, Fig. 49 showing a sectional view of the transmitter assembled, and Fig. 50 the various working parts in detail. The working parts are all contained within a two-piece cup, the two parts of which are permanently riveted together, as shown at *a a*, after the transmitter is assembled. By thus permanently closing the cup it is not easy to tamper with the working parts, which as a result are usually left in their original state. The diaphragm, *D*, of this transmitter is of metal, but in front of it is placed an auxiliary diaphragm, *D'*, of silk, the two diaphragms being separated from each other by a ring, *d*, resting

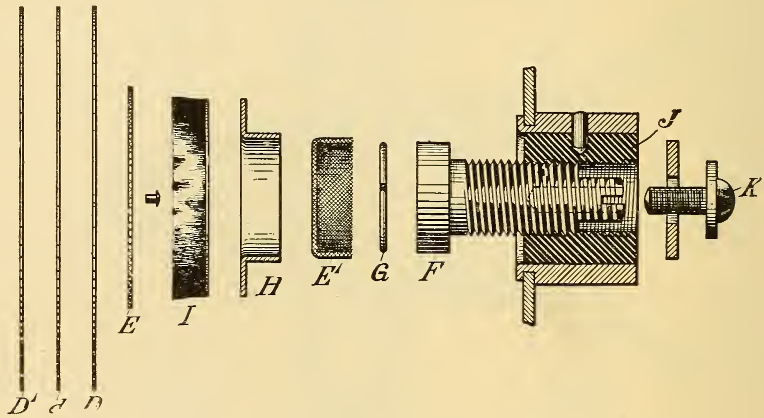


FIG. 50.—DETAILS OF STROMBERG-CARLSON TRANSMITTER.

between them. Against the rear of the metal diaphragm rest two double-armed damping springs, these being secured to the rear of the case and serving to hold the diaphragm against the front of the case and also to prevent too great an amplitude of its vibration. Riveted to the center of the diaphragm is the front electrode, *E*, this consisting of a circular piece of woven wire gauze, heavily gold plated. The rear electrode, *E'*, is in the form of gold-plated wire gauze also, pressed into cup shape and adapted to fit tightly over the enlarged head of the screw-threaded brass stud, *F*. A wire ring, *G*, is placed within the cup, *E*, before it is placed on the head, *F*, thus serving to prevent the inner face of the wire-gauze cup from coming into actual contact with the face of the head of the stud, *F*. A flanged collar, *H*, is forced tightly over the gauze cup, *E*, after it has been placed on the head of the stud, and this serves to clamp the gauze tightly on the stud.

Cemented to the front face of the flanged collar, *H*, is a thick washer of very light plush, *I*, this virtually forming the cylindrical wall of the chamber containing the granular carbon. The granular carbon used is fine enough to pass through the meshes of the back electrode, *E*, and this occupies the space between the rear face of this electrode and the front face of the stud, *F*, this space being caused by the presence of the ring, *G*, between the two. The space in front of the electrode, *E'*, and between it and the front electrode, *E*, is almost entirely filled with granular carbon, as shown in the assembled drawing. The screw-threaded portion of the stud, *F*, which carries the rear electrode, engages an internal screw-thread in the heavy rubber bushing, *J*, mounted within the rearwardly projecting collar extending from the cup, and by means of turning

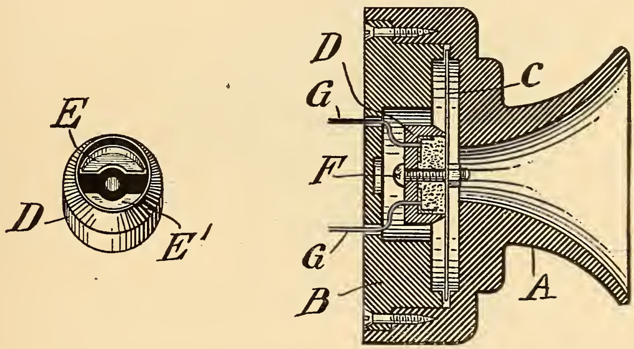


FIG. 51.—THE COLVIN TRANSMITTER.

this stud in this bushing the adjustment of the transmitter electrodes may be effected. A machine screw, *K*, passing through a washer as shown, serves to engage a tapped hole in the end of the stud, *F*, and thus bind the latter in place in the rubber bushing, *J*.

This transmitter has been put into use by customers of the Stromberg-Carlson Company to a very large extent and it has given uniformly good service, having proved to be thoroughly reliable, and remarkably free from the troubles which often beset granular carbon transmitters.

In Fig. 51 is shown a transmitter designed by Mr. F. R. Colvin which is unique in its mode of action. This was at one time put into quite extensive commercial use by Mr. Colvin, but it is not now used.

The shell is formed of two pieces, *A* and *B*, of wood, the former carrying the mouthpiece. The space in which the diaphragm fits is made large enough to hold the diaphragm very loosely so that it may vibrate with great freedom. Upon the diaphragm, which is of aluminum, is supported a hollow cylindrical cell, *D*, of insulating material (shown in the small cut at the left), carrying two metallic electrodes, *E E'*, insulated from each other. To these electrodes are connected the circuit terminals, *G G*. The shell, *D*, is clamped firmly to the diaphragm, *C*, by a bolt, *F*, thus closing the chamber containing the granules. To prevent the access of moisture to the cell, the joint between the diaphragm and its edge is hermetically sealed by an adhesive compound. The striking feature of this instrument is that the two electrodes, *E E'*, are fixed with relation to each other, the variation in resistance being obtained by the varia-

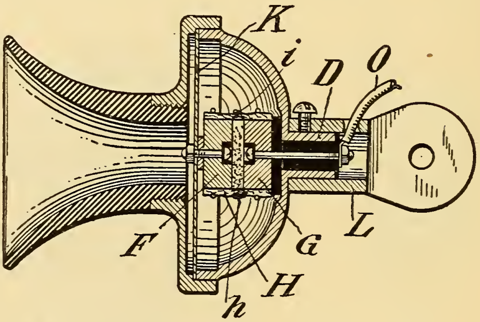


FIG. 52.—THE SUTTON TRANSMITTER.

tion in pressure between the electrodes and the carbon granules, due to the inertia of the latter, and also to the shaking up of the granules themselves, and the consequent variation of their intimacy of contact with each other.

Fig. 52 shows a transmitter typical of a large number of instruments made by the various independent manufacturing companies. This particular one was called the Sutton transmitter.

The variable resistance parts comprise a pair of carbon buttons, *F* and *G*, each surrounded by a sleeve of cloth, *H* and *I*, the abutting edges, *h* and *i*, of which are frayed out so as to form an intimate but yielding contact. These form with the buttons, *F* and *G*, a closed chamber in which the granular carbon is placed. The button, *F*, is secured to the diaphragm, *K*, as shown, while the button, *G*, is rigidly secured to the case of the instrument, and is insulated therefrom. The wire, *O*, leading from the bolt, *L*, which secures the button, *G*, in place, forms one terminal of the instrument, the casing itself the other.

The Ericsson transmitter, manufactured in Sweden, is being imported into this country to a considerable extent as a companion piece to the Ericsson receiver. This transmitter gives a very clear, soft tone, and requires little battery power. On the whole it is a very efficient instrument, except where great power is required. It is shown in section in Fig. 53, in which *a* is the sound-receiving diaphragm held against a shoulder in the brass casing, *c*, by two thin leaf-springs, not shown, each spring having two branches, so as to give in all four points bearing on the diaphragm.

For preventing moisture, especially that of the breath, from entering beyond the diaphragm a thin disc, *b*, of silk impregnated with lacquer is placed in front of the diaphragm.

The metal plate, *d*, mounted on the rear side of the diaphragm

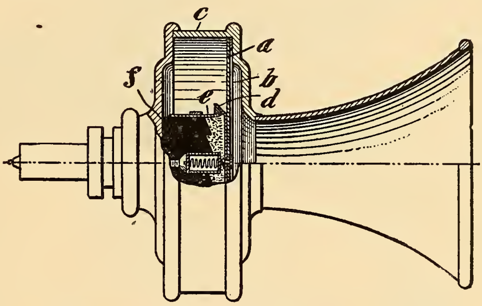


FIG. 53.—THE ERICSSON TRANSMITTER.

forms the front electrode, and for that purpose is gold-plated. The backwardly bent rim of the plate, *d*, surrounds the forepart of a soft ring, *e*, on the carbon block, *f*, and serves to prevent the carbon grains from falling out of the chamber. This soft ring is made of raveled felt, and therefore allows the free vibration of the diaphragm.

The diaphragm is damped by the coiled spring in a chamber in the center of the carbon electrode. This spring rests on a tuft of cotton or felt, which in turn bears on the center of the front electrode.

The transmitter of the old Western Telephone Construction Company (Fig. 54) is probably the simplest ever manufactured. The whole front case, *A*, of the transmitter is of a turned brass casting. It is shouldered inside to form a seat for the diaphragm, *D*, and threaded to engage an insulating cup, *B*, carrying the back electrode, *C*. This cup is screwed directly on a flange of the supporting arm, *E*, from the inside. The central screw which holds the back electrode in place also passes into the arm, thereby making the arm one terminal of the transmitter. The back electrode, *C*, is large, being $1\frac{1}{2}''$ in diameter and $\frac{3}{8}''$ thick. The chamber in which this block is mounted allows about $\frac{1}{8}''$ space all around the electrode, which space, as well as that between the diaphragm and the back electrode, contains granular carbon. The diaphragm, *D*, is of carbon, usually .016″ thick and 2 3-16″ diameter, the free portion being 1 13-16″ in diameter. The distance between the back electrode and the diaphragm is 5-64″. The chamber is only half filled with granular car-

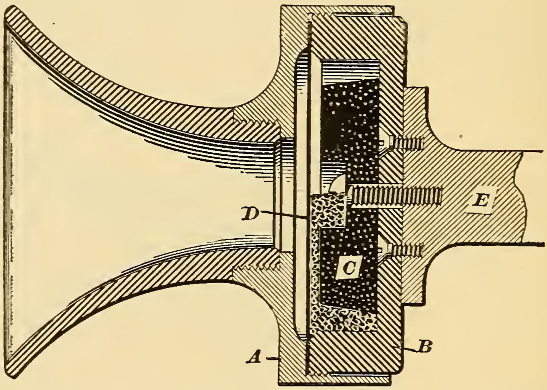


FIG. 54.—WESTERN TELEPHONE CONSTRUCTION COMPANY'S TRANSMITTER.

bon, and only the lower half of the diaphragm, therefore, is actively engaged as an electrode.

In Fig. 55 is shown a transmitter patented by Mr. T. F. Ahearn, changes in *area of contact* without changes of pressure.

E is a carbon electrode attached to the center of the metal diaphragm, *A*, and forms the terminal electrode to which the wire, *D*, is attached. This electrode consists of a plate or plates, of either semi-circular or triangular form, as shown.

The back electrode, *G*, is of similar form and is carried on the spring, *f*, in such manner as to overlap and rest on the front electrode, *E*. The pressure between the two may be regulated by the thumb-screw, as shown.

It is claimed by the inventor that in this no variation in pressure can be caused by the vibration of the diaphragm, but that the electrodes simply slide over each other, the shape of the surfaces in contact amplifying the changes in contact area.

In granular-carbon transmitters much trouble has been experienced with what is commonly known as "packing." This consists in the granules assuming such relation among themselves as to form a more or less compact mass, thus preventing the diaphragm from vibrating properly, and also failing to act as a variable resistance medium to the vibrations of which the diaphragm is capable. This may be due to a variety of causes. Sometimes, where the granules are of varying sizes, and particularly where there is a considerable amount of fine dust mingled with them, they tend to arrange themselves in layers in accordance with their size, the small ones working toward the bottom. In this state the entire mass of granules may become very compact, particularly at the bottom of the chamber, the

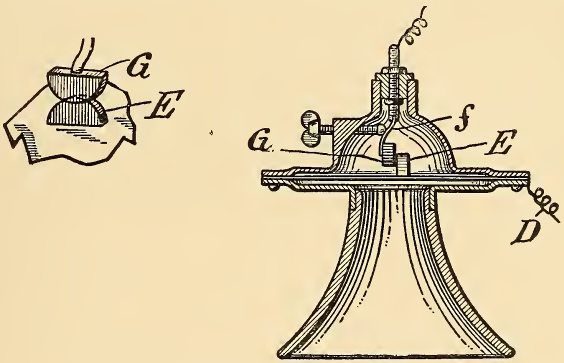


FIG. 55.—THE AHEARN TRANSMITTER.

fine dust tending to almost entirely fill the interstices between the larger particles.

Probably a more common cause for packing is that a few of the granules may become wedged between the front and back electrodes, thus preventing the vibration of the front electrode. Sometimes, in response to a very heavy sound wave, while the diaphragm is at the limit of its return stroke and the electrodes therefore at the farthest possible distance apart, the mass of granules will settle momentarily between the electrodes, and the diaphragm will be unable to spring back to its normal position. This may be demonstrated in almost any granular-carbon transmitter by placing the lips firmly against the mouthpiece, and drawing in the breath so as to draw the diaphragm forward. Upon releasing the pressure the instrument will probably be found to be perfectly dead. This is a trick often resorted to by salesmen to throw a bad light on a competitor's transmitter. To remove the possibility of packing from this cause to a large extent, most manufacturers are now either drilling a hole through the side of the mouthpieces close to the base or are making slots in the mouthpiece near its base so as to prevent the formation of a partial vacuum in front of the diaphragm. Almost any transmitter when packed may be again put in working condition by a sharp rap from beneath, as with the fist. Some transmitters, notably those where the chamber is mounted on the diaphragm, as in the type shown in Fig. 47, will gradually unpack, due to the action of the sound waves in speaking. This is due to the fact that the whole chamber vibrates with the diaphragm, thus tending to more effectually shake up the granules than when the front electrode alone vibrates.

In order to prevent packing various forms of carbon-granules have been used, among others those of spherical shape. None of these, however, have proved so effective in practice as the irregular shapes caused by merely crushing the carbons. The greatest pains should be taken, however, to secure granules of a uniform size, only those being accepted which will pass through a sieve having a certain sized mesh and which will not pass through a sieve having a slightly smaller mesh.

Before transmitters had reached their present state of perfection in design and construction, many attempts were made to insure against packing by means of mechanical agitators, some of which worked automatically. A type which was widely used employed means whereby all of the working parts of the transmitter, including the outer case, could be rotated by merely twisting the mouthpiece. The form of transmitter shown in Fig. 54 was at one time arranged in this manner, the result being that if, at any time, it appeared dead this condition could be relieved by turning it over, allowing the granules to rearrange themselves. Another scheme for accomplishing the same result automatically was to provide mechanism for revolving the transmitter, a little at a time, at every stroke of the switch hook. A ratchet was mounted on the periphery of the transmitter casing, which was engaged by a pawl carried by the switch hook. All of these devices proved futile and have been abandoned. They were based on wrong principles, their object being to correct an evil rather than to prevent it. Moreover, they introduced unnecessary complexity which the whole tendency of telephone progress is to eliminate.

CHAPTER VI.

INDUCTION COILS FOR LOCAL BATTERY TELEPHONES.

It has already been pointed out in Chapter II. that the use of the induction coil in connection with the local battery and variable resistance transmitter, is advantageous in that it allows the changes in the resistance of the transmitter to bear a much larger ratio to the total resistance of the circuit in which these changes occur than would be the case were the same transmitter and battery placed directly in series in a line of comparatively high resistance; and further, that by virtue of the transformation from a comparatively low to a high voltage, the currents are much better adapted to traversing long lines and higher resistances. It may be further pointed out that with the same battery power the current in the primary circuit is much greater, owing to the lower resistance, than if the same battery were placed in the line circuit, and therefore the transmitter is not only able to produce a greater relative change in the current flowing, but to cause these changes to act on a larger current.

Such a system of transmission as uses a battery, associated with an induction coil at each telephone, is termed "local battery" transmission, and such a telephone a "local battery" telephone. Recent tendency in a large class of telephone work has been to dispense with the local battery, using instead a single large battery for supplying a large number of lines and instruments from a single central point. Such systems of transmission are termed "common battery" or "central energy" transmission, and this distinction must be kept in mind. The present chapter, as its name indicates, deals only with induction coils for local battery work.

It should be remembered that in local battery transmission the current in the primary circuit is an undulating one, being always in the same direction. The current in the secondary, however, is alternating in character, its direction depending on whether the primary current is increasing or diminishing in strength.

The quality and dimensions of the iron core, the relation between the number of turns in the primary and secondary windings, and the mechanical construction of the induction coil are matters of importance, and have not in general received the attention they merit. A number of attempts have been made to calculate mathematically the best dimensions and resistances of the telephone induction coil, but the matter is of such an extremely complex nature, and all of the quantities are subject to such complex and almost indeterminate variations, that the results so far produced have been in general uncertain.

Fig. 56 shows a sectional view, and Fig. 57 a view in perspective of a coil which in its general method of construction is typical of practice to-day. This coil, which is that formerly used by the Western Telephone Construction Company with the transmitter

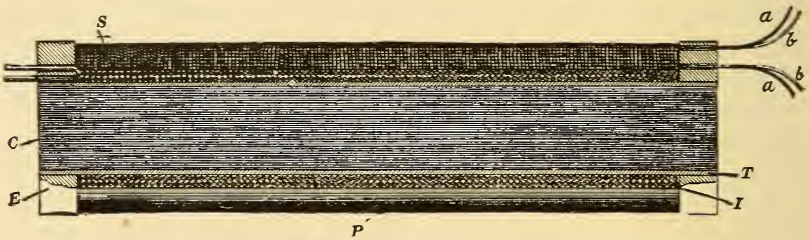


FIG. 56.—SECTIONAL VIEW OF INDUCTION COIL.

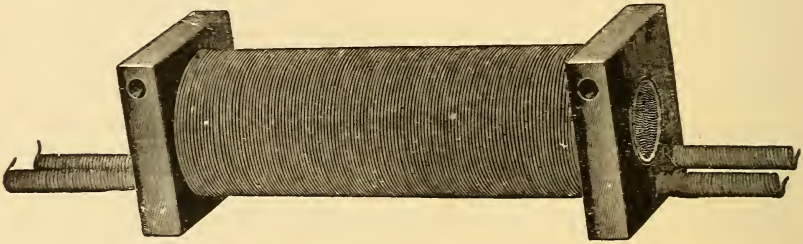


FIG. 57.—PERSPECTIVE VIEW OF INDUCTION COIL.

shown in Fig. 54, has, however, a few eccentricities which may prove instructive. The core, *C*, is formed of a bundle of about 500 strands of No. 24 B. & S. gauge Swedish iron wire, and is 4 inches in length and 9-16 of an inch in diameter. The spool is formed of a thin fiber tube, *T*, over the ends of which are slipped the heads, *E*, of similar material, the parts being glued together. On this core are wound about 200 turns of No. 20 single silk-covered wire. This is two layers deep, so that the ends of the primary both emerge from the same end of the coil. Over the primary winding are wrapped several layers of oiled paper, after which the secondary is wound, this consisting of about 1400 double turns of No. 34 wire, two in parallel. These two wires are wound side by side throughout their length, and give the equivalent area of one No. 31 wire. The resistance of the primary coil is .38 ohm and that of the secondary 75 ohms. The terminals of the secondary coil are shown at *a b* and *a b* in Fig. 56. After the coil is wound, the small wires of the secondary are attached to larger wires inside of the spool-head, so that the danger of breakage will be diminished. These leading-out wires are coiled in a tight spiral, as shown in Fig. 57, in order to avoid breakage and also to give a considerable length of wire in making connections where it is needed.

More recent experience shows that a smaller diameter of core than that used in the above-described coil gives better results, the smaller core losing, perhaps, a little in loudness, but gaining perceptibly in clearness and crispness. The use of two fine wires in parallel, as found in this coil, is illustrative of a worn-out fallacy.

FIG. 58.—INDUCTION COIL WITH TERMINALS ON HEADS.

This practice was once quite commonly resorted to in various coil windings for telephone use, on account of some fancied theoretical gain in efficiency. The gain, however, was not real and the practice was undesirable, expensive and useless. Undesirable, because two small wires are more easily injured mechanically than one large wire of the same carrying capacity; expensive, because the labor in winding is considerably greater than in the case of a single wire, as is also the first cost of the finer wire.

In modern coils a paper tube is generally used in place of the fiber, as, being thinner, it allows the winding to be placed closer to the core, an advantage in point of efficiency and economy.

A much better method of terminating the wires leading from an induction coil than that of ending them in "pigtails" is to solder them directly to brass or German silver contacts secured to the coil heads as shown in Fig. 58, or, where the coil is mounted on a separate base, to similar clips mounted on the base as shown in Fig. 59.

By either of these methods the liability of breaking the wires of the coil close to the head, or within the head, rendering repair difficult or impossible, is largely obviated. A coil built in this way

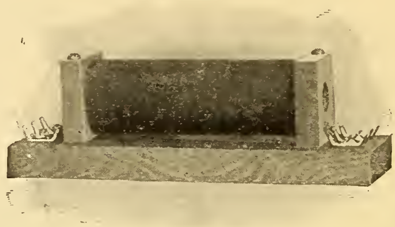


FIG. 59.—INDUCTION COIL WITH TERMINALS ON BASE.

is much more readily connected in the circuit of a telephone, on account of the substantial nature of its terminals.

A coil constructed as shown in Fig. 60 is being manufactured by the Varley Duplex Magnet Company. The core consists of a bundle of small cables, each composed of seven strands of rather fine Swedish-iron wire. On this the primary, consisting of three

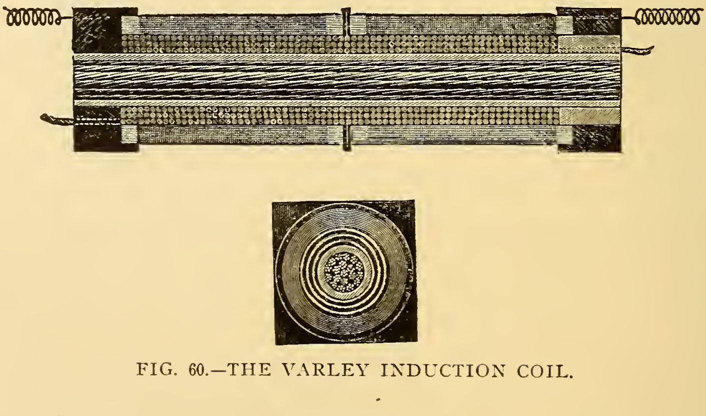


FIG. 60.—THE VARLEY INDUCTION COIL.

layers of cotton-covered magnet wire, is wound. The secondary is wound in two sections, the right-hand head of the spool being made removable, so that the sections may be removed for making repairs. Bare wire is used in winding the secondary, the adjacent convolutions of the wire being held apart by a fine thread of silk wound alongside and parallel with the wire, as shown in Fig. 61. This method of winding coils is old, having been invented by Dr. Leverett Bradley and patented by him in 1865; but it has recently been introduced by the Varley Company in the various branches of telephone work with much success. A layer of paper is introduced between each layer of wire, and in this way the insulation is made complete. The machines for winding in this manner have been perfected with such nicety that several coils are simultaneously wound, the layers of paper being automatically introduced between each layer of winding without stopping the machinery, which is run at a very high speed. Considerably more wire can be placed on a coil in a given space than with the ordinary method of winding; and the fact that bare wire is used tends to render the coil cheaper.

This same company has carried the idea of sectional windings throughout the entire field of telephone work. They construct their

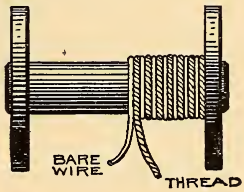


FIG. 61.—MANNER OF WINDING VARLEY COIL.

spools in such manner that the heads may be readily removed and a coil replaced without the necessity of rewinding.

It is now quite common to mount the induction coil in the base of the arm on which the transmitter itself is mounted, such construction being shown in Figs. 62 and 63. The base and arm here shown are made of cast iron joined in such manner as to allow a considerable vertical movement of the transmitter, in order to accommodate it to the heights of different users. The coil has sometimes been mounted upon the back board of the telephone, so as to be covered by the base of the arm when secured in place, but a more desirable method is to mount it in the arm-base, as shown, the various terminals being brought out to binding posts on the front of the base. This construction, however, is bad, unless well carried out, and great pains should be taken in insulating the various posts and wires from the conducting base. A considerable advantage has been claimed for this type of coil mounting, due to the presence of the iron case about the coil, thus rendering the magnetic circuit more complete. This, however, is a point of doubtful validity, as it may be claimed with equal force that the presence of the case gives rise to undue impedance and to eddy currents which would have a detrimental effect. As a matter of fact, the presence of the case has little

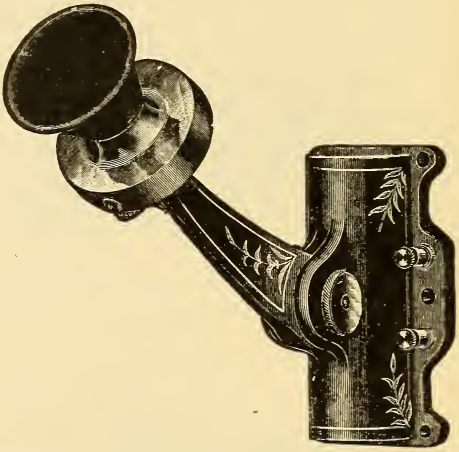


FIG. 62.—TRANSMITTER MOUNTED ON ARM.

appreciable effect one way or another on the quality of the transmission.

Only a few series of experiments are on record from reliable sources giving the results of comparative tests between induction coils of various dimensions. It may be said that definite results from any such series of tests are hard to get, as the quality and loudness

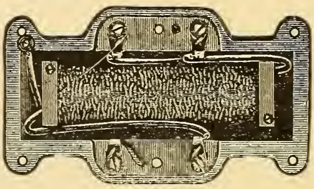


FIG. 63.—INDUCTION COIL IN BASE OF ARM.

of transmission is subject to more or less personal error, even in the case of experienced experimenters.

A series of experiments, cited by Preece and Stubbs and performed by the adminstration of the Swiss telephone department, is of interest. In this test a good Blake transmitter was used throughout, the object being to determine the best of a set of ten induction coils. Table I. gives the most important data concerning the primary and secondary windings of each coil.

TABLE I.

Number of Coil.	Primary Winding.			Secondary Winding.			Results for Various Lengths of Line.									
							31 mile		38 miles		49 miles		53 miles.		67 miles	
	Number of Convolutions.	Number of Wire, B. & S.	Resistance Ohms.	Number of Convolutions.	Number of Wire, B. & S.	Resistance Ohms.	Intensity.	Clearness.	Intensity.	Clearness.	Intensity.	Clearness.	Intensity.	Clearness.	Intensity.	Clearness.
1..	61	24	.25	1956	35	100	.3	.9	.9	1.0	.3	.7	.7	.8	.2	.9
2..	62	24	.25	3191	35	180	.7	.9	1.0	1.1	.9	1.0	1.0	1.3	.7	1.0
3..	62	24	.25	4080	35	250	.9	.9	1 0	1.3	.9	1.0	.9	1.3	.6	1.0
4..	116	24	.50	3952	35	250	1.5	1.3	1.7	1 5	1.3	1.5	1 3	1.5	1.2	1.5
5..	230	24	1.00	3865	35	250	1.3	1.0	1.3	1.2	1.1	1.3	1.3	1.5	1.0	1.3
6..	232	24	1.20	4420	35	300	1.5	.9	1.6	.9	1.7	1.3	1 7	1.6	1.5	1.5
7..	295	24	1.50	4278	35	300	1.3	.9	1.5	.9	1 1	1.1	1.5	1.4	1.6	1.3
8..	368	24	2.00	4735	35	350	1.3	1.0	1.5	.9	1 1	1.0	1.5	1.4	1.6	1.2
9..	368	21	1.17	4735	29	130	1.7	1 0	1.6	.9	1.7	1.4	1.6	1.6	1 7	1.3
10.	1350	24	10.00	3950	35	400	.3	.3	.8	.5	.3	.3	.3	.4	.3	.1

The results obtained over five different lengths of line are shown in the right-hand portion of the table. In each case the intensity and clearnes of the Blake transmitter with a standard coil was taken as unity, and the results are expressed in terms of this standard. The resistance of the primary wire of this standard coil was 1.05 ohm and that of the secondary 180 ohms. It will be noticed from the results that coils Nos. 4, 6 and 9 were, all things considered, the best, while coils Nos. 1 and 10 were very inferior. The table also shows in general that a coil that was good for a short distance was also good for a long distance, and this is perhaps the most insti uctive lesson to be gained from these tests. It is hard to draw any definite conclusions from the performances of the various coils as to their relative merits and to point out why coils Nos. 4, 6 and 9 should give better results than the others, or why coils Nos. 1 and 10 should be so much inferior. It shows, moreover, that good results may be obtained with the same transmitter and with coils differing widely as to their characteristics; this being shown particularly in the case of coils Nos. 4 and 9, the former having a secondary of 250 ohms and a primary of ½ ohm, while the latter had a secondary of 130 and a primary of 1.17 ohm. The coil adopted for the Blake transmitter in this country has a primary winding of ½ ohm and a secondary of 250 ohms, which, it will be seen, corresponds exactly to coil No. 4 in this table, which gave the best results.

With modern transmitters for local battery work, which use a much stronger current than the Blake tendency among the manufacturing concerns whose practice may be considered the best, is to reduce the ratio of transformation by making the number of turns on the secondary windings very much lower than was formerly the case. As an extreme example of this, it may be cited that the coil recently used to a large extent with the solid-back transmitter on the long-distance lines of the American Telephone and Telegraph Company had a primary of .3 ohm and a secondary of but 14 ohms resistance. This coil was provided with a very large core composed of a bundle of soft-iron wires, and its total length between the heads was six inches. This coil proved effective, but undoubtedly had too much iron in its core for clear articulation. Its use has therefore been generally abandoned.

Table II. shows the principal data for the induction coils used for local battery telephones by several different manufacturers. These various manufacturers have evidently adopted the coil design, which seemed to them to give the best results with their particular transmitters. This table is of interest in showing how widely diversified the practice is in this regard.

The matter of comparative tests for induction coils deserves some attention. Since the induction coil in the local battery telephone plays no part save in the transmission of speech, it follows that the best coil is that which will give the best transmission, and by best transmission is not meant, necessarily, that which is loudest, but that which, all things considered, is best and most easily understood over those lines on which the induction coil is to be used.

It may be said in general that in making comparative tests as to the transmission efficiency of any piece of telephone apparatus, it is of great importance that all possibility of prejudice on the part of the experimenter be removed, and, in order to do this, it is desirable that he be in ignorance at all times of the particular instrument that he is testing.

Another thing to guard against in making tests of this kind, is that the hearer shall not give undue consideration to the factor of loudness. That piece of apparatus which gives the loudest transmission is not necessarily the best, and even greater stress should be placed on the quality of tone and clearness.

Tests are frequently made by reading certain subject matter to the listener, using one piece of apparatus in the transmission, and then reading the same matter, using another piece of apparatus for

TABLE II.—DATA CONCERNING LOCAL BATTERY INDUCTION COILS.

MAKE OF COIL.	Primary Winding.				Secondary Winding.				Length of Core.	Diameter of Core.	Diameter of Winding.	Depth of Winding.	Distance Between Heads.
	Resistance.	Kind and Size of Wire.	No. Turns.	No. Layers.	Resistance.	Kind and Size of Wire.	No. Turns.	No. Layers.					
Stromberg-Carlson.......	.90	No. 22 single silk	450	3	70.	No. 30 single silk	2,285	11	$4\frac{1}{8}''$	$\frac{7}{16}''$	1″	$\frac{9}{32}''$	$3\frac{1}{2}''$
North Electric Co.......	1.6	No. 25 single silk	620	5	290.	No. 36 single silk	3,360	10	$3\frac{1}{4}''$	$\frac{5}{16}''$	$\frac{3}{4}''$	$\frac{7}{32}''$	$2\frac{1}{2}''$
Kellogg Switchboard and Supply Co............	.35	....	...	..	32.	....	......	..	$3\frac{1}{8}''$	$\frac{1}{4}''$	..	..	..
Western Electric (Bell No. 13)...............	1.7	No. 22 single cotton	400	3	20.6	No. 28 single cotton	1,700	$12\frac{1}{3}$	$3\frac{1}{4}''$	$\frac{1}{4}''$	1″	$\frac{5}{61}''$	$2\frac{1}{2}''$
Western Electric (Bell No. 16)...............	1.7	No. 26 single silk	400	3	18.	No. 28 single silk	1,700	10	$3\frac{1}{4}''$	$\frac{1}{4}''$	$\frac{3}{4}''$	$\frac{1}{4}''$	$2\frac{1}{2}''$
Sun Electric Co..........	.33	No. 18 single silk	385	3	22.4	No. 26 single silk	2,260	10	$5\frac{1}{8}''$	$\frac{1}{2}''$	$1\frac{1}{8}''$	$\frac{5}{16}''$	$4\frac{1}{2}''$
Western Telephone Construction Co............	.66	No. 22 single silk	295	2	100.	No. 30 single silk	2,430	6	4″	$\frac{1}{2}''$	$\frac{7}{8}''$	$\frac{3}{16}''$	$3\frac{1}{2}''$

comparison. This is always unfair to the merits of the first piece of apparatus, for the listener will be more familiar with the matter on the second reading than on the first; will understand certain words the second time that he missed the first time, and is very liable to attribute this to better transmission rather than to the fact that he has had two chances instead of one of understanding the matter read. The method of reading passages of considerable length, first over one instrument and then over another, is also faulty, because the person transmitting cannot maintain the same loudness and distinctness of articulation throughout the entire test, nor can the person listening make a distinct comparison between what he hears over one instrument and that which he hears over another, on account of the lapse of time between the two tests. A better way of making transmission tests, and one which has been adopted by those most experienced in this line of work, is to so arrange the apparatus that the several instruments or apparatuses under test may be switched into and out of the circuit of the line instantly, so that no loss of time occurs between the tests. Instead of transmitting long sentences of unfamiliar matter, the person at the transmitting end repeats alternately over each instrument, some short and perfectly familiar matter, designating in each case the number of the instrument over which he is speaking. Good subject matter for transmission in this way is by merely counting up to five on each instrument, and stating at the end the number of the instrument over which the count was made, thus: "1, 2, 3, 4, 5, on No. 1," and "1, 2, 3, 4, 5, on No. 2," etc. Constant repetition of this, first on one instrument and then on another, may be made without the transmitting party changing his tone, and the party listening may finally decide whether No. 1 or No. 2 is the better, by noting the several characteristics of each transmission and carefully fixing them in his mind at each recurring time until he finally reaches a definite conclusion. He may then transmit his conclusion back to the sending party, informing him that No. 1 or No. 2 has made the better test.

These are apparently unimportant points, but the quality of voice transmission on telephone lines is such a subtle characteristic that it is only by eliminating, as far as possible, the personal equation of the experimenters, that results of any value may be obtained.

Coming more particularly to the subject of testing induction coils, Fig. 64 shows the circuit for making a comparative test between three different coils, using a fourth as a standard. The same set of apparatus is used at each end of the line, the circuit arrangement being such that by placing any one of the four-lever, double-throw switches to the left or right, the particular coil to which the switch thrown corresponds will be switched into or out of the proper circuit relation with the line, and the receiver, transmitter and battery at each end. Throwing any switch will connect both primary and secondary coils simultaneously. When all of the switches are in their normal positions, the coil connected at the end of the series of switches, as that marked "Standard" in the figure, will be connected. Thus, in making comparison between the "Standard" and any of the other coils, it is only necessary to throw the switch be-

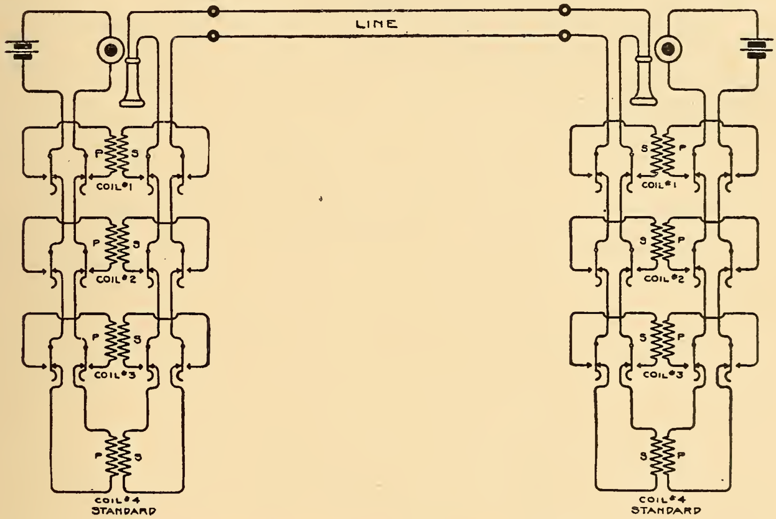


FIG. 64.—CIRCUIT FOR COMPARATIVE TESTS OF INDUCTION COILS.

longing to that coil which it is desired to compare with the "Standard." If coil No. 3 is to be used as a standard its switch would be thrown, and then coils No. 1 or No. 2 could be compared with it by throwing their respective switches.

Mr. R. H. Manson, of Chicago, using circuits and apparatus arranged as shown in this figure, conducted a comparative test on a line extending between Columbus and Cleveland, Ohio. All of the coils, the data of which are shown in Table II., were used in this test, the Western Electric or Bell No. 16 coil being used as a standard.

The conclusions arrived at in this experiment favored the coils having the small core and small winding area. It was found that the coils having large cores and large winding areas were uniformly louder but poorer in quality than those having smaller cores and smaller winding areas.

Experiments were made in talking over a large coil at the transmitting station to a small coil at the receiving station and vice versa, each of these latter tests proving that the small coil would lose in transmitting but would gain in receiving. The small coil at the receiving end with a large coil at the transmitting end would always give better results than where two large coils were used together, and two small coils always gave better results, all things considered, than a large and a small coil.

In tests using the same kind of coil at each end, it was found that on noisy lines the large coils, with their large volume of transmission, were not as efficient as the small coils with their clearer but weaker transmission.

CHAPTER VII.

PRIMARY BATTERIES.

If a sheet of zinc and one of carbon be separated from each other and immersed in a liquid capable of chemically attacking the zinc, a difference of potential will at once be formed between the two plates. If the two plates are then connected together by a wire, a current of electricity will flow from one to the other through the wire, and while the current is so flowing the zinc will be eaten away by the solution with more or less rapidity. Such a combination is called a voltaic cell, and two or more of such cells may form an electric battery. Of course other substances than zinc and carbon may be used, it only being necessary that both plates be of conducting material and that one of them shall be of such a nature as to be chemically attacked by the fluid. The two plates of the cell are called electrodes, and the solution in which they are immersed the electrolyte.

The current is assumed to flow from the plate which is attacked through the electrolyte to the one which is not, and therefore in the cell under consideration from the zinc to the carbon plate. The plate which is attacked is therefore always called the positive plate or electrode, and the one which is not attacked the negative.

Starting from the surface of the zinc, where the chemical action is taking place, the current flows through the electrolyte to the surface of the carbon electrode, thence by means of the wire back to the zinc electrode.

It will be noticed that the current flows from the carbon to the zinc in the wire, outside the electrolyte; and therefore in order to make the terms positive and negative properly refer to the poles with respect to the current flowing in the external circuit, the carbon terminal is called the positive pole and the zinc terminal the negative pole. It seems at first a little confusing to have a positive pole on a negative plate, and a negative pole on a positive plate; but if the direction of the current be kept in mind as being always from positive to negative, no confusion will arise.

The part of the circuit outside of the battery connecting the two poles is called the external circuit. The internal circuit is of course through the two electrodes and the electrolyte, and the resistance of this latter path is called the internal resistance of the cell.

Zinc forms the active or positive electrode of most primary cells, while the negative electrode is usually of carbon or of copper. No matter, however, of what materials the electrodes are formed, that which is attacked by the electrolyte while the battery is in action forms the positive plate of the cell, the current flowing always from it in the electrolyte.

In nearly all cases hydrogen is liberated from the electrolyte at the negative plate—that is, at the plate which is not attacked. This forms a film over the surfaces of the negative electrode which, unless removed or destroyed, tends to greatly weaken the strength of the cell, for two reasons: first, the film of gas is of very high resistance, and therefore raises the internal resistance of the battery enormously, thus causing a correspondingly small flow of current; and second, the gas is itself attacked by the electrolyte, hydrogen having almost as great an affinity for the oxygen in the latter as has the electrolyte itself for the zinc. This causes a counter-electromotive force to be set up which to a large extent neutralizes that set up by the action of the electrolyte with the zinc. The phenomenon of the collection of hydrogen on the negative electrode in a cell is called polarization; and it is necessary to adopt some means to prevent it to as great an extent as possible, as otherwise a cell would become useless after a very short period of use.

The LeClanche cell, which is used to great extent for telephone work, has a negative electrode consisting of carbon and peroxide of manganese, a positive electrode of zinc, and an electrolyte of a solution of sal ammoniac. The sal ammoniac attacks the zinc, forming zinc chloride and liberating hydrogen and also ammonia gas on the surface of the carbon. The peroxide of manganese, which is usually in small lumps, closely associated with the carbon, is exceedingly rich in oxygen, which slowly unites with the free hydrogen to form water, thus getting rid to a large extent of the polarizing effect of the hydrogen. The peroxide of manganese is, however, not merely a depolarizer, as it is usually considered, but is an essential part of the negative electrode. This is proved by the E. M. F., which is as great as we have a right to expect between zinc and peroxide of manganese in a sal ammoniac solution, but is greater than we are justified in expecting or can obtain from a zinc carbon couple in a like solution. In use, cells of this type polarize rather quickly, but as soon as the external circuit is opened they slowly recover, owing to a combination of the hydrogen with the oxygen. This cell is therefore suitable only for cases where the circuit will be closed for a few minutes at a time; and this is exactly the condition met in telephony.

The cell shown in Fig. 65 was once widely used by the Bell companies, one cell with each Blake transmitter. The zinc electrode is in the form of a rod, while the carbon electrode is imbedded in a porous pot of clay which is immersed with the zinc in the electrolyte. Around the carbon within the porous pot is packed a mixture of black oxide of manganese and broken carbon, the latter

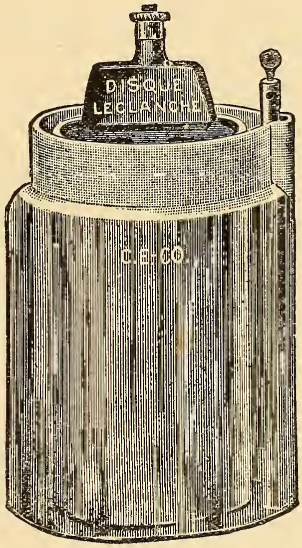


FIG. 65.—THE LECLANCHE CELL.

to give greater conductivity to the mixture and a greater surface to the carbon electrode.

A cell using practically the same materials for its various parts, but dispensing with the porous cup of clay, is shown in Figs. 66 and 67, the latter being a sectional view. The carbon electrode is in the form of a corrugated hollow cylinder, 1 (Fig. 67), which engages by means of an internal screw-thread a corresponding thread on the under side of a carbon cover, 2. Within this cylinder is a mixture, 10, of broken carbon and black oxide of manganese.

The zinc electrode, 6, is in the form of a hollow cylinder almost surrounding the carbon electrode, and separated therefrom by means of heavy rubber bands stretched around the carbon. The rod forming the terminal of the zinc passes through a porcelain bushing on the cover-plate, so that a short-circuit cannot take place. The terminal pin, 8, is imbedded as shown in a hole, 4, in the carbon cover, by first heating the cover to a high degree and then pouring in melted lead. This forms, with the nut, 7, and the washer, 6, a very secure form of connector for the positive pole. Unless some such precaution as this is taken, corrosion soon sets in around the metallic connection to the carbon, thus causing a poor connection. These cells are used to a large extent by the independent telephone companies in this country. They have an electromotive force of about 1.55 volts, and recuperate very quickly after severe use.

Another form of sal-ammoniac battery differing from that shown

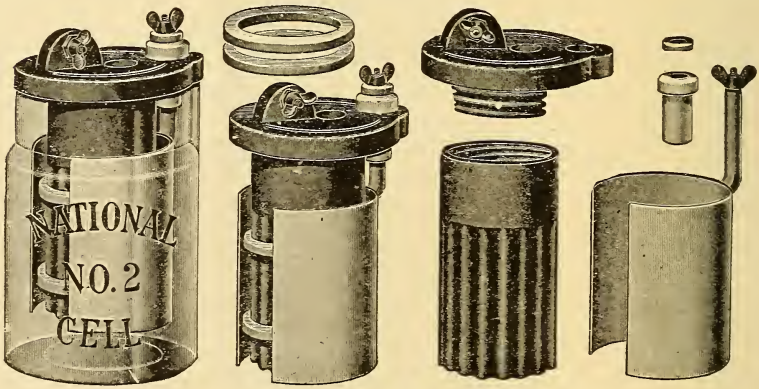


FIG. 66.—CARBON CYLINDER LECLANCHE CELL.

in Fig. 67 principally in that the parts of the negative element are contained in a canvas bag rather than in a porous cup of clay is shown in Fig. 68. This bag is suspended from the fiber plate forming the cover for the containing jar, which cover also has a hole through which the zinc rod forming the positive element may pass. This type has proved a success in practice and has largely replaced the type using the clay cup in those places where wet batteries are still used.

Many other forms of sal-ammoniac cells are in common use. Some of these consist merely of a zinc rod hanging in the center of a carbon cylinder, no depolarizer being furnished. In other forms the carbons have molded with them the manganese depolarizer and are in various shapes, but all act in the same general way.

The advantages of the LeClanche type of cell for telephone work are many. They are inexpensive in first cost and in renewals. They are very cleanly, giving out no noxious fumes and containing no highly corrosive chemicals. They require almost no attention, the addition of a little water now and then to replace the loss due to

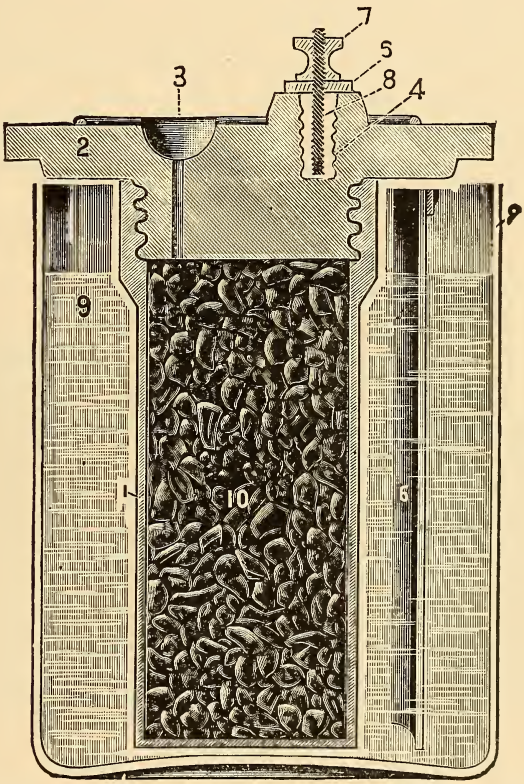


FIG. 67.—SECTIONAL VIEW OF CARBON CYLINDER LECLANCHE CELL.

evaporation being about all that is generally required. They give a rather high electromotive force and have a moderately low internal resistance, so that they are capable of giving a considerable amount of current for a short time, and lastly, if properly made, they recuperate quickly after polarization due to heavy use.

The following directions should be observed in setting up and maintaining LeClanche cells: To set up, place not more than four ounces of prime white sal ammoniac in the jar. Fill the jar one-third full of water and stir until the sal ammoniac is all dissolved. Then place the carbon and zinc elements in place. A little water poured in the vent-hole of the porous-pot forms will tend to hasten the action. Unless a cell is subject to very severe use, it will require but little attention if it is a good one. Water should be added to supply loss by evaporation. If the cell fails to work, examine its terminals for poor connections. If the zinc is badly eaten, replace it with a new one. If this fails to improve it, throw out the solution and refill as at first. If now the cell does not work properly, the porous pot or carbon element may be soaked in warm water, and if this gives no better results they should be replaced. In the cells shown in Figs. 66 and 67, the depolarizer may be removed by unscrewing the carbon from the cover. In commercial work, however,

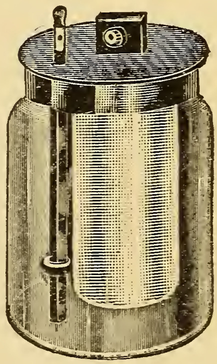


FIG. 68.—BAG TYPE LECLANCHE CELL.

it seldom pays to attempt to repair a negative element after it has become ineffective.

The Bell Companies before their almost universal adoption of common battery systems used in their long-distance work, in connection with the solid-back transmitter, another form of cell known as the "Standard" Fuller. In this the positive electrode is a heavy block of zinc molded into conical form around a heavy copper wire, which forms the negative pole. The negative electrode is a block of carbon hanging through a slot in a wooden cover. The separate parts are shown in Fig. 69. The zinc rests in the bottom of a porous cup when in place. The electrolyte for this cell is made as follows:

Sodium bichromate	6 ounces
Sulphuric acid	17 ounces
Soft water	56 ounces

Dissolve first the sodium bichromate in the water and then add slowly the sulphuric acid. (Never pour the water into the acid.) The mixture should be made in an earthen vessel, or if in a glass jar, the jar should be placed in cold water in order to prevent over-heating.

Another solution called electropoin fluid may be used as the electrolyte in this cell. It is made of bichromate of potash instead of bichromate of sodium.

The cell is set up according to the following directions:

Place the quantity of solution made by the above formula in the glass jar.

Put one teaspoonful of mercury in the bottom of the porous cup,

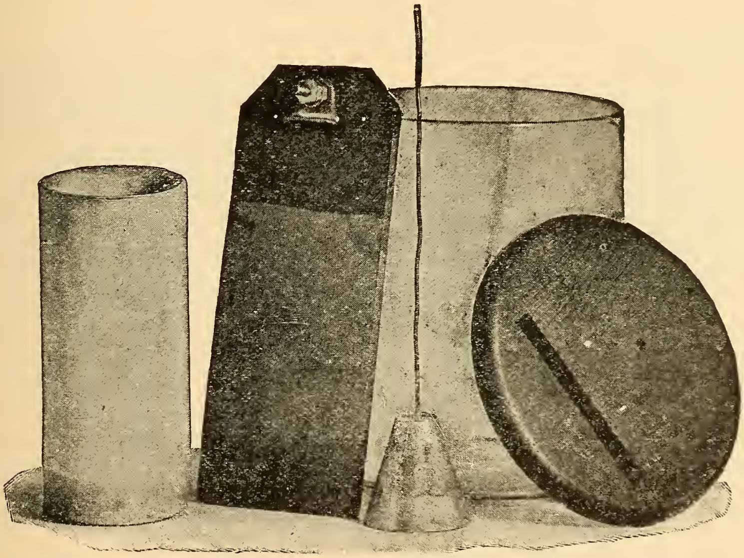


FIG. 69.—PARTS OF "STANDARD" FULLER CELL.

add two teaspoonfuls of common salt, place the zinc in the bottom of the cup, and fill to within two inches of the top with soft water.

Place the porous cup in the jar and put on the cover, passing the wire from the zinc through the hole provided for it. The cell is then ready for use.

The active element in the electrolyte in this cell is the sulphuric acid, which of course attacks the zinc. The bichromate of sodium or of potash serves as a depolarizer, the oxygen in it combining with the hydrogen, liberated at the positive pole, to form water.

The character of the electrolyte, containing as it does a most vigorous acid, makes necessary great care that the proper methods and materials be used in the construction of Fuller cells.

The following specifications governing the furnishing of these cells have been used with good results:

One cell of "Standard" Fuller battery shall consist of the following parts: 1 glass jar; 1 wooden cover; 1 carbon plate with binding post and lock-nuts; 1 cast zinc; 1 porous pot—all as hereinafter specified.

Glass Jar: The glass jar shall be of first quality flint glass, cylindrical in form, 6 inches in diameter and 8 inches in depth.

Wooden Cover: The cover shall be of clear, kiln-dried whitewood. It shall be thoroughly coated with two coats of asphalt paint, and be of such dimensions as to form a proper cover for the jar.

Carbon Plate: The carbon plate shall be of rectangular form and approximately 4 inches wide, 8¾ inches long, and ¼ inch thick, no dimension to vary more than 1-16-inch. It shall be of good quality, homogeneous and free from flaws, cracks, and other defects, and completely carbonized. Each carbon shall be provided with a suitable clamp or terminal. The parts of the clamp shall be of bronze, and shall be nickel-plated. Before attaching the clamp to the carbon, the carbon shall be heated in a temperature of at least 250 degrees Fahrenheit, and the top portion of it shall be immersed in paraffin at a temperature of about 250 degrees Fahrenheit, the immersion to continue until the immersed portion of the carbon is saturated. After the clamp is attached to the carbon, but before the lock-nuts are in place, the carbon shall be immersed in melted paraffin at a temperature less than 170 degrees Fahrenheit. The carbon plate is then to be completed by attaching the lock-nuts.

Cast Zinc: The zinc shall be in the form of a truncated cone 2½ inches in diameter at the base, 2½ inches high and 1 inch in diameter at the top. It is to be made of Rich Hill spelter. Cast into the zinc shall be a soft copper wire .1018 of an inch in diameter (No. 10 B. & S. gauge). The wire is to extend 8 inches above the zinc. The zinc and the copper wire shall be amalgamated to a height of 4 inches.

Porous Pot: The porous pot shall be cylindrical in form, 3 inches in diameter and 7 inches deep.

The Fuller cell made according to the above specifications gives an E. M. F. of 2.1 volts, and was found by the New York Telephone Company to be the most practical cell then available for its heaviest telephone service. A still more powerful cell, and one somewhat more convenient to handle, is shown in Fig. 70.

In this the zinc is very heavy, and in order to present a greater surface to the electrolyte has a horizontal cross-section in the form of a cross. The carbon electrode is in the form of a hollow cylinder completely inclosing the porous pot. The carbon cylinder has a flaring top provided with a flange which fits over the upper edge of the glass jar, thus forming a very complete cover for the entire cell.

The following are the data given by a manufacturer concerning the main points of this form of Fuller cell:

E. M. F., 2.1 volts.

Current, about 8 amperes.

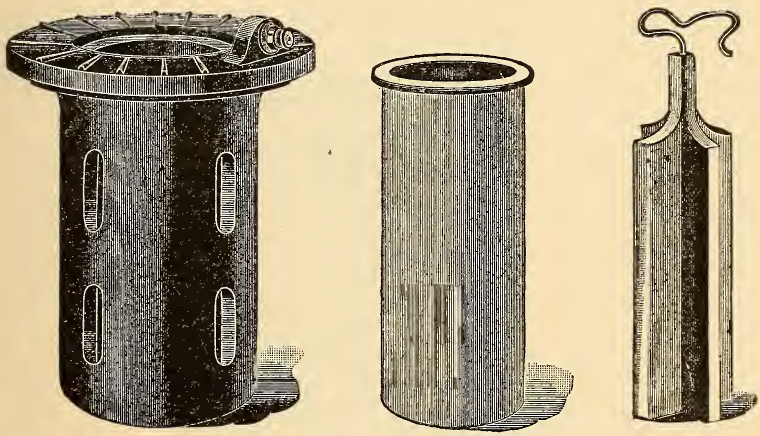


FIG. 70.—PARTS OF FULLER CELL WITH CYLINDRICAL CARBON.

Carbon, 4½ inches diameter by 8½ inches over all.

Carbon surface exposed to solution, 156 square inches.

Zinc weighs 2 pounds; 2¼ inches across; total length, 8 inches.

Zinc surface exposed, 54 square inches.

Porous cup, 3 inches diameter, 7 inches long.

Jar, 6 inches diameter, 8 inches deep.

Solutions same as "Standard" Fuller cell.

Cell, complete, weighs 8 pounds 12 ounces.

The internal resistance of Fuller cells is very low, especially in the cylindrical carbon type. They will stand for several months on open circuit with but little local action.

Formerly three cells in series, giving six volts, were used in local battery work with the solid-back transmitter, but it has been found that two cells give, all things considered, as good or better results.

Still another form of battery, of entirely different type, is shown in Fig. 71. This is known as the gravity battery, and is used to a very large extent in telegraph service, and also in telephone work where it is necessary to have a small but constant current always flowing. In this cell the negative electrode is of sheet copper, 3 strips of which are riveted together at their centers, after which the ends are bent outwardly, so as to present a large surface to the electrolyte. The zinc is in the form of a "crow foot," cast with a lug adapted to hook over the edge of a glass jar. In setting up this battery the copper is first put in place in the bottom of the jar. Sulphate of copper, or blue vitriol, as it is called, is then filled in

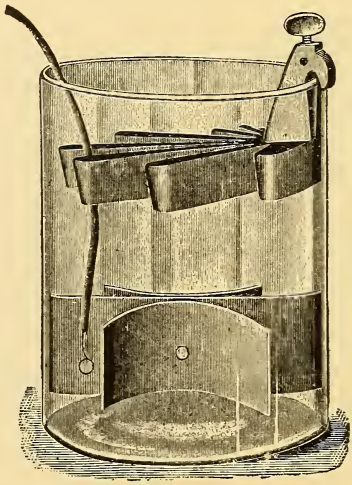


FIG. 71.—THE GRAVITY CELL.

around the copper to a height almost sufficient to cover it. The jar is then filled with water and the zinc put in place.

In this battery sulphuric acid is formed, which attacks the zinc to produce zinc sulphate. This fluid is lighter in weight than the solution of copper sulphate and therefore occupies the upper portion of the cell. The fact that the two solutions in this battery are kept apart by gravity instead of by the use of a porous pot, as in the Fuller cell, is accountable for the name, "gravity cell." As the zinc sulphate is colorless, while the copper sulphate is of a dark-blue color, the separating line between the two liquids is easily distinguished. This line is termed the "blue line," and should be kept about midway between the copper and the zinc. If the blue line rises too high, so as to come in contact with the zinc, it should be lowered. This can be done by short-circuiting the battery for a short time, or by drawing off some of the blue fluid with a siphon and filling in with water or with zinc sulphate from another battery. In cases, however, where the battery is in constant use, it very rarely happens that the blue line reaches too high a level, and the reverse is more likely to take place. If the blue line reaches the upper portion of the copper, more crystals of bluestone should be dropped in, and if this does not remedy the difficulty some of the zinc sulphate from the top of the cell should be siphoned out and replaced by clear water. These batteries are very satisfactory

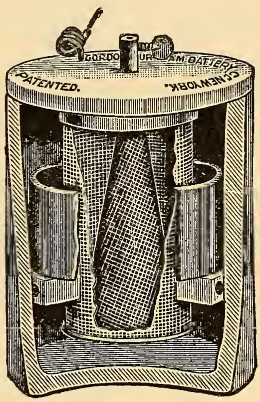


FIG. 72.—THE GORDON CELL.

for closed-circuit work, but are not well adapted to telephone work in general on account of their high internal resistance.

A cell of more recent origin than any of the types so far described has come into limited use for certain classes of telephone work. This is the Gordon cell, shown, assembled and in parts, in Fig. 72. The negative element consists of a perforated tin cylinder, filled with black oxide of copper, which is a powerful depolarizing agent. Three porcelain lugs or cleats are attached by iron bolts to the lower portion of the tin cylinder, and upon these rest the rolled zinc cylinder forming the positive element. This electrolyte is a strong solution of an alkali termed by the manufacturers "electro-sodium." It is probably simply caustic soda. The size of the zinc for a 6″ x 8″ cell is $5\frac{1}{2}$″ in diameter and $2\frac{1}{2}$″ wide, containing about $1\frac{1}{2}$ pound of amalgamated zinc. A No. 12 B. & S. gauge insulated copper wire fastened to the zinc extends through a porcelain bushing in the cover and forms the negative pole. The positive pole is formed of a metal rod passing through a porcelain bushing in the center of the lid. This rod serves to support the entire negative element to which it is fastened. After the cell is set up complete a layer of oil is poured over the top of the solution to prevent evaporation.

The electromotive force of this cell is low in comparison with most other cells, being very close to .66 volt under working conditions. The internal resistance is about .04 ohm. The 6″ x 8″ cell has a capacity of 300 ampere-hours when discharged at a rate varying from one to six amperes. Larger sizes of cells are made, with capacities said to be as high as 1000 ampere-hours.

This cell is adapted to open or closed-circuit work, particularly the latter, where a small current is required steadily for a long time. It has the advantage of requiring little or no attention until completely exhausted, of maintaining a constant electromotive force throughout its life, of being non-freezing at all ordinary temperatures, and of being free from local action. It is frequently used as a reserve battery in small common-battery exchanges to supply current, if for any reason the charging current for the storage battery fails. It is, however, not economical to use it for the regular source of current supply in such exchanges, as has often been proven.

When any battery is idle there should be no action between the electrolyte and the zinc. This would be the case were it economical to use perfectly pure zinc, but inasmuch as commercial zinc always contains impurities, frequently consisting of other metals, a local galvanic action is set up, the impurities forming with the zinc minute galvanic couples. In order to reduce this action to a minimum, it is advisable, especially in such cells as the Fuller, to amalgamate the zinc—that is, to coat it with mercury. This seems to give a perfectly homogeneous surface to the zinc, which prevents local action. The fact that this local action takes place on account of impurities in the zinc makes it very clear that the quality of metal used is a matter of very great importance.

A type of primary cell, known as the dry cell, is coming into constantly increasing favor in telephone work. These cells are not strictly dry, for their very action depends on the presence of moisture. If they become really dry chemical action ceases, and with it their capabilities to generate a current. The term "dry cell" is not, however, amiss, as these cells have none of the disadvantages due to the possible spilling of liquid possessed by all of the cells so far described.

In these cells the electrolyte, instead of being in the form of a free liquid, is held absorbed by some porous substance, such as sawdust, blotting paper, or like material, the cell being sealed to prevent evaporation.

One of the best of these dry cells is shown in section in Fig. 73.

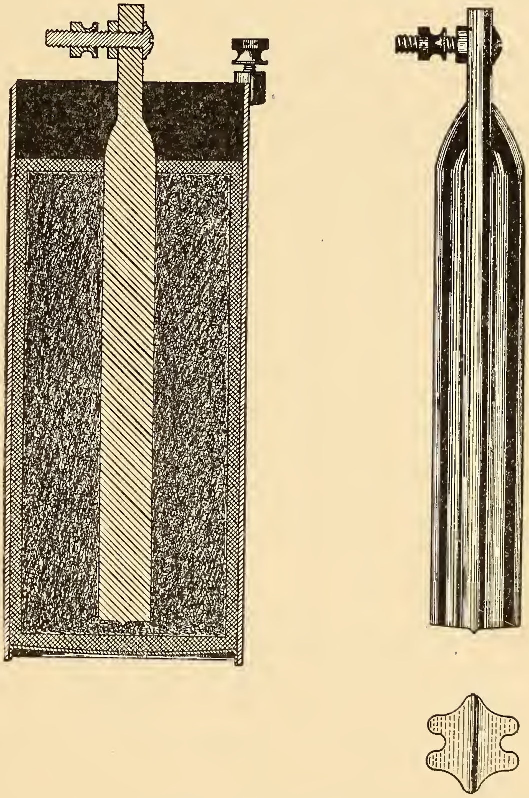


FIG. 73.—DRY CELL.

The outer casing is of zinc, carefully formed into a cup, so that it serves not only as a retaining chamber but also as to the positive electrode. The negative electrode is a carbon rod, shown in detail at the right. This is held in the center of the cup, out of contact with it, the intervening space being filled with a mixture of peroxide of manganese, powdered carbon, and some moisture-retaining porous substance, the whole being saturated with a solution of sal ammoniac. The exact formulæ used by various manufacturers are not made public. A cylinder of several thicknesses of blotting-paper lining the inside walls of the zinc chamber serves to prevent the carbon and manganese from coming directly in contact with the zinc.

After assembling, the zinc chamber is closed with a substance resembling sealing wax poured in while hot, and an outer casing of pasteboard put on. This outer casing has no other function than to insulate the zinc cup from surrounding objects. The end of the carbon plate projecting through the sealing material is provided with a binding post, serving as the positive pole of the cell, while an upwardly extending rod from the zinc casing carries a binding post which serves as the negative pole.

The early forms of dry cells were uniformly condemned by telephone men, and justly so, as they proved to be wholly unreliable. This fact, together with the fact that some of the old forms are still manufactured, has served to prevent the adoption of dry cells in some localities, to as great an extent as their real merit warrants.

It is now believed that for local battery telephone work the dry cell, when properly made, is superior to any of the wet forms of zinc-carbon cells using sal ammoniac as an electrolyte. They have been so perfected chemically and electrically that they have as great, or greater, outputs, and better recuperative power than any of the other types of LeClanche batteries, while in point of convenience and economy, their small size and non-breakable and non-spillable features and low cost leave no room for comparison.

Among companies using large numbers of local battery telephones, the question of the electrical efficiency and of the life of the battery is of much importance, yet the choice of a battery is too often made on account of low first cost or on account of the claims of the selling agent rather than on the basis of a practical commercial test. The significance of this will be apparent when it is stated that among the well-known dry cells now on the market in the United States, there is a difference in point of "telephone life," in the ratio of about four to one. In other words, the best types will remain effective in actual telephone service practically four times as long as the poorer types. This would mean that in exchanges where the poorer type of cells was used, the batteries would have to be renewed practically four times as often as would be necessary if the better grade were used under the same conditions. Thus, beside the actual cost of the cells, the company is forced to pay for labor and carfare for four renewals, where only one would be necessary with the better cell.

Frequently battery tests are made by simply short-circuiting the cell for a given period, or by closing its circuit permanently through a certain resistance and noting the time taken for a cell to completely discharge or to discharge until its voltage is reduced to a certain amount. These methods are not fair and lead to erroneous conclusions. These conditions are not those of practical telephony;

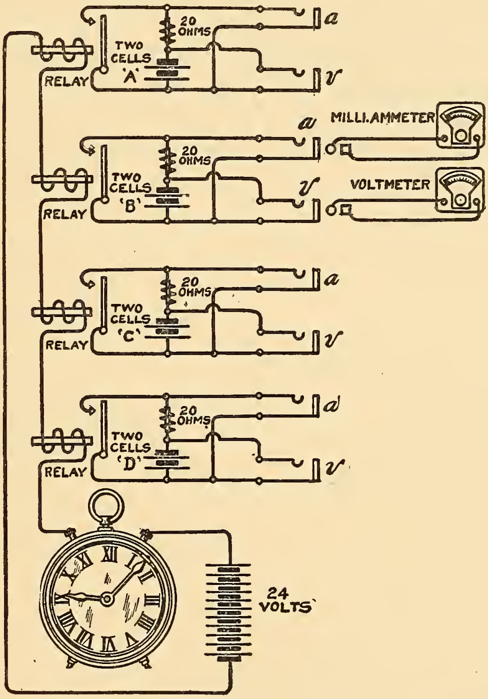


FIG. 74.—METHOD OF TESTING PRIMARY BATTERIES.

cells designed for open-circuit work only being thus tested under the conditions of work that would be given to a closed-circuit cell.

In Fig. 74 is shown in diagram a method of making comparative battery tests which may be made to closely approximate the actual conditions of service. A clock is equipped with three contacts on its face, each adapted to be engaged once each hour by a wiping contact carried by the minute hand. Each of these contacts extends over an arc equal to that traversed by the minute hand in the time during which it is desired to have the battery on closed circuit, say five minutes. The circuit will thus be closed in the clock for a period of five minutes three times each hour, there being an intermediate open-circuit period of fifteen minutes between each closure. Any ordinary "dollar" clock may easily be thus equipped.

In circuit with the contacts of the clock are placed in series, the windings of a number of relays, and a battery of 24 volts, as shown. A relay is provided for each battery to be tested and each relay is adapted when operated to close the circuit of its battery through a resistance equal to the average resistance of the transmitter with which the battery is designed to be used.

In order to facilitate the daily reading of the current and voltage, two double-contact spring jacks, *a* and *v*, are connected, as shown,

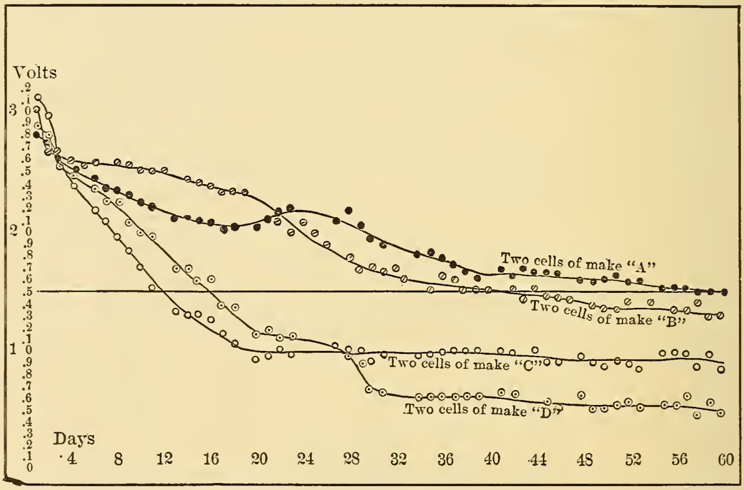


FIG. 75.—CURVES OF BATTERY TESTS, CONSTANT-RESISTANCE METHOD.

with the circuit of each battery under test. The jack *a* is so connected as to include between its terminals both the coil and the battery under test, thus giving the reading of the current when a plug in circuit with the milliammeter is inserted into it. The jack *v* is connected across the terminals of the battery only, so as to make a direct reading of the voltage when a similar plug connected with a voltmeter is inserted into it.

The results of a set of tests made by Mr. R. H. Manson with apparatus thus arranged are shown plotted in the form of curves in Fig. 75. In these tests each battery was closed through its resistance for a period of six minutes three times an hour. All readings of each battery were taken at intervals of twenty-four hours, while the relay contacts were not closed; in other words, while the batteries were on open circuit. Inasmuch as the current was found at all times to be substantially proportional with the voltage, the voltage readings alone were deemed a sufficient indication as to the condition of the cell. These curves, therefore, show the voltage of each battery for every day during the test. In this test it was assumed that when a battery of two cells dropped in potential below one and a half volts, it was unfit for service. For this reason a horizontal line has been drawn across the curve sheet at a height indicating one and a half volts, and the number of days required by each battery, under the conditions of the test, to fall below this voltage, is shown by the point at which the curve crosses this horizontal line. Reference to the curves will make clear that battery *A* lasted sixty days before dropping to this voltage, while the battery *C* lasted not quite twelve days. Battery *D* was somewhat better in this respect than battery *C*, although both showed poor results. Battery *B* was somewhat inferior to *A*, although both of these were first class.

If we assume as a basis of comparison that in a given exchange there are ten calls a day, lasting three minutes each, we have thirty minutes a day of actual use of the battery. As battery *A* was in use during the test in all 25,920 minutes, it would seem that under the assumed conditions of practice, using a local circuit having a resistance of 20 ohms, this battery would have a telephone life of 864 days. Battery *C* would have a life of about 173 days. These figures are probably too high, although there are cases on record where dry batteries have given service for over two years without any attention whatever.

One reason why the figures mentioned are probably too high, is that in practice where the service would ordinarily be very much less severe than that imposed during the test, the batteries would stand idle for a much longer time. During this time it is probable that there is a slight amount of chemical action and this would, of course, serve to reduce the actual life of the battery.

In making tests of this nature it is an easy matter for the experimenter to vary the conditions to meet the requirements of his exchange. The coil through which the discharge takes place should, of course, be made equal to the average combined resistance of the transmitter and primary winding of the induction coil. The clock is easily made to close the circuit more frequently, and for a less period of time, if desired. Again, in order to more nearly approach the actual average conditions of telephone service, the circuit of the clock may be opened at night so as to give a complete rest to all the batteries during the time when telephones are least busy. Inasmuch, however, as it is usually desirable to obtain the results of such a test without waiting too long a period, the conditions of the test cited are recommended as giving fair results.

A modification of the method of battery testing just described has been used by some of the large Bell companies. This involves changing the resistance in the circuit with each cell under test from time to time so as to keep the current delivered by the batteries constant throughout the test.

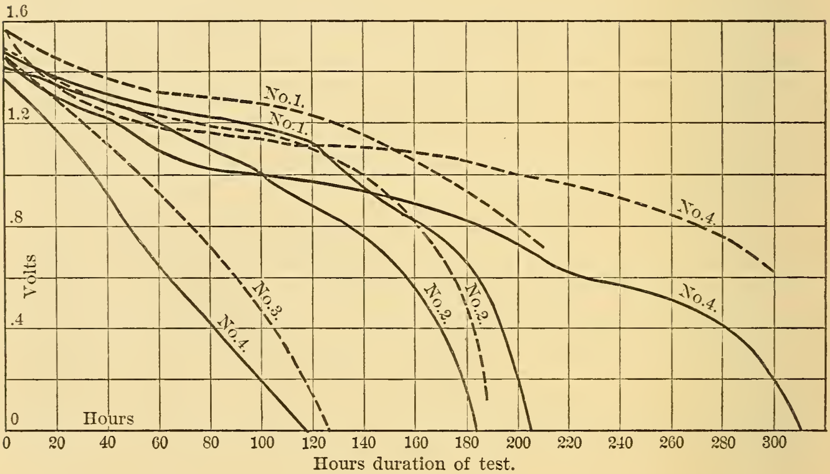


FIG. 76.—CURVES OF BATTERY USING CONSTANT-CURRENT METHOD

In Fig. 76 are shown the results of testing four different types of dry cells, these results being in each case the average of six cells of each type, four of the most prominent makes early in the year 1902 being represented. The circuit was alternately closed and opened five minutes at a time, conditions being in this respect more severe than those in the tests the results of which are shown in Fig. 75. By changing the resistance in circuit with each cell the current was kept as nearly as possible to two amperes throughout the entire time of the test. These curves, therefore, show the ability of a cell to produce a current equivalent to two amperes. As soon as any cell was unable to deliver two amperes it was discarded. The solid lines show the voltages taken on closed circuit, and the dotted lines the voltages taken on open circuit, the readings being taken always at the beginning of the open-circuit periods. As a result of tests under these conditions we find that the poorest cell failed in a little less than 120 hours, while the best one lasted about 310 hours. The reason for keeping the current constant at two amperes is not apparent. This condition is not met in practice and it seems that the constant resistance method is to be preferred.

Either of these sets of curves show several facts of importance. First, among standard makes of dry cells of good repute some are vastly superior to others. Second, that cell which gives the highest voltage at the start and maintains it for a considerable period after the beginning of service is not necessarily the best; in fact, the reverse is apt to be true.

CHAPTER VIII

MAGNETO CALLING APPARATUS.

So far we have dealt solely with the apparatus by which the actual transmission of speech is accomplished. While these are, of course, the most vital parts of a complete telephone, they would be of little use were not means provided whereby one party might call the attention of another in order to bring about a conversation.

Ordinary vibrating bells, using current derived from a battery, were at first used for calling, and as the battery for operating the transmitters could also be used for this purpose, this plan seemed to offer many advantages. It was found, however, that the voltage furnished by a telephone battery was insufficient to operate call-bells at great distances.

Another way of using the energy of the battery for calling, is to use an induction coil to obtain a high voltage, impulses in alternate directions being sent to line by making and breaking the primary circuit in which the battery is placed. In this way practically as high voltage as is desired may be obtained, and bells adapted to respond to alternating currents may be rung at great distances. This method has been put into practice in several instances, but it is found to produce too heavy a drain on the battery and thus impair its life and effectiveness for talking purposes.

The magneto generator is largely used for generating the calling current. Its use was almost universal in exchange work until the comparatively recent advent of the so-called common battery or central energy systems. In spite of the well-deserved popularity of these latter systems, the magneto generator still has and, it is thought, will have a very wide field of usefulness in telephony, on account of its reliability and adaptability to purposes and conditions for which common battery calling is not available.

The magneto generator is the simplest form of the electric dynamo, and consists of an armature of the Siemens type, wound with many turns of fine wire, and so mounted as to enable it to be rapidly revolved between the poles of a permanent horse-shoe magnet. Its theory of action is very simple and depends on the principles of magneto electricity discovered by Faraday and Henry, and pointed out in a previous chapter—that if the number of lines of force passing through a closed coil be varied, currents of electricity will be generated in this coil, the direction of these currents depending upon the direction of the lines of force and on whether their number is decreasing or increasing.

In Fig. 77 is shown a simple loop of wire, *a*, which may be revolved about a horizontal axis in the field of force of a permanent magnet. The horizontal arrows represent the direction of the lines of force set up by the magnet through the loop. Suppose the loop to be turned in the direction of the curved arrow. When it is in the horizontal position no lines of force will pass through it. As it approaches the position shown by the full line it will include a

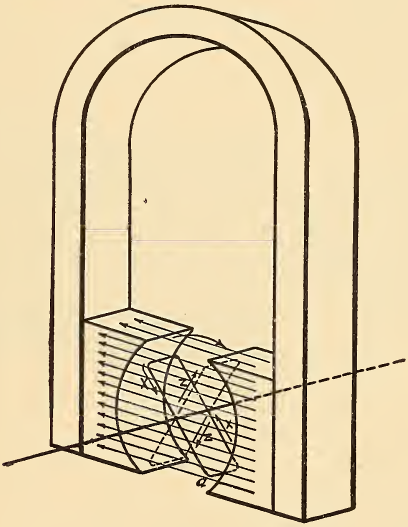


FIG. 77.—FIELD OF FORCE IN MAGNETO GENERATOR.

larger and larger number of these lines. The current induced in the coil will then be in the direction indicated by the arrows, *x*, and will so continue until the loop is in its vertical position. The number of lines passing through the loop then begins to decrease, and the current therefore takes the opposite direction, as indicated by the arrows, *z*. The current increases in strength in this new direction until the coil is horizontal. At this point the rate at which the number of lines through the coil is changing is greatest, and the current is therefore a maximum. As the coil passes through the horizontal position the number of lines passing through it begins to increase again. This would cause another change in the direction of the current, were it not for the fact that the direction of the lines of force through the coil also changes. The same cycle of events takes place during the next half-turn, when the coil is in the position from which it started.

We thus see that the current generated is an alternating one, changing its direction twice during every revolution.

In practice the armature, instead of having a single turn of wire, as in Fig. 77, has a great number of turns of fine wire wound on a cast-iron core of the form shown in Fig. 78. In this figure, *A* represents a shuttle-shaped core of cast iron, on which the coils of wire, *w*, are wrapped. One end of the wire forming the coils is fastened to the pin, *p*, which is fastened to and is in metallic connection with the core, *A*. The other end is fastened to the pin *p'*, which is insulated from the core, but connects with the pin, *c*, projecting from the end of the armature shaft and is insulated there-

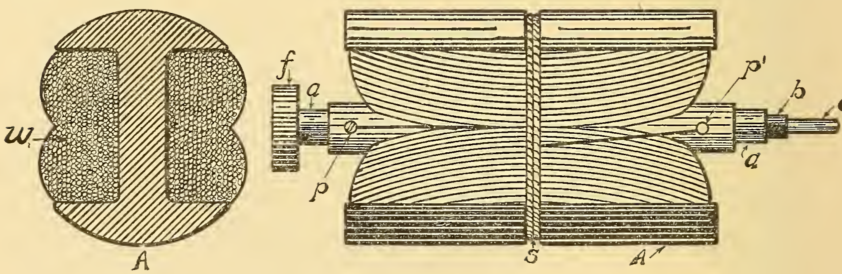


FIG. 78.—ARMATURE OF MAGNETO GENERATOR.

from by the fiber bushing, *b*. Projections, *a a*, integral with the core, are turned down to form bearings for the armature. A pinion, *f*, is carried on the end of the shaft, in order to transmit to the armature the motion received from a large driving-gear wheel with which it meshes.

A magneto generator in connection with a call-bell is shown diagrammatically in Fig. 79. To the poles of the permanent magnets, *N S*, of the generator are attached cast-iron pole-pieces, *P P*, bored out so as to allow the armature, *A*, to turn freely between them. The bearings of the armature are usually mounted on brass plates firmly attached to the ends of the pole-pieces, but not shown in this figure. By means of a crank attached to a suitable gear wheel engaging a pinion on the armature shaft, the armature may be made to turn rapidly.

As the currents generated are alternating, a polarized bell or ringer is needed. *C C* are the two coils of an electromagnet, pivoted in front of the poles of which is a soft-iron armature, *A*, carrying a hammer, *H,* on the end of a thin rod extending it at right angles from the center of the armature. A permanent magnet, *N S*, is so mounted as to magnetize by induction the armature, *A*, and the cores of the coils, *C C*.

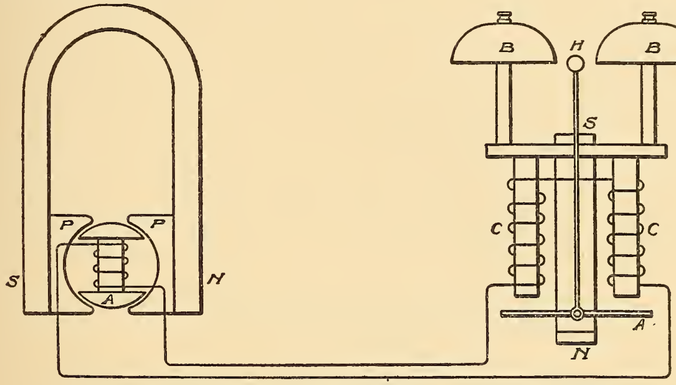
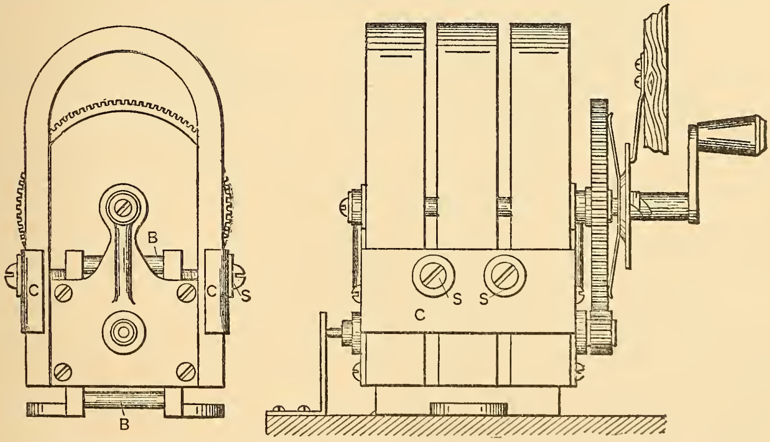


FIG. 79.—DIAGRAM OF GENERATOR AND BELL.

The two poles of the electromagnet will thus have a given polarity, say, north, while the two ends of the armature will have an opposite polarity, south. As a result, the armature will have a tendency to



FIGS. 80 AND 81.—DETAILS OF TYPICAL MAGNETO GENERATOR.

stick to one pole or the other of the magnets. The two coils are oppositely wound, and when a current passes through them it strengthens the magnetism of one pole and weakens that of the other. The next instant the current reverses, and the strong pole becomes the weaker, and *vice versa*. As a result the armature vibrates with each reverse of current and causes the hammer, *H*, to strike the bells, *B B*.

The details of a typical magneto generator are shown in Figs. 80 and 81. This instrument is very similar to the one used by the Bell companies. In it the pole-pieces are of cast iron, riveted together by means of the shouldered brass rods, *B B*. After this they are bored by a special tool to the required internal diameter to receive the armature. The core of the latter is of cast iron and is shown in Fig. 82, being accurately turned to fit freely between the pole-pieces. The bearing plates are of cast brass with a shoulder also turned to fit between the pole-pieces so as to be self-centering when secured in place. They are each fastened to the ends of the pole-pieces by four screws, as shown. The gears are cut from heavy

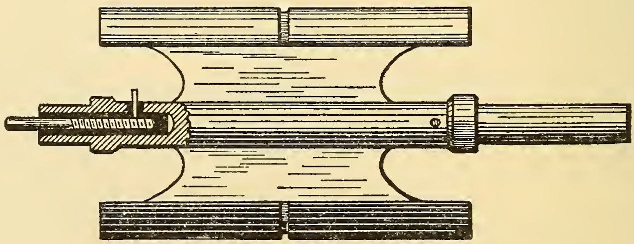


FIG. 82.—ARMATURE CORE OF TYPICAL GENERATOR.

cast brass, the large gear being mounted on a shaft journaled in the same bearing plates as the armature itself.

The magnets are bent cold from $\frac{3}{8}$" x $\frac{7}{8}$" magnet steel, and are secured in place by clamping plates, *C C*, and screws, *S S*, the latter passing between the magnets and into the pole-pieces. The air gap in machines of this type may be reduced to about 1-100 of an inch without endangering the smooth running of the armature.

A typical form of magneto bell or ringer is shown, minus its gongs, in Fig. 83. This form has been in wide use and well made gives excellent results. In this the two coils are wound on cores of round Norway iron, the heads of the spools consisting of fibre washers forced on the ends of the cores. The cores are fastened by means of screws to a soft iron yoke, *A*, which serves as a support for the working parts of the ringer, in mounting it in the telephone box.

The armature, *B*, is pivoted between two trunnion screws carried on bent-up ears from the brass strip, *C*. The strip, *C*, is supported at each end between two nuts carried on the brass bars, *D D*, these bars being riveted, or otherwise secured, to the yoke, *A*. The permanent magnet, *E*, is secured to the center portion of the yoke, *A*, at one end, its other end bending around the armature support but not touching it. The adjustment of the ringer may be altered by moving the armature support lengthwise on the rods, *D D*, by means of the nuts on these rods between which it is fastened. By doing this the armature may be made to approach or recede from the pole-pieces, thus altering the strength of the magnetic pull on the armature, and also the length of stroke of the tapper which is carried by the armature.

The gongs of this type of ringer are mounted independently of

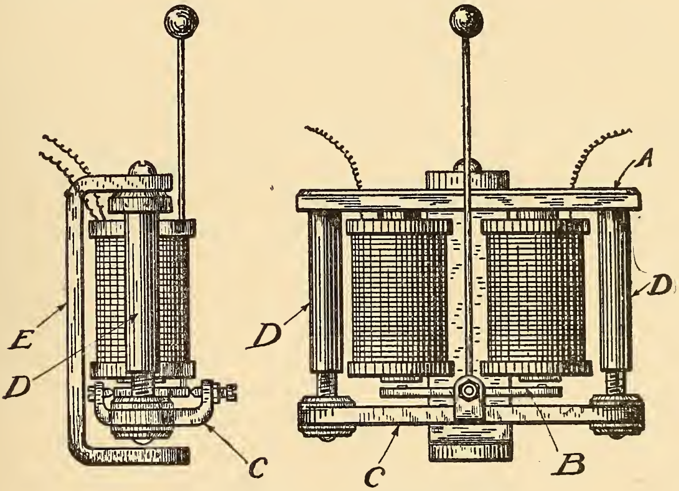


FIG. 83.—TYPICAL MAGNETO BELL.

the striking mechanism shown in the cut and on the opposite side of the supporting board from this mechanism, the tapper wire or rod extending through a hole in this board, to allow the tapper to play between the gongs. Means are provided in the gong supports for allowing the adjustment of the gongs toward or from the tapper to meet the various requirements of service. The supporting board usually forms the front cover, or some other portion of the telephone box, and this arrangement, therefore, brings the working parts of the bell within the box so as to be protected from dust and accidental derangement, while the gongs are on the outside where their sound may be more easily heard.

In later forms of ringers, this independent mounting of the gongs is done away with, the whole ringer being made self-contained, which is a feature finding more and more favor in all branches of telephone design.

The details of design and construction of magneto calling apparatus have received much attention, and improvement has been effected during the last few years, owing undoubtedly to the strong competition between manufacturers supplying this apparatus. The essential features of a good generator are that it should have an electrical output as great as possible; that it should be so strongly and durably constructed as to secure good wearing qualities and permanent adjustments; that its magnets should be permanent so as not to lose their strength in the lapse of time, and that it should be as nearly noiseless and smooth in its operation as possible.

In order to secure the greatest output of electrical energy, it is, of course, necessary that the permanent magnets should be as strong as possible. With a given set of magnets, however, and therefore with a given available magnetizing force, the design and construction of a generator may be so altered as to give widely different results in regard to output. With a given magnetizing force, the number of lines of force extending from one pole of the magnet to the other will depend on the material between the poles and also on the distance between them. Certain substances, of which iron is pre-eminent, if placed in a magnetic field of force, will have set up in them a vastly greater number of lines of force than would air, if subjected to the same magnetizing force. Such substances in which a given magnetizing force will produce a high degree of magnetization, are said to possess a high degree of permeability. A piece of soft rod iron placed between the poles of a permanent magnet would allow more lines of force to pass through it than would a piece of hard cast iron. The soft iron is therefore said to be more permeable of the two.

One important point in the design of magneto generators as, in fact, in dynamo design in general, is to cause as great a number of lines of force as possible to pass through the core of the armature. Since in a magneto generator the magnetizing force when once determined, is, for all practical purposes, invariable, there are three factors which determine the number of lines that shall pass through the armature core. First, the quality, as effecting permeability, of the iron in the armature core and in the pole-pieces; second, the cross section of the iron in the armature core and in the pole-pieces taken in a plane at right angles to the direction of the lines of force;

and third, the amount of air gap between the armature core and the pole-pieces. From this we may reason that to secure a maximum efficiency the iron of the pole-pieces and of the armature core should be of the greatest possible permeability and cross-section, while the air gap should be as small as possible. The tendency has been during the past few years to construct armature cores by building them up of thin layers of soft sheet iron, forming what is known in electrical design as a laminated core. This practice generally succeeded the old practice of building the armature cores of cast iron, but quite recently several manufacturers have gone back to the cast armature core, paying particular attention, however, to securing a very soft grade of iron. The argument for this latter practice is that with later designs it is possible to secure a greater cross section in an armature core, thus allowing substantially the same number of lines of force to pass through as with the smaller cross section and better quality of iron in the older types.

A cast armature, however, even though soft, is subject to another objection, in that eddy currents are generated in the core, which interfere to some extent with the efficiency of the machine. The laminated core tends, of course, to greatly reduce the liability to eddy currents. This objection is not thought to be of much moment, and it may be said in conclusion that excellent generators are now being manufactured, some of which use laminated cores and others cast cores.

The length of the air gap between the armature core and the pole-piece is a matter to be determined by mechanical conditions. The gap should be made as small as possible without endangering the smooth running of the armature. If the air gap is made too small and the generator poorly built, a little wear or change of adjustment will cause the armature core to strike the pole-pieces at every revolution, thus destroying the running qualities of the machine. In very good generators, where sufficient care is taken in their manufacture to secure accurate dimensions and permanent adjustment, the air gap is sometimes reduced without practical difficulty to about 1/100 of an inch. Where generators are poorly made this distance should be correspondingly greater with a resulting loss of efficiency.

The wire used in the armature winding should be of the largest size that will give the desired number of turns without unduly filling up the winding space. The winding space should not be so completely filled as to cause the wires to bulge out and strike the pole-pieces of the generator in its rotation, thus wearing away the insulation and frequently breaking the wire itself.

In a given generator rotated at a given speed the voltage will depend on the number of turns of wire in the armature. The best size of wire to use is therefore readily experimentally obtained by first finding the number of turns required to give the proper voltage on an open circuit, and then using the largest size of wire for which there is room to wind on that many turns.

Cast iron has been almost universally used in the construction of the pole-pieces, although some generators have been made using soft sheet iron pole-pieces stamped and formed into the desired shape. This forms a cheaper pole-piece than can be procured by the use of cast iron, because the latter must necessarily be subjected to a considerable amount of machine work, such, for instance, as

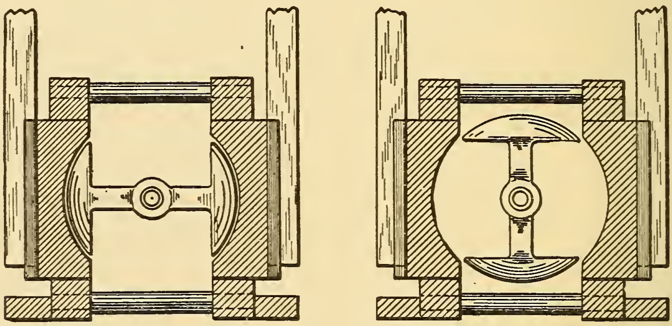


FIG. 84.—DETAILS OF GENERATOR POLE-PIECES.

the boring of the concave cylindrical surfaces between which the armature revolves. A point in favor of the cast iron pole-piece is that the air gap may be made much smaller because of the greater accuracy that can be secured by boring than by forming the pole-pieces in dies. Another advantage of the cast pole-piece is that with them a greater cross section of iron may be secured in the path of the lines of force, as well as a more direct path, than by using any of the formed sheet iron pole-pieces so far produced. The only argument in favor of the sheet iron pole-piece, aside from its cheapness, is that the quality of iron is better, but this, in view of the great cross section available in the cast iron, and of the smaller air gap, is not of considerable importance.

In the construction shown in Fig. 84 the pole-pieces are of cast iron firmly secured together by shouldered brass rods. After being thus fastened together they are bored out with a special tool, after which the magnets are put in place and clamped by any suitable means. This is a very good, although somewhat expensive, construction when properly done.

The efficiency depends to a considerable extent upon the form of the current wave generated by the machine. This is governed largely by the relation between the width of the pole of the armature and the distance between the flat surface of the generator pole-pieces. In Fig. 84 the best relation between these dimensions is illustrated quite clearly. It will be noticed in the figure at the left that the curved portion of the armature pole exactly corresponds to the concave portion of the pole-pieces, while in the figure at the right, which shows the armature in a different position, the poles of the armature are just sufficient in width to bridge across the space between the pole-pieces without overlapping.

The sine wave has been found to be most efficient in the ringing of magneto bells, especially on lines of considerable length and possessing a high degree of self-induction and capacity; and the relation between the armature poles and the pole-pieces shown in the above figure gives a fair approximation to this form of wave. Where the armature poles do not fill the space between the pole-pieces, the current curve will have four distinct humps in each complete cycle. There will be a break in the magnetic circuit just as the armature pole leaves the pole-piece on one side, which will cause a sharp fluctuation in the electromotive force; and another sharp fluctuation will occur immediately after, when the opposite points of the armature poles approach the corners of the pole-pieces. These two fluctuations will occur twice in each cycle. When the armature poles are so wide as to overlap, when in the position shown in the right-hand portion of Fig. 84, the wave is flattened unduly and does not, therefore, give as high an electromotive force as could otherwise be obtained.

The effective pressure of the ordinary magneto generator, when rotated at the ordinary speed by hand, is from 65 to 75 volts, and it may be made, of course, higher or lower to meet certain requirements by winding with a greater or less number of turns or by gearing the armature so as to rotate with greater or less speed.

Some telephone lines, as for instance party lines, using a large number of instruments in series, require magneto generators capable of producing a very high electromotive force in order to successfully overcome the great resistance offered. Inasmuch as all of the bells are in series, the current required is not large. The ordinary generator for series work has a three-bar field, and has its armature wound to a resistance of about 550 ohms with No. 35 B. & S. gauge wire silk insulated.

In a bridged line, however, where all of the ringer magnets are connected across the line in parallel, the current required is heavy, while the voltage need not, as a rule, be so high. In long lines of this latter type using a high-resistance wire, it becomes necessary to develop enough pressure to overcome the resistance of the line wire in order to ring the bell at the farthest end, and also a sufficient current to pass in multiple through all of the ringers. In this case a rather high voltage is required and a heavy current, so that the total amount of energy is large. This greater amount of energy cannot be obtained by merely winding the armature to a higher resistance, and therefore in generators of this type it is customary to use heavy and very powerful permanent magnets and to exercise the greatest care in the construction to produce the highest efficiency. Instead of using three permanent magnets, as in the series type of generator, it is customary to use four or five, the armature and pole-pieces being made correspondingly longer. A good generator for bridging work may be wound with No. 33 B. & S. gauge wire to a resistance of 350 ohms.

The construction of the polarized call-bell, or ringer, is a matter requiring no less attention to detail than that of producing an efficient generator. The old form of ringers, using a cast iron frame polarized by small permanent magnets, was subject to very grave defects. The frame became readily polarized in one direction or the other, due to the passage of a heavy current through the magnets, and would thus give the armature a set to one side or the other, which frequently succeeding currents of a weaker nature could not overcome. This, with the fact that with every reversal of the current the entire magnetic field set up through this heavy mass of poor quality iron had to be completely reversed, was a point rendering the construction of an efficient ringer almost an impossibility. The tendency in the present form of ringers is to make a magnetic circuit which is subjected to the changes due to the magnetizing force as short as possible and of the very best material. Swedish or Norway iron, cold drawn and annealed, has been found to meet these requirements most perfectly. The sticking of the armature to one pole or the other is further prevented by the interposition of a thin sheet of non-magnetic material, usually copper, between the faces of the armature and the pole-pieces. Sometimes this is accomplished by inserting a small rivet either into the center of the pole-piece or into the armature face itself.

The length of the rod carrying the hammer plays a considerable part in the sensitiveness of the bell. A long rod will secure for the hammer a long and powerful stroke, but the sensitiveness is correspondingly reduced. On the other hand, a short rod will produce a short and comparatively weak stroke, but the bell will be more sensitive than with the long rod.

The ordinary construction of ringer magnets is to drive the fiber heads directly onto the cores, and after insulating the surface of the latter to wind the spools thus formed with silk-insulated wire of the desired size. Fig. 85 shows one of the sectional coils of the Varley Duplex Magnet Company, this being wound separately, with bare wire separated by silk thread. After winding, the coils may be slipped on the core and locked by the end washer or head. The

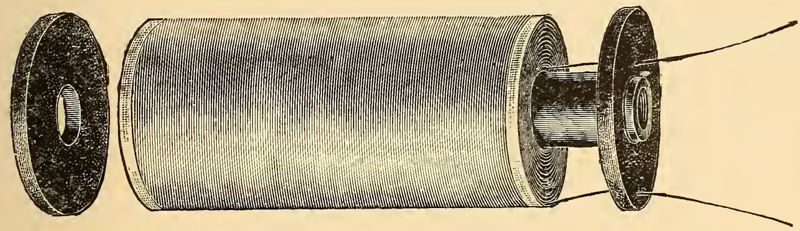


FIG. 85.—VARLEY RINGER COIL.

advantages of this construction are in the ease of replacing burned-out or otherwise injured coils, and also in the perfect uniformity of the winding.

The ringer magnets for series work are usually wound with No. 31 B. & S. gauge silk-insulated wire and have a resistance of from 75 to 100 ohms.

Ringer magnets for bridging work must possess a very high degree of self-induction. This is obtained by winding them to a high resistance with a comparatively coarse wire, so as to obtain a large number of turns. The length of the cores is increased for the double purpose of getting more iron in the magnetic circuit, and therefore a higher retardation, and also for affording a greater amount of room for the winding. The Western Electric Company wind their bridging coils to a resistance of 1000 ohms, using No. 33 single-silk magnet wire. Some companies use No. 38 wire and wind to a resistance of 1200 or 1600 ohms. This does not give such good results, however, as using the coarser wire and the lower resistance with long cores. Some companies wind, or once wound, their bridging-bell magnets partly with German silver wire, in order to make a high resistance at a low cost. Resistance in itself, however, is not the thing desired, but a great number of turns in the winding, which, of course, incidentally produces a high resistance.

The standard series generator and ringer for ordinary exchange work are usually so wound that the generator will ring its own bell, or another like it, through a resistance of 10,000 ohms. Such an outfit is spoken of as a 10,000-ohm magneto, and the 10,000 refers not to the resistance of the bell magnets or the generator armature, as is often supposed, but to the external resistance through which they will successfully work.

A good bridging generator should ring twenty 1000-ohm bells in multiple over a resistance of 1000 ohms between the generator and the first bell.

On account of the high resistance of the generator armature and its great retarding effects, it is, under some circumstances, desirable

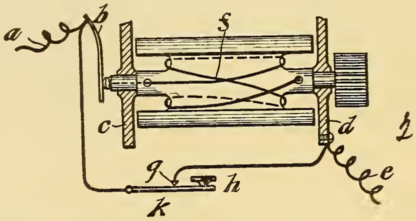


FIG. 86.—MANUALLY OPERATED SHUNT.

to have the armature winding shunted out of the line when the generator is not in use. Especially is this desirable where more than two telephone instruments are placed in series in the same circuit. Under these conditions, unless some by-path is afforded around the armature of the generators that are not in use, the voice currents and also the ringing currents from other stations would be compelled to traverse the winding of the generator armatures not in use, thereby reducing both the talking and ringing efficiency. Such devices are usually called "generators shunts." These are of two types, automatic and manual. The manual shunt is indicated in principle in Fig. 86. In this, *a* and *e* represent the two wires leading from the generator, the circuit through the generator between these wires being traced from *a* to spring *b*, which bears against the terminal pin of the armature, thence from the wire, *c*, forming the winding, to the frame, *d*, of the generator, and to the wire, *c*. Its path, however, is normally short-circuited by means of the manually-operated spring, *k*, normally resting against the back contact, *g*, in such manner as to complete a circuit of practically no resistance between the terminals, *a* and *e*. Under such circumstances, any currents coming over the line would follow the shunt path rather than traverse the armature. Pressure on the button, *h*, however, will break the shunt path, under which circumstance a current generated in the armature winding, upon operating the generator, would pass to line, not being able to traverse the shunt path.

Automatic devices have now almost entirely supplanted the manual, as the latter were never satisfactory, owing to the inability or ignorance of careless persons to properly manipulate them. Many

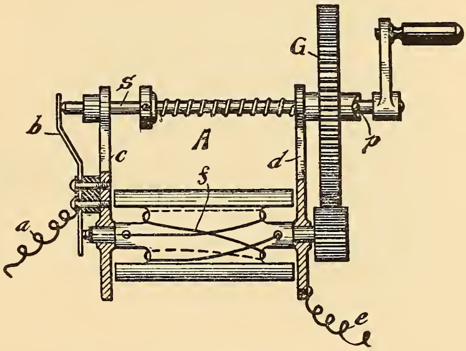


FIG. 87.—AUTOMATIC SHUNT.

styles of these automatic shunt devices have come into general use, the one shown in Fig. 87 being typical. This particular shunt was introduced by the Western Electric Company in the early days of telephony. Referring to this figure, *a* and *e* represent the terminals of the generator, the path between them through the armature being traced from the terminal, *a*, through the lower portion of the spring, *b*, which bears against the armature pin, thence through the winding, *f*, of the armature and the frame of the generator to the terminal, *e*. When a generator is not being operated, however, a low-resistance shunt exists around the armature which may be traced from the terminal, *a*, through the upper portion of spring, *b*, which rests against the end of the shaft, *s*, which in turn is in contact with the terminal, *e*, through the bearing plates, *c* and *d*, to the frame of the machine.

The large gear-wheel, G, is loosely mounted on the shaft, s, the shaft passing through a notched collar, forming the hub of the gear. The rotary motion of the shaft is transmitted to the gear-wheel by means of the pin, p, projecting from the shaft and engaging the notch in the collar. A coiled spring surrounding the shaft, pressing at one end against the shaft bearing, d, and at the other against a collar fixed to the shaft, serves to press the shaft normally to the left into contact with the spring, b. A coiled spring on the shaft also serves to keep the pin, p, normally at the bottom of the notch in the hub of the gear-wheel.

When th generator crank is turned, the pin, p, rides partially out of the notch in the hub of the gear-wheel, and in so doing pulls the

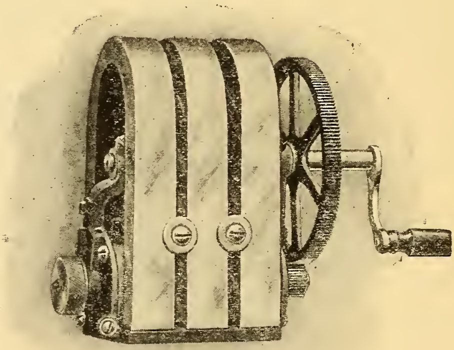


FIG. 88.—HOLTZER-CABOT THREE-BAR GENERATOR.

shaft out of contact with the spring, b, thus breaking the shunt around the armature and leaving the latter effectively in the line.

This is only one of many forms of automatic shunting devices, some of which will be shown in connection with commercial forms of magneto generators.

Instead of shunting the generator armature when not in use, some forms of telephone service require that it shall be left on open circuit when not in use. Such a device is called a "generator cut-in," and is almost always automatically operated by the turning of the crank, although, of course, they may be manually operated by a button. These devices differ from the automatic shunts only in that they serve to normally hold the armature circuit open and to close it when the generator is operated, instead of serving to break the circuit around the armature when operated.

Coming now to commercial types of magneto calling apparatus, the Holtzer-Cabot Company, of Brookline, Mass., are manufacturing an excellent magneto generator, two types of which are shown in Figs. 88 and 89.

The end plates in which the generator armature is journaled are of cast brass and are secured directly to the cast iron pole-pieces,

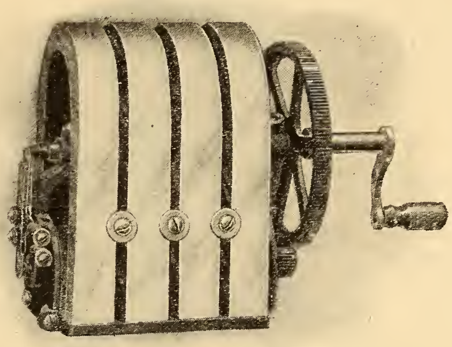


FIG. 89.—HOLTZER-CABOT FOUR-BAR GENERATOR.

the ends of which are flanged and machined so as to fit accurately the internal curves of the pole-pieces. The armature core is of soft iron laminations, the layers being in the form of punchings clamped together on a steel rod which therefore serves as the armature shaft. The construction of the armature and the shape of one of the punchings or laminations is clearly shown in Fig. 90. After being built

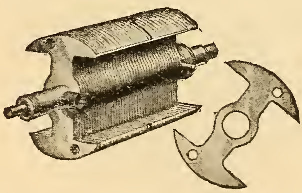


FIG. 90.—LAMINATED ARMATURE.

up in this manner, the core is properly insulated with cloth saturated with shellac, after which the winding is put on.

The most common method of transmitting the motion of the crank to the armature shaft is by means of a large gear-wheel on the crank shaft, meshing with a pinion on the armature shaft, the ratio of speed in rotation between the two shafts being about as one to five. The Holtzer-Cabot Company introduced, and once used to a large extent, a chain-drive, by means of which a chain, having links of steel wire passed over two sprockets, as shown in Fig. 91, in practically the same manner as in the ordinary chain-driven bicycle. This afforded a very smooth-running, quiet drive,

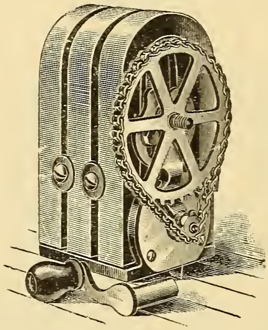


FIG. 91.—CHAIN-DRIVEN MAGNETO GENERATOR.

but this has been almost entirely superseded by the direct meshing spur gears, a detail of which is shown in Fig. 92. In this, both the large gear and pinion are of brass, having wide faces cut to secure smooth running. In order to prevent the jerk occasioned by the

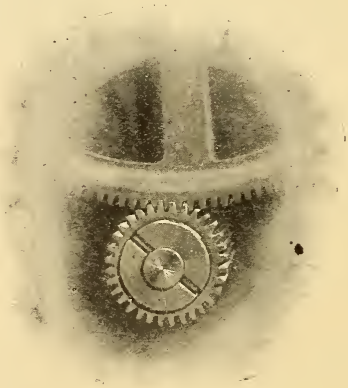


FIG. 92.—SPUR GEARING FOR GENERATORS.

magnetic pull of the field on the armature, with its consequent back-lash, the pinion, instead of being rigidly secured to the shaft, has a flexible connection therewith. This consists of a coiled spring within the pinion, being secured at one end to the armature shaft and at the other to the pinion itself, so that whatever motion is transmitted from the pinion to the armature shaft is through the medium of the spring. This point illustrates one of the niceties of detail now required by the telephone-using public.

The shunt used to a large extent by the Holtzer-Cabot Company is shown in Fig. 93. It is an ingenious little device consisting of a small cylindrical case or cup of brass mounted directly on the projecting portion of the armature shaft, and in metallic contact therewith. One terminal of the armature winding is therefore connected through the armature core to this cup. The insulating pin with which the other terminal of the armature winding is connected projects into the chamber formed by this case; but does not come into metallic contact with the casing nor the armature shaft itself. The chamber is partially filled with small bits of metallic wire which normally form a connection between the central pin and the casing itself, thereby forming a short circuit or shunt around the armature winding. When, however, the armature is rotated, the centrifugal

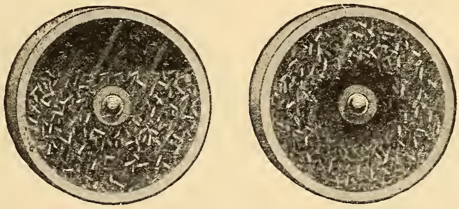


FIG. 93.—HOLTZER-CABOT SHUNT.

force, due to the rotation acting upon the bits of wire, causes them to fly to the outer portion of the casing, thus breaking contact with the central pin and removing the shunt from the armature. This is probably the simplest shunt on the market, and is reliable. In order to prevent corrosion of the parts, the casing and the small particles of wire are silver-plated. The cut at the left of Fig. 93 represents the condition of affairs when the armature is at rest, and that at the right when it is in use.

Another form of shunt used on the generators of the Holtzer-Cabot Company is shown on the type of generator of Fig. 89, already described. In these, by means of a device similar to that shown in Fig. 87, the crank shaft is automatically given a longitudinal movement to the left when operated. This presses the long spring which bears against the insulated end of this crank shaft out of contact with the right-hand spring of the group of three with which it normally makes contact, and into engagement with the left-hand spring of this group with which it is normally out of contact. It is evident, by using the long spring and the right-hand spring only, that this device may be used as a generator shunt, while if the long spring and the left-hand spring only are used, it may be used as a generator cut-in.

Fig. 94 is of interest as showing, in side and front elevation, a form of generator now obsolete, but once manufactured by the Williams-Abbott Company, of Cleveland. This is one of those generators in which an attempt was made to use pole-pieces formed from sheet iron instead of making them of cast iron, as is now done. Inspection of the end elevation of this figure will show a poor magnetic path between the ends of the terminal magnets and the pole-

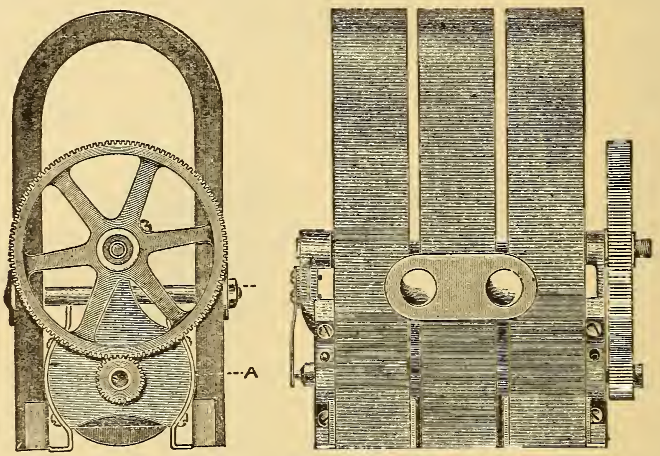


FIG. 94.—WILLIAMS-ABBOTT GENERATOR.

pieces. The only direct path is through the *line* of contact, as at *A*, another path being afforded down through the thin cross section of the metal forming the lower portions of the pole-pieces.

In Fig. 95 are shown the parts of a generator recently put on the market by the Kellogg Switchboard and Supply Company, this being built along standard lines with the exception of the method of constructing the armature, which, if not new, is at least a radical departure from modern practice. Instead of forming the shaft integral with the armature core, the two ends of the shaft are separate, and are secured to the ends of the armature core by means of flanges properly turned and fitted and secured in place by screws. The armature core itself is of cast iron and is provided with a channel throughout its length on both sides to afford space for the winding.

Under this construction the shaft is not continuous and therefore does not interfere with the winding space, as in the usual armature construction. As a result, more winding space is available, which

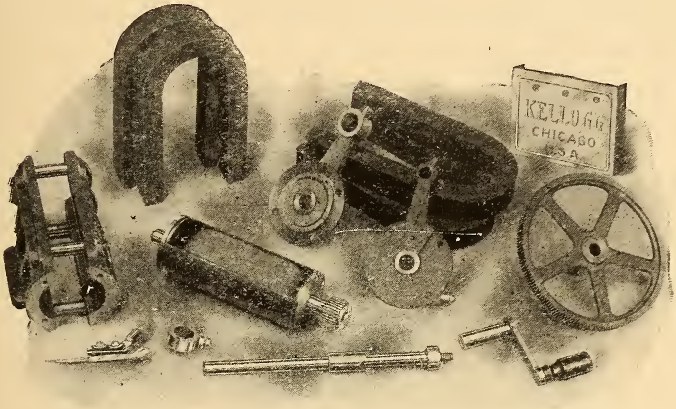


FIG. 95.—PARTS OF KELLOGG GENERATOR.

may be used in obtaining more turns in case high voltage is necessary, or in obtaining more current in case that is necessary. The

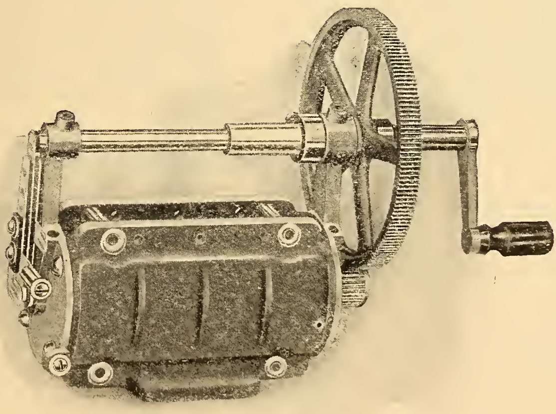


FIG. 96.—KELLOGG GENERATOR PARTLY ASSEMBLED.

outcome of this form of armature in practice will be watched with interest.

This generator is shown partly assembled in Fig. 96, the magnets only being removed. This figure shows clearly the method of operating the shunt or cut-in, this being of the same type as in the Holtzer-Cabot generator of Fig. 89.

The standard ringer used by the Holtzer-Cabot Company is shown in Fig. 97.

Another view, showing also the method of mounting it in proper

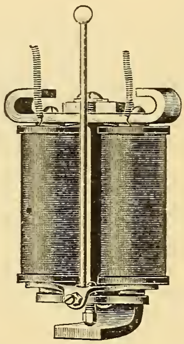


FIG. 97.—HOLTZER-CABOT RINGER.

relation with the gongs, is shown in Fig. 98. This general construction may be considered standard, and has given long-continued satisfaction in use. The gongs are mounted on adjustable standards pivoted at their upper ends and each held by a screw engaging a slot in its lower end. This ringer differs from that shown in Fig. 83 in that the yoke in which the armature is pivoted is of heavy,

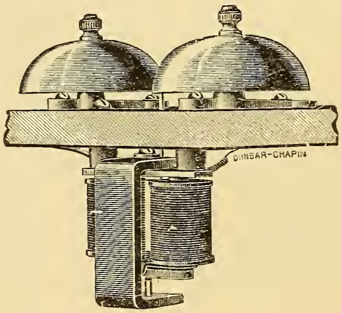


FIG. 98.—HOLTZER-CABOT RINGER.

spring brass, its ends being fitted over the pole-pieces of the magnets which project slightly through it. The adjustment of the armature toward or from the pole-pieces is effected by means of a screw, best shown in Fig. 97, this screw being threaded into the center of the yoke piece and passing freely through a hole in the armature, its head engaging the under surface of the permanent magnet. Upon turning this screw in a left-handed direction with the head bearing against the under side of the permanent magnet, the center portion of the yoke is forced downward against its natural tendency, thus allowing the ends of the armature to approach more nearly the pole-pieces. Turning the screw in the other direction allows the spring of the yoke to force the armature further from the pole-pieces, thus securing a coarser adjustment.

Fig. 99 shows two views of the working parts of the Stromberg-Carlson ringer. This is similar to that of the Holtzer-Cabot Company, save for the method of adjustment. In this, the adjustment screw, *B*, projects entirely through the turns freely in the end of the magnet, *A*. The armature, *C*, is carried by the spring yoke, *D*, which fits over the pole-pieces, *E E*, which are held together by

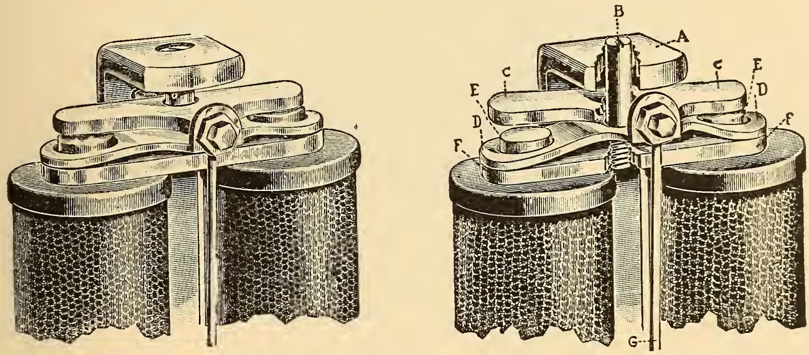


FIG. 99.—STROMBERG-CARLSON RINGER.

a separate yoke, *F*. The screw, *B*, passes freely through the armature and engages by a shoulder, as shown, the spring yoke, *D*, through which it also passes, being threaded into the yoke, *F*. It is evident that turning the screw in one direction or the other will press the center of the yoke carrying the armature toward the yoke *F*, or allow it to spring further away from it, thus effecting the adjustment between the armature and the pole-pieces.

Fig. 100 shows an excellent form of ringer designed by Mr. E. E. Yaxley, and now being extensively manufactured by the Monarch Telephone Manufacturing Company, of Chicago. This differs from the old Western Electric ringer in the method of supporting the armature yoke. Instead of supporting this on separate rods outside of the coils as shown at *D D*, in Fig. 83, Mr. Yaxley provides the free end of his magnet cores with screw threads, upon each of which fit two hexagonal nuts which carry between them the armature yoke. This is, therefore, the same form of adjustment as used in the Western Electric ringer save that the cores, instead of the extra rods, are made to serve as parts of the frame carrying the armature yoke.

The new ringer of the Kellogg Switchboard & Supply Company is shown in Figs. 101 and 102. This possesses two features not shown in any device so far considered. Perhaps the most important of these is that the whole ringer, including the gong and gong supports, is self-contained, the ringer being a complete entity regardless of the front board of the telephone upon which the various parts are usually separately mounted. In this the gong posts are mounted on levers pivoted at one end on the heel-piece, upon which the magnets are also fastened. Screws passing through the slotted portions of these levers serve to allow, when loosened, a certain longitudinal motion of the gongs with respect to the clapper and to bind them firmly into position when tightened. The other unique feature about this ringer is that adjustment is effected by carrying the pole-piece toward or from the armature rather than moving the armature with respect to the pole-piece. The pole-pieces are, in fact, hexagonal screws of iron engaging internal

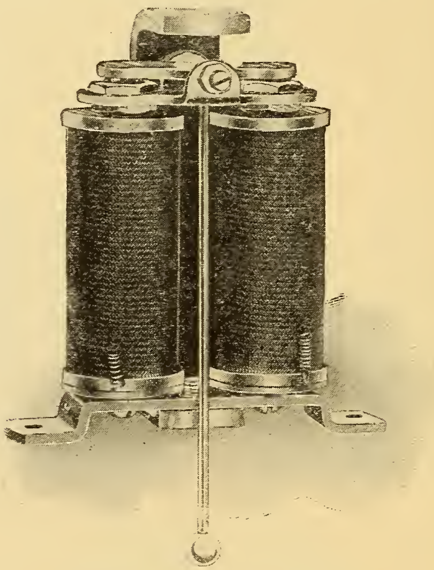


FIG. 100.—YAXLEY RINGER.

threads in the cores of the magnets, these screws being moved toward or from the armature in order to secure a fine or coarse

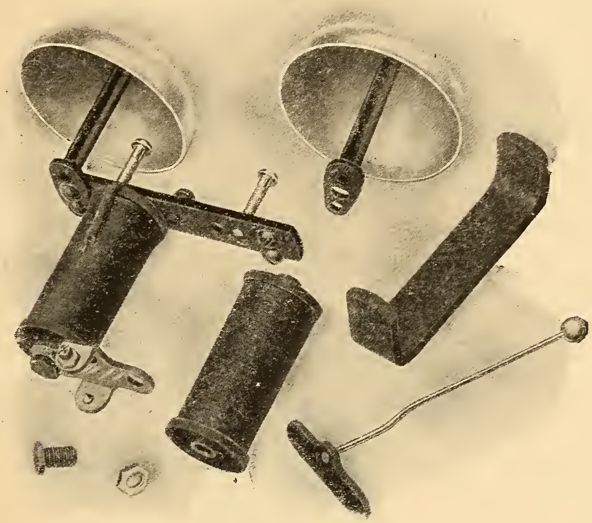


FIG. 101.—PARTS OF KELLOGG RINGER.

adjustment. A hexagonal nut is carried on each screw in order to lock the screw in any desired position.

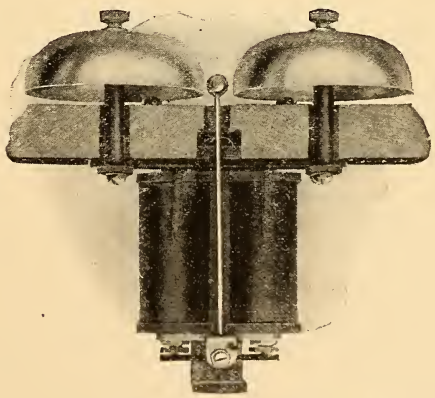


FIG. 102.—KELLOGG RINGER ASSEMBLED.

The ringer shown in Fig. 103 is unique and embodies several desirable features, although it has become obsolete. The two ends of the U-shaped permanent magnet are of the same polarity, its middle being of the opposite polarity. The two coils are mounted on an iron cross-bar extending between the legs of this permanent magnet. The poles of the electro-magnets therefore partake of the polarity of the permanent magnet ends, while the armature, supported from the center of the permanent magnet, becomes of the opposite polarity. The action of this ringer is usually misunderstood at first sight, the natural supposition being that the limbs of the permanent magnet are of opposite polarity. This ringer is very efficient, and it is surprising that it should not have remained in service, perhaps in a somewhat modified form. Besides being desirable in point of efficiency, it has the advantage of having its working parts partially enclosed by the rigid permanent magnet, which serves to protect them from mechanical injury.

All of the generators so far described have been adapted to give

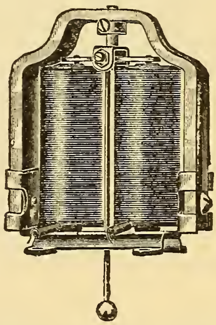


FIG. 103.—OLD WILLIAMS-ABBOTT RINGER.

only alternating currents, the current consisting of a positive and negative impulse for every complete revolution of the armature. It is sometimes desirable to make all of the impulses in the same direction, as in certain classes of party line ringer, and for this purpose a form of commutator is sometimes applied to the end of the armature shaft which will rectify current reversing every alternate impulse. Such current is frequently spoken of as "direct" current, but more often as "pulsating" current, and a generator provided with this device is termed a "direct current" or "pulsating current" magneto generator.

In party line working it is often necessary to make ringers that will respond to only one direction of current; that is, to impulses of one direction only, whether positive or negative. This is accomplished by adding to the ordinary ringer a little coiled spring tending to hold the armature normally in engagement with one pole or the other. This is quite clearly illustrated in principle in Fig. 104. Various methods of adjusting the tension of this spring have

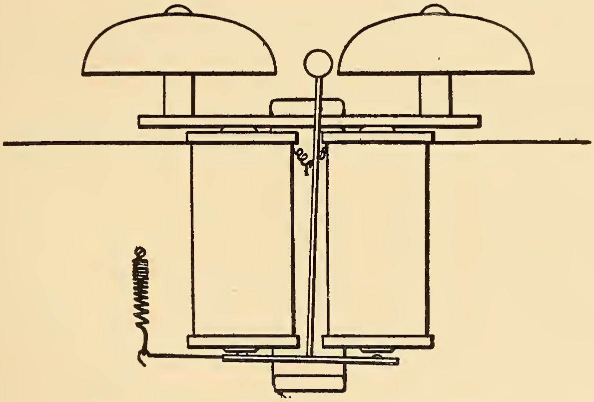


FIG. 104.—DIAGRAM OF BIASED BELL.

been put into practice, probably the best form being that wherein a linen or silk thread tied to the free end of the spring is wound around a screw in a similar manner to the method used in adjusting

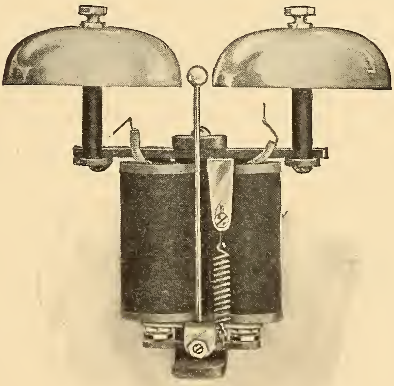


FIG. 105.—MODERN BIASED BELL.

Morse relays. Such an adjustment as applied to a modern ringer is shown in Fig. 105.

A ringer equipped for this purpose is usually termed a "biased" bell or "biased" ringer. It is evident that when the current impulses are in such direction as to attract that end of the armature

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which is already held near its pole-piece by the spring, no further effect will take place. If, however, the current is in opposite direction, it will cause the opposite end of the armature to be attracted to its pole-piece against the tension of the spring, thus causing the bells to ring. Biased bells require very careful adjustment and are not altogether satisfactory, yet, as will be described later, they are widely used in certain classes of work.

CHAPTER IX.

LOCAL BATTERY SUB-STATION EQUIPMENTS.

So far talking apparatus and calling apparatus have been considered separately. When both talking and calling apparatus are properly combined for meeting the requirements of actual service, it is called a complete telephone set, or a sub-station equipment. The term, "sub-station," probably an abbreviation of "subscriber's station," is now commonly used to designate the premises of any telephone user or subscriber, hence the term sub-station equipment.

Sub-station equipments may be classified under two heads in accordance with the kind of system with which they are adapted to be used; thus we may have local battery sub-station equipments, also termed magneto sub-station equipments, on account of the magneto generator being usually found in sets of this kind; or, we may have common battery or central energy sub-station equipments, in which no local battery or magneto generator is found. Only local battery or magneto sub-station apparatus will be considered in this chapter, as that for common battery systems may be better understood after a discussion of common battery systems in a subsequent chapter.

Local battery sub-station apparatus may in turn be classified under two heads, series and bridging. The series type of telephone is that wherein the arrangement is such as would be used were a number of instruments placed in series in the same circuit, a practice no longer very common. They are, as has been before stated, usually provided with a comparatively low resistance ringer magnet and with a generator having its armature normally shunted. The instruments of the bridging type are such as are adapted to be placed in multiple or bridge relation with the line, as is commonly done in lines having more than one sub-station. The bridging telephone set should be provided with a ringer magnet of high resistance and retardation, the generator being very powerful and normally on open circuit instead of being shunted, as in series instruments.

It is obvious that as the calling and talking apparatuses of a sub-station equipment are used alternately, some means is necessary for switching one or the other into the circuit. An instrument when not in use must always be ready to receive a call, and the call bell or ringer must therefore normally be left in the circuit of the line. Furthermore, as the retardation of the ringer coils would be in many cases detrimental to the transmission of talking currents, this coil must in such cases be switched out of the circuit of the line when the talking instruments are in use.

At first, hand switches were used to accomplish this result. Before the adoption of the battery transmitter, instruments were provided with ordinary two-point hand switches, so arranged as to alternately close the line circuit through either of two branches, one containing the call bell and generator and the other the magneto telephone. Such an arrangement is shown in Fig. 106, where *a* is a switch lever pivoted at one end and adapted with its other end to make contact

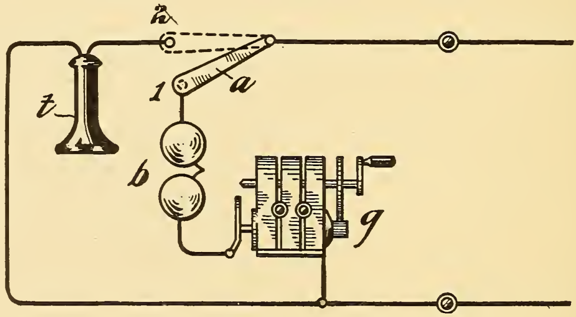


FIG. 106.—HAND-SWITCH CIRCUIT.

with either of the metallic buttons, 1 or 2. One side of the line circuit is connected to the pivot of the lever, *a*, while button No. 1 is connected through the call bell, *b*, and generator, *g*, to the other side of the circuit. Thus, when the switch lever is in the position shown, the call bell and generator only are in the circuit. Between the button 2 and one side of the line circuit is attached the magneto-telephone, *t*, so that when the lever, *a*, is in the position shown in dotted lines, the circuit between the two sides of the line is completed through this telephone, the calling apparatus being out of circuit.

This manual operation of the switch proved very unsatisfactory. People would continually forget to move the switch lever into its normal position in contact with button No. 1, after using the telephone, and thus would leave their sub-station apparatus in such condition as to render it impossible to receive a call. It was soon after found necessary to make the switch as nearly automatic as possible, and to attain this end the switch lever was so designed as to be held down by the weight of the receiver in contact with the terminal of the calling circuit, and when released therefrom by the removal of the receiver for use to be moved by a spring into contact with the talking circuit terminal. Soon after, battery transmitters having come into general use, it became necessary to provide means for opening and closing a local circuit containing the local battery, the primary of the induction coil, and the variable resistance transmitter. This was necessary in order to have the battery in use only when the telephone instrument was being used, and was accomplished by the addition of a single contact point with which the lever made contact when released from the weight of the receiver. In order to make the lever a convenient place on which to hang

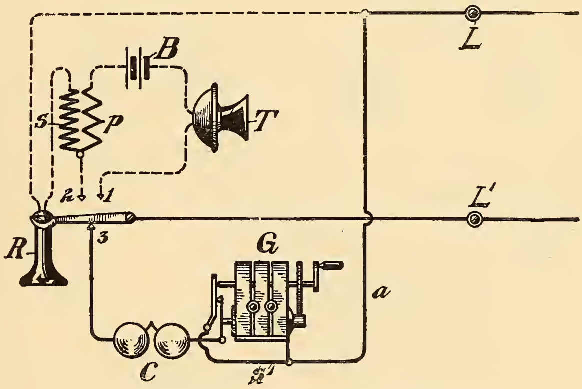


FIG. 107.—SERIES CIRCUIT—HOOK DOWN.

the receiver, its free end projected from the side of the instrument within convenient reach of the user, and was provided usually with a forked hook upon which the receiver might be supported. It is from this hook that the name hook-switch or switch-hook has been derived.

Fig. 107 shows, in somewhat modified form, the circuit of an ordinary magneto or local battery instrument. In this the hook lever is represented by *H*, and as will be seen, it is adapted to vibrate between the contacts 1 and 2 in its raised position and contact 3 in its depressed position. A restoring spring, not shown, serves to lift the lever into such a position that it will make contact with the points 1 and 2 when released from the weight of the receiver, while, when the receiver is hung on the fork of the hook this spring is overcome, the lever being brought into contact with the point 3. In its normal position, that is, when the receiver is hung up, all talking circuits are inoperative, being open at the points 1 and 2, and are therefore, for the sake of clearness, represented in the figure by dotted lines, those parts of the circuits which are in operative relation with the line being represented by full lines. Under these conditions a calling current from some other station coming in over the line to the binding post, *L*, forming one terminal of the instrument, will pass through wire, *a*, the shunt, *s'*, of the generator, *G*, thence through the winding of the call bell magnet, *C*, to contact, 3, and through the lever to the binding post, *L'*, connected to the return side of the circuit. When the instrument is used for sending a call, the generator crank is turned, automatically

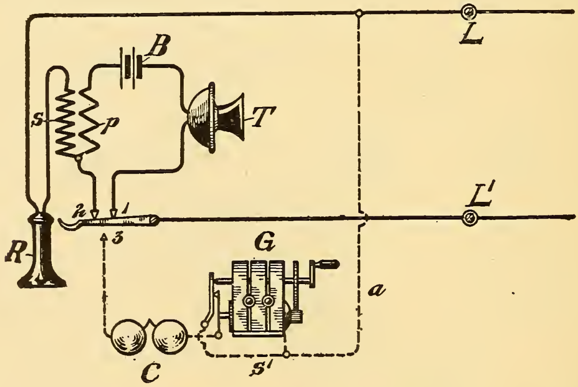


FIG. 108.—SERIES CIRCUIT—HOOK UP.

breaking the shunt around the armature, and thereby allowing the current generated in the armature to pass out over the line and ring the bell at a distant station.

In Fig. 108 the hook is shown in its raised position as when released from the weight of the receiver. The breaking of the contact, 3, renders the generator and bell inoperative, and therefore the circuit through them in this figure is shown in dotted lines. The closing of the contacts 1 and 2 by the raising of the hook puts the talking apparatus, including the receiver, *R*, the battery, *B*, the transmitter, *T*, and the primary and secondary, *p* and *s*, respectively, of the induction coil in operative relation with the line. The battery, transmitter and primary winding of the induction coil are in a local circuit between the contacts 1 and 2, while the line circuit is closed through the receiver and secondary winding of the induction coil and the contact, 2, of the hook-switch. In transmitting, undulatory currents set up in the local circuit will be transformed into alternating currents in the secondary of the induction coil, which currents will pass out over the line circuit and through the receiver and secondary coil of the distant receiving station, provided, of course, the hook at that station is also in its raised position.

The arrangement shown in Figs. 107 and 108, just described, is that of the ordinary local battery or magneto-telephone adapted to series work in common use to-day. The hook lever alternately renders inoperative either the talking apparatus or the calling apparatus by opening their circuits. Another method has been proposed and used to some extent, although it is now not in common

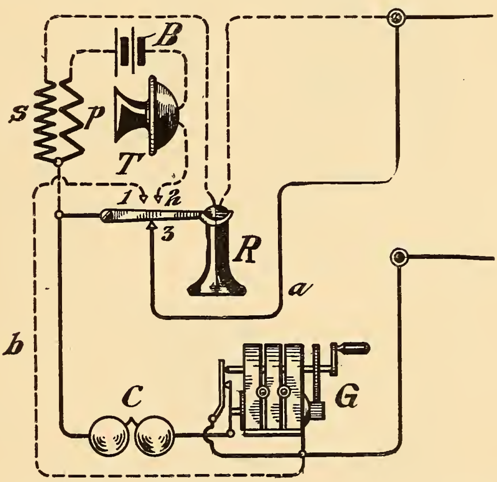


FIG. 109.—SERIES SHUNTING CIRCUIT—HOOK DOWN.

use. It is to have the hook lever render the talking apparatus or the calling apparatus inoperative by short-circuiting them instead of opening their circuits. Such an arrangement is shown in Figs. 109 and 110, where it will be seen that when the hook is down the generator, *G*, and the call bell, *C*, are in the proper circuit relation with the line for use, while the receiver and secondary winding of the induction coil are short-circuited by the closure of the contact, 3. Thus a calling current either outgoing or incoming would pass through the calling apparatus to the hook and thence through the shunt wire, *a*, around the receiver and secondary winding, these being shunted out of the circuit by the low resistance of this wire. On the other hand, when the hook is raised, as shown in Fig. 110, the shunt wire, *a*, is broken at the contact, 3, thus placing the receiver and secondary winding in proper relation with the line for use, while the shunt path, *b*, closed at the contact, 1, serves to direct the voice currents around the generator and call bell, thus shunting them out of circuit. The local circuit is closed and opened with this arrangement at the contact, 2, in the same manner as shown in Figs. 107 and 108. This shunting arrangement has an advantage over the other in that bad contact in the switch-hook does not completely spoil the operation of the instrument. If, for instance, the hook does not make the proper contact or makes no contact at all when depressed against point, 3, the calling apparatus would

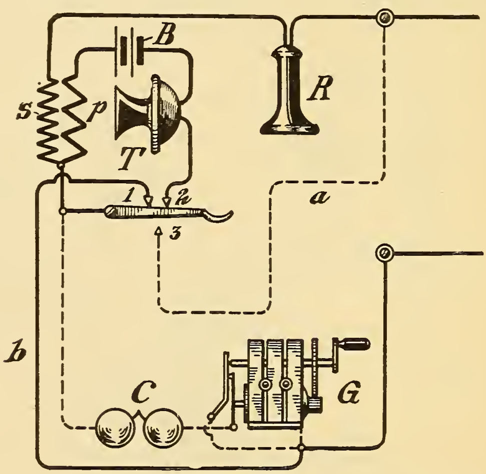


FIG. 110.—SERIES SHUNTING CIRCUIT—HOOK UP.

still be effective, as a path for the calling currents would still exist through the receiver and secondary winding of the induction coil.

In Figs. 111 and 112 are shown two circuits representing in simplified form the arrangement of apparatus commonly used in bridging telephones, the first figure showing the condition of affairs when the hook-switch is depressed for receiving or sending a call, and the second showing the condition for talking when the hook is raised. As in the preceding figures, the apparatus and circuits rendered inoperative by the position of the hook-switch are shown in dotted lines. Referring to Fig. 111, where the receiver is represented upon its hook, it will be seen that the talking apparatus is all on open circuit. The bell, *C*, is, however, permanently bridged across the line, its circuit in relation with the line depending in nowise on the position of the hook. The generator, *G*, is likewise independent of the hook in regard to its connection with the line, but is normally on open circuit at the point, *a*, which is closed only while the generator is being operated. The call bell, *C*, is adapted to receive incoming calling currents in an obvious manner, it being the only path closed across the two sides of the line circuit. The

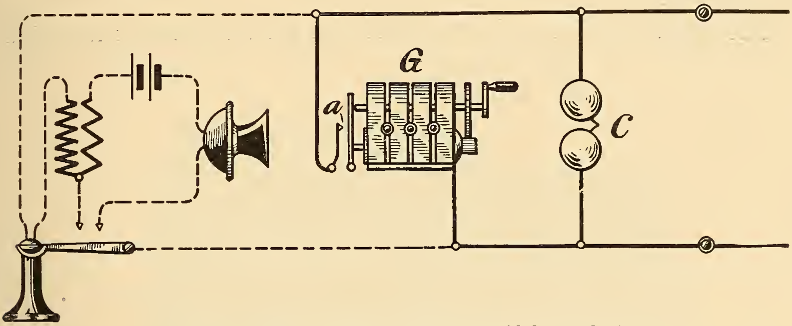


FIG. 111.—BRIDGING CIRCUIT—HOOK DOWN.

generator, *G*, when operated automatically closes the contact, *a*, and sends current out to the line past the terminals of the call bell, *C*. Where used on party lines the call bells of all the stations on the line are placed in multiple and are therefore all responsive to ringing current sent over the line.

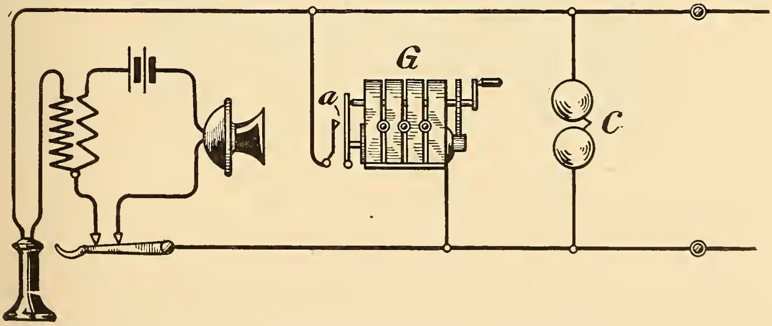


FIG. 112.—BRIDGING CIRCUIT—HOOK UP.

When the hook is raised, as shown in Fig. 112, the talking apparatus is properly connected with the line for use, in the manner already described, but the condition as to the generator and ringer is not altered. The generator circuit is, however, open, so that its circuit need not be considered as affecting the voice transmission. The bridge across the talking circuit afforded by the presence of the ringer magnets, *C*, would at first be thought detrimental to the talking efficiency, as it apparently affords a leak through which a portion of the voice currents may pass. The very high retardation of the ringer magnets, however, effectually prevents this, and it is found in practice that the presence of one or a comparatively large number of these magnets across the line does not affect the voice transmission.

The diagrams of circuits so far shown were somewhat modified

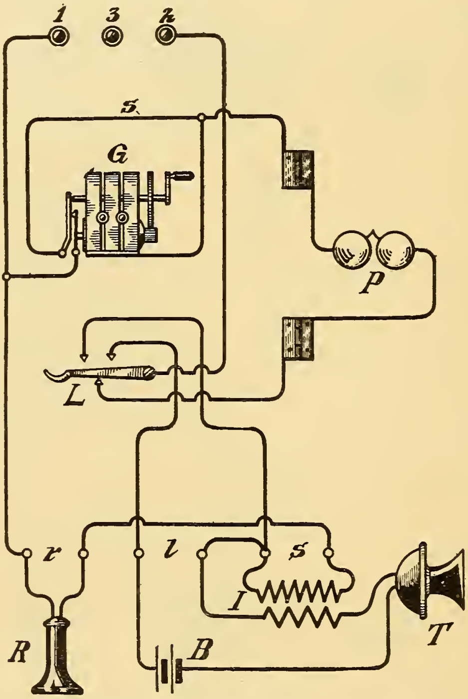


FIG. 113.—CIRCUIT OF COMPLETE SERIES TELEPHONE—COIL IN BASE OF ARM.

in order to render clearer an understanding of the working of the circuits. In Fig. 113 are shown the circuits of a complete series local battery telephone set of the type shown in Figs. 107 and 108, the connections being arranged as in actual practice. It is customary to mount the generator, *G*, the polarized bell, *P*, the hook-switch, *L*, and sometimes the induction coil, *I*, all in one box, as shown in Fig. 114, such a box with its contents being commonly known as a magneto-bell box. Frequently the induction coil is omitted from the box, as is the case in this figure. When this is done the induction coil is mounted in the base of the transmitter arm. The circuit of Fig. 113 is adapted to such arrangement.

In order to facilitate the work of making connections between the parts contained in the generator box and the other parts, that is, the transmitter, receiver, battery and induction coil, in case this is not placed within the box, and also with the line, the terminals of the circuit in the box are brought out to binding posts on the top and bottom of the box. In Fig. 113 the binding posts 1 and 2 on the top of the box are for attaching the line wires. These form

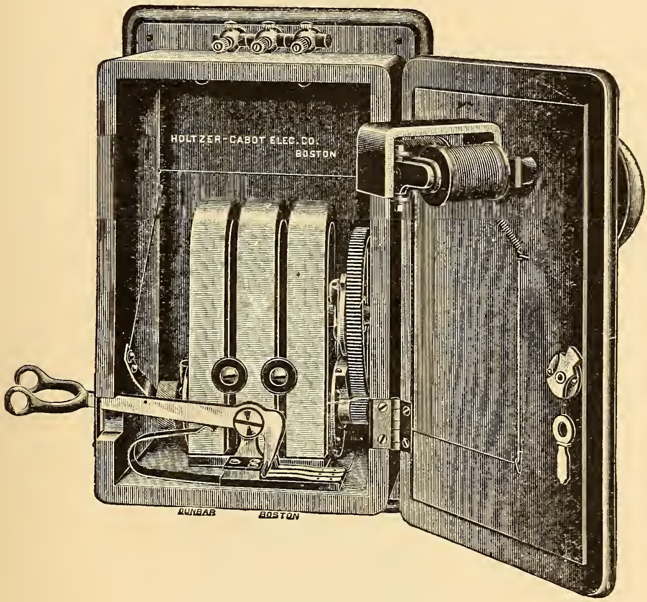


FIG. 114.—MAGNETO BELL BOX.

the terminals of the instrument as a whole. The center binding post forms the ground terminal of the lightning arrester, not shown in this figure, and has no connection within the box.

The six binding posts at the bottom of the generator box are in three pairs, *r*, *l*, and *s*. The pair, *r*, form terminals for attaching the receiver cord. The two posts forming pair *l*, are for the local circuit, the battery, *B*, the transmitter, *T*, and the primary of the induction coil, *I*, being connected in series between them. Between the right-hand pair of posts, *s*, is connected the secondary of the induction coil, *I*. The bell, *P*, is mounted on the door of the box, connection to it being made through the hinges.

The connections of the automatic shunt are clearly shown in this figure. Normally a short circuit exists around the generator, through the wire, *s*. This is broken between the pair of springs when the generator is operated as already described.

In Fig. 115 is shown a view of a complete instrument using the circuits just described, this type of telephone being well known and, until recently, being almost the only form in which magneto telephones for wall use were produced. In this type of instrument the

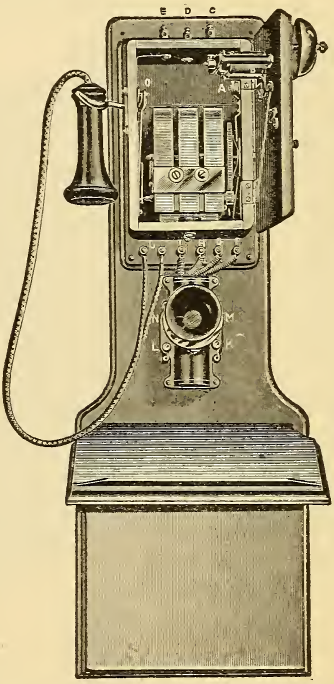


FIG. 115.—COMPLETE WALL TELEPHONE SET.

battery, usually consisting of two wet cells of the LeClanche type, is located in the box at the bottom of the wall board, the battery resting on a cast iron shelf secured to the wall board and being completely exposed for inspection by the removal of the box. Various methods of fastening the box have been used, but one, consisting of two clamps on the inner side of the battery box adapted to engage two similar clamps secured to the back board, has come into wide use. The box is engaged or disengaged by a downward or upward motion with respect to the back board.

The complete circuits of the bridging bell telephone set are shown in Fig. 116. This shows the arrangement used in practice, embodying the simplified circuits shown in Figs. 111 and 112. It will be seen that the bell, *P*, is permanently bridged across the two sides of the line between the binding posts 1 and 2, the connections being made through the hinges of the bell box. The generator, *G*, is in a second bridge circuit, normally open, but adapted to be closed when the generator is operated.

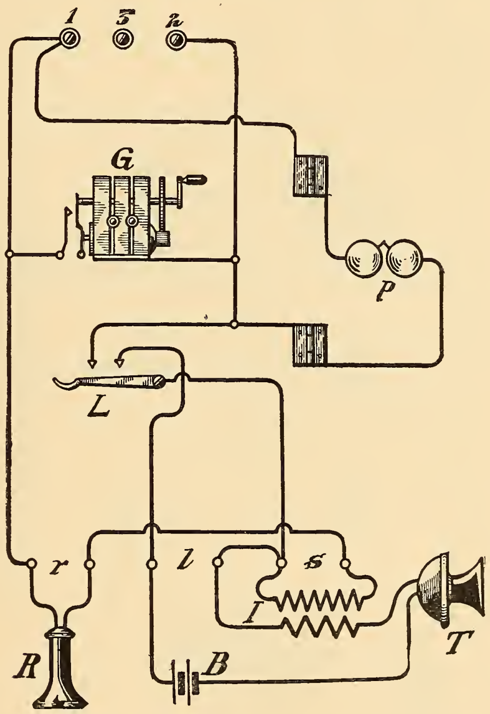


FIG. 116.—COMPLETE BRIDGING BELL TELEPHONE CIRCUIT—COIL IN BASE OF ARM.

In Fig. 117 are shown the complete working circuits of a series telephone wall set in which the induction coil is mounted in the bell box rather than in the base of the transmitter arm. Fig. 118 shows the circuits of a bridging telephone using a similar arrangement. This practice of mounting the induction coil in the bell box rather than in the base of the transmitter arm is probably, all things considered, the best. There is no good reason why the coil should be mounted in the base of the transmitter arm and the circuit wiring of the box is made somewhat simpler by mounting the coil in the bell box.

Since the use of the dry cell has become very common for local battery telephones, a new type of wall set has come into vogue wherein the call bell, generator, switch-hook, induction coil and batteries are all mounted in a single box divided off into compartments, as shown in Fig. 119. Another view of this box with the door closed is shown in Fig. 120. This type of set is being made

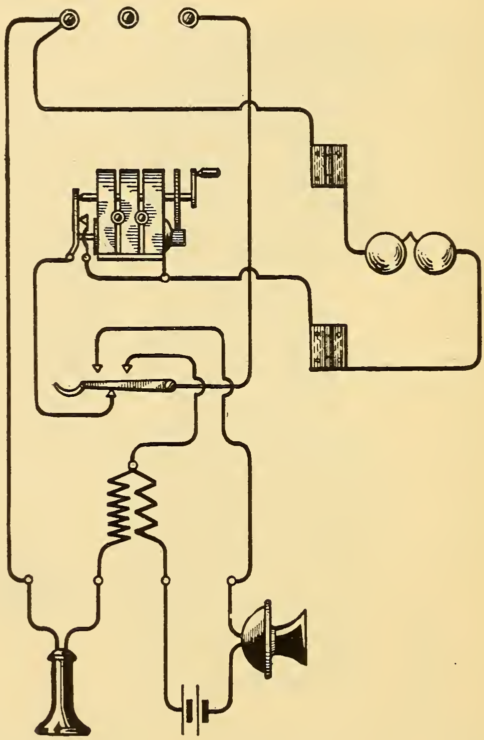


FIG. 117.—SERIES CIRCUIT—COIL IN BELL BOX.

by nearly all of the telephone manufacturers and is proving popular. It is perhaps more convenient, and neater in appearance than in the old types wherein a large battery box is provided for the wet cells. In this latter type a shelf for the convenience of the subscriber in writing is mounted on the lower part of the cover of the box instead of using the top of the battery box for this purpose, as in the old type.

The arrangement of transmitter, receiver, induction coil and hook-switch shown in Fig. 121 deserves mention. It is that used by the Stromberg-Carlson Company, which company has persistently adhered to this type for a large portion of their local battery and common battery telephones, for several years past. In this the hook-switch and induction coil are both mounted in the base of the transmitter arm, this base being a hollow box of cast iron in the form shown. The hook lever projects through the opening in the left-hand portion of this box, for supporting the receiver.

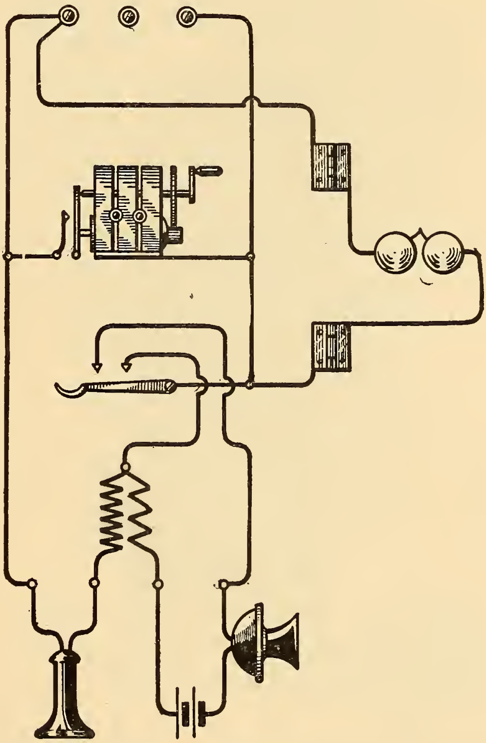


FIG. 118.—BRIDGING CIRCUIT—COIL IN BELL BOX.

All the wiring between the terminals of the receiver, transmitter, induction coil and hook-switch is concealed within this box, the terminals of their combined circuit being brought out on binding posts on a connecting rack at the top of this box. This piece of apparatus therefore contains all of the talking apparatus of the ordinary telephone; and it is only necessary to properly connect it in circuit with the generato:, ringer and battery in order to obtain a complete magneto sub-station apparatus. Such a set in its complete form is shown in Fig. 122.

The so-called "desk set" has become more and more popular, particularly in the case of busy men who are compelled to use their telephones many times a day. Desk sets are usually made in this country of the general type shown in Fig. 123, although the various manufacturers have modified the design in many details in order to meet the demands of trade. In the case of magneto-desk sets, it is customary to mount the magneto generator and ringer separately from the desk stand, sometimes in two separate boxes. The

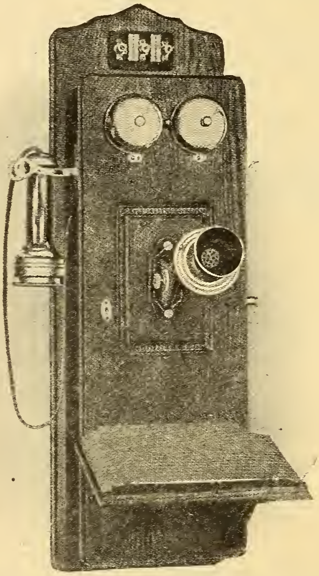


FIG. 119.—DRY-BATTERY WALL SET—CLOSED.

battery is usually arranged in a drawer of the desk or on the floor at some convenient point near the desk. The arrangement of circuits in a desk set involves several considerations not found in the circuit of a wall set. The wall set is usually complete in itself, so that the wiring may be completed in the factory, the only wires that need be applied to the instrument externally being those leading to the line and ground. In the desk set, the separate mounting of the generator, the ringer and the battery, makes their connection in their proper circuit relation, without an undue amount of wiring (the presence of which would be an inconvenience to the user of the desk) a matter which requires careful study. In order to make the desk stand proper portable it is usual to connect it to the other parts of the circuit by a flexible cord having a sufficient number of separate conductors. This cord usually has an outer braiding

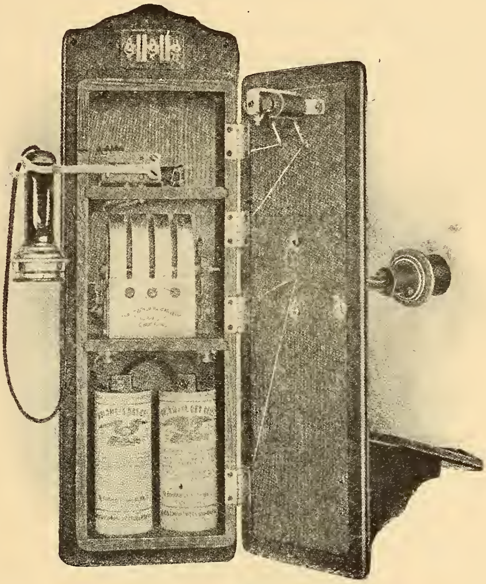


FIG. 120.—DRY-BATTERY WALL SET—OPEN.

of green silk and is long enough to give sufficient range of motion to the desk stand. The number of conductors in this cord is a

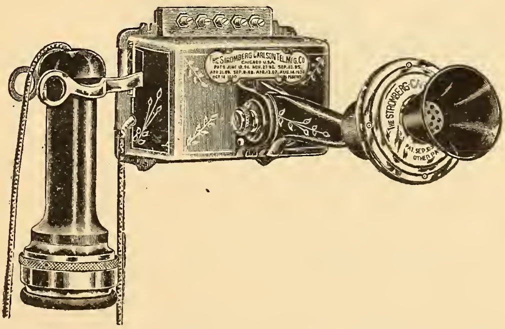


FIG. 121.—STROMBERG-CARLSON "TRIPLET."

matter which should be given some weight in laying out the scheme of wiring, as the cord is an item of no inconsiderable expense, and on general principles, the fewer the number of conductors in a flexible cord the better. As an aid to desk set wiring it is not uncommon to use a separate connecting rack having several binding posts which may be mounted in any convenient part of the desk and to which the various wires leading to the generator, bell, battery, etc., may be attached. Fig. 124 shows the general scheme of wiring used by the Stromberg-Carlson Company in their series magneto desk set arrangement, the generator being mounted in the box on which the desk stand rests and forming a sort of shelf therefor if desired. In case it is wished to keep the desk stand on the desk proper, the generator box may be mounted under or beside

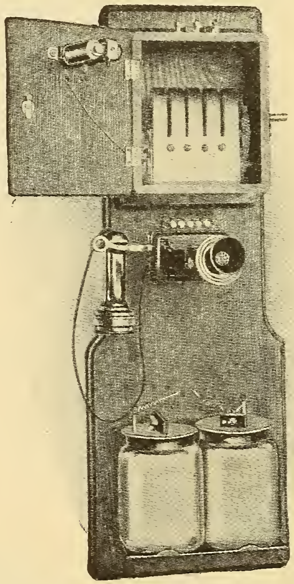


FIG. 122.—STROMBERG-CARLSON TELEPHONE USING "TRIPLET."

the desk so that its crank may be in easy reach of the subscriber. This shows the standard Stromberg-Carlson desk stand, in which the induction coil is carried in the base of the stand.

In Fig. 125 is shown a different arrangement, wherein the induction coil is mounted on the connecting rack, and the ringer is enclosed in the generator box. This cut shows the standard Kellogg desk stand.

In Figs. 126 and 127 are shown respectively the circuits of series and bridging desk sets, the apparatus being so arranged that the induction coil, generator and bell are all within a single box, binding posts on the base of this box serving as terminals for the attachment of the flexible cord leading to the desk stand proper, as well as the battery terminals and the line terminals. In this case, which is probably the simplest of all magneto desk set arrangements, a four-conductor cord from the desk stand to the generator box is required for the series set, a three-conductor cord serving for the bridging instrument. Besides this the only external

FIG. 123.—TYPICAL DESK STAND.

wiring necessary is that from the line and the battery to the posts on the base of the box. In Figs. 128 and 129 are shown similar circuits for series and bridging instruments respectively, the difference in this case being that a separate connecting rack is employed upon which the induction coil is mounted, the magneto box in this case containing only the generator and the call bell. In these a three or four-strand flexible cord is needed from the connecting rack to the desk stand; two wires lead from the connecting rack to the bell box, two from the connecting rack to the battery and two from the connecting rack to the line. This arrangement is advantageous

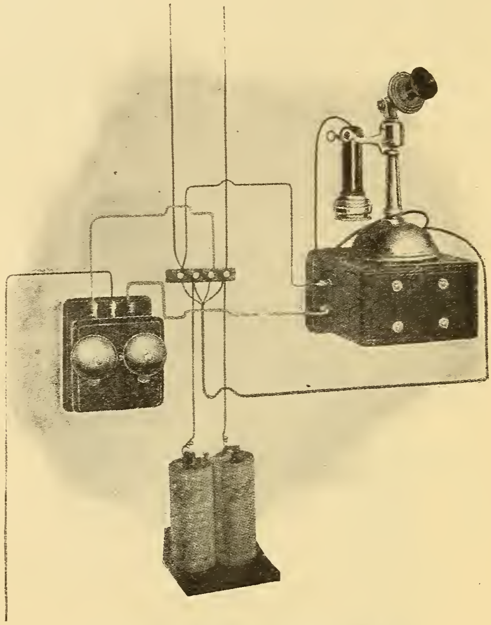


FIG. 124.—WIRING OF DESK SET.

where, for any reason, it is undesirable to run a flexible cord leading from the desk stand to the generator box. By mounting the in-

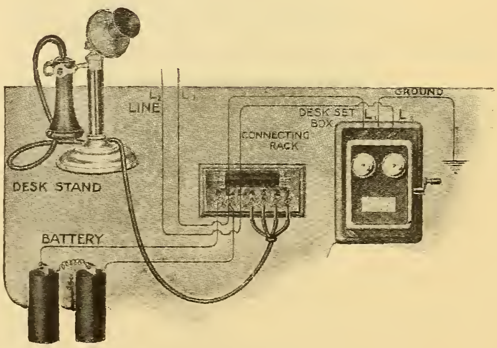


FIG. 125.—WIRING OF DESK SET.

duction coil on the connecting rack, the four wires leading to the primary and secondary of this coil may be connected permanently to their respective binding posts on this rack, thus somewhat simplifying the external wiring.

Still another arrangement of desk stand wiring is that wherein a separate connecting rack without induction coil is used, the induction coil being carried in the generator box. The circuit arrangement for this or any other modification may easily be worked out from the diagrams shown.

For bridging instruments, the Bell companies usually employ the circuit arrangement shown in simplified form in Figs. 111 and 112,

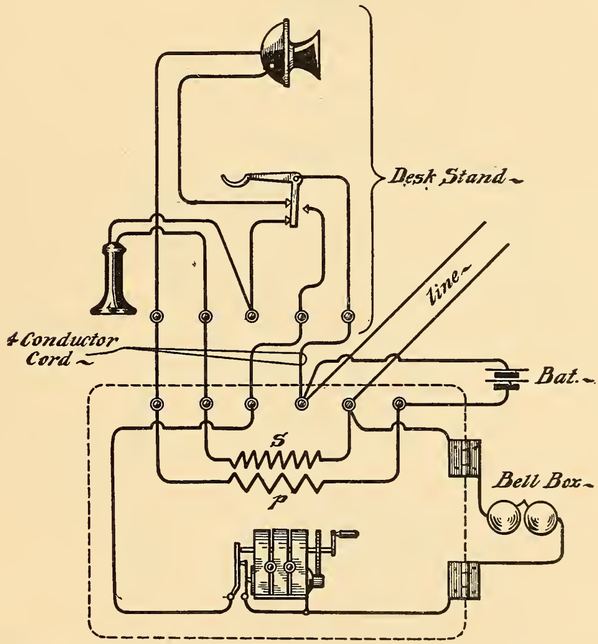


FIG. 126.—SERIES DESK SET CIRCUIT—COIL IN BELL BOX.

the generator and bell being independent of the position of the hook. This was the arrangement of the Carty patent. Several modifications of this arrangement are used by different Independent companies, these owing their existence either to the demand for slightly different kind of service or directly to a desire to dodge the claims of that patent.

The simplest of these modifications is shown in Fig. 130, where both generator and bell are rendered incapable of sending current to, or receiving it from, the line when the hook is raised.

In Fig. 131 the bell circuit only is under the control of the hook, the generator being connected directly across the binding posts of the instrument at all times.

In Fig. 132 the circuits of both generator and bell are controlled at the hook, and furthermore the circuit of the bell, normally closed, is opened by the action of the generator, which at the same time cuts itself into the circuit of the line. With this arrangement the

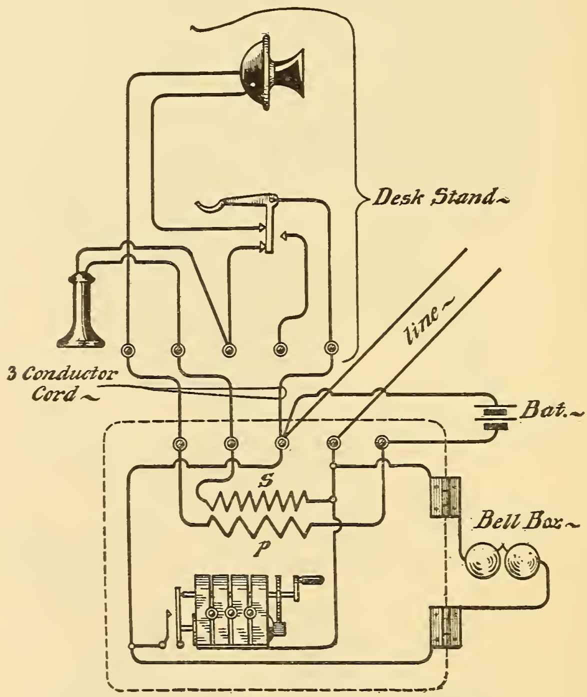


FIG. 127.—BRIDGING DESK SET CIRCUIT—COIL IN BELL BOX.

generator can never cause its own bell to ring, a feature desired by many users.

The apparatus by which the automatic switching between the signalling and the talking apparatus is accomplished—the switch-hook—while very simple, merits attention in detail. Much care is necessary in its design and construction. The energy available for the operation of the switch is limited to that due to the attraction of gravity on the receiver, and it becomes somewhat difficult to so arrange the contacts that they will be firmly and positively made, and surely broken at the proper time. For this reason all the points of contact are in all good types provided with platinum tips to prevent corrosion, and, if possible, a slight sliding action at the point of contact is also obtained. A sliding contact tends to clean the points and at the same time prevent particles of dust from keeping the two apart. Too much sliding action is, however, worse than none, as it is sure to cause cutting. The springs for restoring the lever and those serving as contacts should be so arranged that no movement of which the lever is capable will strain them beyond

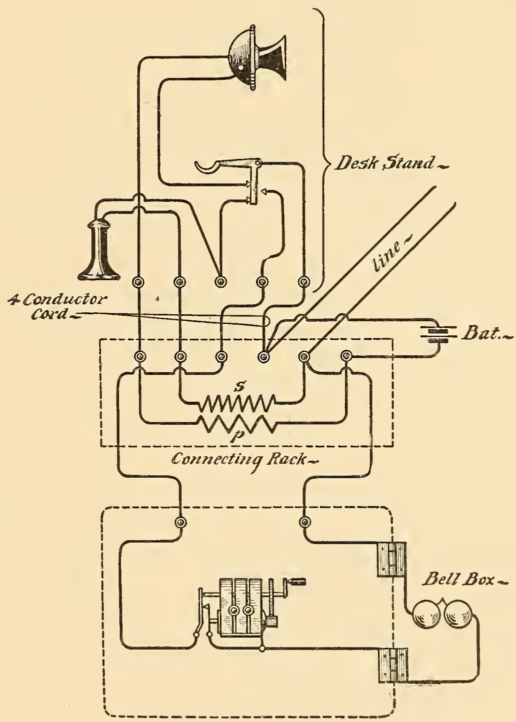


FIG. 128.—SERIES DESK SET CIRCUIT—COIL ON RACK.

their elastic limit or to such a degree that they will eventually lose their tension or break. It is bad practice to have the same part of a contact slide alternately over a conducting material, as of brass, and an insulating material, as of hard rubber, as small particles from either surface are sure to be carried upon the other surface, thus forming a partial electrical connection on the insulating surface and a defective connection on the brass or metal surface. Where a long sliding contact is used much trouble is often caused by the cutting of the two surfaces. The extent of this cutting, even where the pressure is very light and the movement very limited, is often astonishing.

In Fig. 133 is shown the hook-switch now almost universally used by the Bell Telephone Company, and known as the "Warner Switch." The hook lever is pivoted to a bracket by a screw as shown, and is provided with a lug, *f*, and a strip of insulating material, *g*, on its short arm. On the under side of the lever is an

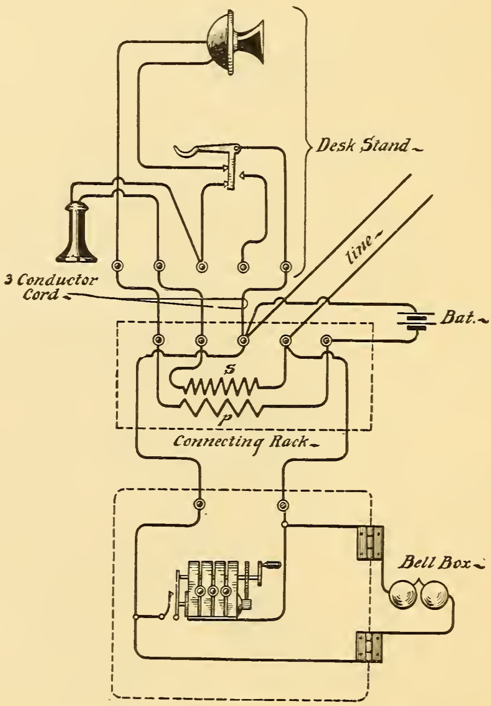


FIG. 129.—BRIDGING DESK SET CIRCUIT—COIL ON RACK.

insulating pin, *h*, and a contact point, *i*. A spring screwed to the generator box under the lever by the screw, *b*, bears alternately upon the insulating pin, *h*, and the contact point, *i*, and tends to press the lever into its elevated position. Springs, *c* and *d*, screwed to the side of the generator box, bear alternately upon the insulating piece, *g*, and the conducting lug, *f*, according to whether the lever is depressed or elevated. The spring, *c*, is connected through the secondary winding of the induction coil and the receiver to one side of the line. The screw, *b*, is connected through the calling apparatus to the same side of the line. The binding screw, *a*, connected with the lever, *e*, forms the terminal of the other side of the line. The local circuit terminates on one side of the spring, *c*, and

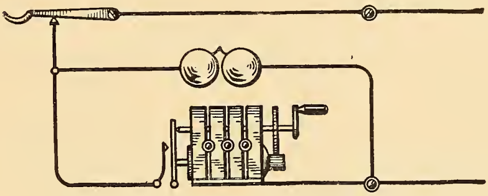


FIG. 130.—GENERATOR CIRCUIT.

on the other side in the spring, *d*. When the hook is depressed, point, *i*, is connected through the lower spring with the screw, *b*, and the calling circuit is complete. Both the local circuit and the line

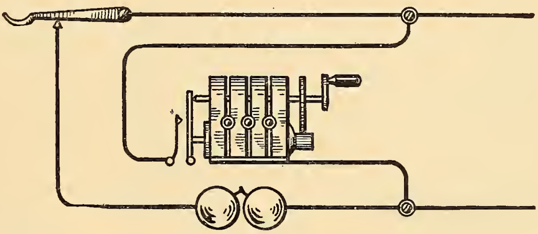


FIG. 131.—GENERATOR CIRCUIT.

circuit through the talking apparatus are broken at springs, *c* and *d*. When the hook is elevated, the calling circuit is broken at the point, *i*, and the local and line circuits are completed by the springs, *c* and *d*, and lug, *f*.

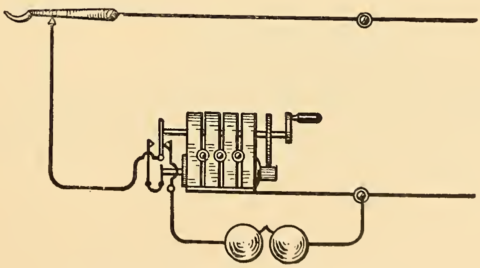


FIG. 132.—GENERATOR CIRCUIT.

It cannot be denied that this piece of apparatus was for a long time the best switch-hook made, and that it gives satisfactory and reliable service now. It is, however, not self-contained as are most modern hooks, its various springs and contacts being scattered around over the inside of the box, and therefore subject to faults due to inaccurate mounting, and to subsequent changes in position due to warping or shrinking of the woodwork. For the sake of economy, if for no other reason, it would seem that the Western Electric Company would adopt its customary modern methods in this case also.

In Fig. 134 is shown the hook-switch now embodied in all the subscribers' instruments manufactured by the Kellogg Switchboard and Supply Company. The hook lever, *L*, is of brass, pivoted in a bracket, *B*, secured at the side of the box. It is normally maintained in its raised position by a strong spring, *S*, secured to the bracket. Springs, 1, 2, 3, 4, and 5, are secured by two screws to

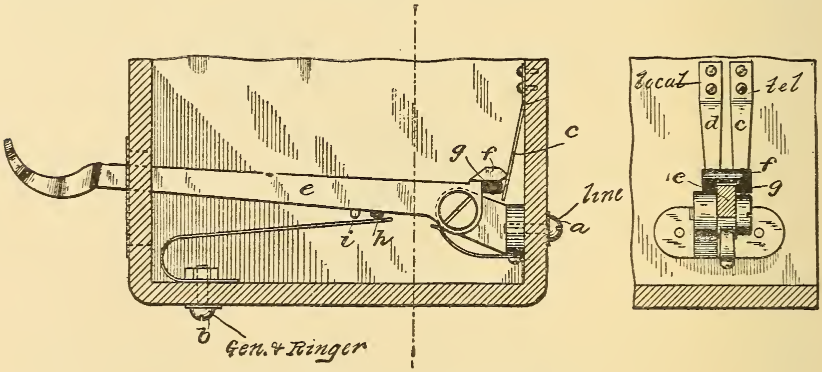


FIG. 133.—WARNER HOOK SWITCH.

a lug on the bracket, *B*, these springs being insulated from each other by hard rubber blocks and bushings. Spring, 4, is made longer than the others, so as to engage in a slot in the lug, *l*, cast on the side of the hook lever. The springs are platinum-pointed, as shown, the arrangement being such that when the hook is in its raised position the spring, 4, presses 3, 2, and 1 together, leaving spring, 5, disconnected as shown. When, however, the hook is lowered by the weight of the receiver, the springs, 1, 2, and 3, break contact with each other and with spring, 4, the latter making contact with spring, 5. The long spring, 4, is connected with one side of the line, and serves to complete the talking circuits when the lever is raised, and the signaling circuit when the lever is depressed.

This switch has a distinct advantage over most other types, in that the lever itself and the restoring spring, *S*, form no part of the circuit, and, therefore, no provision has been made to prevent loose contacts between them. The contact springs are all platinum-pointed, so that there is small liability of trouble. A strong point in favor of this form of switch is the ease with which it may be

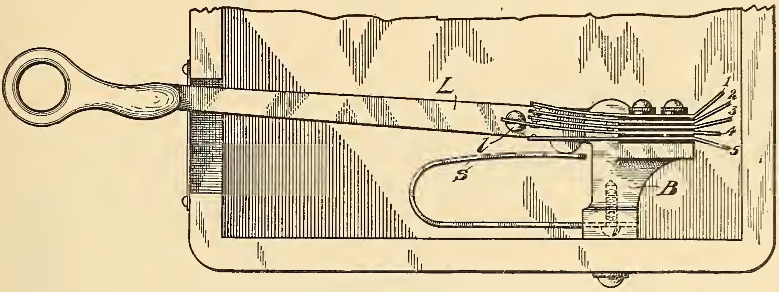


FIG. 134.—KELLOGG HOOK SWITCH.

adapted to meet the requirements of almost any circuit, it being very easy to add more springs or to so arrange them that their contacts will be made and broken in a definite order upon the raising or lowering of the hook.

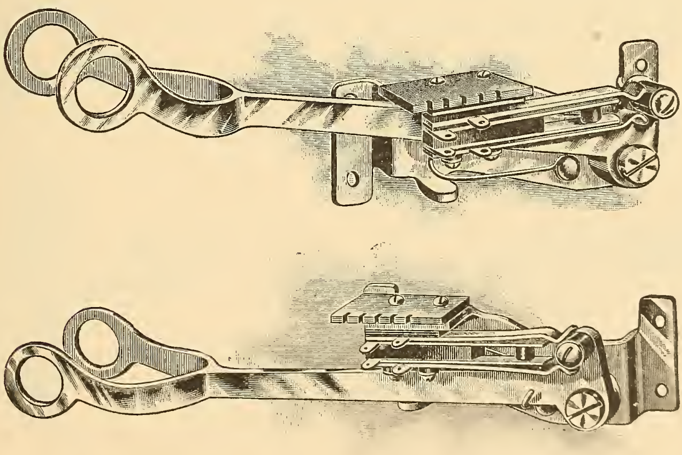


FIG 135.—STROMBERG-CARLSON HOOK SWITCH.

This method of mounting all of the springs of a group together, being fastened by screws and bushings in the manner shown, was for a long time typical of the Kellogg apparatus, but has now been adopted by several other manufacturers. This hook, moreover, is entirely self-contained, and is, in that respect, a decided improvement over many earlier types.

Fig. 135 shows the hook-switch recently put on the market by the Stromberg-Carlson Company, which also has the advantage of being self-contained and of allowing a ready adaptation of the con-

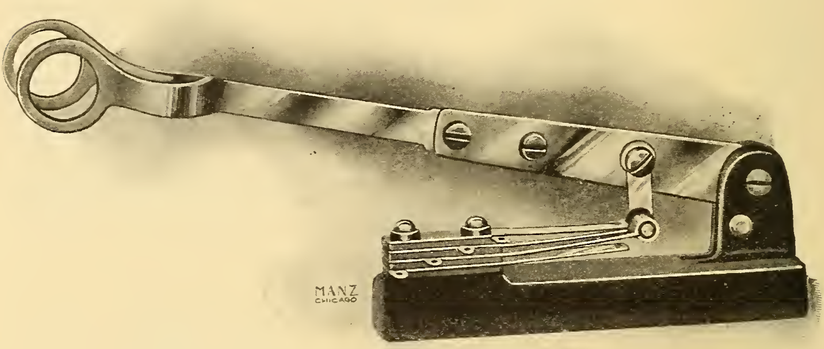
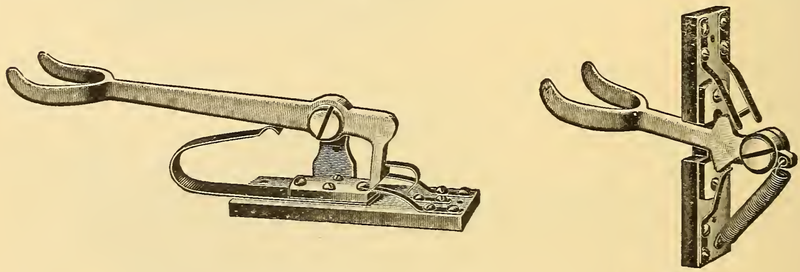


FIG. 136.—MONARCH HOOK SWITCH.

tact springs to any circuit requirements. In this the springs are mounted on a lug bent up from the base, the two outside springs being operated upon by a hard rubber cam carried on an upwardly projecting arm on the hook lever. This cam, when the hook is depressed, wedges the two long springs apart, thereby causing them



FIGS. 137 AND 138.—FAULTY TYPES OF HOOK SWITCHES.

to break contact with the two inner springs. This particular combination is adaptable to bridging telephones, the two long springs being wired together to form a single line contact, in which case the upper spring may carry the battery and the lower one the secondary circuit.

In Fig. 136 is shown another form of switch-hook recently put on the market by the Monarch Telephone Manufacturing Company. This hook also possesses a group of springs fastened together as in the two preceding types of hooks, and mounted upon a cast-iron base. The hook lever is pivoted to an upwardly extending lug on this base. The motion of the hook is imparted to the long spring by a vertical link member, as is clearly shown. The hook is raised when released from the weight of the receiver by a coiled spring within the base, this spring acting on a bell-crank arm extending downwardly within the base from the end of the lever.

The lever of this hook is made in two pieces, being fastened together by two screws, as shown. This enables the hook to be easily removed from the telephone without taking off the escutcheon plate used to cover the hole in the box through which the hook passes.

Figs. 137 and 138 show two hook-switches which are examples of bad practice. They have only the advantage of being self-contained, and cheap—no platinum being used.

CHAPTER X.

TELEPHONE LINES.

Up to this point the apparatus used in transmitting speech and signals over telephone lines has been considered, but nothing has been said of the properties of the lines themselves. It is best to discuss these properties before passing to the subject of the telephone exchange, as the lines form an important part of the exchange, the connecting links between the sub-stations and the central office.

In the early days of telephony, the fact discovered by Steinheil, that the earth could be used instead of the return wire of an electric circuit, was made use of, and telephone lines were generally constructed accordingly—that is, with but a single wire, using the earth as the return. Such lines are commonly termed "grounded" or "ground return" lines, one of them being shown diagrammatically in Fig. 139, connecting two telephones. The ground connections in this figure are shown at *G G*, this being the now universally adopted way of showing such connections or "grounds" as they are called.

Lines so constructed were soon found to be subject to serious difficulties, chief among which were the strange and unaccountable noises heard in the receiving instruments. There are many causes for such noises, some of which are not entirely understood. The swinging of the wire, in such manner as to cut through the lines of force of the earth's magnetic field, or the sudden shifting of the field itself, causes currents to flow in the line wire which may produce sounds in the receiver. On long grounded lines the variation in the potential of the earth at the ground plates, due to any cause whatever, will cause currents to flow in the line. The passing of clouds or bodies of air charged with electricity will induce charges in the line, and cause currents to flow to or from the earth through the receiving instruments. Electric storms and auroral displays apparently greatly heighten these effects. These noises are of varying character, and Mr. J. J. Carty well describes them in saying:

"Sometimes it sounded as though myriads of birds flew twittering by; again sounds like the rustling of leaves and the croaking of frogs could plainly be heard; at other times the noises resembled the hissing of steam and the boiling of water."

The noises due to these natural phenomena, whatever their true cause may be, are chiefly annoying on long lines, short lines being disturbed only during heavy electrical storms. This is not the case, however, with the noises arising from the proximity of other wires carrying varying currents. Telegraphic signals can be plainly heard in a telephone instrument on a line running parallel with a neighboring telegraph line for a very short distance. The establishment of an electric railway or electric lighting plant in a town using grounded telephone lines will always cause serious noises in the telephones, and if the lighting current is alternating the use of the telephones is usually out of the question at night time, while the plant is running.

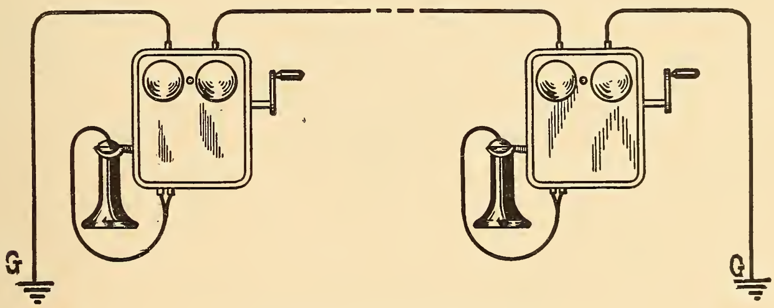


FIG. 139.—GROUNDED LINE.

Disturbances on telephone lines from neighboring wires may be attributed to one or all of the following three causes: leakage, electromagnetic induction, and electrostatic induction.

Leakage may occur through defective insulation between the two circuits; or even when the insulation of the wires themselves is practically perfect a heavy return current from a grounded circuit, such as of an electric railway, may, upon its arrival at the grounded end of the telephone line, have the choice of two paths, one through the telephone line, and the other a continuation of its path through the ground. This is the greatest source of trouble due to railway work, on grounded telephone lines.

Electromagnetic induction on a telephone line is due to the fact that the line wire lies in the field of force set up by current flowing in the disturbing wire. About every wire carrying a current there is a field of force, or "magnetic whirl," consisting of closed lines of force surrounding the conductors. Such a condition is represented in Fig. 140. If the current is a continuous one, the lines of force will not vary after being once set up, and the telephone wire lying in this field will not be affected. If the current in the disturbing wire is fluctuating, the number of lines of force in this field will vary; or, by a clearer way of expressing it, the field of force will expand and contract accordingly. This expansion and contraction of the field will cause its lines of force to cut the telephone wire, and will by the laws of electromagnetic induction cause currents to flow in the latter. If the current in the disturbing wire is an alternating one, the field of force around it will be established in one direction, destroyed and established in the reverse direction,

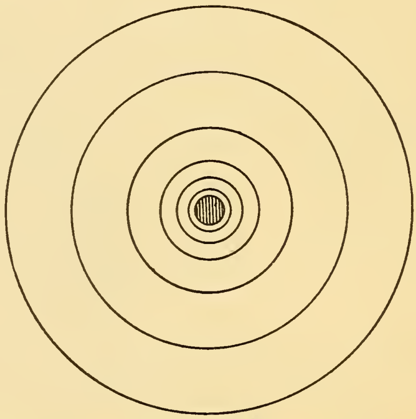


FIG. 140.—MAGNETIC LINES AROUND A CONDUCTOR.

and again destroyed, with every complete cycle of the current. This is the condition for a maximum disturbance in the telephone wire.

Electrostatic induction may be explained by reference to Fig. 141, where a grounded telephone line is shown running parallel with a disturbing wire, which we will say is carrying an alternating electric current. The disturbing wire will receive from its source of current alternate positive and negative charges of electricity, and its potential will pass from a maximum in one direction through zero to a maximum in the other, and again through zero to the maximum in the first direction during each cycle.

Consider the condition when the potential of the disturbing wire is zero. No charge will then be induced on the telephone wire, so that its potential will also be zero, unless subject to other influences. The charge on the disturbing wire then becomes, we will say, positive, and this induces a bound negative charge on the side of the telephone wire nearest the disturbing wire, and an equal positive charge on the opposite side. This latter charge is not bound, and flows to earth through the receivers at each end. This flow will be toward the ground, through each receiver, and the current is therefore from the center of the wire in each direction to the ground. The next instant the potential of the disturbing wire becomes zero, thus relieving the bound negative charge on the telephone wire, which flows to earth, or, more properly, is neutralized by a flow of positive electricity from the earth. Thus each change in potential of the disturbing wire causes a flow of current through the receivers at each end, this flow always being toward or from the middle point in the length of the wire. These currents produce noises in the receivers at each end in the ordinary way.

When two grounded telephone circuits run side by side, each

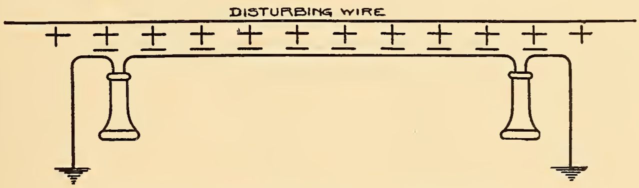


FIG. 141.—ELECTROSTATIC INDUCTION.

acts inductively on the other, so that a conversation carried on over one circuit may be heard in the telephones on the other. This phenomenon is aptly termed cross-talk, and is usually explained in text-books and articles on the subject by the supposition that it is chiefly if not entirely due to electromagnetic induction.

In 1889, however, Mr. J. J. Carty, in a paper before the New York Electric Club, and again in 1891, in another paper before the American Institute of Electrical Engineers,* described a series of experiments which show conclusively that cross-talk between lines is due almost entirely to electrostatic induction, electromagnetic induction playing so small a part as not to be noticeable.

The arrangement of circuits in one of his experiments is shown in Fig. 142, in which *E F* and *C D* are two well-insulated lines, each 200 ft. long, and placed parallel with each other throughout their entire length, at a distance of $\frac{1}{8}$ in. apart. *E F* is the disturb-

* These papers are classics, and should be read by all interested in this subject.

ing line and is left open at *E*. At *F* it is connected through the secondary of an induction coil, *L*, with the ground. In the primary circuit of this coil is a battery, *B*, and a Blake transmitter, *T*. A tuning fork vibrating before the transmitter acted on the diaphragm in the usual way, and caused impulses on the line *E F* of practically the same strength as voice currents. These impulses are, of course, alternately positive and negative, and may be considered in the same light as the impulses on the disturbing line in Fig. 141. Three receivers, *x*, *y*, and *z*, were placed in the line *C D*, the receiver, *y*, being at the middle point in the line. Upon operating the tuning fork, its musical note could be distinctly heard in receivers, *x* and *z*, while *y* remained silent.

In explaining the action of static induction in connection with Fig. 141, it was pointed out that the flow of induced currents would be either toward or from the middle point in the length of the wire.

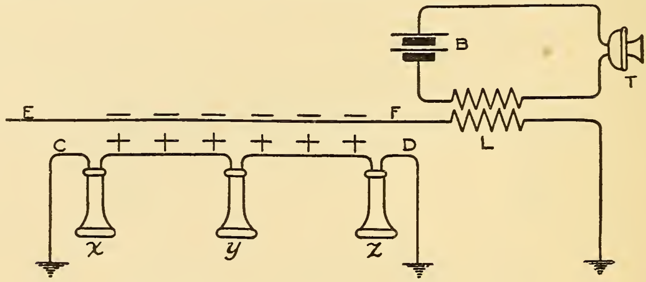


FIG. 142.—ELECTROSTATIC INDUCTION.

The silence of the receiver, *y*, in this case bears out that statement, showing the central point to be neutral. If this were electromagnetic induction, the induced current would pass from one end of the line, *C D*, to the other, returning through the ground, in which case all the receivers would be affected. As it is, however, the induced charges flow in each direction from the receiver, *y*, to the ground at each end, or from the ground at each end to the receiver, *y*, thus in no case causing its diaphragm to vibrate. The same results were obtained by grounding the point *E* through an ordinary telephone. The receiver, *y*, still remained silent, while *x* and *z* were both affected to an equal degree.

It was also found that opening the central point of the line, *C D*, produced no effect whatever on the existing conditions; the noises in the receivers, *x* and *z*, were plainly heard and of equal loundess.

Many other experiments were tried, the results in each case pointing conclusively to the induction from voice currents being of an electrostatic instead of an electromagnetic nature.

There is no doubt, however, that induction from wires carrying heavy currents, such as are used in lighting and power work, is partly due to electromagnetic effects, and this can be easily proven by experiments similar in nature to those described.

The one remedy for all the troubles due to disturbing noises from

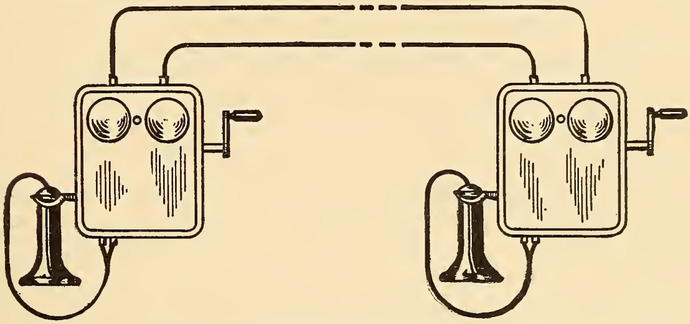


FIG. 143.—METALLIC CIRCUIT LINE.

any of the causes is to make the line a complete metallic circuit. By this is meant a circuit having both its sides formed of a wire, each wire being individual to the circuit and not forming a portion of other circuits. A metallic circuit line connecting two telephones is shown in Fig. 143.

This alone, however, will not completely stop noises from most of the causes, and additional precaution must be taken, by making the two sides of the circuit alike in all respects and properly transposing them at frequent intervals, in order that they may be as

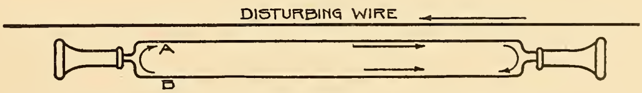


FIG. 144.—ELECTROMAGNETIC DISTURBANCES.

nearly symmetrical with respect to the disturbing source or sources as possible.

Merely making the line a metallic circuit, as in Fig. 143, does not give complete freedom from inductive troubles from other wires, whether the induction be electromagnetic or electrostatic. Considering the question from the standpoint of electromagnetic induction, a current flowing in the disturbing wire, Fig. 144, would set up a field of force, the lines of which would cut conductors, *A* and

B. *A* being closer, however, would be cut by more lines than *B*, and consequently any currents induced in *A* by changes in this field will be stronger than those in *B*. If a current starts to flow in the disturbing wire from right to left, as shown, the induced currents in *A* and *B* will each be from left to right, as indicated by the arrows. These currents will partially annul each other, but that in *A*, being the stronger, will predominate, and the resultant will flow in the circuit in a direction indicated by the small curved arrows.

A single transposition in the center of the metallic circuit will completely annul the electromagnetic induction if the disturbing wire is parallel to the two wires throughout its entire length, and if it carries the same current in all its portions. Here an impulse in the direction of the arrow in the disturbing wire (Fig. 145) will cause impulses in the opposite direction in both wires, *A* and *B*. As the average distances between the disturbing wire and *A* and *B*, respectively, are the same, the strength of the induced currents

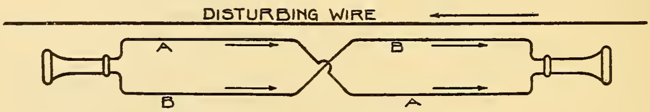


FIG. 145.—ELECTROMAGNETIC DISTURBANCES.

in *A* and *B* will be equal, and they will, therefore, annul each other, producing no sound in the receivers.

It is found, however, that a single transposition in the center of the metallic circuit will not free the line from cross-talk, even though the average distance from the two wires and the disturbing wire is the same, and the current strength is uniform throughout the entire length of the disturbing wire.

Mr. Carty's experiments throw much light on this point. In Fig. 146 is shown a disturbing wire and a metallic telephone circuit composed of two wires, *A* and *B*, of which *A* is nearer the disturbing wire than *B*. At a time when the charge on the disturbing wire is positive, as shown, a negative charge will be drawn by it toward the disturbing wire and a positive charge will be repelled from it. The result is that the distribution of charges on the two wires, *A* and *B*, will be somewhat as shown, a negative charge being held on the wire, *A*, and a positive charge driven to the wire, *B*.

In order for this rearrangement to have occurred, it is evident that a flow of electricity must have taken place from *A* to *B*, and as two paths were afforded from the center point, *a*, on the wire *A*, of equal resistance, this flow must have been from that point in each direction as indicated by the arrows, through the receivers and toward the center point, *b*, on wire, *B*, where the two currents met. Upon the charge on the disturbing wire becoming zero the potentials on *A* and *B* become equal, by a flow of positive electricity from the center point of wire, *B*, to that of wire, *A*. The negative charge

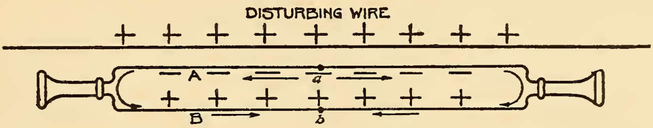


FIG. 146.—ELECTROSTATIC DISTURBANCES.

on the disturbing wire, which follows the positive charge, will cause this latter to flow from *b* to *a*, until *A* is positively and *B* negatively charged.

It is evident, therefore, that alternating currents flow through the two receivers, and that these currents differ in phase from that in the disturbing wire by 90 degrees, which is characteristic of the action of condensers. Further consideration will show that the points *a* and *b* are neutral, and experiment bears out this conclusion, for by opening the wires at those points the sound in the receivers at the ends still continues. Again, if receivers are connected in the circuit at *a* and *b* no sound is heard in them, although plainly audible in the end receivers.

A single transposition in the center of the line, as shown in Fig. 147, will tend to reduce the sound in the end receivers, but will not

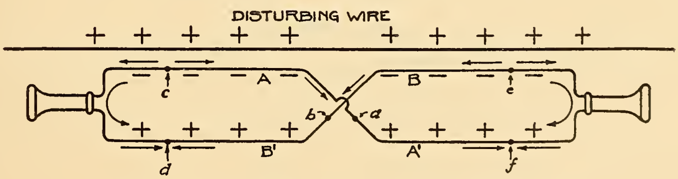


FIG. 147.—ELECTROSTATIC DISTURBANCES.

cause silence. The static charges on the portions of the wires nearest to the disturbing wire now find four paths instead of two to the more remote portions of the circuit, the flow being clearly indicated by the arrows. The center points, *a* and *b*, are no longer neutral, and receivers placed in the circuit there will be subject to noises.

It is evident that if receivers of equal impedance to those at the ends of the line were placed at *a* and *b*, the neutral points, *c*, *d*, *e*, and *f*, would be found at the quarter points on the line; *i. e.*, midway between the transposition and each end. As a matter of fact, however, no instruments are placed at the point of transposition, and the neutral points are shifted toward the ends of the line, because the impedance of the receivers at those points makes it easier for most of the current to pass through the transposition wires.

Theoretically, the currents set up in a metallic circuit by electrostatic induction from another circuit can be eliminated only by making an infinite number of transpositions. Practically, however, it is found that on long circuits transpositions every quarter or half-mile are sufficient to render them unnoticeable.

The scheme of transposition used by the American Telegraph

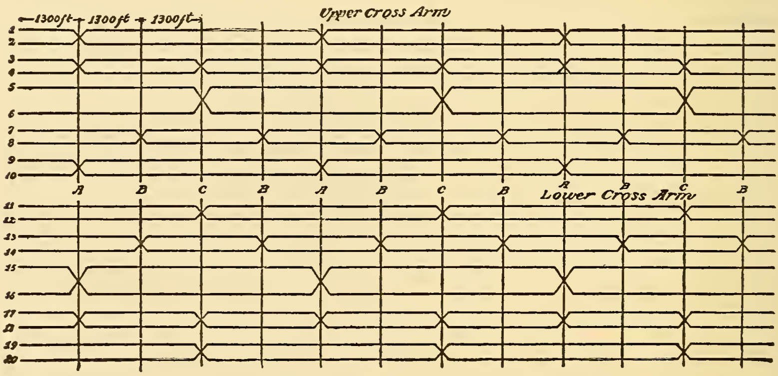


FIG. 148.—DIAGRAM OF TRANSPOSITIONS.

and Telephone Company on the New York-Chicago telephone line is shown in Fig. 148. It will be seen from this figure that transpositions are made on this line practically four times in every mile, that is, upon every tenth pole. While this involves the placing of transposition insulators on poles a quarter of a mile apart, it does not follow that every circuit is transposed at each of these intervals. The reason for this arrangement is that if two lines running side by side were transposed in exactly the same manner throughout their lengths, the desired non-inductive condition would not be secured, for the relation between the corresponding wires in the two circuits would then be the same as if no transposition whatever had been made. In order to overcome this difficulty, transpositions on the second circuit should be made twice as often as those on the first.

This is the scheme adopted in Fig. 148, where it will be seen that the center pair of wires on each set of cross-arms is transposed every mile, while the pair immediately adjacent to it on each side is transposed twice as often. The outside pairs on each cross-arm are transposed only once in each mile, but these transpositions are staggered with respect to those on the center pair. The same scheme is followed out on every cross-arm, but the transpositions on the top set of cross-arms are staggered with respect to those on the set immediately below—this being the case throughout the entire number of cross-arms on a pole; the 1st, 3d, 5th, 7th and 9th being transposed according to the scheme shown in the upper part of Fig. 148, while the circuits on arms Nos. 2, 4, 6, 8 and 10 are transposed according to the scheme in the lower part of this figure.

A very perfect transposition is effected by twisting two sides of a circuit together, and this idea has been followed to some extent

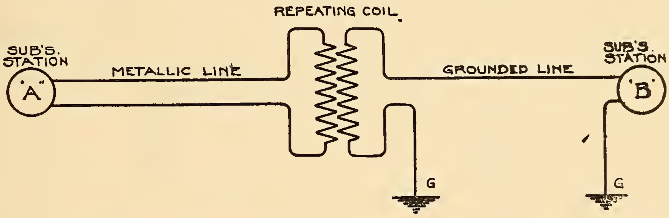


FIG. 149.—CONNECTION OF METALLIC TO GROUNDED LINES.

in European pole-line construction, where the two sides of the circuit are not only transposed laterally, but also pass successively over and under each other several times in each mile, thus effectually giving the circuit a number of complete twists. This method, however, involves several disadvantages in the stringing of wires, and increases the liability of crosses between them.

The twisted pair of insulated wires used so largely in inside wiring, and also in cable work, accomplishes the transposition of circuits very thoroughly, it in fact amounting to a complete transposition for every twist of the wires. This method is now depended upon entirely in the construction of telephone cables, with so great a degree of success as to absolutely prevent all induction between the circuits. This will be discussed at greater length in the chapter on cables.

It frequently becomes desirable to connect a grounded line with a metallic line, and for this purpose what is known as the repeating coil forms the most ready solution. A repeating coil is merely a special form of induction coil, having two windings on a single core, these windings often being the same in number of turns and resistance. They are frequently completely enclosed in iron, for the purpose of affording a more complete magnetic circuit for the magnetic lines of force set up by currents in the coils. In Fig. 149 is shown in diagram a metallic circuit line connected with a grounded line through a repeating coil. The two terminals of the metallic circuit line are merely brought to the two terminal binding posts of one of the coils, while the end of the grounded line is brought to one of the terminal posts of the other coil; the remaining post is then grounded. Any varying currents set up in one of the circuits will act inductively on the other circuit through the windings of the coil, each of which may thus be called upon to act alternately as a primary and a secondary. By the use of the repeating coil in this manner, two lines may be connected for conversation

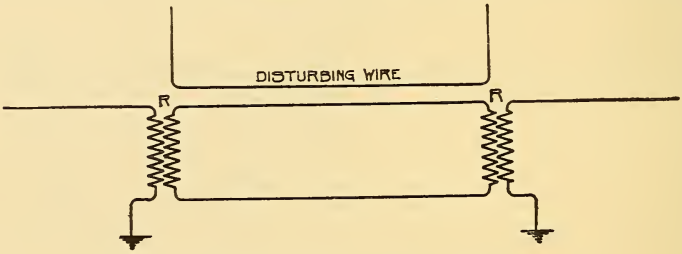


FIG. 150.—ELIMINATING LOCAL INDUCTION.

without grounding one side of the metallic circuit, which would be necessary were the repeating coil not used.

There is a very common impression among many telephone users that a repeating coil is a panacea for all of the evils connected with grounded lines. It is perhaps well to correct this impression by saying that no number of repeating coils will render a noisy grounded line quiet. A repeating coil will, however, prevent the unbalancing of a metallic circuit line, and therefore in many cases insure a degree of quietness on two connected lines which would otherwise be unattainable.

It sometimes happens that a long grounded line is paralleled throughout only a portion of its length by some disturbing wire, such, for instance, as an electric light line. Where it is not possible from commercial considerations to make the entire line a metallic circuit, relief may sometimes be had by resorting to the plan shown in Fig. 150, which consist in making only that portion of the line a metallic circuit which is within the direct influence of the disturbing wire. The two ends of the grounded line may then be connected with the intermediate metallic portion by means of the repeating coils, *R R*, as shown. By this arrangement the disturbing wire produces no effect on the metallic circuit between the repeating coils, if proper precautions are taken in the way of transposing its two sides. Telephonic communication may be had over the entire length of line, the currents undergoing two transformations at the repeating coils.

Much trouble is often had where it is necessary to ring through repeating coils, especially if the lines are very long. It is therefore advisable that repeating coils should always be placed, if possible, at a station where there is an attendant, and such arrangements made that it will not be necessary to ring through them. However, a coil properly constructed with a magnetic circuit completely closed should serve as a fairly efficient transformer, even for the slowly alternating currents of a magneto generator, and good results may be obtained with such coils on good lines even when it becomes necessary to ring through them.

CHAPTER XI.

THE TELEPHONE EXCHANGE IN GENERAL.

THE object of a telephone exchange is to afford means for telephonic intercommunication to a community. The word community may be restricted to a small body of people having common interests, as, for instance, those within the employ of some firm, perhaps housed within a single building; it may refer to the people of a city with its suburbs; to the people of an entire section of a country, or, in its largest sense, to the people of a whole country or perhaps of a continent enjoying the same laws, rights and privileges. Upon the scope given the word community, therefore, depends our idea of a telephone exchange.

It is unquestionably proper to refer to an organization embodying but a few telephones placed within the offices of a business firm for supplying telephone service to its various employees as a telephone exchange. Again, it is proper to refer to the telephonic organization of a great city with its outlying suburbs, as a telephone exchange. These two ideas of the exchange are well accepted.

If, however, we use the term community in its broadest sense as applying to the people of an entire country or continent, it is also thought proper to refer to the telephone system of that country as an exchange, wherein the systems of the large cities are connected by long-distance lines with each other, the small cities all being connected by similar lines to their nearest larger city, thus affording means for the people in any portion of this great community to secure telephone communication with those in any other portion. This idea is in accordance with the following statement, made in a lecture by the writer several years ago:

"Those who have the best interest of the telephone business at heart are now designing their apparatus and circuits on the basis that telephone systems in small villages must have as good transmission as those in the largest cities, with the idea in view that in the future the whole continent will be one vast telephone exchange, the various large cities being the main offices, and the long-distance lines, the trunk lines between them, and the small villages the branch exchanges."

It is usual to have the subscribers in a certain community, or where this is too large, in a certain portion of the community, connected by means of telephone lines with a certain central point, at which apparatus is provided for inter-connecting lines in accordance with the wishes of the subscribers. Such a central establishment is usually called a central office, or a telephone office. May we not then define as follows:

A telephone office is an establishment in which telephone lines center, containing equipment for interconnecting the lines.

A telephone exchange is an organization of one or more telephone offices and the connecting lines and sub-station equipments necessary for supplying telephone service to a community.

Under these definitions a telephone exchange may consist of one or more telephone offices. A telephone office may in itself form the only means of connecting the subscribers in an entire exchange, or

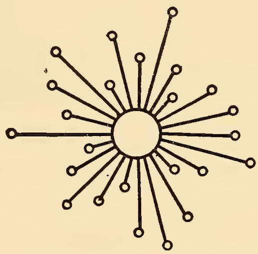


FIG. 151.—SINGLE-OFFICE EXCHANGE.

it may form the center of the lines of only one group of subscribers in an exchange.

Where there are more offices than one in an exchange, lines must be provided extending between them to afford a means for connecting a subscriber's line terminating at one office with the line of a subscriber terminating at another office.

The simplest form of an exchange is that containing but one central office, this office being isolated so that no means is provided for connecting it with other offices. Such an exchange may be represented diagrammatically as in Fig. 151, wherein a large circle in the center represents the central office, the small circle surrounding it represents the subscribers' stations or sub-stations, as they are more commonly called, and the lines connecting the large circle with the respective small circles, the subscribers' lines.

In Fig. 152 is shown an exchange having two central offices, each represented in a manner similar to that shown in Fig. 151, and having extending between them trunk lines through the medium of which any subscriber's line in one office may be connected with any subscriber's line in the other.

In Fig. 153 is shown an exchange having three central offices, each office being connected with each of the other two by means of trunk lines. In a similar manner we might indicate by a diagram an exchange for a very large city having, perhaps, twenty-five telephone offices, and in this case a trunk line should be extended from each office to each one of the twenty-four others.

Exchanges may be classified in several ways: Thus, as single office exchanges or multi-office exchanges, according to whether there are one or many offices.

If classified according to the kind of lines used, we may have

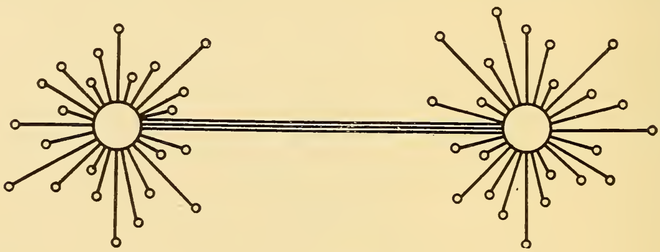


FIG. 152.—TWO-OFFICE EXCHANGE.

metallic circuit exchanges, grounded line exchanges, or common return exchanges.

If classified on still another basis, we may have manual exchanges, where the connections at the central offices are made manually by means of operators, in accordance with the spoken desires of the subscribers; or we may have automatic exchanges, where automatic machines are provided at the central offices manipulated over the lines by the calling subscribers to complete the connection as desired.

Again, we may classify according to the location of the sources of electrical energy for supplying current to the subscribers for talking and signaling. Under this classification we have a local battery exchange, where each sub-station apparatus contains a local battery for supplying current to his transmitter, or we may have a common battery or central energy exchange where all sources of energy for both calling and talking are located at the central office. In the local battery exchange the sub-station apparatus usually comprises a magneto generator for enabling the subscriber to call the central office, for which reason such an exchange is often spoken of as a magneto exchange.

It may be said that the grounded circuit or common return exchanges are gradually giving way to the exchange using only complete metallic circuit lines, and that the local battery or magneto exchanges are gradually giving way to the common battery or central energy exchange wherein all sources of electrical energy are located at the central office. Particularly is this true in large exchanges. The magneto or local battery exchange still has, however,

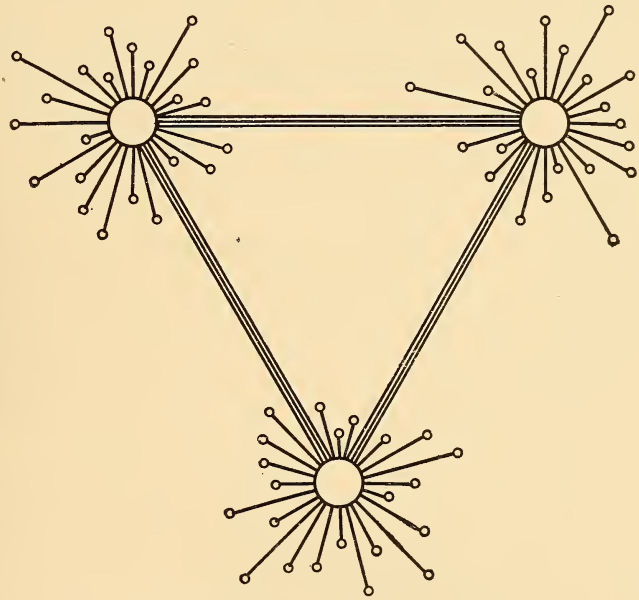


FIG. 153.—THREE-OFFICE EXCHANGE.

a wide field of usefulness in small exchanges, and will probably never be completely supplanted.

In an automatic exchange wherein no operators are supposed to be employed, each subscriber must have at his own station, mechanism which, when properly operated by him, will continue the circuit of his line through auxiliary circuits and mechanisms at the central office, to the line of the subscriber desired, and after this connection is made to ring the bell of that subscriber. Further means must be provided by which the subscriber may clear his line from such connections after he is through talking.

It may be said that up to the present time the automatic exchange has come into only very limited use, although there is at present a movement on foot which promises to have installed automatic exchanges in several large cities of this country within a comparatively short time. The success of this movement will be watched with great interest.

In every manual exchange means must be provided for enabling the subscriber desiring a call to attract the attention of the operator at the central office to which his line extends. Means must also be given the operator for connecting her telephone to the subscriber's line in response to a call in order that she may ascertain his wishes. The operator must also be provided with facilities for ringing the bell of the subscriber called for, in order to attract his attention, and thereafter, for connecting the lines of the two subscribers for conversation. Lastly, the subscribers must be afforded means for attracting the attention of the operator after the connection has been made, in order to inform her that the connection is no longer desired, or that another one is wanted.

The first idea of central office exchange work that I am able to find suggested, is in a British patent to Dumont, in February, 1851. This imperfectly describes a system of telegraph lines radiating from a central station, with means at the central station for placing any line in telegraphic connection with any other. Like the idea of Bourseul, this of Dumont was long ahead of its time—occurrences found in the early development of almost every industry.

In 1874, before the birth of the telephone, a telegraph exchange system was put into use in New York City. It was for connecting lawyers who chose to subscribe, and was, for this reason, called the law system. The telegraph instruments, which were of the dial pattern, were subsequently replaced by telephone instruments, and thus originated, as far as I am able to find out, the first telephone exchange system. It was from this particular system that the well-known Law telephone system, widely used in later years, took its name.

All of the early telephone switch-boards by which the lines were connected, as described by the subscribers served, were built upon a plan which had proven successful in telegraphy; the lines usually terminating in vertical conducting strips across which were placed horizontal conducting strips for connectors. Any two lines could be connected together by connecting each by means of a plug to the same horizontal strip. Indicators in the form of electromagnetic drops, or annunciators, were used in connection with each line, and also spring switches, or spring jacks, by means of which the operator could connect her telephone in the circuit with any line.

It very soon became apparent that a far greater number of lines would have to be handled in the telephone business than in telegraphy, and for this reason the old telegraph switchboard soon became inadequate. In order to met the new demands, the development began in a new direction. Each line terminated in a spring jack, and an indicator, and a connection was made between any two lines by means of flexible conducting cords terminating in plugs adapted to fit into and make connection with the spring jacks. Thus we find about the beginning of the eighties, the prototype of our modern switchboard. The development of the switchboard will be treated in many of the subsequent chapters in this book.

CHAPTER XII.

THE MAGNETO SWITCH-BOARD FOR SMALL EXCHANGES.

By a magneto switch-board is meant a switch-board adapted to interconnect lines, equipped with magneto sub-station apparatus. In other words it is a switchboard, the signal-receiving apparatus of which is adapted to be operated by magneto generators at the subscribers' stations.

For the sake of simplicity a switch-board for grounded cricuit lines will be first discussed. In Fig. 154 the numerals 1 to 12 inclosed in

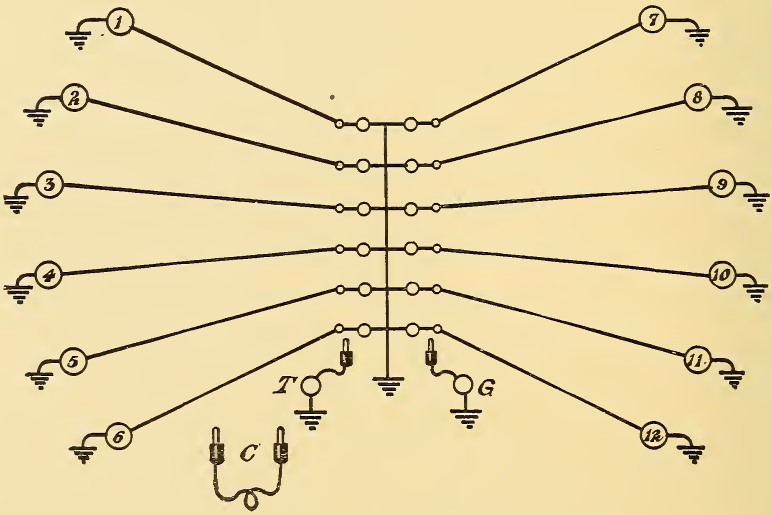


FIG. 154.—GROUNDED-CIRCUIT SWITCH-BOARD.

circles represent sub-station apparatus, it being understood that each such apparatus comprises the usual call sending and call receiving apparatus of the magneto type, as well as the usual talking apparatus. One terminal of each sub-station apparatus is connected with the earth, as indicated, the other being connected to the line wire leading to the central office. At the central office each line wire passes first through a switch socket or spring-jack, represented by a small circle, and then through the winding of the annunciator or electro-magnetic drop, represented by a larger circle. From this the circuit of each line passes to a common wire leading to the earth. The spring-jack serves the purpose of allowing the operator to make a connection between a flexible conductor and any line circuit, while the drop serves the purpose when actuated by a current from the subscriber's generator to display a visual signal to the operator, as an indication that her attention is required on that line. After the call has been received on a line, the drop is of no further use, while the line is being used by the subscriber for conversation, and therefore arrangements are made in each spring-jack to cut off the drop of each line when the connection is made. Each operator is provided with a number of pairs, *c*, of flexible conducting cords and plugs by means of which and the spring-jacks she may connect any two lines

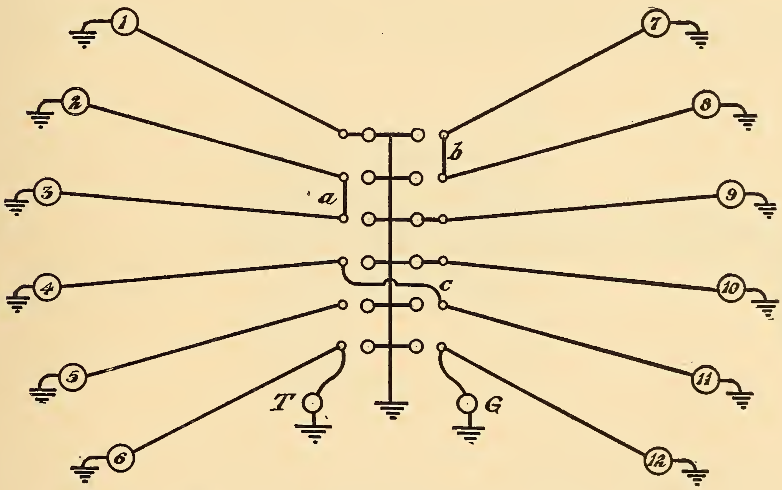


FIG. 155.— GROUNDED-CIRCUIT SWITCH-BOARD.

for conversation, at the same time cutting off the call-receiving devices or drops belonging to those lines. The operator is also provided with a telephone set represented at *T*, and a calling generator represented at *G*. One terminal of each of these is connected with the ground, as shown, and the other terminal of each may be put in connection with a flexible cord or plug, enabling the operator either to converse with a subscriber by means of her telephone set or to ring the bell of a subscriber who is called for, by means of her generator.

Looking now at Fig. 155, we see that lines 2 and 3 have been connected for conversation by means of a flexible cord, *a*, similarly lines 7 and 8 and lines 4 and 11 have been connected by cords *b* and *c*.

Each of these pairs of lines, it will be seen, are cut off from the call-receiving devices, and each pair of subscribers thus enjoys an exclusive circuit extending between their respective stations. Line No. 6 is shown in Fig. 155 as connected with the operator's telephone, *T*, the operator having connected her telephone with the line by means of a jack and the flexible cord, in response to the call from that subscriber. Line No. 12 is shown in the conditions that would exist when the operator was calling the subscriber at its sub-station, the generator, *G*, having been connected by the operator with the spring-jack of that line, thus also cutting off the annunciator or drop.

It will be seen from this very elementary discussion that the circuit of each line is normally completed to earth at the central station through the spring-jack and the annunciator. By means of a plug and flexible cord the operator may connect her telephone with

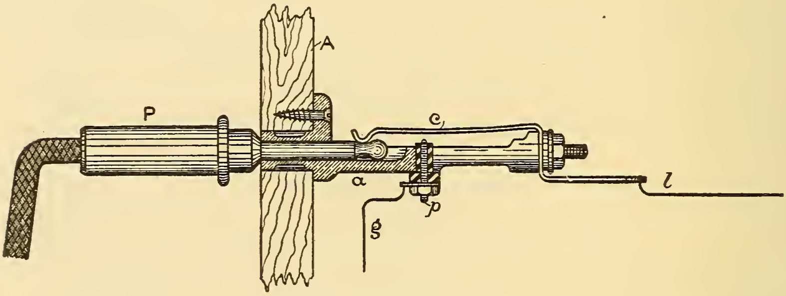


FIG. 156.—SPRING-JACK.

the line, thus changing the circuit of the line to include the operator's telephone instead of the drop. Also by means of a plug and flexible cord, the operator may connect the calling generator with a line, thus changing the circuit to include the generator instead of the drop. Again, by means of two flexible cords and plugs the operator may connect any two lines for conversation, cutting out the annunciators of both lines. Upon the withdrawal of any plug the line is at once connected again with its annunciator.

In Fig. 156 is shown a simple spring-jack with the connecting plug inserted. The metallic base, *a*, of the jack, usually of brass, is drilled from its forward end to receive the shank of the plug, *P*.

A forwardly projecting sleeve on this base fits snugly into a hole bored in the front board, *A*, of the switch-board, to which it is fastened by the shoulder and small wood-screw, as shown. Firmly secured to the rear end of the piece, *a*, is the line spring, *c*, formed with a rearwardly projecting tongue, to which the wire, *l*, leading from the line is soldered. The forward end of the spring, *c*, rests normally against the pin, *p*, carried by, but insulated from, the base, *a*. A wire, *g*, leads from this pin, and through the coil of the line annunciator or drop to ground. When the plug is inserted in the jack its conducting tip makes contact with the tip of the line spring and at the same time forces it out of engagement with the pin, *p*. Normally, therefore, the line wire is connected to the ground through the wire, *l*, spring, *c*, pin, *p*, wire, *g*, and line-drop to the ground connection. When the plug is inserted in the jack, however, the line is disconnected from the branch leading through the drop, but is connected through the medium of the plug to the flexible cord.

Fig. 157 shows a common form of switch-board drop. The pur-

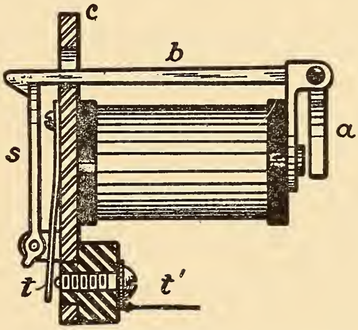


FIG. 157.—SWITCH-BOARD DROP.

pose of the drop is to attract the attention of the operator whenever any subscriber wishes a connection. The coil of the electromagnet is mounted on the back of the front plate, *c*, of the switch-board, as shown. To the armature, *a*, pivoted at its upper end, is attached a rod, *b*, passing forward through a hole in the front plate and provided with a hook on its forward end, adapted to engage the upper portion of a pivoted drop-shutter, *s*, and to hold it in its raised position. The attraction of the armature due to a current passing through the coil causes the hook to rise, thus releasing the shutter, which falls to a horizontal position and displays to the operator the number by which that line is designated.

In order to attract the attention of the operator at night or at such times as she may not be in sight of the board, a night-alarm attachment is provided on each drop, which serves to close the circuit through a battery and vibrating bell whenever the shutter is down. The small cam surface on the lower portion of the shutter, *s*, forces the light spring, *t*, into contact with the pin, *t'*, when the shutter is down, thus accomplishing the above result.

Fig. 158 shows diagrammatically the circuits of two lines con-

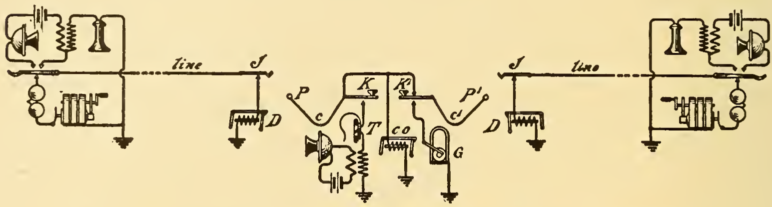


FIG. 158.—CIRCUITS MAGNETO SWITCH-BOARD—NORMAL.

nected at the central office to ground through their spring-jacks, *J*, and annunciators, *D*. Between these lines is also shown the circuits and apparatus of a pair of plugs, *P* and P^1 with their flexible cords *c* and c^1, together with the operator's telephone set, *T*, the magneto generator, *G*, and the keys, K^1, by which either the talking apparatus or the calling generator may be put in circuit with the plugs.

Considering now the means by which a subscriber may attract the attention of the operator at the central office, reference is made to Fig. 159, which, it will be seen, shows the complete apparatus of one line only, as indicated in Fig. 158. By turning the crank of his

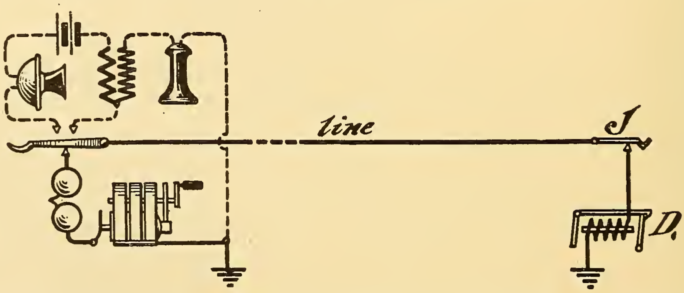


FIG. 159.—CIRCUITS MAGNETO SWITCH-BOARD—SUBSCRIBER CALLING.

generator without raising the receiver from its hook a subscriber at this sub-station may actuate the drop, *D*, at the central office over the circuit extending from ground at his station through his generator and bell to line, thence through the spring-jack, *J*, and its anvil, *a*, to earth at the central office through the drop, *D*. This current will cause the release of the shutter, attracting the attention of the operator. Seeing the signal she will at once respond by placing the answering plug, *P*, of the pair into the jack, the spring of this jack making contact with the tip of the plug, and at the same time being raised clear of the anvil, *a*, thus cutting the drop out of circuit. By depressing key, *K*, the operator is enabled to converse with a subscriber who has, meanwhile, removed his receiver from its hook, thus placing his talking apparatus in the circuit of the line, rendering his generator and call bell inoperative. The circuit conditions are now those shown in Fig. 160. The operator's talking apparatus, *T*, at the central office consists of a transmitter and battery placed in the local circuit containing the primary winding of the induction coil, *I*. The secondary of this induction coil is included in the operator's receiver in the circuit between the earth at the central office and the anvil of the switch, *K*. The circuit

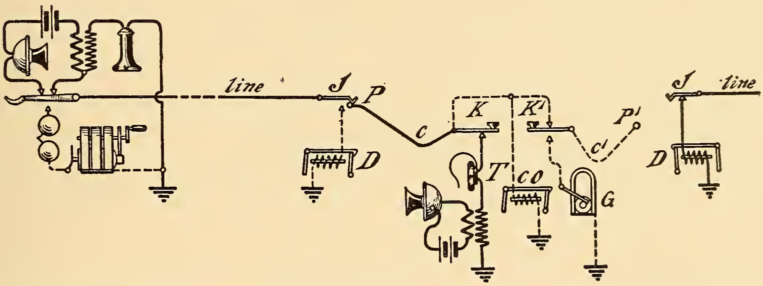


FIG. 160.—CIRCUITS MAGNETO SWITCH-BOARD—OPERATOR ANSWERING.

over which the subscriber is able to converse with the operator is obvious. Having learned the number the subscriber wanted, the operator inserts the calling plug, P^1, associated with the plug, *P*, into the jack of the calling subscriber, and depresses the ringing key, K^1. The current sent out from the generator traverses the line of the calling subscriber and passes to earth through his bell. The parts of the circuit operative at this time are shown in full lines in Fig. 161. In response to this call, the subscriber raises his receiver from its hook, thus placing his talking apparatus in condition for use. Meanwhile the operator, having released the key, K^1, the current of the calling generator is cut off from the line, and the talking circuit is made complete. This circuit over which the conversation takes place is shown in Fig. 162.

In Figs. 159 to 162, inclusive, those parts actually engaged in the particular operation illustrated by each figure, are shown in heavy lines, the parts which, for the time being, do not enter into the operation, being shown in dotted lines.

Since during conversation both line drops are cut out of circuit, it becomes necessary to provide means for enabling either or both

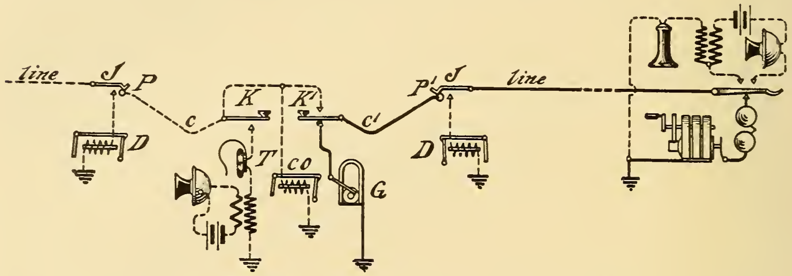


FIG. 161.—CIRCUITS MAGNETO SWITCH-BOARD—CALLING SUBSCRIBER.

subscribers to again attract the attention of the operator, in order to signal that the conversation is finished, or for the purpose of asking for another connection. For this purpose, the clearing out drop, *C O*, is provided in connection with each cord circuit, this drop being bridged between the cord and ground at the central office, and therefore ready to respond to the calling current sent out from either subscriber's generator. At the end of the conversation either subscriber, by turning his generator crank, after having hung up his receiver, is enabled to send a current over the circuit of the line, which passes to earth through the clearing-out drop at the central office as a signal to the operator. In these figures but a single pair of cords and plugs with their corresponding keys and clearing-out drop, are shown, in order not to confuse the diagrams. It is usual,

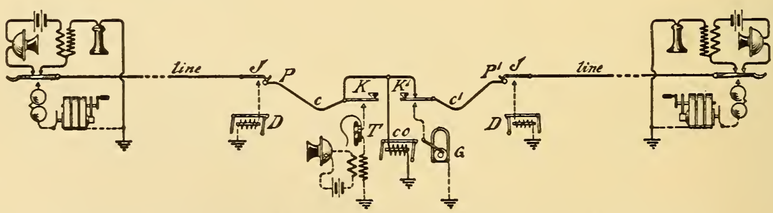


FIG. 162.—CIRCUITS MAGNETO SWITCH-BOARD—SUBSCRIBERS CONVERSING.

however, to place approximately 10 such pairs for each 100 subscribers in the system, it being found that this number is sufficient to meet the requirements at the busiest periods of the day. This, of course, provides service permitting one of 10 per cent. of the subscribers to be engaged in conversation with another 10 per cent. of the subscribers at the same time. But a single operator's telephone set is provided for each operator as, by means of the keys, *K*, associated with the various cord circuits she may, at will, connect her telephone set with any one of the pairs of cords. Likewise, a single generator, *G*, may serve the entire exchange.

The line drops in a board of this type are wound to a resistance of about 80 ohms, unless designed for multiple or bridged telephone lines, in which case the resistance of the drops is usually made much higher, from 500 to 1000 ohms. The clearing out drops are usually wound to a resistance of 500 ohms.

It has already been pointed out that in order to avoid induction and other sources of trouble, metallic circuits are rapidly superseding ground circuits in telephone exchanges. The switch-boards in common use for small metallic-circuit exchanges are built on the same general principles as those for grounded circuits just described, differing from them only in such details as to render

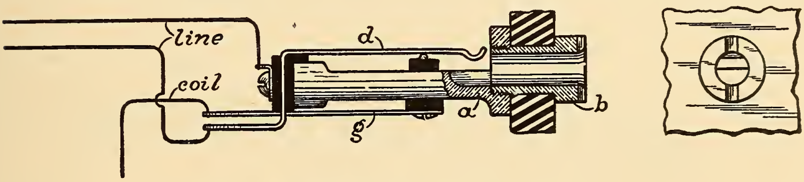


FIG. 163.—METALLIC CIRCUIT JACK.

possible the connections of the two sides of one line with those of another line through the cord circuits. For this purpose two separate contacts are provided in each jack forming the terminals of the two sides of the line. The plugs also have two separate contact-pieces adapted to register with the contact-pieces in the jack when a connection is made. Each contact on one plug is connected to a similar contact on the other plug of a pair through the medium of a double-conductor flexible cord.

One form of metallic circuit jack is shown in Fig. 163. Here the tubular portion, *a b*, forms a terminal for one side of the line, while the flexible spring, *d*, forms the terminal for the other side. The terminal, *g*, connected with the pin upon which the spring, *d*, normally rests, forms one terminal for the coil of the line-drop. The other terminal of this coil is attached to the terminal, *a*, so that when the spring, *d*, is in contact with its pin the circuit is complete from one side of the line to the other through the drop coil. The tubular frame of this jack is made in two pieces, *a* and *b*. The front portion, *b*, is a hollow screw, threaded to engage a tapped hole in the front of the piece, *a*. By this arrangement any jack may be readily removed from the board by unscrewing the piece, *b*, until it disengages the rear portion, *a*. A slot for receiving a screw-driver is provided on the front of the piece, *b*, to accomplish this.

In Fig. 164 is shown another form of metallic circuit jack. This

FIG. 164.—METALLIC CIRCUIT JACK.

jack is self-contained and is mounted on the board by means of a screw-threaded thimble, in much the same manner as the jack shown in Fig. 163. The two springs are secured rigidly to the frame of the jack, but are insulated from it and from each other by strips of hard rubber and by insulating bushings for the screws. This is typical of good modern construction where the jacks are individually mounted.

A metallic-circuit plug in common use is shown in Fig. 165. The tip conductor is formed of a rod of brass slightly enlarged at its forward end. This is encased in a bushing, *b*, of hard rubber, and over this is slid a tube, *s*, of brass forming the sleeve of the plug. A second bushing, b^1, covers the rear portion of the sleeve, *s*, and the rear portion of this latter tube is in turn covered by the tube, b'', of hard rubber, forming the handle of the plug. The tube, *s*, forming the sleeve, has a portion which projects rearwardly into the handle, and is there provided with a connector, *c*, to which the terminal of one conductor of the flexible cord is attached. The other con-

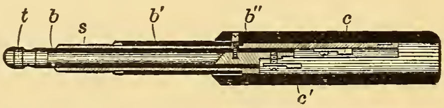


FIG. 165.—METALLIC CIRCUIT PLUG.

nector, c', is attached to the rear portion of the tip piece, *t*, and forms the terminal for the other conductor of the cord.

In Fig. 166 is shown another two-conductor plug with cord attached, the plug being cut partly away so as to give a better understanding of its internal construction. The cord is also partially dismembered for the same purpose. It will be seen that the cord has two conductors, each composed of twisted tinsel with a few strands of copper wire to give additional strength and conductivity. Around each conductor separately is placed a wrapping of silk and then a braiding of cotton, after which the two conductors, together with a braided string of considerable strength, are inclosed together in a spiral wrapping of spring brass wire. Over this wrapping, which extends throughout the entire length of the cord, are placed two layers of linen braiding extending over the whole length of the cord; a third, or reinforcing braiding, also extending for about a foot from the plug end of the cord. One of the conductors is provided at the plug end with a metallic clip, which, by means of a small machine screw and washer, is fastened to the tip conductor of the plug, which extends back into the opening within the shell. The sleeve conductor of the plug extends in the form of a hollow plug to the extreme rear portion of the plug, where it is provided

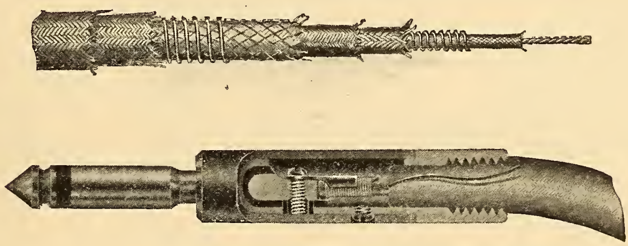


FIG. 166.—CORD AND PLUG.

with a very coarse internal screw-thread, into which the braiding of the cord, after being wrapped with linen thread, is tightly screwed for the purpose of fastening the plug to the cord. The sleeve conductor of the cord is merely bent back over the wrapped end of the cord, and this makes contact with the sleeve conductor of the plug, being held in place by the pressure of the braiding against the internal screw thread of the sleeve.

In Fig. 167 is shown in diagrammatic form the circuits of a switch-board of this class. Here the line wires, l^1 and l^2, forming the two sides of a metallic circuit, enter the spring-jacks, e, e^1, and e^2, in the manner described in connection with Fig. 162. It will be noticed that while the tip-spring, d, is in its normal position, circuit is traced from the line, l^1, through the coil of the drop, f,, and back to line l^2, so that current sent from the subscriber's station will actuate the drop, thus indicating a call. When one of the plugs, P or P', is inserted into the jack spring, d, is raised from its normal resting-place and breaks contact with the terminal leading to the drop-coil, thus cutting the drop out of the circuit. At the same time, the connection is continued from the two line wires, l^1 and l^2, to the two strands of the cord circuit. When an operator notices that a drop has fallen she inserts the answering plug, *P*, into the jack corresponding to that drop, and by pressing the button, *K*, belonging to that cord circuit, bridges her telephone set, *T*, across the two strands, 1 and 2, of the cord circuit. This enables her to communicate with the subscriber calling, to ascertain his wants. She then inserts the calling plug, *P′*, into the jack of the called subscriber and presses the button, *K′*, thus connecting the terminal of the generator, *G*, with the two sides of the line of the subscriber called.

It will be noticed that when the key, *K′*, is in its normal position the conductors from the tip and sleeve of the answering plug to the tip and sleeve of the calling plug are made continuous by the springs of the calling key resting against their inside anvils.

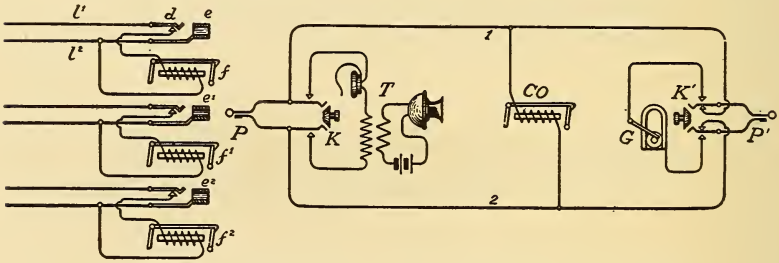


FIG. 167.—SWITCH-BOARD CIRCUIT FOR METALLIC LINES.

When the key is depressed the springs break contact with the inside anvils, thus severing the connection between plugs, *P* and *P′*, and immediately afterward connect with the outside anvils forming the terminals of the generators, *G*, thus sending current over the called subscriber's line.

The clearing-out drop, *C O*, is permanently bridged across the cord circuit as shown, in order to indicate to the operator when either subscriber rings off. In order that the efficiency in talking may not be impaired, this drop is made of high resistance and high impedance.

The line-drops may be of the ordinary type described in connection with the grounded-circuit switch-board. The clearing-drops, however, must be made to meet more difficult requirements than the line-drops. As they are always bridged across the circuit of two connected subscribers, it is found that unless special precautions are taken much trouble will be experienced from cross-talk due to induction between two adjacent drops. This difficulty cannot be overcome as in the line-drops, by cutting them out of the circuit whenever two subscribers are connected, inasmuch as the very purpose for which they exist requires them to be always in such circuits. Neither can it be overcome by placing the drops at such a distance from one another that this induction will not be felt, for the limited space on switch-boards requires that they be put as close together as mechanical conditions will allow.

It has thus been found necessary to design a drop which would neither affect nor be affected by any similar drop in its immediate

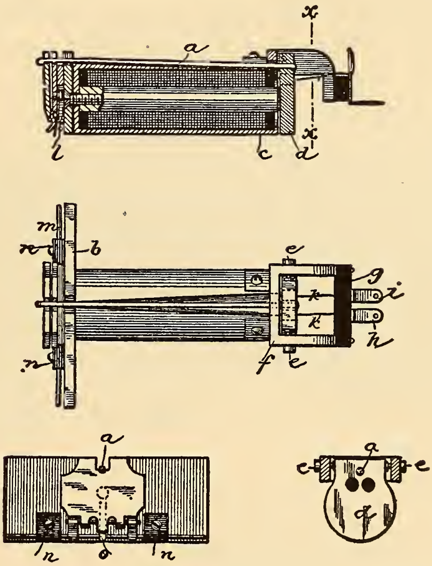


FIG. 168.—THE WARNER TUBULAR DROP.

vicinity. This has been accomplished in several ways, but the best example is that shown in Fig. 168, which illustrates what is known as the "Warner Drop." In this the coil is wound in the ordinary manner on a soft-iron core and is then encased in a tubular shield, *c*, also of soft iron. The armature, *d*, is pivoted at points, *e*, in a bracket, *f*, mounted directly on the rear portion of the tubular magnet. From this armature, a rod, *a*, extends forward through a notch in the front plate, *b*, in such manner as to engage the upper portion of the shutter and thus hold it in its raised position. A screw, *l*, passing through the front plate, *b*, serves not only to hold the magnet in place, but to hold the core in its place within the shell. The terminals of the coil are led out through two small holes in the armature, and are connected with the terminals, *h i*, mounted on an insulating strip, carried on the bracket, *f*.

These drops should be so nicely made that the armature, *d*, will fit closely against the end of the tube, *c*, in such manner as to almost completely close the magnetic circuit in which the coil is placed. The lines of force generated by the passage of a current through the coil follow almost entirely the path provided for them by the shell and the core of the magnet, thus not only producing a very efficient electromagnet, but also preventing any of the lines of force from extending beyond the limits of the shell. These drops are usually wound to a resistance of 500 ohms, and may be mounted as closely

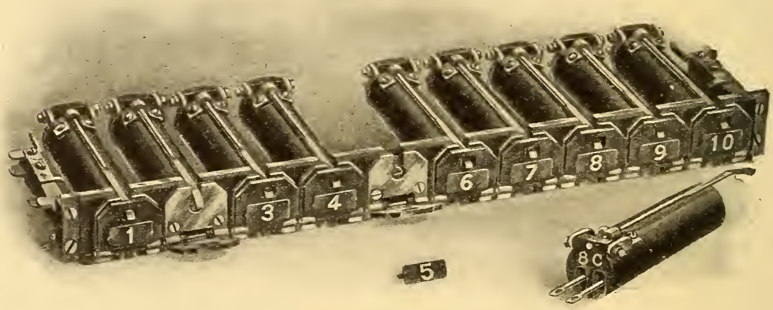


FIG. 169.—STRIP OF TEN DROPS.

together as desired without producing perceptible cross-talk. The impedance due to the great number of turns in the coil, and to the perfect magnetic circuit surrounding the same, is so great that practically no diminution in the strength of speech transmission is felt due to its being bridged across the line.

In the modern construction of the Warner Drop, instead of the rearwardly extending bracket being provided for carrying the terminals of the coil, these terminals are made in the shape of heavy pins of brass, firmly screwed into the rear head of the coil, and to these pins the terminals of the coil winding are soldered. These pins project through the armature of the coil in substantially the same manner as in the original Warner Drop, and form terminals of sufficient strength to need no outer support.

The Warner type of drop has proved so satisfactory and is of such compact construction that it has been adopted for use as line, as well as clearing out purposes.

For use as both line and clearing out drops it has become common practice to mount a number, usually ten, of these drops on a single strip; this strip being provided with means for securing it into the framework of the switch-board, and forming a common support for all of the drops on it. Such a strip of 10 drops is shown in Fig. 169.

Instead of mounting the jacks individually, as in the types so far considered, it is common practice to build them in strips, usually of 10 or 20, such a strip, comprising a number of jacks, being an integral piece of apparatus, no means being provided for separating the various jacks from the strip without entirely dismembering their parts. Such a strip comprising 10 jacks is shown in Fig. 170. In

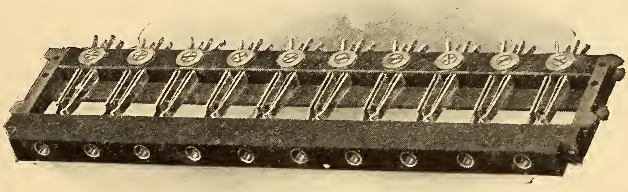


FIG. 170.—STRIP OF TEN JACKS.

this the front strip is of hard rubber, having ten holes drilled in its face, into which are inserted the sleeve contacts, these being of German silver or brass. Projecting from the rear of each sleeve, and, in fact, made of the same piece of metal, is a connection shank which extends back through the hard rubber strip forming the rear of the jack framework, where it ends in a suitable clip, to which the wire may be soldered. The other contacts of the jack are mounted in the rear strip only, each of them being provided with clips projecting rearwardly from this strip for the purpose of soldering the connecting wires. Such a strip of jacks is provided with means for fastening it rigidly in the iron framework of the switch-board. This construction has many advantages over the individually mounted jack, the principal ones being that of greater rigidity and economy of space. The spacing of the jacks in this strip is the same as that on the drops shown in Fig. 169, and therefore these jacks may be used in connection with the drops, being mounted directly above or below them in the same switch-board cabinet.

The ringing and listening keys, by which the operator's generator or telephone may be connected with the circuit of any line through a cord circuit, have assumed a great variety of forms, only a few types

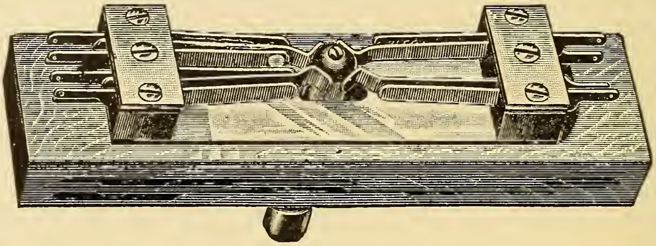


FIG. 171.—RINGING AND LISTENING KEY.

of which have survived. One of the most common types is shown in Fig. 171, in which is represented the under side of the key shelf. The handle by which the key is operated projects through the shelf, and is shown at the top of the cut. This handle is pivoted within the shelf, and operates a ball cam in a manner to cause it to slide between one or the other pairs of springs, between which it normally rests. This is called a combined ringing and listening key, the act of ringing being accomplished by pressing the handle to the left, causing the ball to move to the right, while the action of listening is caused by a reverse movement of the handle, causing the cam to move between the left-hand set of springs. The circuit connections of such a key are shown in Fig. 172, where P and P' are respectively the answering and calling plugs. The tip and sleeve strands of the answering cord are respectively connected to the

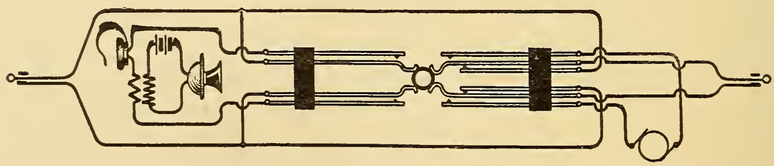


FIG. 172.—CIRCUIT OF COMBINED RINGING AND LISTENING KEY.

springs 1 and 2, and also to the springs 3 and 4. Normally resting against the springs 3 and 4 are the springs 5 and 6, which are permanently connected with the tip and sleeve strands, respectively, of the calling cord. The springs 7 and 8 form the terminals of the operator's telephone set, while the springs 9 and 10 form the terminals of the calling generator. It will be seen that the tip strand is normally continuous from the tip of the plug, *P*, to the tip of the plug, *P′*, through the springs 3 and 5 of the ringing key; likewise the sleeve strand is normally continuous from the springs 4 and 6 of this key. If the ball cam, *A*, is pressed to the left by means of the cam handle the operator's telephone is bridged across the circuit by causing the springs 1 and 2 to make contact with the springs 7 and 8, respectively. If the ball cam is pressed to the right the

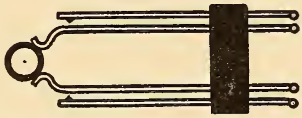


FIG. 173.—DIAGRAM OF LISTENING KEY.

connection between the plug *P* and *P′* is entirely severed by the breaking of the contact between the springs 3 and 5 and 4 and 6 respectively. A little later in the movement of the cam the springs 5 and 6 make contact with the springs 9 and 10, thus connecting the generator terminal with the tip and sleeve of the calling plug. The reason for breaking the connection between the two plugs in the ringing operation is to prevent the current from the calling generator also being sent out on the line of the calling subscriber, with which the plug, *P*, is connected. If this happened the current would be likely to traverse the receiver coil held to the ear of the waiting subscriber, giving him what is commonly known as a "ring in the ear," a decidedly unpleasant and sometimes dangerous experience. In diagrammatic illustrations of cord circuits it is usually more con-

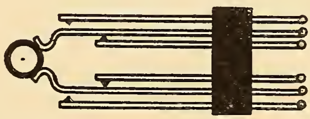


FIG. 174.—DIAGRAM OF RINGING KEY.

venient to show the ringing and listening keys separately, although they may, in fact, form virtually one piece of apparatus. Thus Fig. 173 would represent the listening key, and Fig. 174 the ringing key. It is also very common in circuit diagrams to omit entirely the ball cam, and also to omit the supporting blocks upon which the springs are mounted.

It may be said in general that in diagrammatic illustration of telephone circuits the details of mechanical construction must often be sacrificed entirely to clearness, in order to represent the circuit in an intelligible manner. The telephone circuit is often such a complicated thing that it should not be required to carry with it any degree of accuracy as to mechanical construction or arrangement.

It is frequently desirable to provide in connection with the cord circuit what is commonly called a ring-back key, by means of which the operator may send a calling current out on the line of the calling subscriber, *i. e.*, over the answering plug. This feature is not, however, thought to be desirable except in special cases, because ringing of the calling subscriber is not, as a rule, necessary, and if it is necessary the operator may always accomplish it by changing plugs, that is, by placing the calling plug into the jack of the calling subscriber. This disadvantage, on account of the comparatively rare necessity of ringing the calling subscriber, is not sufficient to warrant the disadvantage in the point of complexity and expense of having an extra set of ringing key springs. Such an arrange-

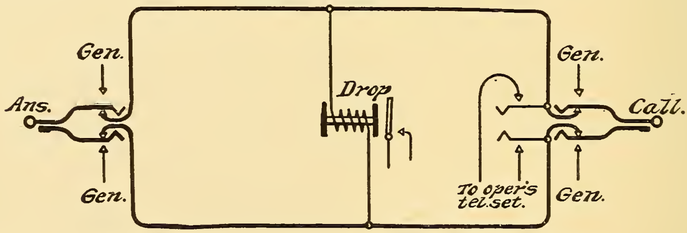


FIG. 175.—CORD CIRCUIT WITH RING-BACK KEY.

ment, however, is shown in Fig. 175, where an extra ringing key is provided in connection with the answering plug.

In diagrams of cord circuits, in order to avoid the complexity caused by showing the generator and telephone set of the operator, it is often sufficient to indicate these in some such manner as is shown in Fig. 175. A still better way of indicating the connection of the generator is to label the leads from the ringing key to the generator with the algebraic "plus or minus" sign (+ —), this indicating that the leads run to a source of current which alternately changes its sign or direction. This symbolic representation will be largely used in this work hereafter.

It frequently becomes necessary to connect grounded to metallic circuit lines in switch-boards, and in order to do this without unbalancing the metallic circuit line the best way is to have a certain number of cord circuits equipped with repeating coils in such manner that the voice currents coming over one of the line circuits will pass through one winding of the repeating coil, thereby inducing similar currents in the other line circuit through the medium of the other winding of the coil. Such an arrangement is shown in Fig. 176, where a metallic circuit line is shown connected with a grounded line. It is evident that the voice currents in the metallic

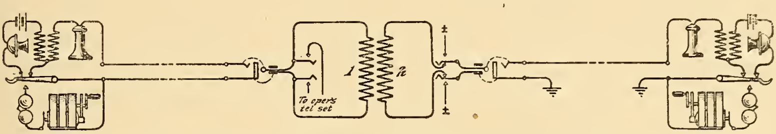


FIG. 176.—CORD CIRCUIT FOR GROUNDED AND METALLIC LINES.

circuit line will pass through winding, 1, of the repeating coil in the cord circuit, thereby inducing similar currents in winding, 2, which will flow through the circuit of the grounded line. This circuit may be traced from ground at the central office through the sleeve contact with the jack and plug through the winding, 2, of the induction coil, thence through the tip of the plug and jack to line and to ground at the subscriber's station.

The only objection to the plan shown is that it is sometimes necessary for the operator to change cords; for instance, if she had answered with the plug belonging to the pair of metallic circuit cords and found that the call was for a grounded line, she would have to change the answering plug, using one belonging to the combination pair of cords, as shown in Fig. 176. In order to obviate this, what is termed a repeating coil key is sometimes used in connection with all the cord circuits, this key being similar in con-

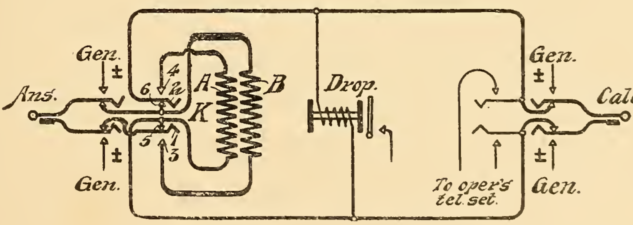


FIG. 177.—REPEATING COIL KEY IN CORD CIRCUIT.

struction to the ordinary ringing key, except that it is adapted to lock in either direction. This arrangement is shown in Fig. 177, in which, besides the regular cord circuit having a ring-back key, an additional key, *k*, and a repeating coil are provided. With the key in the position shown, it will be seen that the repeating coil is cut out, the tip and sleeve strands of the cord circuit being continuous from the answering to the calling plug. With the key thrown in its opposite position, however, that is, with the springs 1 and 2 in contact with the springs 3 and 4, instead of with the springs 5 and 6, it will be seen that the answering plug is completely separated from the calling plug, the circuit of the answering plug being traced from the tip of this plug through the winding, *A*, of the repeating coil to contact, 3, of the repeating coil key, thence to contact, 1, and back to the sleeve of the plug. The circuit of the calling plug may be traced from the tip of this plug to the spring, 2, thence to the spring, 4, and through the winding, *B*, to the repeating coil, back to the sleeve of the calling plug. It will be seen that with this arrangement the circuit assumes the same aspect as that shown in Fig. 176.

Very few switch-boards are now made having single contact plugs and jacks, as described in connection with Figs. 158 to 162, inclusive. By this is meant that few boards are now constructed that are adapted to grounded or common return lines only. A board for metallic circuit lines is equally well adapted to serve common return or grounded lines, in which case that side of the jack which is not connected to line is grounded. Thus, if all the sleeve contacts of the jack are connected with earth, as shown at the right-hand side of Fig. 176, it is evident that the talking circuit will be established through the tip side of the cord circuit, the sleeve side of the cord circuit being practically dead, where repeating coils are not used.

It is generally considered of great advantage to have switch-boards so arranged that it will be unnecessary for the operator to manually restore the drops. The reason for this is that every movement on the part of the operator, in establishing a connection between two subscribers, requires a certain amount of time, and that in the busier portions of the day an operator is worked almost to the extremity of her endurance, and therefore that the saving of any movements in handling these connections will be a gain in the rapidity with which the board can be operated. Such saving of the work of the operator not only insures a quicker and therefore a better service, but also may reduce the cost of the operation of the exchange by enabling fewer operators to handle the system. There are, however, some who contend that the greater part of an operator's time is necessarily taken up in talking or listening to the subscriber in order to ascertain his wishes, and that while she is doing this she may restore the drops by hand without loss of time. Notwithstanding this, however, the number of exchanges using self-restoring drops is rapidly increasing, and many inventions have recently been made and put into practice to bring about this result.

Nearly all of the so-called independent manufacturing companies are supplying "combined drops and jacks," the drop and jack being associated so as to form a single piece of apparatus. In these the drop is so arranged as to be restored by some mechanical movement brought about by the insertion of a plug into the corresponding jack. The Bell companies, where they use "self-restoring" drops (which they seldom do in small boards), accomplish the result electrically, a restoring coil being placed on the drop, to retract the shutter when energized by the insertion of a plug into a jack.

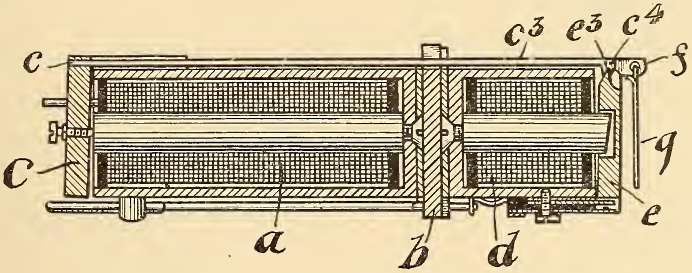


FIG. 178.—BELL SELF-RESTORING DROP.

In Fig. 178 a side elevation and partial section is given of the electrically restoring drop of the Bell companies, this being the product of the Western Electric Company. In this, *a*, is a tubular electromagnet, carrying on its rear end an armature, *C*, pivoted at *c*, which armature carries an arm, c^3, which projects forward and is provided with a catch, c^4, on its extremity. So far the arrangement is almost identical with that of the Warner tubular drop already described. A second tubular electromagnet, *d*, is secured to the front of the mounting strip, *b*, which also supports the magnet, *a*. This second magnet has its poles facing the front of the board. An armature, *e*, is pivoted at its lower side. The catch, c^4, on the rod, c^3, is adapted to engage a lug, e^3, on the armature and retain it in its vertical position. Pivoted on the bracket, *f*, which is insulated from the magnet, is a light shutter, *g*, of aluminum. The tendency of the armature, *e*, when released is to fall outward, and in so doing it presses against the light shutter, *g*, just below its pivotal point, and forces it into a horizontal position.

The coil of the electromagnet, *a,* is usually termed the line coil, and is included in the circuit of the line wire. The coil of the electromagnet, *d,* termed the restoring coil, is in a local circuit containing a battery which is closed by the insertion of a plug into the spring-jack of the line belonging to that drop.

Various arrangements associating drops of this type with the line circuits and with the local circuits at the switch-board have been devised and put into practical operation, the arrangement in Fig. 179 being typical. The actuating coil, *a,* is permanently bridged across the two sides of the line wire, it being wound to a resistance of about 500 ohms to prevent short-circuiting the voice current.

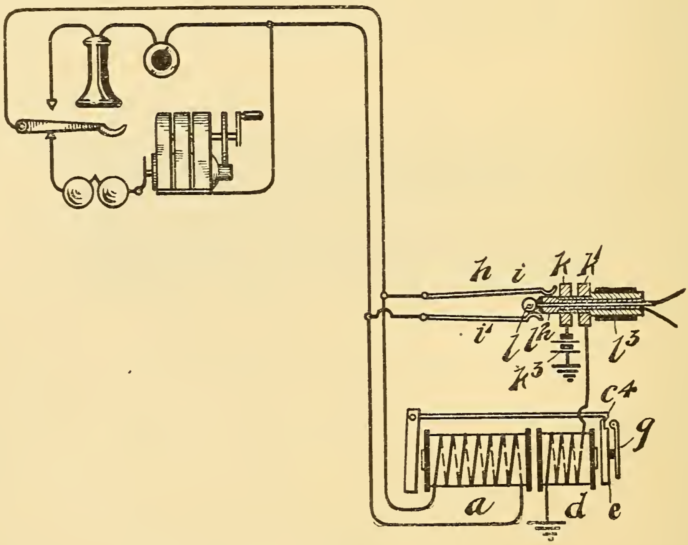


FIG. 179.—BELL SELF-RESTORING DROP.

Two sleeves or thimbles, k k^1, are shown on the jack, the inner one, *k,* being connected permanently to ground through a battery, k^3. The outer thimble, k^1, is connected to the ground directly through the restoring coil, *d.* When with this arrangement a plug is inserted, the two thimbles of the jack are short-circuited by the sleeve on the plug, and the circuit through the restoring coil is thus closed through the battery, k^3. This pulls the armature, *e,* back until it engages the catch, c^4, and thus allows the shutter to swing into its normal position.

The combined drop and jack, when properly made, possesses some advantages not to be found in the electrically restoring type of drop. In the first place, all the additional coils on the drops, and the additional contacts on the spring-jacks and the additional wiring between the two, are entirely done away with. Another advantage, and one that is usually overlooked, is that when the drop falls the eye of the operator is attracted directly to the point into which she

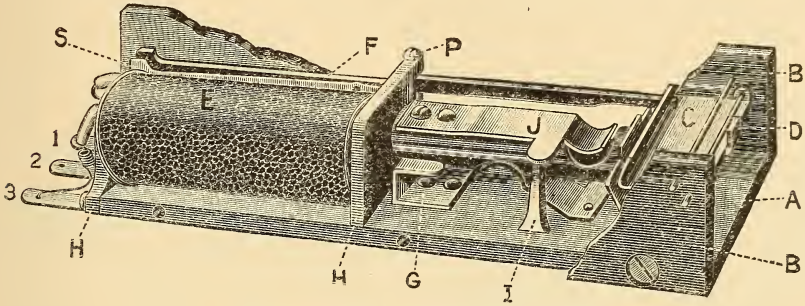


FIG. 180.—WESTERN COMBINED DROP AND JACK.

must insert her plug; while in the forms where the jacks and the drops are entirely removed from each other the operator must first look at the drop, ascertain its number, and then look for the corresponding number of jack on the board below. This very materially increases the ease of operation and consequently tends in itself to give more rapid service.

One of the first mechanically, "self-restoring" drops to be put into

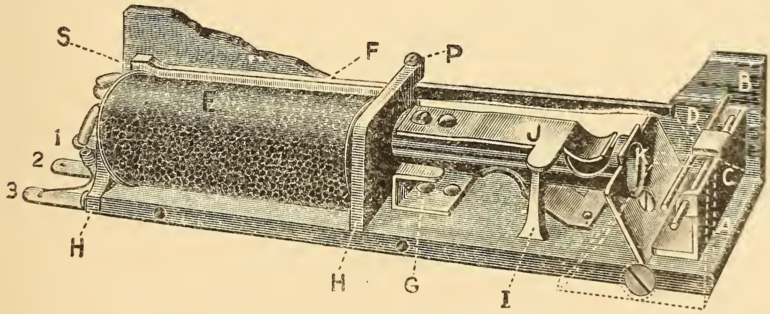


FIG. 181.—WESTERN COMBINED DROP AND JACK.

successful commercial operation was that of the Western Telephone Construction Company. It is shown in Figs. 180 and 181, the former figure showing the shutter in its normal position, and the latter, after it has been thrown down by an incoming call current. In these figures the arrangements are such that the spring-jack lies directly in front of the actuating coil, *E*, and the shutter, *C*, is so arranged as to fall directly in front of the jack when released by the armature, *F*. The combined jack and drop are mounted on a base of hard rubber, *A*. The armature, *F*, is pivoted in the front head, *H*, of the electromagnet by the pivot screw, *P*, and has a forwardly extending arm adapted to support the shutter, *C*, in a horizontal position. A small leaf spring, *S*, normally holds the rear end of the armature away from the rear head, *H*, of the coil and in a position to be attracted by that head when a calling current is sent through the coil. The attraction of the rear end of the armature causes its front end to move sidewise and release the shutter, thus allowing it to fall into a vertical position and display itself to the view of the operator, as shown in Fig. 181.

In order to make conection with the line the operator inserts her plug directly against the shutter, which is down, and in so doing restores the shutter to its normal horizontal position by the direct thrust of the plug. The plug is guided into its jack by the shield or guide-plate, *K*. In entering the jack the spring, *J*, is lifted off the anvil, *I*, by the sleeve of the plug, thus breaking the connection through the coil of the drop. The spring, *J*, makes contact with the sleeve of the plug, while the spring shown on the under sides of the jack makes contact with the tip, thus continuing the two sides of the line to the two strands of the cord.

These drops and jacks are mounted into a sort of an "egg case" composed of the bases, *A*, and the hard-rubber side-pieces, *B B*. These egg cases usually contain one hundred compartments, ten wide and ten high; 1⅛ inches is allowed in each direction between the centers of the jacks. The wires on which the shutters are hung are common to each horizontal row of ten, and the other wire shown is also common to each row of ten. These two wires form the terminals of the night-alarm circuit, and when a shutter is down the lug, *D*, on the shutter strikes against the rear wire, thus making connection between the two and causing the night bell to ring.

This combined jack and drop has given good service, but has several rather serious faults, chief among which is the fact that the tip and sleeve-springs are too short and therefore liable to lose their tension. Also with the "egg case" construction repairs are almost impossible without taking down the entire structure. These defects have been to a large extent removed in a more recent form of apparatus put on the market by this company, and designed by Mr. A. M. Knudsen. In this, shown in Fig. 182, the general arrangement of the various parts is the same as in the type just described, but the springs are made longer by mounting them upon the sides of the jack base, and in fact making them continuations of the frame itself. The rear portions of these springs are provided with thumb-screws carrying thumb-nuts, 1 and 2, which pass through a back panel in the board and secure the entire drop and jack in position, and at the same time afford means for connecting with the tip and sleeve sides

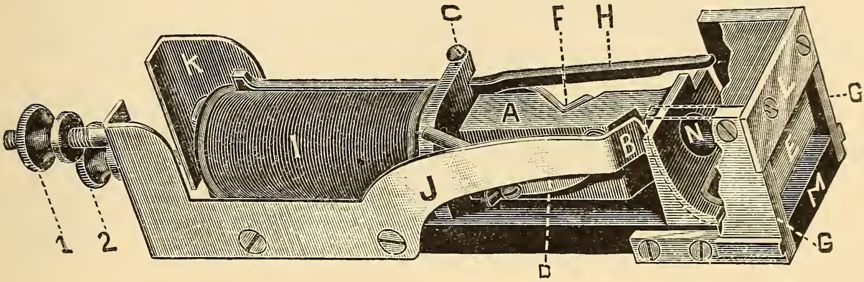


FIG. 182.—WESTERN IMPROVED DROP AND JACK.

of the line. The jack-tube, *A*, and the shield for guiding the plug into the socket are formed from a single casting of brass firmly secured to the jack base, *M*, thus providing a much more rigid construction than that shown in Figs. 180 and 181. The shutter, *E*, operates in the same manner, it being shown in its exposed position, the path through which it swings being indicated by the curved dotted line. Repairs on these drops may be readily made, as the entire structure of any drop and jack may be withdrawn from the front face of the board by removing the thumb-nuts, 1 and 2.

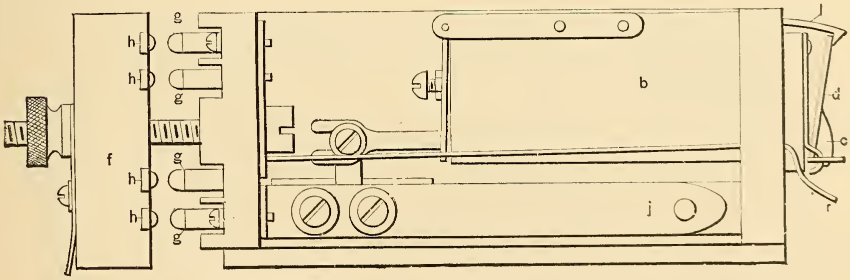


FIG. 183.—SIDE ELEVATION AMERICAN DROP AND JACK.

Great sensitiveness can never be attained with this drop, because the shutter rests upon the armature rod in such manner as to bear upon it with its entire weight. It can therefore only be released by a considerable effort on the part of the armature, this effort being due to the friction between the shutter and the armature rod.

Another form of mechanically self-restoring drop is that now

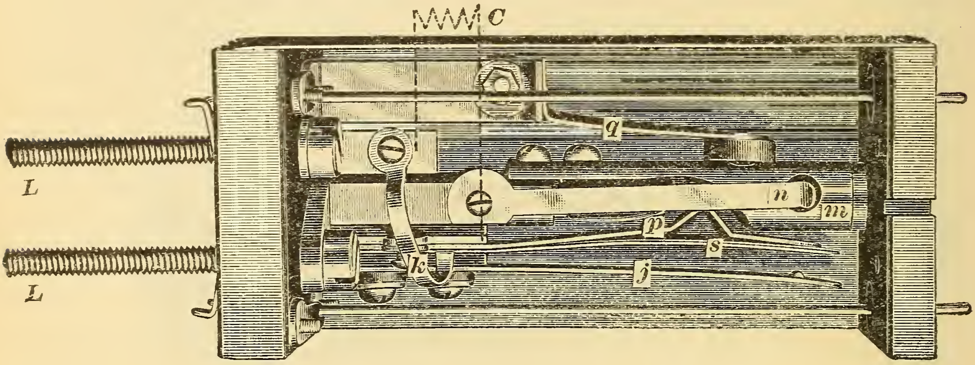


FIG. 184.—TOP VIEW, WITH COIL REMOVED.

manufactured by the American Electric Telephone Company. In this drop, which is shown in Figs. 183, 184 and 185, the actuating coil is mounted directly above the spring-jack. The coil is inclosed on the sides in a sheet-iron frame or box, *C*, for lessening the amount of induction between adjacent drops. The armature of the magnet is pivoted at the rear of this shield, and carries a forwardly project-

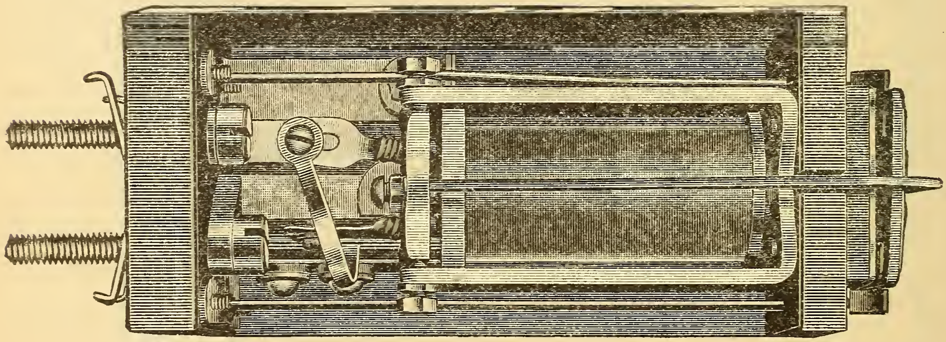


FIG. 185.—TOP VIEW, WITH COIL IN PLACE.

ing lever, *l*, which in turn carries on its forward end a catch for holding the shutter, *d*, in its vertical position. On the shutter is placed a cam, *c*, which, when the shutter is down, lies in front of the opening of the jack. The plug shown in Fig. 186 carries an enlargement or collar, *k,* which collar engages the cam, *c,* on the shutter when the plug is inserted into the jack, and forces the shutter into its normal position.

No cut-out is provided for the coil, which is therefore left in series in the line during a conversation. The coil therefore serves as a clearing-out drop, and when so actuated the cam on the shutter falls in front of the collar on the plug. When, therefore, the plug is withdrawn from the jack, after the clearing-out signal has been sent, the cam again engages the collar on the plug and the shutter is restored again to its vertical position.

The entire structure of the combined drop and jack is removable from the board by taking the thumb-nuts off the screws shown in the rear. These screws pass through the board forming the frame of the switch-board, and serve not only to hold the jack and drop in place, but to establish a connection between the line wires and the line springs of the jack. Small springs, *g g,* on the back of the jack register with corresponding contacts on the front side of the backboard, thus serving to extend the night alarm and generator cir-

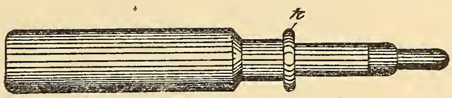


FIG. 186.—AMERICAN PLUG.

cuits from the jacks to the other parts of the switch-board. By this means the proper connections are automatically made when the jack is slipped in place.

The drop illustrated in side elevation in Fig. 183 is of the common-return type, and is therefore provided with but one line terminal. Figs. 184 and 185 show a later pattern adapted to metallic circuits and operating in the same general manner so far as the restoring of the shutter is concerned. Fig. 184 is a horizontal view of the annunciator removed, showing the arrangement of the various parts of the jack. In this figure the coil is indicated at *C* in order to better illustrate its circuit connections. Fig. 185 is a similar view of the complete apparatus, with the annunciator in place. The various circuits of the apparatus will be understood most readily by considering Fig. 184. In this *m* is the jack-tube which is directly connected with the line terminal screw, *L.* This tube is provided with a spring, *n,* which serves to establish a firmer contact with the sleeve of the plug when inserted into the jack. The coil, *C,* of the annunciator is connected directly between the line terminal screw, *L'*, and the tip-spring, *p*, the sharply bent portion of which spring is adapted to make contact with the tip of the plug when inserted into the jack. A spring, *q*, is connected by means of one of the small springs, *g*, in Fig. 183 to one terminal of the generator. This spring, *q*, is provided with a metallic pin which projects through a hole in the jack-tube, *m*, to a sufficient distance to make contact with the enlarged sleeve of the plug when the latter is inserted into the jack to its fullest extent, but not far enough to engage the tip contact when the plug is in its normal position in the jack. By this means, when the plug is inserted as far as it will go into the jack, one terminal of the generator is connected with the line terminal screw, *L*, by means of the sleeve spring, *n*, and the generator spring, *q*, both coming in contact with the sleeve of the plug. The other terminal of the generator is connected with the spring, *j*, through the medium of one of the small contact springs, *g*, on the back of the jack. Upon pushing the plug as far as it will go into the jack, the tip-spring, *p*, rides upon the insulated portion of the plug, thus pressing the thin spring, *s*, which lies parallel with, but is insulated from, the tip-spring, into engagement with the generator spring, *j*. This connects the line terminal screw, *L'*, with the generator spring, *j*, through the medium of the strap conductor, *k*, and the calling current is therefore sent to line. It will be noticed that the path by which the generator current passes to line is not through the coil of the annunciator, but through the strap, *k*, instead; and it will also be noticed that the tip conductor of the plug is disconnected from the tip-spring, *p*, before the contact is made with the generator-spring, *j*, and therefore no calling current will pass back over the cord circuit through the operator's telephone. Upon removing the pressure from the plug, a coiled spring in its handle forces it out of the jack for a short distance until it assumes the normal or talking position.

In later practice the two plugs of a pair are provided with a long and a short tip respectively, so that one of the connected lines will have its coil shunted out of circuit, the other being left in as a clearing out drop.

In Fig. 187 is shown several views of a combined drop and jack designed by the writer, this being the device used in the magneto switch-board of the Kellogg Switchboard & Supply Company. The annunciator consists of an ordinary tubular drop mounted upon but insulated from the upper portions of the brass strip, *C*. The jack is mounted immediately below the drop and consists of a sleeve, *A*, and a frame, *B*, both of brass, the sleeve, *A*, being in the form of a hollow hexagonal-headed screw. The sleeve passes through the mounting strip and engages a thread in the frame, *B*, clamping the jack firmly on the mounting strip, *C*, so that there is no possibility of short circuits between the jack and the mounting strip. The tip-spring, *B*, of the jack has a forwardly projecting lug which passes through the hole in the mounting strip and is adapted to engage the shutter when down. The insertion of the plug into the jack

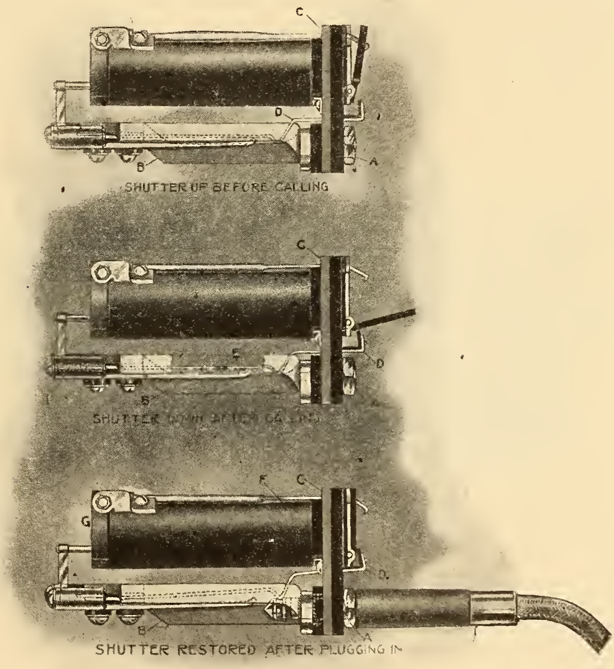


FIG. 187.—KELLOGG COMBINED DROP AND JACK.

lifts this spring, *B*, out of contact with the spring, *E*, with which it normally engages, and as this spring rides upon the tip of the plug its forwardly projecting portion engages the drop, thus restoring it to its normal position.

The entire electromagnet of the drop may be removed from the board indepndently of the jack and the jack may also be removed independently of the drop.

One of the line terminals is formed by a rearwardly projecting lug which is a part of the casting of the frame, *B*, while the other terminal is formed by a similar lug, *I*, fastened directly on the line spring, *D*. The drop coil is connected between one of the line terminals and the spring, *E*, so as to be cut out of circuit by the inser tion of the plug.

Five of these combined jacks and drops are usually mounted on the common plate, *C*, as shown in Fig. 188. The front of this plate is covered by a heavy hard rubber strip serving as part of the insulation used in separating the drop and jack from the metallic mounting plate and also giving a finish to the front of the strip. The night alarm wire is carried on the front of this strip and the shutter in falling serves to press a contact spring secured on the

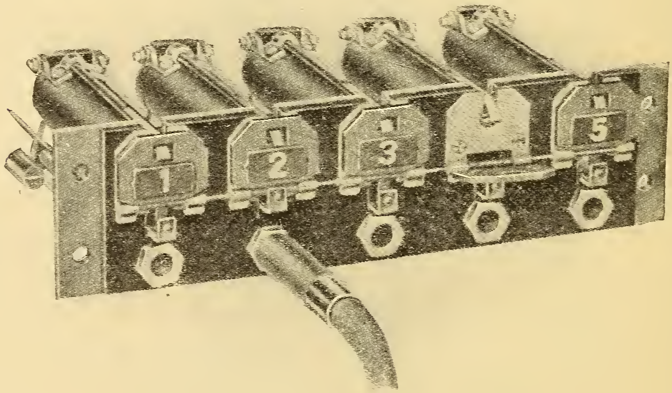


FIG. 188.—STRIP OF KELLOGG COMBINED DROPS AID JACKS.

inner face of the mounting plate into engagement with this wire to close the night alarm circuit. A better idea of the construction of one of these drops may be had from the perspective view of the rear of one of them, shown in Fig. 189.

Many other forms of mechanically self-restoring drops have been devised, but the types here described have come into by far the most general use.

As an illustration of the saving which either the electrically or mechanically self-restoring drops bring about in the operation of switch-boards, certain boards may be cited that have been put into use where the drops are of the ordinary hand-restoring type, placed in series in the line and not cut out by the insertion of the plug.

In the establishing and tearing down of a connection between two subscribers, the operator was required to restore a switch-board drop four different times. First she restored the drop of the line of the calling subscriber, next when she sent a calling current to the line of the called subscriber this current passed through the drop of that line, causing it to fall. This she also restored by hand, and lastly when one or both of the subscribers rung off, the drops of each line fell and were restored by hand, thus making four in all. Such switch-boards are, of course, necssarily slow. Moreover, they are almost invariably much larger and more cumbersome than the more modern types, but even these drawbacks have not interfered with their giving satisfactory service in some cases in small exchanges.

It is sometimes desirable to have the line signal at a switch-board

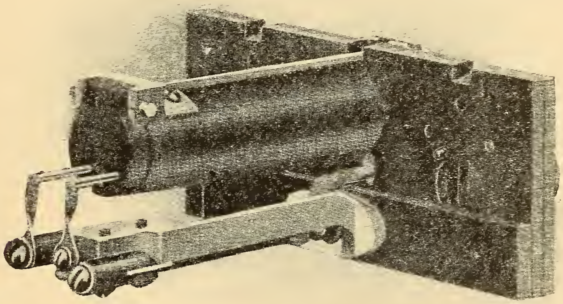


FIG. 189.—REAR VIEW KELLOGG DROP AND JACK.

give an audible signal which will cease sounding as soon as the line current ceases. Of course, the ordinary magneto drop, if provided with a night alarm attachment, may be made to give an audible signal, but this signal persists as long as the drop is allowed to remain down, regardless of whether or not the actuating current has ceased to flow through the coil of the drop. In small switch-boards sometimes employed in village exchanges, the amount of attention required at the board does not warrant the constant attendance of an operator. The lines running into such an exchange are frequently party lines of the bridging type, and more often than not a call on such a line is for another party on the same line. Such a call would throw the switch-board drop and bring the operator to the board, unless some means were provided for the operator to distinguish between calls that required her attention and those that did not. Obviously the night alarm method of attracting the operator does not answer in this case, for with it all calls are alike at the switchboard.

Frequently the magneto bell is used as a line signal in place of a drop. This serves admirably unless there are several lines to be so equipped, in which case confusion is liable to exist as to which bell sounded. This may be overcome by using a magneto bell and a drop both bridged across the line, the drop serving to indicate which bell sounded. This, however, makes two bridges across each line where one should suffice, which is often a disadvantage in case

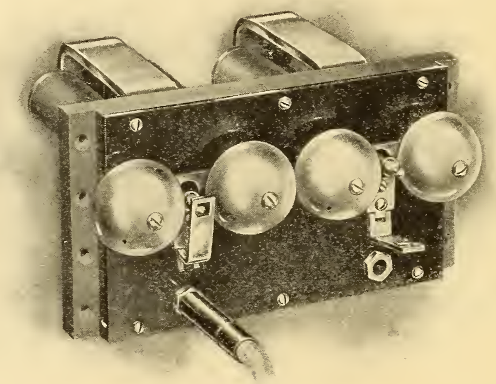


FIG. 190.—COMBINED DROP AND RINGER.

of heavily loaded lines. To obviate this a combined magneto bell and drop is sometimes used.

Two of these mounted on a common strip are shown in Fig. 190, the particular device illustrated being that of the Kellogg Switchboard and Supply Company. In this, as in types of other manufacturers, the bell tapper carries a small conical latch which projects forwardly to engage the shutter when in its raised position. The first movement of the tapper in either direction releases the shutter, after which the tapper is free to play between the gongs. This device is usually arranged to mount directly on the front of the switchboard, and for that purpose the line jack is often associated directly with the bell as shown in this figure.

The principal circuits used in magneto switch-boards, and also many of the various pieces of apparatus, such as drops, jacks, ringing and listening keys, etc., which go to make up such boards, have been discussed. The matter of properly organizing these various parts to form a complete switchboard is not of less importance than the proper design and construction of the parts themselves. The

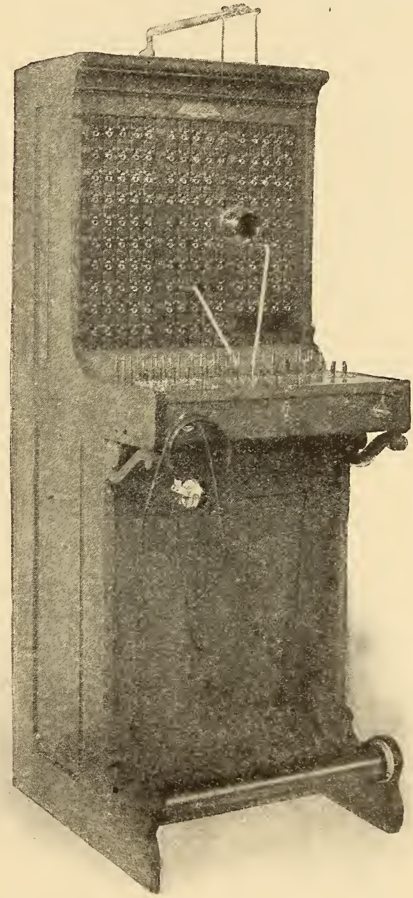


FIG. 191.—STANDARD TYPE OF SWITCH-BOARD—FRONT VIEW.

main points to be sought in assembling the separate pieces of apparatus into a complete switchboard, are that the arrangement may be such as to facilitate the work of the operator; that all parts liable to get out of order shall be readily accessible for repairs; that all wiring shall be systematically arranged in a manner that shall preclude as far as possible the possibility of short circuits, crosses, and open circuits; that the various pieces of apparatus, as well as the circuits in which they are placed, shall be free from inductive influences upon or from the other adjacent apparatuses or circuits; that the framework and enclosing cabinet upon which the various parts are mounted shall not, by virtue of shrinkage or warping, affect the proper working of the apparatus; that the design shall be such as to prevent, as far as possible, the injurious presence of dust; and lastly, and of least importance, it is desirable to make the entire structure of pleasing appearance.

In Fig. 191 is shown a typical form of magneto switch-board, this being one of the Kellogg Switchboard and Supply Company's make, employing the combined drop and jack shown in Figs. 187 and 188. In this particular board these are arranged in three panels, each panel having room enough for ten strips of five combined drops and jacks, and a single strip of five clearing-out drops placed at the bottom. When equipped with the less number of strips, the space is blanked with a wooden strip, as shown in the lower portion of the right-hand panel, where a single strip of drops and jacks is omitted. The pairs of plugs rest in sockets on a horizontal shelf or table below the drop and jack space and in front of these on a hinged shelf are mounted the ringing and listening keys. This hinged shelf is usually called the key shelf, and the stationary portion behind it which carries the plugs, the plug shelf. In front of the key shelf at the right-hand side of the cabinet may be seen the crank of the operator's generator, while in a corresponding position at the left of the cabinet may be seen the operator's head telephone with its band, temporarily hung on the operator's "cut-in plug," which is inserted in the operator's "cut-in jack." By means of this cut-in plug and jack the operator is enabled to connect her head receiver with the remaining portions of the talking circuit, or to disconnect it in case she desires to leave the board. The operator's transmitter is shown hanging from an arm in front of the drop and jack space.

In Fig. 192 the rear view of this same board is shown, this figure serving to give an idea of the arrangement of the apparatus and wiring, the rear enclosing panel being removed for this purpose. About the middle of this cut will be seen the cord circuits upon which the fixed ends of the flexible cords terminate, and to which the cord circuit wiring extends. The cord weights which serve to keep the cords taut may be seen at the bottom of this view, and just above them the connecting rack to which all the circuits of the drops and jacks are led, the connections being made on the front side of this board. The clips on this board extend entirely through it, and therefore form a convenient means for connecting the circuits of

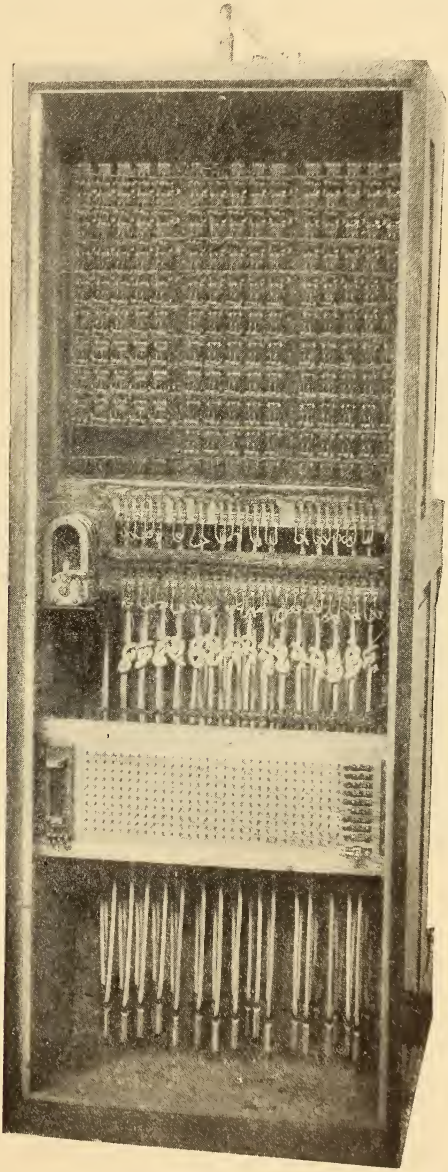


FIG. 192.—STANDARD TYPE OF SWITCH-BOARD—REAR VIEW.

the outside lines. A more common practice now is to extend the pairs of wires leading from the drops and jacks in a cable perhaps

10 feet long, in which case the connections with outside lines are made at the extremity of this cable.

It is often desirable to make a switch-board cabinet wide enough to accommodate more than one operator, and such a cabinet is shown in Fig. 193, this particular one being arranged with the idea of allowing room for two operators if the business of the exchange grows sufficiently to require two. At present, however, this board has only one operator's position equipped. From this view a better idea may be obtained as to the arrangement of the plugs and keys,

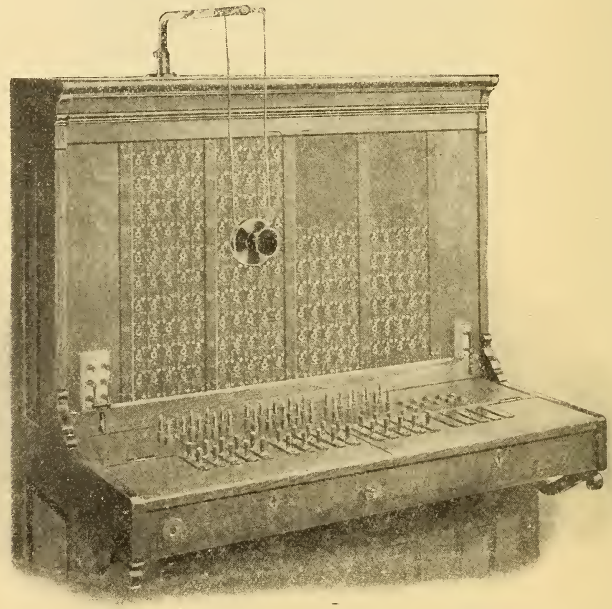


FIG. 193.—TWO-POSITION SWITCH-BOARD.

and it is also instructive as showing the method commonly used of arranging for a greater ultimate equipment of cords, plugs and keys than that required in the first installation. As will be seen, 15 pairs of cords and plugs are equipped in the switch-board of Fig. 193, while room is provided, and the holes drilled, for five additional sets at the right-hand portion of the key and plug shelf. In order to prevent the unsightly appearance of these holes they are covered by suitable blanks which may be easily removed when the apparatus is eventually installed.

There are many different ways of mounting the operator's transmitter upon the switch-board, one of which is shown in Figs. 191 and 193. A somewhat different and better arrangement is shown in Fig. 194, where the bracket or arm is supported on an upright secured to the roof board of the switch-board cabinet. The flexible cords forming a portion of the circuit of the transmitter pass over pulleys at each end of the arm and through holes in the roof board where counter-weights serve to balance the weight of the transmitter. This arrangement allows for the vertical adjustment of the transmitter to suit the convenience of the operator. The transmitter may also be adjusted toward or from the operator by sliding the

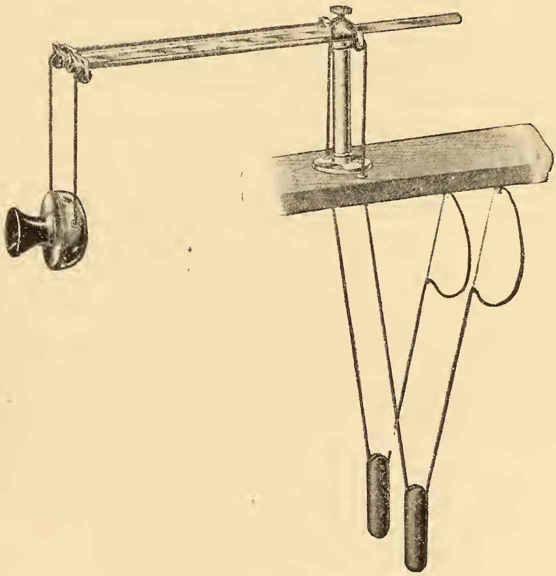


FIG. 194.—OPERATOR'S TRANSMITTER SUSPENSION.

horizontal arm through its socket in the vertical parts which are clamped in position by the thumb-screw as shown.

In Fig. 195 is shown an arrangement of the switch-board apparatus where the drops and jacks are separately mounted, this being one of the recent boards of the Stromberg-Carlson Company. It will be seen that the jacks are mounted in strips of ten as are also the drops, the two being arranged in separate banks.

Another board of the Stromberg-Carlson manufacture is shown in Fig. 196. This shows a two-position board of the type where the drops and jacks are separately mounted, both positions being fully equipped. In this the clearing-out drops are arranged just below the line drops, there being one of these for each pair of cords and plugs. At the left-hand portion of this cut is shown a cabinet to which all of the wiring from the switch-board is led, and to which also the various line wires are adapted to be brought for the purpose of connecting them with the switchboard wires. In some cases

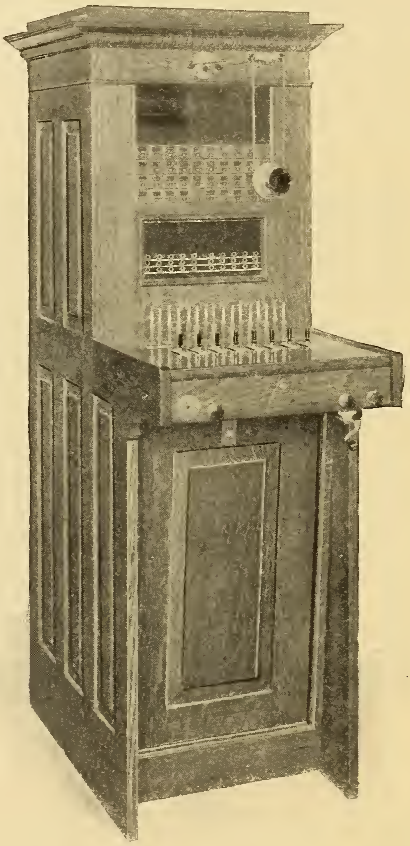


FIG. 195.—STROMBERG-CARLSON MAGNETO BOARD.

the lightning arresters which form the connecting links between the outside and the inside wiring are often mounted in such a cabinet.

The idea of constructing switch-board parts in units which may be removed or placed at will, and by means of which a switch-board may be added to without deranging the parts already installed has been gaining more and more in favor. This idea, however, is perhaps most fully exemplified in the switch-board of the Sterling Electric Company, of Lafayette, Ind., which is shown in Fig. 197. In this switchboard the drops and jacks are mounted in strips of ten, the strips being vertical instead of horizontal. Each strip of ten drops and jacks also carries with it a portion of the plug shelf, together with a pair of cords and plugs, ringing and listening key, clearing-out drops, and the necessary wiring. One of these units may be removed without disturbing any of the others, and conversely it will be obvious that in order to increase the board by

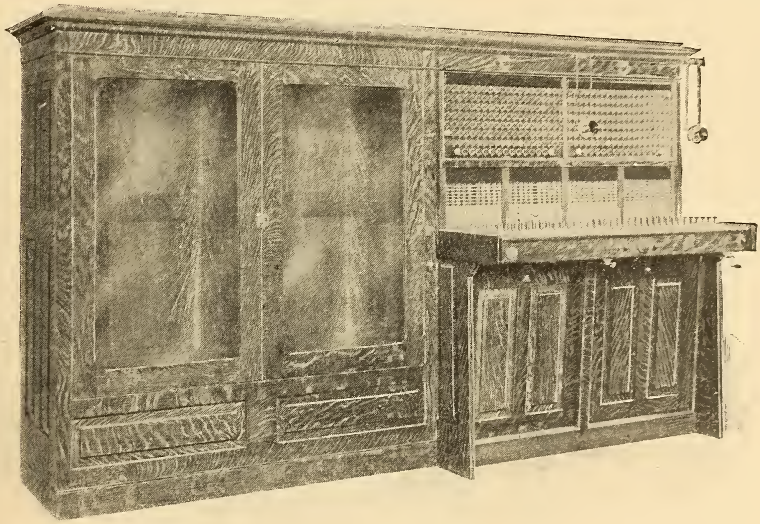


FIG. 196.—TWO-POSITION STROMBERG-CARLSON BOARD WITH TERMINAL CABINET.

ten lines at any time, it is only necessary to secure one of these units into the framework, this being accomplished by means of four machine screws. With this arrangement the proper proportion (10 per cent.) of the pairs of cord circuits to the line circuits is always maintained.

In the Sterling board the drops are not of the self-restoring type, but each strip of ten drops is provided with a rack adapted when raised to restore any of the drops that are down in that strip. This rack is provided with a convenient handle to enable the operator to raise it at the same time that she inserts the plug.

In Fig. 198 is shown a type of switch-board cabinet sometimes used in small village exchanges, these cabinets being mounted directly on the wall of the room. In order to allow inspection of the wiring, such cabinets are usually hinged on their backboards so as to allow them to swing out from the wall, the cable leading to

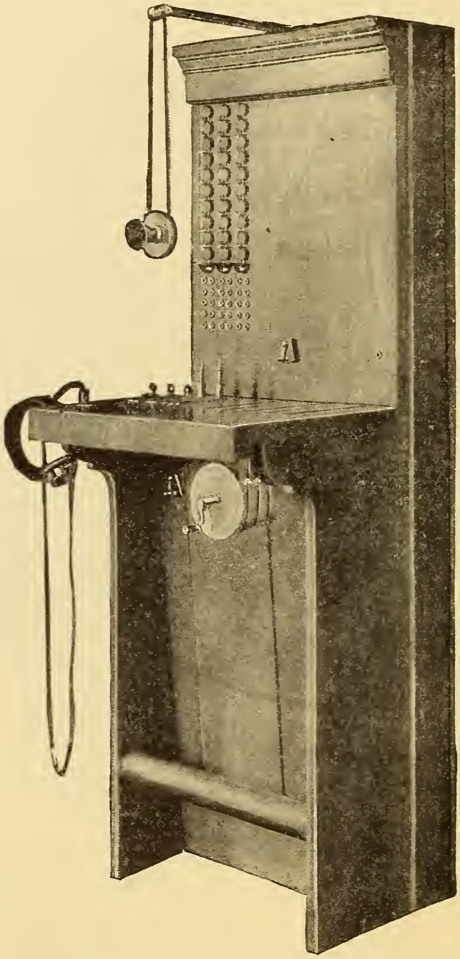


FIG. 197.—STERLING SECTIONAL BOARD.

the apparatus within being provided with a knee or hinge to allow a sufficient movement of the cabinet.

The particular switch-board shown in this cut is one manufactured by the Stromberg-Carlson Company, and, as will be seen, the lines are in each case equipped with a combined drop and ringer, these being equipment for 14 lines in all.

In very small exchanges an ordinary wall telephone is frequently used as an operator's set, the binding posts of this telephone being connected to a two-conductor flexible cord terminating in a two-conductor plug. When a call is received over any line, the attendant may answer by taking the telephone receiver off its hook, and inserting the plug into the jack of the line on which the call was received. If the attendant desires to ring out on the line, she has only to insert the telephone plug into the jack of that line, and turn the generator crank of the wall set after having hung up the receiver.

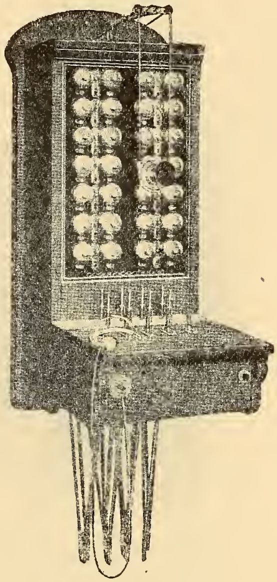


FIG. 198.—WALL TYPE SWITCH-BOARD WITH RINGERS.

This arrangement has the advantage of simplicity and cheapness, and the fact that it is not capable of quite such rapid manipulation is not a disadvantage where only a few lines are to be handled.

The idea in the previous paragraph of using an ordinary wall telephone for an operator's set is embodied in the device shown in Fig. 199, in which the telephone really serves for an operating set of two lines only, or more properly for the two ends of one line. In addition to this, the ringer of the telephone set may be made to serve as a signal on one of the lines. As will be seen the switch-board consists of an ordinary extension bell box containing a ringer and three jacks. The circuit for this outfit, which is called a "toll cut-in box," is shown in Fig. 200. In this line No. 1 terminates in the tip and sleeve contacts of jack No. 1. Line No. 2 similarly terminates in the tip and sleeve contacts of jack No. 2. With the two jacks in their normal conditions, the two lines are connected together with the ringer bridged across their circuit at jack No. 3. When a call is received over the toll line for such a station, the operator in response to the ring plugs into jack No. 2, thus cutting out the normally bridged ringer and placing her telephone set across the line. If it is found that the party calling is on line No. 1, the at-

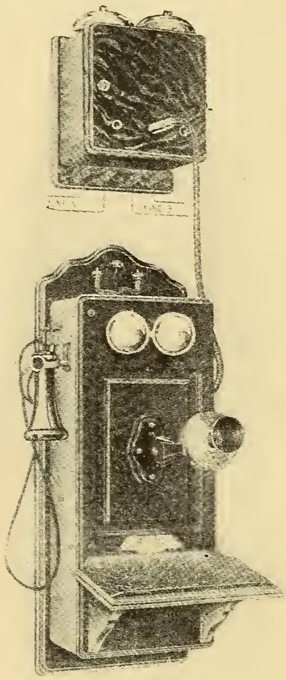


FIG. 139.—TOLL CUT-IN STATION.

tendant may, for the purpose of obtaining better conversation, plug into jack No. 1, thus connecting the telephone with line No. 1 and cutting off line No. 2. When this is done, line No. 2 is still able to signal this station, because the ringer in the extension bell box is left bridged across its circuit. Similarly the party at this telephone may talk or ring on either line to the exclusion of the other by inserting the plug in the corresponding jack. If it is desired for any reason to leave the two lines temporarily separated, the plug may be placed in jack No. 2, in which case the ringer of the telephone set will serve as a signal-receiving device for line No. 1, the ringer in the extension bell box then serving for line No. 2.

These devices are used to a very large extent as intermediate stations on toll lines where it is necessary to place apparatus of the simplest possible nature on account of cheapness and ease of maintenance.

Owing to the multitude of wires and connections that necessarily occur in wiring the various parts of switch-board apparatus, it is of the greatest importance that the wiring be done with a proper regard

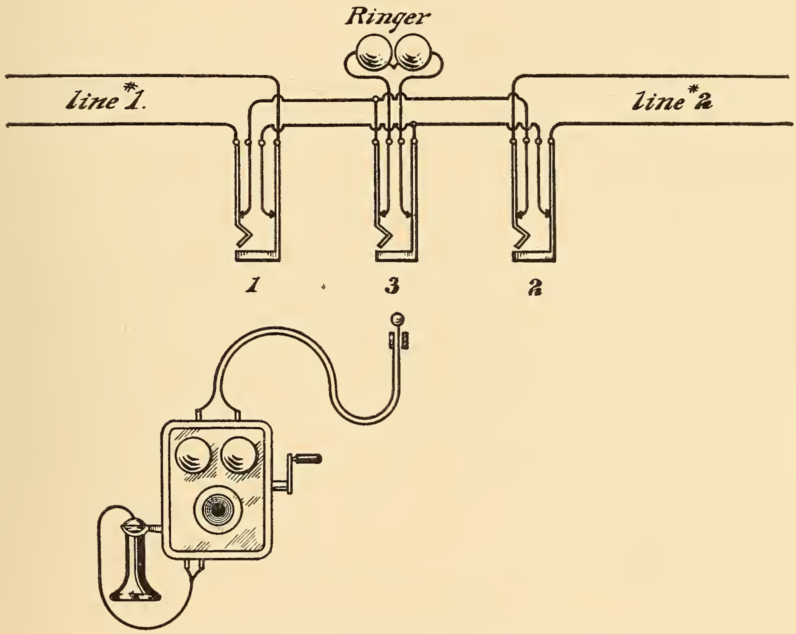


FIG. 200.—CIRCUITS OF TOLL CUT-IN STATION.

for systematic arrangement. For this reason the use of cables has come into almost universal adoption for this purpose, the various wires leading to the different parts of the switch-board being bunched into a compact mass, forming a cable. The individual wires are led out from the cable at points most convenient for attachment to their various terminals. The wires used in this work are usually of No. 22 B. & S. gauge copper, tinned in order to facilitate their being soldered to their terminals. The insulation usually consists of one layer of Tussah silk and one or two layers of cotton; or sometimes two layers of silk and one of cotton. If the wires are to be used in forming cables by hand they are usually impregnated with beeswax and afterwards bound into a cable by means of a strong linen twine. If, however, the wires are to be used in a machine-made cable which is to have its ends properly formed for attachment to the switch-board, they are usually not saturated with paraffin but bunched into the proper form of cable, then wrapped with heavy manilla paper, the whole being covered with a braiding of cotton. This outer covering may be and usually is impregnated with beeswax or with some so-called fireproof paint, according to the requirements of the service.

With few exceptions all connections between wires and the terminals of apparatus should be soldered. The only cases where it is impossible to follow this rule are where there is a likelihood of the necessity to break the connection, as, for instance, to take a piece of apparatus out of circuit. Where such a connection is not soldered the wire should always be clamped firmly in place by means of a machine screw, this screw passing into metal so as to allow no possibility of its loosening. The fewer such connections exist, however, the better, and the absolute reliability of a soldered joint should not, as a rule, be sacrificed to the greater convenience of a screw-made joint. In soldering the connections of switch-board and other telephone apparatus the use of flux containing acid should be carefully avoided. The best flux for this purpose is resin and the most convenient form of applying it is in the form known as resin core solder. In this the solder is rolled into a hollow wire which is filled with resin.

CHAPTER XIII.

THE THEORY OF THE MULTIPLE SWITCH-BOARD.

When the number of subscribers in an exchange exceeds approximately 500 the form of switch-boards so far considered becomes inadequate. To afford room for the number of operators needed to properly handle all of the calls, the board must be made of considerable width, and thus becomes too wide for the operators to reach over its entire face.

When the number of lines becomes greater than can be handled by one operator more operators are employed, and to each is apportioned the signals of as many lines as she can properly attend. Each operator therefore answers the calls of her particular group of lines. So far as the *answering* of calls is concerned, therefore, the division of work between the operators may be made in a satisfactory manner. Not so, however, with the completing of the connection with the subscriber called for—for his line may terminate on some remote portion of the face of the board, to reach which the operator would be required to leave her position and carry the calling plug to its jack. This might be possible if the cords were long enough, but it is not difficult to see that the arrangement would have serious disadvantages.

If a sufficient number of operators could be placed within reach of a switch-board of such size as to enable any one of them to reach its entire face, there would be no need for the multiple board, or for any of the expedients which are now necessary in order to construct a switch-board for a large number of lines.

It is therefore the size of the operators, or more specifically, their *width*, that causes the difficulty where a large number of lines must be accommodated. It is not due to the engineer's inability to place the required amount of apparatus in a given space, as is the popular impression, for the terminals of many thousand lines can be placed within an area easily reached by a single girl of ordinary size. To make this clear, it would be an easy matter to place the jacks and signals for ten thousand lines in a vertical space, say five and a half feet long, and not too high for an operator to reach. If now, a breed of operators be thought of, so thin as to enable one hundred of them to stand in a row before such a board, and yet tall enough to have the reach of our present type of operators, each one of these slender young ladies might be given the care of a group of one hundred lines, the calls of which she would answer, and at the same time be able to reach the jack of any line that might be called for.

It is fortunate for switch-board manufacturers, and perhaps for the human race in general, that girls are made as they are.

The fundamental object of the multitple switch-board is to place within the reach of every operator a line terminal or spring-jack for every subscriber's line entering the central office. The switch-board is divided into sections, each section being of such size as to allow an operator, without undue exertion, to reach over this entire surface. Such a section usually affords room for comfortably seating three operators before it. On each section are placed a number of line signals, by means of which a subscriber is enabled to attract the attention of the operator, and a corresponding number of line jacks, by means of which the operator may make the initial connection with the line in response to a signal. These jacks, which are associated with the line signals, are termed answering jacks.

In addition to the line signals and answering jacks are provided what are termed multiple jacks, there being one of these on each section for every line centering in the office.

To express this in a little different way, the various lines entering the central office are divided into suitable groups, the lines in each terminating in a group of signals and answering jacks. Each of such groups is arranged at a certain position of the multiple switch-board, before which position an operator sits. As many answering jacks and signals are provided at any operator's position as can be properly attended to by the operator at that position. In addition to this, all the lines entering the office are carried to every section of the switch-board, each line terminating in every section in a multiple jack. Each operator is provided with a certain number of pairs of cords and plugs.

The operator seated at any position may, therefore, in response to the call indicated on one of her line signals, insert one plug of the pair into the corresponding answering jack, and having ascertained the number of the subscriber desired, may insert the corresponding plug of the pair into the multiple jack of the subscriber called for. As every subscriber's line has a multiple jack at every section of the switch-board, any operator is able to complete by herself any connection called for over one of the group of lines, to the calls of which she attends.

The underlying principle of the multiple switchboard, as just stated, is very simple. In practice, however, the greatest complexity is met, but this is due largely to the great number of repetitions of a single circuit which may, in itself, be comparatively simple.

The general operation of the multiple switchboard and the general scheme of its principle may perhaps be better understood by reference to Fig. 201, which has no regard whatever for the actual circuits, but merely for the arrangement of some of the most essential parts. In this, three lines are shown entering a switch-board from the left, each line passing continuously through the three or more sections of the board, and being provided on each section with a spring jack or terminal, m', m^2 or m^3. Connected also with each line, at one only of the sections, is a signal, s', s^2 or s^3, and an answering jack, a', a^2 or a^3. From this it follows that the call of the subscriber on any one line may be answered at only one of the

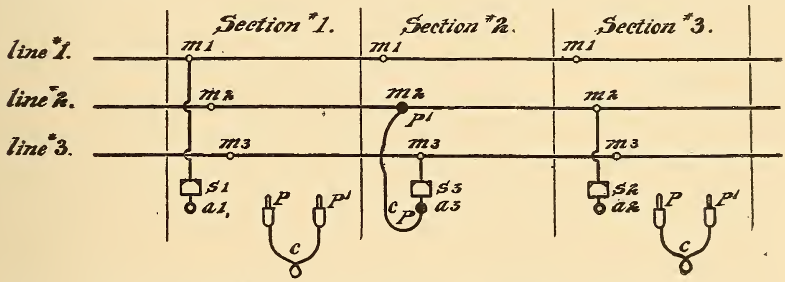


FIG. 201.—ARRANGEMENT OF PARTS IN MULTIPLE SWITCH-BOARD.

sections, since his line signal appears at one section only. It is also evident that since a multiple jack is provided for each line on every section, that a subscriber may be called from any section. It thus follows that any operator, while she may answer the calls of but a few lines (those having signals at her position), may complete a connection between one of these lines and any other line in the entire office. Each operator, as in the case of small switch-boards, is provided with a certain number of pairs of plugs, P P', connected by suitable flexible cords, c, and auxiliary apparatus. It will be seen that at section 2 connection has been made between lines Nos. 2 and 3 by means of such a pair of cords and plugs, the answering plug P having been inserted into the answering jack a^3, in response to the signal s^3, and the connection having been made with line No. 2 by inserting the corresponding plug of the pair into the multiple jack m^2 of that line at that section.

It is evident that the appearance of a jack for each line on each section completely solves the problem of enabling the operator to make any connection without moving from her section, but a little further thought will show that a difficulty is thus brought about. The presentation of a number of connection points belonging to a single line, to different operators located at the several sections of the board, makes possible more than one connection with any line at the same time. For instance, while line No. 3 is connected with line No. 2 at section No. 2, line No. 3 might also be connected with line No. 1 at section No. 1, and it might also be connected with any other line at any other section. Such a condition would, of course, bring about confusion.

In order to prevent more than one connection being made with any line at the same time, what is termed the "busy" test has been provided, by means of which, as soon as any line is connected with another at any section, its electrical condition is so changed that an operator at any other section in attempting to make a connection with it will be given warning of the fact that a connection had already been made with it. This warning is usually given by means of a click in the operator's head telephone, given when she attempts to make connection with a line already switched at another section.

The size of the section is limited by the reach of the operator, and it is this fact that places a well-defined mechanical limit to the size or capacity of an ordinary multiple switch-board. Since each section is to contain as many multiple jacks as there are lines centering at the office, it follows that the size of the jack determines the number of lines that can be placed on any section, and therefore the number of lines that can be served by the multiple board. Until quite recently it has been found impracticable to build jacks occupying less space on the face of the board than one-half inch in both horizontal and vertical dimensions. This limited the number that could be placed within the reach of an operator to approximately 6000 and at most to about 7200. Later improvements have, however, made possible a material reduction in the size of the jack, so that it is now possible to place approximately 25,000 jacks within the reach of a single operator, thus raising the ultimate capacity of a multiple switch-board to that number of lines.

While the size of the jack and the reach of the operator determine the number of multiple jacks that can be put on any section, and therefore determine the ultimate capacity of a switch-board, the number of line signals that can be handled by any one operator determines the number of sections that must be provided in the switch-board. Thus in a central office having 6000 lines, if three operators could handle all of the calls originating in the entire office, there would be no need of more than one section, for the three operators located in front of it would be all for which room need be provided. As a matter of fact, however, the number of line signals that can be handled by one operator is very limited, and varies from perhaps 10, in the very busiest lines of a large commercial center, to about 400 in communities where subscribers make but few calls a day. Probably 100 lines for each operator is a fair average in modern work, and on this basis 300 answering jacks and signals will be placed on each section to be handled by the three operators located at that section. For a multiple switch-board of 6000 lines, therefore, there would be need for 20 sections, and, of course, on each of these 20 sections 6000 multiple jacks would be placed. In such a switch-board, therefore, while there would be 6000 line signals and 6000 answering jacks, there would be 120,000 multiple jacks.

As showing how the number of jacks increases as the number of lines increases, consider a 24,000-line multiple switch-board instead of one of 6000 lines. In a 24,000-line board there would be need for 240 operators' positions, or approximately 80 sections, still retaining the assumption that each operator would be able to handle the calls of 100 lines. Since each section would contain 24,000 multiple jacks, the entire switch-board would be provided with eighty times this many, or 1,920,000 multiple jacks. Thus, in comparing the 6000-line and the 24,000-line boards, it is found that while the number of lines has been increased fourfold, in the larger board, the number of jacks has been multiplied by 16. A little consideration will show that with the same assumption as to the number of subscribers to be handled by any operator, the number of multiple jacks will vary directly as the square of the number of lines served by any multiple switch-board. This is not quite an accurate statement, because the conditions are slightly modified by the fact that multiple jacks are usually extended somewhat beyond the last operator's position at each end of the board for the purpose which will be pointed out later.

In general, however, it may be said that the number of line signals and answering jacks in a multiple board varies directly as the number of lines served, as do also the number of sections, the number of operators' positions, the number of operators' equipments, and the number of pairs of cords and plugs. The number of jacks, however, varies approximately as the square of the number of lines where the average number of lines served by one operator is the same.

Since three operators occupy each section in a multiple switch-board and since the size of the section is such that one operator standing in the middle of the section can conveniently reach any of the jacks in that section alone, it follows that the middle operator at each section is the only one that can reach all over that particular section. The operator at the right-hand end of the section cannot, without undue exertion and without discommoding the operator in the middle position, reach to the extreme left-hand end of the section, and the same is true of the operator at the left, with respect to the right-hand end of the section. It is fortunate that this is not necessary. While the operator at the right-hand end of the section cannot reach the left-hand third of the same section, she can reach the left-hand third of the section at her immediate right; and as this is an exact duplicate, so far as the multiple jacks are concerned, of the left-hand third of her own section, it serves her purpose equally well. The same is true of the operator at the left-hand position of the section. The operator at the left-hand position of the section uses the multiple jacks of the right-hand one-third of the section at her left, and of the left-hand two-thirds of her own section. The operator at the center of the section uses the multiple jacks of her own section only. The operator at the right of the section uses the multiple jacks of the right-hand two-thirds of her own, and the left-hand one-third of the section at her right.

Unless special arrangements were provided the operator at each end position of the switch-board would have within her reach only two-thirds of the section; thus the operator at the right-hand end position of the switch-board would have no left-hand third of a section to reach. There are two solutions of this difficulty. One is to place no operator at the end positions, equipping its panels, however, with multiple jacks, as usual. This is the solution that is adopted by most of the independent manufacturing companies of this country. The Bell companies, however, as a rule, place an extra third section on the end of the multiple board, this section containing the multiple jacks necessary to complete the full quota of jacks necessary for the reach of the operator at that end of the board. These two solutions amount to practically the same thing, although the latter requires an odd size section at the end of the board while the former does not.

CHAPTER XIV.

THE MAGNETO MULTIPLE SWITCH-BOARD.

All the early multiple switch-boards were adapted to magneto signaling, the subscriber sending a call by turning the crank of the magneto generator. The signal receiving device at the central office, responsive to the current thus generated, was always some form of electromagnetically operated drop or target, several types of which have already been discussed.

The first of these boards were adapted to use on grounded lines. The line circuit passed first through the spring of the jack of the first section, thence through the back contact of that jack to the spring of the jack located in the second section, and so through a jack in every section to the last, after which it passed through the coil of the annunciator to ground. Separate contact rings or

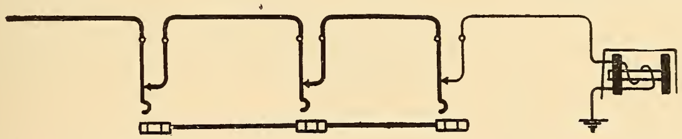


FIG. 202.—GROUNDED LINE CIRCUIT FOR SERIES-MULTIPLE BOARD.

thimbles were used in each jack for the purpose of giving a proper busy test. The test rings belonging to a line were wired together and so arranged that whenever a connection was made with that line all of the test contacts would be connected to a battery associated with the cord circuit used in making the connection. By this means an operator attempting to make another connection with a line already connected to at another section would receive a click in her head receiver.

The circuit of such a line extending through the jacks on three sections is shown in Fig. 202. A cord circuit for association with such a line is shown in Fig. 203. This is a single-conductor cord circuit, carrying the usual listening key, *L*, two ringing keys, *R* and *R'*, and a double-coil clearing-out drop, *C O*, in series with the cord strands. The operator's telephone circuit, including a test battery, *T*, of one or two cells, was bridged to ground from the point of junction between the coils of the clearing-out drop.

It will be seen that normally the circuit of the line extends through the contacts of the jack on each section to earth through the annunciator. A subscriber could therefore signal the central office at any time. The operator at whose position this annunciator was placed would respond by inserting the answering plug into the answering jack corresponding to the annunciator, which act would establish connection with the line and at the same time cut off the circuit of the drop by opening the contact between the spring and its anvil. The operator could then by means of her listening key ascertain the number of the subscriber called for, and before completing the connection would test his line by touching the calling plug to the test ring of the multiple jack at her section,

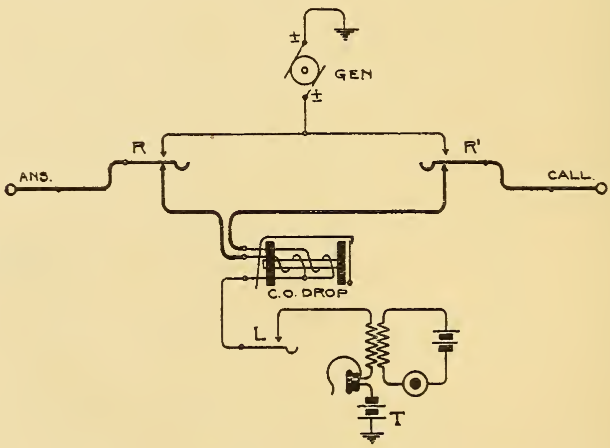


FIG. 203.—CORD CIRCUIT FOR SERIES-MULTIPLE BOARD.

at the same time keeping her listening key closed. If his line was free its test thimbles would have no ground connection, and there would be no flow of current through the operator's telephone set. She would therefore complete the connection by inserting the calling plug into the jack tested and ringing up the called subscriber by depressing the ringing key associated with the plug used. If, however, the line called for were already switched at another section, its test rings would all be connected to earth, and therefore a flow of current would take place on testing which would cause a click in the telephone of the operator making the test. The path of this current flow would be from the test battery, *T*, through the operator's telephone to the test rings of the line, and to ground through the telephone of one talking subscriber or both.

It was not long before metallic circuit lines became a necessity, particularly in multiple-board work, and after a long period of evolution the line circuit shown in Fig. 204 became the standard of the American Bell Telephone Company. This figure shows three lines passing through three separate sections in the multiple board. One side of each line, for instance of line 1, passes to all the contact rings, *b*, of the jacks belonging to that line. It then passes to one line terminal of the line drop, *d'*. The other side of the line passes to the spring, *a*, of the jack belonging to that line on section 1, this spring resting against the anvil, *c*, to which a wire is connected running to the spring, *a'*, of the jack belonging to that line

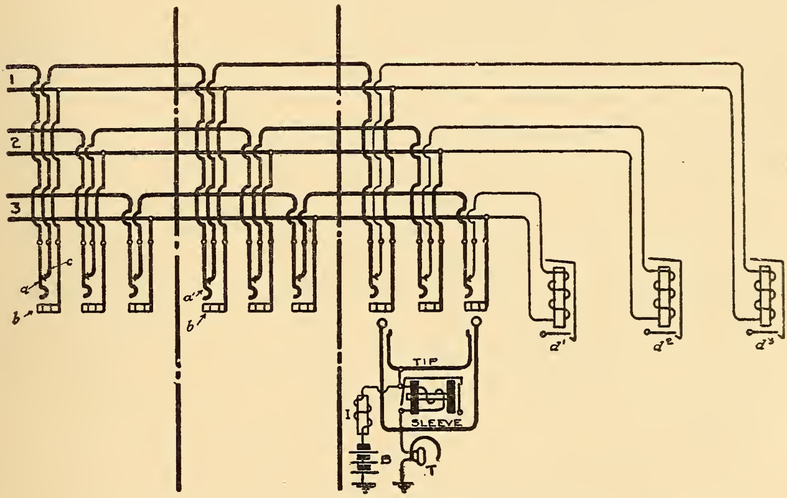


FIG. 204.—SIMPLIFIED DIAGRAM SERIES-MULTIPLE BOARD FOR METALLIC CIRCUITS.

on the second section. So on the connection is made to all of the jacks belonging to this line, a wire leading from the anvil of the last jack to the other terminal of the annunciator. Lines 2 and 3 pass successively through the sections in the same manner. This figure also shows the cord circuit stripped of details, the arrangement shown being best adapted to give an idea of the method of testing.

When a subscriber operates his generator, the current passes over the line wire through all of the contacts, *a* and *c*, in series, through the drop-coil, and back over the other side of the line. When an operator inserts a plug into a jack, the spring, *a*, is lifted from contact with the anvil, *c*, by the tip of the plug. The sleeve of the plug makes connection with the test ring, *b*, and thus the tip and sleeve strands of the plug are connected, respectively, into the metallic circuit of the line, while the circuit through the drop is cut off at the anvil, *c*.

The operator's telephone, *T*, may be then bridged across the cord circuit in order to enable the operator to converse with the subscriber who has called. Means for connecting the operator's telephone in the circuit in this manner are not shown in Fig. 204, the details of the cord circuit being described later in connection with another figure. This telephone in Fig. 204 is shown connected in a ground branch from the tip side of the cord circuit, in order to better illustrate the principles of testing in this system.

The sleeve strand of each cord circuit is grounded through a battery, *B*, and in order that this ground may not produce serious effects in unbalancing or crossing the circuit of two connected lines, an impedance coil, *I*, is placed in this circuit. Whenever any plug is inserted into a jack, one side of the test-battery, *B*, is thrown on to all of the test-rings, *b*, of the line to which that jack belongs. If now an operator at another board desires to make a connection with that line she touches the tip of her answering plug to the test-ring, *b*, of that line. This will connect the test-ring, *b*, to ground through her telephone, *T*, and a click will be heard, due to the passage of the current from battery, *B*. The operator will therefore know that that line is busy, and will refrain from making the connection.

In Fig. 204 the three lines have their drops located at section 3. It must be remembered that other lines would pass through jacks on the various sections in a similar manner, but would have their drops located on sections 1 or 2. The operator at any section will, of course, answer calls on lines terminating or having drops on her section only, but she may be required to connect one of these lines to any other line in the exchange by means of the multiple jack.

The details of the cord circuit for this system are shown in Fig. 205. *K* and *K'* are ringing keys for connecting the calling generator with either of the plugs *P* or *P'*. The circuit between the plugs is normally maintained continuous, through the tip and sleeve strands, as can be readily seen. When the listening key, *K''*, is depressed, the condenser, *C*, is looped into the tip strand, and at the same time the operator's telephone circuit is bridged between the tip and the sleeve strand. A point in the operator's telephone circuit between the receiver and the secondary winding of the induction coil is grounded so as to make the receiver available for testing. The test is made when the key, *K''*, is depressed, the test circuit then being from the tip of the plug, *P'*, through the tip strand to the right-hand spring of the key, and through its anvil and the receiver coil to the ground. The condenser, *C*, is for the purpose of preventing disturbances in the line with which the plug, *P*, is connected from giving a false busy test.

The line circuit and cord circuit shown in Figs. 204 and 205 were at one time standard with the American Bell Telephone companies, the most notable case of their use being in the old Cortlandt Street exchange in New York. This was at the time the largest multiple switch-board in existence. While the old switch-board has been torn out to be substituted by one of modern construction, it formed a

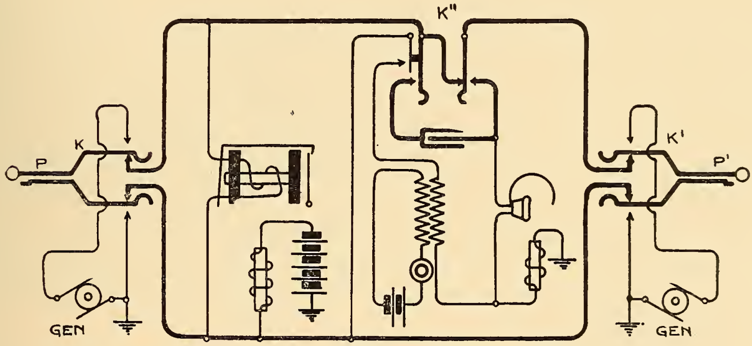


FIG. 205.—CORD CIRCUIT FOR METALLIC CIRCUIT SERIES-ULTIPLE BOARD.

landmark in switch-board development, and therefore the actual circuits employed in it may be of interest. There were both grounded and metallic circuit lines used in this exchange, the wiring of each line, as well as that of the cord circuit, being shown in Fig. 206, in which the line at the left of the figure is a metallic circuit, and that on the right a grounded circuit. There were in all 44 sections to this switch-board, the jacks in all of which, except the 44th, were provided with a tip spring normally resting against a contact point, the circuit being broken on the insertion of the plug. This jack is diagrammatically shown in detail, *a*, of Fig. 206. The jacks at the 44th section were provided with a double break—that is, they were adapted to break both sides of the line instead of only one. The arrangement of springs in the jacks at this section is shown in detail, *b*, in Fig. 206.

Section No. 44 was the first section to which the lines passed after entering the office, and this section was placed in the long-distance operating room on the floor below the other sections. The object of making a double-contact jack in this section was in order to completely cut off all connection with the main switch-board beyond the 44th section when a connection was made between a local line and some long-distance line.

The operator's cord circuit, as will be seen, was like that shown in Fig. 205. The condenser was individual to each operator's position rather than individual to each cord. The purpose of this condenser was, as has been stated, to prevent a false "busy" test. With the condenser not present it is evident that the tip of the calling plug when used in making a test would receive potential from the test battery over the circuit from ground, the test battery and 500-ohm retardation coil to the sleeve side of the cord, thence through the circuit of the line with which the answering plug was connected to the sub-station, and back to the tip side of the cord circuit and to the tip of the calling plug. This would render possible the flow of current from the tip of the plug used in testing to the sleeve of the line being tested whether that line was busy or not. It may be stated, therefore, more briefly, that the object of the condenser was to prevent the flow of current from the test battery to the tip of the calling plug through that portion of the circuit connected with the answering plug.

It is evident that when a metallic circuit line was connected with a grounded circuit line the talking circuit would be traced from ground at the subscriber's station on the grounded circuit line, through the line circuit to the central office, thence to the tip side of the metallic circuit line and back over the sleeve side of this line to the sleeve side of the cord circuit and thence from the sleeve contacts of the jacks on the grounded circuit line to ground at the central office. The presence of the 600-ohm non-inductive resistance in the ground connection at the central office on the grounded line was to prevent the "dead grounding" of the test rings so as to keep their potential above that of the earth when a connection was made with the line so that the line would give the proper "busy" test while so connected. It is evident that if the test contacts of the grounded circuit lines had been dead grounded the potential of the test rings would have remained the same as that of the earth, regardless of

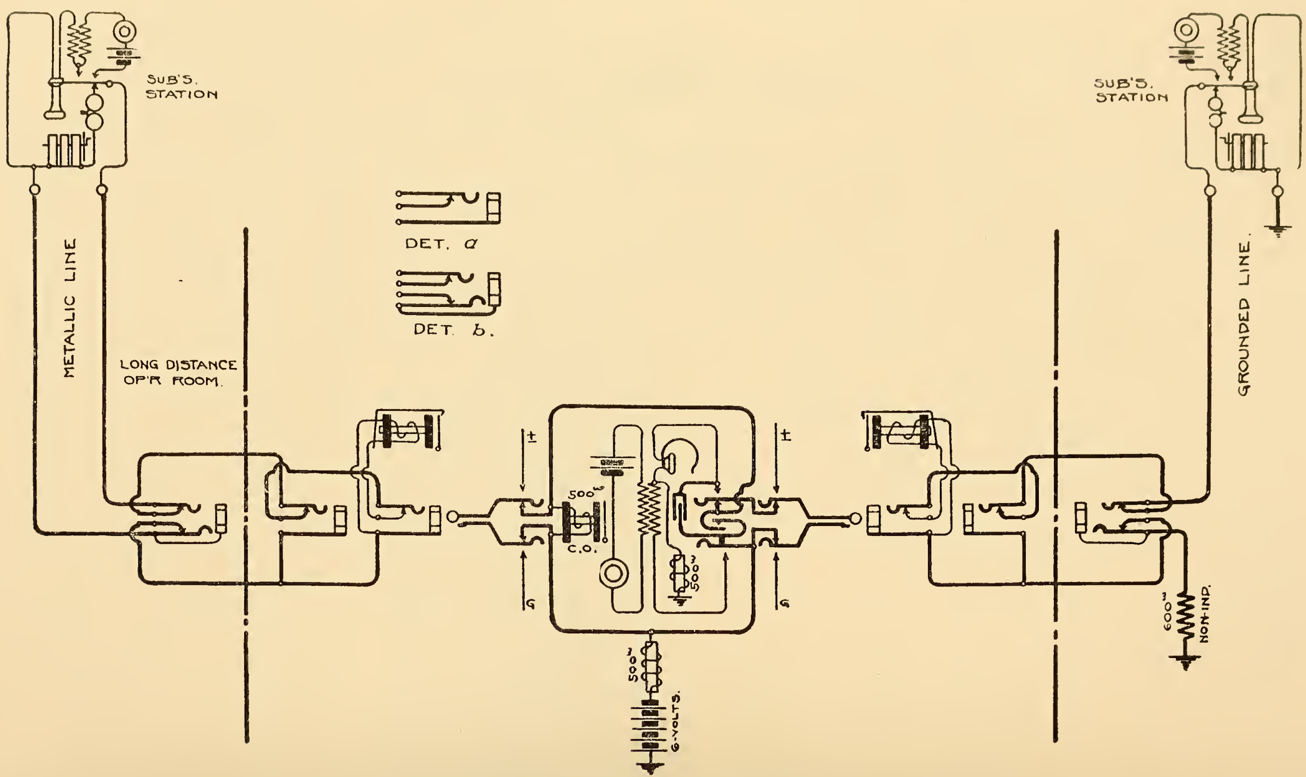


FIG. 206.--CIRCUITS OF CORTLANDT STREET OFFICE, NEW YORK.

whether the line was switched for use or not. Moreover, this condition would have short-circuited the test battery.

The operation of the test is very simple. The test battery being permanently connected to the sleeve side of the cord circuit serves to raise the potential of all the test rings of the line as soon as, and as long as, any plug is inserted into a jack. When not connected the test rings are supposedly at the same potential as that of the earth. Therefore when an operator tests with the tip of a calling plug no current will pass through the circuit traced from the tip of her calling plug through her telephone receiver to ground in case the line is not busy, because there is no source of current in the circuit. If, however, the line is busy, the difference of potential between the test ring and the tip of the testing plug will be noticed by a click of the receiver. The circuit over which this testing current passes may be traced to ground at the central office through the test battery, through the sleeve of the testing plug, thence to the sleeve contact of the jack at which the test is being made, through the tip of the testing plug to ground through the operator's receiver.

The test battery used in connection with the Cortlandt Street Exchange consisted of 3 cells of a storage battery giving approximately 6 volts.

The multiple switch-board circuits so far shown are those of what are termed the series-multiple board, the name series being derived, of course, from the manner in which the line circuit passes through the contact springs and anvils of the multiple jacks. This system, although once widely used, is subject to grave defects and may now be considered obsolete. The series-multiple board has been replaced by another form of multiple board known as the "bridging" or "branch terminal multiple." In the series-multiple an open circuit may be caused in any one of the jacks by a particle of dust or other foreign insulating matter becoming lodged between the line-spring and its anvil, or by virtue of one of the springs becoming weak and failing to bear upon its anvil. The liability to open circuits, therefore, is very great, especially in large exchanges.

Another serious objection to the series board is that when a plug is inserted into a jack, one side of the line is cut off at the anvil of that jack, but the test side is not cut off, and is continuous through the drop of that line and back to the anvil of the jack which is plugged. This, in a large exchange, means that to one side of the line is attached an open branch, perhaps several hundred feet long, and containing the drop coil. This destroys to a certain extent the balance of the line, and is liable to produce cross-talk.

The branch-terminal system was designed to remedy the defects inherent in the series system, and possesses many advantages over it, chief among which are the facts that when a connection is made with any line the balance of that line is in nowise affected, and that the liability of open contacts in the jacks, which is such a serious defect in the series system, does not exist. The branch-terminal system, moreover, lends itself more readily to the use of self-restoring drops, as will be described later.

In Fig. 207 is represented the highest type of the branch-terminal

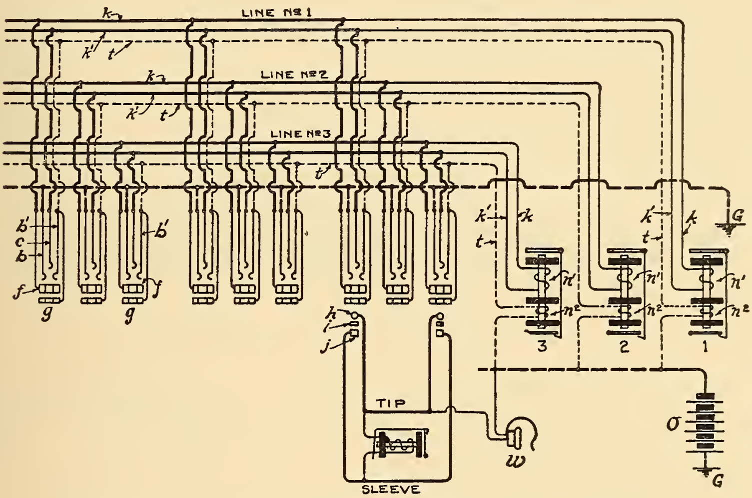


FIG. 207.—SIMPLIFIED DIAGRAM OF BRANCH TERMINAL MULTIPLE BOARD.

system, as applied to magneto signaling. This is sometimes called the three-wire system on account of the fact that three wires for each line extend throughout the multiple. In this figure three distinct line circuits are shown passing through three sections of board. The wires *k* and *k'* of each line have branch wires leading off to a jack on each board; the branches from wire *k* leading to the contact-thimbles *f*, and the branches from wire *k'* leading to the short springs *c*, in the same jacks. Bridged across the two wires of each line is the line coil *n'* of the individual annunciator belonging to that line. This coil is high wound in order that it may be left permanently bridged across the line without materially affecting the efficiency of the system in talking.

A third wire, *t*, passes through the board in parallel with each line. From this wire branch wires are run to the test-thimble, *g*, and to the spring, *b'*, in each jack belonging to that line. The test wire, *t*, after passing through all of the boards, runs through a low-resistance coil, n^2, on the drop of the line to which that particular test wire belongs, and then passes to ground through a battery, *o*, common to all test wires. These test wires are represented by dotted lines in the figure in order to distinguish them more readily from the line wires. The remaining spring, *b*, in each jack is permanently connected to a ground wire, *G*, common to all of the jacks.

Each plug in this system is provided with two contacts, *h* and *j*, which form terminals respectively of the sleeve and tip strands of the cord circuit. The tip, *h*, registers with the spring, *c*, when the plug is inserted into the jack (see Fig. 208), and the sleeve, *j*, registers with thimble, *f*. A conducting ring, *i*, entirely insulated from all other portions of the plug, registers with the springs, *b*, and *b'*, in the jack, and connects them together electrically.

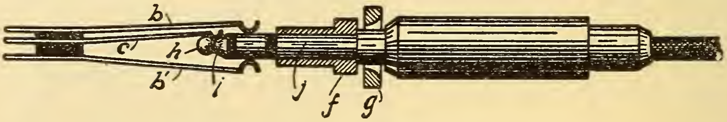


FIG. 208.—THREE-CONDUCTOR PLUG AND JACK.

Three general results are accomplished by the insertion of a plug into a jack. The tip and sleeve strands of the cord circuit are connected respectively with the sides, *k'* and *k*, of the line, thus continuing the line circuit to the cord circuit. The connecting of springs, *b* and *b'*, by the ring, *i*, completes the circuit of the battery, *o*, through the restoring coil, n^2, of the annunciator, to the ground wire, *G*, and thus allows current from this battery to energize the coil, n^2, and restore the shutter of the annunciator. Lastly, the connecting of springs, *b* and *b'*, by the ring, *i*, connects the test-thimble, *g*, to ground by a short circuit, so that when an operator at any other board touches the test-thimble of that line with the tip of her plug, a signal will be given denoting the line as busy.

In the normal or idle condition of a line, the test-ring, *g*, is electrified to a difference of potential from the earth by the battery, *o*, which finds circuit through the restoring coil, n^2, of the annunciator of that line to all the different test-rings, *g*, belonging to that line at all of the sections of the board. If when the line is in that condition the tip of the test-plug, which is grounded through the operator's receiver and the same battery, be applied to the test-ring, no current will flow through the receiver because both the tip and the

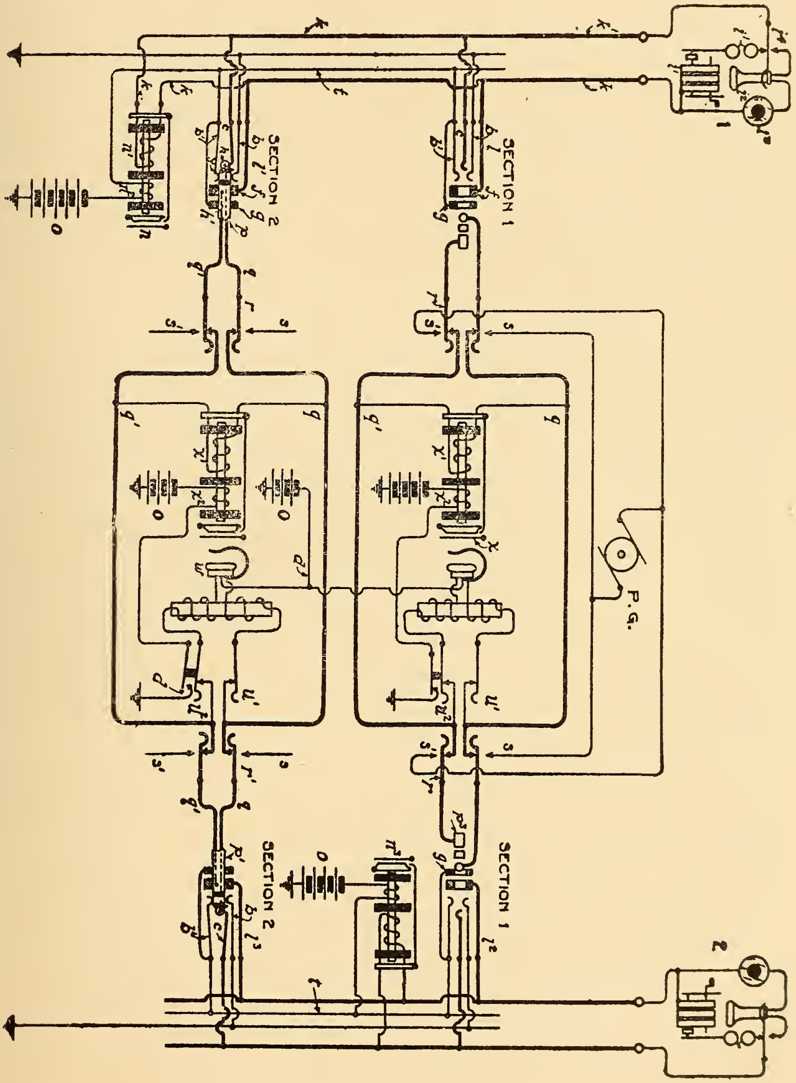


FIG. 209.—LINE AND CORD CIRCUITS OF BRANCH TERMINAL MULTIPLE BOARD.

test-ring are at the same potential. Silence will therefore indicate a free line.

When, however, the line has been put into use by the insertion of a plug into the spring-jack thereof, the springs, *b* and *b'*, are connected by the contact-ring, *i*, carried on the plug, whereby all the test-thimbles, *g*, belonging to that line are connected directly to earth through a short circuit, and therefore no difference of potential exists between them and the earth. Thus, when a test is made on a spring-jack of that line there will be a flow of current through the operator's receiver to ground, and a click will be the result.

Fig. 207 is stripped of all unnecessary detail in order to enable the general underlying principles to be more readily grasped. In Fig. 209 the same system is shown more in detail as to circuits, connections, and apparatus. Fig. 207 will give the reader a better understanding of how the jacks are grouped into sections, and of the relative location of the parts, while Fig. 209 will enable a better study of the circuits.

In this figure two subscribers, 1 and 2, are shown connected by line wires, *k* and *k'*, with the exchange. Jacks *l* and *l'*, at sections 1 and 2 of the board, are shown in connection with the line leading from station 1. Jacks l^2 and l^3 are shown connected at the same sections with the line leading from station 2. Across the line leading from station 1 is bridged the line coil, *n'*, of the annunciator, this annunciator being placed at section 2 of the board. The line coil of the annunciator of line 2 is similarly bridged across the two sides of the line, and is placed at section 1 of the board. A little study will show that the circuit of the line wires and the test wires are the same in Figs. 207 and 209, although represented in an entirely different manner. Like letters correspond to like parts in these two figures.

Two pairs of connecting plugs and their accessory appliances are shown complete, one at each section of the switch-board. The tips of the two plugs of a pair are connected together by one of the conductors, *q*, of the flexible cord, and the sleeves, *j*, are likewise connected by the conductor, *q'*, of the same cord. Included in circuit between the two plugs of a pair are two calling keys, *r* and *r'*, each adapted to disconnect both contact-pieces of one of the plugs from those of the other, and to connect them to the anvils, *s* and *s'*, which form the terminals of the calling generator, *P. G.*

A listening key, *u*, is provided for each cord circuit, having contact points or anvils connected with the conductors, *q* and *q'*, as shown, and having its contact-spring, *u'* and u^2, connected with the terminals of the operator's telephone, *w*. When the plunger of the listening key, *u*, is allowed to rise, the operator's telephone is connected in a bridge across the two sides of the cord circuit, as is shown at section 1. A wire is connected from the middle point of the coil of the operator's telephone receiver to ground through the battery, *o*, so that when a test is made of any line, as was described above, a circuit will be completed from the contact-thimble, *g*, of the jack through the tip strand, *q*, of the cord circuit, and thence through one-half of the operator's receiver coil to the ground. As this wire leads from the center part of the operator's receiver coil, it may be left connected permanently, as it does not desroy the balance of the line.

A clearing-out annunciator, *x*, similar in construction to the line annunciator, has its high-resistance coil, x', bridged permanently across the two sides of each cord circuit. The restoring coil, x^2, is connected in a normally open local circuit, including the battery, *o*, and terminating in the ground on one side, and in a spring, u^3, on the other. This spring, u^3, is arranged in conjunction with the listening key in such a manner that when the key is raised the spring will make contact with a grounded anvil, *d*. Thus, whenever the operator listens in on any cord circuit she at the same time restores the clearing-out drop if it happens to be down.

In order to give a clearer understanding of the system so far described, it will be well to follow the operation in connecting one subscriber with another. Suppose Subscriber 1 desires connection with Subscriber 2. He operates his generator, *i*, and the current therefore passes over the line wires, *k* k', and through the coil, n', at section 2 of the board. The operator, noticing this signal, inserts plug, *p*, into jack, l'. This completes the circuit from ground, through battery, *o*, coil, n^2, of the line annunciator, thence to spring, b', through the ring, *i*, on the plug to spring, *b*, and to ground. The front armature of the annunciator is therefore attracted and the drop restored.

The operator then connects her telephone across the cord circuit by raising the key, *u*, and communicates with Subscriber No. 1, in order to ascertain his wishes. Having found that he desires a connection with Subscriber No. 2, she takes up plug, p', of the same pair and tests to find out whether line No. 2 is connected to at some other board. If it is busy a current will pass from battery, *o*, through one-half of the coil of her receiver, and one part of the secondary to the spring, u', in the listening key. From this spring it passes to the tip strand, *q*, of the cord circuit, to the tip, *h*, of the testing plug. As the test-thimble to which the plug is applied is grounded by the insertion of a plug at another board, the current will pass through it to ground. This will produce a click, which will indicate to her that the line is busy, and she will not complete the connection called for. If, however, she finds the line to be free she thrusts the plug entirely into the jack, in which position it is shown in the figure, and depresses the key, r', in order to throw current from generator, $P. G$, upon the line of Subscriber No. 2.

The two subscribers are now connected for conversation. When either rings off the current passes through the coil, x', bridged across the cord circuit, and actuates the clearing-out drop. The operator, noticing this, again listens in, by raising the key, u, in order to find out whether they are through talking, or whether one of them desires another connection. The act of listening in closes spring, u^3, against anvil, d, and thus restores the shutter of the clearing-out drop. If the subscribers have finished talking, the plugs are removed and placed in their normal resting place.

If, while subscribers 1 and 2 were connected together at section 2, as above described, someone at section 1 had desired connection with, say, line No. 2, the operator at section 1, in applying the tip of her plug, p^3, to the test-thimble, g, as shown, would receive a click in her receiver for the reason, as pointed out above, that contact, g, is connected to the ground by a short circuit by the plug inserted in jack, l^3. No difference of potential would, therefore, exist between thimble, g, and the ground, and hence a current from the battery, o, would pass through the telephone of the operator making the test.

Success in practical telephone working can be attained only by the greatest attention to matters of detail. Nowhere is this fact better illustrated than in the design of the various parts which go to make up a multiple board. In the construction of large boards of this type, the possible capacity of the board is limited by the number of spring-jacks that can be placed within the reach of a single operator. It is evident, therefore, that space must be economized to the last degree, and yet the jacks must be substantial, in order to resist the wear and tear of years of service; must be made easily removable so as to be accessible for repairs; must perform their electrical functions with absolute certainty, and at the same time be so arranged as to facilitate the orderly and systematic connection of the wires leading from the line cables.

Moreover, when it is considered that single multiple boards often contain many hundred thousand spring-jacks, it may be easily realized that the cost of producing these jacks must be seriously considered. It is well to state here, however, that any economy in the construction of a switch-board that will tend to decrease its durability and reliability of action is poor economy indeed.

As an illustration of the highest development attained in spring-jack construction during the period when the magneto branch-terminal multiple board was in greatest use, the spring jack used in that board will be described. The jacks were mounted in strips of twenty and so arranged that each strip could be removed from the

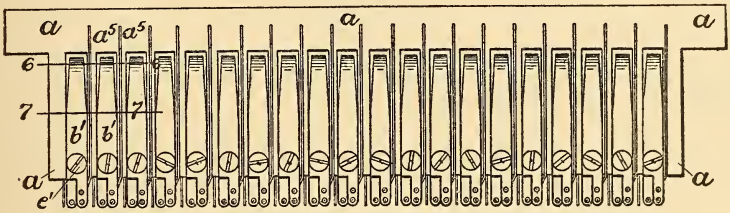


FIG. 210.—PLAN VIEW OF MULTIPLE JACK STRIP.

board by the removal of two screws which bound it firmly to the framework. Figs. 210 to 213, inclusive, show the details of the construction of one of these jack strips.

The hard rubber strip, *a*, forms the framework for each strip of twenty jacks. The projections at its ends provide for attachment to the switch-board. In this strip are milled, on its upper side, the transverse grooves, a' a', and on its lower side similar grooves, a^2 a^2; these being best seen in the right-hand portion of Fig. 213.

Holes are drilled from the front of the strip, one perforation to

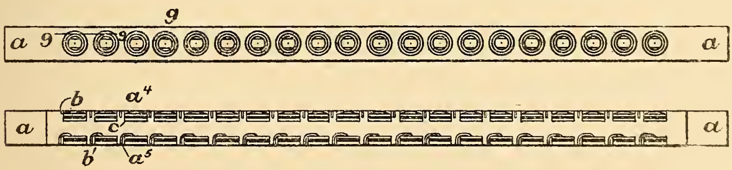


FIG. 211.—FRONT AND REAR VIEWS OF MULTIPLE JACK STRIP.

each pair of grooves, each hole having its axis centrally located and parallel with respect to the grooves. A small portion of the hard rubber is removed from between the grooves so as to leave a rectangular opening, a^6, as shown in Figs. 212 and 213, through the strip connecting the two grooves at those ends which are nearer the front of the jack. In the grooves, a', upon the upper surface of the rubber strip are mounted springs *b* and *c*. The spring, *b*, is the longer of the two, so that its curved extremity is presented close to the end of the perforation through the front portion of the strip, *a*. The springs are insulated from each other by a strip or tongue, *d*, of hard rubber, thin and flexible enough not to prevent the flection of the two springs. In the under groove, a^2, is mounted another spring *b'* similar to spring *b*, and of equal length.

The three springs, *b*, *c*, and *b'*, are firmly secured to the strip *a*, by a bolt *e*, passing through them and the body of the strip, *a*. The bolt is insulated from the springs, *b'*, and *c*, by rubber washings and bushings. In the perforations, a^3, in front of the strip, are inserted short tubes, *f*, of brass. Each tube or thimble, *f*, is provided with a shoulder, which bears against a corresponding ledge in the perforation, a^2, so as to prevent the tube from being thrust toward the rear of the jack by the insertion of the plugs. The thimble, *f*, is provided with an extension, *f'*, to afford electrical connection with it from the rear of the jack. This strip, *f'*, extends through an oblique

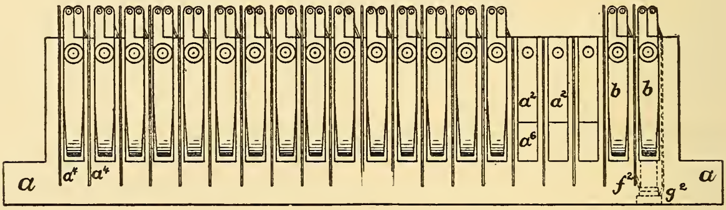


FIG. 212.—BOTTOM VIEW OF MULTIPLE JACK STRIP.

duct, f^2—shown in dotted lines in Fig. 212—and thence through a transverse slot or saw-cut, a^4, to the rear of the strip.

In front of the thimbles, *f*, in the perforations, a^3, are placed the test-rings, very short tubes of brass, *g*. These are forced into place against other ledges in the perforation. The ring, *g*, is also provided with an extension, *g'*, projecting to the rear of the strip of spring-jacks. These extensions, *g*, are of wire and pass through another duct, g^2, in the front portion of the strip, *a*, into a saw-cut, a^5, thence to the rear of the strip, where they are connected with the spring, *b*.

The springs in these jacks are of hard German silver, which has been found the most desirable material for this and similar purposes.

It will thus be seen that each of these jacks had five contacts, three springs, and two sleeves or thimbles. Each thimble contact was formed of two pieces, the thimble proper, and its rearwardly extending wire. These jacks, on account of their complexity, could not be made small enough to be mounted on less than half-inch centers, and therefore the limit of the capacity of multiple boards of this type was approximately 6000 lines. One of the greatest problems in switch-board engineering has been the production of systems that would allow of a spring-jack of much simpler construction.

A section of one of the plugs used with these jacks is shown in

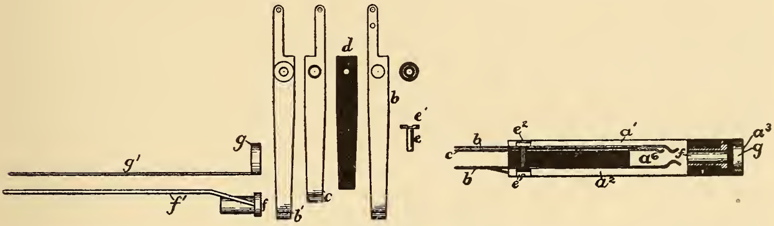


FIG. 213.—DETAILS OF JACK.

Fig. 214. The tip, *h*, of brass is secured by the rod, *h'*, to the block, h^2, also of brass. Insulated from the tip portion by a rubber bushing is the sleeve contact, h^4, of the plug, which projects rearwardly and forms the main body of the plug. Over this portion is slipped a shell, h^6, of hard rubber or fiber, which forms a handle for the plug. Between the tip and sleeve, and insulated from each, is the ring, h^7, which, as was described before, is for short-circuiting the springs, *b* and *b'*, when the plug is inserted in the jack.

Screw connectors, h^3 and h^5, form convenient terminals for attaching the strands of the cord to the tip and sleeve, respectively, of the plug. These connectors are always readily accessible for inspection or repair by the removal of the sleeve, h^6.

Typical of the highest development of the magneto mutiple switch-board is the board used at Paris, France, installed by the

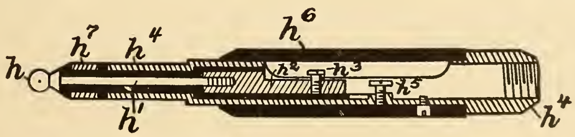


FIG. 214.—DETAILS OF PLUG.

Western Electric Company. This is not only the largest magneto multiple board ever installed, but is one of the largest single multiple boards of any kind in the world. A front view of a portion of this switch-board is shown in Fig. 215, this view comprising a little over one section. Immediately above the key-shelf are the answering jacks, above which are the trunk jacks in which lines leading to other exchanges terminate. Above these, and occupying by far the greater portion of the jack space, are found the multiple jacks.

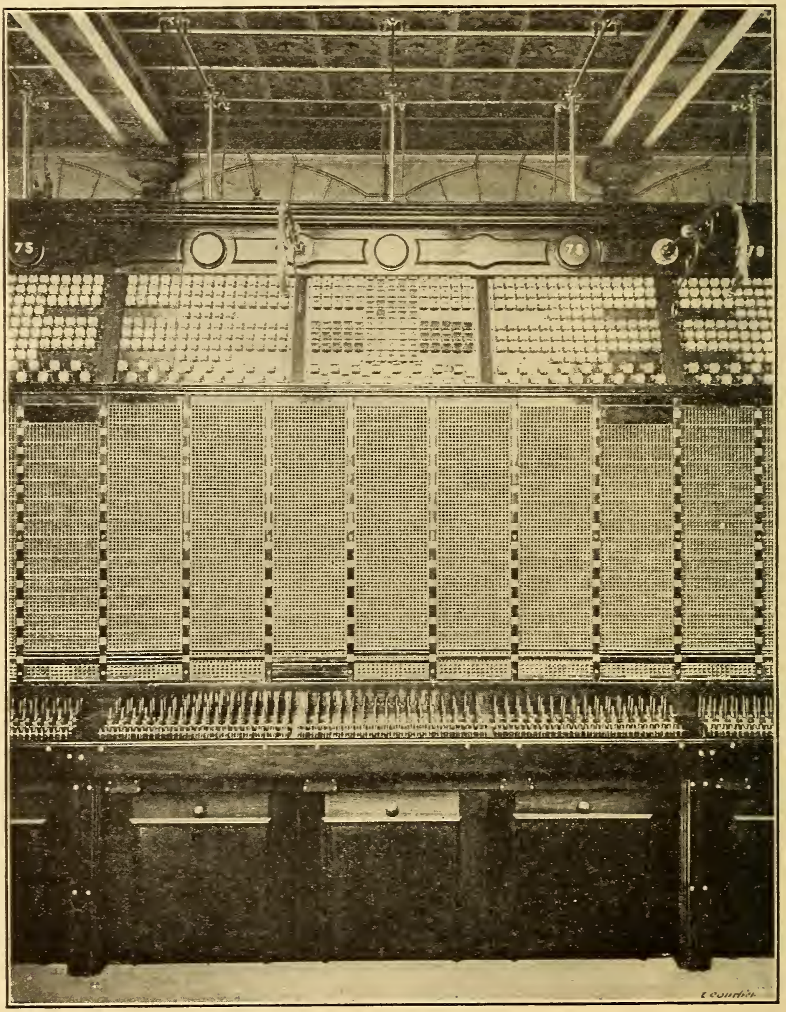


FIG. 215.—FRONT VIEW OF PARIS SWITCH-BOARD SECTION.

Above the multiple jacks are shown the line and clearing-out signals. Those at the top of each space are the line drops, the clearing-out drops occupying the two lower rows. All drops are of the electrically self-restoring type shown in Fig. 178. The drop spaces at the top of the board are divided in accordance with the operators' positions, there being three such positions to each section. The key shelves are also divided in the same manner. The face

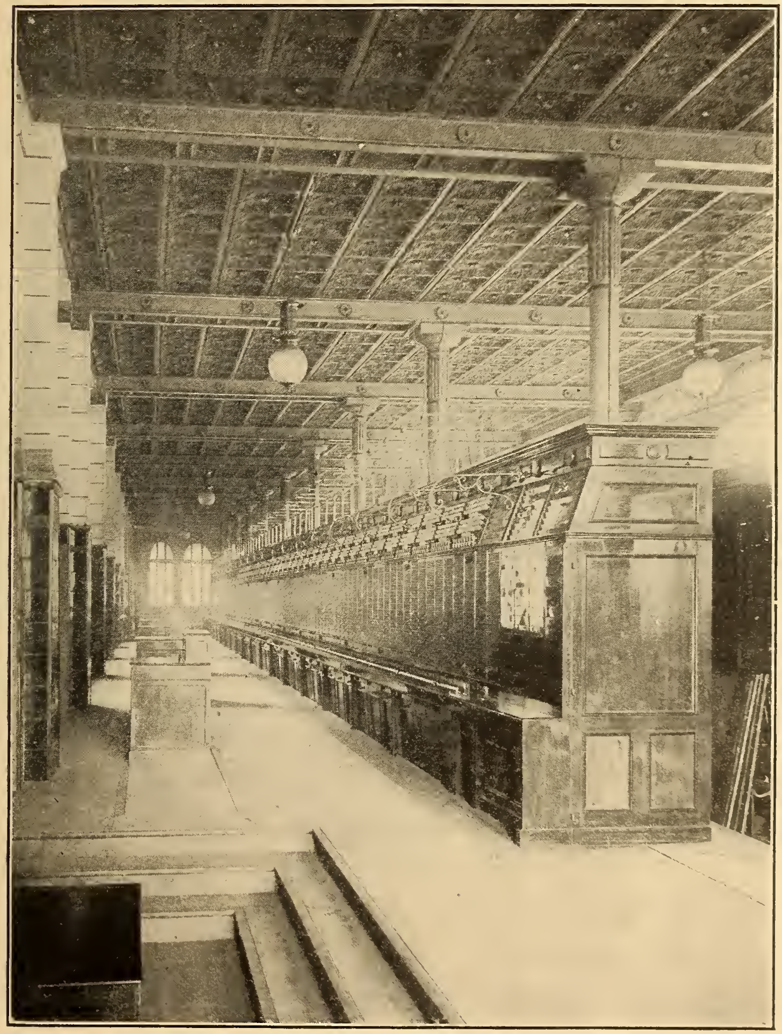


FIG. 216.—GENERAL VIEW OF PARIS SWITCH-BOARD.

of the board, however, which includes the jack, is divided into seven panels for each section. The horizontal white lines extending through the face of the board are dividing lines between each bank of 100 jacks, there being 5 strips of 20 each in each panel between each two horizontal white lines. Each jack panel, except the seventh, has thirteen banks of jacks, the seventh having twelve. There are thus ninety banks, or 9000 multiple jacks in each section. It is thought that practice has shown that this section is too large, and that with the size of jack used this number (9000) cannot be well handled.

The disadvantage of having the answering jack separate from the calling signal is particularly marked in the case of this board. The operator has first to look up to the top of the section and fix the number of the signal displayed, in her mind, and then look down to pick out the corresponding answering jack in which to insert the plug. In such large multiple boards the placing of the line signal so far above the normal range of vision of the operator renders necessary an unnatural position of the head of the operator, with a consequent strain upon her nerves.

In Fig. 216 is shown a view of one-half of this great Paris switchboard, the sections being arranged in two rows, of which one only is here shown. It has an ultimate capacity of 9100 lines.

CHAPTER XV.

TRANSFER SYSTEMS.

No person of intelligence can visit a modern central office containing a large multiple switch-board, without being deeply impressed by a certain magnificence of the equipment, as a whole, as well as by the perfection of the system in its minutest detail. If he is conversant with telephone matters, he must also be impressed by the fact that while the multiple switch-board gives the subscriber what he needs—quick, reliable service—it gives it only at a great initial cost to the operating company. There is no question that at the present stage of telephonic development the multiple-board systems represent the highest type of central-office equipment, and while one form or another of them is in use in nearly all the really large exchanges the world over, there are a few notable exceptions. On account of the apparent success of some of these, and of the expense necessarily entailed in the installation of large multiple boards, it is not to be wondered at that telephone men are constantly seeking a system which, while it may in some degree embody the plan of multiple jacks, will mainly depend for its action on other ideas.

In the multiple switch-board one part of the cost of installation increases as the the square of the number of the subscribers. This is clearly an objection which increases in seriousness as the exchange grows.

The enormous multiplying of jacks in the multiple system is for one purpose—to enable each operator to have within her reach a terminal of every line in the exchange, to the end that she may be able herself to complete any connection called for over any one of the lines under her immediate supervision: that is, that she may be able to answer any call arising at her section, and, without requiring the aid of any other operator, make the connection called for. In other words, in the switch-board for 24,000 lines, cited on page ? , 1,944,000 spring-jacks would be used, instead of only 24,000, in order to accomplish this result. This appears to be a great cost to pay for such a simple result, but up to the present date practical experience has proved that the end justifies the means.

When two or more operators instead of one must handle the connections between two subscribers, as must always be the case where the multiple system is not used, the liability of error is about doubled, and the fact that the attention of both is simultaneously required on the same connection, necessarily slows down the service. The saving in cost over the multiple system is not as great as it appears at first, for in order to make the co-operation of the operators as effective as possible, a complicated system of automatic signals must be installed, which adds greatly to the complexity of the apparatus and circuits. It is a fact, however, that many medium-sized exchanges, and one large one, are being operated with apparent success without the use of multiple boards.

Systems depending for their operation on the transfer of a connection from one portion of a board to another are termed transfer systems, and one of the most successful of these is the so-called "express system" of Messrs. Sabin & Hampton of San Francisco. This system has been used for several years in San Francisco, and has long been cited as having demonstrated its capability of handling with success an exchange having over 6000 lines, and several times that many subscribers.

The system is so radically different from anything so far described that its consideration in detail should be a matter of interest. One striking feature in it is that no magneto generators are used at the subscriber's station, the calling being accomplished automatically by the raising of the subscriber's receiver from its hook. The doing away of the magneto, however, is not an essential feature of this express system, but is one of the advantages incident to its use.

Briefly stated, the underlying ideas of the express system are as follows: The boards are divided into two classes, termed for convenience "A" and "B." Similarly, the operators at the respective boards are termed "A" operators and "B" operators. There is but one line jack for each line in the exchange, and these are divided into groups of one hundred each and are placed only at the "B" board. At the "A" boards, which are entirely removed from the "B" boards (they may even be in another office), are placed plugs which form the terminals of trunk lines leading *from* the various "B" boards; and also jacks forming the terminals of other trunk lines leading *to* the "B" boards.

The trunk lines terminating in plugs at the "A" boards also terminate in plugs at the "B" boards. These are termed "A" trunk lines. The trunks terminating in jacks on the "A" boards terminate in plugs on the "B" boards, and are termed "B" trunk lines. When a call is received it attracts the attention of one of the "B" operators by displaying an annunciator in the ordinary manner. The "B" operator at whose board the call is received pays no further attention to it than to insert one of the plugs of an "A" trunk into the jack of that line, thus transferring the call to an "A" operator, who answers it with a listening key in the ordinary manner. No means whatever are provided for a "B" operator to listen in on a subscriber's circuit, this duty being confined solely to the "A" operators.

The "A" operator, having learned that the subscriber calling desires to be connected with a certain other subscriber, conveys this information, by means of a special order wire, to the "B" operator at whose board the called-for subscriber's line terminates. The "B" operator then tells the "A" operator what "B" trunk line to use, and the "A" operator then inserts the plug of the "A" trunk line used into the jack of the "B" trunk line thus designated. This brings the connection as far as the board of the second "B" operator; that is, the "B" operator at whose board the called-for subscriber's line terminates. This operator, in order to complete the connection, simply inserts the plug of the "B" trunk used into the jack of the called-for subscriber's line, and presses a ringing key in order to call that subscriber.

It will be seen that the connection has really been handled by three different operators, but that the first of these operators does no more than to insert a plug into a jack, giving the matter no further attention.

All signaling between the subscribers and the operators and between the various operators, whether it be for establishing or clearing out a connection, is entirely automatic, and therefore not dependent upon the volition of the parties concerned.

Fig. 217 shows the arrangement of the circuits at the subscribers' stations, and also the arrangement of the spring-jacks and annunciators on the "B" boards. One side of the line wire at the subscriber's station is normally grounded through the polarized ringer, *R*. This means that calling a subscriber from the central office must be accomplished over one limb of the line wire and ground, instead of over a metallic circuit, as in case of talking and other signaling in this system. The other circuits and apparatus at the subscriber's station are of the ordinary arrangement and type, the only difference being that the magneto-generator is omitted entirely The line wires of each subscriber terminate in two springs, *a* and *b*, of their spring-jack, *J*. These springs normally rest on two anvils, *c* and *d*, one of which connects through an annunciator, *e*, with a heavy wire leading to one pole of the calling battery, and the other of which leads to a similar wire connecting with the other pole of this battery.

This annunciator, *e*, has a shutter which is simply lifted by the attraction of the armature, and again dropped into its normal posi-

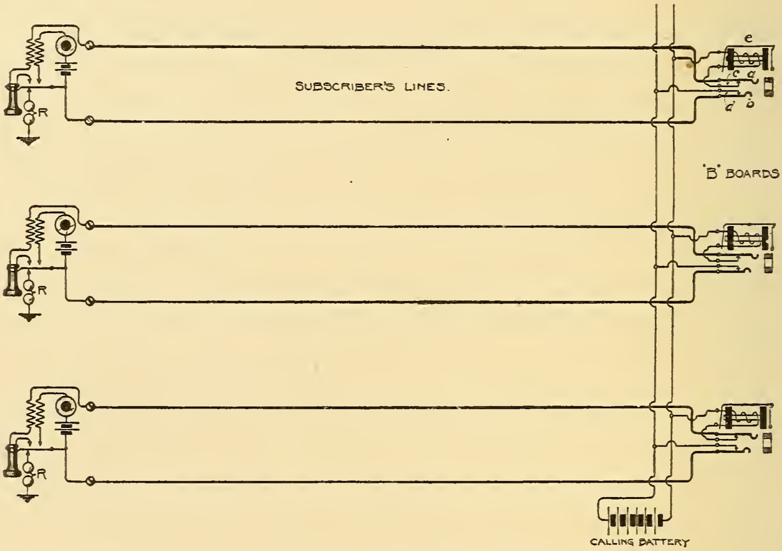


FIG. 217.—SUBSCRIBERS' CIRCUITS—EXPRESS SYSTEM.

tion when the armature is released. It is, therefore, the simplest type of self-restoring drop. The circuit of the call-battery is normally open only at the subscriber's station. It is automatically closed through the receiver and secondary winding of the induction coil at the subscriber's station whenever the subscriber removes his receiver from its hook. This allows enough current from the calling battery to pass through the drop, *e*, to raise its shutter, and thus attract the attention of the "B" operator at that board.

The shutter remains raised until the operator inserts the plug of one of the "A" trunk lines in order to transfer the call to the "A" operator. The insertion of this plug, however, lifts the springs, *a* and *b*, from the anvils, *c* and *d*, thus cutting off the battery and allowing the shutter of the annunciator, *e*, to drop to its normal position, and the "B" operator therefore pays no more attention to it.

A single battery is made to serve for actuating the signals of every line in the exchange, no matter how great their number may be. Storage cells are used for this purpose, ten cells being connected in series so as to give a pressure of about twenty volts. It is said that the average flow of current from this battery is about one and one-half amperes, and never exceeds two amperes, in the San Francisco exchange of approximately 6000 subscribers. It will be thus seen that the cost of current supply for these batteries is trifling.

Another good feature of this arrangement is that, should a "B" operator by mistake withdraw a plug from a jack before a subscriber has finished talking,—that is, before he has hung up his receiver,—she will be at once notified of her mistake by the display of a signal belonging to that line.

In Fig. 218 is shown a simplified diagram of the express system. At the bottom and top of this figure are shown the subscribers' lines, leading in each case from the subscriber's telephone apparatus to the drop and jack at the central office. This part of the apparatus is the same as that shown in Fig. 217, but in this figure the details of the local circuit at the subscribers' stations have been omitted for the sake of clearness.

The jacks and drops belonging to these lines are, as has already been stated, stationed at the "B" boards of the exchange. The subscriber's indicator battery is represented at *S I B* and the indicators at *I*. Leading from the section of the "B" board shown at the top of the figure is a trunk line leading to a plug on the second section on the "A" boards. It will be noticed that this trunk line terminates in a plug at each end, and is termed the "A" trunk. An intermediate jack and plug are shown in the circuit on this "A" trunk, but these at present need not be considered. Suffice it to say that the plug at the "B" board is connected by a metallic circuit to the plug at the second section of the "A" board. Leading from a certain jack on the second section of the "A" board is a trunk line extending to a plug on another section of the "B" boards. This is termed a "B" trunk. Only one "A" trunk and one "B" trunk are shown, but it must be remembered that a number of "A" trunks lead from each of the "B" boards to the "A" boards, and that from the "A" boards a number of "B" trunks lead back to each of the "B" boards.

When a subscriber, as for instance the one shown at the top of the figure, removes his receiver from its hook, his indicator, *I*, is displaced automatically, and the operator at the particular "B" board at which this indicator is located extends the circuit of his line to one of the "A" boards over an "A" trunk. This she does by inserting the plug of an "A" trunk into the jack of the calling subscriber.

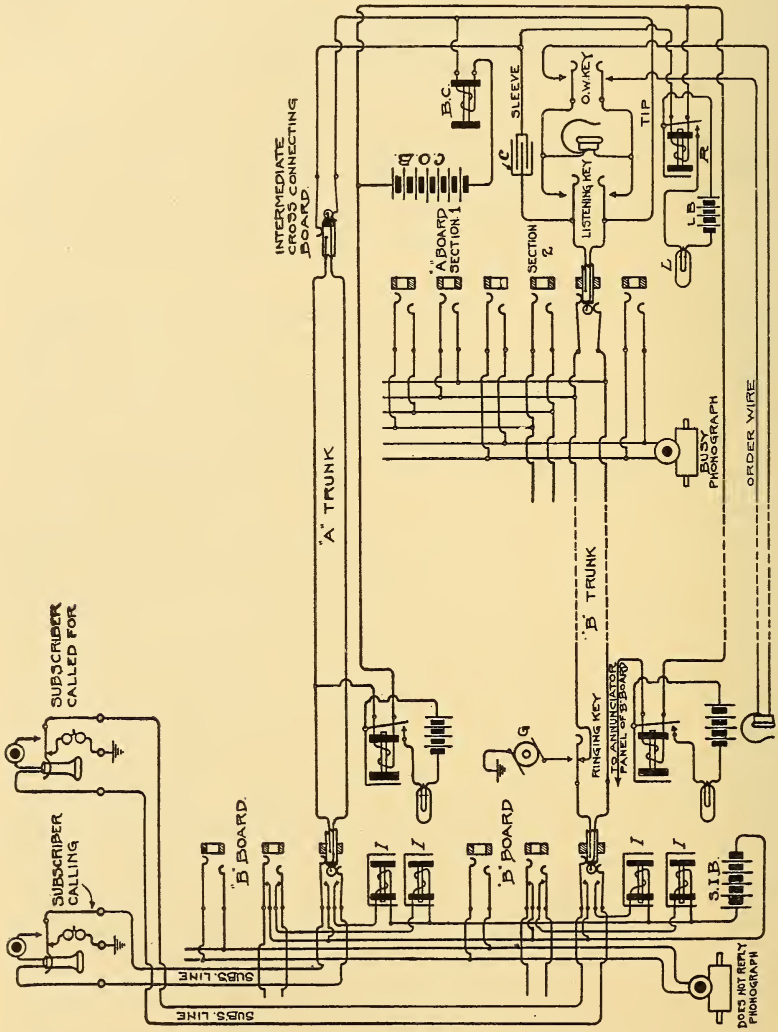


FIG. 218.—SIMPLIFIED DIAGRAM—EXPRESS SYSTEM.

The operator at the "A" board, having learned the desire of the calling subscriber, extends the circuit to that subscriber's line by means of the "B" trunk, still further on to the particular "B" board at which the jack of the called subscriber is placed. This the

"A" operator does by inserting the plug of the "A" trunk used into the jack of a "B" trunk at her board. The "B" operator at whose board the calling subscriber's jack is placed then completes the connection between the two subscribers by inserting the plug of the "B" trunk used into the jack of the calling subscriber's line. The two subscribers' lines are shown connected in Fig. 218 by the process and over the circuits just described.

In order to facilitate matters it is evidently necessary that a most complete set of signals must be provided between operators. The first in this series of signaling operations is to notify the "A" operator that her attention is desired on a certain "A" trunk. This must always occur just after the "B" operator has inserted one of the "A" trunk plugs into the jack of the calling subscriber's line. It will be noticed in Fig. 218 that the relay, *R*, operating signal lamp, *L*, is bridged across the tip and sleeve strands of the "A" trunk circuit, and this bridge may be traced from the tip strand through the balance coil, *B C*, thence through the clearing-out indicator battery, *C O B*, to the battery wire, thence through the coil of the relay at the "A" board, and thence to the sleeve strand of the "A" trunk. Remembering that the calling subscriber at the top of the figure has removed his receiver from its hook, then the insertion of the plug of the "A" trunk will restore the line drop, *I*, and at the same time will close the circuit from the clearing-out indicator battery, *C O B*, and the relay, *R*, through the subscriber's line and telephone instrument. This will operate the relay and cause it to close the circuit of the signal lamp, *L*, thus calling the attention of the "A" operator to the fact that an unanswered call is upon the trunk line to which that lamp belongs.

The apparatus of the "A" operator is shown more clearly in Fig. 219. The sleeve and tip strands of the "A" trunk are shown at the extreme left of this figure. When the armature of the relay, *R*, is attracted, as described above, the circuit from the local battery and white lamp is completed at the point, *b*, of the relay. It will be noticed that this local circuit extends through two of the springs, *e* and *f*, normally closed, on the listening key of the "A" operator, and also through a pair of contacts, *l* and *c*, held closed by the weight of the plug of the "A" trunk in its socket. The white lamp will therefore remain lighted until one of the following three things happens: until the operator listens in, which causes the local circuit to break at the listening key; or until she removes the plug of that trunk line from its socket, which would break the local circuit at the point, *c*; or until the calling subscriber hangs up his receiver, which would cause the relay to let go of its armature, and thus break the circuit at point *b*. The white lamp remains lighted, therefore, as long as the call on its "A" trunk is unattended to.

The first act of the "A" operator on seeing this light is to throw her lever corresponding to that light into its horizontal position, thus connecting her telephone to the terminals of the "A" trunk in the usual manner. This enables the "A" operator to communicate with the calling subscriber in the ordinary manner. It should

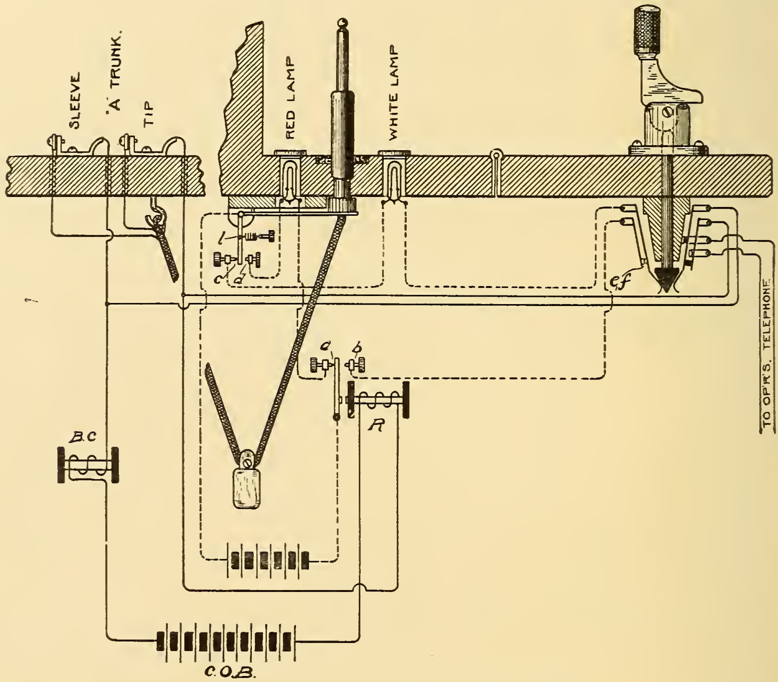


FIG. 219.—TABLE OF "A" BOARD.

be noted that these keys on the "A" operator's board are the only means afforded to any operators for communicating with subscribers. The operation of this key breaks the circuit of the white lamp at the points, *c f*. As soon as the listening key is thrown again into its normal position the white lamp is again lighted, thus calling the operator's attention to the plug to be used in making the connection.

This precaution is a wise one, for before making the next move in the connection the "A" operator must communicate with the

"B" operator at whose board the called-for subscriber's line terminates. The "A" operator does this by depressing her order-wire key, shown in Fig. 218, but omitted from Fig. 219, which act connects the "A" operator's telephone directly with the telephone set of the outgoing "B" operator. The "A" operator then tells the "B" operator the number of the line with which connection is desired, and the "B" operator in return tells the "A" operator the number of the trunk line she is to use in making the connection.

It will be noticed that the trunk jacks of the "B" trunks are in reality arranged on the plan of the multiple board. This is for the purpose of placing within the reach of every "A" operator a jack belonging to every "B" trunk line. No test system, however, is required on these jacks, as an "A" operator always first learns from an outgoing "B" operator which "B" trunk to use, and of course a "B" operator would never designate any trunk which was already in use, or "busy."

We have now carried the connection, or extended the circuit of the calling subscriber's line, as far as the trunk line plug at the outgoing "B" board. The outgoing "B" operator then completes the connection by inserting this plug into the jack of the called subscriber. The "B" operator then depresses her ringing key, shown in simplified form in Fig. 218, which sends calling current from the generator, *G*, over the sleeve strand of the plug cord, thence to line and to ground through the polarized call-bell at the subscriber's station.

The next feature to consider is that of the automatic clearing-out signals. As the connection between the two subscribers is made by three operators, it is evident that three distinct clearing-out signals should be given, one at each of the boards of the operators who help establish the connection. Turning again to Fig. 219, it will be seen that the raising of the "A" trunk plug from its socket changed the circuit of the local battery from the white lamp to the red lamp, by moving the selecting lever, *l*, from the point, *c*, to the point, *d*. Remembering now that as long as the calling subscriber's receiver is off its hook, the circuit from the clearing indicator battery is closed through the relay, *R*, at the "A" board, thus attracting its armature; as soon, therefore, as the calling subscriber finishes his conversation, he hangs up his receiver, and thereby breaks the circuit through the relay at the "A" board, thus closing the circuit through the red lamp. This lamp will therefore be lighted as a notification to the "A" operator that disconnection on that trunk is desired. The replacing of the plug in its socket opens the circuit of the red lamp at the point, *d*, thus extinguishing the lamp. This apparatus at the "A" board is very ingenious, and deserves special attention. It should be noticed that should an operator by mistake remove one of the "A" plugs, and replace it in its socket before the subscriber connected had hung up his receiver, the white lamp

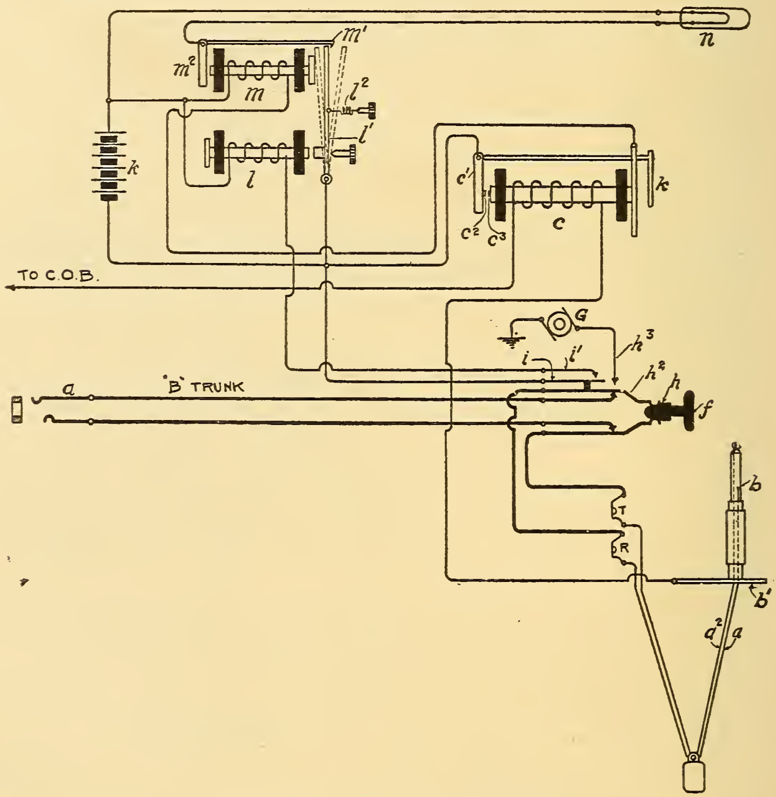


FIG. 220.—TABLE OF "B" BOARD.

would be relighted, thus calling the attention of the operator to the error.

The clearing-out signal is given to the incoming "B" operator in much the same way as that on the "A" board, the clearing indicator, or relay, on the "A" trunk of the "B" board being wired in multiple with the relay on the "A" board.

The clearing-out signal on the outgoing "B" board is accomplished by much more complicated means, and will be explained by reference to Fig. 220. In this figure the ringing key, *f*, is shown in more detail than in Fig. 218. The "B" trunk line jack on the "A" board is represented by *a*. In the normal position of the key the two strands of the "B" trunk are connected to the tip and sleeve of the corresponding plug on the outgoing "B" board. When, however, the key is depressed, the sleeve strand of the cord is connected with the calling generator, the other terminal of which is grounded. When the operator depresses this ringing key, a secondary pair of contacts, $i\ i^1$, are closed, thus actuating the lower magnet, *l*, of the compound relay, and causing it to attract its armature, l^1. When the operator allows the key, *f*, to rise, the armature *l*, falls back, but is caught by the hook, m^1, of the upper coil, *m*, of the relay. The hook, m^1, and the tip of the armature are platinum-pointed, and their contact causes the signal lamp, *n*, to be lighted. This lamp remains burning until the called subscriber takes his telephone off the hook, which act closes the circuit through the combined clearing-out relay and signal, *c*, in exactly the same manner as the relays on the incoming "A" trunk line were operated. The operation of this relay therefore closes a circuit at the points, $c^2\ c^3$, through the upper magnet, *m*, causing it to raise the hook, m^1, and allow the armature, l^1, to drop back. This extinguishes the lamp, *n*, and shows the operator that the subscriber has responded. The armature, c^1, of the relay, *c*, remains attracted until the called subscriber hangs up his receiver, which de-energizes the magnet, *c*, and allows the signal carried by the armature to resume its normal position. This is the clearing-out signal for the outgoing "B" operator, and she accordingly pulls out the plug.

To review the action of the indicators at the outgoing "B" board, the releasing of the key for transmitting a calling signal to the subscriber lights the lamp, *n*, and shows the operator that this part of her work has been attended to. The response of the subscriber is indicated by the going out of the lamp, and by the raising of the signal, *k*. The clearing-out signal is given by the lowering of the signal, *k*.

We have now traced through the operation of all the signals between the subscribers and the operators, and between the operators themselves, which were necessary to establish a connection between two subscribers; and also the subsequent signals between the subscribers and the operators, indicating that a disconnection is desired. The striking feature of all this elaborate system of signaling is that each signal is automatically given without the volition of the operator or subscriber, inasmuch as it is brought about by some action necessary in the actual connection or disconnection.

In order to reduce the work of the operators to the last degree, two phonographs are placed in connection with the exchange, one of which is constantly and politely repeating the sentence, "Busy. Please call again," while the other repeats with equal regularity, "Subscriber called for does not reply." Each of these phonographs speaks to a transmitter arranged in connection with an induction coil and battery in the ordinary manner. The terminals of the secondary of the induction coil of the "busy" phonograph terminate in a jack on each section of the "A" boards. In like manner the "does not reply" phonograph is connected with a jack on each section of the "B" boards. When, therefore, an "A" operator learns that a line called for is busy, she inserts the plug of the "A" trunk to which the calling subscriber is connected into the phonograph jack, and the familiar but disappointing message, "Busy. Please call again," is automatically conveyed to the calling subscriber.

In a similar manner the outgoing "B" operator may inform the calling subscriber that the subscriber called for does not respond.

The writer is indebted to an able article by Mr. George P. Low, in the *Electrical Journal*, for much information concerning this very interesting exchange system.

Perhaps the best argument that can be given for the multiple board, as against various transfer systems, is that this system is soon to be replaced in San Francisco by the modern multiple switch-board system. It was tried with modifications by the Bell company in Chicago. The result of this Chicago trial, conducted with great care in two offices in actual service, was to establish the great value of automatic signals but not to establish that the express form of divided switch-board was as good and as economical as the multiple form. This led to the design of the central battery multiple system.

Fig. 221 is a schematic representation of the system used several years ago, in the larger exchanges installed by the Western Telephone Construction Company, of Chicago. This system proved fairly successful for exchanges up to fifteen hundred subscribers, although with a larger number certain difficulties were met in the disposal of the transfer plugs. In this figure 1, 2, 3, 4, etc., represent different sections of the board, each section having one hundred combined drops and jacks of the type shown in Figs. 180 and 181, together with a complete operator's equipment. One answering plug, *A*, together with one calling plug, *B*, is shown at each section. These are connected together in pairs through clearing-out drops, *O*, by ordinary flexible cords which contain the necessary switching apparatus for enabling an operator to listen and to ring out over either cord as desired. Connected with each of these sets of plugs is a trunk line to which is connected at every third section a transfer plug, *C*, as shown. Thus, a pair of plugs, *A* and *B*, shown at section 1, is connected by means of a trunk line to a transfer plug at section 4, another at section 7, another at section 10, and so on. A careful consideration of this figure will show that the same is true for each pair of plugs, *A* and *B*, at the other boards. Fig. 222 shows in

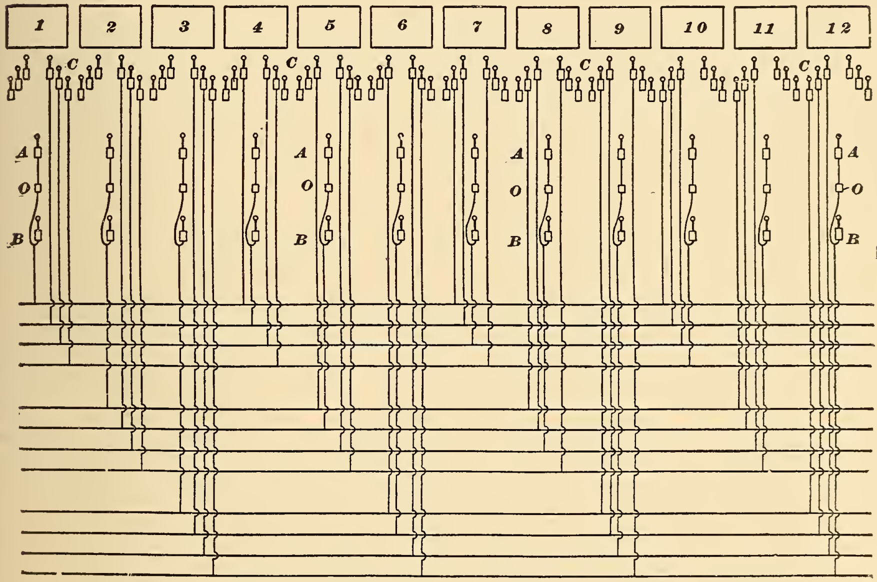


FIG. 221.—GENERAL SCHEME OF WESTERN TRANSFER SYSTEM.

greater detail one pair of plugs, *A* and *B*, connected by a trunk line to the several transfer plugs according to this system. The plugs, *A* and *B*, are in this case at section 4, while the transfer plugs, *C, C, C*, are at sections 1, 7, and 10, or in other words, at every third section on each side of section 4. By throwing the lever, *L*, to the left, its two springs are connected with an operator's circuit through the secondary winding of the induction coil, as shown, while when the lever is thrown to the right the terminals of the generator, *G*, are connected with the plug circuit.

The system can now be more readily understood by describing its operation. If a subscriber whose line terminates in section 4 calls up, the call is answered by the operator at that board by inserting one of her plugs, *A*, the insertion of this plug restoring the shutter mechanically. The operator then throws the lever, *L*, to the left, connecting her telephone set, *E*, with the line of the subscriber calling. Having learned that a connection with, say, subscriber No. 1001 is desired, the operator at 4 depresses the key, *K*, which connects her telephone set with an order-wire circuit, *J*, terminating in the telephone set of the operator at section 10. The operator at section 4 is thus enabled to communicate with the operator at section 10 over this circuit, and the former informs the latter of the number desired, and of the particular transfer plug, *C*, she is to use in making this connection. The operator at section 10 then takes up

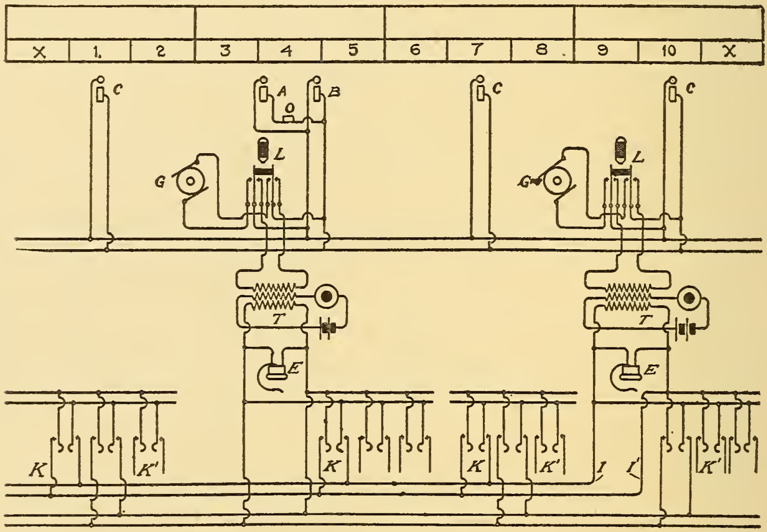


FIG. 222.—TRANSFER AND ORDER-WIRE CIRCUITS.

the plug, *C*, designated and inserts it into the jack of the called subscriber, the operator at section 4 meanwhile holding the lever, *L*, of the particular plugs used, into the ringing position. As soon as the connection is completed at section 10 the first operator is informed of the fact by the operation of a buzzer placed in the cord circuit, so that she knows that the signal has been properly transmitted to the line of the subscriber 1001. After the conversation is completed, one or both subscribers ring off, which throws the clearing-out drop, *O*, and informs the operator at section 4 that a disconnection is desired. She therefore removes her answering plug and places it in the socket, informing the operator at section 10 to do likewise.

It will be seen that, in addition to the transfer lines extending from the answering and calling plugs at each board to transfer plugs at each third board therefrom, a system of order-wire circuits is also provided, each circuit terminating in an operator's set at one board and connected with push-butttons at every third section therefrom, so that an operator is enabled to communicate only with those operators located at every third section from her own board. This peculiar arrangement serves several advantageous purposes, among which is the reduction of plugs necessary for the successful operation of the board, and also the reduction of the number of operators talking over any one instruction circuit. It moreover enables any operator to reach, by means of her own calling plug or transfer plug handled by another operator, any portion of the board. It has been shown how a connection is made between section 4 and some section at which one of the transfer plugs of that section is located. If, however, the subscriber on section 4 had called for a subscriber at section 9 the operator at 4 would have signaled the operator at 10, who would then have completed the connection, using transfer plug, *C,* with her left hand. If the called-for subscriber had been upon section 8, operator No. 4 would have signaled No. 7, who would have used a plug, *C,* at her section with her right hand to complete the connection. Ten pairs of calling and answering plugs are furnished for each section of 100 drops, each pair being connected by trunk line with transfer plugs distributed through the system as already described.

A system of lamp signals for facilitating the work upon these boards was devised and used in many of the later exchanges. In this a white light is so arranged in connection with the night-alarm circuit as to be illuminated, upon each board, whenever a drop is thrown. A similar lamp in series with this is also arranged to be displayed on the chief operator's table, thus serving as a telltale to call the attention of the chief whenever a drop remains unattended on any section. A colored lamp is arranged in connection with each set of transfer plugs and controlled by normally open contact points in the plug seats of the transfer plugs and normally closed contact points in the plug seats of the answering points. Two lamps are arranged in series in each circuit, one at the set of transfer plugs to which it belongs and the other at the set of answering plugs with which these transfer plugs communicate. Whenever an operator raises an answering plug in order to establish a connection the lamp circuit is opened at that point by the operation of the contacts in the plug seat. When another operator removes the transfer plug to complete the connection this same lamp circuit is closed at that point by the operation of the contacts in the transfer plug seat. When a clearing-out signal is received, and the operator removes the answering plug to take down the connection, the lamp circuit is closed at its only open point, which lights the lamp in front of each operator. This shows the transfer operator that a disconnection is desired, and also shows the answering operator that the disconnection has not yet been made. The cycle of events is completed when the transfer operator removes the transfer plug and replaces it in its seat, which act opens the lamp circuit at that point, thus putting out both lamps.

The switch-board of the Delmarvia Telephone Company at Wilmington, Del., is shown in Fig. 223. This board embodies all the features mentioned above and is representative of the highest development attained by the "multiple plug" transfer system.

What is known as the Cook-Beach transfer system was once used to a considerable extent by some of the Bell and Independent exchanges of medium size. The subscribers' lines terminate in drops and jacks on the various sections of the board, no multiple connection whatever being used between them. A set of transfer jacks is also provided on each section, these jacks being connected by trunk lines extending to transfer plugs located at the several sections. When a call is received at any section, the operator answers it by inserting one of her answering plugs into the corresponding jack. Having learned the number of the subscriber called for, she inserts the corresponding connecting plug into the transfer jack connected by a trunk line with a plug at the board where the line of the subscriber called for terminates. She then communicates by order wire with the operator at that board, who picks up the transfer plug designated and inserts it into the jack of the called subscriber. The connection between any two subscribers is thus made complete by the use of three plugs. This style of transfer system has proven its adaptability to service in magneto systems of medium size, where the number of calls per subscriber per day was not excessive.

The most notable success made in the handling of transfer systems in the Eastern portion of the United States has been made by the City Telephone Company of Grand Rapids, Mich. The system

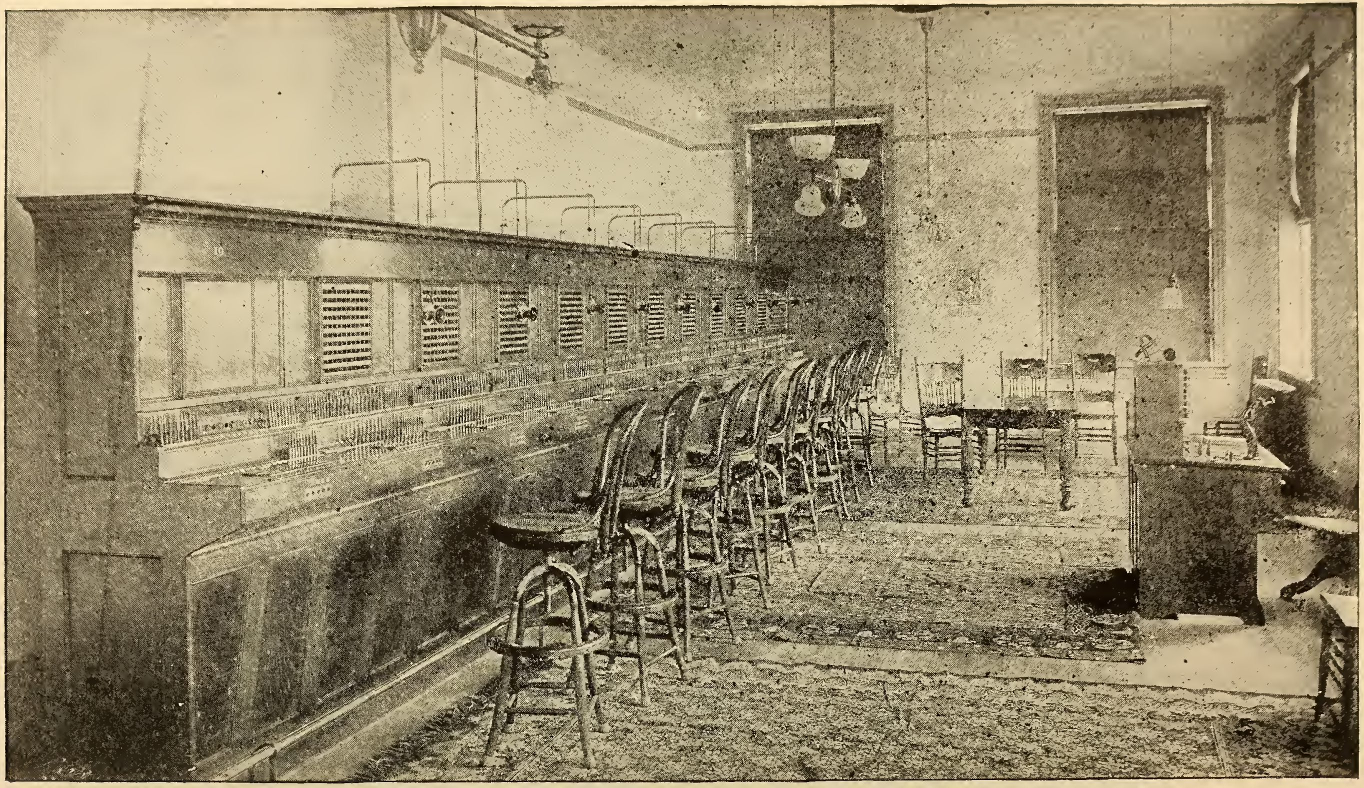


FIG. 223.—WESTERN SWITCHBOARD AT WILMINGTON, DEL.

used in the exchange of this company is a modification of the Cook-Beach system, being shown in some detail in Fig. 224.

It may be said that as applied to manual switch-boards the transfer system has been, and is being, gradually relegated to the past.

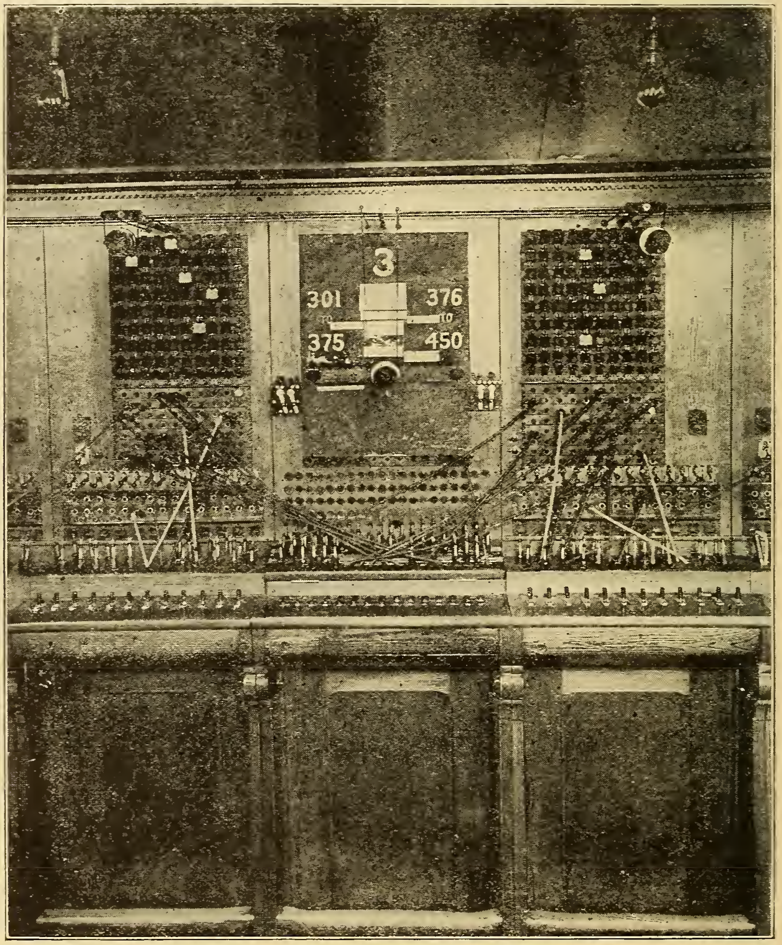


FIG. 224.—GRAND RAPIDS TRANSFER BOARD.

Of the two largest transfer systems the one at San Francisco, already described, is about to be replaced by a multiple system. The next largest, that of the Citizens' Telephone Company at Grand Rapids, Mich., giving service to over 5000 lines, is now replaced by an automatic switch-board of the Strowger type.

It is not to be inferred from this, however, that the transfer system has no present field of usefulness. Many small exchanges which at the start require no multiple board or transfer system, soon grow to such an extent as to render necessary increased switch-board capacity. The switch-board thus enlarged often becomes too large for a single set of operators to reach over its entire face, and therefore either the adoption of the multiple or the transfer system becomes necessary. To adopt the former would be to throw away the present switch-board equipment and install a multiple board—too expensive an operation for many small companies to afford. Small magneto switch-boards usually lend themselves readily to the addition of the transfer system, which may thus make the old equipment serve its enlarged field of usefulness.

In such transfer systems great speed is not, as a rule, required, and therefore as good a form of transfer circuit as any is one terminating in a jack at each end. Two of these transfer circuits are usually led from each 100-line section to every non-adjacent section.

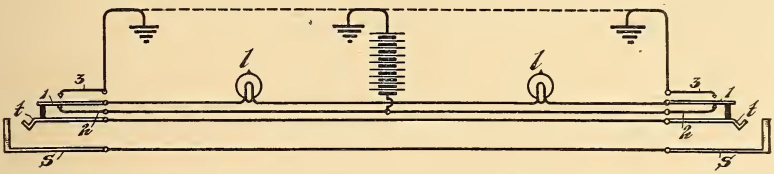


FIG. 225.—TRANSFER CIRCUIT FOR SMALL BOARDS.

One of these circuits is shown in Fig. 225. The jack at each end comprises a tip and sleeve contact, *t* and *s*, respectively, connected by the two sides of the talking current. Moving with the tip spring of each jack is a spring, 1, which normally rests against a contact, 2, but when a plug is inserted, breaks the contact and moves into contact with the spring, 3. Two signal lamps, *L L*, one at each section between which the transfer circuit extends, are arranged in series between the springs, 1, of the two jacks. The springs, 2, are connected together and to one pole of a battery, while the springs, 3, are connected to ground or a common return, as is also the remaining pole of the battery. With these connections, it will be seen that if a plug is inserted into a jack at either end, the other jack remaining normal, both lamps will be lighted. If both jacks are vacant, or both plugged, the lamps will be extinguished. The operation of such a transfer system is as follows: When a call is received at any section of the board, the operator plugs into the corresponding jack and answers the call in the ordinary way. If the subscriber desired is within the reach of this operator, that is, on her own section or that at her right or left, this operator completes the connection with her own pair of plugs and cords in the ordinary manner. If, however, the call for the subscriber is on some section not within the reach of the answering operator, this operator inserts a calling plug into the jack of the transfer line leading to the section of the subscriber called for, and notifies the operator at that section by order wire of the connection required.

The insertion of the plug by the first operator lights the lamp at each end of the transfer line. This serves as a guide to the second operator as to the transfer line she is to use. This operator therefore inserts the answering plug of one of her regular pairs into the transfer jack, thus putting out both lamps and indicating to the first operator that the connection has been made. The second operator then completes the connection by inserting the calling plug of the pair used in the jack of the called subscriber, and rings in the ordinary manner. When a clearing-out signal is received the clearing-out drops of the cord circuit at both sections fall.

CHAPTER XVI.

SYSTEMS OF TRANSMISSION IN COMMON BATTERY EXCHANGES.

It is an obvious disadvantage to have two separate sources of current at every subscriber's station in an exchange; and it is only natural that early efforts were made to centralize the transmitter batteries and the calling current generators. By bringing about such a centralization of the sources of energy many desirable results are attained. The idle capital represented by the local batteries and the calling generators is done away with—no small consideration in large exchanges, because the magneto-generator is in itself the most expensive part of an ordinary telephone set. The labor and expense of visiting or inspecting the subscribers' apparatus is greatly reduced; that neccessary to repair and renew batteries, together with the expense of material for such renewal, being rendered nil. The subscribers' instruments are made neater, simpler, and more compact. The electrical efficiency of the plant is greatly increased by having a few large units in operation practically all of the time, instead of a great number of small units in operation but a small portion of the time. No freezing of the local batteries occurs; there is no spilling of the acids or other chemicals, and no corrosion of the various parts by fumes therefrom.

The above advantages are those which at once become apparent when the subject is considered from the standpoint of maintenance and first cost. There are other and no less important advantages, however, of the common battery system, due to the fact that these systems lend themselves to automatic signaling to a degree not attainable in the old magneto system. The fact that a large source of electrical energy stands ready at the central office to be drawn on at any time by the subscriber, makes possible the conveying of a definite signal to the central office when the subscriber removes his receiver from its hook, and of another when he again hangs it up after use. As a result, the signals which the subscriber unconsciously sends to the central office are much more dependable and intelligible to the operator than those he sent, or was supposed to send, under the old regime by turning the crank of his magneto generator. This latter thought suggests the fact that by taking away from the subscriber all voluntary acts as far as possible, another advantage is gained; all work is performed by skilled operators trained for the purpose, rather than leaving it to be done partially by the public, made up of people of varying intelligence, and at best, unskilled. The subscriber thus gets with common battery systems service with less effort, and as a direct result of this better service.

Besides the advantages mentioned of reducing the work on the part of the subscriber, the labor of the operator has been so greatly lessened by modern methods of signaling in common battery systems as to enable her to handle with success an average of about twice as many subscribers as with the old system.

A general preliminary discussion of common battery systems naturally resolves itself into two divisions: first, the means by which speech transmission is effected; second, means by which the various signals necessary to the proper working of the system are

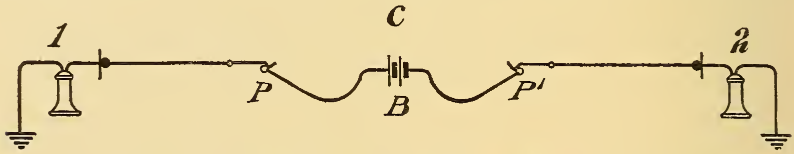


FIG. 226.—SERIES COMMON BATTERY TRANSMISSION—GROUNDED.

transmitted. This chapter will deal mainly with the first of these divisions.

Some of these advantages of the common battery system were appreciated by telephone men long ago, and many attempts were made at an early date to realize them in practice. The first efforts involved a return to first principles, doing away with the induction coil and placing the transmitters and receivers of two connected subscribers directly in series with the circuit of the two connected lines. In one of these, made in 1881, by George L. Anders, the transmitter batteries were placed in a loop used to connect the circuit of two lines. In this the switch-board was of the old crossbar type, and, while it used no cord circuits, the batteries were placed in series in the connecting wire corresponding to the cord circuit in later exchanges.

This general method, as applied to a board having plugs and flexible cords is illustrated in Fig. 226, where 1 and 2 represent two subscribers' stations, connected at the central office, *C*, by a pair of plugs, *P* and *P'*, having a battery, *B*, included in circuit between them. The transmitter and receiver of each subscriber's station are placed in series on the line wire, and each transmitter when operated serves to vary the resistance of the entire circuit formed by the two connected lines, and to thereby vary the strength of the current

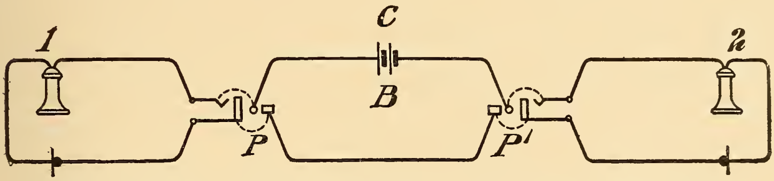


FIG. 227.—SERIES COMMON BATTERY TRANSMISSION—METALLIC.

flowing from the battery, *B*, producing corresponding effects in the receivers.

In Fig. 227 the same principle of operation is applied to metallic-circuit lines, two of which are shown connected at the central office, *C*, by the pair of metallic-circuit plugs, *P* and *P'*. In both of these cases, in which the battery is included in the cord circuit in series with the combined ciruit of the two lines, the use of a separate battery for each cord circuit is, under ordinary circumstances, necessary. This is always true of the grounded system shown in Fig. 226, and is also true of the metallic-circuit system shown in Fig. 227, unless the battery, *B*, is made to have a very low internal resistance. This fact was pointed out by Mr. Anthony C. White, who, in 1890, stated

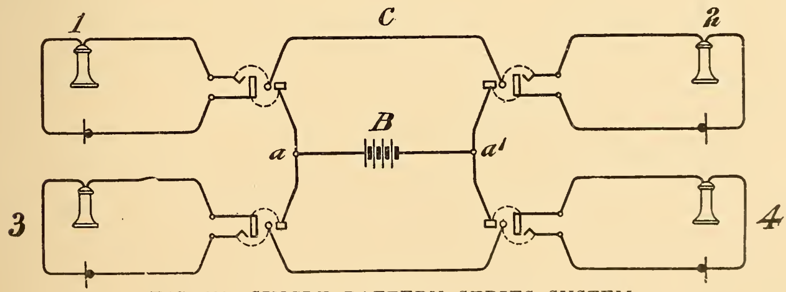


FIG. 228.—SINGLE BATTERY SERIES SYSTEM.

that it was possible to supply all of the cord circuits from a single battery by connecting them in the manner shown in Fig. 228. This involves the bunching together of one side of each of the cord circuits, the battery supplying current in multiple to the various pairs of lines in use at one time. This figure shows four stations, 1, 2, 3 and 4, connected in pairs by two cord circuits and pairs of plugs.

Fluctuations set up by the transmitter in the line of subscriber, *L*, will circulate in the combined circuit of the lines of subscribers, 1 and 2. Similar fluctuations set up by the transmitter at 3 will flow through the circuit of the lines, 3 and 4. The battery, *B*, is common to both of these line circuits, and if the resistance from the point, *a*, to the point *a'*, through the battery is considerable in amount, a part of the fluctuations flowing in the circuit of subscribers 1 and 2 will be shunted by this resistance through the combined circuits of the subscribers 3 and 4. If, however, the resistance from the point, *a*, to the point, *a'*, is made extremely small, practically all of the current changes will flow through the battery instead of being shunted around through the circuit of the subscribers 3 and 4, owing to the comparatively high resistance and impedance of that circuit, with its included instruments. The desired reduction in the resistance between the points, *a* and *a'*, may be accomplished by making the battery, *B*, of extremely low resistance, and by shortening

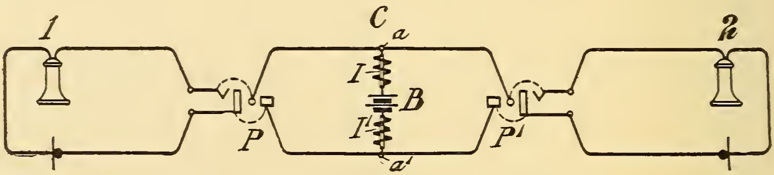


FIG. 229.—STONE COMMON BATTERY ARRANGEMENT.

the wire, *a a'*, which is common to all of the circuits. The former result is accomplished by using a storage battery of rather large capacity, and the latter by joining the various cord circuits individually to the bus-bar of the battery, so as to practically eliminate all resistance in the wire, *a a'*.

In all arrangements where the transmitters are in series with the battery and the combined circuit of the two connected subscribers' lines, the transmitter is required to vary the resistance of the entire circuit connecting the two stations, and, in the case of long lines, this may be very high. Such systems are faulty, in that the resistance variation caused by the transmitter may be extremely small as compared with the total circuit resistance, and when this is the case the variations of current will, therefore, be small. Moreover, on account of the high line resistance the steady current from the battery will be small unless a large number of cells are used.

The common battery arrangement shown in Fig. 229 is one which has come into extensive use, and was designed by Mr. John S.

Stone in 1892. It eliminates to some extent the objection just mentioned.

In this figure 1 and 2 are, as before, two subscribers' stations connected by metallic-circuit lines, with the central office at *C*. The transmitter and receiver at each station are connected in series in the line circuit. The battery, *B*, however, is connected *between* the two sides of the cord circuit, terminating in the plugs, *P* and *P'*. On each side of the battery is placed an impedance coil, *I* and *I'*, as shown. The action in this is as follows: The current from the

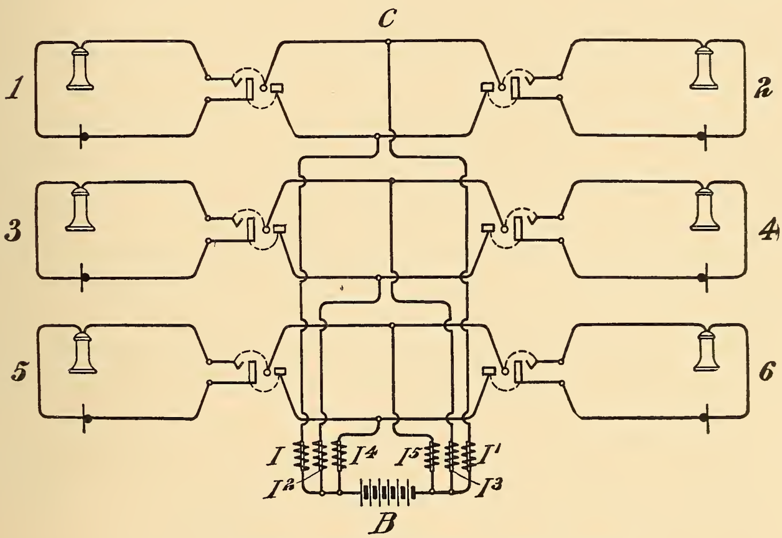


FIG. 230.—STONE COMMON BATTERY ARRANGEMENT.

positive pole of the battery, *B*, flows through the impedance coil, *I*, to the point, *a*, where it divides, a part passing through the receiver and transmitter of each of the subscribers' stations. The two parts of the current, after flowing back to the central office through the opposite sides of the lines, unite at the point, *a'*, and flow through the impedance coil, *I'*, to the negative pole of the battery. Inasmuch as the impedance coils are of low ohmic resistance, they offer but little obstruction to the passage of this current. If, now, the transmitter at station 1 is caused to lower its resistance, the difference of potential between the points, *a* and *a'*, will be lowered. This will result in a diminution in the current flowing in the line of subscriber 2. On the other hand, if the resistance of the transmitter is raised, the difference of potential between *a* and *a'* will be raised.

thus causing a greater current to flow through the instrument of subscriber 2. Every fluctuation in the resistance of the transmitter, caused by sounds at either station, will thus cause corresponding fluctuations in the current flowing through the receiver at the other station, thus causing them to reproduce the sounds. The same battery, *B*, is used to supply a large number of cord circuits, the arrangement being then, as shown in Fig. 230, each side of the various cord circuits being connected to the poles of the battery through impedance coils, as before. The fluctuations set up in the circuit of the two subscribers 1 and 2, while perfectly free to pass through these two particular lines, cannot find a path to any other lines, as, for instance, those of subscribers 3 and 4, without passing through the impedance coils, I and I' and also I^2 and I^3.

An objection to the Stone system is that when a long line is connected to a short one, the short one, on account of its low resistance, takes a comparatively large current, thus causing a considerable drop in potential through the coils, I and I', and thus reducing the difference of potential between the points a and a'. As a result the long line gets little current, while the short line, which needs less, gets more.

Early in 1892 Mr. Hammond V. Hayes devised the method of current supply to transmitter batteries shown in Fig. 231, this hav-

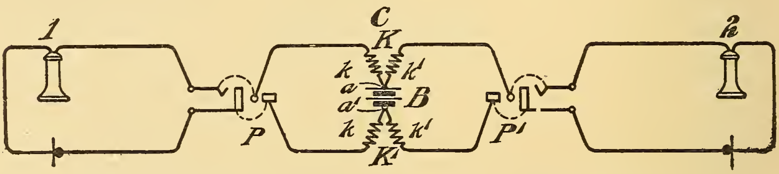


FIG. 231.—HAYES COMMON BATTERY ARRANGEMENT.

ing come into very extended use in the Bell companies, and it has formed the basis of some of the most successful common battery systems in the world. The apparatus at the subscribers' stations, 1 and 2, may for present purposes be considered arranged in all of the preceding systems. At the central office, K K' are repeating coils, each having two windings, k and k'. The two windings of the coil, K, are connected together at the point, a, which is connected with one pole of the battery, B. The other ends of these two windings are connected with the tip contacts of the plugs, P and P', as shown. In an exactly similar manner the two windings of the repeating coil, K', are connected together at the point, a', which is connected with the other pole of the battery, *B*, the other two ends of these windings being connected with the sleeve contacts of the plugs, *P* and *P'*. By this arrangement the battery is included in a bridge conductor between the sides of the circuit formed by the two connected lines, and one limb of each line includes one of the windings of one of the repeating coils. The current from the battery, *L'*, will, when the subscribers' receivers are removed from their hooks, divide at the point, *a*, and pass in multiple through the two windings of the repeating coil, *K*, thence the two portions of the current will pass through the transmitter and receiver of the two subscribers' stations, respectively, and back to the repeating coil, *K'*, through the windings of which they pass to the negative terminal of the battery.

Any changes in the current in either circuit, produced by the operation of one of the transmitters, will act inductively through the repeating coils upon the other circuit, causing corresponding fluctuations in current to flow through that circuit and actuate its receiver. Thus, when the subscriber at station 1 is transmitting, the windings, *k k,* will operate as primary windings of a transformer, of which the secondary is formed by windings, *k' k'*. When the subscriber, 1, is transmitting, this action is reversed, *k' k'* serving as primary windings, and *k k* as secondary windings. The transmitter at any station is compelled to vary the resistance of its own line circuit only, and in this way some of the advantages of a local circuit are gained.

While two repeating coils, *K* and *K'*, have been referred to in the foregoing description, they have a common core, which has therefore four windings. These are, under ordinary circumstances, all of the same number of turns. Such a coil is often referred to as a "split repeating coil," the windings, *k k,* together forming one side—say the primary—while the other two coils, *k' k'*, form the other side, or secondary.

The system of supplying battery current to subscribers' transmitters, used by the Kellogg Company, has points in common with the system of Stone, although it differs from it materially. In the Stone system, as has already been pointed out, a serious disadvantage exists due to the fact that when a high resistance line is connected with a low resistance line the difference of potential at the terminals of the impedance coils will be greatly lowered by the presence of the short line, thus cutting down the amount of current that would be received by the long line. This must always be the case where two lines of unequal resistance draw their current supply from the battery through the same coils. This defect is clearly overcome in the Hayes system.

In the Kellogg system each line draws its current through a separate pair of impedance coils, and in fact from a separate battery. The scheme of using two batteries for central battery work was proposed by the writer, and has been adopted as the universal practice of the Kellogg Switch-board and Supply Company. The particular arrangement of circuits shown in Fig. 232, which is

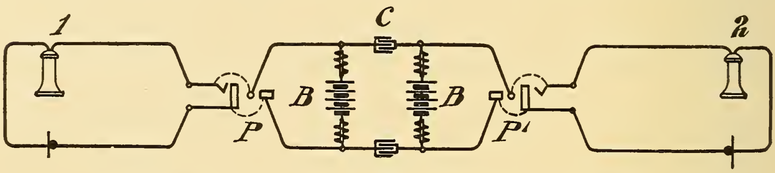


FIG. 232.—KELLOGG TWO-BATTERY ARRANGEMENT.

also representative of present Kellogg practice, was proposed by Mr. W. A. Taylor. In this plan, instead of depending upon direct conductivity between the two lines, as in the system of Stone, or upon the electro-magnetic induction between two sides of a repeating coil, as in the system of Hayes, the electro-static induction afforded between the plates of two condensers is depended upon for transmitting the fluctuations in current from one line to the other. The using of two batteries instead of one has some practical advantages, while the presence of the condensers, instead of cutting down the talking efficiency, as might be inferred from casual observation, tends rather to improve it. In fact, experiments made with a circuit of this kind have shown that the transmission was better with the condensers connected, as shown, than it was when the condensers were short-circuited.

In all the systems so far described current has been supplied to the subscriber's talking apparatus over two limbs of the line in series. Mr. J. J. Carty is responsible for the broad idea of supplying current to the transmitter of the subscriber's station over the two sides of a metallic line in parallel, using the ground as return. This method, as worked out by Mr. Carty, has been improved upon by Mr. W. W. Dean, who has produced an extended series of inventions embodying this feature. One of them is shown stripped of details in Fig. 233, in which 1 and 2 are two subscribers' stations, and *C* the central office. *I* is an impedance coil bridged across the two sides of the cord circuit of the plugs, *P* and *P′*. The center point, *a*, of this coil is grounded through the common battery, *B*. The receivers at the subscribers' stations are connected serially with the secondary coil, *s*, of an induction coil in the metallic circuit formed by the two sides of the line wire. *I′* is an impedance coil bridged between the two sides of the line circuit at each subscriber's station, the center point, *f*, of this coil being connected with one side of a primary circuit containing the transmitter, *T*, and the primary coil, *p*, of the induction coil. The opposite side of this primary circuit is grounded at the point, *g*. Current from the battery, *B*, flows to the center point, *a*, of the impedance coil, *I*, in the cord circuit; thence through the two sides of this coil in multiple to the points, *b* and *c*, on the opposite sides of the cord circuit. From these points the current flows over the two line wires in multiple to the points, *d* and *e*, from which they flow through the two sides of the impedance coil, *I′*, at the subscriber's station to the point, *f*, where they unite. The current then passes to the primary circuit, where it again divides, part passing through the transmitter, *T*, and part through the primary coil, *p*. It reunites at the point, *g*, and passes to the ground and back to the battery, *B*.

Variations in the resistance of the transmitter at one of the stations cause more or less of the supply current to be shunted through the primary, *p*, of the induction coil, and these varying currents through the primary induce corresponding currents in the secondary, *s*, placed directly in the line circuit with the receiver. These currents flow over the metallic circuit formed by the two connected lines, and are

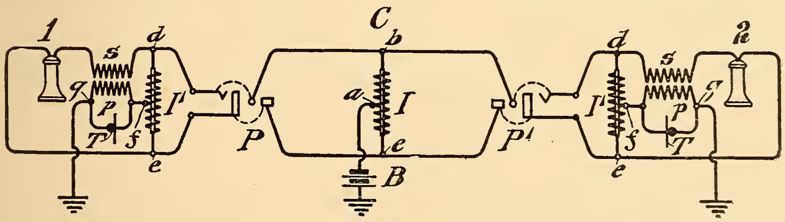
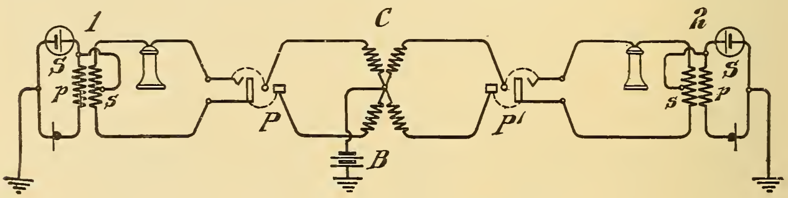


FIG. 233.—DEAN COMMON BATTERY ARRANGEMENT.

prevented from flowing through the bridge wires, *d e* and *b c*, by the presence of the coils, *I′* and *I*, contained therein. In the modification of this scheme Mr. Dean uses a transmitter having two variable-resistance buttons, one of which decreases the resistance of its circuit, while the other increases the resistance of its circuit. One of these buttons is placed in each of the branches of a primary circuit, such as is shown at the subscriber's station in Fig. 233, each side of the circuit also containing the primary of an induction coil. These are so arranged with respect to the secondary that an increase in current flowing through one of them produces the same effect on the secondary as a decrease of current in the other, and, therefore, the effects produced by the two variable-resistance buttons of the transmitter are added.

The use of secondary batteries at the subscribers' stations supplied by some source of current, either at the central office or elsewhere, has received attention since the very early days of telephony. Storage batteries are, in many respects, peculiarly fitted for telephone work. Their extremely low internal resistance, and their ability to maintain a constant E. M. F. for a considerable period, are obvious advantages over the primary battery. Charles E. Buell, of Plainfield, N. J., was, in 1881, the pioneer in this line. He was followed by Stearns in 1883, Dyer in 1888, and Dean, Stone, Scribner, McBerty and others, who have accomplished much in this line of work since 1893. The idea of Dyer in 1888 was to charge the storage battery from the ordinary lighting mains of a city, the battery then acting in a local circuit containing the transmitter and primary of an induction coil, in the same manner as when a primary battery is used.

In Fig. 234 is shown one of Stone's methods, which involves the use of an electrolytic, or secondary cell at each of the subscribers' stations. In this, advantage is taken of the fact that if, when a stor-



234.—STORAGE CELL AT SUBSCRIBER'S STATION.

age cell is entirely discharged, a charging current is sent through it, a considerable counter E. M. F. is set up by the cell. One terminal of the battery, *B,* at central is grounded, its other terminal being connected to the center point of a divided repeating coil, bridged across the cord circuit of the plugs, *P P′*, after the manner of the Hayes system. Across the terminals of the line wires at each subscriber's station is connected the secondary, *s*, of an induction coil, the center point of which is grounded through a secondary cell, *S*. In circuit with this cell is the primary, *p,* of the induction coil, together with the transmitter. The current from the battery, *B,* passes in multiple over the two line wires, through the transmitter and secondary cell in multiple, and returns by ground. When the transmitter is operated variations in current in the local circuit at the sub-station are produced, and these act inductively on the line circuit containing the receivers by means of the induction coil. If the cell, *S*, is discharged the transmitter may be considered as acting solely by means of the battery, *B*, the counter E. M. F. of the electrolytic cell serving to divert a considerable portion of this current through the transmitter, and thereby accomplishing the same result as if the current originated in the cell, *S*, itself. If, however, the cell, *S*, is fully charged, then the transmitter may be considered as working upon the current generated by it, and would so work whether the battery, *B*, were in circuit or not. The fact that the secondary cell possesses practically no resistance and no inductance renders it especially advantageous for this work.

The use of storage batteries or electrolytic cells at subscribers' stations makes possible a full realization of the advantages of the induction coil, but, of course, introduces the disadvantages of having fluid cells at points remote from the central office. They have been used in some cases with apparent success, but their advantages have not been sufficient to overcome the disadvantages mentioned.

An electrolytic cell acts in a circuit very much in the same manner as a condenser, and systems have been devised in which condensers were used at the subscribers' stations in place of the cells, *S*, shown in Fig. 234. If we assume these cells to be replaced by condensers, the other arrangements of the circuit being left as shown, current from the battery, *B*, will pass over the two line wires in multiple, as before, and to ground through the transmitter, none of it being allowed to pass through the other branch of the primary circuit, by virtue of the condenser. When, however, the transmitter is caused to vary its resistance, the fluctuations in the current set up by it are readily transmitted through the condenser, which offers to them little impedance. These fluctuations therefore act inductively upon the secondary coil, *s*, of the induction coil, thus causing corresponding currents to flow in the metallic circuit in the ordinary manner.

Instead of using a storage battery at the subscriber's station, Mr. Dean has proposed the use of a thermal generator, or thermopile, to produce the necessary current. As is well known, if the alternate junctions of a thermopile are heated, the others remaining cooler, an E. M. F. will be set up by the pile. An obvious way of supplying the heat is to wrap the juncture with high-resistance wire, which may be heated by the passage of a current through it. This Mr. Dean does, and his simplest arrangement of circuits and apparatus is represented in Fig. 235, in which the wires of a telephone line are shown leading to the central office of the telephone exchange. The telephone receiver, *R*, and the secondary, *s*, of the induction coil are placed in the line circuit, as in the instruments now in use. This line circuit is normally open, but is closed by the hook-switch when released from

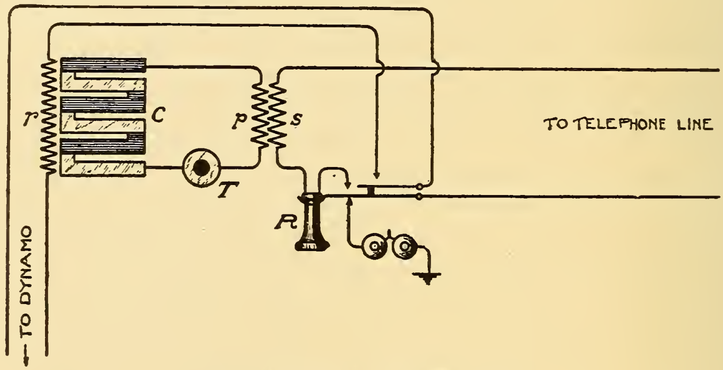


FIG. 235.—DEAN THERMOPILE.

the weight of the receiver. The transmitter, *T*, the thermopile, *C*, and the primary, *p*, of the induction coil, are placed in series in the local circuit, which is permanently closed.

The resistance coil, *r*, which is here shown in proximity to the thermopile, instead of being wrapped around it, is in a circuit in which is included a generator (either a dynamo or a battery). It is obvious that this generator may be placed at the central station, or that the current may be derived from the street mains of an ordinary electric light circuit. The circuit through this coil, *r*, is normally broken at the hook-switch. When, however, the receiver is lifted this circuit is completed, and the coil, *r*, becoming heated, puts the thermopile into action. The thermopile therefore generates the current only as long as the telephone is in use, and the breaking of the primary circuit becomes unnecessary. The action of the apparatus in talking is precisely the same as if a chemical battery were used.

Mr. Dean has worked out a system by which the current is applied to the thermopile over the two wires of the telephone circuit in multiple, the return being made through the ground. Properly arranged retardation coils prevent the short-circuiting of the voice currents, but allow the passage of the comparatively steady battery or dynamo currents. These thermopile systems have not been used in practice.

CHAPTER XVII.

SIGNALING IN COMMON BATTERY SYSTEMS.

In the magneto system the subscriber signals the central office by turning his generator crank. In common battery systems he signals by merely taking his receiver from its hook, or hanging it up again. Evidently, then, in common battery systems, there is some change in the electrical condition of the line brought about by the changing of the position of the hook. One of the requirements of all the systems in use is that current must flow over the metallic circuit of the line when the receiver is off its hook in order to energize the transmitter. Since it is necessary to have a flow of current when the receiver is off its hook, and since, for the purpose of signaling, the condition must differ when the receiver is hung up, the plan has been adopted of having no current flowing on the line when the telephone is not in use. In order to accomplish this the hook switch when depressed maintains the circuit of the line open to direct currents and closed when raised.

In common battery systems a different class of signals from those used in magneto systems is rendered available. In magneto systems signals are almost universally of such type as employ a shutter which has to be restored either by hand or by some mechanical device. In other words, the signals are of such type as to prolong their display after the current which actuates them ceases. This is made necessary in order that the subscriber may not be forced to continually turn his hand generator until he secures the response of the operator. In common battery systems, however, as soon as a subscriber removes his receiver from its hook current begins to flow and continues to flow without further effort on his part until something happens at the central office. Therefore signals may be employed which will be displayed as long as the current which actuates them flows, and which will be obliterated as soon as the current flow ceases.

Several types of mechanical signals operating on this principle have been produced and have been fairly successful. In these the armature is simply made to lift a target within the range of vision of the operator and to hold it in its displayed position as long as the current flows through its coil. As soon as the current ceases the target drops back, either by the force of gravity or of a light spring.

A much better class of signal, however, for many reasons, is the miniature incandescent lamp, which is now quite universally used for signaling purposes in place of any of the forms of electric mechanical signal. The use of the incandescent lamp as a signal was probably first proposed by Mr. J. J. O'Connell of Chicago.

The advantages of the incandescent lamp over electro-mechanical signals are many, and among them may be mentioned the following: They are much more compact than even the simplest electro-mechanical signals; they are free from mechanical complication; they are automatic in operation, being always restored to their normal condition by the cessation of current through them; they are capable of attracting the attention of the operator with more certainty than the ordinary mechanical shutter; they are easily replaced when destroyed; they are cheaper than almost any conceivable form of mechanical signal, and by the use of different colored glass lenses in front of them they may be used in the same board to indicate different kinds of information to the operator. In the early days of the use of lamps for telephone signaling purposes it was necessary to cite against the advantages pointed out the very serious disadvantage brought about by the inability of lamp manufacturers to produce a uniform grade of miniature lamps. Many of the lamps furnished to operating companies proved utterly unfit for use, and, as a result, the difficulty in procuring good lamps in some cases caused the abandonment of the lamp signal system. In recent years, however, the lamp manufacturers have risen to the occasion and are producing lamps of such efficiency and uniform character as to leave little to be desired.

To sum up the requirements thus far considered for enabling the subscriber to convey signals to the central office, it is seen that the signal at the central office is of the kind which continues displayed as long as the current through it continues, and that the control of these signals is affected by the position of the subscriber's hook switch, this switch allowing direct current to flow over the metallic circuit of the line when the hook is raised, but barring such current when depressed by the weight of the receiver.

This condition brings about a difficulty when the problem of signaling the subscriber from the central office is considered. It is of course necessary to ring the subscriber's bell when his receiver is on its hook, and therefore at a time when there is no conductive path between the two sides of the line at his station. The fact that an alternating current may be made to pass through a circuit that is not conductively continuous affords the most ready solution to the problem, and is the one now almost universally adopted. An ordinary polarized ringer wound with a comparatively large number of turns is bridged across the two sides of the line in series with a condenser. The arrangement at the sub-station then becomes that shown in Fig. 236. The presence of the con-

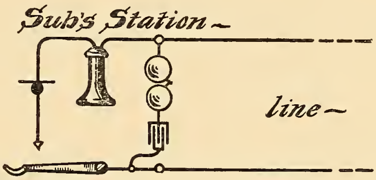


FIG. 236.—SIMPLIFIED SUB-STATION APPARATUS.

denser prevents the passage of direct currents across the line circuit when the receiver is on its hook. An alternating current sent over the line from the central office will, however, find ready passage through the condenser and will thus ring the bell. Thus without destroying the conditions necessary to enable the subscriber to signal the central office the sub-station bell is made responsive to ringing current sent by the operator to call the subscriber.

Obviously, there are two methods of associating incandescent lamps with the circuits of subscribers' lines. The first of these, and without mature consideration the most desirable, is to place the lamp directly in the circuit of the subscriber's line and operate it automatically by the closure of the circuit of the line caused by the

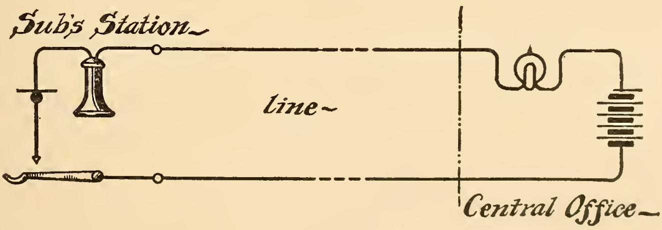


FIG. 237.—LINE SIGNALING WITHOUT RELAY.

raising of the subscriber's receiver from its hook. Such an arrangement is shown, stripped of all details, in Fig. 237, the subscriber's station being shown at the left connected by a metallic circuit line with the signaling apparatus at the central office. When the subscriber's receiver is on its hook the line circuit is open, and therefore no current will flow. As soon, however, as the receiver is removed, the circuit will be closed through his talking apparatus, thus allowing current to flow from the central office battery through the lamp, causing its illumination.

The second method is to have the lamp in a local circuit at the central office, this circuit being controlled by a relay. The relay coil with this arrangement is placed directly in the line circuit, and is therefore adapted to be operated by the current caused to flow when the subscriber removes his receiver from its hook. This arrangement is shown in Fig. 238 where the coil of the relay, *R*, is

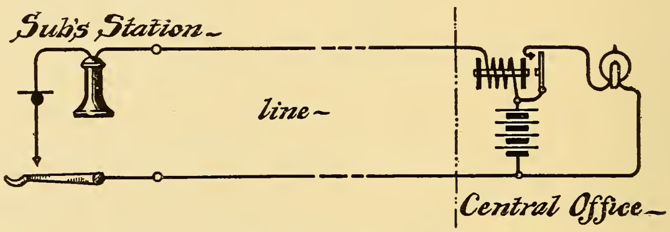


FIG. 238.—LINE SIGNALING WITH RELAY.

placed in the circuit of the line instead of the lamp, as in Fig. 237. When the relay is energized by a current flowing over the circuit of the line it attracts its armature, thus causing the illumination of the lamp which is placed in the local circuit containing the battery and the relay contacts.

Considering the first method—that is, where the lamp is placed directly in the circuit of the line, we are confronted by several rather serious objections. The resistance of no two subscribers' circuits are the same owing to the differences in the lengths of the lines and other causes, and therefore, unless some steps are taken to overcome this objection, no two lamps will receive the same current. The variation of the resistance of the lines will be such that the long lines would be of such high resistance as not to allow sufficient current to pass for the illumination of the lamp, while the shortest lines would be of such low resistance as to subject the lamp to an undue current. This featuure may be overcome by equalizing the resistance of the lines by placing resistance coils in series with the lamps on all except the longest lines, thus making the resistance of all lines practically equal to that of the longest.

Another difficulty brought about by the use of the lamp directly in the circuit of the line arises from the fact that lines are always more or less liable to crosses or short circuits, in which case the lamp would under ordinary circumstances be subjected to such a voltage as would cause it to burn out. It is this latter objection that has proved the most serious in practice, and has largely brought about the abandonment of this plan of associating the line lamp with the line. Of course, in underground systems, this objection has not been such a serious one.

Although this plan has been universally abandoned, so far as the writer is aware, there seems to be a tendency recently developed to again revert to it. The expediency of the plan now seems to depend on what lamp manufacturers will be able to do in the way of manufacturing a lamp with sufficiently wide limits of operating conditions. It is evident that if a lamp could be built which would stand the full voltage of the battery without injury, the difficulty due to burnt-out lamps caused by short-circuiting the line-conductors would be obviated; in other words, a short circuit would do no harm to the lamp, but would simply cause its illumination to its full candle power. Under this condition the lamp would be self-protected. The other practical requirement for such a lamp would be that it should be sufficiently illuminated through a resistance equal to that of the longest line.

Lamps have been built in small quantities adapted to fairly meet this requirement. A few such lamps tested by the writer had a resistance of 1200 ohms, and were illuminated to full candle power by a pressure of 48 volts. In a system using such lamps this would therefore, be the pressure of the central office battery. These lamps proved capable of giving a signal good enough for practical purposes, even when placed in circuit with an 800-ohm line. As few lines in common battery exchanges ever have a greater resistance than this, it would seem that these lamps would be able to meet the requirements of practice in regard to their illumination over all ordinary lines, fairly well. Of course, the question as to the durability of such lamps, and as to whether their manufacture in large quantities would be commercially possible or not, is yet to be determined.

The method of operation of the line lamp by means of a relay, as shown in Fig. 238, is, however, eminently satisfactory, its only disadvantages being the first cost and subsequent maintenance of the line relay. It is doubtful, therefore, whether even the production of a perfectly satisfactory lamp to be used directly in the line circuit would bring about the abandonment of the use of the line relay.

In Fig. 239 is shown a more complete circuit of a common battery line, as adapted to use in small exchanges, the jack, by which connection is made to the line for the purpose of conversation, having been added to the arrangement shown in Fig. 238. This jack, as will be seen, is of the *cut-off* type, being adapted, when a plug is inserted into it, to cut off the battery and the line relay, and thus extinguish the lamp. The operation, therefore, of this circuit from the time the subscriber called until the operator answered by inserting the plug is this: Upon removing his receiver from its hook the circuit of the line is completed, allowing current to flow from the

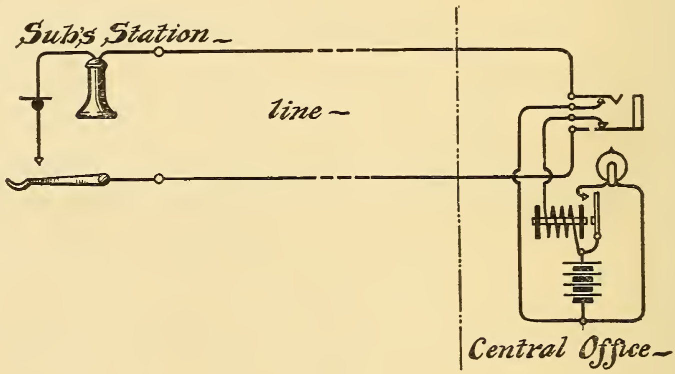


FIG. 239.—LINE CIRCUIT.

battery through the line relay, thus causing the operation of this relay which attracts its armature, and allows current to flow through the lamp. Upon inserting a plug into the jack the two sides of the signaling circuit are broken at the contact points, *a* and *b*, in the jack, thus breaking the circuit through the line relay, which, therefore, allows its armature to fall back and extinguish the lamp.

The methods by which the subscriber, by removing his receiver from its hook, is enabled to attract the attention of the central office operator, have now been discussed in general. It remains now to show how the subscriber by hanging up his receiver at the close of a conversation is again enabled to signal the operator. The old clearing-out drop of the magneto exchange has given place, in modern common battery systems, to what are termed supervisory signals. One of these signals is placed under the control of each subscriber as soon as his line is connected to for the purpose of conversation. To accomplish this result a signal (usually a lamp) is associated with each plug used by the operator, there being two such signals, therefore, for each pair of plugs used for connecting subscribers for conversation. The signal associated with the answering plug is therefore called the answering supervisory signal, and that with the calling plug the calling supervisory signal. The significance of the word "supervisory" will be obvious when it is stated that these signals enable the operator to supervise a connection when made, since they keep her informed as to the condition of the connection, with regard to whether the called subscriber has responded; whether the subscribers are in communication; whether the conversation is finished, and whether one of the subscribers desires another connection.

As soon as the connection is made with a line by means of a plug and cord the line signal is automatically taken from the control of the subscriber, and in its place is substituted a signal belonging to the particular plug and cord used in making the connection. Under these conditions, as long as the subscriber's receiver is off its hook—that is, as long as the subscriber is using his telephone, the supervisory signal will not be displayed. As soon, however, as he hangs up his receiver, the signal will be displayed, thus informing the operator that the subscriber has finished the use of his telephone. The operation, therefore, of the two supervisory signals, associated with any cord circuit used in making a connection, is as follows: When an operator answers a call by inserting the answering plug into the jack of the calling subscriber, the answering supervisory signal will not be displayed because that subscriber has his receiver removed from its hook. When the operator inserts the calling plug into the line of the subscriber called for the calling supervisory signal will be displayed, because that subscriber has not yet removed his receiver from its hook. The calling supervisory signal will therefore serve as a ringing signal to the operator, she ringing the subscriber at short intervals until she knows that he has responded, by the retirement of the calling supervisory signal. Both supervisory signals will be undisplayed as long as the two subscribers are in conversation. When either subscriber finishes the conversation and hangs up his receiver the corresponding supervisory signal will be displayed, and the display of both such signals will convey to the operator the information that she is to take down the connection. If she sees one signal displayed while the other is undisplayed she will know that one of the subscribers probably desires another connection. It will be seen that this system of supervisory signaling is not dependent upon any voluntary act upon the part of the subscriber, and for this reason the greatest unsatisfactory element of the old clearing-out signal, the inability to depend on the subscriber to turn his generator crank for the purpose of conveying the clearing-out signal, has been removed.

Coming now to a general consideration of the means by which the supervisory signal is thus put under the control of the subscriber during a connection, reference is made to Fig. 240. At the left of this figure is shown the circuit of the subscriber's line, the line signal having been omitted. At the right is shown a cord circuit equipped with a split repeating coil, between which is bridged the common battery for supplying current to the subscriber for talking, as in the Hayes system of common battery transmission. It is obvious that when two plugs are connected with the jacks of two lines the talking circuit of the two lines will be the same as that shown

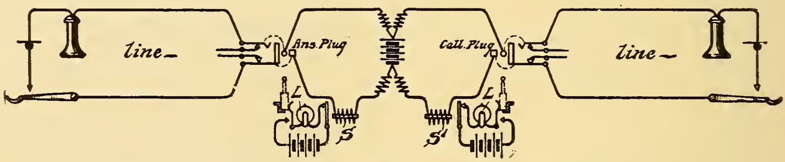


FIG. 240.—SUPERVISORY SIGNALING WITH PLUG-SEAT SWITCH.

in Fig. 231, in Chapter XVI. *S* and *S'* are supervisory relays, one being connected in the sleeve strand of the answering plug, the other being similarly connected in the sleeve strand of the calling plug.

When the armature of either of these relays, say *S*, is unattracted —that is, when no current is traversing the relay coil—the relay contacts will be closed, so that the corresponding lamp, *L*, would be lighted if its circuit were open at no other place. It is evident, however, that when the plug is idle—that is, when it is not placed in the jack of the line—the relay, *S*, will be de-energized, which would cause the constant illumination of the lamp, *L*. This would be wasteful of current, wasteful of the life of the lamp, and confusing to the operator, because, under the condition of idleness, the lamp should not be displayed. For this reason, some means is necessary for preventing the illumination of the lamp when the plugs are idle. One of such means is shown in Fig. 240, where what is termed a plug-seat switch is employed. This is a switch associated with the seat in which the plug normally rests, so arranged that when the plug is in its seat the switch contacts are held open. These switch contacts are included in the circuit of the corresponding supervisory lamp, and therefore when a plug is not in use the circuit of the supervisory lamp is held open at the plug-seat switch, although it is closed at the contacts of the relay.

As soon, therefore, as the operator, in response to a call, raises the plug from its seat, the supervisory lamp, *L*, will be lighted on account of the closure of the plug-switch contacts, but it will immediately go out when the answering plug is thrust into the jack of the line, because that subscriber, having his receiver removed from its hook, current will flow though the supervisory relay, *S*, and open the local circuit of the lamp at the relay contacts. As long as the plug is in the jack the illumination of the lamp, *L*, depends only on the position of the armature of the relay, *S*, and it will be seen that this armature is under the control of the subscriber with which that plug is connected. As long, therefore, as the subscriber's receiver is removed from its hook the lamp, *L*, will not be illumi-

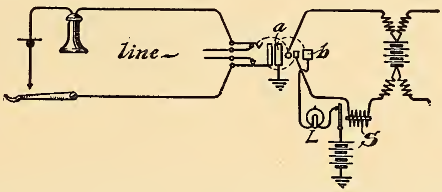


FIG. 241.—SUPERVISORY SIGNALING WITH THIRD STRAND IN CORD.

nated, but as soon as he hangs up his receiver at the termination of a conversation, the relay armature will fall back and the lamp will be lighted to be put out again by the replacing of the answering plug in the plug-seat switch.

It will thus be seen that the circuit of each supervisory lamp is controlled by two separate pairs of contacts—one, the plug-seat switch, being under the control of the operator, and the other, the relay contacts, being under the control of the subscriber, after a connection has been made with a line.

Another, and what is usually considered a better way of accomplishing the same result, is shown in Fig. 241. Here the line circuit and apparatus is the same as that of Fig. 240, with the exception that an additional contact ring, *a*, has been added to the jack. The cord circuit is provided with three strands for each plug instead of two, a third contact, *b*, being provided on each plug for registering with the extra contact ring, *a*, of the jack. The connection from the tip and sleeve contacts of the plug to the repeating coil and battery is the same as that in Fig. 240, the sleeve strand including the supervisory relay, *S*. The third contact, 6, on the plug is connected through a third strand in the cord to one terminal of the supervisory lamp, *L*, the other terminal of which is connected to the back contact of the relay, *S*, the armature of which is connected to the ungrounded terminal of the battery.

No plug-seat switch is used in this case, but it is obvious that its equivalent exists in the contact, *a*, on the jack and *b*, on the plug, for as soon as the plug is inserted into the jack the registering of the contacts, *a* and *b* closes the normally open breach in the lamp circuit, thus placing the supervisory lamp under the full control of the relay, *S*, which, as before, is governed by the subscriber.

This scheme, with certain modifications, is almost universally used by the Bell companies and many of the Independent companies. The actual connection of the lamp itself is generally modified by

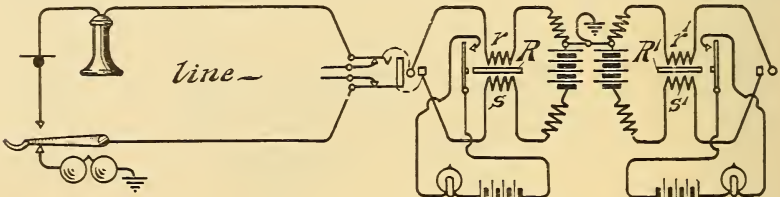


FIG. 242.—SUPERVISORY SIGNALING WITH DIFFERENTIAL RELAY.

causing the relay to operate on the lamp by *shunting* it out of circuit rather than by opening its circuit. These modifications will be fully pointed out in a subsequent chapter dealing with common battery circuits in practice.

There is a radically different method of operating supervisory signals which, however, causes the same code of signaling as already described to be put into effect. This system was designed by the writer, and has been put into extensive use in several large exchanges in this country, including those of the Independent companies at Baltimore, Pittsburg, Scranton and other cities in the East. This system is interesting as being the only one the writer can call to mind where the supervisory lamp is controlled by a single pair of contacts, and also as perhaps embodying the simplest possible form of cord circuit for accomplish complete double-lamp supervision.

This system is shown in simplified form in Fig. 242. The arrangement at the subscriber's station differs from those already pointed out in that the call-bell is connected between the lower contact of the hook and the ground in such manner as to ground the sleeve side of the line at the subscriber's station when the receiver is hung up. The removal of the subscriber's receiver from its hook operates the line signal in the usual manner, as pointed out in Fig. 238. The plugs used in the cord circuit have two contacts only and the cords two conductors only. The two plugs belonging to a pair are inductively connected by means of a repeating coil, a separate battery being connected in the middle of each side of this coil, that pole of the two batteries which feeds the tip side of the cord circuit being grounded. In the tip strand of each cord is one winding, r or r', of the supervisory relay, R or R'. Similarly connected in the sleeve strand of this cord is the other winding, s or s', of the same relay. The two windings of each relay are concentric and wound in such manner, each having the same number of turns and resistances, as to produce no effect on the core when traversed by current flowing in series in the metallic circuit of the line. The nature of the winding is also such as to produce practically no impedance to voice currents passing over the metallic circuit. Each supervisory relay controls by its armature the circuit of its supervisory lamp. It is obvious that under normal conditions when the plugs are not in use the armatures of the supervisory relays will be back, thus keeping the circuit of the lamp open. When a plug is inserted into a jack of the line, of which the receiver is removed from its hook, current will flow only through the metallic circuit of the line. Equal currents will then flow in opposite directions through the two coils of the supervisory relay, and no attraction of the armature will result. The lamp will therefore not be lighted. As soon, however, as either subscriber hangs up his receiver the metallic circuit of the line will be broken and a new circuit will be established, which may be traced from ground at the central office through the battery and the winding, s or s', of the supervisory relay, R or R', to the sleeve side of the line, thence to ground at the subscriber's station. Under this condition only one coil of the supervisory relay will be energized and the armature will be attracted, thus lighting the corresponding supervisory lamp.

While this system is still largely used, it possesses an objection not found in those systems wherein the supervision is accomplished over the metallic circuit of the line without the use of ground. Ground connections at the subscribers' stations are somewhat expensive to install and maintain, and in some cities trouble is experienced on account of earth currents caused principally by faulty ground returns in electric railway circuits. Sometimes differences of potential as high as 60 volts have been found in American cities between the ground at the central station and that at some of the outlying subscribers' stations. Of course, with such potentials as this, which are not constant, the use of grounded circuits for signaling becomes objectionable. Furthermore, this system does not lend

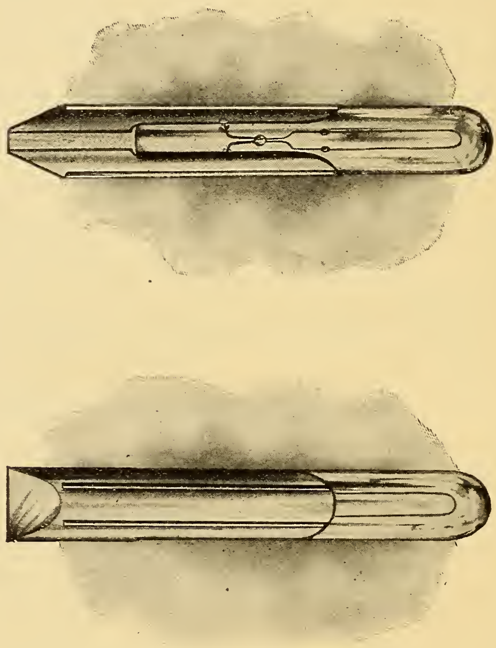


FIG. 243.—SWITCH-BOARD LAMP.

itself as readily to party line signaling as do some of the others which have been described.

At first the lamps used for telephone purposes were adapted to screw sockets, the base being threaded in much the same manner as the present lamps used for commercial electric lighting. It was not long, however, before this form was changed to one in which the lamp was provided with two contact plates, arranged on opposite sides of the bulb, these plates forming the terminal of the filament, and being adapted to slide into their sockets. In this case the sockets consisted of two springs arranged to properly register with the contact terminals on the lamp. This is present practice. In order to economize in room with respect to the available space on the face of the board, the bulbs are made of small glass tubes about five-sixteenths of an inch in diameter.

Types of switch-board lamps are shown in Figs. 243 and 244. In each of these the two contact terminals are seen on each side of the bulb. In the lamp shown in Fig. 243 these contact terminals project back of the bulb for a distance of about three-eighths of an inch and clamp between them a small wooden block which serves to make the structure more rigid. In the lamp shown in Fig. 244 the wooden block is replaced by a kind of insulating cement resembling plaster of Paris, this cement being poured in after the terminals are fastened to the lamp.

It will be seen that the lamp of Fig. 243 has a pointed tip or front, while that of Fig. 244 has a rounded front. The pointed front construction is faulty, because the point tends to obstruct the passage of light from the front where light is most needed. This point in

FIG. 244.—SWITCH-BOARD LAMP.

the front of the bulb is caused by the fact that the lamp is sealed at that end in manufacture. In the construction shown in Fig 244 the lamp is sealed at the opposite end, the front of the bulb being previously rounded so as not to obstruct the passage of light from that end.

Where lamps are used as line signals they are usually mounted in strips of 10 or 20 in such manner as to be immediately adjacent to the answering jack of the corresponding line. To facilitate this mounting the sockets into which the lamps are adapted to slide are arranged in strips of 10 or 20, the strips usually being composed of a single block of hard rubber, properly shaped and drilled for the reception of the lamps.

The lamps are adapted to slide into place, so that their contact terminals will register with the contact springs in the sockets or lamp-jacks, as these sockets are usually called. In front of the lamp is placed a small lens, usually of opalescent glass, through which the light shines when the lamp is illuminated. Such a strip of jacks is shown in Fig. 245, which figure also shows a lamp and lamp cap.

Telephone lamps are now most commonly built for 24-volts pressure, although both higher and lower voltages are frequently used. The present tendency seems to be to increase the voltage rather than to diminish it, and many systems are being installed where the 48-volt lamps are used. At first lamps of 2 and 4 volts were employed, but for various reasons, not the least among which was the trouble in securing proper contacts at the various switch points for such low voltages, and the necessity for using low resistance conductors in order to effect the proper illumination of the lamps, the voltage was gradually increased as stated.

Mr. A. V. Abbott, formerly of the Chicago Telephone Company, some years ago gave some interesting figures concerning the life of incandescent lamps in switch-board work, and mentions one case in which a lamp was flashed over a million times without showing serious signs of deterioration. His test seemed to indicate that for

FIG. 245.—STRIP OF LAMP JACKS.

general service in switch-board work the average lamp will live for a period of about 1200 hours, although in laboratory tests a much longer life proved possible. He pointed out, as a result of his observations, that, according to theory, the lamps used in subscribers' line circuits should last about 25 years, and those used in the cord circuits as supervisory or clearing-out lamps, from one to two years. He also says that such a life has already been obtained in the cord circuit lamps, but it is doubtful if the theoretical limit of the line lamp will ever be closely approximated.

It is the experience of the writer that Mr. Abbott's figures for the average life of a lamp is very much too high, and that 500 hours of illumination is more nearly correct than 1200.

It has been said in this chapter that the lamp signal is almost universally used for line and supervisory signals in common battery exchanges. There are, however, certain exceptions to this general rule. In some very small common battery exchanges where but a small amount of current is available, and where for that reason it becomes necessary to economize in current as much as possible, electro-mechanical signals are used, these taking their place in the circuit in the same relation as that usually occupied by the line or supervisory relays, where lamp signals are used.

An electro-mechanical signal of this type is that used by the Kellogg Company, shown in Fig. 246, and commonly termed the "gridiron" signal. In this a small aluminum target, marked on its face with alternate black and white strips about one-eighth of an inch wide, is attached to the armature lever in such manner as to be moved in its vertical direction by the attraction of the armature through a distance just equal to the width of one of the black or white strips. Directly in front of the target is placed a black strip, having cut in it four horizontal slots equal in width to the width of the strips on the target, and equal in length to the width of the target. When the magnet is de-energized the relative position of the

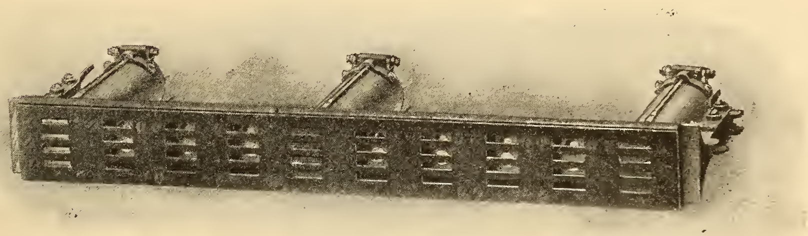


FIG. 246.—GRIDIRON SIGNAL.

target with respect to the front strip is such that the black strips on the target come directly in front of the openings in the front strip, thus presenting a continuous black surface to the eye of the operator. When, however, the armature of the signal is attracted, the target is raised slightly so that the white strips come in front of the openings in the front strip, thus displaying four white horizontal patches where before all was black. The object of this "gridiron" arrangement is to secure the display of a white surface of considerable size with a relatively small movement of the armature and target.

Another form of signal during the past few years has been quite extensively applied by the Western Electric Company. This is shown in Fig. 247. In this the core of the magnet is clamped by means of a screw, *a′*, to the mounting strip. Held between the core and the mounting strip is a U-shaped pole-piece, *c′*, in which to pivot the rotating armature, *e'*. This armature normally hangs in the position shown in the upper cut of Fig. 247, but when attracted by the core of the magnet is drawn into the position shown in the middle cut of this figure. Carried on the same frame with the armature in such manner as to always partake of its movement is a target, *f*, made of aluminum, and stamped into the form of a seg-

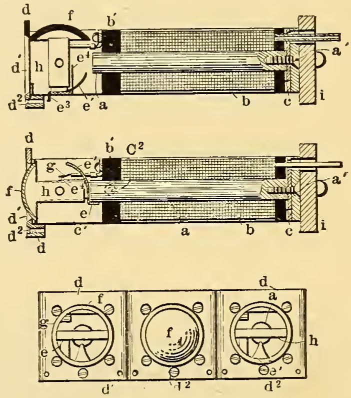


FIG. 247.

ment of a sphere. Under normal circumstances this target lies in the position shown in the upper cut of Fig. 247, the weight of the armature, *e'*, serving to overbalance the weight of the target. When, however, the armature is attracted the target fills the opening, *d*, in the front plate, under which circumstances the target forms a conspicuous signal. A front view of the three signals as mounted in practice is shown in the lower part of the figure, the signal in the middle being displayed while the other two are not.

CHAPTER XVIII.

COMMON BATTERY SWITCH-BOARDS FOR SMALL EXCHANGES.

In the two preceding chapters are given the elements of circuit arrangement, and of apparatus by which voice transmission and the transmission of signals are effected in common battery exchanges. These elements were, in a large measure, separately considered, but from them the arrangement of circuits and apparatus for a complete

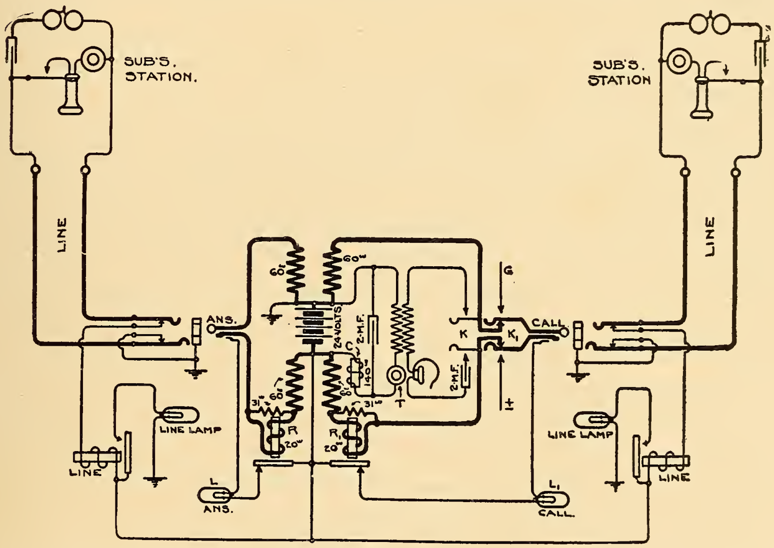


FIG. 248.—TYPICAL CIRCUITS FOR SMALL COMMON-BATTERY BOARD.

switch-board, suitable for small exchanges, may easily be determined. In this chapter a few of the combinations of line and cord circuits, with their necessary details, will be considered; this subject-matter leading naturally to the discussion of the more complex multiple switch-board systems for common battery work.

In Fig. 248 are shown line and cord circuits, suitable for a small switch-board working on the common battery plan with lamps for both line and supervisory signals. These circuits are typical of this class of switch-boards, as in parallel in this country to-day. In this figure two lines are shown, at the right and left-hand portion of the page, with a cord circuit between them, and adapted to connecting these, or any other two lines, for conversation. The jack consists of a tip and a sleeve spring, which form the line terminals, and which normally rest against contacts leading to the ground on one side, and to the line relay on the other. A ring contact is also provided on the jack for the purpose of making connection with the third strand in the cord for supervisory signaling purposes. It is obvious that under normal circumstances the circuit of the line is held open at the subscriber's station, and that therefore the line relay does not operate because no current flows through it. When, however, the subscriber's circuit is closed by the raising of the receiver, current from the common battery flows through the line and causes the line relay to attract its armature.

The two plugs of a pair have each three contacts, which may be designated in their order, tip, ring and sleeve. Of these the tip and ring are connected for voice transmission through the split repeating coil in accordance with the plan of the Hayes system, already referred to in connection with Fig. 231. Connected with the calling plug is the usual ringing and listening key, *K'*, which needs no explanation. The operator's telephone circuit brought into play by the listening key, *K*, merits attention, however. Current is supplied to the operator's transmitter and the primary of her induction coil from the 24-volt battery which supplies the cord and line circuits. In series with the transmitter and primary winding is an impedance coil, *C*, having a resistance sufficient to cut down the current through the transmitter to a proper value for efficient working. With the solid back transmitter, used by the Bell companies, this resistance is about 140 ohms. A 2 M. F. condenser is bridged across the operator's primary circuit in such manner as to shunt the transmitter and the primary coil, the purpose of this being to allow the free passage of fluctuating currents through the primary coil when the transmitter is operated. Were the condenser not present the fluctuation set up by the transmitter would be forced to pass through the retardation coil, and their intensity would thus be greatly diminished. The operator's receiver and the secondary of her induction coil are associated with the primary circuit in the same manner as in magneto boards, with the exception that a condenser is placed in series with the receiver, the purpose of this being to prevent the operator from getting an undue click in the ear when she throws her listening key.

Two supervisory relays, *R* and *R'*, are connected in series in the sleeve strands of the answering and calling plugs, respectively.

When a plug is inserted in a jack it is evident that the corresponding supervisory relay is thus placed directly in the circuit over which battery current is fed to the line for conversation, and, therefore, the operation of this relay, when a connection is made with the line, will depend on whether or not the subscriber on that line has his receiver on or off its hook. These relays are usually shunted by a suitable non-inductive resistance, as shown, for the purpose of providing a non-inductive path around the relay coils for the voice currents. Sometimes condensers are substituted for these resistances.

Between the third, or sleeve contact on the plug and the ungrounded side of the battery is connected the supervisory lamp, L, or L', this connection also including the normally closed back contacts of the corresponding supervisory relay. The sleeve contacts of the jacks are permanently grounded. The arrangement is therefore such that when a plug is inserted into a jack, and the supervisory relay is not operated, the lamp will be lighted, the current passing from ground at the cord circuit, through the battery, thence to the lamp, and through the third contact on the plug and the sleeve of the jack to ground. The operation of the supervisory relay caused by the subscriber removing his receiver from its hook opens the circuit of the lamp, thus keeping it extinguished as long as the subscriber's receiver is in use.

The operation of the system may now be understood. A subscriber, desiring a connection, removes his receiver from its hook, thus lighting the line lamp. In response to this the operator inserts an answering plug into the jack, thus cutting off both sides of the normal signal circuit at the jack, and establishing connection through the cord circuit instead. Since the subscriber has his receiver off its hook, the relay, R, is actuated, and therefore the lamp, L, is not illuminated. By throwing her listening key, K, the operator bridges her telephone across the calling side of the cord circuit, and is enabled to converse with the calling subscriber in an obvious manner. Learning the number of the called subscriber, the operator will insert the calling plug into his jack and operate the ringing key, K', which will ring the bell of that subscriber. As soon as the calling plug was inserted in the called subscriber's line, the supervisory lamp, L', became lighted, because, the subscriber's receiver being on its hook, no current passed through the supervisory relay, R', and therefore the circuit of the lamp was not opened at that point. As soon, however, as the called subscriber responds, the supervisory relay, R', receives current and the lamp is put out.

After conversation, when either subscriber hangs up his receiver the corresponding supervisory lamp will be lighted by the falling back of the corresponding supervisory relay armature, and when both of the lamps are lighted the operator will know that disconnection is desired.

In Fig. 249 is shown the circuits of a common-battery system used for small exchanges based on the Stone system of transmission shown in Fig. 228. While this may not have gone into extended use, it is instructive, particularly with reference to the method of associating the electro-mechanical supervisory signals with the cord circuit.

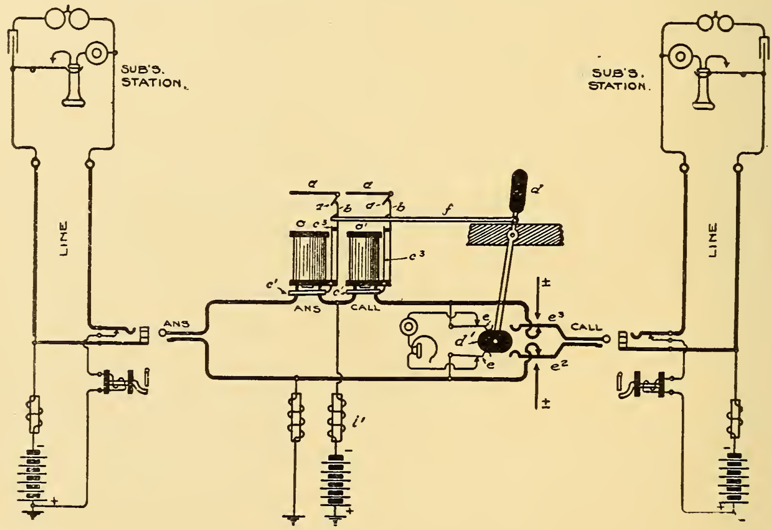


FIG. 249.—SCRIBNER COMMON-BATTERY SYSTEM.

The line signal is automatically operated by the removal of the subscriber's receiver from its hook, and is effaced by the insertion of a plug into the jack, which act opens the signal circuit at the jack. Current from the battery now circulates through the impedance coils, *i* and *i'*, and through the circuits of two connected lines, after the manner of the Stone system, already described. The listening and ringing key is so arranged that when the lever, *d*, is moved to the right the wedge, *d'*, will be forced between the springs, *e* and *e'*, thus connecting the operator's telephone across the circuit. The springs and the wedge are so formed that the lever will remain in this position until moved by the operator. When pressed in the opposite direction, the wedge is forced between the springs, e^2 and e^3, thus connecting the generator with the calling plug. These springs are so formed that the wedge will be forced from between them when the pressure on the lever is released.

Arranged in one side of the cord circuit in the ordinary manner are the supervisory signals, *o* and *o′*, these signals being constructed as shown in Fig. 250, which also gives a better view of the construction of the listening and ringing key. The indicators or shutters, *a*, are pivoted at their edges in cavities formed in the horizontal key-table. Each shutter is provided with a lug, *a′*, upon which bears the free end of a flat spring, *b*, whose other end is fixed to the frame of a tubular magnet, arranged under the key-table. This spring tends to bring the indicator into a horizontal position, as shown in Fig. 250. The armature, *c′*, of the tubular magnet carries an arm, c^3, which, when the

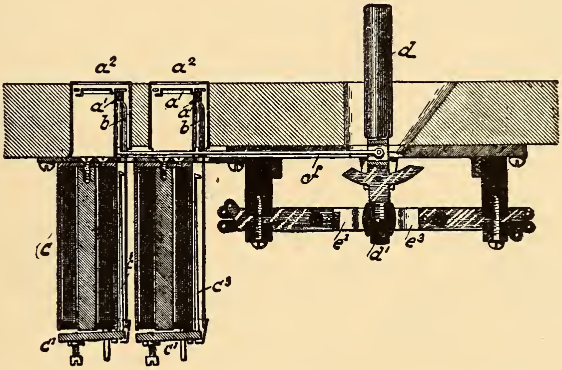


FIG. 250.—SUPERVISORY SIGNALS FOR SCRIBNER SYSTEM.

armature is attracted, is thrown against the spring, *b*, thus pushing it out of engagement with the lug, *a′*, on the shutter and allowing the shutter to fall from view. The lever, *d*, of the listening and ringing key is connected by a rod, *f*, with the springs, *b*, of the annunciators in such manner that when the lever is pressed into the listening position, as shown in Fig. 249, the springs, *b*, will be withdrawn from the shutters, thus producing the same effect as if the magnets were energized, and allowing the shutters to drop out of sight.

With this arrangement the keys are normally left in their listening positions, so that when an operator inserts an answering plug, *k*, into a jack in response to a call, she is at once placed in communication with the subscriber. Having inserted the calling plug, *k′*, into the jack of the called subscriber, she moves the key to the ringing position, and allows it to spring back to an intermediate position in which neither the telephone nor the generator is connected with the cord circuit. This releases the springs, *b*, from the influence of the rod, *f*, but signal, *o*, will not be displayed, because current from the battery, *t*, is passing through the line of the calling subscriber, thus energizing its magnet and preventing its display. As the called subscriber has not yet responded, the signal, *o'*, will be displayed because sufficient current cannot pass through the high-resistance bell of the called subscriber to energize its magnet. As soon, however, as the called subscriber responds, current will pass through his line and the signal, *o'*, will be effaced. This condition will be maintained until

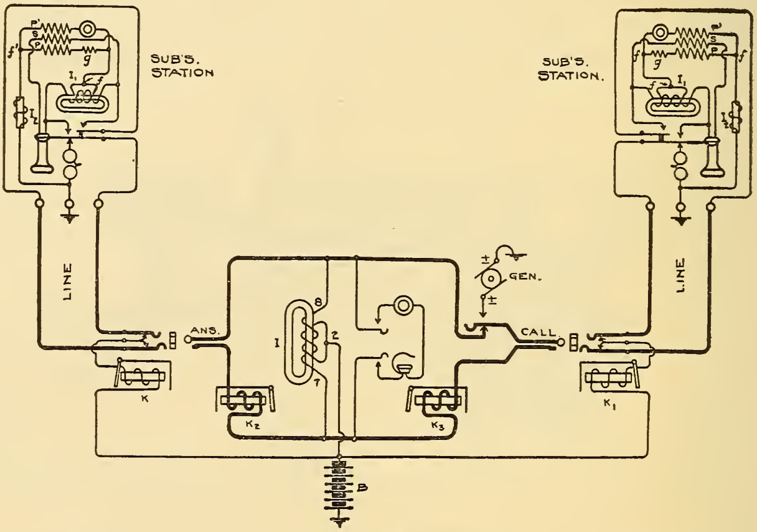


FIG. 251.—CIRCUITS OF DEAN COMMON-BATTERY SWITCH-BOARD.

one or both of the subscribers hang up their receivers, when the currents through the respective supervisory signal magnets will be cut off, their armatures will be released, and the shutters will be displayed by being forced into a horizontal position. The operator will then withdraw the plugs, and will move the lever into the listening position in anticipation of the next call. This latter act will cause the rod, *f*, to pull the springs, *b*, out of engagement with the shutters, thus allowing them to fall.

The Dean system of voice transmission, already described in connection with Fig. 234, is illustrated more in detail in Fig. 251, which represents the circuits as they have been used in a few small exchanges. The impedance coil, *I*, at the central station has two windings, 7 and 8. One terminal of the coil, 7, is connected to the sleeve strand, while one terminal of the coil, 8, is similarly connected with the tip strand, the other terminals of these coils are connected together at the point, *l*, which forms one terminal of the common battery, *B*. In a similar manner the impedance coil, *I*, at each subscriber's station is provided with two windings, connected respectively with the two sides of the line circuits, and having their other terminals joined at the point, *f*. The two windings on each coil consist of about 3000 turns of No. 22 silk-covered wire. As a result of this construction, the coils are of low ohmic resistance, especially when placed in parallel as they are with respect to the battery currents; but they present a very high impedance to the voice currents flowing in the metallic circuit formed by the two line wires, for it is evident that in order to pass from one side of the circuit to the other these currents would necessarily pass through the two windings of the impedance coil in series. The currents from the battery, *B*, passing through the two windings in parallel, produce no magnetic effect upon the cores of the impedance coils, and therefore these coils are in a condition to offer a maximum amount of retardation. This is due to the fact that a mass of iron when in a neutral magnetic state is more susceptible to a magnetizing force than when the mass is polarized.

At the sub-stations the supply circuit, after being united at the point, *f*, again divides and passes through the two halves of the primary circuit in multiple; but in this case two primary coils are provided, one in each side of the primary circuit, so that the changes in each side of the circuit may be utilized in producing an inductive effect upon the secondary coil. Thus, at station, *A*, the circuit divides at the point, *f*, one part passing through the side of the primary circuit containing the transmittter, and one of the primary coils, *P′*, and the other half passing through the branch containing the resistance, *g*, and the other primary coil, *P*. The two branches reunite at the point, *f′*, which is grounded through the impedance coil, I_2. The coil, *g*, has about the same resistance as the transmitter in its state of rest, so that the supply current will divide equally between the two halves of the primary circuit, and therefore normally produce no magnetization of the core. A decrease in the resistance of the transmitter will cause a greater current to flow through the primary coil, *P′*, and a correspondingly less current through the primary coil, *P*.

As the two primary coils in this circuit are oppositely wound, a decrease of currrent in one of them will produce the same inductive effect on the secondary as an increase in the other, and when these two effects take place simultaneously in the primary coils, the inductive effects upon the secondary coil are added. An increase in the transmitter resistance will in the same manner induce a current in the opposite direction in the secondary.

Both limbs of each line circuit terminate in contacts on the hook-switch, so that when the hook is raised the connection is completed from the line wires through the telephone apparatus already described. When the hook is down, one limb of the line is left open and the other is closed to ground through a high-resistance polarized bell.

At the central office the circuits are as already described, with the addition of the line annunciators, *K* and *K′*, and the clearing-out or supervisory signals, K_2 and K_3. The operator's talking set is adapted to be bridged across the cord circuit by the listening key, while the generator may be connected between the ground and the tip of the calling plug.

Assuming the apparatus to be in its normal position, when the subscriber at the left of the figure desires a connection with the subscriber at the right, he raises his receiver. This act grounds both sides of his line through his station apparatus. A current from the battery, *B*, thus flows through the drop, *K*, to the two sides of the line in multiple, by virtue of the fact that the tip- and sleeve-springs of the jack rest upon a common anvil. The current flows through the two sides of the subscriber's circuit in multiple, and to ground, and is of sufficient strength to cause the annunciator, *K*, to raise its target. The operator seeing the signal inserts the answering plug, thus cutting off the circuit through the annunciator, *K*, and allowing its target to assume its normal position.

The circuits are now completed from the battery, *B*, through the two halves of the impedance coil, and to ground at the subscriber's station, as already described. The operator then bridges her telephone set across the cord circuit, and communicates with the subscriber. She inserts the calling plug into the jack of the line called for, and depresses the ringing key, which connects one terminal of the grounded generator with the tip strand of the cord, and therefore with one side of the line. A current flows from the generator to ground at the subscriber's station, and operates the polarized bell. That subscriber then removes his receiver from the hook, and the two converse over the metallic circuit formed by the two connected lines.

While the subscribers' receivers are removed from the hooks the current from battery, *B*, flowing through the sleeve strand of the cord circuit energizes the magnets of the clearing-out anunciators, K_2 and K_3, and causes them to lift their targets. As soon as either subscriber hangs up his receiver this current ceases to flow, because the line wire, with which the sleeve strand is connected, is opened at the hook. This allows the target of the annunciator, K_2 or K_3, to fall, showing that that subscriber has ceased to use his insrument.

This represents, perhaps, the highest development attained in any of the methods for centralizing all sources of energy in telephone systems by feeding over the two sides of the line in multiple.

A line circuit wherein the lamp signal is connected directly in the line instead of in the local circuit of a relay, as is usual, is shown in Fig. 252. This is also interesting as showing a practical application

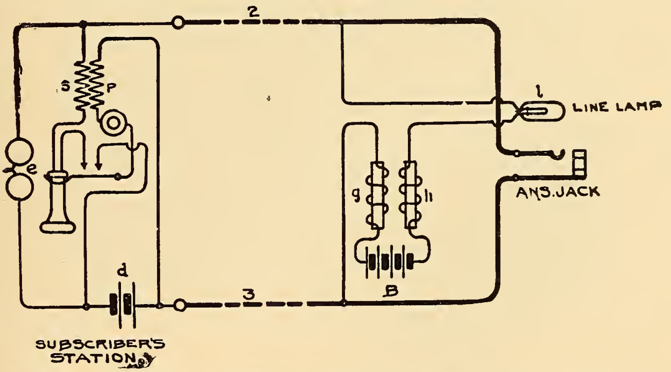


FIG. 252.—LINE CIRCUIT WITH ELECTROLYTIC CELL.

of the scheme already mentioned of placing a secondary battery at the sub-station charged from the central office over the line circuit.

In this the subscriber's apparatus is shown at the left, and the central-office apparatus at the right. The line wire, 2, forming one side of a metallic circuit, is connected with the tip-spring of the jack, and passes through an incandescent lamp, *l*, and through an inductive resistance, *h*, to one pole of a battery, *B*. The other side, 3, of the metallic circuit passes through an inductive resistance, *g*, to the other pole of the same battery. When the subscriber's receiver is on its hook the circuit at the subscriber's station between the two sides of the line wire is completed only through the high-resistance call-bell, *c*, and as this bell has a resistance of about 1000 ohms, the current from the battery through the line circuit is not sufficient to illuminate the lamp, *l*. When, however, the subscriber's receiver is removed from its hook a circuit of low resistance is closed in parallel with the bell magnets, *e*, this circuit including the secondary windings of the induction coil, and the receiver in series. As this circuit may readily be made less than 40 ohms, sufficient current will be allowed to flow from the battery to illuminate the signal, and thus attract the operator's attention.

Whatever current passes through the bell magnets from the battery at the central office, must also pass through the battery, *d*, at the sub-station. This consists of two cells of storage battery of the Planté type. Whenever the apparatus at the subscriber's station is not in use this battery will therefore be receiving a charge from the central-office source, the strength of the latter and the resistance of the circuits being so proportioned that the storage cell will receive a constant charging current of about .02 of an ampere. When the subscriber's apparatus is put in use, however, the battery is thrown in a local circuit including the primary winding, *p*, and the transmitter, and will then perform the functions of an ordinary primary battery in connection with the transmitter. The alternative functions which this battery, *d*, may perform are interesting. It is well known that if a storage cell of the Planté type becomes almost or quite discharged it will develop a counter E. M. F., when a current is sent through it in the direction necessary to charge it, and that this counter E. M. F. will be very nearly equal to the E. M. F. of a similar cell fully charged. Supposing, now, that from some cause or other the cell, *d*, becomes discharged to such an extent that it is incapable of furnishing enough current to operate with the transmitter in the usual manner. In this case, when the receiver is raised, the current from the battery at central, which tends to pass through the storage battery, will meet with a considerable counter E. M. F., which will compel most of the current to pass from the line wire, 2, through the secondary, *S*, receiver, hook lever, transmitter and primary, *P*, to the line wire, 3.

The transmitter will therefore receive current from the battery, *i*, sufficient to operate it, and yet it will be operating with all the advantages to be derived from a local circuit and induction coil; for, although the current operating it comes from the central office, any fluctuations in this current caused by the transmitter will pass through the low-resistance battery, *d*, which will act in this case very much in the same manner as a condenser.

The same general designs of switch-board cabinets as are used in small magneto-switch-boards are often made to serve for common battery boards, their dimensions and construction being changed

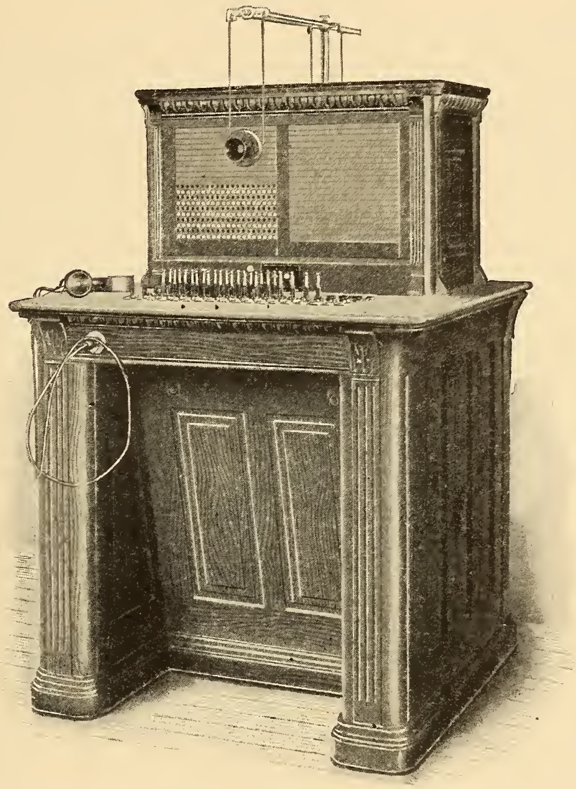


FIG. 253.—COMMON-BATTERY SWITCH-BOARD FOR SMALL EXCHANGES.

sufficiently to accommodate the different class of apparatus. A complete switch-board adaptable to exchanges, having not over one hundred lines, is shown in Fig. 253.

CHAPTER XIX.

COMMON BATTERY SUB-STATION EQUIPMENT.

The essential features of the sub-station equipment for common battery work are the speech-receiving and transmitting apparatus, or receiver and transmitter; the call receiving apparatus, or ringer, the switch-hook for alternately bringing the talking apparatus and the call receiving apparatus in proper relation with the line; and a device, usually a condenser, for preventing direct currents from flowing over the metallic circuit of the line when the telephone is not in use, but adapted to allow alternating currents to pass for the purpose of ringing the bell.

It has been shown in the three preceding chapters that the conditions required of the sub-station in order to bring about the oper-

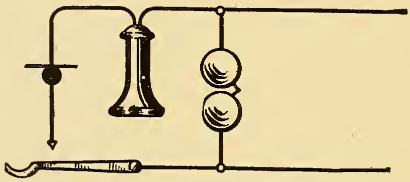


FIG. 254.—SIMPLE SUB-STATION CIRCUIT.

ation of the various signals at the central office, are that the circuit of the line, when the telephone is not in use, shall be open to direct currents, at the same time allowing alternating currents to pass for the purpose of ringing the subscriber's bell. When the telephone is not in use the circuit between the two sides of the line must be complete with respect to both direct and alternating currents.

The simplest form of circuit for the subscriber's station adapted to meet these requirements, is shown diagrammatically in Fig. 254. In this the talking apparatus consists of the transmitter and receiver, placed directly across the two limbs of the line when the hook is raised. The call bell is permanently bridged across the line, no condenser being used in its circuit, and, in order to prevent the operation of the signals at the central office by the flow of direct current through the call bell, the magnets of the latter are wound to a very high resistance, say 10,000 ohms. With this arrangement the relays at the central office would necessarily be adjusted so as not to work through 10,000 ohms, but to respond properly when the shunt circuit through the transmitter and receiver was closed around the call bell, as when the telephone is in use.

This was the arrangement first proposed, and used to some extent in early common battery work. It proved faulty, however, for the following reasons: The constant flow of current from the central office battery through the call bells made necessary a marginal adjustment of the relays at the central office, and also proved a constant drain on the storage batteries, especially severe when a large number of lines were served.

These defects are removed by placing a condenser in series with the bell, in which case the extremely high winding of the coils is unnecessary, 1000 ohms being ample. The circuit arrangement with the condenser added then becomes that shown in Fig. 255.

While the addition of the condenser in this manner removes com-

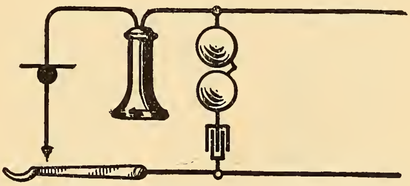


FIG. 255.—SIMPLE SUB-STATION CIRCUIT WITH CONDENSER.

pletely the difficulties due to the waste of current and to the marginal adjustment of the central office relays, it leaves several undesirable features with respect to the talking apparatus. This is due to the fact that the direct current which supplies the transmitter passes also through the receiver coils. Unless, therefore, a receiver is properly "poled;" that is, placed in the circuit of the line in such manner that the steady flow of current through it increases rather than diminishes the strength of its magnets, a serious loss of talking efficiency results. Very often when the receiver is wrongly placed in the line, the flow of current through it proves about sufficient to neutralize the effect of the permanent magnets, thus almost completely destroying the effectiveness of the receiver. This disadvantage does not exist if the receivers are placed in the line so that the current strengthens rather than weakens their pull on their diaphragms. This can be effected by marking the positive and negative terminals of the receiver so that by due care the installers and inspectors may properly connect them. It frequently happens, however, that in making changes in line connections, perhaps in a manhole or on a pole, the two sides of the line will be transposed, which, of course, subjects a receiver, previously connected properly, to current in the wrong direction and makes necessary a trip of the inspector to that station.

This arrangement has another objection in that a receiver properly adjusted for maximum efficiency on a line having a certain current strength, may not be properly adjusted for a line having a stronger current. Frequently when placed on a very short and therefore low resistance line, the magnetic attraction of the cores is sufficient to pull the diaphragm into contact with the pole pieces, thus destroying all possibility of its vibrating.

The prevention of the flow of direct current through the receiver has been solved in a number of ways, perhaps the most common way being that employed in instruments made by the Western Electric

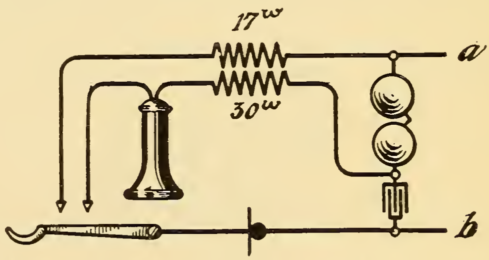


FIG. 256.—WESTERN ELECTRIC SUB-STATION CIRCUIT.

Company for the various Bell companies. In this arrangement, which is shown in Fig. 256, the receiver is included in a local circuit which also includes, when the hook is raised, one winding of an induction coil, and a two-microfarad condenser, which is also employed for transmitting the ringing currents. When the hook is depressed by the weight of the receiver there is no path for direct currents between the limbs, *a* and *b*, of the line on account of the presence of the condenser. The only path for alternating currents is that through the condenser and bell. When the receiver is removed from the hook, however, direct current may flow from the central office over the limb, *a*, of the line through the 17-ohm winding of the induction coil and the transmitter to the limb, *b*, of the line. This flow of current causes the operation of relays for signaling at the central office, and also supplies the transmitter with direct current for talking. When the transmitter is actuated by sound waves it will cause undulations in the current flowing in the line which, passing through the translating devices at the central office will cause corresponding undulations in the receiving line, and thus effect the transmission of speech.

When a station is receiving speech the fluctuating currents caused by the operation of the transmitter at a different station, will pass from the limb, *a,* to the line through the 17-ohm induction coil, and the transmitter to the limb, *b,* of the line, and by induction between the two windings of the induction coil, these fluctuations will be repeated into the local circuit containing the receiver, the 30-ohm winding of the induction coil, the condenser and the transmitter.

The manner in which this circuit is supposed to operate is explained by Mr. W. W. Dean in the following paragraphs, in connection with a diagram of which Fig. 257 is a reproduction:

"The secondary coil of the induction coil, *S,* measures 17 ohms,

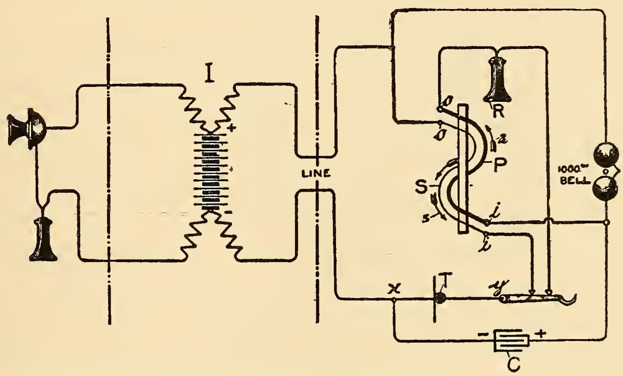


FIG. 257.—WESTERN ELECTRIC SUB-STATION CIRCUIT.

and has 1700 convolutions of wire; the primary circuit, *P,* measures 30 ohms, and has 1400 convolutions of wire. The ends of the primary and secondary coils, marked *o,* are the outside ends, and the ones marked *i* are inside ends; both coils are wound in the same direction on the core. The action of this current is as follows: Suppose the transmitter, *T,* is at rest and has a certain fixed resistance. Current will flow from the positive side of the battery over the line through the secondary winding of the induction coil in the direction of the arrow, No. 1, through the hook contact, transmitter, *T,* to the other side of the line, to the negative side of the battery. Between the points, *x* and *y,* there will be a certain electrical potential, the condenser, *C,* will be charged to the same potential that exists between the points, *x* and *y,* and the direction of this charge will be as indicated in the sketch. In speaking into the transmitter, *T*, a sudden lowering of its resistance is caused. The potential between the points, *x* and *y*, will be reduced; in other words it will be lower than the charge existing in the condenser, *C*. A discharge will now take place from the condenser through the primary, *P*, of the induction coil, through the receiver, *R*, the hook, the transmitter, *T*, to the negative side of the condenser. This discharge of current will be in the direction indicated by arrow No. 2. The flow of current through the primary, *P*, as indicated, will cause a current to be induced in the secondary winding, *S*, in the direction of the arrow No. 3. This current, on account of the "step-up" effect of the induction coil, will be of a higher potential than the original current, and, as it is in the same direction as the current indicated by arrow No. 1, will augment it. When the transmitter, *T*, returns to its normal position, the potential will be again raised between the points, *x* and *y*. Cur-

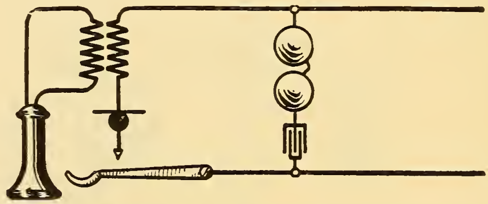


FIG. 258.—STROMBERG-CARLSON SUB-STATION CIRCUIT.

rent will, therefore, flow into the condenser from the point, *y*, through the hook to receiver, *R*, through the primary winding, *P*, in a direction opposed to arrow No. 2, to condenser, *C*, to the point, *x*. An induced current will be generated in the secondary, *S*, in a direction opposed to arrow No. 3. This current will oppose the main line current flowing in the direction of arrow No. 1, but on account of the increase in resistance of the transmitter, *T*, this current is on the decrease, and the last mentioned induced current will still further tend to decrease it. It will thus be seen that the current changes taking place in the telephone line are of much greater range than they would be if induction coil were not used.

"In order to prove that the action of the coil augments the transmission, connect a switch so that the terminals of the secondary coil can be instantaneously reversed, or, in other words, change the relative positions of the points, *o* and *i*, of the coil, *S*, and a difference in volume of transmission of about 50 per cent. will be noticed."

An additional function of the induction coil and the local circuit in the Western Electric Company's arrangement is that of putting the receiver in inductive relation to the line without subjecting it to the passage of direct current through it.

In Fig. 258 is shown the current arrangement of the common battery sets manufactured by the Stromberg-Carlson Telephone Manufacturing Company. In this the induction coil has one of its wind-

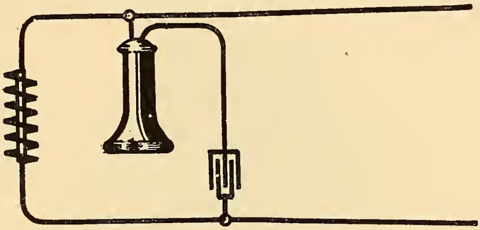


FIG. 259.—SIMPLIFIED KELLOGG SUB-STATION CIRCUIT.

ings placed directly in series with the transmitter when the hook is up, this path shunting the path containing the bell and condenser. The receiver is placed in an entirely local circuit in series with the other winding of the induction coil. This arrangement accomplishes the removal of the receiver from the action of direct current in a very simple manner.

The method by which the Kellogg Company places the receiver in proper relation with the line without subjecting it to the passage of direct current is shown in simplified form in Fig. 259, which shows the condition when the hook is raised. In this the transmitter is

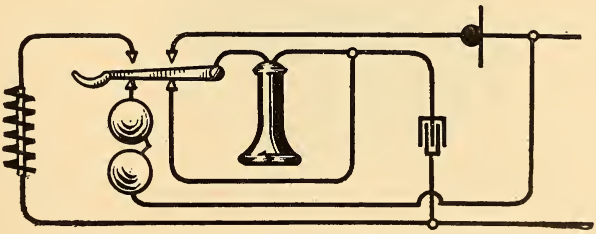


FIG. 260.—KELLOGG SUB-STATION CIRCUIT.

placed in series across the line with an impedance coil of low resistance, but of high retardation. Direct current from the central office, therefore, flows readily through this path for the operation of the signals and for the supply of current to the transmitter. Around the impedance coil is placed a shunting circuit containing the receiver and a two-microfarad condenser, and through this path, instead of through the impedance coil, the fluctuating voice currents pass. It might be thought that the presence of the impedance coil would materially reduce the receiving efficiency of the station, but whatever reduction of efficiency does occur due to its presence is so slight as to be unnoticeable even by an expert.

In Fig. 260 is shown the actual working connections of this arrangement through the hook switch by means of which the bell or

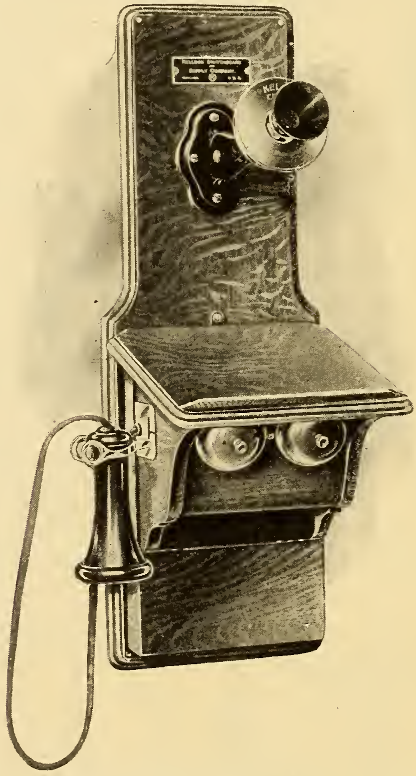


FIG. 261.—COMMON BATTERY WALL SET—CLOSED.

the talking apparatus are alternately brought into service. It will be seen that when the hook is raised the conditions shown in Fig. 259 exist. When, however, the hook is depressed the transmitter circuit is open, as is also the circuit of the impedance coil, while the receiver is short-circuited; the only circuit across the line is that through the bell and the condenser in series, which is the condition required by modern central office circuits.

The various Bell companies employ in their ringing circuit a bell wound to 1000 ohms and a two-mocrofarad condenser. This arrangement gives thoroughly satisfactory results and has been largely adopted among the various Independent companies. It is found, however, that almost equally satisfactory results may be obtained by the use of a 500-ohm bell with a two-microfarad condenser. When, however, the capacity of the condenser and the resistance of the bell are both materially reduced from that of the

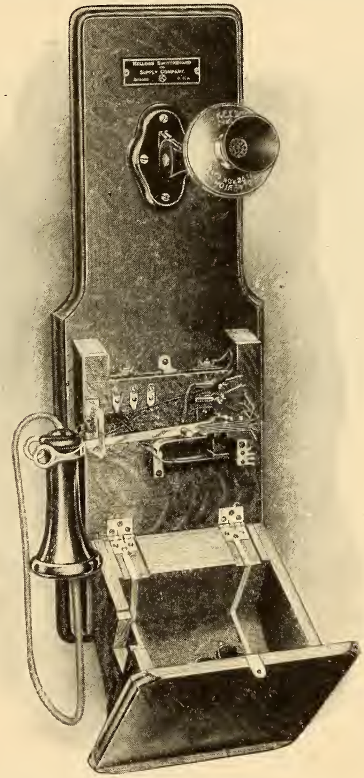


FIG. 262.—COMMON BATTERY WALL SET—OPEN.

Bell standard a decided falling off in efficiency is found; for instance, a 500-ohm bell with a one-microfarad condenser, while operative, does not give satisfactory ringing with the average central office generator. Many of the Independent companies are therefore using a two-microfarad condenser with a 500-ohm bell, the bell being of the usual long-core type and wound for a maximum number of turns by using as large a wire as the winding space will permit.

As illustrative of the arrangement of parts in a modern common battery wall telephone, that of the Kellogg Company may be taken from among numerous good designs. This is shown in Figs. 261 and 262, the latter figure showing the box opened for inspection or repairs. The ringer is mounted on the movable portion of the box, connection to it being made through the hinges. The hook retardation coil and various binding posts are mounted on the front face of the condenser receptacle, which is permanently secured to

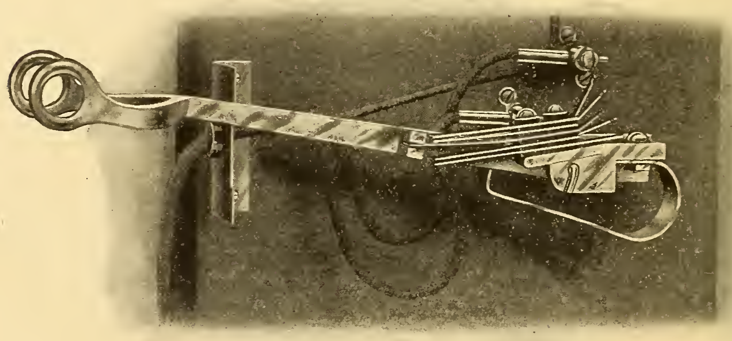


FIG. 263.—DETAIL OF HOOK AND CORD MOUNTING.

the back board. In order to allow the box when opened to swing clear of the hook lever, the hook escutcheon is split, part of it being secured to the condenser receptacle and part of it to the movable box. The receiver cord is carried through a hole in the stationary part of the escutcheon, in order to prevent its being pinched by a careless closing of the box. These features are well shown in Fig. 263.

CHAPTER XX.

THE COMMON BATTERY MULTIPLE SWITCH-BOARD.

In the development of the common battery multiple switch-board the tendency has been, on account of the great cost of the multiple jacks and cables, and further, on account of the ever-increasing necessity to economize room in the jack space, to simplify the multiple jack, reducing the number of its contacts and the number of wires for each line in the multiple cable. We have seen that in the old branch-terminal magneto-multiple board each jack had five contacts, three springs and two sleeves or rings. Two of these contacts were strapped together in each jack, thereby making them, electrically speaking, one contact, while another of the contacts in each jack was connected to a common or ground wire. The circuit was such as to necessitate the use of three individual wires besides the common wire, all running through the entire length of the multiple board and connected to contacts in a jack on each section.

In some of the early common battery systems the circuits used were of such complexity as to require as many as four individual wires in the multiple cables for each line, together with one or more common wires.

In the common battery multiple switch-board, universally adopted by the Bell companies and manufactured by the Western Electric Company, the circuit has been so simplified as to require only three contacts in the jack. Three wires, individual to each line, run through the multiple board connected respectively to the three contacts of each spring-jack belonging to that line.

Recent developments have produced common battery switch-boards wherein only two contacts are required in the multiple jacks, and consequently but two wires for each line connecting with these jacks in the multiple board. On account of the keen rivalry between manufacturers employing three wires for each line in the multiple cable and those employing but two, the names, "two-wire multiple switch-board" and "three-wire multiple switch-board," have recently come into use. These names signify, of course, the number of wires, individual to each line, necessary to be carried throughout the sections in order to make connections with the contacts of each multiple jack.

Typical of all three-wire switch-boards is that of the Western Electric Company, used by the Bell Telephone companies and adopted as the standard by those companies. The line circuit in this system is shown in Fig. 264, which also includes the apparatus at the subscribers' stations shown at the right of the figure. The apparatus at the subscriber's station is, as will be seen, that already described in a previous chapter as being the standard Bell sub-station equipment. It may be well, however, to reiterate that when the receiver is on its hook the circuit of the line is open on account of the condenser, while, when the receiver is removed from the hook, the circuit of the line is closed through the talking apparatus.

At the central office the two sides of the line pass to the tip and ring contact springs, respectively, of each multiple jack and of the

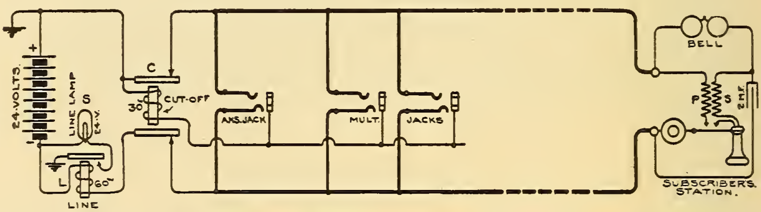


FIG. 264.—WESTERN ELECTRIC MULTIPLE SWITCH-BOARD LINE CIRCUIT

answering jack, after which they connect respectively with two back contacts of a relay, *c*, called the cut-off relay. These contacts normally rest against two movable levers, of which the one connected with the tip side of the line is connected to the grounded side of the central office battery, and the one connected with the ring side of the line to the ungrounded side of the battery through the coil of the line relay, *L*. The winding of the cut-off relay is included in a circuit between the grounded side of the battery and a wire extending to all of the sleeve rings of the jacks.

The line relay, therefore, normally stands ready to be operated by current flowing in the metallic circuit of the line, and when so operated lights the line lamp, *S*, by the attraction of its armature. This lamp draws current from the same battery that supplies current to the relays. It is evident, therefore, that the line relay is under the control of the subscriber, who, by removing his receiver from its hook, will close the circuit of the line, allowing current to flow from the battery through the line relay. At all times, however, when the subscriber's receiver is on its hook the circuit of the line is held open to direct currents by the condenser at the subscriber's station, thus preventing the operation of the line relay.

The cut-off relay, being in an entirely local circuit, is under the control of the operator in a manner which will be pointed out when the cord circuit is considered. This relay, as will be seen by reference to Fig. 264, serves, when operated, to sever the signaling apparatus and battery from both sides of the line circuit, thus rendering the line relay and lamp irresponsive to any movement of the subscriber's hook.

One of the cord circuits is shown in Fig. 265. In this the answering and calling plugs are shown at the extreme left and right-hand portions, respectively. Each plug has three contacts, two of which

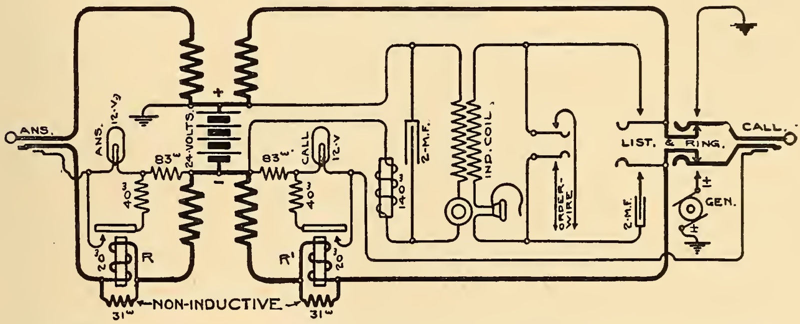


FIG. 265.—WESTERN ELECTRIC MULTIPLE SWITCH-BOARD CORD CIRCUIT.

—the tip and ring—are connected, as indicated by heavy lines, so as to complete the talking circuit between the two plugs. The third contact of each plug is connected through the supervisory signaling apparatus to the live side of the battery, as shown. The tip and ring contacts of the answering plug are connected through the two halves of one side of the repeating coil, between which is connected the battery. In the same manner the tip and ring strands of the calling plug are connected by the two halves of the other winding of the repeating coil, between which is connected the same battery. This battery is the same as that used to supply current to the line signals, as indicated in Fig. 264.

The repeating coil (there is one for each pair of cords and plugs) has four windings, each having approximately 3300 turns, all of the windings being on the same magnetic core. It is evident that these connections allow direct current from the storage battery to pass out over the metallic circuits of two connected lines to energize the sub-station transmitters, in accordance with the system of Hayes, already described in theory. In this way conversation between two connected subscribers is made possible.

In the ring strand of the cord attached to each plug is connected a supervisory relay, *R* or *R'*, which is energized, as is readily seen, only while current is flowing over a line with which the corresponding plug is connected, which occurs only while the receiver of that line is off its hook. Each relay controls the illumination of the supervisory lamp corresponding to the plug to which the relay belongs. When a plug is inserted in a jack the relay, when actuated, serves to close a 40-ohm shunt about the lamp which prevents its illumination. Current is fed from the non-grounded side of the battery through an 83-ohm resistance coil to each lamp, the return side of this circuit being made, when the plug is inserted in a jack, through the cut-off relay to earth. Under normal circumstances, therefore, when the plug is not inserted in a jack the supervisory relay will remain unlighted even though unshunted, because the circuit to the grounded side of the battery is broken. When a plug is inserted into a jack, however, the lamp will be lighted as long as the supervisory relay is not actuated. Since the actuation of the supervisory relay depends upon the subscriber with whose line the plug is connected, having his telephone off the hook during conversation, it follows that when a connection is made with a line the supervisory lamp will be shunted while the subscriber's receiver is off its hook, and therefore the lamp will not be illuminated. If, however, the subscriber's receiver is on its hook the supervisory relay will not be energized and the shunt will not exist about the lamp, which will therefore be lighted.

A ringing and listening key are shown at the right-hand portion of this figure, and need no description. The operator's transmitter receives current constantly from the battery through a 140-ohm retardation coil and the primary of the induction coil. Bridged across the circuit from ground to a point between the transmitter and the retardation coil is a two-microfarad condenser for the purpose of allowing the fluctuation set up by the transmitter to circulate in the circuit formed by the condenser and the primary winding of the induction coil without passing through the retardation coil. The connections of the secondary winding of the operator's induction coil and the operator's head receiver are made in the usual manner. Bridged across the secondary side of the operator's talking circuit is an order wire key adapted to make connection between the operator's telephone set and an order-wire circuit, for the pur-

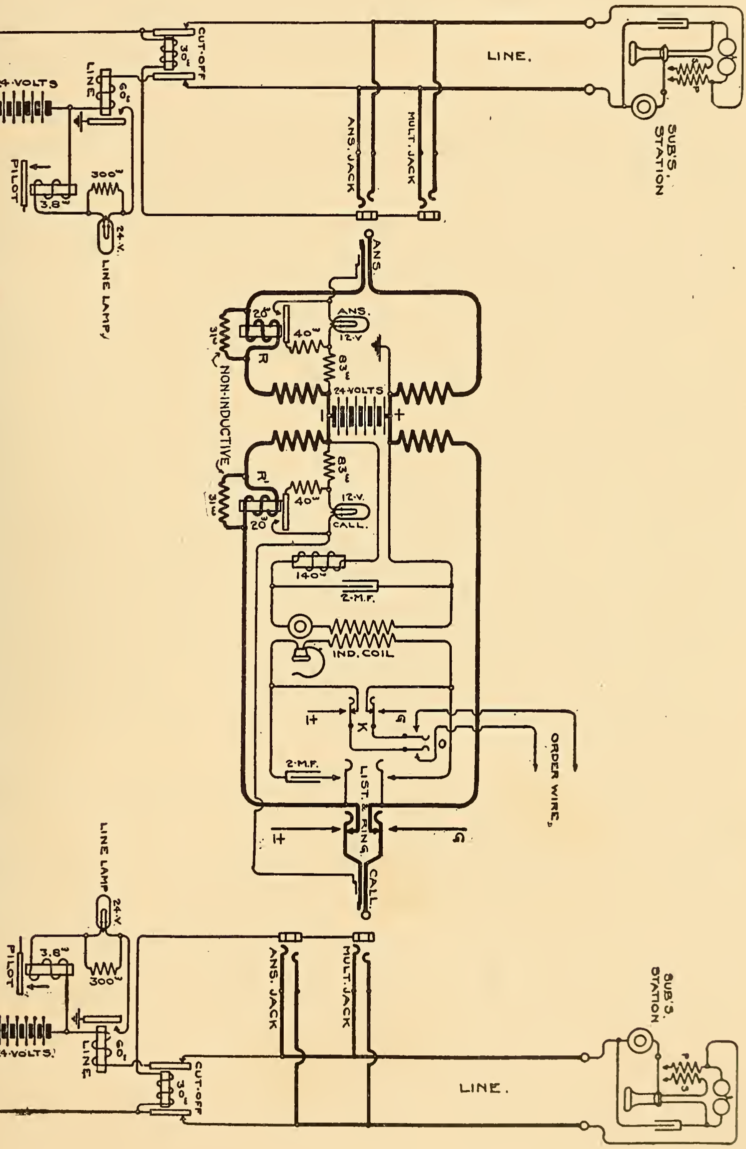


FIG. 266.—CONNECTION BETWEEN TWO SUBSCRIBERS THROUGH ONE OFFICE—WESTERN ELECTRIC SYSTEM.

pose of allowing the operator to communicate with some other operator, usually at a distant exchange, for purposes that will be pointed out in subsequent chapters. The supervisory relays are shunted in all cases where they are placed in the talking circuit by a non-inductive resistance of about 30 ohms, this resistance being wound on the relay spool in addition to the active winding. A non-inductive path for the voice currents is thus afforded around the relay windows.

In Fig. 266 the cord circuit of Fig. 265 is shown connecting two of the line circuits of Fig. 264. While the arrangement of the apparatus of the line circuits of this latter figure differ slightly in appearance, it will be seen that the actual circuit connections are the same, the change having been made in the diagrammatic arrangement for the purpose of giving a clearer understanding.

Considering the line at the left to be that of the calling subscriber, and the line at the right that of the called subscriber, the operation is easily understood in view of what has already been said. With both plugs removed from the jacks, the raising of the calling subscriber's receiver from its hook illuminates the lamp of that line, which remains lighted until the operator answers by the insertion of the answering plug into the answering jack. The insertion of this plug not only establishes the circuit over which speech is transmitted, but the third contact on the plug engages the sleeve of the jack, thus allowing current to flow from the live side of battery through the third strand of the cord and the third wire of the jack to the coil of the cut-off relay and to ground. This operates the cut-off relay which breaks the circuit between both sides of the line and the line-signaling apparatus.

By means of her listening key the operator is then enabled to converse with the subscriber through the windings of the split-repeating coil in the cord circuit.

The operator before inserting the calling plug into the multiple jack of the called subscriber must ascertain whether or not the line of that subscriber is busy, and upon touching the tip of the calling plug to the sleeve contact of the multiple jack of the called line she will get a click in her head telephone if the line is busy and silence if it is free. The reason for this is as follows: If the line is not connected to, at another section, all of the test contacts of the jacks of that line will be at the same potential as that of the earth, and when the operator applies the tip of the plug which also is connected to ground to such a contact no current will flow, because there is no source of electro-motive force in the circuit. If, on the other hand, the line is connected to, at another section, as would be the case when the line was busy, all of the test rings of the jacks of this line will be raised to a certain potential above that of the earth by virtue of being connected to the live side of the battery through the third strand of the cord circuit and third contact of the plug. As a result of this raising of potential of the test rings, the operator will get a click in her head telephone when she applies the test plug, due to the flow of the current from the test ring through the tip of her plug to ground through a portion of the repeating coil. This alters the potential across the operator's receiver circuit, thus giving a click in the operator's ear.

If the line is free she inserts the plug to its full extent and presses her ringing key, which rings the bell of the called subscriber. The insertion of the plug also operates the cut-off relay of the called line, thus cutting off its signaling apparatus. As soon as the calling plug is inserted in the jack of the called line the supervisory lamp associated with that plug will be illuminated, the same current serving to illuminate the lamp and to operate the cut-off relay. As soon, however, as the subscriber responds he will close the circuit between the two sides of the line and thus allow current to pass through the line and furnish current to the transmitter. This current will pass through the supervisory relay, which will then be operated, and close the low resistance shunt about the lamp, thus extinguishing it. The answering supervisory lamp did not light at all when the operator answered the call, because the subscriber's telephone being off its hook, current at once passed through the answering supervisory relay, thus shunting the answering supervisory lamp.

Both supervisory lamps, therefore, remain out during a conversation, but as soon as either subscriber hangs up his receiver the corresponding supervisory lamp will light, because the armature of the supervisory relay will fall back and allow the full strength of current to traverse the lamp.

An important feature associated with the line-calling apparatus has been omitted from the circuits of the Western Electric Company, so far considered. This has been done for the sake of simplicity in describing the main functions of the system.

In order to afford additional means for attracting the attention of the operator when a call is made, what is termed a "pilot lamp" is placed on each position of the multiple switch-board, this lamp being so wired as to be lighted whenever any line lamp on that position is lighted in response to a call. This lamp (there being one for every position) is located on a prominent portion in the face of the board, and is provided with a much larger lens than the line lamps, so as to be easily distinguishable, even to a person in a distant part of the room. The circuit arrangement by which a single pilot lamp is associated with all of the lamps on a position, and by which a single night alarm-bell for the entire central office is associated with all the pilot lamps, is shown in Fig. 267.

Included in the common battery lead, which feeds all of the line lamps on any position, is placed a pilot relay, *P*, which is of low resistance so as to allow sufficient current to pass through it to

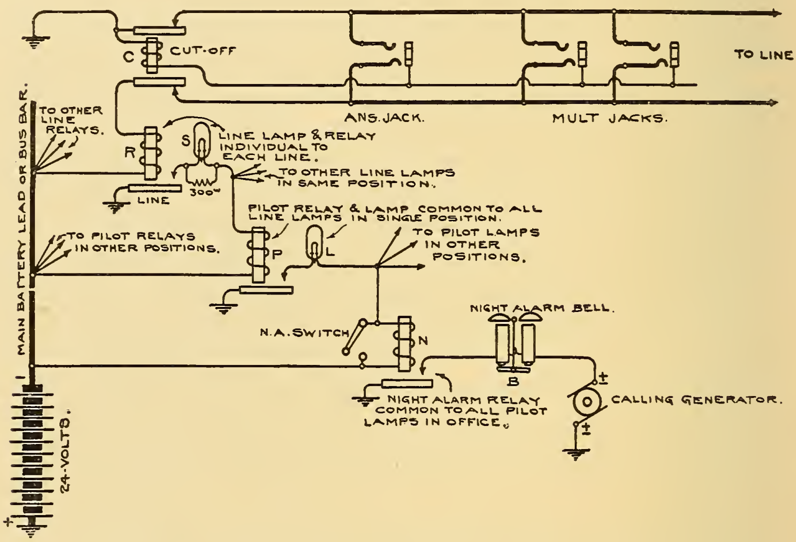


FIG. 267.—WESTERN ELECTRIC LINE AND PILOT CIRCUITS.

properly light several of the line lamps simultaneously. This relay is therefore in a portion of the circuit common to all of the line lamps on a position, and will therefore be operated whenever any line relay closes the circuit of any lamp on that position. The operation of this pilot relay will light the pilot lamp, *L*, on that position. The 300-ohm resistance coil shown in multiple with the line lamp, *S*, in Fig. 267 is furnished, so that the subscriber, whose line lamp has burned out, can signal the exchange by lighting the pilot lamp.

It is also customary, especially for use at night, to provide an alarm-bell, *B*, adapted to ring when a call is received on any line in the entire office. This is usually termed a "night alarm." For this purpose a single relay, *N*, is wired in the common portion of the circuit through which current flows from the battery to all of the line pilot lamps, this relay occupying the same relation to all of the pilot lamps in the office as each line pilot does to all of the line lamps on any one position. It therefore follows that whenever any pilot lamp is lighted the common night-alarm relay will be actuated, which will close the circuit of the night-alarm bell. This bell may be an ordinary vibrating bell, but better practice is to make it a magneto bell, having it actuated by current from the regular ringing generator.

The common battery multiple switch-board of the Western Electric Company, the circuits of which are shown in Figs. 264 to 267, is by no means the only one using three wires in the multiple, but it has the distinction of having been put into far greater use than any other common battery switch-board, probably greater than all other systems combined. It represents the highest development of the three-wire system, and the fact that it has been the standard system of the Bell companies for a number of years speaks for its efficiency.

It will be seen that in this system the circuit is carried through the jacks to the third conductor of the cord circuits for the purpose of securing a reliable busy test and for securing the operation of the cut-off relay and the supervisory apparatus. In this way all of these functions are performed by circuits separate from those used in the actual transmission of speech. In the design of the two-wire multiple switch-board, of which brief mention has already been made, a most difficult problem had to be faced at the outset. Since two wires or two conductors were absolutely necessary for talking purposes, it was necessary that means be devised by which all of these results could be accomplished over the same set of conductors, or such portion of them as were used for talking, and all this had to be accomplished without in any way interfering with the talking efficiency, which, after all, is of paramount importance. The problem is, however, infinitely more complex when applied to the modern common-battery system, because of the necessity of providing for the automatic operation of both line and supervisory signals, and the obtaining of a reliable test without having any of these functions interfere with each other or with the proper supply of transmitter current from the central office battery to the subscribers. The first practicable common battery two-wire multiple switch-board system to come into extended commercial use is the one developed by the engineers of the Kellogg Switch-board and Supply Company and put into extensive use by that company.

The line circuit, which has been the standard circuit used in the Kellogg system for several years, is shown in Fig. 268. At the left of this figure is shown the typical, simplified sub-station apparatus, the sub-station circuit, actually used in the Kellogg system, having already been described in Chapter XIX. The two limbs of the line extend directly to two spring levers of the cut-off relay. Each of these springs normally rests against a back contact point when the relay is not energized, each being adapted to break this contact and make contact with another normally open point when the relay is energized. The back contact of that relay spring, which is connected with the sleeve side of the line, is connected through the coil of the line relay and the common battery to the ground.

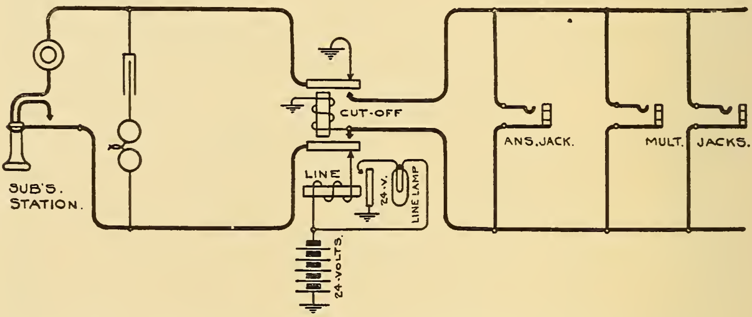


FIG. 268.—KELLOGG MULTIPLE SWITCH-BOARD LINE CIRCUIT.

The back contact of the spring connected with the tip side of the line is connected directly to ground. With the cut-off relay in its normal position, therefore, the line relay is placed under the control of the subscriber in the same manner as in the line circuit of the Western Electric Company. This line relay controls a lamp placed adjacent to the answering jack.

When the cut-off relay is energized the spring connected with the tip side of the line makes engagement with a contact connected to a wire leading to all of the tip springs of the answering and multiple jacks belonging to that line, while the spring in connection with the sleeve side of the line engages a contact connected with all of the sleeve contacts of the jacks. The jacks have but two contacts, a tip and a sleeve, the sleeve forming the test ring as well as one terminal of the talking circuit. The coil of the cut-off relay is permanently connected between the sleeve contacts of the jacks and the earth, so that the circuit over which it is operated embraces a portion of the talking circuit.

Normally, when no plug is inserted into a jack of a line, the cut-off relay is not energized and the jacks are entirely disconnected from the line, while the signaling apparatus is operatively connected with the line. When a cut-off relay is operated by the insertion of a plug into a jack the line relay and line-signaling apparatus is cut completely clear of the line by the breaking of the back contacts on the cut-off relay, while the jacks are connected with the line by the making of the front contacts.

In Fig. 269 is shown, stripped of some details for the sake of clearness, a cord circuit commonly used in connection with switch-boards employing the line circuits just shown. This circuit em-

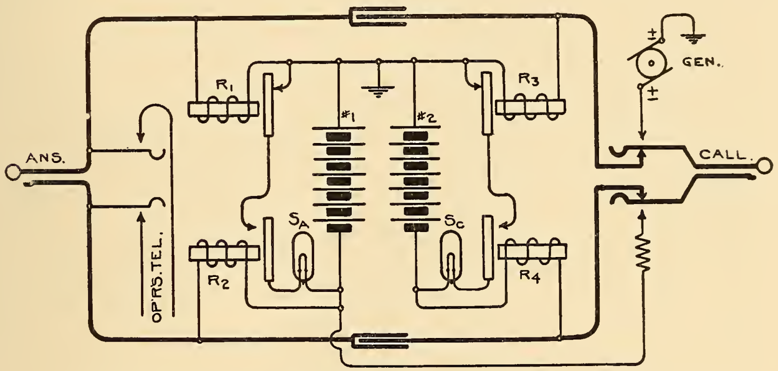


FIG. 269.—KELLOGG MULTIPLE SWITCH-BOARD CORD CIRCUIT SIMPLIFIED.

ploys two-conductor plugs and two-conductor cords, the answering plug being shown at the left and the calling at the right. It will be seen that the tip of the answering plug is connected with the tip of the calling plug through a condenser, the sleeve of the answering plug being connected to that of the calling plug through another condenser. It is through these condensers that the fluctuating voice currents pass during a conversation between two subscribers. Two batteries, 1 and 2, are employed, each having the positive pole grounded. The grounded pole of battery, 1, is connected to the tip side of the answering cord through the winding of relay, R_1, while the ungrounded pole of this battery is connected to the sleeve side of the same cord through the relay, R_2. It is through the windings of these relays that current is fed from battery, 1, for use in talking on the line to which the answering plug is connected. In the same manner the relays, R_3 and R_4, connect the poles of battery, 2, with the tip and sleeve strands, respectively, of the calling plug, thus supplying current to the line with which this latter plug is connected.

The relays, R_1 and R_2, control the circuit of the supervisory lamp, *Sa*, while the relays, R_3 and R_4, similarly control the circuit of the lamp, *Sc*. The relays, R_1 and R_3, have normally closed contacts in the circuits of their lamps, while relays, R_2 and R_4, normally hold their contacts open, these contacts also being in the circuits of their respective lamps.

Considering now the relays on the answering side of the cord circuit only, it is quite evident that the relay, R_2, which is connected from the sleeve side to battery, will be actuated as soon as the answering plug is inserted into the jack, the circuit over which the current flows being traced from the battery through relay, R_2, the sleeve strand of the cord circuit to the sleeve side of the jack, thence to ground through the cut-off relay and to the opposite pole of the battery. This current also serves to operate the cut-off relay, and both this relay and the relay, R_2, remain closed as long as the plug is in the jack of the line, regardless of the position of the subscriber's switch-hook, and, in fact, regardless of any other changes.

The operation of the relay, R_2, will cause the lighting of the supervisory lamp, *Sa*, provided the relay, R_1, is not actuated at the same time. It will be seen that if the subscriber on the line to which the connection is made has his receiver off its hook the relay, R_1, will be operated over the following path: from the ungrounded pole of battery, 1, through the relay, R_2, to the sleeve side of the line to the subscriber's station and through his talking apparatus back to the tip side of the line, thence through the tip side of the cord circuit to the winding of relay, R_1, to the grounded pole of the battery. The completeness of this circuit depends on whether the subscriber's receiver is on or off its hook, and therefore the relay, R_1, is under the control of the subscriber. Since, when a connection is made with a line the relay, R_2, is always operated, the only thing needed to control the lamp is the operation of the relay, R_1. From this it follows that when the connection is made with the line the lamp is under the control of the subscriber on that line.

Instead, therefore, of making the supervisory lamp ready for operation by completing its normally open connection at the third contact of the plug and jack, as in the Western Electric system, this is done in the Kellogg system by a separate relay, which relay is operated by the insertion of a plug into the jack. This being the case it will be seen that the relay, *R'*, of the Kellogg system corresponds exactly in function with the supervisory relay of the Bell system.

The terminals of the calling generator are associated with the ringing key, so as to ring a subscriber in the ordinary manner. A little consideration will show, however, that if no other than the usual means are provided, the operation of a ringing key would, by cutting off the other portions of the cord circuit, cut off all battery from the line, and thus allow the de-energization of the cut-off relay. This would then be under the influence of the ringing cord, with the result that its armature would be rattled back and forth, alternately connecting and disconnecting the jacks from the line. In order to prevent this the back contact of the ringing key on the sleeve side is

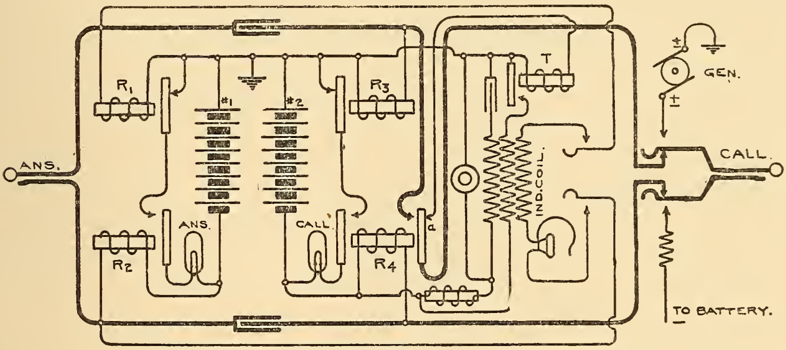


FIG. 270.—COMPLETE KELLOGG CORD CIRCUIT.

connected with the ungrounded terminal of the common battery, so that, although the original connection with the battery is broken by the operation of ringing, it is at once re-established by the back contact of this key when thrown in the ringing position. A flow of direct current thus takes place from battery, through the back sleeve contact of the ringing key, and thence through the cut-off relay to ground. This serves to hold the cut-off relay in its operated position during ringing. A resistance coil of about 50 ohms is placed in the lead from battery to the back contact of the ringing key on the sleeve side, to prevent possible damage due to excess current should a ground occur in some of the key springs.

In order to simplify the explanation of the supervisory circuits some of the features by which a suitable test is made for "busy" lines were omitted from the cord circuit shown in Fig. 269. In Fig. 270

these features have been added. It will be noticed that in the latter figure the relay, R_4, is provided with an armature, *a*, which was not shown in Fig. 269, this armature serving normally, or when the relay is not operated, to hold the tip side of the calling cord circuit open. In this position the tip of the calling plug, instead of being connected with the tip of the answering plug, as is necessary for conversation, is connected to ground through the test relay, *T*.

The test relay, when operated, simply closes a circuit including an extra winding on the operator's induction coil, and battery No. 2, thus, by induction, causing a current to flow through the operator's head receiver and causing the customary click.

The operation of the test system may now be described: When a line is not busy each of the test rings or sleeve contacts of the jacks belonging to that line is maintained at the same potential as the earth, these contacts being connected to no source of electromotive force and being connected to earth through the coil of the cut-off relay. If, under these circumstances, the tip of the calling plug is applied to the test contact of the jack no effect will be produced on the test relay, because there will be no source of electromotive force in the circuit thus closed, and the relay will not respond. Moreover, there will be no chance of the test rings being raised to a potential above that of the earth from some extraneous source, as, for instance, a cross on the line, because these test rings are entirely removed from connection with the external lines, being separated from them at the cut-off relay.

If, however, the line tested is busy by virtue of being connected to at some other section, all of the test rings belonging to that line will be raised to a certain potential above the earth, since they will be connected directly with the ungrounded side of the battery through the sleeve contact of the plug. When a test of a jack of a busy line is made at any position, current will flow from the test ring through the tip of the calling plug used in making the test, to the armature, *a,* of the relay, R^4, thence through the back of this armature to the coil of the test relay, thence to ground. The current thus flowing will energize the test relay, and by closing its local circuit through the extra winding on the operator's induction coil, will cause a click in the operator's telephone. In order for this test to be operative the relay, *T*, must be quick-acting, so as to respond to the slightest touch between the tip of the calling plug and the ring on the jack being tested.

The line pilot and night alarm circuits have been omitted from the figure illustrating the Kellogg system. They are associated with the line lamp circuit in practically the same manner as in the Western Electric system. The operation of these will, therefore, be made clear from the description of the Western Electric pilot circuit already given in connection with Fig. 267.

The Kellogg Company also applies the pilot feature to the supervisory signals in such a manner that a pilot lamp will light on any position whenever the subscriber who originated the call hangs up his receiver. In other words, the pilot lamp will light whenever the subscriber to whose line the answering plug is connected hangs up his receiver. The night alarm bell will also sound if the switch controlling it is in the proper position. This is readily accomplished by placing in series with the supervisory lamp associated with the answering plug a pilot relay which controls the pilot lamp for that position, it being understood, of course, that this lamp is common

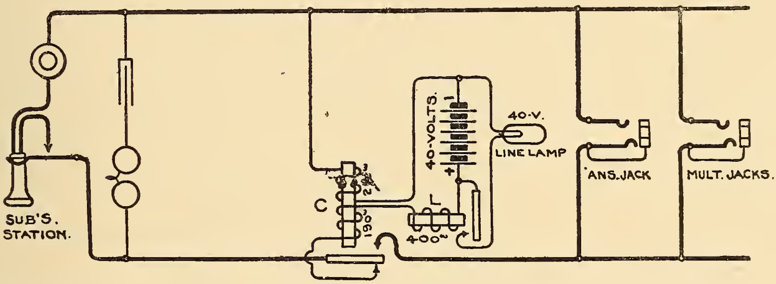


FIG. 271.—STROMBERG-CARLSON TWO-WIRE MULTIPLE SWITCH-BOARD LINE CIRCUIT.

to the circuits of all the answering supervisory lamps on that position.

In a common portion of the circuit belonging to all of the supervisory pilot lamps in the office is placed a night alarm pilot relay in the same manner as the night alarm relay was applied to all the line pilot lamps. This supervisory night alarm is useful at night for calling the attention of the operator to the fact that a disconnection is desired on some portion of the board.

The Stromberg-Carlson Company during the last few years has installed in a number of places a two-wire multiple common battery system, the line circuit of which is shown in Fig. 271. In this circuit the cut-off relay, *C*, is provided with two coils differentially wound, so that when the two windings are traversed by equal currents in opposite directions no effect will be produced upon the core. These windings are put on the core "in tandem," so to speak, one winding being on each end, and in order to have the rear winding as effective as the one nearest to the armature the former is given a few more turns, and, therefore, a slightly greater resistance. Included between the windings and in series with them is the coil of the line relay, *L*, and a 40-volt storage battery, this latter being common to all lines.

The tip side of the line is connected to one terminal of one of the windings of the cut-off relay, and also to the tip springs of all the jacks of that line. The sleeve side of the line is connected to the armature of the cut-off relay, the back contact of which is connected with one terminal of the second coil of the cut-off relay. Under normal conditions, therefore, that is, when the cut-off relay is not energized, the two windings of the cut-off relay, together with that of the line relay and the common battery are all connected in series across the circuit of the line. It will be evident that when a subscriber's receiver is removed from the hook, thus closing the circuit of the line at the sub-station, current will flow through all of these relay coils operating the line relay and illuminating the line lamp. The cut-off relay will not, however, be operated because of its differential winding.

The front contact of the cut-off relay is normally open, but is permanently connected to all the sleeve contacts of the jacks of the line. These latter contacts are, therefore, normally disconnected from the line, but are connected therewith when the cut-off relay is actuated.

As will be seen from the discussion of the next figure the cut-off relay will be operated when the operator plugs into a jack in response to a call, this act completing a circuit through one of the coils of the cut-off relay and causing it to attract its armature. The attraction of the armature of the cut-off relay by breaking the back contact, opens the circuit from the battery through the line relay and the front coil of the cut-off relay, thus de-energizing both of these coils. The line lamp is thus extinguished, and it is evident that the line relay cannot be again operated until the cut-off relay is de-energized.

While this line circuit has been used almost exclusively in the common battery work of the Stromberg-Carlson Company for several years past, the cord circuit used with it has been subject to many changes.

In Fig. 272 is shown one of these cord circuits, connecting two of the line circuits shown in Fig. 271. In this cord circuit the answering and calling plug are of the two-conductor type and are connected by two-conductor cords, as in the Kellogg system. The sleeve side of the circuit of each plug contains a supervisory relay, each of these relays being permanently shunted by a two-microfarad condenser in order to prevent the retardation of the relay coils from

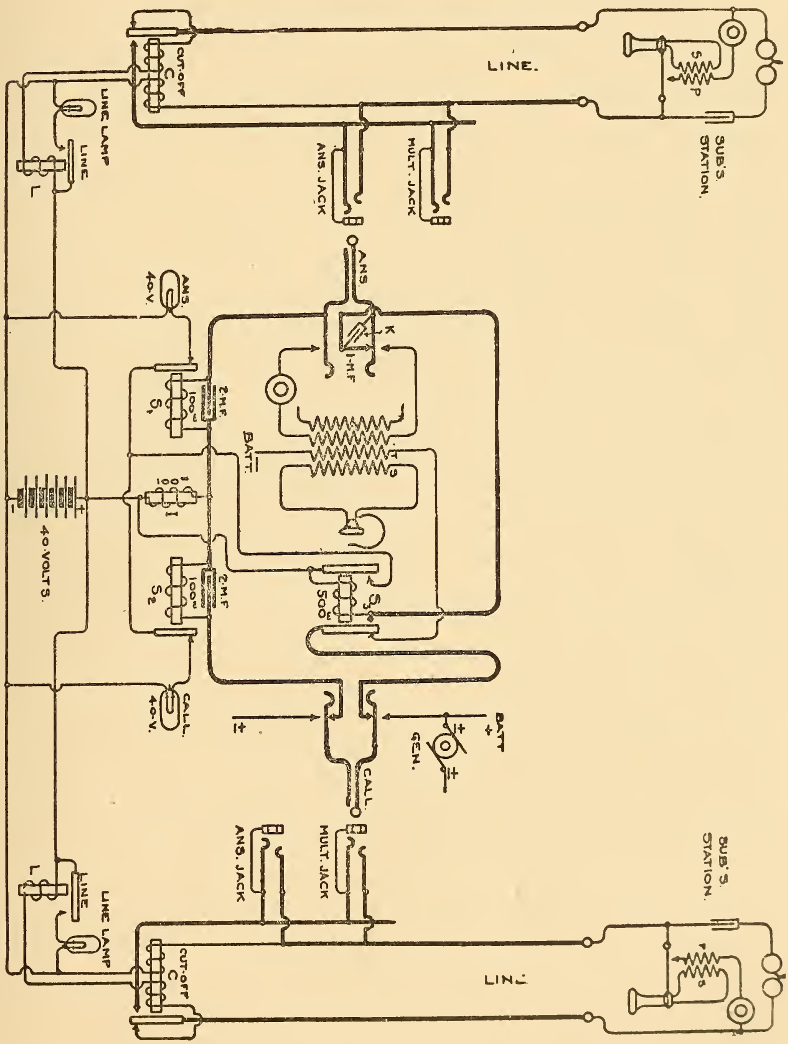


FIG. 272.—CONNECTION BETWEEN TWO SUBSCRIBERS THROUGH ONE OFFICE—STROMBERG-CARLSON TWO-WIRE SYSTEM.

interfering with the transmission of the voice currents through the sleeve side of the cord circuit. The relay, S_3, has its coil connected between the positive side of the battery and the tip of the answering plug under normal circumstances. This relay, when operated, serves to connect by one of its armatures the positive side of the battery with the local circuits of the supervisory lamps and by its other armature to break the normally closed test circuit and close the talking circuit between the answering and calling contacts of the plugs.

The operation of this system may now be understood. Assuming the subscriber of the left hand line to be making a call, his line lamp lights in response to the removal of his receiver from its hook, as already described. In response to this signal the operator inserts the answering plug into the answering jack, which, beside completing the talking circuit between the line and the cord circuit also establishes the following circuit which includes one coil of the cut-off relay. This circuit may be traced from the positive side of the battery through the winding of the relay, S_3, to the tip of the answering plug, thence over the tip side of the line through the rear winding of the cut-off relay to the negative side of the battery. This unbalances the cut-off relay and causes its operation, which, as before stated, causes the de-energization of the line relay and the extinguishing of the line lamp. The operation of the cut-off relay also completes the connection between the sleeve contacts of the jacks and the sleeve side of the line, whch connection had hitherto been open at the cut-off relay.

The same current which thus causes the initial operation of the cut-off relay also causes the operation of the relay, S_3, which therefore attracts both of its contact levers. The attraction of the left hand lever of this relay completes the connection between the positive side of the battery and one side of the circuit of both supervisory lamps, so that with this relay actuated, the lighting of the supervisory lamps depends entirely on the condition of the relays, S_1 and S_2. If either of these relays is de-energized while the relay, S_3,is energized the corresponding lamp will be lighted. It will thus be seen that the relay, S_3, of this system, so far as its left-hand lever is concerned, corresponds in function with the relays, R_2 and R_4, of the Kellogg system, as shown in Fig. 270, in that it is operated when the plug is inserted into a jack, and that when so operated the supervisory lamps are placed under the exclusive control of their supervisory relays.

Current for talking purposes is now fed to the left-hand line from the positive pole of the battery through the impedance coil, I, to the sleeve side of the line, and from the negative pole of the battery through the rear winding of the cut-off relay, C, to the tip side of the line. This current flows only when the subscriber's receiver is removed from its hook and therefore the supervisory relay, S_1, which lies in the path of this current, is under the control of that subscriber. When the operator plugged into the jack in response to a call, therefore, the supervisory relay, S_1, was operated, thus preventing the lighting of the answering supervisory lamp.

In order to communicate with a subscriber the operator throws her listening key, which connects the talking circuit with the line in the usual manner, and at the same time cuts a condenser, K, into the tip side of the cord circuit. The purpose of this condenser will be pointed out later.

In order to test for a busy line the operator will apply the tip of the calling plug to the test ring of the jack in the usual way. As in the Kellogg system, the tip side of the calling cord circuit is normally broken; in this case, by the right-hand contact lever of the relay, S_3. The tip of the calling plug is by the back contact of this lever normally connected to the negative side of the battery through an extra winding on the operator's induction coil. Instead of using an extra test relay, as in the Kellogg system, the test circuit is run directly through one winding of the induction coil, so as to throw the test current directly into the operator's coil, rather than doing it through a local circuit controlled by a relay. If the line tested is free its test rings will be disconnected from the line at the cut-off relay, and they will have no source of electromotive force upon them. When, therefore, the test is made with such a line, no current will flow, and the operator receiving no click will know that the line is free. If, however, the line is busy, the test rings will be in electrical connection with the positive side of the battery through the sleeve strand of the cord connected with the line at another section. Under these conditions current will flow from the test ring at the section where the test is made through the extra winding on the induction coil to the negative side of the battery, giving the operator a click in the ear.

It will be noticed that the test can only be made when the relay, S_3, is de-energized, as otherwise the extra winding in the induction coil would be disconnected from the tip of the calling plug. Since the relay, S_3, was energized when the operator plugged in with the answering plug, it becomes necessary in making a test to de-energize this relay temporarily, and this is the function of the condenser, K, already referred to. This condenser is interposed in the tip side of the cord circuit when a test is made so as to prevent direct current from flowing through the winding of the coil, S_3, thus allowing the contact levers of this relay to fall back into proper position for testing. As the throwing of the listening key must necessarily be performed before a test can be made, the de-energization of the relay, S_3, is brought about without additional effort on the part of the operator. The temporary cutting-off of the current through the relay, S_3, while listening in, does not de-energize the relay, C, because the current for talking purposes flows through one of the coils of this relay from the negative side of the battery, through the tip of the cord, the primary winding of the operator's induction coil, the transmitter, the windings of relay, S_1, and retardation coil, I, to the positive side of battery.

Having learned that the line is free, the operator inserts the calling plug into the multiple jack tested, and by means of a ringing key calls the subscriber in the usual manner. After a connection is thus completed and the two subscribers are conversing, the act of listening in by the operator will not de-energize the relay, S_3, because that relay will still receive current, which passes through it and the primary of the operator's telephone set. The presence of the condenser, K, when interposed in the tip side of the talking circuit during a conversation between two subscribers by the act of the operator's listening in does not, of course, prevent conversation between those subscribers. After the called subscriber has answered the relay, S_3, remains energized as long as the connection is established, and therefore both of the relays, S_1 and S_2, are under control of their respective subscribers. As soon as either of the subscribers hangs up his receiver the corresponding relay will be de-energized, thus lighting the corresponding supervisory lamp and conveying the supervisory signal to the operator in the usual manner.

In establishing the connection, as soon as the operator answers by plugging in with the answering plug, the calling supervisory lamp will be lighted, because the relay, S_3, will be operated, while the relay, S_2, receiving no current, will remain inert. This lamp should not light until the operator had plugged into the jack of the called subscriber, as is the case in the standard code of supervisory signaling. This premature lighting of the calling supervisory lamp, however, probably does little harm, except that it tends to slightly confuse the operator in interpreting the supervisory signals, and also causes a slightly greater consumption of current than is actually necessary.

In order to prevent the operation of the ringing key from disconnecting the battery from the called line during the ringing of a subscriber, and thus allowing the ringing current to rattle the armature of the cut-off relay of that line, the tip side of the ringing key, which carries one terminal of the generator, is also connected to the positive terminal of the battery, so that battery current is thrown onto

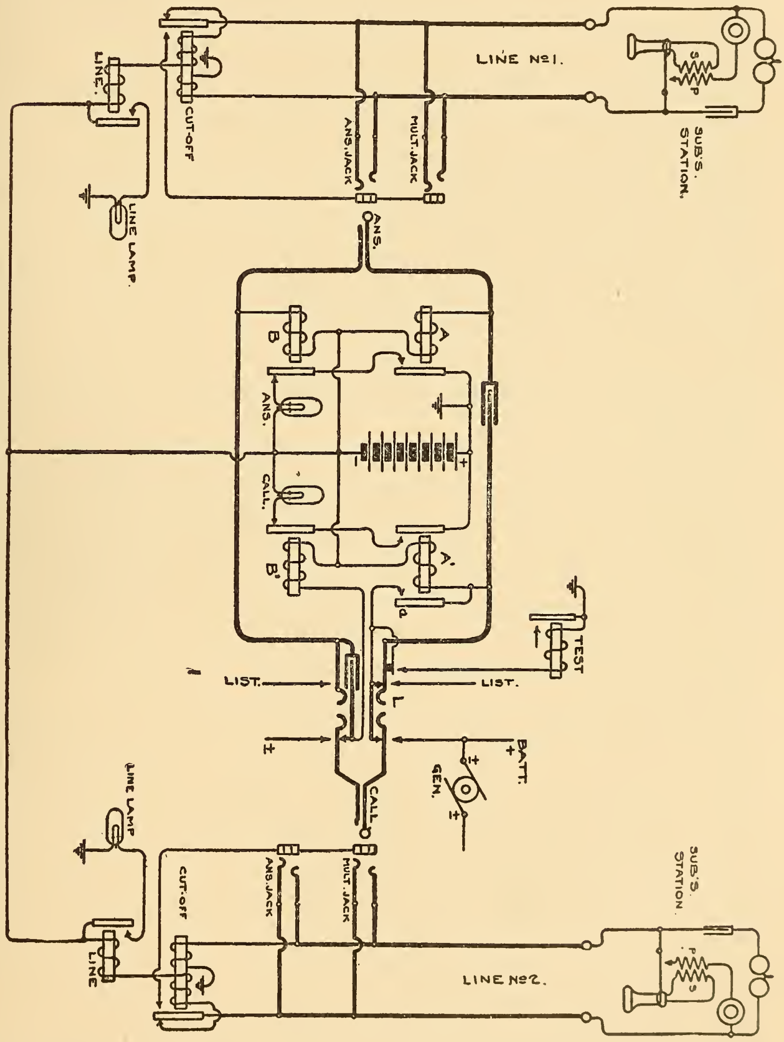


FIG. 273.—CONNECTION BETWEEN TWO SUBSCRIBERS THROUGH ONE OFFICE—STROMBERG-CARLSON THREE-WIRE SYSTEM.

the calling line during the ringing for the purpose of keeping the cut-off relay constantly energized, this feature being almost the same as that described in the Kellogg system.

The Stromberg-Carlson Company has recently adopted a three-wire system which it is now installing in the several large offices in the new Kansas City, Missouri, exchange. The line and cord circuits of this system are shown in Fig. 273.

The line circuit is very similar to that of their two-wire system, the cut-off relay being differentially wound and normally connected across the line in series with the line relay and the common battery. This circuit through the line relay and battery is broken at the back contact of the cut-off relay when the latter relay is operated. Instead of having the test rings connected directly with the sleeve spring of each jack, a third wire runs throughout the multiple jacks, which is connected with a test ring at each section. This wire terminates in the front contact of the cut-off relay in such a manner that when this relay is operated all of the test rings will be connected directly with the sleeve side of the line. Under normal circumstances, however, all of the test rings belonging to the line are insulated from ground and from all other portions of the system. The sleeve springs in the jacks are permanently connected with the sleeve side of the line.

Each side of the cord circuit is provided with two relays, one, *A* or *A'*, adapted to be energized when the operator plugs into a line jack, thus closing a normally open point in the circuit of the corresponding supervisory lamp. The other relay, *B* or *B'*, is in the path over which current is fed to a subscriber's line for talking, and is thus placed under the control of the subscriber with whose line the corresponding plug is connected. This relay, after the first relay has been operated, absolutely controls the supervisory lamp.

When the operator plugs in in response to a call, current at once flows from the ungrounded pole of the battery through the coil of the relay, *A*, to the tip side of the line and to ground through one coil of the cut-off relay. This operates the cut-off relay, causing it to cut off the line relay and at the same time to connect the test rings of the line with the sleeve side of the line. Current is fed to the subscriber's instrument from the ungrounded pole of the battery through the coil of the relay, *B*, to the sleeve side of the line, and from the grounded pole of the battery through one coil of the cut-off relay to the tip side of the line.

The test, as is usual, depends upon the condition of the test rings as governed by the insertion of a plug in a jack at another section. If the line is free the test rings will be insulated from everything except the other test ring on that line, while, if the line is busy, they will be connected to the negative pole of the battery through the coil of the relay, *B*, or *B'*, belonging to the cord connected with the line at another position. The test rings of the busy line will therefore be raised to a potential above that of the earth. The listening key, *L*, is provided with the ordinary contacts for connecting the operator's telephone, and with an auxiliary pair of contacts for connecting the tip of the calling plug to ground through a test relay when the listening key is operated. The relay, *A'*, corresponding with the relay, *A*, on the answering side carries an additional contact lever, *a*, which, when operated, by the insertion of a plug in a jack closes the tip side of the calling cord around the contacts on the listening key in such manner that the listening key, when operated, will not disturb the continuity of the tip conductor. Until the relay, *A'*, is operated, however, the operation of the listening key interrupts the continuity of the tip conductor, and at the same time connects the tip of the calling plug to ground, through the testing apparatus.

In testing a busy line with the listening key, *L*, thrown into the listening position, current will flow from the test ring through the tip contact of the calling plug to ground through the test relay, thus giving the operator a click in the ear in the same manner as with the test relay in the Kellogg system. Under this condition the throwing of the listening key opens the tip strand of the cord circuit. When the calling plug is inserted into a jack, however, the subsequent operation of the listening key on the part of the operator will not interrupt the continuity of the tip conductor, because, owing to the operation of the relay, *A'*, the open contact in the listening key will be shunted by the armature, *a*, and its contact. The operation of ringing is the same as has already been described in connection with other circuits.

The supervisory signals are controlled in practically the same manner as those of the Kellogg system, the relays, *A* and *A'*, closing the normally open contacts in their respective lamp circuits when their plugs are inserted into the jacks of the connected lines, after which the current, flowing through the relays, *B* and *B'*, to the subscribers' stations, operates these relays to prevent illumination of the corresponding lamps as long as the lines are in use. As soon, however, as either subscriber hangs up his receiver the current from the relay, *B* or *B'*, ceases to flow, thus allowing the armature to drop back, lighting the lamp.

Of considerable interest is the circuit of the Sterling Electric Company, of La Fayette, Ind., shown in Fig. 274. This is a three-wire multiple system and has the distinction of possessing the simplest cord circuit of any common battery multiple system in existence. Moreover, there is but one relay for each line, this relay serving not only as a line relay, but also as a supervisory relay after a connection has been made.

In this the line relay has two active windings, which, however, are not differentially wound. One of these windings is connected between one side of the battery and one side of the line, the other winding being similarly placed with regard to the other side of the battery and line. As this relay is permanently connected with the

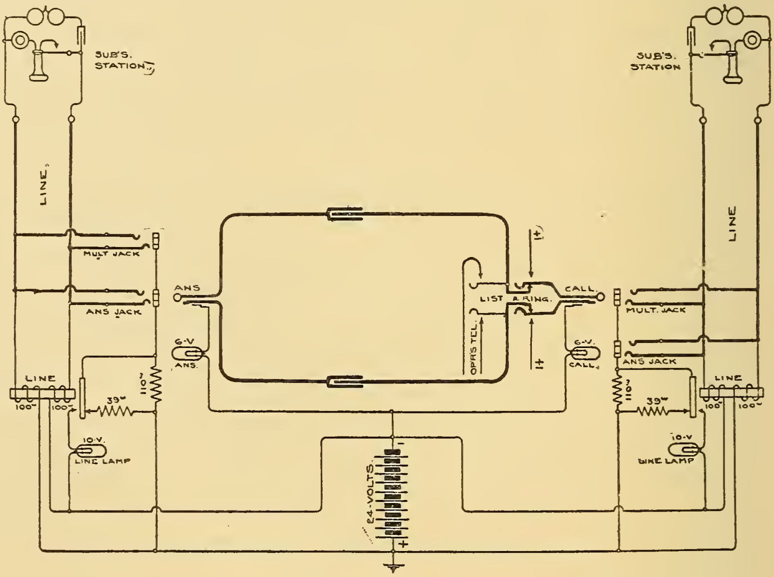


FIG. 274.—CIRCUITS OF STERLING MULTIPLE SWITCH-BOARD.

line, it is always under the control of the subscriber, the current for talking purposes being fed through the two windings of this relay to the line, this being the only connection at any time between the line and the battery.

When a subscriber removes his receiver from the hook for the purpose of making a call the relay is operated, thus closing the circuit of the line lamp, which circuit also includes a 110-ohm resistance coil. The line lamp is adapted to 10 volts, and is thus brought to its full candle power when subjected to 24 volts through the external resistance of 110 ohms. When the operator inserts the answering plug connection is made between the tip and sleeve side of the line and the corresponding conductors of the cord circuit, and also the third strand of the cord is connected with the third conductor of the jacks, this conductor being connected with the test rings of the jacks and with the contact lever of the line relay. The third strand of the cord includes the supervisory lamp, which is adapted to six volts. The insertion of the plug does not de-energize the line relay, which still attracts its armature, but it extinguishes the line lamp by placing in shunt with it the 6-volt supervisory lamp of the cord circuit. In this condition, while both lamps receive some current, neither is illuminated because of the presence of the 110-ohm resistance with which the two shunted lamps are

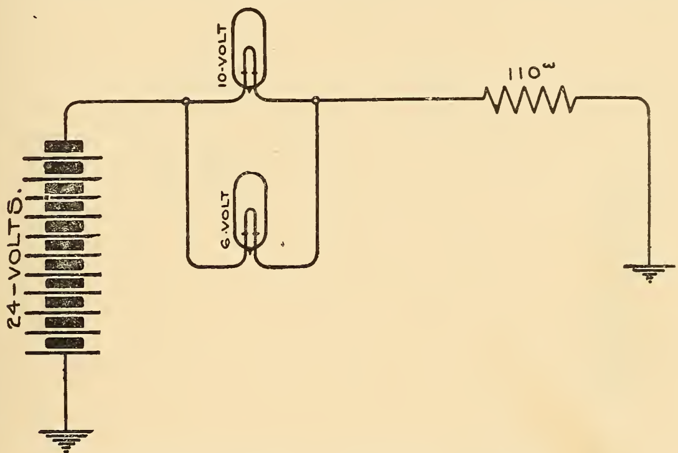


FIG. 275.—DETAILS OF STERLING CIRCUIT.

in series. The circuit of the line and supervisory lamp under this condition is shown diagrammatically in Fig. 275.

The system is such that a line will test "busy" as soon as a subscriber removes his receiver from the hook, or, in other words, as soon as the line relay is operated. As will be seen, the test rings are normally connected to earth in such a manner as to include no source of potential. As soon, however, as the line relay is operated they are connected through the line lamp with the ungrounded terminal of the common battery, thus raising their potential above that of the earth. The same result also occurs, regardless of whether the subscriber's receiver is on or off its hook, when the operator plugs into the jack of any line, for then the potential of the test rings on that line are raised by being connected to battery through the supervisory lamp and the third strand of the cord. When, therefore, an operator tests by applying the tip of the calling plug to the test ring of a line, she will get a click if a subscriber has removed his receiver from the hook or if the line is connected with at another section, while she will get no click if the line is free.

When either subscriber hangs up his receiver the corresponding line relay will be de-energized, thus allowing its armature to fall back. This removes the shunt of the 10-volt lamp from about the 6-volt supervisory lamp, and at the same time puts a low resistance shunt (39 ohms) about the 110-ohm resistance coil. The circuit through the supervisory lamp is then changed from that shown in Fig. 275 to that shown in Fig. 276. The supervisory lamp is not shunted itself, while it has in series with it the combined resistance

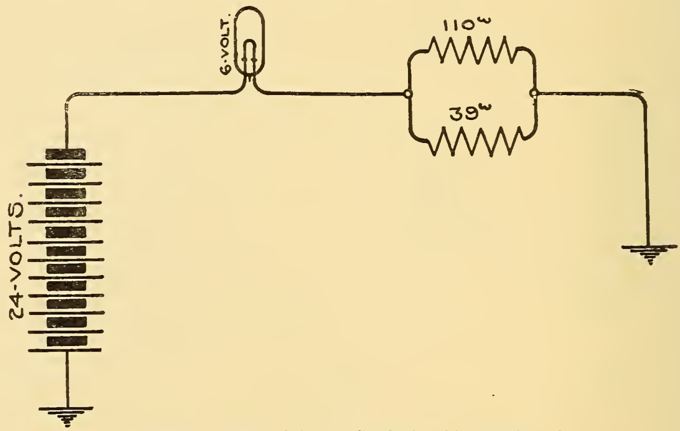


FIG. 276.—DETAILS OF STERLING CIRCUIT.

of the 110-ohm and the 39-ohm coil in parallel, under which conditions this lamp is lighted to its full candle power, thus giving to the operator the supervisory signal.

In order to separate the two sides of the cord circuits from each other, and thus prevent the signals of one line interfering with those of another line connected with it, two condensers are used in each cord circuit, one being placed in each strand of the talking circuit.

In practice, both of the resistance coils used in connection with the line and supervisory lamp are wound on the core of the line relay, thus giving this relay in all four windings, two of which, however, are in the nature of dead resistance.

This system has one very objectionable feature in that it is impossible, without extremely complex arrangements, to provide for either line or supervisory pilot lamps, and the advantages of these lamps, which are unquestionably great, are not attained in practice.

Another disadvantage inherent in such a system is that of the difficulty of obtaining the proper uniform illumination of the lamps for line and supervisory purposes. Switch-board lamps when newly made are not as uniform with respect to voltage and candle power as are the larger lamps used for general illuminating purposes. Moreover, they change with age even more rapidly than larger lamps. When, therefore, the lamp must necessarily work in circuit with a considerable external resistance, and when the illumination or non-illumination of the lamp is dependent on certain changes in the amount of this external resistance; in other words, when the lamp is governed entirely by the different arrangements of certain fixed resistances in its circuit, a considerable amount of difficulty is experienced in properly maintaining the required illumination or non-illumination under the conditions of practice. This would not be the case were the lamps of uniform resistance and candle power, or if the voltage of the battery supplying the current were constant. As is well known, however, a storage battery cell may vary in its voltage, according to the state of charge, from 2.5 volts down to 1.7. Here we have (under extreme conditions) a variation of approximately 40 per cent. with respect to the normal working pressure, usually assumed to be 2 volts. It is, of course, possible to keep the voltage of the storage cell between much narrower limits than this, which would reduce this percentage of fluctuation by half. Inasmuch as the two resistance coils associated with the line relay must of necessity be fixed in their resistance value, such a circuit brings us in practice against the difficulty of maintaining a rather close adjustment between the circuit arrangements of these resistances with respect to the lamps and the voltage of the battery when both the condition of the lamps and the voltage of the battery are subject to variation. The difficulty in this respect is enhanced by the fact that after an exchange has been in operation some time new lamps have to be added to replace those burned out which gives a condition wherein lamps of various ages must be used under the same conditions. Such considerations as this have not, however, prevented such systems from being successful in practice.

The line and cord circuits of the North Electric Company, of Cleveland, Ohio, is shown in Fig. 277. The arrangement of the line relay in this circuit is not unlike that of the Sterling circuit just described, this relay having a split winding, including between them the common battery, the two windings and the battery in series being connected permanently across the metallic circuit of the line.

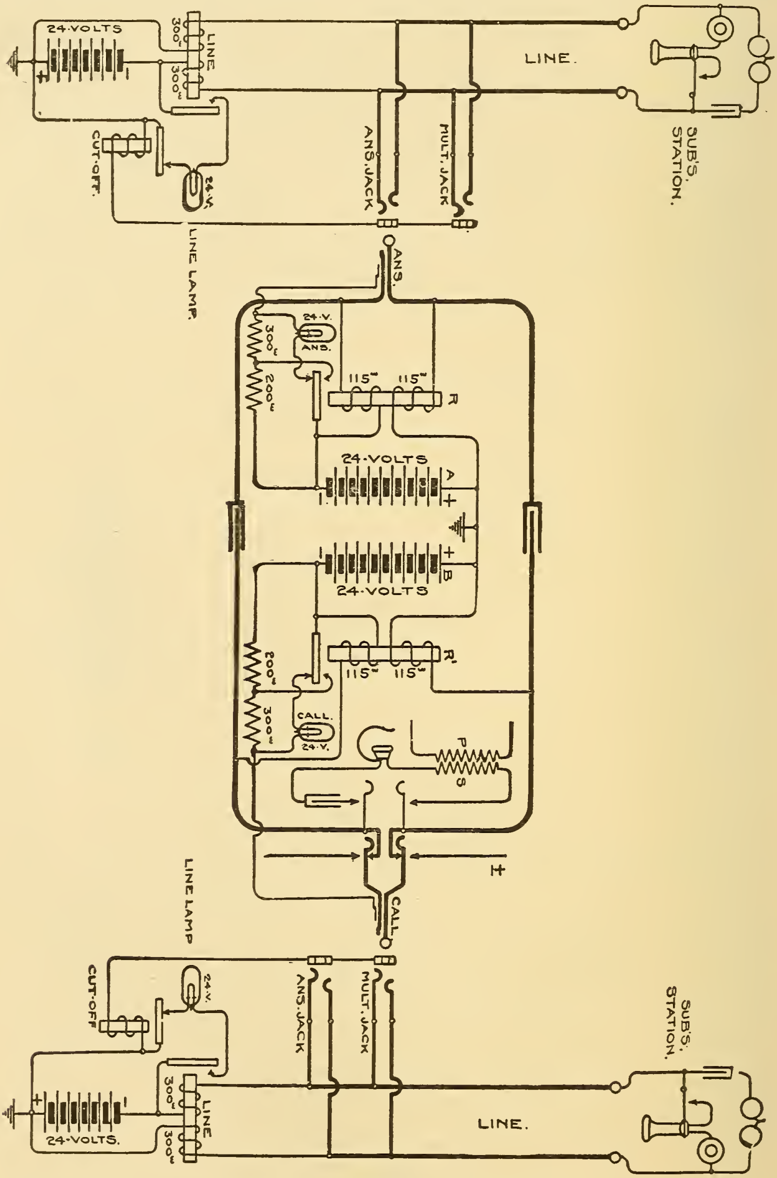


FIG. 277.—NORTH ELECTRIC COMPANY'S MULTIPLE SWITCH-BOARD CIRCUIT.

The third contact on the jack is wired through the coil of a cut-off relay to ground, the arrangement in this case beig similar to that employed by the Western Electric circuit. The cut-off relay, however, in the North circuit, instead of serving to separate the line relay and signaling apparatus entirely from the line, simply serves to open the circuit of the line lamp, this circuit being controlled at two places, one by a normally open pair of contacts in the line relay, and the other by a normally closed pair of contacts in the cut-off relay.

The cord circuit has three-conductor cords and three-contact plugs, two batteries being used as in the Kellogg system. Current is supplied from battery, *A*, to the two talking strands of the answering cord through the two windings, respectively, of the relay, *R*, current being similarly supplied to the talking strands of the calling cord through the two windings of the relay, *R'*. These two relays which control the supervisory lamps are not differentially wound, their windings both operating in the same direction to energize their cores. The third strand of each cord circuit has two branches, controlled by the armature of the corresponding relay, *R*. One of these branches leads, when the relay armature is not energized from the ungrounded pole of the battery through the supervisory lamp in multiple with resistance coils, to the third contact of the plug. Under this condition, the lamp is shunted by two resistance coils in series, having a combined resistance of about 500 ohms, which is too high a shunt to prevent the lamp from lighting. When the armature of the relay, *R* or *R'*, is attracted the circuit of each lamp is opened, the circuit of the third strand then leading from the ungrounded pole of the battery through a 300-ohm resistance coil alone to the third contact on the plug. When a plug is inserted into a jack the circuit of the third strand is completed by means of the test ring of the jack through the coil of the cut-off relay to ground. With the circuit so established the cut-off relay is operated and the lighting of the supervisory lamp depends on the non-attraction of the armature of the supervisory relay. As will be seen, the energization of the supervisory relay depends on the subscriber having his receiver off the hook for conversation, and therefore the supervisory lamp is placed under control of the subscriber with whose line the corresponding plug is connected.

When a subscriber calls, the line relay is energized by the current flowing through his instrument, thus lighting the line lamp When the operator inserts the answering plug the cut-off relay is energized, which performs no other function than to open the circuit of the line lamp, leaving the line relay still energized. The line lamp is thus extinguished. An additional path is maintained for the flow of battery current to each side of the line, this being through the coils of the relay, *R*. As the coils of the relay, *R*, are of about 115 ohms resistance each, while those of the line relay each have a resistance of about 300 ohms, a greater portion of the current flowing to line passes through the supervisory relay coils, and this relay is, of course, energized. Like the line relay, it remains energized as long as the subscriber's receiver is removed from its hook. The conditions so far described are exactly reproduced with respect to the calling plug and the line called for, and therefore, when a connection is made between two lines the talking circuit may be represented as in Fig. 278. The current from battery, *A*, is supplied to the line of the calling subscriber through the coils of the line

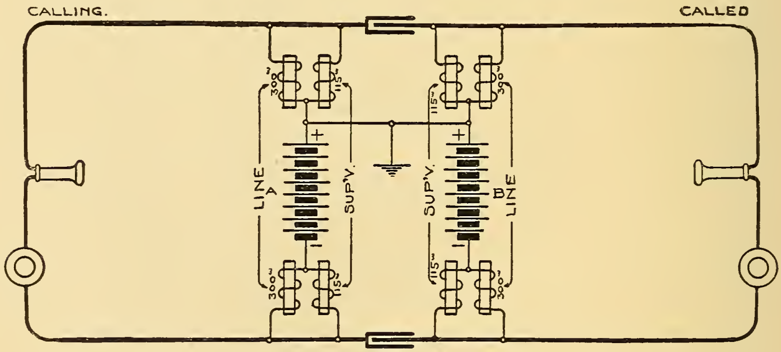


FIG. 278.—SIMPLIFIED NORTH CIRCUIT.

relay belonging to that line and the supervisory relay of the answering plug. Similarly, the current is supplied from battery, *B*, to the line of the called subscriber through the coils of the line relay belonging to that line and the supervisory relay of the calling plug. It will be seen that this resolves itself into the same scheme of supplying current to the subscriber as that shown in Fig. 232 of a previous chapter.

As in most of the systems already described, the test rings of a free line are connected to earth and are at the same potential as the earth. The test rings of a "busy" line are subjected to the potential of the battery through the third strand of the cord used in making a connection with the line, and are therefore raised to a certain potential above the earth. If, therefore, when an operator tests by applying the tip of a calling plug to the test ring she will get no click if the line is free, and will therefore insert the plug and ring. If, however, the line is busy, current will flow from the tip of the calling plug used in making the test over the sleeve side of the line through one winding of the supervisory relay, *R'*, and to ground. This will momentarily raise the potential of the tip side of the cord circuit, thus causing a flow of current through the operator's receiver bridged across the cord circuit when the test is made.

When the answering plug was inserted into the jack of the calling subscriber the answering supervisory lamp did not light because of the immediate energization of the relay, *R*, due to the subscriber having his receiver off its hook. When the calling plug was inserted into the jack of the called subscriber, however, the calling supervisory lamp was at once lighted, remaining so until the subscriber responded, at which time the energization of the supervisory relay, *R'*, extinguished this lamp. When either subscriber hangs up his receiver the corresponding supervisory relay will be de-energized, thus lighting the supervisory lamp.

The line and cord circuits of the International Telephone Manufacturing Company, of Chicago, are shown in Fig. 279. In the line circuit of this system a 500-ohm line relay and a 100-ohm cut-off relay are connected in series with the battery between the tip and sleeve strands of the line, respectively, this connection being permanent. When a subscriber removes his receiver from the hook for the purpose of calling, the line relay only will respond, although the current flowing traverses the coils of both relays. This is because the line relay is much more easily operated than the cut-off relay on account of its higher resistance and more delicate adjustment. The circuit of the line lamp is controlled by the armature of both the line and the cut-off relays, the cut-off relay having its contact normally closed, that of the line relay being normally open. When, therefore, the line relay only is operated, the line lamp will be illuminated. The cord circuit contains three relays, two of which, *A* and *B*, are connected between the negative side of the battery and the tip strands of the answering and calling plugs, respectively, the points of connection between these two relays and their respective tip strands being separated by a two-microfarad condenser. The relay, *C*, is connected between the negative side of the battery and the sleeve strand of both the calling and answering plugs, this latter strand being continuous from the sleeve of the answering plug to the sleeve of the calling plug. This latter relay serves to control the connection between the negative side of

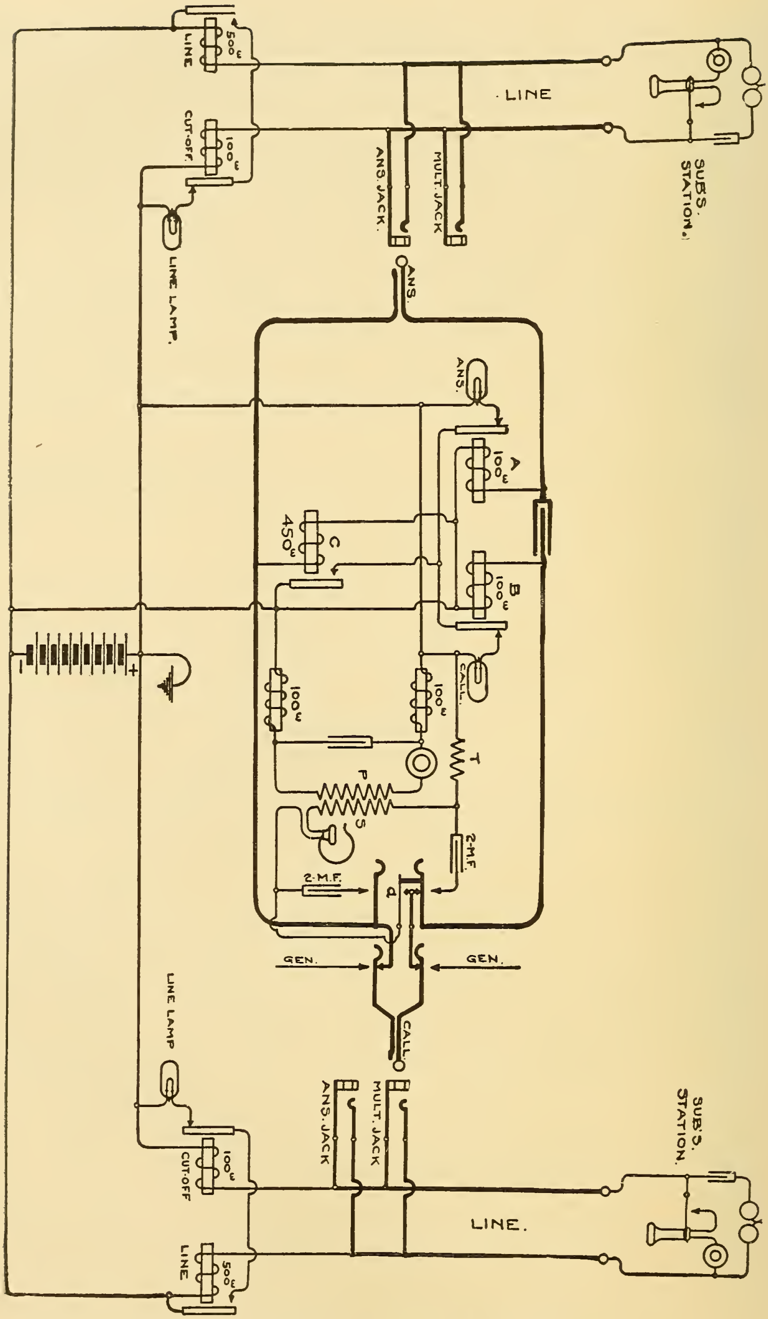


FIG. 279.—INTERNATIONAL MULTIPLE SWITCH-BOARD CIRCUIT.

the battery and both supervisory lamps, this contact being normally open, but closed upon the operation of the relay.

When the answering plug is inserted into the jack of a calling subscriber the cut-off relay of the line, and the relay, *C*, of the cord circuit are at once operated, the circuit being traced from the negative side of the battery through the coil of the relay, *C*, thence over the sleeve strand of the answering cord to the sleeve contact of the jack, thence to the positive pole of the battery through the coil of the cut-off relay. The energization of the cut-off relay opens the circuit of the line lamp, thus extinguishing it, and at the same time relay, *C*, completes the circuit between the negative side of the battery and both of the supervisory lamps. The calling supervisory lamp will thus be lighted upon the insertion of the answering plug, because the relay, *B*, which controls the other side of the circuit of the calling supervisory lamp will not be energized. The answering supervisory relay will not, however, be lighted, because the relay, *A*, will receive current, this current flowing from the negative side of the battery through the coil of this relay to the tip side of the cord circuit and the tip side of the line, thence to the subscriber's station and back to the positive side of the battery through the coil of the cut-off relay. This will therefore hold the circuit of the answering supervisory lamp open as long as the calling subscriber keeps his receiver off its hook.

When the operator inserts the calling plug into the jack of the called subscriber, in case his line is found to be free, the calling supervisory lamp will remain lighted until the subscriber responds, at which time the energization of the relay, *B*, due to current flowing through the called subscriber's instrument, will open the circuit of this lamp and cause its illumination to cease. When either subscriber hangs up his receiver the corresponding relay, *A* or *B*, will be de-energized, thus illuminating the corresponding lamp. Except for the premature illumination of the calling supervisory lamp, when the answering plug is inserted into the line of the calling subscriber, the operation of the supervisory signals is in accordance with standard practice.

In a free line the test rings are supposed to be subjected to no potential from the battery, these rings being grounded through the coil of the cut-off relay. When, however, a line is busy by virtue of being connected to, the test rings will be raised to a potential above that of the earth on account of being connected to the ungrounded side of the battery through the supervisory relay, *C*, and the sleeve strand of the cord. In applying the tip of a calling plug for the purpose of a test, the listening key being, of course, thrown, currrent will flow from the test ring of the busy line through the tip of the calling plug and the auxiliary pair of springs, *a*, closed when the key is in its listening position, through the operator's telephone receiver and the secondary winding of her induction coil, and through the test coil, *T*, to ground. This will produce a click in the operator's receiver, whereas, if the line is not busy no such current will flow, the test circuit then being from ground to ground and the operator will know that the line is free.

This test circuit would appear faulty, as, in fact, is almost any test circuit wherein the test rings are permanently connected with one side of the line. To illustrate: If in this system the sleeve side of the line is crossed with some circuit on the outside of the central office, and thereby subjected to an electromotive force, all the test rings on that line would be raised to a potential above that of the ground and the result would be that the line would test *busy*. If the two sides of the line were crossed, current would flow from the tip side of the line to the sleeve side of the line, thus raising the potential of all the test rings belonging to that line, under which condition it would again test *busy*. The same result would be produced in testing a line on which a subscriber had raised his receiver from the hook, but which line had not yet been connected to at the central office. This, however, would not prove an objection, as no harm would be done if such line did test busy.

It may be said in general that practice has proved that the test rings should either be completely localized by means of a separate test ring and test wire, as in the Western Electric, North and Stromberg-Carlson three-wire systems, or that the test rings should be entirely disconnected from the external line during the time when the line is free. Unless one or the other of these methods is followed, false "busy" tests are liable to result.

In Fig. 280 are shown the line and cord circuits of the American Electric Telephone Company, of Chicago, which is the latest circuit used by this company which has been brought to the attention of the writer.

In this the line relay, *A*, has one of its terminals permanently connected with the tip side of the line, the other terminal being grounded through a 175-ohm retardation coil, *R*. The sleeve side of the line is permanently connected through a 175-ohm retardation coil, *R'*, to a 40-volt storage battery, the other terminal of which is grounded.

As a result the line relay is permanently bridged across the two sides of the line in series with the two retardation coils and battery, and

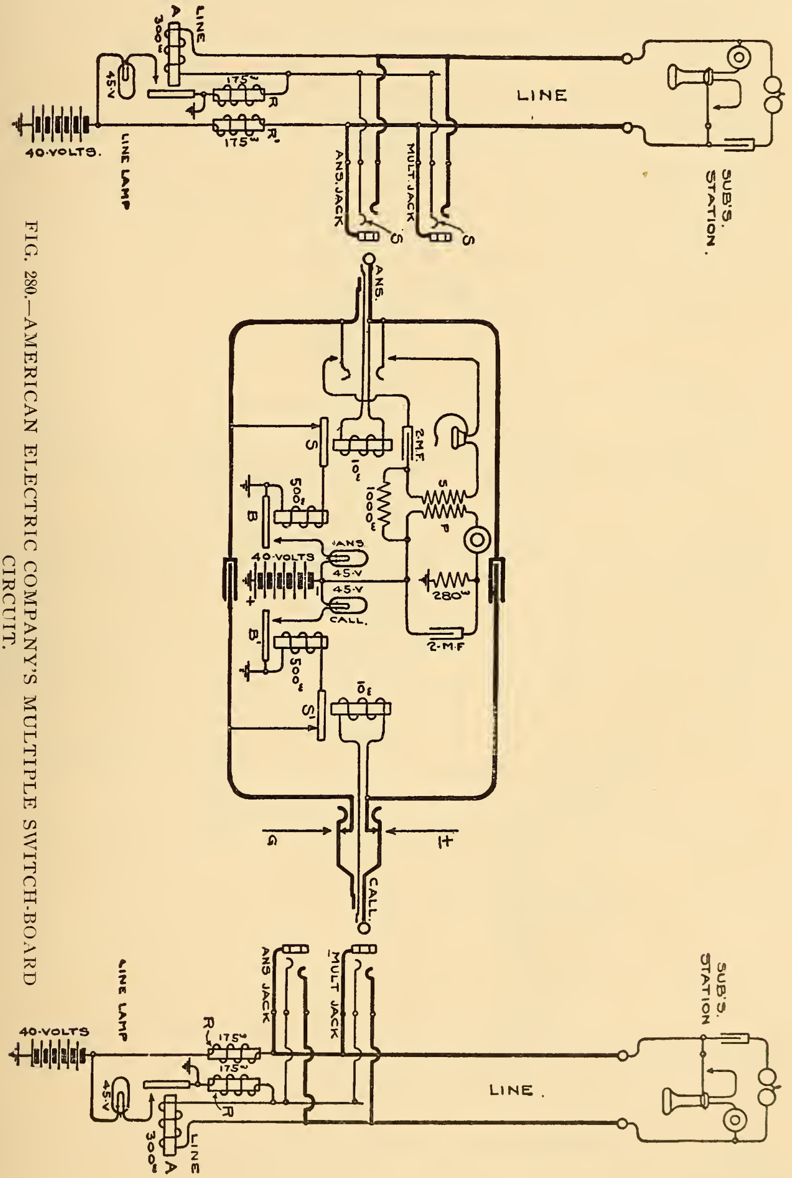


FIG. 280.—AMERICAN ELECTRIC COMPANY'S MULTIPLE SWITCH-BOARD CIRCUIT.

this relay will, therefore, be operated by the removal of the subscriber's receiver from its hook.

The auxiliary spring, *s*, in the jack, which makes contact with the corresponding sleeve on the plug is connected to that terminal of the line relay which is not connected to the tip side of the line. Between the corresponding contact on the answering plug and the tip

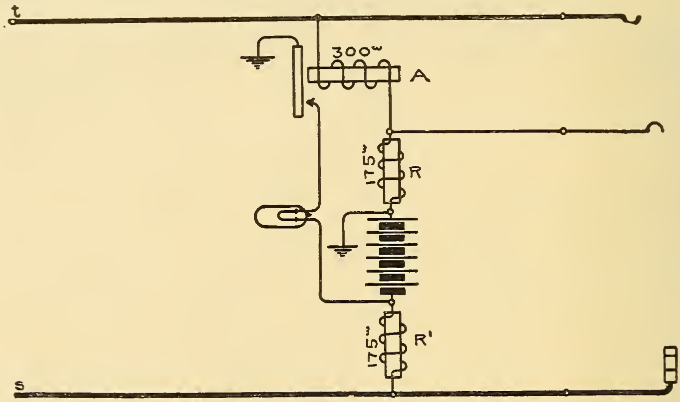


FIG. 281.—DETAILS OF AMERICAN ELECTRIC CIRCUIT.

contact is permanently bridged the 10-ohm coil of the relay *S*. As a result of these connections the line relay, *A*, is shunted by the 10-ohm coil whenever a plug is inserted into a jack.

The line circuit, simplified to illustrate more clearly the action when a subscriber is calling, is shown in Fig. 281. The condition

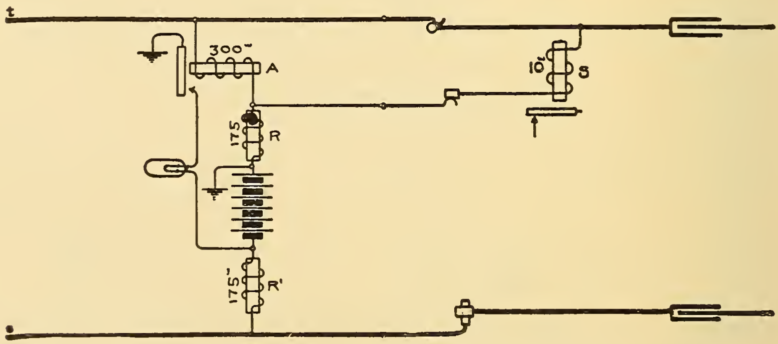


FIG. 282.—DETAILS OF AMERICAN ELECTRIC CIRCUIT.

after the operator has inserted the plug, showing clearly the shunting of the line relay coil by the low resistance relay coil, *S*, is shown in Fig. 282.

As a result of the placing of the shunt around the coil of the line relay, this latter relay is deprived of a sufficient amount of its current to cause it to drop back, thus putting out the lighted lamp. The relay, *S*, is thus energized as long as the subscriber's receiver is removed from its hook, this relay being in the path over which current is supplied to the subscriber, and by the operation of its armature it renders impossible the operation of the supervisory relay, *B*, on the answering side of the cord, since the circuit of this latter relay passes through the back contact of the relay, *S*. The arrangement so far treated is the same on the calling as on the answering side of the cord circuit, and therefore when a connection is made between the two lines the line relay of the called line is shunted out of service by the coil of the relay, *S'*, which latter relay is operated as soon as the subscriber removes his receiver from its hook, thus opening the circuit of the supervisory relay, *B'*.

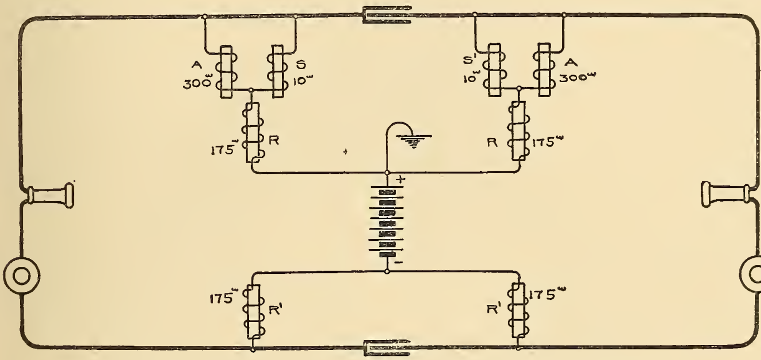


FIG. 283.—DETAILS OF AMERICAN ELECTRIC CIRCUIT.

The talking circuit between two such lines is shown in simplified diagrammatic form in Fig. 283, the two sides of the cord being divided by two two-microfarad condensers in order to prevent the signals on the answering side from interfering with those on the calling side, and vice versa.

Referring again to Fig. 280, it will be seen that both supervisory lamps will remain dark as long as the subscribers are talking, but as soon as either subscriber hangs up his receiver the armature of relay *S* or *S'*, will drop back, thus closing the circuit of the relay, *B* or *B'*, which relay will then receive current over the following circuit: From the ungrounded pole of the battery through the retardation coil, *R'*, of the line with which the corresponding plug is connected, thence through the sleeve contact of the jack and plug to the back contact of the relay, *S* or *S'*, and to ground through the coil of the

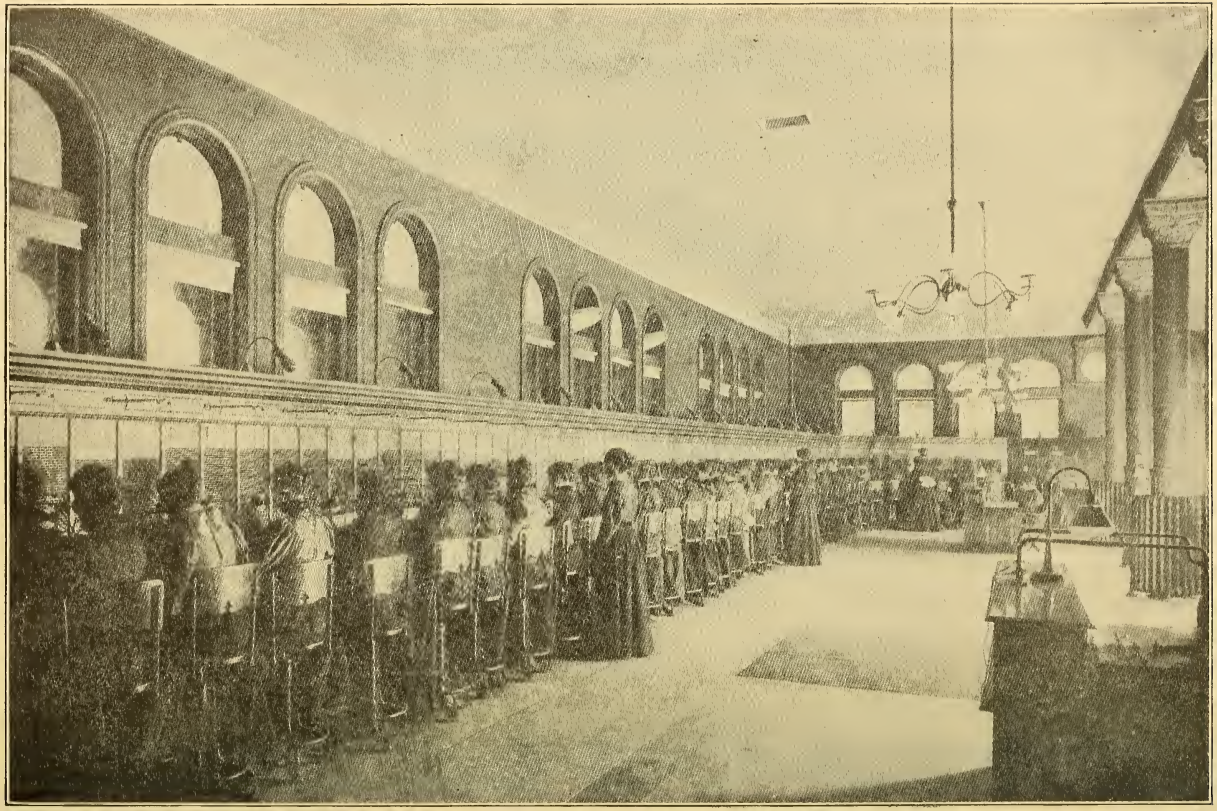


FIG. 284.—MULTIPLE SWITCH-BOARD OF BELL EXCHANGE IN ST. LOUIS.

relay, *B* or *B'*. Upon the actuation of the relay due to this current the circuit of the corresponding supervisory lamp will be complete, which lamp will light and remain lighted until the operator pulls down the connection.

The test of this circuit appears to be faulty for the same reason as pointed out in connection with the International circuit: That is, the test ring is constantly in connection with the line, and therefore is subject to all the uncertainties as to its electrical condition as is the line itself. The test ring, however, in this case, is maintained under normal conditions at a constant potential due to its being permanently connected to the underground side of the 40-volt battery. When a plug is inserted into the jack, however, or when a subscriber's receiver is removed from its hook the potential of this test ring is altered, due to the flow of current over the line or over the cord circuit and to the consequent drop of potential through the coil, *R'*. When the listening key is thrown the circuit from the tip of the calling plug to ground may be traced through the two-microfarad condenser on the tip side, through the contact on the tip side of the listening key through the operator's receiver and induction coil, thence through a 1000-ohm resistance coil to the negative side of the battery. The tip of the calling plug will therefore be held by induction at practically the same potential as that of the ungrounded side of the battery, which is the same potential at which the test rings of the free line are supposed to be held. Under these circumstances, therefore, no click will follow. If, however, the line is busy, the potential of its test ring will be lowered, and when the tip of the calling plug is applied in testing a click will follow. Defective insulation of the sleeve side of the line with respect to the ground or a partial cross between the tip and sleeve sides of the line would lower the potential of the test ring, and thus cause a false busy test.

The general appearance of a modern common battery multiple switch-board, equipped with lamp signals controlled by line and cut-off relays, is shown in Fig. 284, which is taken from a photograph of the switch-board installed by the Western Electric Company for the Bell Telephone Company, of Missouri, in their St. Louis exchange. This board consists of 19 sections, with three operators' positions at each section. It is finished in mahogany, and is about six feet high, four feet wide, with an over-all length of nearly 115 feet. It is at present wired for 4800 lines, and is capable of accommodating an ultimate number of 5600 lines.

In addition to the 4000 multiple calling jacks shown on the upper panels of each section there are on the lower panels of

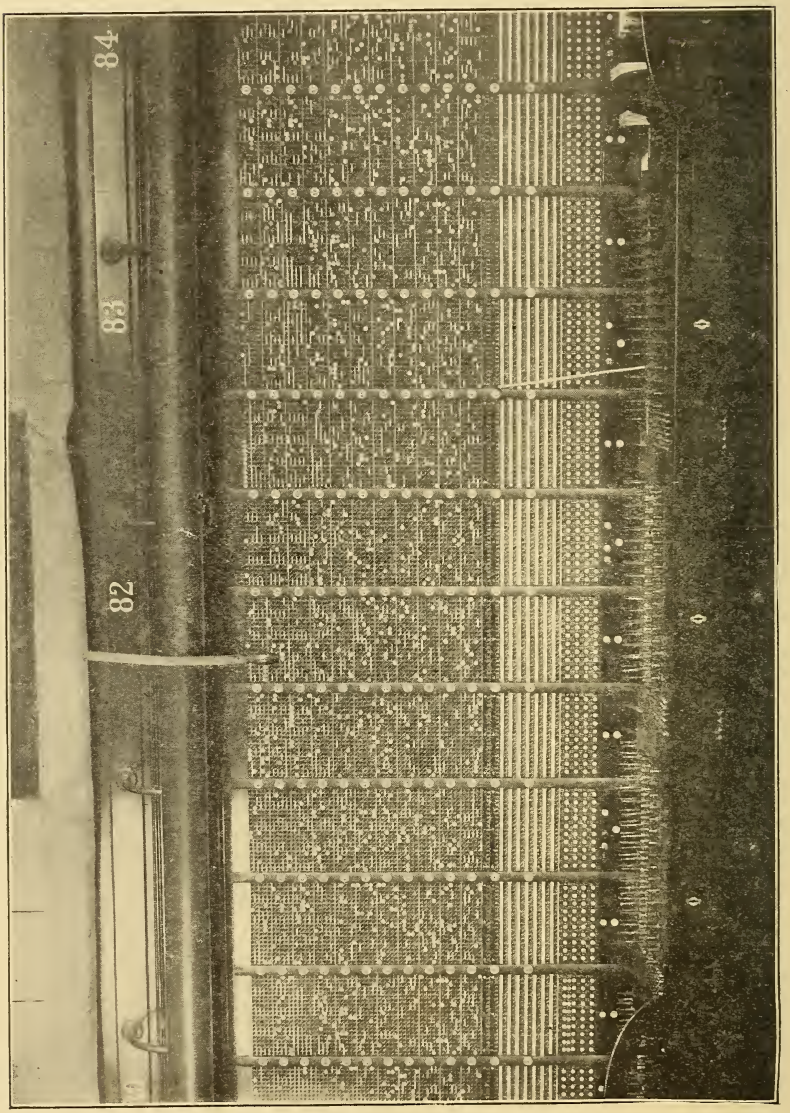


FIG. 285.—FRONT VIEW OF ST. LOUIS SWITCH-BOARD SECTIONS.

the switch-board 260 answering jacks and lamps, representing the set of subscribers' lines over which the three operators at that section receive their calls. Between the answering jacks and the multiple jacks are placed the outgoing trunk jacks, forming the terminals of trunk lines leading to other offices in the exchange.

On the horizontal keyboard, below the jacks, is a double row of plugs, the rear set or answering plugs being those used for insertion in the answering jacks in answering a call, and the front set being used for testing and afterward connecting with the line of a subscriber called for, in the multiple jacks above. The listening and ringing keys may be seen directly in front of the plugs.

The details of the arrangement of apparatus and wiring in central office equipments will be more fully discussed in a succeeding chapter.

In Fig. 285 is shown a front view of somewhat more than one section of the great multiple switch-board of the New York Telephone Company, in its Cortlandt street exchange. In this the method of designating the various types of service at the multiple jacks is clearly shown.

CHAPTER XXI.

TRUNKING SYSTEM BETWEEN COMMON BATTERY OFFICES.

In the preceding chapter the various methods of connecting two subscribers whose lines terminate in a single multiple switch-board were discussed. As already pointed out, however, in Chapter XI., it is frequently found necessary or expedient to employ more than one central office in an exchange, and to make provision for the connection of any subscriber in one office with any subscriber in any of the other offices. For the purpose of making these connections, trunk lines extending between the offices are provided. These trunk lines or trunks, as they are more often called, are usually of the one-way type—that is, they are used for establishing a connection in one direction only. To illustrate: Suppose that there are two offices, A and B, in an exchange. Instead of providing a group of two-way trunks by means of which all connections between the two offices in either direction could be established, two groups of one-way trunks are used, one group for calls originating in office A, the other for those originating in office B. Each trunk may, therefore, be said to have an outgoing and an incoming end, the terms "outgoing" and "incoming" always being made with reference to the particular office under consideration. Thus exchange A will be provided with a number of outgoing trunks and a number of incoming trunks. The same will be true of office B. It is evident that the outgoing trunk of office A is the incoming trunk of office B, and vice versa.

It has now become the almost universal practice in common battery exchanges to terminate the outgoing ends of trunk lines in jacks multiplied throughout the subscribers' sections of one office. These outgoing trunk lines at one office are the incoming ends at the other, and at this latter office the trunk lines terminate in plugs and lamps located on the keyboard of the particular position or positions. The outgoing ends, therefore, always terminate in jacks in front of the operators who look after the subscribers' lines, while the incoming ends always terminate in plugs at a special position or positions, at which positions multiple jacks of all of the subscribers' lines in the exchange are placed.

Those operators who sit at the positions of the board at which the subscribers' lines terminate in answering jacks and lamps are termed, "subscribers'" operators, or "A" operators, and the positions are referred to as "subscribers'" or "A" positions. The positions at which the incoming trunk lines terminate are called "trunk" positions or "B" positions, and the operators who sit at these positions are similarly designated. There is a logical reason for arranging the outgoing and incoming trunks as described. It is evident that in an exchange a subscriber's operator, after answering a call, may find that it is for another subscriber's line at that office or for a subscriber's line at a distant office, and by the arrangement spoken of by which the outgoing lines terminate in multiple jacks, she may complete the connection with her calling cord in the same manner in either case—that is, by thrusting the calling plug into the multiple jack of the local line or trunk line, as the case may be. The operators at the incoming end of the trunk lines are specialized in their line of work, and each handles generally from 25 to 30 incoming trunk lines. On account of the comparatively small number of these lines, which must terminate at any incoming trunk operator's position, ending them in plugs affords the simplest possible means of connecting them with the multiple jacks of the subscribers' lines placed before the incoming trunk operators. The incoming trunk operators, as a rule, have no means of listening in on a conversation, but each is, however, provided with a telephone set to which order-wire lines from other offices are connected. One end of each of these order-wire lines terminates in the telephone set of an incoming trunk operator at one office, and at the other end is multipled through the subscribers' operators' positions at the other exchange, terminating at each position in an order-wire key. By means of this order-wire key the subscribers' operator may, therefore, connect her telephone set with the telephone set of an incoming trunk operator at a distant exchange and thus convey to that operator the information as to what connection is to be established over the trunk line.

When a subscriber whose line terminates at one office desires to converse with a subscriber whose line terminates in a second office he will remove his receiver from its hook in the ordinary way, thus lighting his line lamp at a subscribers' operator's position at the multiple board of his office. The subscribers', or A operator, will answer in the usual way by inserting one of her answering plugs, and learning that the subscriber desired is one whose line terminates at a distant exchange, will press the order-wire key of a circuit terminating in the telephone set of a trunk operator at the desired office, and tell her the number of the line with which the connection is to be established. Before the A operator releases the order-wire key the trunk operator will designate to her over the same order-wire the number of the trunk which is to be used in making the connection. Thereupon, the A operator at the first office will insert the calling plug of the pair used in making the connection, into the jack of the trunk line designated, while the trunk operator will test the jack of the subscriber's line, and upon finding it not in use, insert the plug of the same trunk into this jack. The connection is now established between the lines of the two subscribers, and it remains for the trunk operator to ring the called subscriber, for which purpose each trunk line plug is provided with a ringing key. A calling supervisory lamp at the subscribers' operator's position in the first exchange will light in the same manner as described when the calling plug is inserted directly into the multiple of the subscriber's line. This lamp remains lighted until the called-for subscriber at the distant exchange responds, but will go out when he removes his receiver from the hook, in the same manner as if the connection had been made between two lines in the same exchange.

Associated with each incoming trunk circuit are two lamps—one known as the ringing lamp, which lights as soon as the trunk plug is inserted into the jack and remains lighted until the called-for subscriber answers, when it is extinguished, and cannot be relighted until the plug is removed from the jack. This lamp, as its name indicates, serves the purpose of showing the trunk operator when the called subscriber responds. If this lamp remains lighted for a considerable period after she has rung the subscriber she rings him again, and continues to do so until he responds or until she is convinced that he will not respond. It will be seen that the ringing lamps at the incoming trunk position and the calling supervisory lamp at the subscribers' operator's position at the distant office are extinguished simultaneously by the removal of the called subscriber's receiver from its hook, thus conveying the information to both operators simultaneously that the called-for subscriber has responded.

A second lamp associated with each incoming trunk circuit is known as the disconnect lamp and lights after a conversation has been finished and the connection has been taken down by the subscriber's operator at the originating office. This lamp also serves in some systems as a guard lamp to prevent mistakes in making connections with the trunk lines, as will be pointed out later.

The method by which the signals for taking down a trunk connection is given is briefly this: As long as the subscribers are engaged in conversation both supervisory lamps of the cord circuit at the A position remain unlighted as well as the disconnect and ringing lamps at the trunk position. The hanging up of the receivers of the subscribers operate the supervisory lamps at the A position in exactly the same manner as if the lines of the two subscribers terminated in the same office. In response to the lighting of both lamps the operator at the A position will pull down the connection. The act of withdrawing the plug from the outgoing trunk jack will cause the lighting of the disconnect lamp corresponding to that trunk line at the distant B position. When this disconnect lamp lights the trunk operator withdraws the plug from the line of the called subscriber, thus restoring all apparatus to its normal condition.

As no act on the part of either subscriber will have any effect on the disconnect lamp at the incoming trunk position, it will be seen that the A operator has complete charge of the connection after the called subscriber has answered, the B operator receiving the signal for disconnection when the A operator takes down the connection at her position.

When the trunk operator receives the order from the subscriber's operator at a distant exchange for connection with a certain line she tests the jack of that line with the trunk plug in the same manner as the subscriber's operator tests with the calling plug when a connection is to be completed at her own board. If the trunk operator finds the line free she completes the connection in the manner already described. If, however, she finds it busy she will insert the trunk plug into a "busy back" jack, one or more of which are located within the reach of each trunk operator. This jack is constantly connected with a source of interrupted e.m.f., which will place a "tone" on the line. The placing of the trunk plug in the "busy back" jack will also cause the calling supervisory lamp at the subscriber's position at the distant office to flash at regular intervals. The calling subscriber, hearing the tone, will, if he understands its significance, hang up his receiver, thus lighting the supervisory lamp associated with the answering plug used in making the connection, whereupon the operator, seeing both supervisory lamps lighted, will pull down the connection. If the subscriber does not understand the significance of the tone, the A operator, seeing the periodic flashing of the calling supervisory lamp, will throw her listening key and inform the subscriber that the line is busy.

Some systems also employ what is termed a "don't answer" jack, which works in a manner similar to that described for the "busy back" jack. The "don't answer" jack is used by the trunk operator if the subscriber whom she has been calling does not respond. By placing the trunk plug into this jack a tone different from the busy back tone is put on the line, and the calling supervisory lamp at the distant station is caused to flash at either a slower or more rapid rate, so that both the operator and the calling subscriber may understand the meaning of the signals.

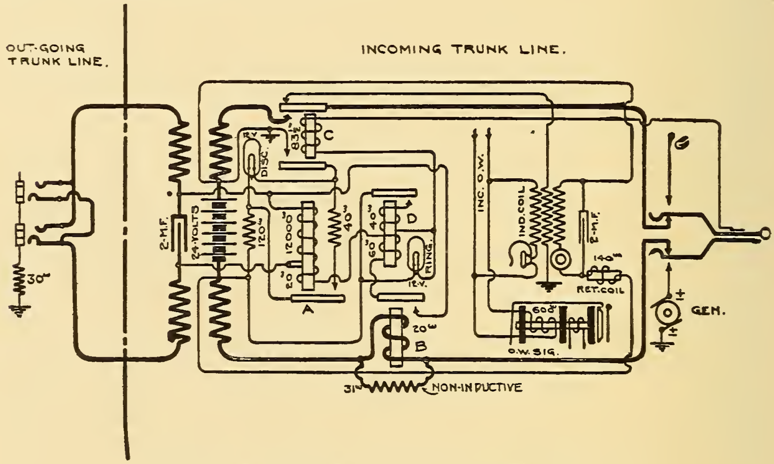


FIG. 286.—WESTERN ELECTRIC TRUNK CIRCUIT.

The standard trunk circuit of the Western Electric Company, used in connection with the subscriber's line and cord circuits, shown in Figs. 264, 265 and 266, is shown in Fig. 286. In this the outgoing end is shown at the left of the figure, the apparatus consisting merely of jacks multipled throughout the regular subscribers' positions at one office. The apparatus at the incoming end of the trunk line is shown at the right of the figure, and, as will be seen, the entire complexity of the circuit is thus placed at the incoming end.

It will be seen that at the incoming end the two sides of the trunk circuit are separated by a repeating coil of the ordinary common battery type. Between the windings connected directly across the trunk line is bridged a two-microfarad condenser, and in multiple with this, one winding of a relay, *A*, this winding having a resistance of about 12,000 ohms. Between the two windings of the repeating coil, which are connected with the incoming trunk plug, is bridged the common storage battery of the office. Included between the ring contact of the trunk plug and one terminal of the repeating coil is a supervisory relay, *B*, this relay having, it will be seen, the same circuit connection, so far as these windings are concerned, as the regular supervisory relays in the subscribers' operator's cord circuits at the *A* position. The remaining features of the incoming trunk circuit can be best described in studying their operation.

Fig. 287 shows the complete circuit of two subscribers' lines extending to different offices, connection being made between the two by the subscribers' operator's cord circuit at the A position of one exchange, and the trunk circuit extending between the two exchanges. If, after answering a call, the A operator ascertains that the connection is for a subscriber in a distant exchange, she will by order wire inform the operator at that exchange and receive in return the number of the trunk to be used. She will, therefore, at once insert the calling plug into the outgoing jack of the trunk designated, and the trunk operator will insert the trunk plug into the multiple jack of the subscriber's line. Assuming that the originating or A operator inserted the plug into the outgoing trunk jack before the trunk operator inserted the trunk plug in the subscriber's line, the following conditions would exist: The relay, *A*, would be energized, since it receives current from the battery at the originating office over the metallic circuit of the trunk line. This relay will attract its armature and place a 40-ohm shunt about the disconnecting lamp to prevent its subsequent illumination. It is evident, therefore, that no matter whether the circuit of the disconnect lamp is completed or not, it will not be illuminated until the relay, *A*, is de-energized, so as to remove the shunt from the lamp. It is furthermore evident that the relay, *A*, cannot be de-energized as long as the calling plug is in the outgoing jack at the originating office. The calling supervisory relay, *R*, of the A operator's cord circuit at the first exchange will not be operated by the current flowing through it over the metallic circuit of the trunk line on account of the very high ressitance of the relay, *A*, at the incoming trunk position. As soon as the B operator inserts the trunk plug into the line of the called subscriber a circuit will be closed from the ungrounded side of the battery at the second office through the ringing lamp, and through the winding of the re-

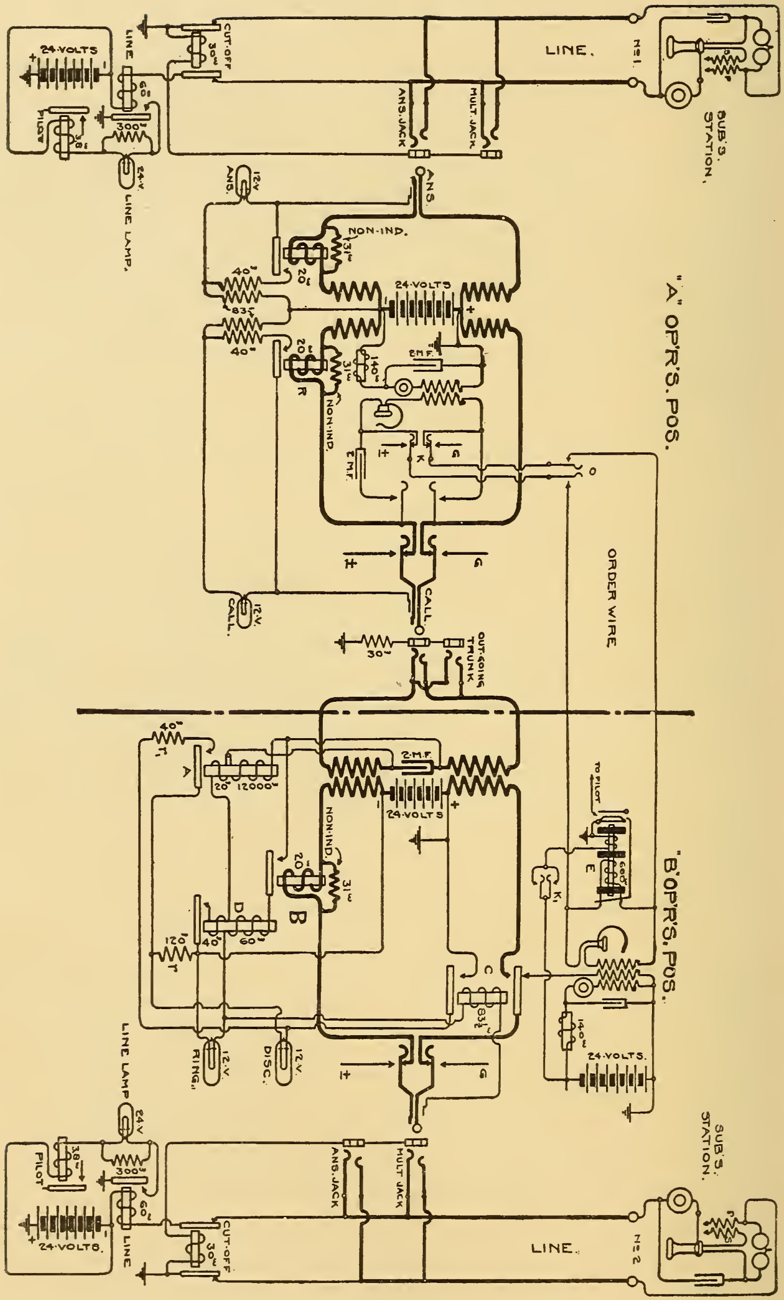


FIG. 287.—CONNECTION BETWEEN TWO SUBSCRIBERS THROUGH TWO OFFICES—WESTERN ELECTRIC SYSTEM.

lay, *C*, to the third contact on the plug to the test ring of the multiple jack of the subscriber's line, thence through the cut-off relay of the subscriber's relay to ground. The closure of this circuit will serve three functions: It will illuminate the ringing lamp; it will operate the relay, *C,* and it will operate the cut-off relay. The illumination of the ringing lamp shows the trunk operator that the subscriber has not yet responded. The operation of the relay, *C*, will close the normally open tip strand of the trunk cord cricuit, and cut off the normally closed circuit from the tip of the trunk plug through the operator's induction coil to ground.

The operation of this relay, *C*, will also close a circuit which may be traced from ground through one of the movable levers of this relay through the disconnect lamp and the resistance coil, *r,* to the negative pole of the battery. This will not, however, cause the illumination of the disconnect lamp, because the lamp is shunted by resistance, *r*, which is brought into circuit by the operation of the high resistance relay, *A*. The operation of the cut-off relay will perform the ordinary function with respect to the subscriber's line of cutting off all signaling apparatus normally connected with it. The conditions, as they exist, may be restated as follows: The disconnect lamp is not lighted because shunted by resistance, *r*. The ringing lamp is lighted, and the test relay, *C*, is operated so as to keep the talking circuit closed through the tip strand of the trunk. The test ring of the multiple jacks of the subscriber's line is raised to a potential above that of the earth, by virtue of being connected with the ungrounded side of the common battery through the third strand of the cord, and therefore the subscriber's line will test busy at all sections of the board. The trunk operator, after ringing the called subscriber in the ordinary manner, will be informed of his response by the going out of the ringing lamp, which will occur when the subscriber removes his receiver from its hook for the following reasons: Current will flow from the battery over the circuit of the line and thus pass through the coil of the relay, *B*, located in the sleeve strand of the trunk circuit. This relay will thus be under the control of the subscriber, and will remain actuated as long as he keeps his receiver removed from its hook.

The attraction of the armature of this relay will close a circuit, including the 60-ohm coil of the relay, *D*, from the ground side of battery at the first office over the tip side of the trunk line through the contact of the relay, *B*, through the 60-ohm winding of the relay, *D*, the low resistance winding of the relay, *A*, to the sleeve side of the trunk line, and to the ungrounded side of the battery at the first office. The operation of the relay, *D,* will close the circuit through a 40-ohm winding on this same relay, which winding will thus be placed in shunt with the ringing lamp, which will cause that lamp to go out. The relay, *D*, is therefore self-locking, as it holds the circuit through its own winding closed as long as operated. This relay will therefore remain operated until the end of the connection, regardless of whether relay, *B*, is operated or not. It is evident that the energization of the relay, *A*, will be maintained as long as the calling plug at the distant exchange remains in the trunk jack. The relay, *A*, therefore, cannot be released until the called subscriber has hung up his receiver and the subscriber's operator has withdrawn her plug from the trunk jack. During conversation both trunk lamps are out. The calling supervisory lamp at the A operator's position at the first office was also put out by the action of the called subscriber in removing his receiver from its hook. This action, it will be remembered, energized the relay, *B*, which, in closing its contact, completed the low resistance shunt abount the 12,000-ohm winding of the relay, *A,* this shunt including the 60-ohm winding of the relay, *D*, and the 20-ohm winding of the relay, *A*. Enough current was therefore allowed to flow through the supervisory relay, *R,* at the first exchange to attract its armature, thereby shunting the calling supervisory lamp and causing it to go out.

In case the B operator in the second exchange completed the connection between the trunk line and the subscriber's line before the A operator at the first exchange inserted the calling plug into the designated trunk line, the disconnect lamp in the trunk circuit would be lighted to be immediately put out when the connection was completed by the A operator. This serves to some extent as a guard against mistakes in making connection with the trunk lines. It sometimes happens that the A operator will mistake the number of the trunk designated by the B operator and plug into the wrong trunk. She would probably notice the error if she attempted to plug into a busy trunk, because of the test. If, however, the trunk into which she plugged by mistake was not busy, she would not notice the error. In that case the B operator would notice that the disconnect lamp, as well as the ringing lamp in the trunk, the plug of which she has inserted into the multiple jack, was lighted, and the A operator, seeing from the fact that the calling supervisory lamp did not go out, that the subscriber did not answer, would again speak to the B operator over the order wire.

At the end of the conversation the hanging up of the receiver of the called subscriber will light the calling supervisory lamp at the A operator's position at the office in the usual manner. The hanging up of the called subscriber's receiver will cause the de-energization of the relay, *B*, in the incoming trunk circuit at the second office and falling back of its armature will open the low resistance circuit about the 12,000-ohm winding of the relay *A*, and cause relay *R* at the first office to release its armature. This will light the calling supervisory lamp. The opening of the contact of relay *B* at the trunk position does not cause the de-energization of the relays *A* or *D*, because battery will continue to flow through the high resistance winding of the former, and relay *D* will be locked by current flowing through its contact and 40-ohm winding, the winding of relay *C* and the cut-off relay. Both trunk lamps will therefore remain dark. As soon, however, as the A operator withdraws the calling plug from the jack of the trunk line the relay *A* will release its armature, which will remove the shunt, *r'*, from about the disconnect lamp and allow the illumination of this lamp over a circuit which may be traced from the ungrounded side of the battery through the resistance coil, *r*, the lamp itself, to ground through one contact of the relay *C*. Seeing the disconnect lamp light the trunk operator will remove the trunk plug from the jack, thus allowing the cut-off relay of the line to assume its normal position, and rendering the line ready to receive a call. The breaking of the circuit between the third strands of the plug and the test ring of the multiple jack will de-energize the relay, *C*, which will release both of its contact levers, thus restoring all circuits to their normal condition.

When a trunk plug is not in use the relay, *C*, being de-energized, the circuit from the tip of the trunk plug is not connected with the repeating coil, as is usual, but is connected to ground through one of the back contacts of the relay, *C*, and the third winding of the *B* operator's induction coil. This is for the purpose of allowing the *B* operator to test the multiple jack of the subscriber's line to ascertain whether or not it is busy, the test, of course, depending on whether the test rings of the line tested are raised to a potential above that of the earth, as would be the case when a plug was connected to one of the jacks at another section, or at the same potential as the earth, as would be the case were the line idle. As soon as the operator plugs into the jack, however, the operation of the relay, *C*, cuts off all connection with the talking circuit and establishes the proper connection for talking over the trunk circuit by connecting the tip side of the trunk from the plug to one winding of the repeating coil. The B operator's telephone set is available only for receiving and transmitting order-wire communications over one of the order-wire circuits. One of these order-wire circuits is shown extending from the order-wire key, *O*, at the A operator's position to the B operator's telephone receiver and secondary coil at the trunk position. The closure of the key, *O*, will therefore permit the two operators to communicate for the purpose of allowing the A operator to designate the subscriber's line called for to the B operator, and the B operator to designate to the A operator the number of the trunk to be used.

It is customary to arrange at each incoming trunk position some means of transferring the incoming order-wire calls in case the trunk operator leaves her position either temporarily or for a period of considerable length. The scheme which is used by the Western Electric Company for this purpose is as follows: If the subscriber's operator at one office presses the order-wire key, and upon attempting to converse with the trunk operator at the second office receives no response, she will press the key, *K*, called a "ringing-down" key, at the same time that she depresses the order-wire key, *O*, which will connect the generator momentarily with the order wire. This will send current from the generator over the order-wire circuit and throw an electrical restoring drop, *E*, bridged across the circuit of the order-wire line. This drop is used simply as a relay to light the pilot lamp at the trunk position, which lamp will remain lighted until the operator, seeing it, responds. The lamp is extinguished by depressing the key, K_1, which closes a circuit through the restoring winding of the drop, thus opening the lamp circuit. This order-wire pilot lamp is connected to the night bell circuit in a similar manner to that in which the line pilot lamps are wired, so that the night alarm will ring whenever the order-wire lamp lights, if the night alarm switch is in the proper position.

In the operation so far described the ringing of the called subscriber has always been done manually by the A operator when no trunk was used in making a connection, or by the B operator where connection was made through a trunk. In some of the exchanges built by the Western Electric Company this necessary act of ringing on the part of the B operator is partially or entirely eliminated, and the method by which this is accomplished is called "automatic" ringing. An automatic ringing device, as applied to an incoming trunk cord circuit, is shown in Fig. 288, from which figure all portions of the apparatus save that actually concerned in ringing the called subscriber are omitted.

In this the ringing key, *K*, is provided with a clutch magnet, *m*, which, when the key is depressed into its ringing position, after the plug has been inserted in a jack, holds the springs of the key in this position and allows ringing current to flow from one brush of the generator, *G*, through the interrupter, *I*, the winding of relay, *R*, over the ring side of the line, through the bell and condenser at the

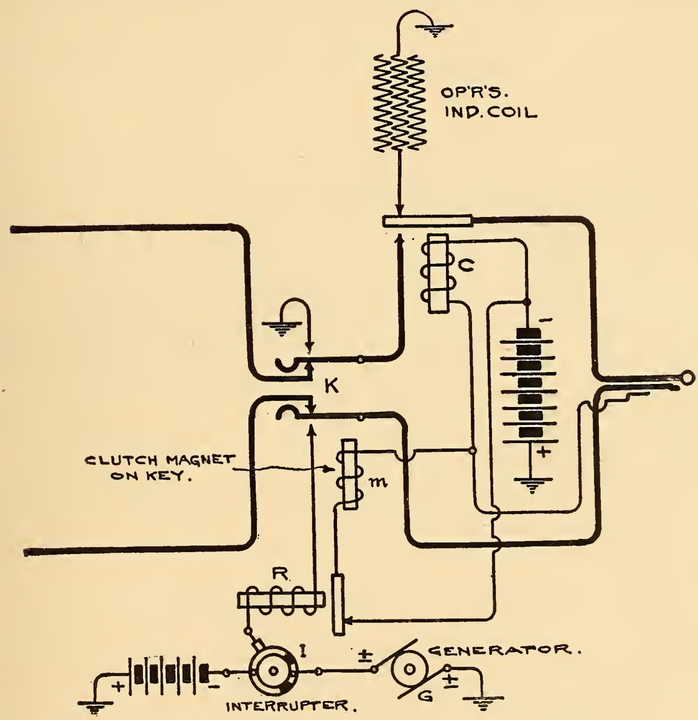


FIG. 288.—WESTERN ELECTRIC AUTOMATIC RINGING CIRCUIT.

subscriber's station and back on the tip side of the line to the grounded generator brush. The interrupter is constantly revolving. It is arranged so that the circuit of the generator will be closed to the ringing key for one second out of every six, but the resistance of the bell and condenser in the subscriber's instrument is great enough to prevent the ringing current from operating relay, *R*, and thus restoring the key. The interrupter is so arranged that during the other five seconds of each revolution the live or non-grounded side of the battery is connected to the wire leading to the ringing key.

When, therefore, the ringing key is depressed the subscriber's bell rings at intervals of six seconds for a period of one second, the battery being thrown on the line during the five-second intervals. Battery current, however, finds no path, on account of the presence of the condenser. As soon, however, as the subscriber responds by removing his receiver from its hook the current from the battery, or from the ringing generator, whichever happens to be flowing at the time, passes through the magnet of the relay, *R*, and trips the ringing key, thus cutting off ringing current before the subscriber has time to get his receiver to his ear. By this means the bell of the

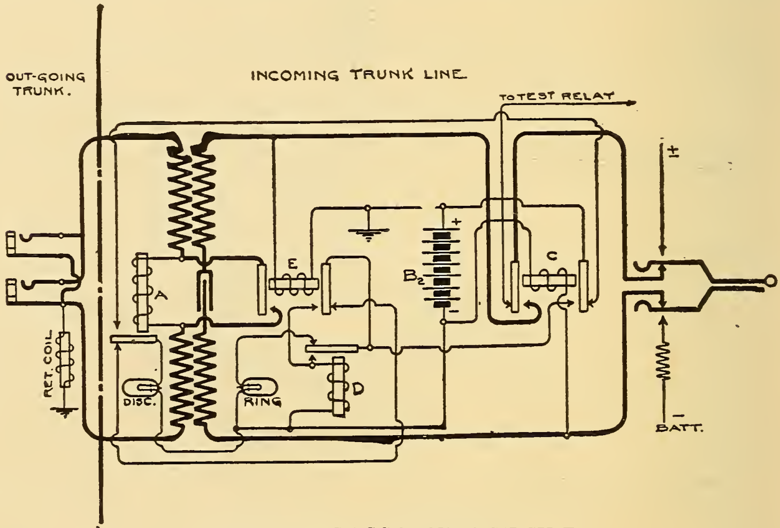


FIG. 289.—KELLOGG TRUNK CIRCUIT.

subscriber is rung at short intervals until he responds without any further attention on the part of the operator.

While the system just described is termed "automatic" ringing, this term is not strictly appropriate, because the ringing key is operated manually by the operator, the only automatic feature being the intermittent ringing and the disconnection of the ringing generator from the line. It is, however, quite easy to arrange for strictly automatic ringing, and this will be described in connection with a later system, although in some cases it has been and is applied to Western Electric circuits.

In Fig. 289 is shown the trunk line circuit employed by the Kellogg Switchboard and Supply Company, as used with their two-wire common battery multiple circuits, already described.

In this the trunk line consists of two wires, forming a metallic circuit, as in the Western Electric system. At the outgoing end the trunk terminates in two-point jacks, multipled throughout the sections in the ordinary manner, the sleeve contact, however, of all the jacks belonging to a line grounded through an impedance coil, this being for the purpose of securing the operation of the relay, R^4, shown in Fig. 270, in Chapter XX.

The trunk circuit is divided by means of a repeating coil, that portion of the coil which is connected with the trunk line proper having connected between its two halves a high resistance relay, *A*, which is operated as soon as the calling plug of the subscriber's cord circuit at the distant exchange is inserted into an outgoing trunk jack. It would be impossible to talk through the winding of this relay, but arrangements are made for short-circuiting it by the contacts of another relay, which condition is maintained throughout the time of the conversation. The other side of the repeating coil, which is connected with the trunk plug, has connected between its windings a two-microfarad condenser. The operation of this circuit will be best understood from the consideration of Fig. 290, which shows the circuit of two subscribers' lines connected through an A operator's cord circuit at the first exchange, and through a trunk line terminating in a plug at a second exchange. For full particulars of these line and cord circuits reference is made to the description accompanying Figs. 268, 269 and 270 in Chapter XX.

Referring, therefore, to Fig. 290, when the A operator at the first office receives an order from a subscriber whose line is shown, for a connection with a subscriber at the second office, after she has designated to the incoming trunk operator at the distant office the number of the line and received from that operator the number of the trunk to be used, the A operator will insert the calling plug of her pair of cords into the outgoing trunk jack designated. Assuming that the A operator inserts the calling plug into the outgoing jack before the B operator inserts the trunk plug into the subscriber's multiple jack, the following conditions exist: The relay, *A*, at the incoming trunk end will be operated from current received from battery, B', at the first exchange, over the metallic circuit of the trunk line, causing this relay to attract its armature. This will cause the lighting of the disconnect lamp over a path which may be traced from ground through the back contact of the relay, *C*, the front contact of the relay, *A*, and the disconnect lamp to the negative side of the battery, B^2, at the second office. On account of the

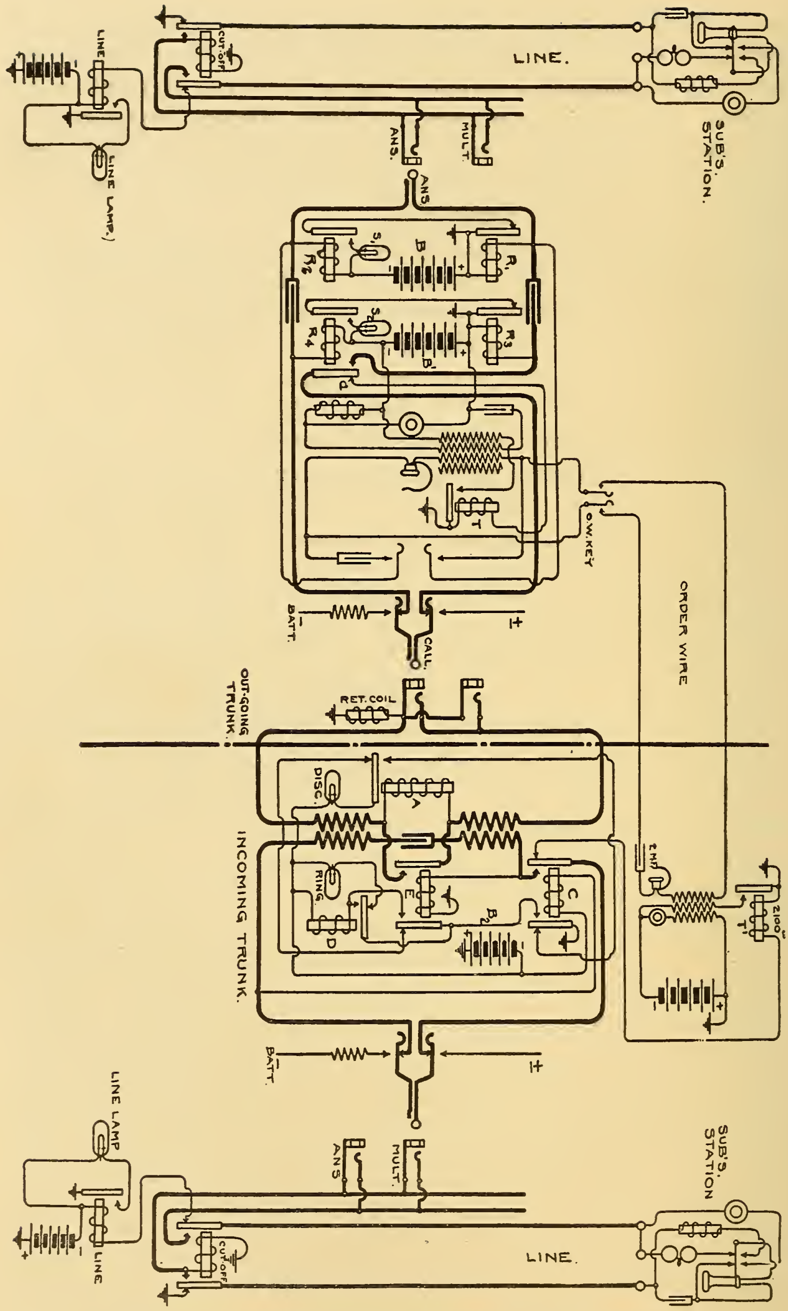


FIG. 290.—CONNECTION BETWEEN TWO SUBSCRIBERS THROUGH TWO OFFICES—KELLOGG SYSTEM.

very high resistance of the relay, *A*, the current flowing over the metallic circuit of the trunk line will not operate the supervisory relay, R^3, of the A operator's cord circuit which will, therefore, leave its contact in the calling supervisory lamp circuit closed. The other supervisory relay, R^4, of the A operator's cord circuit will, however, be operated, current flowing from the live side of the battery, *B'*, through the winding of this relay in multiple through the winding of relays, *A* and R^3, and the retardation coil connected between the sleeve side of the outgoing trunk jacks and ground. The calling supervisory lamp, S^2, of the A operator's cord, will, therefore, be lighted. When the B operator inserts the trunk plug into the multiple jack of the called subscriber the relay, *C*, will be at once operated over a circuit which may be traced from ground at the battery, B^2, through the winding of the relay, *C*, over the sleeve side of the cord circuit to the sleeve of the multiple jack, thence to ground through the cut-off relay of the subscriber's line. The operation of this relay will, by attraction of its right-hand contact lever, cause the breaking of the circuit of the disconnect lamp, therefore causing that lamp to go out. The right-hand contact lever of the relay, *C*, will, when thus attracted, close a contact which will complete a circuit which may be traced from ground through the front contact of the right-hand lever of this relay through the back contact of the relay, *D*, not yet energized, thence through the ringing lamp to the live side of the battery. This will cause the illumination of the ringing lamp. When the subscriber called for responds the relay, *E*, will at once attract its armature on account of current flowing in the metallic circuit of the line. This relay is, therefore, under the control of the subscriber. By attraction of its left-hand lever the winding of the relay, *A*, will be short-circuited, which relay will thus allow its armature to drop back. This will not, however, affect the disconnect lamp circuit, which will be held open at the right-hand back contact of the relay, *E*. The short-circuiting of the winding of relay, *A*, will cause the operation of the relay, R^3, in the subscribers' operator's cord circuit, and will, therefore, extinguish the calling supervisory lamp at the A position at the distant exchange. The closing of the contact by the right-hand lever of the relay, *E*, will cause current to pass through the relay, *D*, which will open the circuit of the ringing lamp, showing the trunk operator that the subscriber has responded. By the attraction of the left-hand lever of the relay, *C*, the normal test circuit will be broken, and the talking circuit between the tip of the trunk plug and the repeating coil will be established.

It was shown that when the A operator plugged into the trunk jack before the B operator plugged into the subscriber's line the disconnect lamp would momentarily light, to be extinguished when the B operator completed the connection. It will also be seen that if the B operator completes the connection first the disconnect lamp will be again momentarily lighted, to be again put out when the A operator completes the connection with the trunk. This is true, because the relay, *C*, will be operated by the act, on the part of the trunk operator, of inserting the trunk plug into the multiple jack, while the relay, *A*, will be inert as will the relay, *E*. The circuit through the disconnect lamp will, therefore, be completed from the back contact of the relay, *C*. As soon, however, as the A operator plugs into the trunk the relay, *A*, will be operated, which will put out the disconnect lamp. It will be seen, therefore, that this is an additional guard against a mistake in the connection of the trunk line, because if the B operator notices that the disconnect lamp lights and remains lighted at the beginning of the connection she will obey its signal and pull down the trunk plug. In this case the calling subscriber will remain without his connection, whereupon the A operator will again communicate with the B operator for a re-designation of the trunk.

During conversation the following conditions exist: Both supervisory lamps at the *A* position of the first office are extinguished. The relay, *A*, at the incoming trunk position of the second office is not energized because short-circuited. The relay, *C*, is operated and will remain operated as long as the trunk plug is inserted in the line jack. The relay, *E*, is operated and is under the control of the called subscriber, as it will be released as soon as he hangs up his receiver. The relay, *D*, which controls the circuit of the ringing lamp is operated and will remain so as long as the connection exists, because when operated it closes a circuit from battery through its own winding, its front contact to ground through the now closed contact of the relay, *C*. It is evident, therefore, that the ringing lamp will not light as long as the connection exists, and cannot be again lighted until the relay, *C*, is de-energized, which will only take place when the trunk plug is removed from the jack at the end of conversation.

When the called subscriber hangs up his receiver the relay, *E*, will be de-energized, thus removing the short circuit from about the relay, *A*, and causing the attraction of its armature. The disconnect lamp will not be lighted, however, because of the energization of the relay, *C*, which keeps the ground circuit leading to the disconnect lamp open. The breaking of the short circuit about the relay, *A*, will, however, cause the relay, R^3, to release its armature, thus causing the lighting of the calling supervisory lamp of the A operator. The calling supervisory lamp at the first office is, therefore, under the control of the called-for subscriber whose line terminates in the second office. When both the supervisory lamps of the A operator are lighted the operator knows that both subscribers have finished the conversation and withdraws the plugs. The removal of the calling plug from the outgoing trunk jack de-energizes the relay, *A*, which allows its armature to fall back and thus light the disconnect lamp. The path over which this lamp is illuminated includes the front contact of the right-hand armature of the relay, *C*. The illumination of the disconnect lamp is a signal for the operator to pull down the connection, and in doing so the relay, *C*, is de-energized, thus putting out the disconnect lamp and leaving all apparatus in its normal condition.

It will be seen that the relay, *C*, when not operated leaves the tip of the trunk plug connected through the test relay to ground, thus securing a test similar to that in connection with the calling plug of the A operator already described.

In offices of the Kellogg system, in which there are two or more trunk positions, the telephone set of each trunk operator is connected to a two-way key. If this key at any position is thrown in one direction and an operator at a distant office presses an order-wire key and attempts to converse with that operator, the order will be received by the operator, and at the same time an order-wire pilot lamp will be lighted at this trunk operator's position, this order-wire pilot lamp being operated by a relay energized by the closure of the order-wire key at the distant station. However, if the key is thrown in the opposite direction, the order and pilot lamp signal will be transferred to another trunk position. If the key at this second position is thrown in one direction the order and pilot lamp signal will be received in this second position, or, if thrown in the other direction, it will be transferred to the third position. In this way if the trunk operator leaves her position either momentarily or permanently she may, by throwing this transfer key, cause both the order-wire signals and the orders coming over her order-wires to be transferred to some other operator. In this way it is possible for one trunk operator to do all of the incoming trunk business at night or whenever the number of incoming trunk calls is small.

As in the Western Electric system, the order-wire pilot lamp is so wired, in connection with the night alarm, as to ring whenever the order-wire pilot lamp lights, if the night alarm switch is in the proper position.

Automatic ringing, as applied to some of the European work installed by the Kellogg Company, is so arranged that the generator will be thrown into circuit with the subscriber's line by the act of inserting the trunk plug into the jack of the called subscriber, the operator not being required to press a ringing key. This method

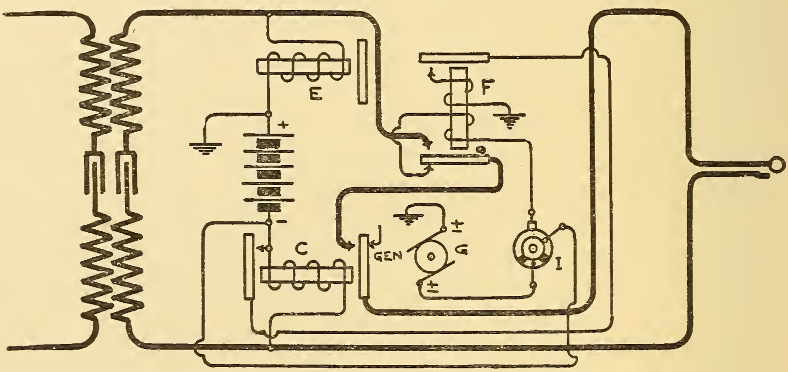


FIG. 291.—KELLOGG AUTOMATIC RINGING CIRCUITS.

of operating is brought about by means of the circuit shown in Fig. 291.

In this it will be seen that the ringing current is thrown on to each cord circuit by an extra armature of the relay, *C*, which is in the sleeve side of the cord, which relay is always actuated when the operator plugs into the jack. A second relay, *F*, placed in the circuit of the ringing current itself, serves, when actuated by the subscriber's removal of his receiver from its hook, to cut off the ringing current in a manner similar to that described in connection with the Western Electric automatic ringing device, Fig. 288.

In Fig. 292 is shown the trunk circuit used in some of the recent exchanges installed by the Stromberg-Carlson Company. This, it will be seen, is quite different from the trunk circuits already described, it having a considerable amount of apparatus at the outgoing end, this end including, beside the multiple jacks, a repeating coil, condenser and two relays. The incoming end also comprises a repeating coil, condenser and the usual apparatus for actuating the disconnect and ringing lamps, as well as the operator's telephone set, ringing keys, etc.

In Fig. 293 two subscribers' lines terminating at different offices are shown through a trunk circuit extending between these offices.

Remembering that the relay, S^3, is energized when the answering plug of the A operator's cord is inserted in the jack of the calling subscriber's line, it will be seen that if the A operator inserts the calling plug into the outgoing trunk jack before the B operator inserts the incoming trunk plug into the jack of the subscriber's line

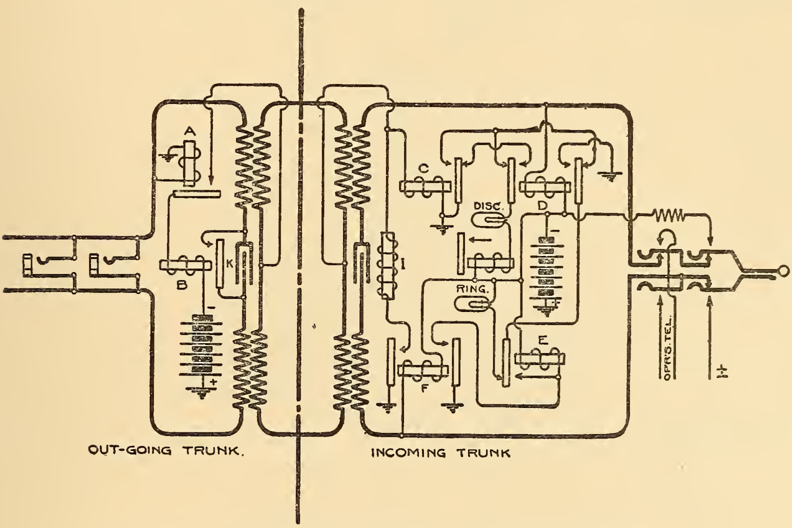


FIG. 292.—STROMBERG-CARLSON TRUNK CIRCUIT.

called for, the following conditions will exist: The relay, *A*, will be operated by current flowing from the battery through the winding of the relay, S^3, to ground, through the winding of relay, A. The operation of the relay, *A*, will cause the flow of current from the ungrounded side of battery through the coil of relay, *B*, to the center point of the outgoing trunk repeating coil, thence over both sides of the trunk line in multiple to the center point of the incoming trunk repeating coil, thence to ground through the relay, *C*, at the incoming trunk end. The relay, *C*, will thus be operated, but the relay, *B*, will not be operated because of the very high resistance of the winding of the relay, *C*, through which the relay, *B*, is not capable of acting. It will thus be seen that the relay, *A*, at the

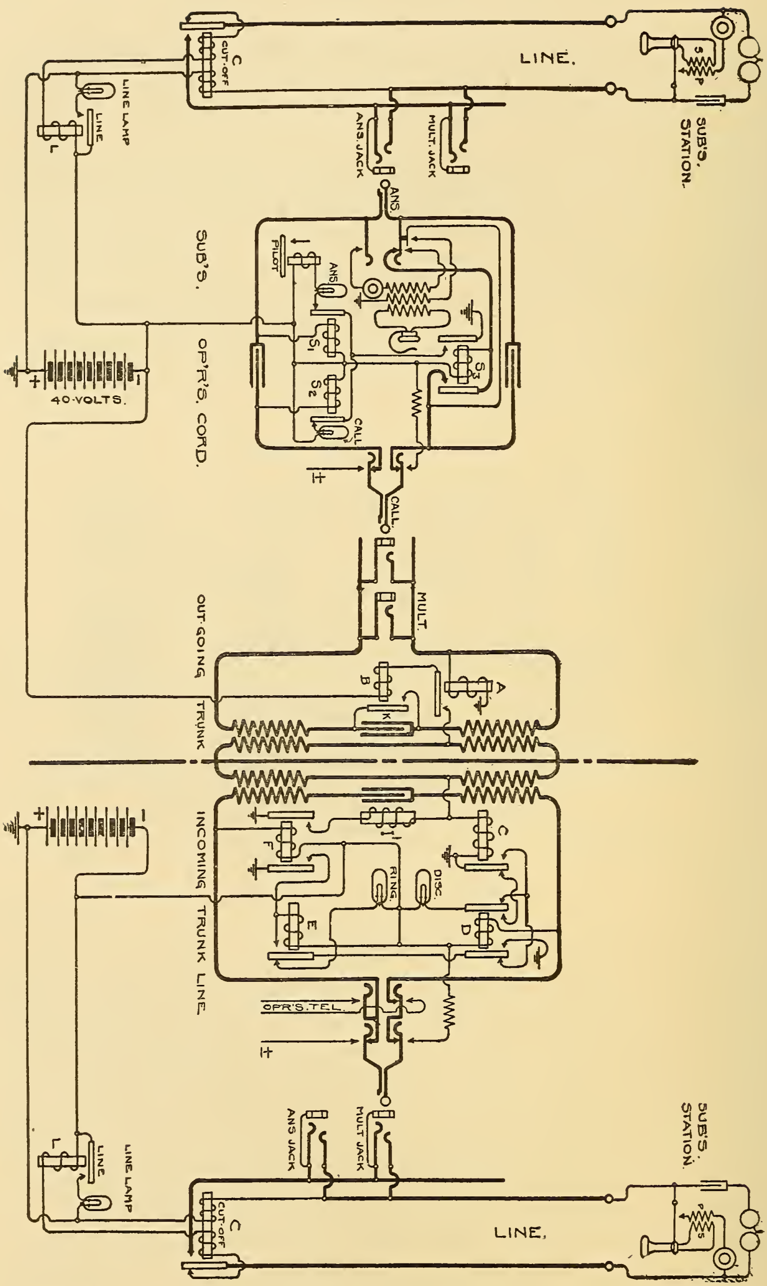


FIG. 293.—CONNECTION BETWEEN TWO SUBSCRIBERS THROUGH TWO OFFICES—STROMBERG-CARLSON SYSTEM.

outgoing end, and the relay, *C*, at the incoming end will be energized when the A operator plugs into the outgoing jack, and will remain energized as long as the connection remains at the outgoing end. The operation of the relay, *C*, closes the circuit of the disconnect lamp, this circuit being traced from the negative side of battery at the second office through the disconnect lamp, the left-hand back contact of the relay, *D*, to ground through the contact of relay, *C*. The energization of relay, *C*, also causes the illumination of the ringing lamp, current flowing from the negative side of battery through this lamp, the back contact of relay, *E*, the closed right-hand contact of relay, *D*, to the grounded side of battery through the closed contact of the relay, *C*.

The calling supervisory lamp in the A operator's cord circuit was illuminated by the plugging in of the A operator, because the supervisory relay, S^2, was not energized on account of the presence of the condenser, *K*, between the windings of the repeating coil in the outgoing end of the trunk. The conditions will be as follows, therefore, when the connection is made at the outgoing end, but not yet made at the incoming end. The calling supervisory lamp in the A operator's cord will be lighted, as will also the disconnect and ringing lamps at the incoming end of the trunk. As soon as the B operator plugs into the multiple jack of the called subscriber the relay, *D*, will be operated over a circuit which may be traced from the ungrounded side of the battery through the coil of this relay over the tip contacts of the plug and jack to ground through one-half of the cut-off relay winding. The operation of the relay, *D*, will open the circuit of the disconnect lamp, thus extinguishing it, the ringing lamp, however, will remain lighted, but the circuit through this lamp to the grounded side of battery will now be established through a contact of relay, *D*, instead of a contact of relay, *C*. After ringing the called subscriber the operator watches the ringing lamp, which will remain lighted until that subscriber responds. The act of raising his receiver from its hook will cause the energization of the relay, *F*, as the talking current for the called subscriber's line will pass from the live side of the battery through the coil of the relay, *F*, over the sleeve side of the line, thence back over the tip side of the line to ground through the coil of the cut-off relay in the line circuit. The operation of the relay, *F*, will cause the energization of the relay, *E*, which will break the circuit of the ringing lamp, causing it to go out. As soon as the relay, *E*, is operated it completes, by its own contact, a circuit through its coil to ground, which circuit also includes the front contact of the relay, *D*. Thus relay, *E*, when once operated, cannot be de-energized until the relay, *D*, is de-energized, which means that the ringing lamp after having been put out cannot be again lighted until the trunk plug is withdrawn from the jack.

It will be remembered that when the calling subscriber responded the relay, *F*, was operated, which completed the circuit from the retardation coil, I^1, to ground, this path being in multiple with the high resistance coil of the relay, *C*, between the middle point of the incoming trunk repeating coil and ground. A low resistance path through the retardation coil, I', is therefore furnished for the current through the relay, *B*, which relay is now for the first time operated and serves to short-circuit the condenser, *K*, bridged across the outgoing trunk repeating coil. This furnishes a low resistance path across the outgoing end of the trunk which causes the operation of relay, S^2, thus extinguishing the calling supervisory lamp at the office at which the call originated. It will thus be seen that the notification of the response of the called subscriber is given to the incoming trunk operator by the going out of the ringing lamp, and to the A operator at the distant office by the going out of the calling supervisory lamp.

The condition then during conversation is that both the answering and the calling supervisory lamps of the A operator's cord circuits, and the disconnect and the ringing lamps at the incoming end of the trunk line are out. At the end of the conversation the hanging up of the calling subscriber's receiver will, of course, illuminate the answering supervisory lamp of the A operator's' cord circuit. The hanging up of the called subscriber's receiver will produce no effect in so far as the signals are concerned at the incoming trunk end, but will cause the lighting of the calling supervisory lamp in the A operator's cord circuit at the distant office in the following manner: When the called subscriber hangs up his receiver the relay, *F*, will be de-energized, thus breaking the circuit to ground through the impedance coil, I', and causing the relay, *B*, at the outgoing end of the trunk line to release its armature, which, by breaking the shunt about the condenser causes the supervisory relay, S_2, of the A operator's cord circuit to release its armature, thus lighting the calling supervisory lamp.

In response to the lighting of both supervisory signals the A operator will pull down the connection which will cause the illumination of the disconnect lamp at the incoming end of the trunk line, for the following reasons: The breaking of the connection between the outgoing trunk jack and the calling plug will cause the de-energization of the relay, *A*, which, by releasing its armature, will break the circuit through the relay, *C*, at the distant office, causing it to release its armature and thus completing the circuit of the disconnect lamp from ground, through the front contact of the left-hand lever of the relay, *D*. In response to this signal the incoming trunk operator will pull down the connection, thus de-energizing the relay, *D*, which, by releasing its armature, will put out the disconnect lamp and will also open the circuit of the locking relay, *E*, thus restoring all apparatus to its normal condition.

It has been pointed out that if an A operator plugged into the outgoing end of the trunk before the B operator plugged into the subscriber's multiple jack, the disconnect and ringing lamps at the incoming end would light, but the disconnect lamp would immediately go out when the B operator plugged into the called subscriber's jack. It will also be seen that if the B operator completes the connection at her end before the A operator plugs into the trunk the disconnect and ringing lamps will also light, owing to the energization of the relay, *D*. In either case, therefore, both lamps will be lighted whenever either operator completes the connection before the other, and the disconnect lamp will go out when the connection is completed at both ends, thus securing the advantages of guarding against mistakes in a manner similar to that of the Kellogg system. This circuit operates in accordance with the standard code of signaling employed in modern work, but it has the disadvantage of requiring two repeating coils through which transmission must always be effected. This is undesirable, though not fatal.

CHAPTER XXII.

THE DIVIDED MULTIPLE SYSTEM.

It has been shown in preceding chapters that the capacity of the types of multiple board so far considered is limited in practice by the size of the spring jack used. Where $\frac{1}{2}$-inch jacks are used, 6000 lines has been usually considered the ultimate capacity of the switch-board. Similarly, switch-boards with a capacity of 9000 lines have been constructed using $\frac{3}{8}$-inch jacks, and with a capacity of 18,000 lines using $\frac{3}{10}$-inch jacks. Where occasion demands it is possible to reduce the size of the jack to $\frac{1}{4}$ inch, making possible a switch-board capacity of 24,000 lines. Beyond this it does not at present seem desirable to go in the reduction of the size of the jack on account of difficulties, from both constructive and operative standpoints.

A method of increasing the possible size of multiple switch-boards has been devised by Mr. Milo G. Kellogg, and is now working in two large exchanges in this country. In this system, which is known as the "divided multiple system," the switch-board and lines are divided into a number of groups, usually four. In the four-division divided multiple board the switch-board consists of four multiple boards, all in the same building, and to each of these is connected one of the groups of lines in the same manner as if they were in separate offices. Primarily, therefore, we have in this arrangement four groups of lines, each group terminating in a multiple switch-board of sufficient size to properly handle all of the lines in that group. With this arrangement, if no further provision were made, it would be possible for any subscriber in one division to obtain a connection with another subscriber in his own division, but not with any subscriber in any of the three other divisions. In order to enable any subscriber in, say, the *A* division, to obtain a connection with a subscriber in the *B*, *C* or *D* divison, means are provided, not for trunking between the divisions, but for enabling the calling subscriber to signal directly to one of the operators in that division in which the line of the desired subscriber belongs. Each line is therefore provided with a signal in each division of the board, and the subscriber may, at will, display any one of the signals belonging to his line, thus calling the attention of one of the operators in the corresponding division. In order to enable the operator to make the connection with the calling line in response to such a signal, an answering jack is associated with each signal. This arrangement, therefore, necessitates the use of four line signals and four answering jacks for each line, one in each division of the board, and of means whereby the subscriber may display any one of the signals belonging to his line to the exclusion of the others. Instead of trunking between exchanges, therefore, the subscriber sends his call directly into the division of the switch-board to which the desired subscriber belongs.

Remembering that each division of the board has a multiple jack on each of its sections for every line belonging to that division, it will be seen that a subscriber may have his line connected with a line in any division by displaying his own signal on the board of the division to which the called-for subscriber belongs. The operator at the position of that board at which the signal is thus displayed may complete the connection between the answering jack of the calling line and the multiple jack of the called-for line, the latter line being provided with a multiple jack on every section of its own division of the board.

By the use of the four-division board it is seen that the ultimate capacity of the switch-board at any office employing a given-sized jack may be increased approximately fourfold; not quite this, however, because the extra line signals and answering jacks take up a portion of the room which would otherwise be available for the multiple jacks.

To illustrate this more clearly the ordinary multiple board, using jacks placed on quarter-inch centers, may be made for a capacity of approximately 24,000 lines, this limit, of course, being reached because it is impossible to put more than 24,000 quarter-inch jacks within the reach of a single operator—that is, within the limits of a single switch-board section. By the use of the four-division system, however, using quarter-inch jacks, four multiple switch-boards, having a capacity of somewhat less than 24,000 lines each, could be used, the arrangement being such that any subscriber could secure a connection with any line without employing the services of more than one operator for any connection, and without any trunking whatever between the boards. On account of the space occupied by the extra answering jacks and signals, the capacity of such a divided board would be somewhat under 96,000 lines. Such, in general, is the plan of the divided multiple board.

It is not necessary that the number of divisions be confined to four. The electrical and mechanical problem involved in the design in such a board would be considerably simplified if two divisions only were used; and it is also possible, at least theoretically, that the number of divisions might be increased to six or eight.

Taking up the simplest form of divided multiple board—the two-division board—the principle of its operation will be readily understood from Fig. 294, where two lines, numbered *A*-101 and *B*-204, are shown entering the central office. In the divided multiple system it is obviously necessary to designate the division to which a line belongs, as well as its number in that division. The board shown consists of two divisions, *A* and *B*, each consisting of six sections of multiple switch-board. Line *A*-101 has an answering jack on section 1, and a drop or signal associated with this jack on the same section. This line also has a multiple jack, *J*, on each sec-

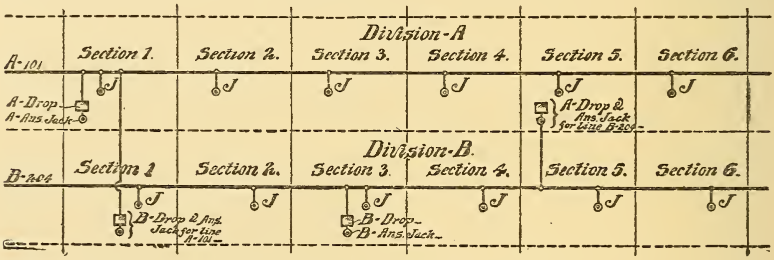


FIG. 294.—SCHEMATIC DIAGRAM OF DIVIDED MULTIPLE SWITCH-BOARD WITH TWO DIVISIONS.

tion of this division. It also has a drop and an answering jack on section 1 of the *B* division of the board.

By pressing either one or the other of two buttons on his telephone set any subscriber may throw the *A* or *B* signal on his line, thus attracting the attention of the operator in the *A* or *B* division of the switch-board. Thus, if subscriber, *A*-101, desires to converse with any other subscriber in the *A* division, he would press the *A* button, thus throwing his *A* drop at section 1 of the *A* division. The operator would connect with this line at the *A* answering jack, and upon learning the number of the *A* subscriber with whom he desired connection, would complete this connection by means of an ordinary pair of plugs and cords, the calling plug being inserted into the multiple jack of the *A* subscriber called for. If, on the other hand, subscriber, *A*-101, desires to converse with some *B* subscriber, he would press his *B* button, which would throw his *B* drop, in this case on section 1 of division *B*. The operator at that section would answer in the usual manner, and upon learning the number of the subscriber called (which, being a *B* subscriber, will have a multiple jack on each *B* section), she will complete the connection by inserting the calling plug into this multiple jack. Line *B*-204, has a multiple jack, *J*, on each section of the *B* division, an answering jack and drop on section 3 of the *B* division and on section 5 of the *A* division.

In a similar manner a schematic representation of a four-division board is shown in Fig. 295, in which four lines, *A*-101, *B*-204, *C*-109 and *D*-1500 are shown, each having multiple jacks on the division bearing the same letter, and each also having an answering jack and drop on one section of each of the divisions. A subscriber de-

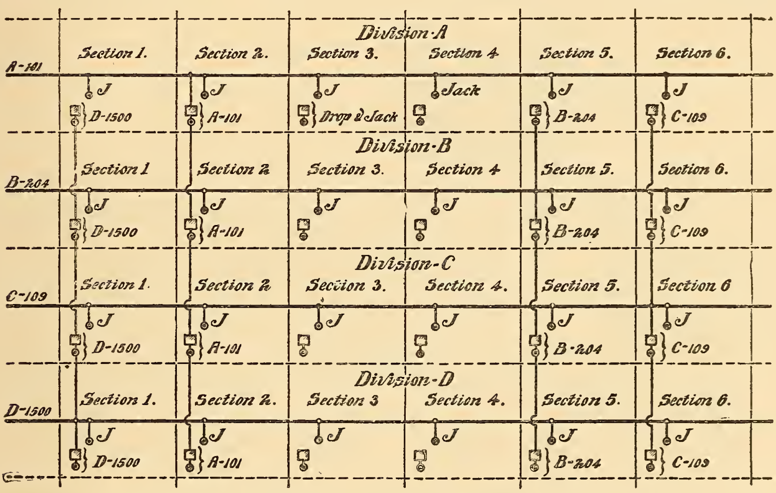


FIG. 295.—SCHEMATIC DIAGRAM OF DIVIDED MULTIPLE SWITCH-BOARD WITH FOUR DIVISIONS.

siring a connection with another subscriber will press the button on his telephone corresponding to the division to which the subscriber wanted belongs, which will throw the drop of the calling subscriber in the division of the called subscriber, and the operator will therefore make connection between the answering jack of the calling subscriber and the multiple jack of the called subscriber.

The two notable examples of the use of the divided multiple system are to be found in the present main exchanges of the Kinloch Telephone Company, of St. Louis, Missouri, and that of the *Cuyahoga Telephone Company, of Cleveland, Ohio. Each of these are

* The divided multiple board at Cleveland has, since this writing, been replaced by a straight multiple common battery board having an alternate capacity of 18,000 lines.

four division boards, their present equipment consisting of 9600 lines each, and their ultimate capacity being approximately 24,000 lines each. These boards were installed before the wide adoption of common battery systems by the Independent telephone companies in the United States, and are not equipped with this desirable feature.

In Fig. 296 is shown a simplified circuit of a subscriber's line as used in these two exchanges. In the board at Cleveland the divisions are given the names of the four letters, *A, C, M* and *R*, respectively, these letters being chosen instead of *A, B, C* and *D*, as used at St. Louis, to avoid the similarity in sound between the letters in the latter set, which had caused some confusion in the

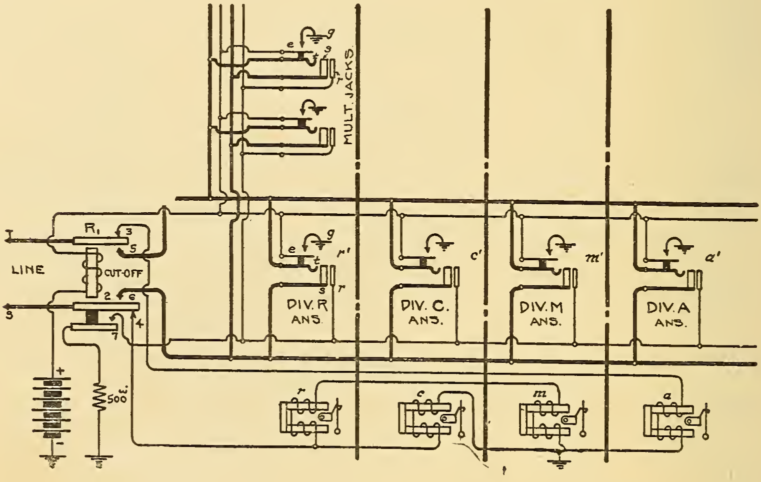


FIG. 296.—LINE CIRCUIT OF DIVIDED MULTIPLE BOARD AT CLEVELAND, OHIO.

earlier St. Louis exchange. The line circuit shown in Fig. 296 is that of an *R* line, as it will be seen that the *R* division is provided with multiple jacks, whereas the other divisions are provided with answering jacks.

The tip and sleeve sides of the line are shown at the left-hand portion of the sketch, these terminating in two movable contact levers, 1 and 2, of the cut-off relay, *R*. These contact levers normally rest against their back contacts, 3 and 4, respectively, which connect the line normally with the signaling devices, *r, c, m* and *a*, corresponding to the four divisions of the board, *R, C, M* and *A*. A simplified scheme of signaling is shown in Fig. 297. It represents the condition existing when the levers 1 and 2 of the relay *R* are in their normal positions. The four signaling devices, *a, c, m* and *r,* each consists of a polarized drop adapted to respond to current flowing in one direction only.

The drops, *a* and *c,* are oppositely polarized and bridged directly across the tip and sleeve sides of the lines, *T* and *S,* respectively, the two drops being included in series. Similarly, the drops, *r* and *m,* oppositely polarized are bridged between the sleeve side of the line and ground, the two drops being in series. It therefore follows that a positive current sent over the metallic circuit of the line will actuate drop *a* only. A negative current over the metallic circuit will operate drop *c* only. A positive current sent over the line to ground will operate drop *r,* while a negative current over the same

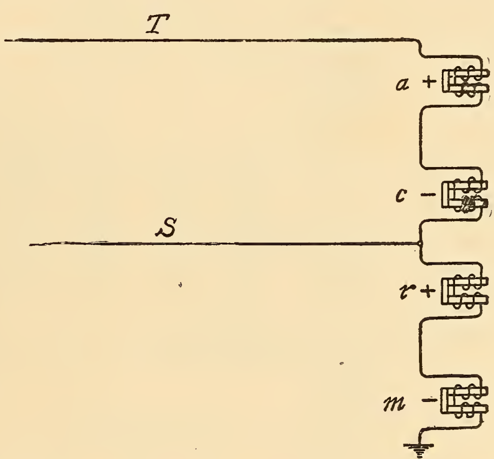


FIG. 297.—SIMPLIFIED LINE SIGNALING CIRCUIT.

path will operate the drop *m* only. The subscriber's apparatus is adapted, by means of four buttons, any one of which the subscriber may push, to send the currents in the proper direction either over the metallic circuit or over the sleeve side of the line and ground so as to operate any one of the drops in the manner thus described.

Referring again to Fig. 296, it will be seen that the condition normally existing with respect to the relation of the drops to the line, is that shown in simplified form in 297.

Coming now to a consideration of the jack circuits, these are normally entirely disconnected from the line, the connecting means between them and the line being the back contacts, 5 and 6, of the cut-off relay and the contact levers, 1 and 2, of that relay. Each jack consists of a test ring, *r*, sleeve contact, *s*, tip contact, *t*, local contact, *l*, and common ground contact, *g*.

The plugs are of the two-conductor type, each adapted when inserted into a jack to have its tip and sleeve register with the tip and sleeve contacts, *t* and *s*, of the jack. When fully inserted into the jack the sleeve of the plug does not touch the test ring, *r*. The insertion of the plug into the jack, besides completing the talking circuit between the contacts, *t* and *s*, of the jack and those of the plug, presses the contact, 1, belonging to that jack against the contact, *g*, thus closing the circuit traced from ground at the jack through the coil of the cut-off relay and the 20-volt battery back to ground. This actuates the cut-off relay, which by levers 1 and 2 breaks the

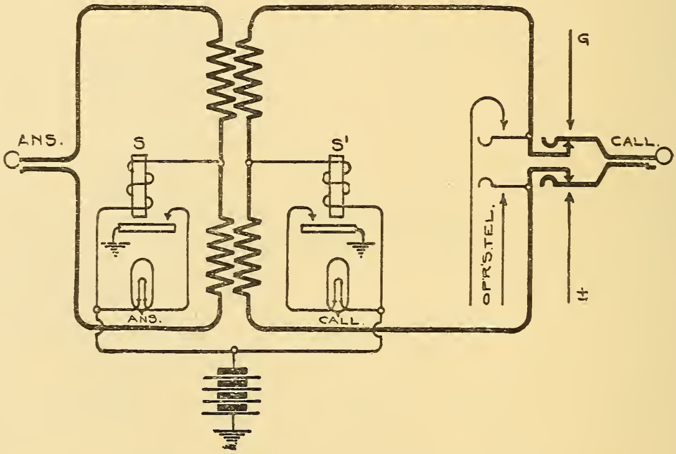


FIG. 298.—CLEVELAND CORD CIRCUIT.

circuit between the line and the various signaling devices, and completes the circuit with the tip and sleeve contacts of the jack. The third lever, 7, on the cut-off relay serves to connect all of the test rings belonging to the line to ground through a resistance coil.

It will be seen that the jacks belonging to this line are multipled throughout the various sections of division, *R*, of the board, while the jacks *a'*, *c'*, *m'* and *r'*, which are answering jacks, are placed one on each division of the board, these jacks being, of course, located in close proximity to the corresponding drops.

The cord circuit of this system is shown in Fig. 298. This is not adapted to common battery talking, but the answering and calling sides are divided by a repeating coil. Between the center points of each side of this coil and ground are connected the coils of the supervisory relays, *S* and *S'*, and the common battery. Each relay, when operated, serves to close the circuit of the corresponding supervisory lamp, and it will be seen that as long as the circuit of the subscriber's instrument remains free from ground, as is the case during talking, the supervisory relays, *S* or *S'*, of the plug connected to that line, will receive no current, therefore the lamp will not light.

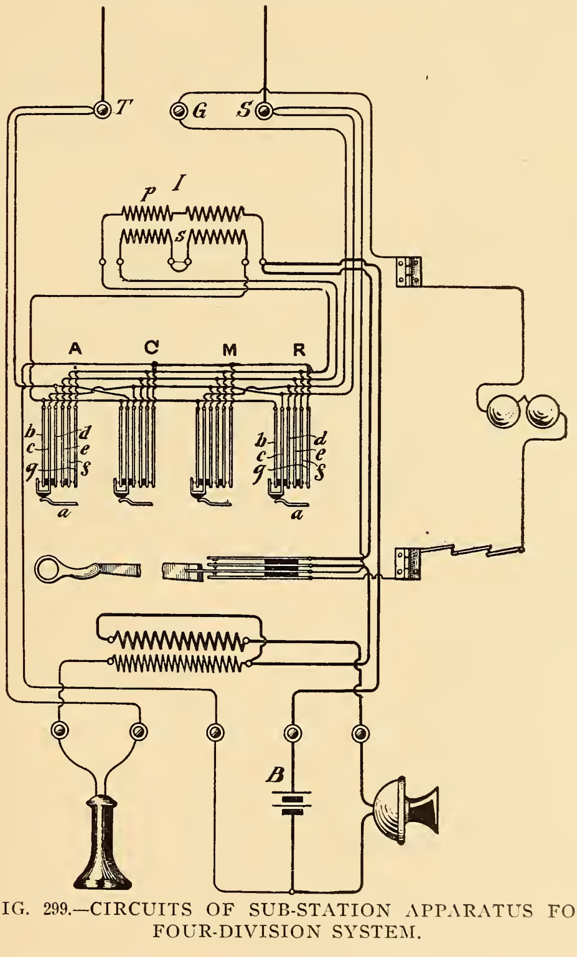


FIG. 299.—CIRCUITS OF SUB-STATION APPARATUS FOR FOUR-DIVISION SYSTEM.

When, however, the subscriber's receiver is hung up current flows from ground at the central office through the battery and the corresponding supervisory relay, thence through one side of the corresponding repeating coil to the ground at the subscriber's instrument. The feature of double supervision is thus secured in accordance with the standard code of signaling.

In the earlier installation of this four-division system at St. Louis, calling was done by means of a magneto generator, having a commutator so arranged as to deliver either positively or negatively polarized current, instead of the usual alternating current. By means of four buttons current in the proper direction, either over the metallic circuit or over the sleeve side of the line and ground could be sent to the central office when the generator was operated, thus causing the operation of the drop at the division corresponding to the letter of the button pressed. At Cleveland, however, the magneto generator was dispensed with and the energy of the local battery at the subscriber's station used for signaling the central office.

In Fig. 299 is shown diagrammatically the apparatus and circuit arrangement of a sub-station equipment as used in the Cleveland exchange. The local battery, *B*, used for signaling is the same one that is used for talking, and the only action necessary on the part of the subscriber to call central is a pressure of the button corresponding to the division of the switch-board desired. The two-line wires are shown permanently attached to the two outside binding posts, *T* and *S*, at the top of the figure, while the center post, *G*, is permanently connected to earth. The hook switch is of the Kellogg type already described, and serves, when depressed, to connect the call bell, which is the ordinary type of polarized ringer, between the binding post, *S*, and ground. When raised the bell circuit is opened and the usual primary and secondary circuits are closed.

A, C, M and *R* represent the call-sending devices, each one of which, when operated, is designed to actuate the corresponding annunciators, *a, c, m* and *r*, at the central office. Each one of these devices contains a bank of seven springs, lettered in their order from the top, *a, b, c, d, e, f* and *g*, the functions of which will be presently pointed out. Operating in connection with these springs is a closed magnetic circuit, induction coil, *I*, which has primary windings, *p*, and secondary windings, *s*. The structure of one of the sets of signaling springs and its mechanical and electrical operation in connection with the induction coil and the battery will be more readily understood by reference to Fig. 300, which shows the circuits stripped of confusing detail. Pressure is applied to the springs, *b*, of any one of the signal-sending devices by means of the push button, *K*, not shown in Fig. 299, but shown in Fig. 300. When depressed the spring *b* depresses first the spring *d* into engagement with the spring *e*, and immediately thereafter spring *f* into engagement with the spring *g*. Meanwhile the spring *c*, also depressed by the spring *b*, has its forward end caught under the retarding spring *a*. When the spring *c* is thus caught by the spring *a*, it is held in its depressed condition as it has not sufficient strength in itself to overcome the retarding action of this spring. The spring *b*, however, is the strongest of the group in its upward tendency, and when relieved of pressure from the button, *K*, engages with the upwardly bent portion of the spring *c*, and serves to drag it back to its normal position against the retarding influence of the spring *a*. When relieved from the influence of the spring *a*, the spring *c* assumes its normal position and breaks contact with the spring *b*.

The cycle of contacts made and broken upon the pressure and

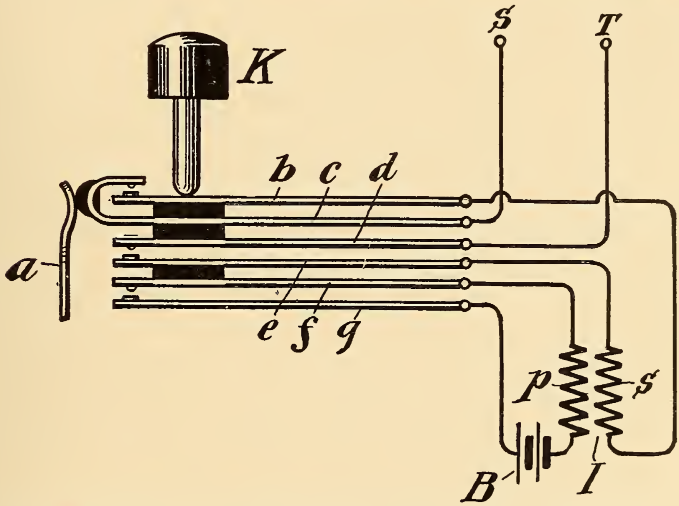


FIG. 300.—DETAIL OF SUBSCRIBER'S SIGNALING APPARATUS.

subsequent release of the button, *K*, is as follows: First, the making of contacts between the springs *d* and *e*; second, the making of contacts between springs *f* and *g*; then, as the button rises, first, the making of the contacts between the springs *b* and *c*; second, the breaking of the contacts between the springs *f* and *g*; third, the breaking of the contacts between the springs *d* and *e*, and fourth, the breaking of the contacts between the springs *b* and *c*.

These makes and breaks occur in a definite order, and with a predetermined time interval between them, the purpose of which will be understood when the circuit connections are considered.

The primary windings, *p*, of the induction coil, *I*, are connected in series with the battery between the springs *f* and *g*. The secondary windings, *s*, of the induction coil are connected in series between the springs *b* and *e*. The binding post, *S*, connecting with the sleeve side of the line is connected to the spring *c*. The spring *d* is connected to binding post *T*. The connections described and shown in Fig. 300 are those of an *A* button.

Normally, therefore, both sides of the secondary and line circuit are open, as is also the primary circuit. When the button, *K*, is depressed, the secondary or line circuit is held open between the springs *b* and *c* as long as there is pressure on the button. The first contact that is made is that of one side of the secondary circuit between the springs *d* and *e*. The flow of current through the primary winding of the induction coil made possible by the closure of springs *f* and *g* would send an impulse to line but for the fact that the line circuit is held open between the springs *b* and *c*. In this manner the sending of the *make* impulse is avoided. When the pressure on the button, *K*, is relieved, the remaining side of the secondary or line circuit is closed between the springs *b* and *c*, thus placing the line in readiness to receive the *break* impulse of the induction coil, which immediately follows by the breaking of the primary circuit between the points *f* and *g*. It is this current which passes over the line to actuate one of the drops or annunciators, at the central office. Immediately afterward, both sides of the secondary circuit are opened and both sides of the secondary coils are thus left free for any subsequent connection. It will be noticed that the primary circuit is kept closed during the change from the downward to the upward movement of the button. This change occupies a certain time interval, during which the current in the primary circuit has time to rise to its maximum strength in order to completely magnetize the core of the induction coil, so as to send a secondary current of maximum strength when the break occurs. The make impulse is eliminated, because it is weaker than the break, and the two being in opposite directions makes it impossible or impracticable to use both of them. The relation of the springs *b* and *c* effectually prevents the possibility of sending the make impulse over the line, and therefore sending the wrong signal, because it is impossible to close the primary circuit between the points *f* and *g* without first breaking the secondary circuit between the contacts *b* and *c*.

Reference to the circuits shown in Fig. 299 shows that the connections are such that the signal-sending devices *A* and *C* will send currents in opposite directions over the metallic circuit formed by the limbs, *T* and *S*, of the line, while the signal-sending devices, *M* and *R*, will send currents in opposite directions, over a circuit formed by the limb, *S*, of the line, with an earth return. The directions in which these signaling currents are sent by each signal-sending device, *A*, *C*, *M* and *R*, correspond to that adapted to operate the respective annunciators, *a*, *c*, *m* and *r*, of Figs. 296 and 297.

The divided multiple system has never yet been extensively applied to common battery systems, although the plan is entirely feasible, particularly with regard to a two-division system. The circuits of the two-division system, adapted to both common battery talking and signaling, are shown in Fig. 301, their operation being as follows: The switch-board is shown as having two divisions, termed *A* and *B*. Two subscribers' lines are shown extending from their respective sub-stations, 1 and 2, to the central office.

At the sub-station is provided the usual common battery equipment to which two push button keys, *A* and *B*, are added, one in each side of the line. Each push button is adapted, when depressed, to open its line conductor and ground it.

The line conductor, 1, is permanently connected with the spring, 3, of a relay, *R*, the normal contact, 4, of which is connected with one winding, 5, of relay, *T*, which winding is connected with the signal lamp, *S*, for the line, located upon the *A* division of the switch-board. The circuit is then extended from the other terminal of the lamp through the pilot relay, *P*, to the live pole of common battery, B^2, the opposite pole of which is grounded. The other line conductor, 2, is permanently connected with the spring or movable contact, 6, of the relay, *T*, the normal contact, 7, of which is connected with one winding, 8, of the relay *R*, and thence to the signal lamp, *S'*, of the line, located in the *B* division of the switch-board. The other terminal of the lamp is connected through the winding of the pilot relay *P'*, to the battery B^2. The relay *R* is provided with a second movable contact, 9, the normal contact, 10, of which is grounded, and the forward contact, 11, of which is connected to one terminal of the coil, 8, on this relay. This movable contact is joined to a similar movable contact, 12, of the relay, *T*, the normal contact, 13, of which is likewise grounded, and the forward contact, 14, of which is similarly connected to one terminal of the coil, 5, on the relay, *T*. The front contact, 15, of the spring, 3, of relay *R*, of line wire, 1, is connected to the tip springs of the answering jacks, *J* and *J'*, in the *A* and *B* divisions, respectively, and the multiple jacks, J^2, in the *B* division, while the front contact, 16, of the

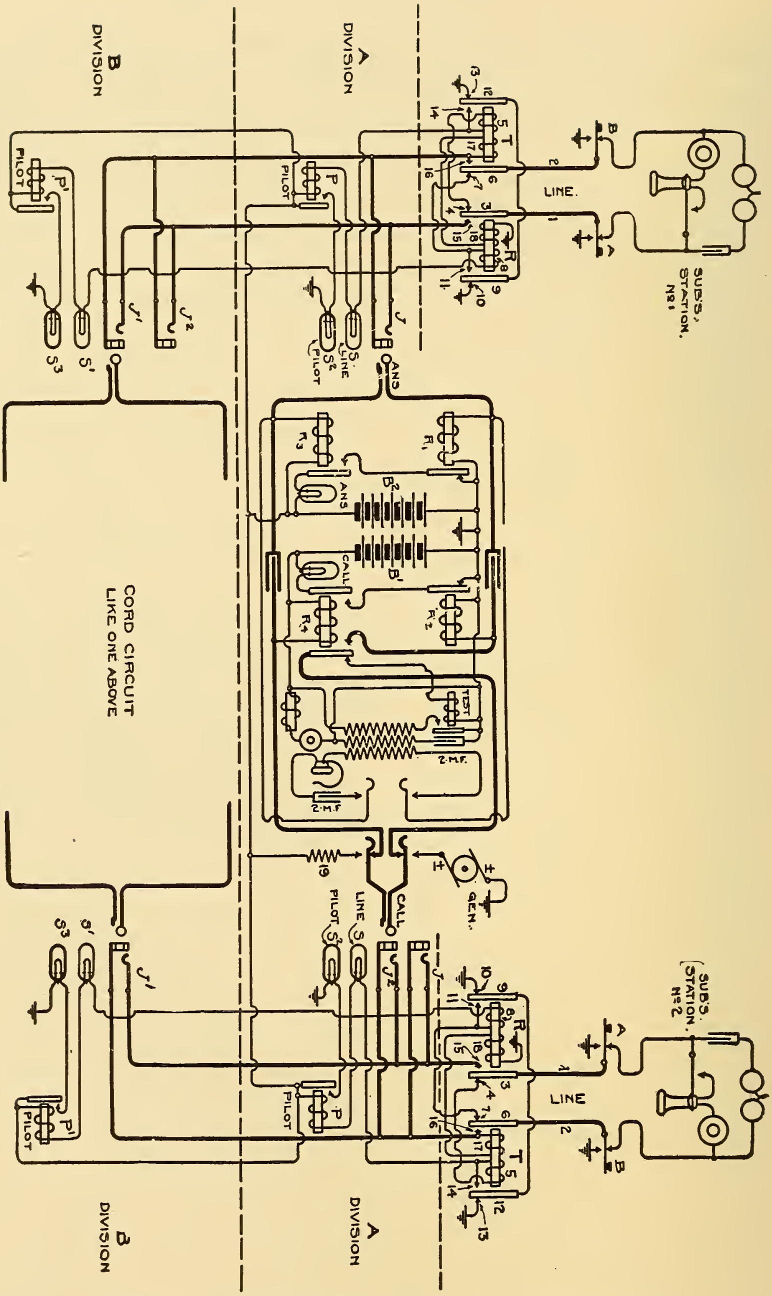


FIG. 301.—TWO-DIVISION COMMON-BATTERY SYSTEM.

spring, 6, of the relay, *T*, is similarly connected with the sleeve contacts of all the same jacks. The multiple jacks, J^2, for this line are located upon the *B* division of the switch-board, this, therefore, being a *B* line. The similar contacts of all the jacks belonging to any line are connected in multiple. The sleeve conductor leading to the jacks is also connected with one terminal of the winding, 17, of the relay, *T*, which winding is connected with a similar winding, 18, of relay, *R*, the other terminal of which latter winding is grounded. The second windings of these relays are, therefore, connected in series between the sleeve contacts, all of the jacks, and ground.

The pilot relay, *P*, located in the *A* division of the switch-board, controls, through its normally open contacts, the circuit of the pilot lamp S^2, this lamp being common to all lines of one position; similarly, the pilot relay *P′*, located upon the *B* division of the board, controls through its normally open contacts the pilot lamp S^3.

The line of station No. 2 is provided with exactly similar apparatus, except that the multiple jacks, J^2, for this line are located upon the *A* division of the switch-board. This is therefore an *A* line.

The cord circuit apparatus used alike at the various positions of both divisions of the switch-board is indicated in the diagram by the single set at the *A* division. The cord circuit will be recognized as being substantially the same as that used in the Kellogg single division board discussed in Chapter XX.

The operation of the system is as follows: The calling subscriber, say on line 1, having ascertained the division upon which the wanted subscriber is listed in the directory of the exchange, would push the button corresponding to that division, the buttons being lettered in accordance with the names of the two divisions. If it be desired to operate the signal located upon the *B* division of the switch-board, the button *B* is depressed, thus grounding the line conductor, 2, and thereby completing a circuit from the live pole of the battery, B^2, through the winding of pilot relay *P′*, the line lamp *S′*, winding, 8, of relay *R*, contacts, 7 and 6, of relay *T*, and over conductor, 2, to ground at the sub-station. The current in this path is sufficient to actuate the relay *R*, which locks by virtue of its armature, 9, closing the circuit through its coil, 8, to ground through the back contact of the spring, 6, of the relay *T*. This locking branch is in parallel with the line conductor, 2, and therefore replaces it in the further operation of this signal and relay. If the resistance of the line conductor is so great as to prevent the full operation of the lamp, *S′*, over the path first completed, the substitute path over the locking circuit being entirely local, is of low enough resistance, so that the current flowing brings the lamp up to full illumination and operates the pilot relay, *P′*. The pilot signal, S^3, located before the operator upon the *B* division, is also lighted by current from the battery B^2.

If the subscriber desired had been listed in the *A* division, the calling subscriber would have depressed button *A* at his sub-station, thus operating relay *T*, which would lock up and light the pilot and line lamps, S^2 and *S*, respectively in the same manner as when the signals on the *B* division were caused to operate.

In either case the relay, *R* or *T*, remains operated by virtue of its locking coil, thus holding the circuit of its corresponding lamp closed after its subscriber releases his button. Thus a subscriber may signal either division of the board.

The operator attending the answering jack of the line, 1, upon the division receiving the signal (say the *A* division), upon seeing the signals exposed inserts the answering plug of her cord circuit into the jack, *J*, and depresses the listening key to connect her telephone with the cord circuit, and receives the order from the subscriber. The insertion of the plug completes another path for current from the battery, B^2, through the sleeve supervisory relay, R^3, to the sleeve strand of the cord and the relay, *T*, and the winding 18 of relay, *R*, to ground, over which path current flows to actuate relays, *R* and *T*, as well as supervisory relay, R^3. The actuation of the relay, *R*, breaks the locking circuit of the relay, *T*, at contact, 10, and therefore breaks the local circuit of the line lamp, *S*, and the pilot relay, *P*. The relay, *T*, is also actuated to prevent any possible lighting of the line lamp, *S′*, upon the other division of the switch-board. At the same time the spring, 3, of relay *R* and spring, 6, of relay *T* engage their forward contacts, 15 and 16, and complete the metallic talking circuit from the line conductors, 1 and 2, to the tip and sleeve conductors leading to the jacks. If the line called for is idle, the plug is inserted in the proper multiple jack and the ringing key is actuated. The insertion of the plug closes a path for current from the battery, *B′*, over the sleeve of the cord circuit to the winding, 17, of relay *T*, winding, 18, of relay *R* to ground, thus actuating both relays, and rendering the line signals of both divisions of the board inoperative, and also connecting the spring-jack contacts of the line to the external line conductors. The operation of the ringing key does not effect any re-arrangement of the relays, *R* and *T*, for the reason that the sleeve side of the key closes a cir-

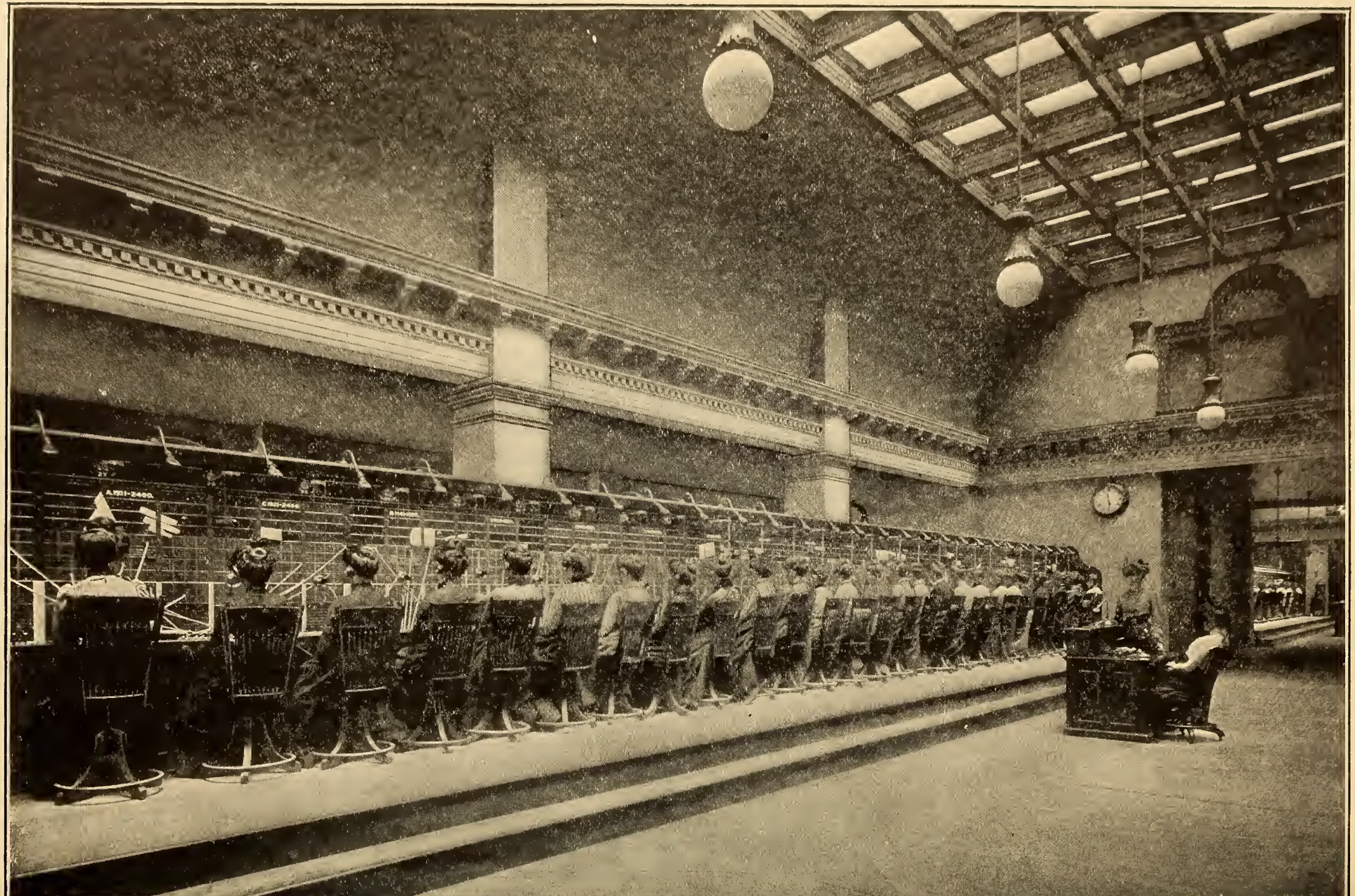


FIG. 302.—GENERAL VIEW OF ONE DIVISION OF CLEVELAND SWITCH-BOARD.

cuit from the battery, B^2, through the resistance, 19, to the sleeve conductor of the jack.

The operation of testing and of the supervisory signals, and, in fact, of the cord circuit as a whole, is the same as in the single division two-wire system of the Kellogg Company.

The part that the divided multiple board is to play in the future development of telephony is now the subject of much discussion. A few years ago there seemed to be a decided need for this system on account of the then present limit of the straight or single division multiple board to approximately 6000 lines. With the advent of the three-wire multiple board, as developed by the Western Electric Company, by which the size of the jacks are reduced to $\frac{3}{8}$ inch between centers, and the further simplification resulting in the production of the two-wire system, with its 3-10-inch or $\frac{1}{4}$-inch jacks, the capacity of the single division multiple board has been increased to such an extent as to make it seem unnecessary to adopt the divided multiple system in central office equipments recently built, these not requiring a capacity above the present limit of the single division multiple board.

The advantages of the single division multiple, when the question of ultimate capacity does not enter, are that its circuits and apparatus are simpler, and that there is no work required of the subscriber other than to remove his receiver from its hook and express his wants in words. The divided multiple necessitates the selection between divisions on the part of the subscriber, and this, while in nowise fatal and perfectly practicable, is better obviated, if possible.

It must be said, on the other hand, that in a large office, say for 18,000 lines, the number of jacks required by a four-division board would be very much less than that required by a single division board. To illustrate: assuming an average of 100 subscribers for each operator's position, the 18,000-line board would have 183 positions, or sixty-one sections. The number of multiple jacks would, therefore, be 1,098,000, and with the 18,000 answering jacks added, we have a grand total of 1,116,000 jacks for the single division board. For the divided multiple, assuming four divisions, each division would be required to handle 4500 lines. Each division would, therefore, require 45 positions, which would be increased to 47 when the end positions were added, and to 48 in order to make the number of sections even. There would, therefore, be 16 sections in each division and 72,000 multiple jacks. Adding to this the 4500 answering jacks, we have a total for each division of 76,500 jacks, and for the four divisions a grand total of 306,000 jacks. We thus have for an 18,000 line board, 1,116,000 jacks for the straight multiple board, and 306,000 jacks for the divided multiple board, a saving of 810,000 jacks. This is not all clear gain, however, for while there would be 18,000 line signals for the straight multiple board there would be 72,000 for the four division board, which latter system would thus require 54,000 more line signals than the straight multiple board. Besides this, the four division board has more complex wiring and apparatus.

If in the near future the increasing demands for telephone service make it desirable to install in a single office equipment for a greater number of lines than can be handled by a single multiple board, it will be necessary to use the divided multiple system unless some radically different means of handling connections than the manual board, as at present conceived, shall come into existence.

Fig. 302 is a view of one of the divisions of the switch-board of the Cuyahoga Telephone Company at Cleveland. This board was installed by the Kellogg Company in 1899, and has a present equipment for 9600 lines. Its ultimate capacity is for about 22.000 lines.

CHAPTER XXIII.

PRIVATE BRANCH EXCHANGE SERVICE.

By "private branch exchange" is meant an exchange, complete in itself, in that it is adapted to bring into communication any two subscribers in a comparatively small community, such as that in a business establishment, and also affording communication between these subscribers and those of a larger exchange, such as that of a city. It is a "private" exchange because it is individual to the particular institution which it serves. It is a "branch" exchange because it operates in conjunction with and forms a part of a larger exchange, hence the term "private branch exchange."

Of all classes of telephone service, the private branch exchange affords one of the greatest conveniences to the business man, and this fact has not been duly appreciated in the past. The telephone men and telephone subscribers are just awakening to a realization of its value.

Methods employed in giving private branch exchange service differ widely among the various operating companies, and there appears to be no standard practice even among the Bell licensees, where the best organization usually exists. For this reason a study of the principal methods of handling this important branch of service will prove of interest.

So far as the handling of local connections between two subscribers in the same private branch exchange is concerned, there is little to be said, as the same conditions exist as in any small exchange. With respect to the method of connecting the private branch subscriber through a trunk line to a subscriber in the city exchange, or of connecting a subscriber in the city exchange to a private branch subscriber, there appears to be a wide diversity of opinion. Some contend that the function of the attendant at the private branch board is merely to secure for the private branch subscriber the proper connection, either incoming or outgoing, after which the connection is to be treated strictly as a main office connection in which the private branch attendant has no further concern. Another and stronger contention is that the private branch attendant's function is to, in every way in her power, serve the private branch subscriber, relieving him of waiting, as far as possible, performing for him all the duties necessary to secure the party with whom he wishes to speak, and supervise for him the disconnection of his line when through speaking, securing another connection if he so desires. At all events, however, the private branch attendant has a most important function in serving as a go-between for the general public and the private branch subscriber with respect to incoming calls. She receives all such calls and distributes them to the various departments of the institution she serves, in accordance with whatever intelligence she possesses.

In nearly all cases a private branch exchange equipment consists of a number of sub-station equipments and of a switch-board of suitable size, from which lines extend to the various sub-station equipments of the branch exchange subscribers. The operation and arrangement of the exchange within itself is practically the same as that of any ordinary common battery exchange.

Connections between a subscriber in a branch exchange and a subscriber in a city exchange are made in the same general manner as between two subscribers in different offices of a city exchange, the connection being through a trunk line extending between the two switch-boards. It is customary, however, in order not to confuse the work of the *A* operators in the city exchange, and on account of economy in the trunk lines, to use two-way trunks in connecting a private branch switch-board with a larger central office, instead of using one-way trunks, as has already been described in connecting two central offices in the same exchange. In other words, borrowing from the nomenclature of railroad systems, a *single-track* instead of a *double-track* system is used.

As in other branches of telephone service, the tendency is to have the subscribers' or A operators at the multiple board of the city exchange perform no more special work than is absolutely necessary. For this reason private branch trunk lines usually terminate in the main office multiple switch-board in the same manner as regular subscribers' lines, the trunk lines being provided at the main office board with an answering jack and lamp at one section of the switch-board, and with a multiple jack on each of the sections. With this arrangement the work of the A operators at the main office is kept standard for handling incoming or outgoing calls over these trunk lines in exactly the same manner as over the regular subscribers' lines. The trunk lines may terminate at the private branch switch-board in different ways; perhaps the most common being to terminate each in a plug and a magneto drop. In some of the latest systems, however, they terminate at the private branch end, each in a lamp and a jack.

A private branch subscriber desiring a city connection usually simply removes his receiver from its hook, and when answered by the private branch attendant tells her to obtain for him a line of a certain number, or, as is frequently the case, not knowing the number, tells her that he wishes to speak with Mr. Jones, of Smith & Co. He believes that the private branch attendant's time is less valuable than his own, and acts on that assumption, allowing her to do the work of looking up the number in the directory, of calling for the proper line in the main exchange, and of waiting for the response of that party. When the connection is secured she rings the bell of the private branch subscriber who called, who, if he has a proper regard for the ethics of telephone service, will remain at his desk so as to respond immediately, and thus avoid keeping Mr. Jones waiting. This is the usual method of handling an outgoing call from a private branch exchange, although there are some who contend that the work should be assumed by the subscriber making the call, the operator serving merely to connect the private branch subscriber's line with the proper trunk at the city office, after which the private branch subscriber would behave exactly as if he were on an individual line extending directly from his instrument to the main office.

It is difficult to see why the first method is not the proper one, for it cannot be denied that the operator's time costs less to the company employing her than does the time of those employes who are deemed of enough importance to be provided with a private telephone. Again, the economy in the time of the use of trunk lines is best secured by allowing the operator to attend to the making up of the connection, and as the charge for trunk lines usually forms the most important item of cost in private branch exchange service, this matter is of importance. In this connection the private branch attendant may perform the important function of supervising the use of the trunk lines, refusing to allow minor employes, such as stenographers, to gossip or to conduct private business over the line, when they are employed for more important purposes.

With regard to incoming calls for the institution served by the private branch exchange, the work of the attendant is of even more importance. Learning the nature of the business of a calling party, she may connect him with the proper department or official without causing him the annoyance of being referred from one department to another. This also relieves the private branch subscriber of the annoyance of being continually called up by persons whose business should be transacted with some one else. In the case of the higher officials of a company, this duty of the private branch attendant is of particular importance, she acting as a doorkeeper, as it were, allowing only those who have proper business with the official to gain access to him by telephone.

Assuming that a connection between two subscribers, one in the private branch exchange and one in the city exchange, has been made, the method of supervising this connection is the subject of much discussion. Of course, the city subscriber will always have a supervisory lamp at an A operator's position, at the city exchange, under his control, and the supervision of his line will, therefore, be the same as in any other connection. There are three general methods, however, of conveying the supervisory signal from the private branch line, which may be briefly outlined as follows:

The first of these is to place in the control of the private branch subscriber during a connection the regular cord circuit supervisory signal at the main office only, so that this lamp will light at the main office when the subscriber hangs up his receiver, in exactly the same manner as if he were on a regular subscriber's line entering the main office directly. With this method in use, when both subscribers hang up their receivers, the main office operator would pull down the connection, and in doing so the removal of her plug from the private branch exchange trunk jack would light the disconnect lamp at the private branch board, after which the private branch attendant would pull down the connection.

In the second of the three methods, the private branch exchange subscriber has within his control during a connection a lamp at the private branch board only, the action of his hook causing no change whatever at the main office. With this arrangement the disconnection is effected when both subscribers hang up, the private branch exchange operator first pulling down the connection in response to the lighting of the lamp under the control of the private branch subscriber (she receiving no signal from the city subscriber) whereupon she pulls down the trunk connection, thus lighting the supervisory lamp at the main office. The main office subscriber having also hung up, the subscriber's operator, who made the connection, seeing both lamps lighted, will then pull down the connection. It will be seen that the operation at the main office is rendered in nowise special, the subscribers' or A operator, receiving both supervisory signals in exactly the same manner as if two local lines had been connected. The only difference is that instead of both supervisory lamps being operated directly by the movement of the connected subscribers' hooks, one of them is operated by the action of the private branch exchange operator in pulling down the connection.

In the third method, which is, perhaps, the most used of all, the private branch subscriber has within his control the supervisory signals at both the private branch exchange and the main office, so that when he hangs up his receiver both lamps light, thus sending a disconnect signal simultaneously to the main office and to the private branch office.

From the standpoint of clean operating at the main board, the first of these methods, wherein the private branch subscriber controls the supervisory signal at the main office only, is perhaps the best. It is found, however, that this arrangement is not desirable from the standpoint of the private branch subscriber, and also has its disadvantages to the city subscriber. To illustrate this: A private branch subscriber will often, when called up by a city subscriber, wish to direct the calling city subscriber to some other member of the firm or some other department where his business may be best transacted. Under this circumstance the private branch subscriber is not able to signal the branch exchange attendant, which he might do if he controlled the supervisory signal at the private branch board; but on the other hand, he is obliged to tell the city subscriber to call up on another line in the private branch exchange. This necessitates the calling party beginning all over again at the main office, and perhaps thereby temporarily losing the use of the trunk line, over which the connection was first established.

This fault is eliminated in the second of the three methods in which the private branch subscriber has within his control during a connection a lamp at the private branch board only. With this arrangement, the private branch subscriber who has been called, and who desires to have the calling party put in connection with another person on another private branch line, has only to move his hook up and down to signal his own private branch attendant, whereupon she will complete the connection between the calling subscriber and whatever other private branch line is designated.

Another advantage of this second system of supervisory signaling is that if the private branch exchange subscriber desires another connection after the close of a conversation he can at once secure the attention of the private branch attendant and have her secure it for him, hanging up his own receiver until notified by the attendant that the connection is ready. This system has the disadvantage, however, of requiring a somewhat more complex cord and trunk circuit at the private branch exchange.

Under the third method, where the private branch subscriber controls the supervisory signal at both the private branch and the main board, some confusion is liable to occur by both operators coming in on the circuit at the same time in response, for instance, to the private branch subscriber's action of moving his hook up and down. In doing this he usually desires the attention of the private branch attendant, rather than of the main office operator. The main office operator, however, may notice this at once and cut her telephone out of the circuit. If the private branch subscriber desires to have

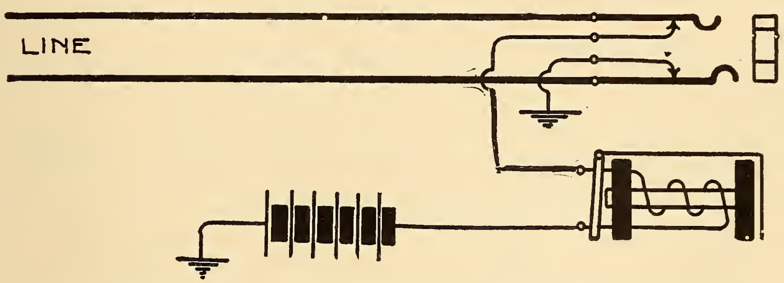


FIG. 303.—PRIVATE-BRANCH EXCHANGE SUBSCRIBERS' LINE CIRCUIT—WESTERN ELECTRIC SYSTEM.

the party with whom he is connected switched on to another private line the main office operator is not likely to pull down the connection in response to the movement of his hook, because the main office subscriber will not have hung up his receiver, as he will be waiting for the new connection.

This method of having the signals at both the main office and the private office under the control of the private branch subscriber has the advantage of simplicity and first cost, the circuit being very simple. It has a further advantage in common with the first method, of tending to clear the main office cord circuits more quickly after a connection than is the case where the second method is used.

The third method is that now most used in the United States, probably on account of its simplicity and the consequent advantage in point of maintenance of the private branch exchange apparatus.

Disregarding the questions of simplicity and cost, the second method of handling supervisory signals is probably the best from the standpoint of the operators and of the subscribers.

Coming now to the consideration of the actual circuits and apparatus used in private branch exchange work, attention will first be

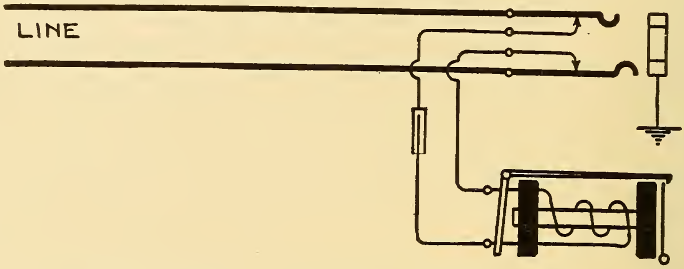


FIG. 304.—PRIVATE-BRANCH EXCHANGE TRUNK LINE CIRCUIT—WESTERN ELECTRIC SYSTEM.

called to a system now in use by many of the Bell operating companies.

The circuit of such a private branch exchange line is shown in Fig. 303, the circuit of a trunk line leading to a main office being shown in Fig. 304. In the subscriber's line the sleeve contact of the

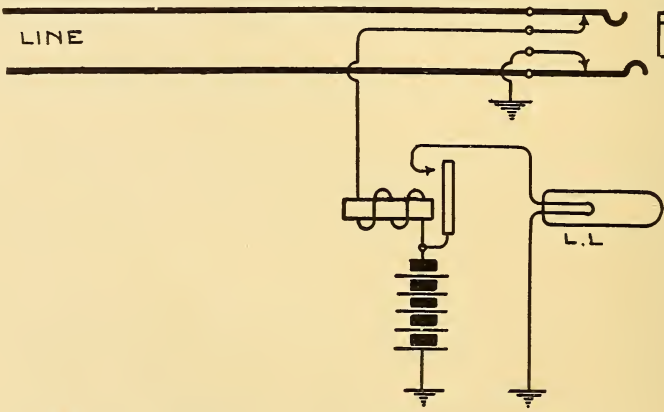


FIG. 305.—PRIVATE-BRANCH EXCHANGE SUBSCRIBERS' LINE CIRCUIT.

jack is left open, while in the trunk line it is grounded. In this line circuit a self-restoring electro mechanical signal is used. Sometimes, however, lamp signals are used, in which case a line relay is substituted for the mechanical signal, this controlling the circuit of the lamp, the connection then being that shown in Fig 305.

A cord circuit often used in connection with these line circuits is shown in Fig. 306. It will be seen that this is practically the same as the Western Electric common battery cord circuit using mechanical supervisory signals, instead of lamps controlled by relays, with the exception that two relays, *A* and *B*, are added. When the relays, *A* and *B*, are de-energized, as they are normally, the talking circuit from the answering plug to the calling plug embraces the windings of the usual common battery repeating coil between the center points of which is bridged the private branch storage battery. When, however, the relays *A* and *B* are actuated the repeating coil is cut out entirely, the tip of the answering cord being then connected directly to the tip of the calling cord, while the sleeve of the answering cord is connected to the sleeve of the calling cord through the coils of the supervisory signals, *S* and *S'*. In this case the battery has no connection whatever with the talking circuit.

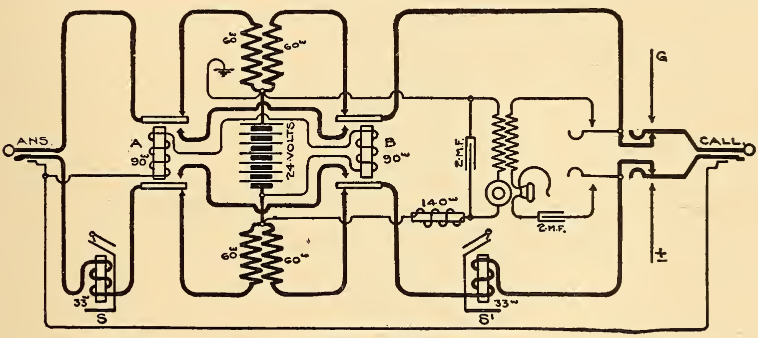


FIG. 306.—WESTERN ELECTRIC CORD CIRCUIT FOR PRIVATE BRANCH EXCHANGE.

The coils of the relays *A* and *B* are connected in series between the live side of the battery and the third contacts on the answering and calling cords, these third contacts being permanently connected. The reason for grounding the sleeve contact on the trunk jack, and leaving it ungrounded on the private branch subscribers' lines, will now be apparent. When a pair of cords and plugs is used to connect two private branch subscribers' lines, the relays *A* and *B* will not be energized because the circuit through them is not completed to ground at the ring of the jack. Under this circumstance the current for operating the subscribers' transmitters, and for operating the supervisory signals is drawn from the battery bridged across the cord circuit. If, however, the private branch subscriber's line is connected through the trunk line to the main exchange both relays, *A* and *B*, of the cord circuit will be energized, because the circuit through them

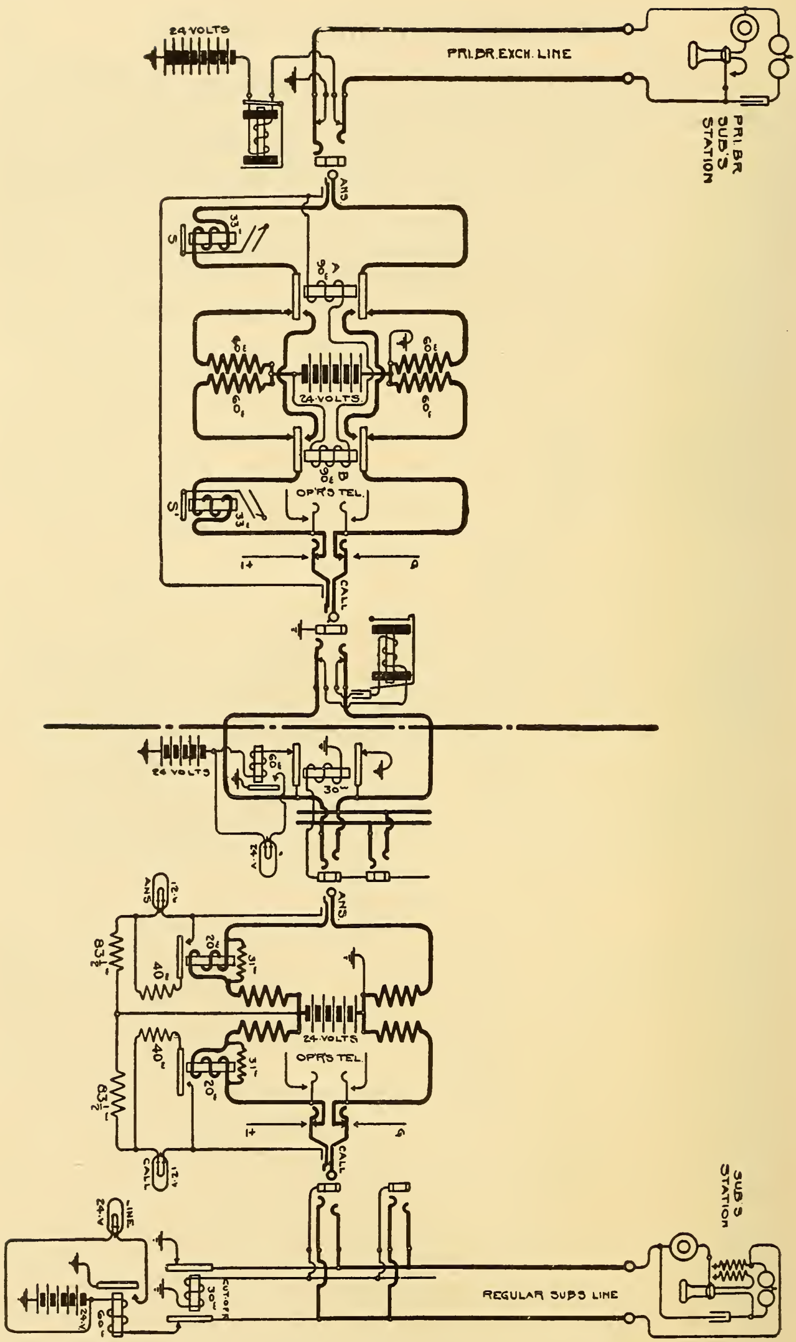


FIG. 307.—CONNECTION, PRIVATE BRANCH TO CITY SUBSCRIBER—WESTERN ELECTRIC SYSTEM.

is completed to ground through the ring contact of the trunk jack. In this case the battery and repeating coil are automatically cut out, and the private branch subscriber draws his battery for talking and for the operation of the supervisory signals directly from the main office battery, his line in this case being merely an extension of the trunk line.

A connection between a private branch subscriber's line and a subscriber in the main office is shown in Fig. 307, the main office subscriber's apparatus being at the right of the figure. Assuming that the private branch subscriber originated the call, and requested simply that his line be connected with the main office, the private branch operator would connect him with the main office switch-board by inserting her calling plug in the trunk jack, which, by the ground upon the trunk jack, would operate relays *A* and *B* and would call the main office operator by reason of the flow of current from the main office battery through the line relay, and thence through trunk, private branch cord circuit, private branch line and private branch telephone, returning through private branch line, private branch cord circuit and trunk, to ground at main office. The main office operator then handles the call exactly as she would any call, answering with her answering plug and completing the connection with her calling plug, and obeying her supervisory signals as for any two connected lines. The operation of the relays *A* and *B* of the private branch cord circuit would release the connection entirely from the battery at the private branch switch-board, and current from the main office battery would flow over the ring-side of the trunk line to the main office. When, therefore, the private branch subscriber hangs up his receiver or moves his hook up and down, desiring another connection, the supervisory signals at both switch-boards are operated. It is seen, therefore, that this circuit employs the third method of supervisory signaling outlined in the beginning of this chapter.

The connection between a main office and a private branch subscriber which originated with the main office subscriber would employ the same apparatus, as shown in Fig. 307, but it would be established, of course, in reverse order. The main office operator, having received and answered the main office subscriber's call in the usual way, with her answering plug, would complete the connection with the multiple jack of the trunk line leading to the private branch exchange in the same manner as if it were an ordinary subscriber's line, using her calling plug in the trunk jack and ringing as in ringing a called subscriber, but in this case the ringing would cause the operation of the trunk drop at the private branch switch-board. The private branch attendant, seeing this signal, would plug in with the answering plug and answer in the name or number of the firm to which the private branch exchange belonged. The calling subscriber then would tell her the nature of his business, or, perhaps, the person to whom he wished to speak, whereupon the attendant would complete the connection with the proper private branch line, using her calling plug, and by the operation of her ringing key would call the subscriber on that line. The operation of the relays *A* and *B* would remove the private branch battery from the cord circuit, and, therefore, when the private branch subscriber responded, three supervisory signals would be operated. In the operation of this circuit, when the call is originated by the main office subscriber, the answering of the private branch attendant actuates the supervisory

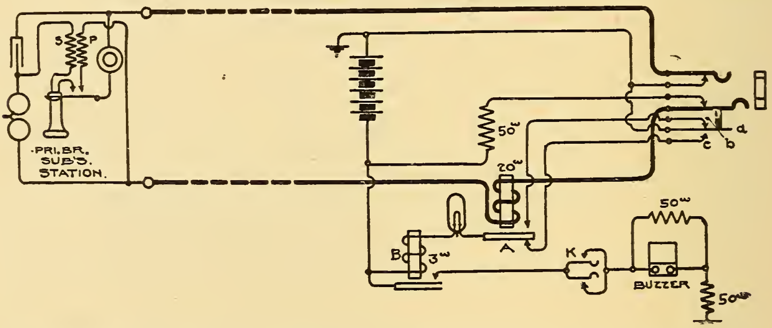


FIG. 308.—PRIVATE-BRANCH EXCHANGE LINE CIRCUIT OF CHICAGO TELEPHONE COMPANY.

circuits upon the calling plug at the main office to show the main office operator that the call has been responded to, and that no further action at the main office is required.

The main office operator performs exactly the same function in connecting with the private branch trunk line as she does in connecting with a regular subscriber's line.

It might be said that the compelling of the private branch operator to restore manually the trunk line drop is a disadvantage, but this is hardly a valid objection, as the private branch attendant has very much more to do in the way of talking and listening than she has with her hands.

In Fig. 308 is shown a line circuit of the latest private branch exchanges used by the Chicago Telephone Company. This employs a jack which cuts off both sides of the line, and also has three additional spring contacts used entirely for modifying the operation of the signals. These three additional contacts comprise a spring, *a,* normally resting against spring *b,* but pressed into contact with spring *c,* when a plug is inserted in the jack. When the circuit of the line is completed at the subscriber's station by the removal of the receiver from its hook, the current flows from the grounded side of the battery through the tip side of the line to the subscriber's station, thence over the sleeve side of the line through the coil of relay, *A,* to the live side of the battery. Both sides of the line are broken at the jack when the plug is inserted, but it will be noticed that the coil of relay, *A,* is left outside of the jack, so as to be in the talking circuit. The operation of the relay, *A,* in response to a call, completes the local circuit of that relay, which may be traced from the live side of the battery through a pilot relay, *B,* and the line lamp to the front contact of the relay, *A,* thence to contact *b* of the jack, and to ground through contact, *a.* This illuminates the lamp and actuates a buzzer or night alarm on account of the action of the pilot relay *B.* Plugging into the jack does not de-energize the relay, *A,* as the talking current from the cord circuit passes through it. It will, however, put out the line lamp, by breaking the contact between the springs *a* and *b* of the jack. After the plug is inserted the spring *a* of the jack makes contact with the spring *c,* and therefore the back of contact of the relay, *a,* is grounded, which means that when the armature of the relay *A,* is again released, which will take place when the subscriber hangs up his receiver, the line lamp will again be lighted, the circuit this time being from the live side of the battery through the pilot relay and lamp through the back contact of the relay *A,* and to ground through the contacts *a* and *c* of the jack. By this means the line lamp is made to serve also as a supervisory lamp, and for that reason no lamps or relays whatever are provided in connection with the cord circuits. This double use of the line lamp is made possible by the alternate positions of the spring *a* in the jack, as governed by the insertion of the plug. The front contact of the relay, *A,* is grounded when the plug is not inserted in the jack, while the back contact of the relay is grounded when the plug is inserted in the jack. This means that the front contact of the relay is adapted to complete the circuit of the lamp, while no plug is in the jack; and that after a plug is inserted the back contact of the relay controls the lamp.

The pilot relay, *B*, controls a buzzer to serve as a night alarm, or to attract the attention of the operator if she is not at the board during the day. This buzzer is controlled by the key, *K,* which is really an ordinary ringing key, its two inside contacts being left dead, while its outside contacts are wired in multiple, thus making the key serve as an ordinary single-throw switch. A 50-ohm resistance is wired in series with the buzzer, and a like resistance in multiple with it, this being for the purpose of reducing the amount of current that would flow through the buzzer from the storage battery, and also to reduce to some extent the noise which might be thrown on any connected lines by the operation of the buzzer.

In Fig. 309 is shown the cord circuit adapted to use with the line circuit shown in Fig. 308. In the left-hand portion of this figure is shown a key, *K'*, which, when in its normal position, connects the common battery between the two sides of the cord circuit, a retardation coil, *R* or *R'*, being placed between each terminal of the battery and the corresponding cord conductor. When this key is

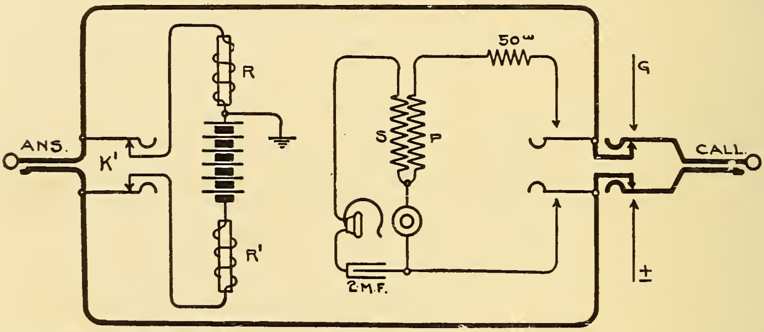


FIG. 309.—PRIVATE-BRANCH EXCHANGE CORD CIRCUIT OF CHICAGO TELEPHONE COMPANY.

thrown the battery is entirely cut off from the cord circuit. At the right of the figure in connection with the calling plug is placed an ordinary combined ringing and listening key, which needs no explanation.

This cord circuit, when used to connect two of the line circuits shown in Fig. 308, supplies battery current to each of the connected lines, the key, *K'*, being left in its normal position so as to connect the battery across the cords. The retardation coils connected between the terminals of the battery and the strands of the cord serve to prevent cross-talk in the usual manner.

The trunk circuit used by the Chicago Telephone Company, adapted to work in connection with the line circuit of Fig. 308 and the cord circuit of Fig. 309, is shown in Fig. 310. In this figure that portion of the circuit at the right of the vertical dotted line shows the arrangement at the private branch end, that at the left being the arrangement at the main office end of the trunk line. The battery *A* is therefore the common battery of the main exchange, while battery *B* is that of the private branch exchange. It will be seen that the main office equipment is nearly the same as that on an ordinary subscriber's line, consisting of an answering jack at one section, and a multiple jack at each section, together with the usual line relay and line signal and cut-off relay. The line relay, *P*, is, however, connected with the grounded side of the battery instead of the live side, as is usual. In the tip side of the line between the battery and the cut-off relay, *C*, a resistance, *R*, is placed. At the private branch end this trunk equipment consists of the same type of jack, *J*, as is used for the ordinary line jacks, as shown in Fig. 308. Besides this, a locking relay, *L*, controlling the trunk line signal, is provided, as is also a condenser, *c*, and a key, *K″*.

The operation of this trunk circuit is as follows: Assuming that a main office subscriber calls for a private branch subscriber, the connection of the calling subscriber with the main office end of the trunk line will be completed in exactly the same manner as in the case of connecting two local subscribers at the main board. When the main office operator inserts the calling plug into the jack of the trunk line no effect will be produced at the private branch exchange on the relay, *L*, because of the presence of the condenser, *C*, which prevents direct current from passing through the coil of the relay. The main office operator must, therefore, ring on the trunk line in the same manner as if she were calling a subscriber, and the alternating current thus sent to line passes over the ring side of the trunk and the condenser, *c*, and thence to ground through the springs, *a* and *b*, of the jack and the battery, *B*. The operation of the relay, *L*, caused by the passage of this alternating current, will close contacts at *d* and *e*. The closure of contact at *d* will complete the circuit from the branch exchange battery through the springs, *a* and *b*, and the coil of the relay, *L*, to ground through the contact at *d*. This will lock the relay and hold it locked until the private branch exchange attendant plugs in. The closure of the contact at *e* by the relay, *L*, will light the trunk line lamp as a signal to the attendant. Meanwhile, the supervisory lamp of the calling plug at the main exchange remains lighted because the presence of the condenser, *c*, at the private branch exchange allows no direct current to pass over the trunk line to operate the calling supervisory relay.

The private branch attendant, seeing the trunk signal illuminated, plugs in with one of the plugs of the cord circuit of Fig. 309, and at the same time throws the key, K', of that cord circuit so as to cut off the local battery from the cord circuit. She thus gets all battery current for talking from the central office, this current being supplied over the metallic circuit of the trunk line from the cord circuit of the A operator. Throwing the listening key of the private branch exchange cord circuit will allow current to flow through the operator's talking circuit over the metallic circuit of the trunk line, and will extinguish the calling supervisory signal at the main office; the main office operator will, therefore, pay no more attention to the connection, seeing both lamps out, and the private branch attendant will find out from the calling subscriber the private branch line he desires. She will then complete the connection by plugging in with the calling plug and ringing. While waiting for the called subscriber to respond, the operator, if she keeps her listening key thrown, will prevent the relighting of the calling supervisory signal at the main office. She will know when the private branch subscriber responds by the going out of the line lamp, belonging to that subscriber, which was lighted when she plugged into his line. When the private branch subscriber responds the connection is in proper condition for conversation, the private branch subscriber drawing his current for talking from the main office battery. When he hangs up his receiver the flow of current over his line and the trunk line will cease, therefore the calling supervisory relay at the main office will be de-energized, as will also the relay, *A*, Fig. 308, belonging to the private branch subscriber's line. This will light the calling supervisory lamp at the main office and the line lamp at the private branch board.

The purpose of the key, K'', in the trunk circuit at the private branch board, is to allow the private branch attendant to break the circuit of the ring side of the trunk line, if for any reason she desires to signal the main office operator during a connection. Alternately pressing and releasing this key will cause the flashing of the supervisory lamp of the cord used in making the connection with the trunk line at the main office, thus giving the private branch attendant the same power of flashing the supervisory signal on the line lamp as is ordinarily held by a subscriber on a regular line.

It is evident that when the attendant plugs into the jack, *J*, the local circuit through the relay, *L*, will be broken between contacts *a* and *b* of the jack, thus restoring this relay to its normal position and putting out the line lamp, as well as breaking the ground connection at the contact, *d*. This relay cannot, therefore, be again operated except by ringing current from the central office.

In establishing a connection in a reverse direction—that is, in response to the private branch subscriber making a call, the attendant at the private branch exchange may call central by plugging into the jack and throwing her listening key, this act allowing the flow of current over the trunk line and operating the line relay belonging to the trunk line. The call will then be answered by the main office operator in exactly the same manner as if it were that of an ordinary line subscriber.

It has been previously stated that the battery at the private branch office is frequently charged from the main office battery over one

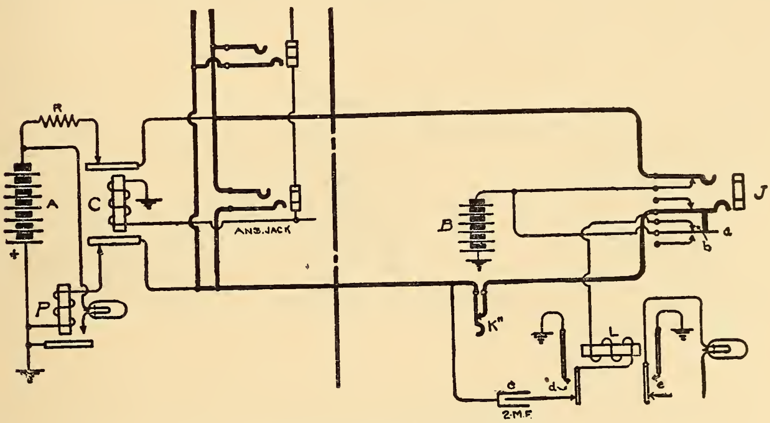


FIG. 310.—PRIVATE-BRANCH EXCHANGE TRUNK CIRCUIT OF CHICAGO TELEPHONE COMPANY.

or more of the trunk lines when idle. This is accomplished in the trunk line circuit shown in Fig. 310, it being obvious that when the trunk line is not in use a flow of current will exist from the live side of the battery, *A*, at the central office over the tip side of the trunk line to the tip contact of the jack, *J*, at the private branch exchange to the ungrounded pole of the battery, *B*, at the private branch exchange, and thence to ground. In order that there may be sufficient flow of current over this circuit, the battery at the private branch exchange is usually made to consist of a fewer number of cells than that at the main office. Eight cells are frequently used at the branch exchange, while 11 are commonly used at the main office. The proper pole of the battery at the private branch exchange is grounded, it being necessary to ground the same pole as is grounded in the main office. With the batteries so connected the flow of current through the private branch battery will be in the proper direction to charge it. A resistance coil, *R*, is placed in the lead which feeds the trunk line circuit at the main office, this resistance being so proportioned as to allow the proper amount of current to pass to keep the private branch battery fully charged

Sometimes in private branch exchange work it becomes desirable to use party lines and to afford means for the different parties on the line to call each other without calling the central office, or to call the central office without calling the other stations on the line. This is often desirable in large institutions covering considerable territory. In giving such service as this in connection with modern exchange systems, it is customary while supplying all current for talking purposes from a common battery to resort to manual

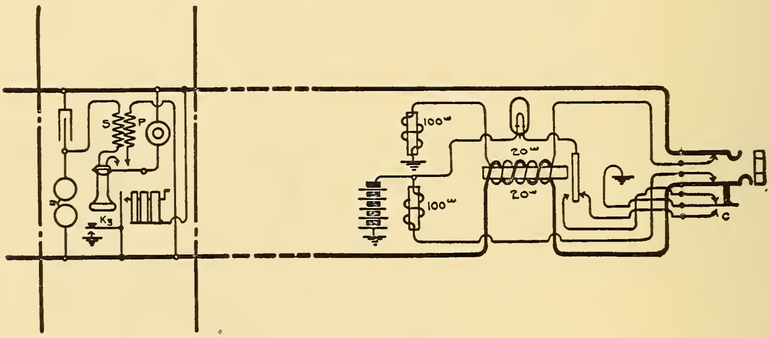


FIG. 311.—PRIVATE-BRANCH EXCHANGE PARTY LINE CIRCUIT—CHICAGO TELEPHONE COMPANY.

calling between the various stations on the line. Thus each station is provided with the usual common battery talking and call-receiving apparatus, and with a magneto generator adapted to be bridged across the line when operated. In order to prevent the line signal at the private branch exchange being operated by current from the line generator, a differential line relay may be used, having one winding in each limb of the line. Any current sent over the metallic circuit of the line will, therefore, not operate this signal, and thus any subscriber on the line is enabled to call another the same as on an ordinary bridging bell line. In order to enable any subscriber to call the private branch office a push button is provided which grounds the live side of the line, thus causing the operation of the line relay and the lighting of the signal.

Such a line circuit as used by the Chicago Telephone Company in connection with the private branch exchange circuits, shown in Figs. 308, 309 and 310, is shown in Fig. 311, this being the circuit extending from the private branch board to several party line stations. Battery is normally fed from the private branch office through two retardation coils and through the two windings of the differential line relay to the two sides of the line. By this means any two subscribers on the same line may talk, both their instruments drawing battery current from the private branch office. This flow of current will not operate the differential line relay. The operation of any subscriber's generator will likewise not influence the differential line relay, but will ring all of the bells on the line in the same manner as in the ordinary bridging bell system, and therefore a code of long and short rings is used to enable the subscribers to call a certain party on the line.

By pressing the key, K_3, at any station the ring side of the party line is grounded, thus allowing the flow over one coil only of the differential relay, which will cause the action of that relay to attract the attention of the private branch attendant. The armature of this relay will, however, fall back as soon as the subscriber releases the pressure on the key, but when the operator plugs into the circuit the tip-wire winding of the differential line relay will be cut off from the talking conductors. Therefore the connection of this line with another private branch line or with the trunk line leading to the main office is the same as that described in an ordinary private branch line, as shown in Fig. 308.

It is sometimes necessary for very large institutions to be provided with two private branch exchange switch-boards. This is so where the same firm has different buildings in different parts of the city. Where this is the case it is frequently desirable to connect the two private branch offices directly by trunk lines in order to avoid the necessity of having calls for connections between subscribers in the two branch exchanges handled through the main offices. Where the two branch exchanges are very large this trunking between them could be accomplished by the double-track system, using two sets of one-way trunks. In most cases of this kind, however, a single-track system using two-way trunks is better on account of economy in the number of trunk lines required. Such a two-way trunk is shown in Fig. 312, this being adapted to use with the private branch circuits shown in Figs. 308 to 311, inclusive. The equipment at each end of this trunk line is the same, and when the operator at one end plugs into the jack of the trunk line the two trunk lamps, one at each end, light simultaneously. Both lamps are extinguished when the operator at the other end plugs in, in answer to a call. The first operator is, therefore, made aware of the response of the operator at the other end of the line. As soon as either operator pulls down the connection at one end both lamps will light, and both are extinguished when the other operator pulls down the connection.

The method of operation by which these results are brought about may be clearly seen in Fig. 312. Two trunk line relays are provided, one at each end of the line, each being in a different side of the line. When an operator plugs in at, say, the left-hand end of the line, with a cord circuit such as shown in Fig. 309, the ring

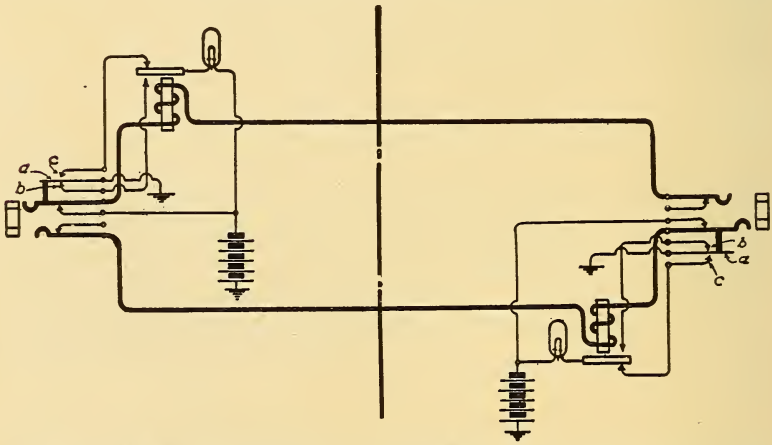


FIG. 312.—TWO-WAY TRUNK CIRCUIT BETWEEN TWO PRIVATE-BRANCH SWITCH-BOARDS—CHICAGO TELEPHONE COMPANY.

spring of the jack will cause the spring, *a*, at that jack to be pressed into contact with the spring *c*, and thus light the lamp at that end of the line, the relay at that end of the line remaining inactive. The insertion of the plug will also ground the tip spring of the jack through the cord circuit at that end, thus allowing the flow of battery to take place from the battery at the second office through a relay at the second office to ground at the first office. As the plug has not been inserted into the jack at the second office the attraction of the armature of this relay will cause the lighting of the lamp at that office. When the operator at the second office responds, the opening of the contacts, *a b*, in the jack at that office will cause the going out of the lamp at that office, while the energization of the relay at the first office caused by the flow of cur-

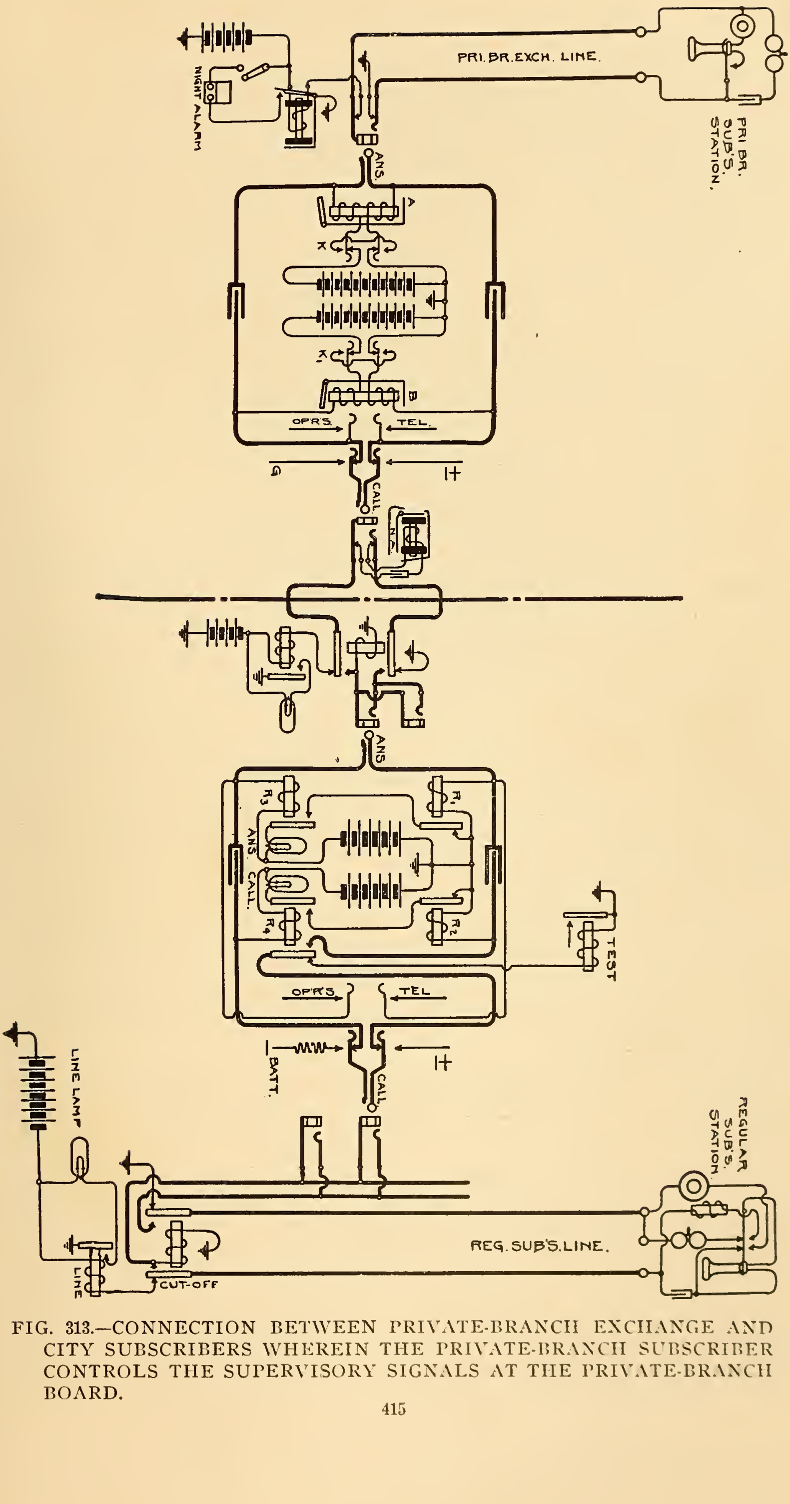


FIG. 313.—CONNECTION BETWEEN PRIVATE-BRANCH EXCHANGE AND CITY SUBSCRIBERS WHEREIN THE PRIVATE-BRANCH SUBSCRIBER CONTROLS THE SUPERVISORY SIGNALS AT THE PRIVATE-BRANCH BOARD.

rent over the line will cause the going out of the lamp at the first office. It is evident that when either operator withdraws her plug both lamps will light, and that both will go out when both operators withdraw their plugs. By virtue of the transposal of the connections between the two sides of the trunk line and the trunk-line jacks, the tip of one jack being connected with the ring of the other, current from the two batteries of the cord circuits at the two exchanges will thus flow in series over the trunk line.

The question of using the lamp associated with the line, as both line and supervisory lamp, as is done in the private branch exchange system of the Chicago Telephone Company, is of considerable interest, and there is no reason, from an operating standpoint, why this should not be considered good practice in small boards in general. Of course it would be impracticable in a multiple board, because one plug of a circuit used in connecting two lines would always be inserted in the multiple jack. As this jack would have no signal adjacent to it no supervisory signal would be provided. This scheme, as applied to small boards, has the distinct advantage of greatly simplifying the cord circuit, which, being devoid of all relays and signals, is reduced to its simplest possible form. The only thing that approaches complication about this system is the jack, which, consisting, as it does, of seven movable spring contacts, is somewhat objectionable. Considering, however, that there are only a few of them used, and that there is unlimited space in which to install them, there is no reason why such a jack should not be made to give perfectly satisfactory operation.

A system wherein the second method of supervisory signaling is employed will now be considered. In this it will be remembered that the supervisory signal at the private branch exchange board, and not that at the central office, is under the control of the private branch exchange subscriber.

A private branch line circuit is shown at the left of Fig. 313. The signal in this is of the mechanical or gridiron type, already discussed in a previous chapter.

This line is shown connected with a regular exchange line at the right of the figure, the connection being made through the cord circuit at the branch exchange, the private branch trunk, and the regular A operator's cord circuit at the main exchange. The arrangement at the main exchange end of this trunk is that of the standard Kellogg line circuit already described. At the private branch end an ordinary ring-down drop is used for the signal, this being bridged

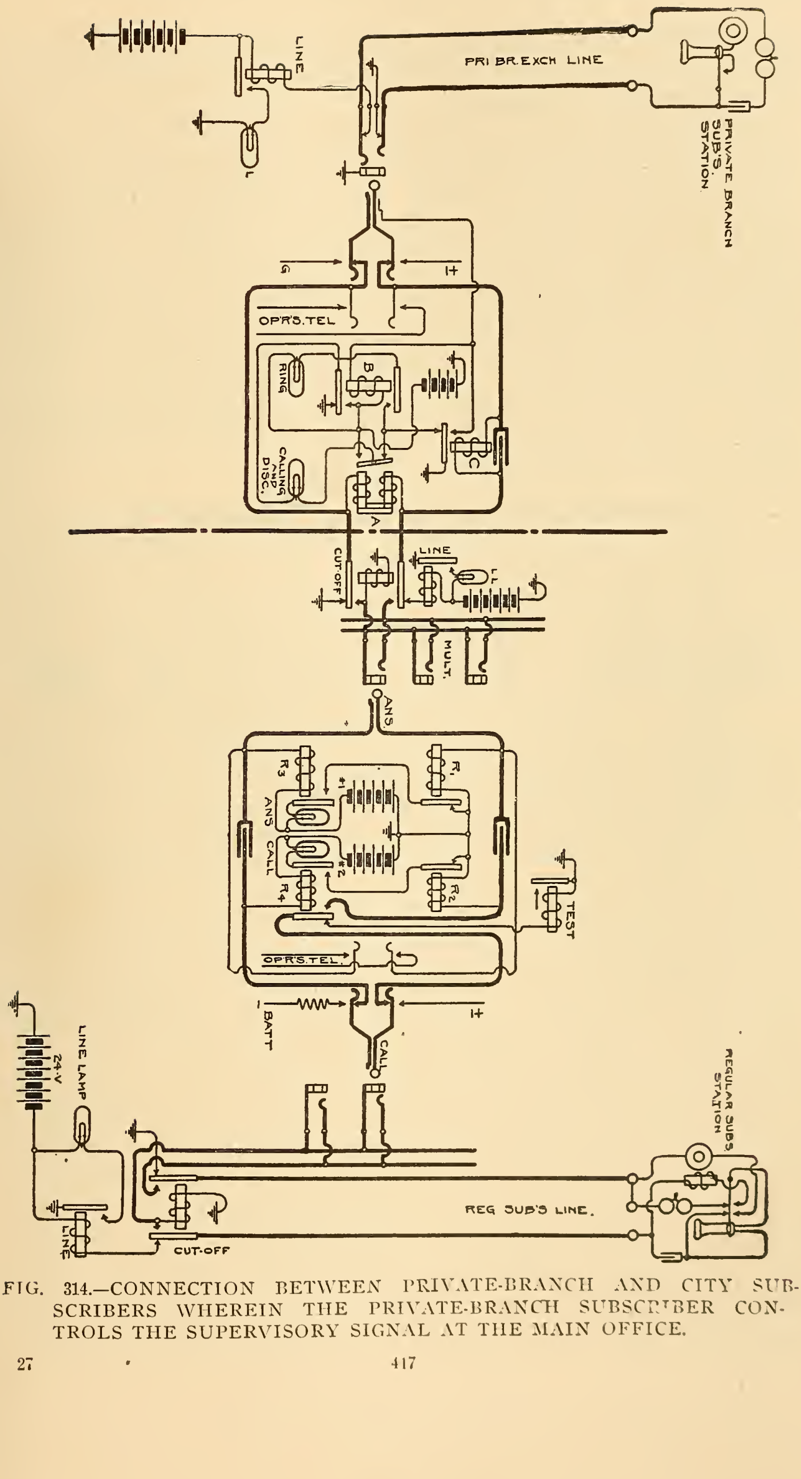


FIG. 314.—CONNECTION BETWEEN PRIVATE-BRANCH AND CITY SUBSCRIBERS WHEREIN THE PRIVATE-BRANCH SUBSCRIBER CONTROLS THE SUPERVISORY SIGNAL AT THE MAIN OFFICE.

in series with a two-microfarad condenser between the two sides of the trunk line. Both sides of the signal circuit are broken at the jack when the plug is inserted.

The cord circuit uses two batteries, feeding respectively the answering and calling cords, through the double-wound magnets of the supervisory signals, *A* and *B*. These coils are not differentially wound, and the signals are therefore displayed as long as current is traversing them. In addition to the supervisory signals and the usual ringing and listening keys, each cord circuit is provided with two keys, *K* and *K'*, each serving, when operated, to cut off battery from its cord and at the same time to close together the two coils of the supervisory signal so that they form a bridge across the cord circuit. Battery may, therefore, be cut off from that plug which is inserted into the trunk jack.

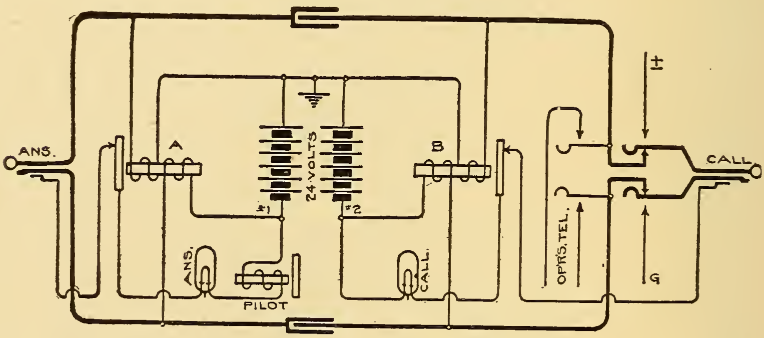


FIG. 315.—CORD CIRCUIT FOR PRIVATE-BRANCH EXCHANGE SYSTEM.

When two private branch lines such as are shown at the left of Fig. 313 are connected by the private branch cord circuit, the keys, *K* and *K'* are left in their normal positions. Current is then fed to each subscriber for talking through the two coils of the gridiron signals, *A* and *B*, which signals are displayed as long as the subscribers are talking, but are effaced as soon as they hang up. If, however, the connection is between a trunk line and a main office subscriber's line, as shown in the figure, that cord which is inserted into the jack of the trunk line has its battery cut off by the key *K* or *K'*, in which case the corresponding supervisory signal is energized by current flowing from the main office as long as the connection is complete at both ends of the trunk line. It is evident that the presence of the signal *A* or *B* bridged across the trunk line at the private branch end will keep the supervisory lamp at the main office unlighted as long as the trunk line connection exists. This condition cannot be effected by any action of the private branch subscriber, and this lamp is only illuminated by the withdrawal of the plug from the trunk jack at the private branch board. When the private branch subscriber hangs up his receiver the signal will be conveyed to the private branch operator only, by operation of the supervisory signal *A* or *B*, connected with the cord making the connection with the subscriber's line. Upon seeing this signal the private branch attendant will pull down the connection, lighting one of the supervisory lamps of the cord circuit at the main board. When the main office subscriber hangs up his receiver, the main office operator will see both signals lighted and pull down the connection.

An example of the first method of handling supervisory signals, that is, where the private branch subscriber during a connection controls a supervisory signal at the main office only, and where the disconnect signal at the private branch exchange is given by the withdrawal of the main office plug, is illustrated in Fig. 314. This shows the private branch subscriber's line circuit at the left, its method of operation being obvious. It also shows the trunk circuit extending from the private branch switch-board at the left of the figure to the main office switch-board at the right.

Fig. 315 shows the cord circuit, which, in this case, is used only to connect two local lines. The operation of the cord circuit for two local lines will be obvious when it is stated that the third contact of the plug is adapted to control the normal circuit of the supervisory lamp, this circuit being completed through the grounded ring contact of the line jack into which the plug is inserted. When so completed the control of the supervisory signals depends only on the energization of the supervisory relays *A* or *B*, through the coils of which current is fed to the subscribers' lines for talking purposes. So far, therefore, as the cord circuit and local lines are concerned, the operation is practically that of any common battery exchange and the signals are conveyed in the same manner.

Considering now the trunk circuit, Fig. 314, it will be seen that the trunk circuit terminates at the private branch exchange end in a plug and cord, and in fact resembles somewhat in its equipment the incoming end of the trunk circuits used in regular trunking between large exchanges. The equipment of this trunk circuit may be best described in connection with the description of its operation.

Assuming that a private branch subscriber calls for a main exchange subscriber, the operator at the private exchange will, after answering the call with an answering plug of a regular cord circuit, withdraw this plug and insert in its place the plug of a trunk line.

The relay, *A,* is polarized and is kept normally in the position shown by current flowing from the main exchange battery. As soon as the trunk plug is inserted into the jack of the private branch line, the line relay at the main exchange, which had previously remained de-energized, due to the high resistance of relay *A*, will operate, and thus cause the line lamp at the main exchange to be displayed. The main exchange operator will answer in the ordinary way, and after finding out the number of the line with which connection is to be established, establish this connection in the ordinary manner.

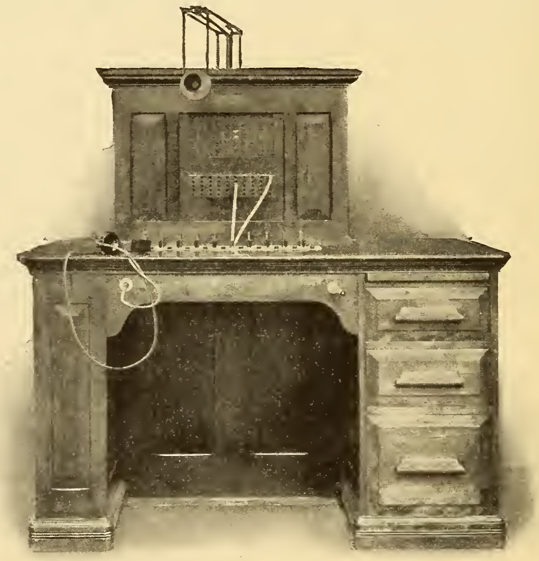


FIG. 316.—PRIVATE-BRANCH EXCHANGE SWITCH-BOARD.

When the private branch subscriber hangs up, the answering supervisory signal at the main office will be lighted and the ringing lamp at the private branch exchange will also be lighted, due to the falling back of the armature of the relay *C*. To this the private branch attendant pays no attention. When, however, the main office operator, in response to the signals, withdraws the answering plug from the private branch trunk line jack, the relay *A*, at the private branch end of the trunk, will be restored to its normal position and allow its armature to fall back, thus lighting the disconnect lamp, which is now included in the circuit which may be traced from the live side of battery to the front contact of the relay *B*, thence through the lamp and back contact of the relay *A* to ground through the back contact of the relay *C*.

With these circuits the private branch operator calls the main office operator by short-circuiting the two sides of the trunk line,

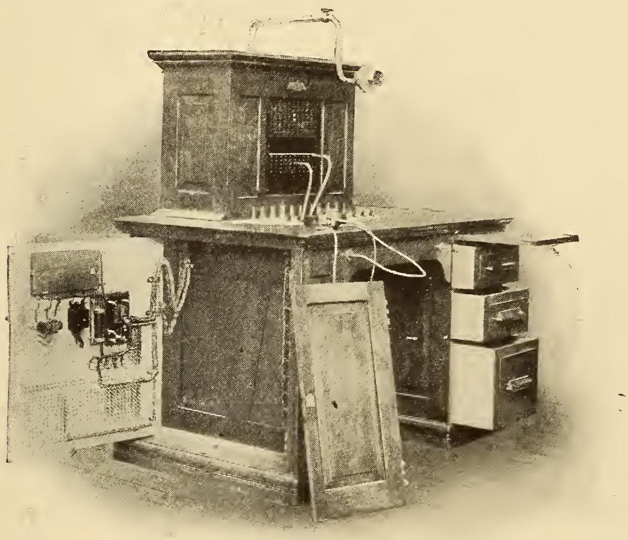


FIG. 317.—PRIVATE-BRANCH EXCHANGE SWITCH-BOARD.

which may be done by merely throwing her telephone in circuit by means of her listening key. It may also be done by plugging in to the short-circuited jack.

In Fig. 316 is shown a type of private branch exchange board which is representative of good practice. By providing a desk at which the attendant may sit, she is thus enabled to attend to other work than that of operating the exchange, particularly in cases where there is not enough telephone work to keep her busy. This type of board is manufactured by the Kellogg Switchboard and Supply Company, and in Fig. 317 is shown another view which gives some idea of how the apparatus is arranged on the connecting rack.

This connecting rack is contained within the left-hand lower portion of the cabinet, which is adapted to be opened so as to expose most of the connections to view. In the case of large private branch installations the use of the multiple board often becomes necessary,

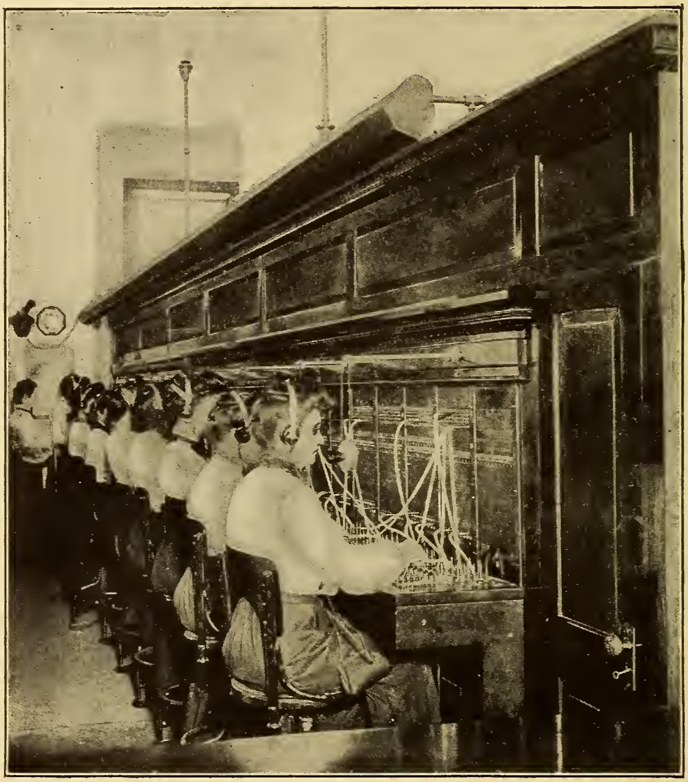


FIG. 318.—MULTIPLE PRIVATE-BRANCH EXCHANGE BOARD.

and where this is true the standard form of cabinet used in multiple board work will apply.

In Fig. 318 is shown a multiple board installed by the Western Electric Company for the Chicago Telephone Company, this board being that of the private branch exchange of Marshall Field & Company in their large department store, this being the largest private branch exchange in the world.

CHAPTER XXIV.

PARTY LINE SYSTEMS.

PROBABLY no branch of telephone work has offered more inducements to the inventor and designer, and consequently received a greater share of ingenious application, than the party line problem.

The term "party line," or multi-party line, as it might be more properly called, refers to a line having more than two stations upon it. In this definition one of the stations may be a central office at which the line terminates.

The term "party line" in exchange working is used in contradistinction to the term "individual line." An individual line serves one subscriber only, while a party line serves to connect two or more subscribers with the central office.

Where it does not run to a central office a line connecting two telephones only would be called a "private line," but if the line connected more than two stations it would be referred to as a "party line."

Party lines may be divided into two general classes:

(1) Those on which the bells of all the telephones ring when any party on that line is called. In such lines a code of audible signals is usually employed to enable the parties at the various stations to distinguish their calls from those of others.

(2) Those where a system of selective signaling is employed, so that any one party may be called without ringing the bells, or in any way disturbing any of the other stations.

The first of these classes may, for the want of a better name, be called "non-selective" party lines, and such lines may be divided into two general sub-classes, according to the connection of the instruments on the line, as follows:

(a) Series party lines where the signaling devices are connected in series in the circuit of the line.

(b) Bridging party lines, on which the signaling devices are connected across the circuit of the line in multiple.

The second of these general classes may be called "selective party lines," and these may be divided into three sub-classes, as follows:

(a) Those employing step by step movements to complete the calling circuit of the desired station.

(b) Those employing currents of different directions or polarity for operating the different signals.

(c) Those using the harmonic system of selecting—that is, wherein currents of various frequencies are used for actuating the different signals.

Non-selective systems will be first considered.

Probably the first party line ever constructed connected the instrument in the line circuit in series, hence the name, "series party

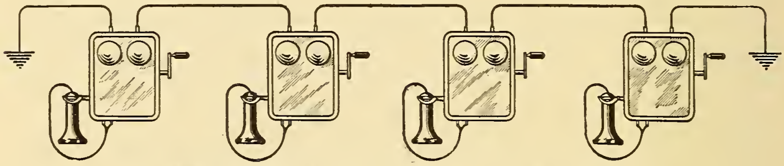


FIG. ~~320.~~ 319—SERIES METALLIC PARTY-LINE CIRCUIT.

line." Such a line connecting 4 instruments on a grounded circuit is shown in Fig. 319. In Fig. 320 are shown 6 instruments, connected in series in a metallic circuit. The usual form of instrument used in this class of work is the ordinary series magneto telephone, the circuits of which are shown in Chapter IX.

A little consideration will show that one of the chief disadvantages of the series line is that the talking circuit of any two stations en-

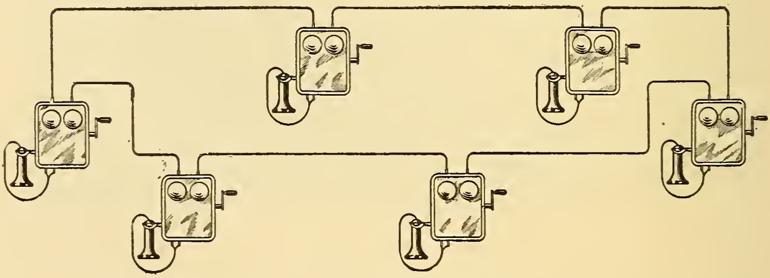


FIG. ~~310.~~ 320—SERIES METALLIC PARTY-LINE CIRCUIT.

gaged in conversation must always pass through the bell magnets of all the other stations which are not in use. As these magnets necessarily possess a considerable amount of impedance, this is a very serious objection, and when a great number of instruments are used the speech transmission becomes very faint. For this reason it is customary to wind the bell magnets on instruments to be used on series lines to a low resistance, rather lower, in fact, than on the ordinary instrument for exchange purposes. Eighty ohms for each complete double ringer magnet has generally been the approximate standard, the winding being of No. 31 B. & S. gauge single silk, insulated copper wire. A better arrangement, however, under most circustances, is to use coils wound as low as 40 ohms, or another good arrangement is to connect the two bobbins of the ordinary 80-ohm ringer in multiple instead of in series, thus giving a combined resistance of approximately 20 ohms.

The armature coil on the magneto-generator in series party lines

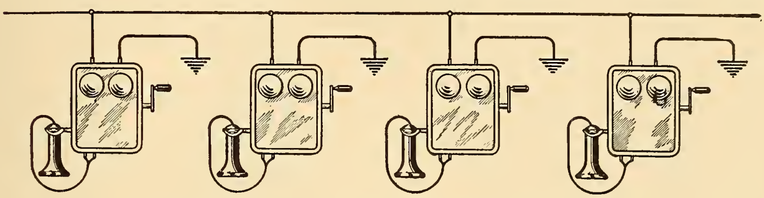


FIG. 321.—BRIDGING GROUNDED PARTY-LINE CIRCUIT.

is, of course, not included in the talking circuit where modern instruments are used, on account of the fact that every generator is provided with an automatic shunt, which, as has already been shown, affords a path of practically no resistance about the generator armature at all times except when the generator is in actual use.

The number of bells that can be rung on a series party line is far in excess of the number that can be talked through. Thus, 50 instruments in series may be satisfactorily operated, so far as ring-

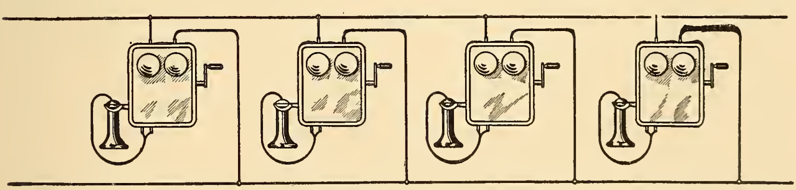


FIG. 322.—BRIDGING METALLIC PARTY-LINE CIRCUIT.

ing is concerned, but even half that number would give intolerable talking service.

Another objection to the series party line is that even where metallic circuits are used it is practically impossible to properly balance the line with regard to inductive disturbances. If all the instruments are placed in one side of the line, using the other side merely as a return, the line will be badly unbalanced on account of one of its sides possessing great impedance, while the other has only that of the line wire. This may be partially remedied by alternately placing the instruments on one side of the line or the other, as is shown in Fig. 320, but often where this precaution is taken a perfectly quiet line cannot be secured where the conditions are at all adverse.

As a matter of fact, the series party line has no place in modern telephone practice, it having been almost universally superseded by

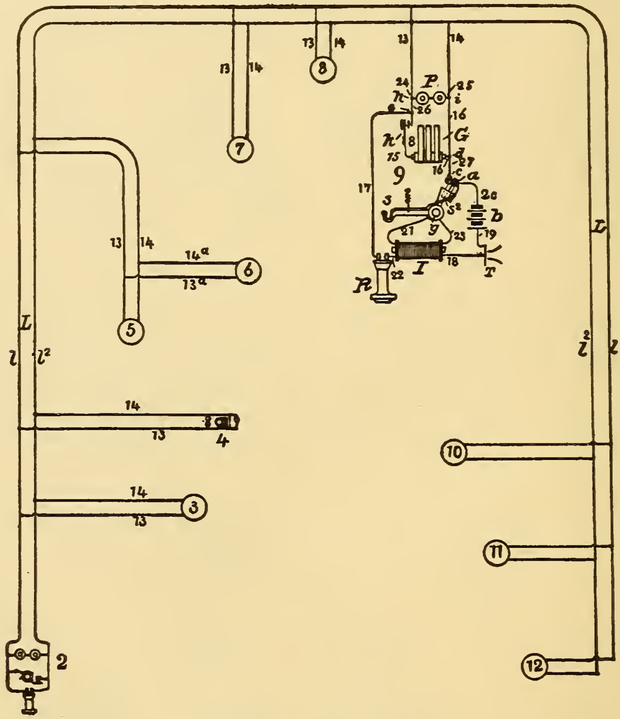


FIG. 323.—CARTY BRIDGING BELL PARTY-LINE SYSTEM.

the bridging or multiple system of party line working, as disclosed in the now famous Carty patent.*

In Fig. 321 is shown the method of connecting four instruments in accordance with the bridging system on a grounded line, and in Fig. 322 four instruments are similarly shown connected on a metallic circuit. It will be seen that the line wire in Fig. 321 or the line wires in Fig. 322 are continuous through all the stations, each instrument being placed in a separate bridge wire either between the line wire and ground or between the two line wires.

* U. S. patent to John J. Carty, No. 449,106.

The circuits of bridging instruments have already been discussed in Chapter IX. The line connections of an 11-station metallic circuit bridged line is shown in Fig. 323, this being a copy of the main figure in the Carty patent referred to. The various instruments, 2, 3, 4, 5, etc., are connected across the two sides, l and l_2, of the line, *L*. Some of the instruments are represented merely by circles, but at station 9 the complete circuits are shown in detail.

If a station is not located directly on the route of the line it is connected simply by running two lateral wires, 13 and 14, from its binding post to the most convenient point on the through route of the line.

In this system the call-bells, *P*, at each station are *permanently* bridged across the two sides of the line, and are made of high *resistance* and *retardation*. The generator, *G*, at each station is in a separate bridge circuit, which is normally open, but closed when the generator is operated. The talking circuit of each instrument, containing the receiver, *R*, and secondary winding of the induction coil, *I*, forms a third bridge circuit, which, like the generator circuit, is normally open.

The telephone circuit of each instrument is automatically closed when the receiver is removed from its hook for use, and this operation also closes the local circuit containing the primary of the induction coil, *I*, the local battery, *b*, and the transmitter, *T*. In order that there shall not be an undue leakage of the voice currents through the permanently bridged call-bell circuits, the magnets of these call-bells are wound to a high resistance (usually a thousand ohms) and are also constructed in such manner that they will have a high coefficient of self-induction. When a generator at any one station is operated, it is connected across the two sides of the line in parallel with all of the call-bell magnets on the line. Part of the currents in this generator will, therefore, pass through each of the call-bell magnets on the line, thus causing them all to operate if the amount of the current generated is sufficient to accomplish this result. The successful operation of this system depends on the fact that a coil possessing a high coefficient of self-induction will transmit with comparative ease alternating or pulsating currents of low frequency, while it will form a practical barrier to similar currents having a very high frequency. The currents generated by the calling generator at any station are of sufficiently low frequency to pass with comparative ease through the call-bell magnets arranged along the line, while the rapidly alternating voice currents impressed upon the line by the telephonic apparatus at any station will be compelled to pass over the main line to the receiving station without being materially weakened by leakage through the call-bell magnets. At the receiving station these voice currents will pass through the telephone receiver and secondary coil of the induction coil, these being connected across the line at that station by virtue of the receiver being off its hook. This path through the receiving instrument is of comparatively low resistance and retardation, and thus practically takes all of the current from the distant station.

The high retardation of the ringer magnets is obtained by winding them to a high resistance with a comparatively coarse wire so as to obtain a large number of turns in the winding. The length of the cores is increased for the double purpose of getting more iron in the magnetic circuit, and therefore a higher retardation, and also for affording a greater amount of room for the winding. The Western Electric Company wind their coils to a resistance of 1000 ohms per pair, using No. 33 single silk magnet wire. Many other companies use No. 38 wire and wind to a resistance of 1200 or 1600 ohms per pair. This does not give such good results, however, as using the coarser wire and the lower resistance and long cores. Some companies wind, or once wound, their bridging bell magnets partly with German-silver wire in order to make a high resistance at a low cost. They should learn, however, that resistance in itself is not the thing desired, but a great number of turns in the winding, which, of course, incidentally produces a high resistance.

The generators for bridging systems should be designed for quantity rather than for high pressure, since they have to supply current to pieces of apparatus arranged in multiple. The fact, however, that a certain amount of voltage is also needed must not be overlooked, for, on long lines, the actual resistance of the line wire is often great, and unless the voltage is sufficient the bells at the distant end of the line will not be rung, no matter how great the current output of the generator may be. On long lines, heavily loaded, sufficient current must be generated to ring the bells in multiple, and sufficient voltage maintained to ring the bells at the farthest end of the line. The question is, therefore, one of watts or horse-power, it being necessary for the generator to hold up this voltage to the required amount to ring the farthest bell on the line even when delivering its maximum amount of current. In order to secure this greater amount of energy it is customary to use a stronger magnetic field, and this is attained by using four or five permanent magnets in the field instead of three, as is ordinarily practiced in series generators. The winding of the generator is also of much importance and must vary to meet different requirements. A generator wound to 350 ohms with No. 33 single silk-insulated wire is perhaps best adapted to meet the average requirements of bridging party line service.

All things considered, it is probably better to use low wound induction coils on bridging lines, so that the voice currents coming along a line will find a readier path through the talking circuit of the station receiving than through the call-bell bridges at the various stations. In many cases 500 and even 1000-ohm induction coils have been used on bridging circuits, which render the impedance of the talking circuit high, exactly what should be avoided when talking efficiency is considered.

High impedance and resistance in the talking circuit is, however, of advantage in cases where the receiver at some station has been accidentally left off its hook, as, in this case, a high resistance coil does not afford such a low shunt to the signaling currents, and therefore allows the bells at the other stations to be more readily rung than if the low resistance coil had been used.

On country lines employing many stations, where the telephone forms the chief means of social as well as business intercourse, it is customary for a great many of the parties on a line to take down their receivers whenever their bells ring, no matter whether the call is for their station or not. This is a practice which it seems impossible for the managers of telephone lines to prevent, and frequently the result is such that the line is thus subjected to such a material shunt as not only to cut down the talking efficiency, but to make it impossible to ring. In order to render it possible to ring over such a line, regardless of whether the receivers are down or up, a scheme has been proposed, and put into practice to some extent, of connecting a one-microfarad condenser or a non-inductive resistance in circuit with the secondary of the induction coil and the receiver at each station. This condenser does not materially cut down the talking efficiency in receiving, while it does very materially increase the effective resistance of the shunt with respect to the ringing currents. In other words, the condenser affords practically no barrier to the high frequency talking currents, while it does materially cut down the transmission through it of the comparatively low frequency ringing currents.

In connecting a party line with a switch-board much trouble is often caused by the use of an improperly wound annunciator coil. It should be borne in mind that the drop magnet really bears the same relation to the line as the ringer magnets, in the various telephones, and should therefore be connected in the same way. For a series party line the switch-board drop should be wound to about the same resistance as the ringer magnets. If the resistance is made higher, as is often done in the attempt to secure a more sensitive drop, two parties on the same line will have much difficulty in talking to each other, because the drop is in series in the line.

In the bridging-bell system the impedance of the switch-board drop should also be about the same as that of the ringer magnets. It is frequently impossible to wind drops to 1000 ohms on account of insufficient wire space, and a tubular drop wound to 500 ohms is perhaps most common. A properly designed bridged drop may be left permanently bridged across the line, to serve as a clearing-out drop when the subscribers are through talking. In small exchanges, operating party lines, it is customary for the operator at such a switch-board to distinguish between the calls for a connection with some other line, and those which are for parties on the same line, by means of the buzz caused by the vibration of the armature of the drop. It is, therefore, desirable to give the drop armature a rather wide adjustment, so that it will make enough noise to enable the operator to readily distinguish the signals. The combined ringer and drop, such as is shown in Fig. 198, gives better results in such a case, if there is room enough for it on the face of the switch-board.

On lines where a toll rate is charged, much loss of revenue is often caused by surreptitious conversations, that is, by parties on the same line calling each other and carrying on their conversation without the knowledge of the switch-board operator, so that no means is afforded for properly charging the use of the line against them. Many arrangements of circuits and apparatus have been devised for obviating this difficulty. One of these, which is suitable only for bridging lines, is to provide at the central office a switch-board drop of extremely low resistance and so arrange it that it will be cut out upon the insertion of the plug. The low-resistance path through this drop acts practically as a short-circuit to all of the high resistance bells on the line, so that when a party rings, nearly all of the current from his generator passes through the switch-board drop, without actuating any of the bells. When the operator plugs in for conversation, or for the purpose of calling up some subscriber on that line, the low-resistance drop is cut out, so that the line is no longer short-circuited. This method cannot be used on any except short lines, because the resistance of the drop, in addition to that of the line wire, proves high enough to shunt some of the current through the magnets of the bells at the distant end of the line, when parties at that end attempt to signal each other. While the drop would short-circuit the end of the line nearest the switch-board, the instruments at the farther end would not be appreciably affected, owing to the high resistance of the line wire between them and the board.

This method is not, on the whole, very satisfactory, and a better one is to arrange the magnetos at the subscribers' stations to generate a current *in one direction only,* instead of the usual alternating current, and to use biased ringers at all the stations, adapted to ring only on pulsations of a different polarity from those of the generators. The switch-board drop, also bridged across the line, is of a non-polarized type, so as to fall when actuated by currents in either direction. Thus, when any subscriber calls, the current will have no effect upon any of the ringer magnets of the other subscribers, because it tends only to pull the armatures closer to the poles toward which they are already attracted, but will cause the switch-board drop to fall in the ordinary manner. Thus, no subscriber can obtain a conversation with any other subscriber without the full knowledge of the operator. The switch-board generator is equipped for sending out currents, of the opposite polarity from those generated by the subscribers' generators so that the operator may ring up the subscribers at will.

Coming now to selective signaling on party lines, those systems employing "step by step" mechanisms will first be considered. In these the general scheme is to employ a disc at each sub-station, each capable of being revolved one step at a time by pawl and ratchet mechanisms controlled by electromagnets. The discs at all the substations on a line may thus be revolved in unison by currents sent out from the central office. At some point in the rotation of each disc certain electrical contacts are made or broken in such a way as to render the talking and call-receiving apparatus at the corresponding station operative. The amount of rotative movement thus required to complete the circuits differs with respect to the discs at the various sub-stations on the line, and therefore the operator at central may successively bring each station into such condition as to allow the use of its talking and call-receiving apparatus. The operator may thus pick out the desired sub-station and ring its bell to the exclusion of all others on the line.

The use of step by step mechanism in this class of telephone work has apparently from the very first offered the most plausible solution of the problem of selective signaling, and while there are no insurmountable obstacles in the way of its being put into successful practice, yet the fact remains that there are comparatively few lines being operated on this plan; and it is only recently that one of the large manufacturing companies has brought the system into what might be called a fit condition for extensive commercial use.

One of the very first to apply step by step mechanism to the party line problem was E. N. Dickerson, Jr., as early as January, 1879. In this two revolvable discs were mounted on a common shaft at each sub-station. One of these was of insulating material, but had at one point on its circumferential surface a conducting segment. The other was of the reverse construction, having nearly all its surface of conducting material. The first-mentioned disc controlled the call bell circuit at each station, the bell being placed under the control of the operator when the conducting segment on the disc had been stepped into such position as to make contact with wiping springs resting against the cylindrical surface of the disc. At this point in the rotation of the bell controlling disc the other disc, which controlled the talking apparatus, had its insulating segment opposite the springs bearing against the surface of this disc, and therefore a short circuit was removed from the receiver.

All discs could be released at the end of a conversation by throwing a strong current on the line, which, by operating another set of magnets caused all the pawls to be lifted from the ratchet wheels connected with the discs, thus allowing the discs to be returned by springs to their normal positions.

The conducting and insulating segments on the rotary discs occupied different relative positions at the different stations, the arrangement being such, for instance, that the segments occupied such a position on the discs at the first station as to be brought in contact with their contact springs upon the first step of their movement. As the segments at the other stations all occupied different relations it follows that the first step places the first station in position to be called while all of the other stations could only be reached by making succeeding steps, as, for instance, two steps for the second station, three for the third and so on. If, therefore, it was desired to call the third station on the line three impulses would be sent on the line, after which that station would be called.

At almost the same time George L. Anders produced a step by step system dependent on a somewhat different idea. All of the call bells were left permanently on the line wire and their hammers were actuated in unison when a pulsating current was sent over the line. A notched disc at each station prevented the bell hammer at its station from striking the bell except at such time as the notch on the disc was opposite the rod which carried the hammer. The discs were so arranged as to be stepped around by vibrations of the bell hammer, while the impulses of one polarity were sent over the line. In calling a certain party a sufficient number of impulses in this direction were sent to bring the notch of the disc at the desired station into a position opposite the bell-hammer rod, after which currents of the opposite polarity were sent over the line to ring that bell. Currents of this direction did not actuate the stepping device, but did actuate all of the bell hammers as before, but the notch in the disc of the desired station allowed that bell to sound, while the notches at the other stations, not being in the proper position prevented their bell hammers from striking the gongs.

Dickerson used his stepping device to control the local circuits at each station. Anders left all of his circuits unaltered and used his stepping device to control merely the length of the stroke of the bell hammer.

These two systems, produced in the very early days of the art of telephony, have been followed by a great number of others, some of them worked out with more completeness and embodying features of more or less merit. It is surprising, therefore, that with the need of a selective party line system clearly in the minds of telephone men, and after the necessary fundamental ideas had been developed, almost at the very beginning of the telephonic art, commercially practical systems have not been produced and found general favor; especially when the marvelous effectiveness of step by step movements, when applied to the telegraphic art, as in the various ticker systems, are considered.

The Stromberg-Carlson Telephone Manufacturing Company is now putting on the market in large quantities a step by step system for party line signaling, which appears to be meeting with great favor, particularly on country lines, and from all appearances is a practical success. This is adaptable to lines having as many as twenty stations.

Coming now to the more commonly used method of operating party line signals selectively, employing currents in different directions, or of different polarities, for operating the different signals, we find that this plan was well known in telegraphy, even before the birth of telephony.

The duplex and the quadruplex systems of telegraphy of the present time offered the best possible demonstration of the utility and practicability of systems operating on this principle when properly developed. The quadruplex system not only admits of sending selective signals one at a time, but even allows four to be transmitted simultaneously over a single grounded circuit, two in one direction and two in the other, a result never even seriously attempted in telephonic signaling. It may be said that at present by far the greatest number of successfully operating party line systems are based on this plan.

As in the case of the step by step system, George L. Anders was a pioneer in this line also, and in 1879 he produced a two-party line system having the call bells at the two stations polarized oppositely and included directly in series in the line wire. This was the birth of what is called the "biased bell," the operation of which was described in connection with Fig. 104 in the chapter on Magnet Calling Apparatus. With two such bells included in series current in a positive direction would therefore operate the bell at one station, and current in a negative direction that at the other.

Abandoning Anders' series system, using two bells in series in the line wire, and adopting the bridging system instead, and applying the ideas to a metallic circuit line instead of a single grounded line, Mr. Angus S. Hibbard, of the Chicago Telephone Company, has produced a four-party line wherein any one of the four stations may be called from the central office without disturbing the other. This is the system now almost universally used by the Bell companies, it being, however, modified to some extent to meet the various requirements of service.

The principle of the Hibbard system, so far as the ability to ring any subscriber on the line is concerned, is illustrated in Fig. 324, where the two limbs, *a* and *b*, of the metallic circuit line are shown extending from four subscribers' stations to the central office. The bell of station 1 is legged from the limb, *b*, to ground and connected in such direction that only a negative current flowing from the line to ground will operate it. The bell at station 2 is similarly connected, except that its polarity is reversed so that it will be operated only by positive currents. In similar manner the bells at stations 3 and 4 are connected with respect to the limb, *a*, of the line.

At the central office is connected a pulsating current generator adapted to send out current in a positive or negative direction, according to which of its terminals is connected with the line. If, therefore, the positive pole of the generator were connected by means of the plug, *c*, and the switch, *d*, to the terminal of the limb, *a*, station No. 4 would be rung. If the switch, *d*, were reversed thus connecting the positive pole to ground, and the negative pole of the generator to line, the bell at station 3 would be rung. In the same manner, by applying the plug, *e*, to the terminal of the limb, *b*, either

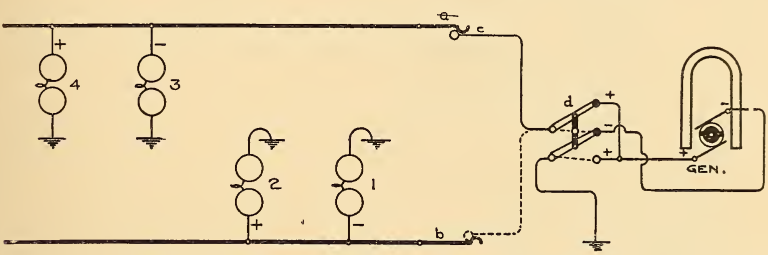


FIG. 324.—HIBBARD PARTY LINE IN THEORY.

station 1 or 2 would be rung. The actual circuits of such a system adapted to common battery talking and signaling is shown in Fig. 325.

This, as will be seen, employs four ringing keys, 1, 2, 3 and 4, in the cord circuit, the operation of any one of which will cause the bell of the correspondingly numbered station on the line with which the calling plug is connected, to ring. Thus, depressing key, 1, will throw positive pulsations from the generator on the sleeve side, *a*, of the line, at the same time grounding the tip side, *a'*. This will cause the bell at station 1 to ring. Similarly any of the other stations may be called up.

In order to prevent undue complication of the ringing keys, and to bring about the further advantage of having a party line handled, so far as the operator is concerned, in exactly the same manner as if it were an individual line, Mr. F. R. McBerty, of the Western Electric Company, has proposed a very ingenious system, shown in Fig. 326. This uses a separate jack on the switch-board for every sub-

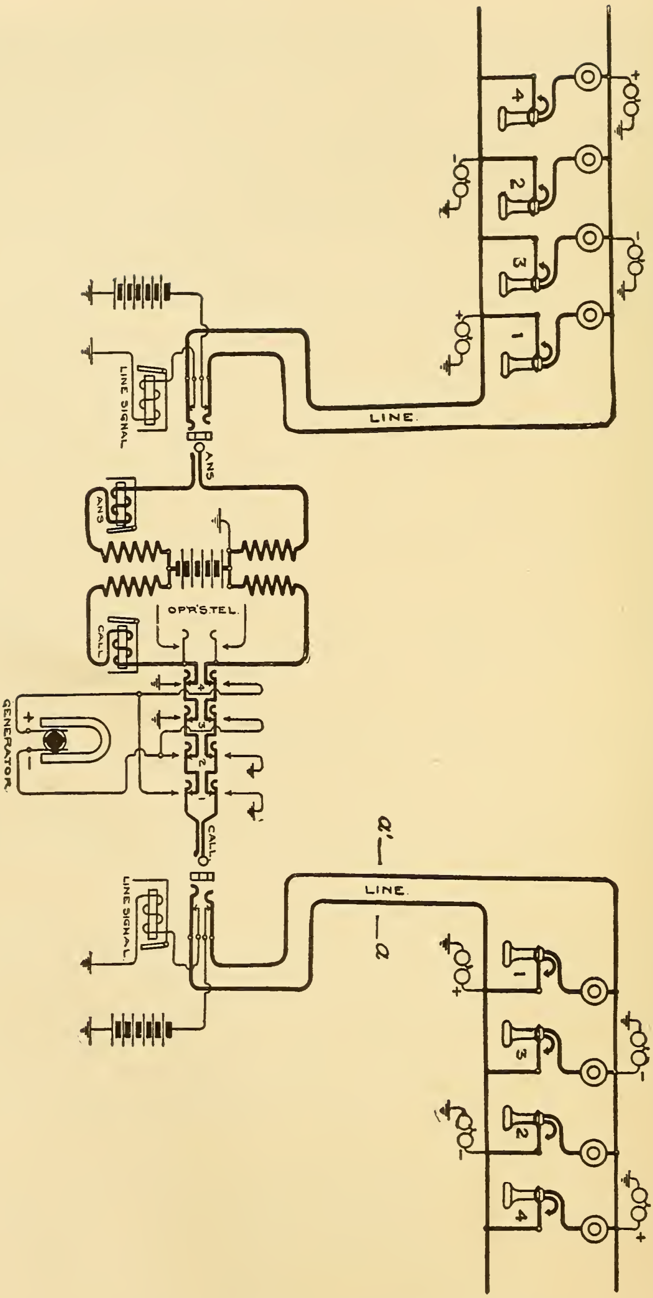


FIG. 325.—HIBBARD PARTY LINE SYSTEM.

scriber on the party line; thus, on a four-party line four jacks would be used for each line, instead of one, as in the original Hibbard system.

The arrangement of the subscriber's apparatus with respect to the line is the same in all respects as in the system just described, and the operation of calling central is obvious from the diagram.

In connection with the line conductors, *a* and *a′* are four spring-

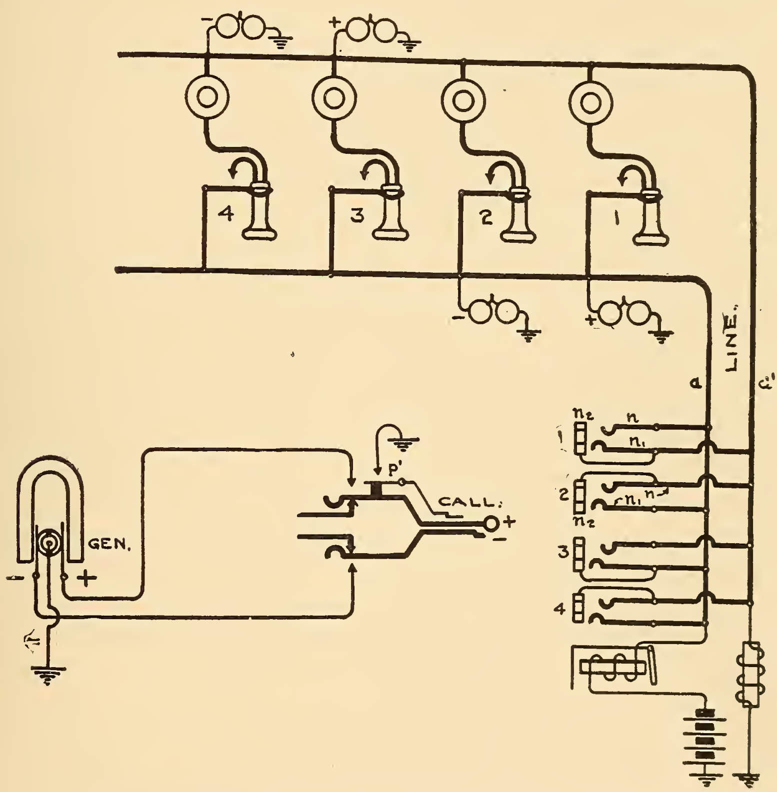


FIG. 326.—McBERTY'S MODIFICATION OF HIBBARD SYSTEM.

jacks, 1, 2, 3 and 4. Each of these has a short line spring, *n*, a long spring, *n′*, and a tubular thimble, n^2. The connection of these springs and thimbles to the conductors of the line is different in the case of each jack as examination will readily show.

The switch-board is provided with the usual plugs and cord circuit, which includes a ringing key. This key, in addition to the usual pair of switch springs and their normal and alternate contact anvils, has a spring, *p*, which is adapted to register with an anvil, *p'*, when the key is operated.

The arrangements of the jacks with respect to the line wires are such that the mere insertion of the calling plug in any jack will establish the proper relations between the generator and the line, to operate the bell at the corresponding station upon the depression of the key. Thus, suppose the operator wishes to call station 1. She inserts the plug in jack, 1, of that line, and depresses the ringing key. A pulsatory current in a positive direction will now flow from the tip of the plug to the spring, *n*, of the jack and to line conductor, *a*, and thence through the bell at station 1 to ground. The limb, *a'*, of the line will be grounded through the jack spring, *n'*, and ring, n^2, and thence through the spring, *p*, of the ringing key. The bell will be operated by this current. The bell at station 2 will also receive part of this current, but not be operated on account of its polarity.

By tracing out the circuits through the other jacks it will be found that in each case the spring-jack into which the plug is inserted determines which of the signals connected with that line shall be operated.

When the operator has made a connection with any spring-jack, and has operated the signal at the corresponding station, the presence of the plug in that spring-jack indicates to her, during the existence of the connection, the station which has been signaled. If it should be necessary to signal the same station again, she does not have to remember which party on that line has been signaled, for she may be sure of again calling the same one by merely pressing the key. If it should be necessary to make any charge, as in the case of a toll connection, the identity of the station signaled is ascertained by the presence of the connecting plug in the corresponding spring-jack.

The arrangement of polarities, circuits and symbols in Fig. 326 differs from that of preceding figures. It is obvious that any arbitrary arrangement of polarities, line conductors and station numbers may be adopted so long as any given telephone exchange is consistent throughout.

A considerable amount of difficulty has been experienced in adopting the Hibbard party line system to operate properly in conjunction with standard common battery circuits as employed by either the Bell or Independent companies, the principal difficulty occurring in securing the proper operation of the line and supervisory signals. It has been shown that nearly all common battery systems depend for signaling on the fact that the line circuit is open at the subscribers' stations when the receivers are on their hooks, and is closed when the receivers are removed for talking. The normally open condition of the line is attained by the use of condensers in series with the bells, the condensers serving to allow the passage of the alternating currents used in ringing, but to prevent the passage of direct current due to the potential constantly placed on the line by virtue of its connection with the battery at the central office. Unfortunately, however, where "biased" bells are used, the condenser must be abandoned, because the effectiveness of biased bells demands the use of pulsating currents, or currents in one direction only. When such a current is applied to a condenser the result is naturally an alternating-current, and therefore biased bells would ring on either polarity of current if placed in series with condensers.

Since in the Hibbard system two bells in multiple are connected between each side of the line and ground, it follows that the two sides of the line are connected through a combination of bells, two in multiple and two in series, giving, therefore, an effective resistance of one bell only. If the bells were of ordinary resistance, therefore, this arrangement would keep the line signal operated at all times, and would also operate the line, or the supervisory relay, whether the receiver was on or off the hook. In order to remedy this the bells are usually wound to a very high resistance, usually 2500 ohms, and placed in series with a non-inductive resistance in some cases as high as 20,000 ohms. Even with this resistance the work of the relays is marginal, that is, the relay must be so adjusted as to work properly through the resistance of the line and the talking apparatus, but it must be made so insensitive as not to work through the resistance of the line and that of the bells. Such conditions are to be avoided, if possible.

A modification which is being used to a considerable extent by the Bell companies, and which effectually removes the difficulty due to the marginal adjustment of the line and supervisory relays, has been devised by Messrs. Thompson and Robes. In this system each station is provided with a relay especially designed for use with alternating currents, each relay being bridged across the metallic circuit of the line in series with a two-microfarad condenser. This arrangement is shown in Fig. 327, which shows two four-party lines connected by the usual Bell multiple switch-board circuits at the central office. The contacts of each of the relays at the subscribers' stations are so arranged that when the relay is operated it will connect the usual

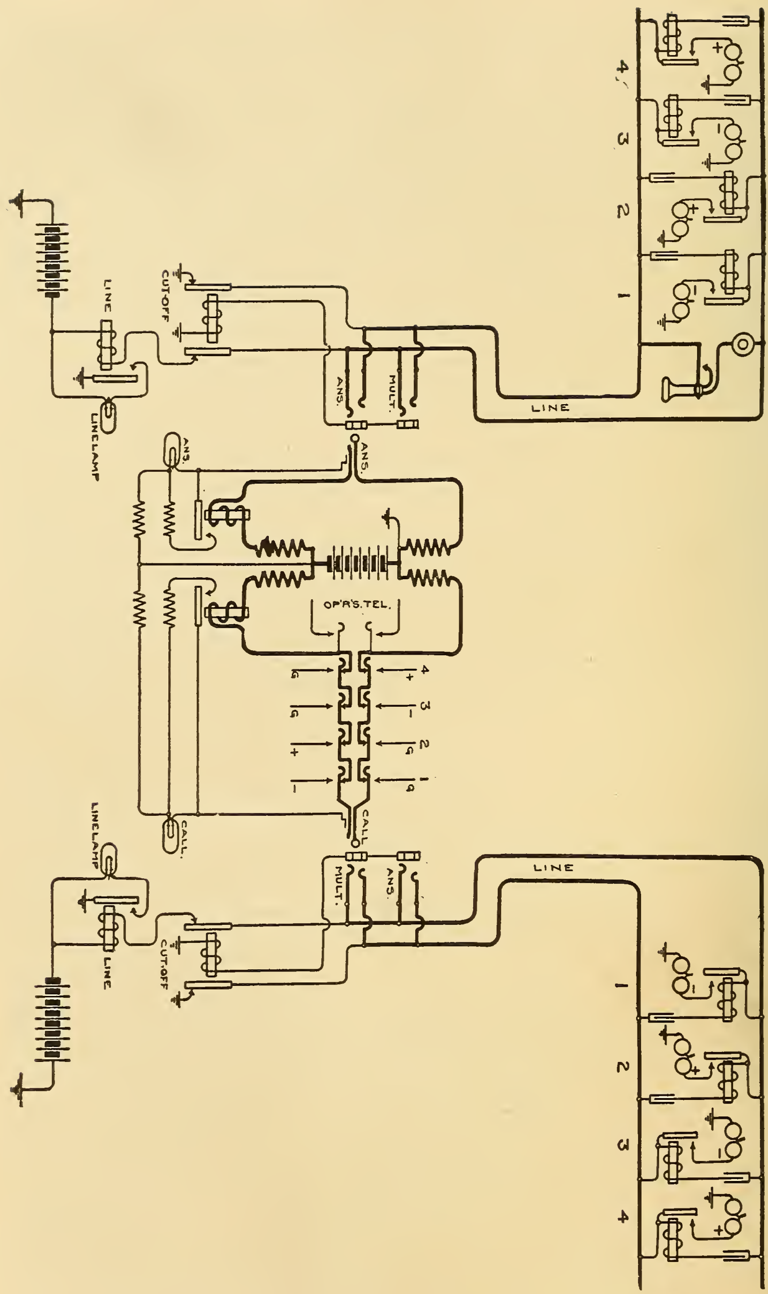


FIG. 327.—THOMPSON & ROBES PARTY-LINE SYSTEM.

biased bell to earth from one leg or the other of the metallic line, such connection being made only during the process of ringing. The ground branches are detached from the line at all times, except during the ringing operation, but are made available for use in ringing by the action of ringing when pulsating current is thrown on the line.

When the proper (say, negative) pulsating current is applied between the sleeve side of the line and ground, current will flow out to the sleeve side of the line through the condensers at all of the stations in multiple, and back to the ground on the tip side of the line at the ringing key. All of the relays at the subscribers' stations will be thus operated, which will establish new ground connections at the subscribers' stations. The negative current then in passing through the bell at station No. 1 to ground will ring that bell, while the bell at station No. 2 will not be rung, because of the current being in the wrong direction.

This solution has the advantage of removing the necessity for the marginal adjustment of the line and supervisory relays at the central office, but it has the disadvantage of placing an extra piece of apparatus, the relay, at each of the subscribers' stations.

There is another system of selecting by polarity on party lines, known as the B-W-C system, from the names of its inventors, Messrs. Barrett, Whittemore & Craft. While this system is not now in use, so far as the writer is aware, it was at one time put into wide use by many of the Bell operating companies, and for that reason and because of the several exceedingly ingenious features in it, it is thought worthy of a careful description. It was not, however, a commercial success, on account of the trouble in its maintenance; and in that respect it serves as an additional example of the fact already pointed out, that undue complexity at the subscribers' stations cannot be tolerated in commercial telephony. This system depends for its operation on the sending of currents of either polarity over either or both of two line wires in combination with each other or with the ground. Thus calling one wire *A*, and the other *B*, and representing the ground by *G*, it is evident that without using wire *B* at all, a current in either direction could be sent over wire *A*, with a ground return, thus giving means for two selective signals. Similarly leaving *A* out of the question, a current of either direction could be sent over *B*, with a ground return, thus providing for two other selective signals. So far the combinations are identical with those of Hibbard. A current may also be sent in either direction over the metallic circuit formed by *A* and *B*, thus providing for two other signals; and lastly, by using *A* and *B* in multiple, currents could be sent in either direction, using a ground return, thus affording means for two more signals, or eight in all. Two other combinations might be obtained by sending currents in either direction over wire *A*, using wire *B* and the ground in multiple as a return; and similarly two others by using *B* for one side of the circuit with the wire *A*, and ground in multiple

	Line A.	Line B.	Ground.
1.	+	o	—
2.	—	o	+
3.	o	+	—
4.	o	—	+
5.	+	—	o
6.	—	+	o
7.	+	+	—
8.	—	—	+

for a return. These latter combinations, however, have been found to introduce undesirable features, as will be readily understood. The eight desirable current combinations may be tabulated as in the table above.

In this table the plus and minus signs indicate which pole of the calling battery at central is connected to either line wire or ground. Thus, in the first combination, the positive pole is connected with line *A*, the negative with the ground in order to utilize the earth return. Line *B* in this combination is not used at all.

Fig. 328 shows diagrammatically such an arrangement of apparatus at eight stations that the call-bell, *D*, at each station will be actuated only when the one particular set of current combinations is sent over the line. *A* and *B* represent two line wires extending from a central station, *C*, to a number of sub-stations, S, S^2, S^3, etc. At each of the sub-stations are two relays, *R* and R^2, placed in earth branches, *m* and *q*, from the two line wires, *A* and *B*, respectively. These two branches are united at *e*, and connected with the ground at *G*. The signal bell, *D*, is connected with the local battery, *s*, in a circuit, the continuity of which is controlled by each of the relays, *R* and R^2. Unless the armatures, 13, of both relays rest against their back stops, 12, the local circuit containing the bell will be opened at one or two points. The relays of each station differ in some way, either in construction or arrangement,

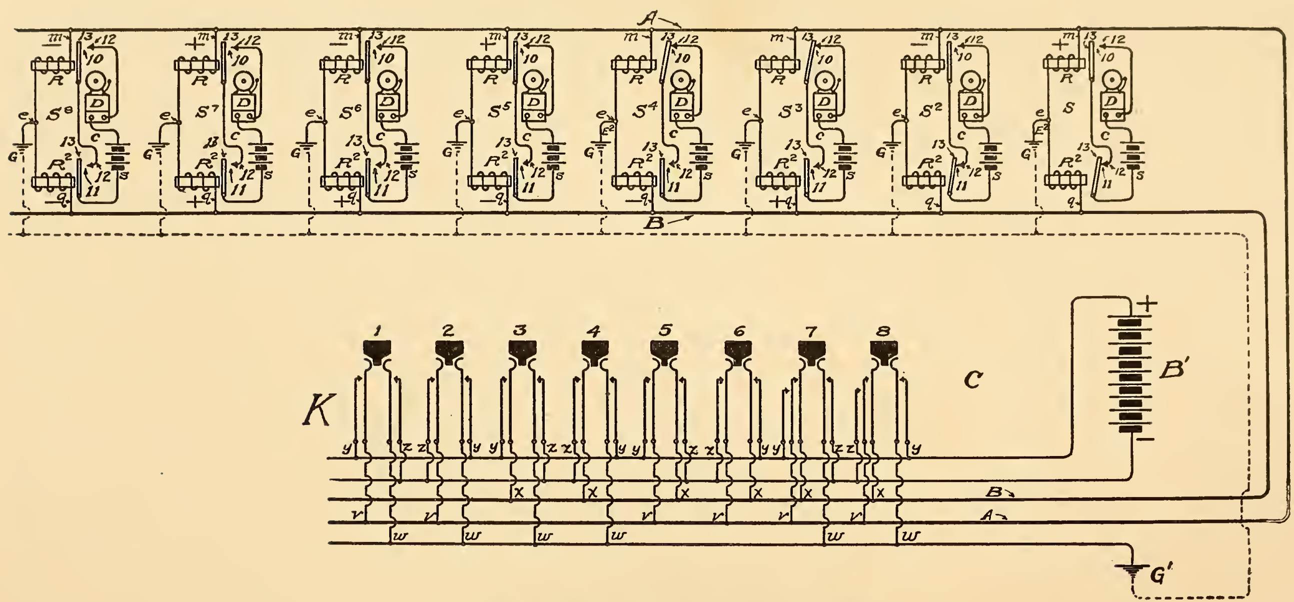


FIG. 328.—SIMPLIFIED B.-W.-C. SYSTEM.

from those of all other stations. Thus at station *S* the main conductor, *A*, is branched through a polarized relay made responsive to positive currents from the central office, and the main conductor, *B*, through a neutral relay, R^2, adapted to respond to currents of either direction from the central office. It is thus obvious that if a positive current is sent over wire *A* without sending any current whatever over *B*, the bell at station *S* will be operated because the positive current will cause the relay, *R*, to release its armature, while the armature of relay R^2 is already released. Thus, both contacts, 10 and 11, will be closed and the bell circuit complete. Station S^2 also has a neutral relay on wire *B* and a negatively polarized relay on wire *A*. The third and fourth stations, S^3 and S^4, each have a neutral relay on wire *A* and a positively or negatively polarized relay on wire *B*. The fifth station, S^5, has two polarized relays, one adapted to respond to positive currents and attached to wire *A*, and the other to negative currents and attached to wire *B*. The sixth station, S^6, also has oppositely polarized relays, but their connection with the line is the reverse of that in station S^5. The seventh station, S^7, has two positive relays and the eighth station, S^8, two negative relays, one in each case being bridged between each limb of the line and ground.

Reference to the table of current combinations will show, in connection with Fig. 328, that the sending of any particular combination to line will operate the relays of the station bearing the corresponding number in such manner as to close the local circuit at that station. Further consideration will also show that no combination will so operate the relays at more than one station.

At the central station, *B′* is a generator of calling current, and *C′* an earth connection complementary to the earth connections, *G*, at the sub-stations. *K* is a group of signaling keys, each corresponding with one sub-station appliance, and when any particular key is pressed it sends the proper current combination to line so that the relays at the particular sub-station represented by it will co-operate to close the local circuit and give the signal there; but at the other stations no such effect will take place. Hence, to give a signal at any desired sub-station, it is only necessary to operate the particular key representing such station. To accomplish this, branch terminals are brought from the line conductors, *A* and *B*, from the ground connection, *G′*, and from the positive and negative poles of the battery to the various terminals on the signaling keys. The arrangement of the terminal contacts in each key is different, the differences corresponding with those of the sub-station relay arrangement.

To illustrate: in key No. 1 the contacts are so disposed that its operation will connect conductor *A*, with the positive pole of the battery, *B′*, at contacts, *v* and *y*, the minus pole of the generator with the earth terminal-contacts, *z* and *w*, and will leave conductor, *B*, disconnected. By this means a positive current is sent over line *A*, and is distributed through all the *A* relays at all of the sub-stations in parallel, finding return through the earth branches; but as no current is transmitted over line conductor *B*, all of the eight *B* relays will remain unaffected. Under these conditions relay *R*, at station *S* will close point, 10, of its local circuit, and the point, 11, being already closed by the armature of relay R^2, the normal position of which has not been changed, the local circuit, *c*, of station *S* will be closed and the bell at this station will be rung. Station S^2 will not be signaled, because plus currents have no effect on its polarized relay, *R*. Station S^3 is not signaled, because the effect of the plus-current on line *A* is to attract the armature of neutral relay *R*, and thus open the local circuit, which is already open at point, 11. Station S^4 receives no signal for the same reason. Station S^5 is not signaled, because, though the positively polarized relay on *A* closes the open point, 10, of its local circuit, the said circuit remains open at 11, there being no current on *B*, station S^6 because neither relay is acted upon, *R* being of minus polarity and R^2 having no current; station S^7, because *R* alone is operated, and station S^8 because both relays are of minus polarity.

In applying the principles already pointed out to a practical multiple-station circuit, it is desirable to reserve two of the current combinations for the operation of locking devices common to all stations.

The seventh and eighth combinations in the foregoing table have been found most convenient for this purpose. The seventh, that is, the positive current over both conductors, *A* and *B*, in parallel, is used for locking the telephone apparatus at all stations, and a negative current over both lines for unlocking the apparatus. Six combinations are thus left for signaling.

The locking device and a visual busy signal are shown in association with complete telephone equipments at two stations in Fig. 329. In these an additional electromagnetic apparatus, R^3, is shown in circuit with the relays, *R* and R^2, at each sub-station.

half of its winding being in the earth branch, *m*, of the relay *R*, and half in the branch, *q*, of the relay R^2.

Two electromagnetic helices, *a* and *b*, have the ends of their cores joined by soft-iron yoke-pieces to form the instrument, R^3. Two soft-iron polar extensions, *h* and *f*, project inwardly from the yoke-pieces as shown. A polarized bar armature, *j*, pivoted at j^2, has one of its poles projecting between the pole-pieces, *h* and *f*, and adapted to move to one side or the other under the influences of said pole-pieces. If current is passed through coil *a*, only, the magnetic polarity developed will be short-circuited through the yoke-pieces and the core of coil *b*, so that very little strength will be manifested in the pole-pieces, *h* and *f*; if current be applied to the coil *b* only, the magnetic polarity will be similarly short-circuited, and, again, little effect will be manifested in the pole-pieces. Again, if current be applied to both coils, *a* and *b*, so as to act in a complementary direction, the yoke-pieces will satisfy the magnetic flux with very little polarity in *h* and *f*; but if current be applied to coils, *a* and *b*, in inductiviely opposed direction, as will be the case when the seventh and eighth combinations are transmitted, consequent poles of full strength and opposite polarity will be formed at *h* and *f*. The polarized lever, *j*, is, therefore, actuated by the seventh and eighth current combinations and remains unaffected by all others.

As shown at the right of Fig. 329, the lever, *j*, serves not only as a lockout device, but also as a busy signal. The apparatus is shown in its locked or busy position at station S^2 of this figure and in its unlocked or free position in station S^3. When the lower portion of the lever is moved to the left it forms a stop to lug, J^3, on the hook-switch, *L*, and thus prevents the latter from rising should the receiver be removed from the hook. At the same time the small target, *B*, on the other end of the lever is displayed through a hole in the box, thus showing the party at that station that the line is busy. When in its other position the busy signal is not displayed and the hook-switch is free to rise.

When the operator at central presses the locking key, say key No. 7, all of the locking levers on the line, including that of the party to be called, will be actuated. In order that the party being called may not be thus locked out, the windings, 27 and 28, are provided around the polar extensions, *h* and *f*, on each instrument. This winding has no function except at the station being called. In that station part of the current from the local

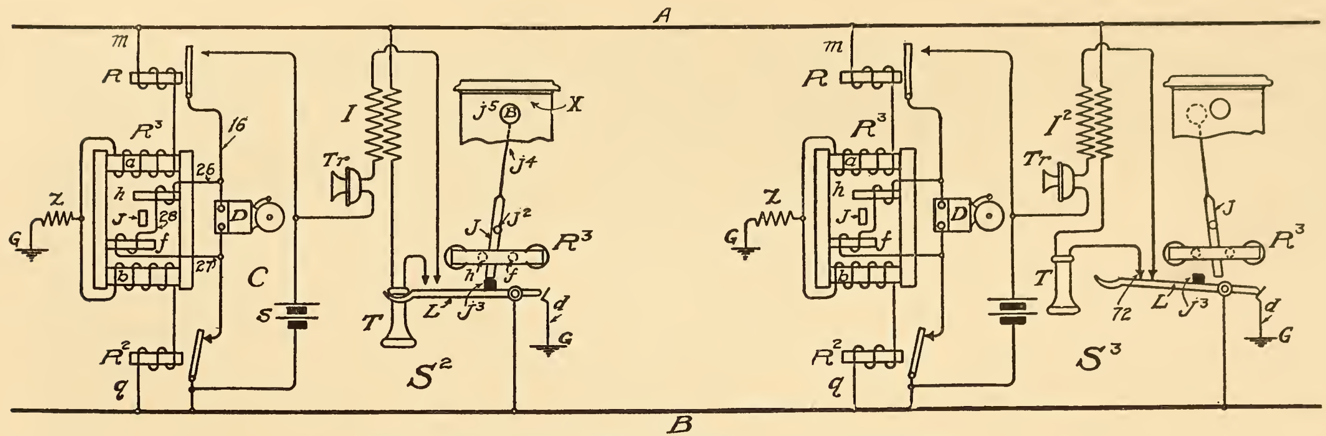


FIG. 329.—LOCK-OUT MECHANISM OF B.-W.-C. SYSTEM.

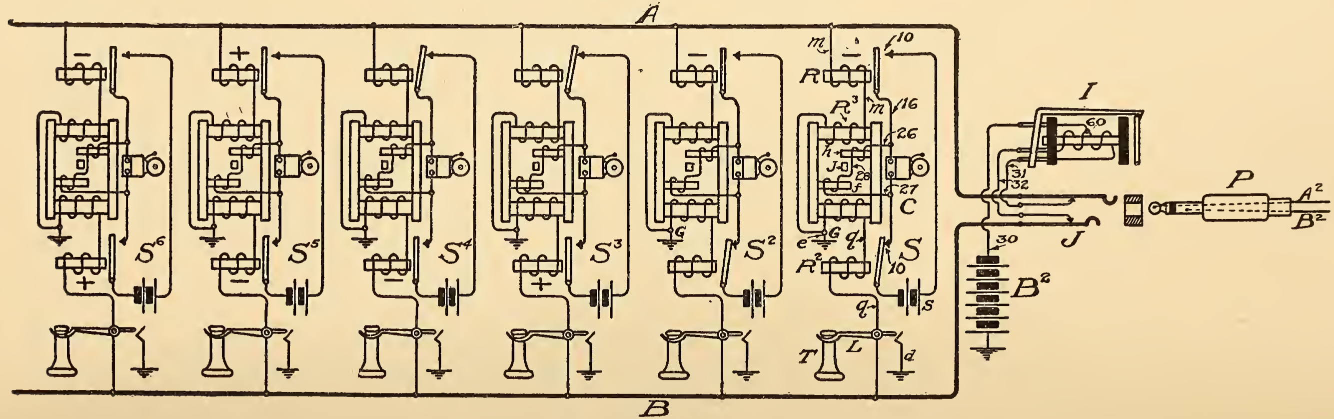


FIG. 330.—CIRCUITS OF SIX-STATION B.-W.-C. SYSTEM.

circuit, which is closed only at that station by the action of the relays, finds path through this winding, and the magnetism so developed serves to unlock the mechanism and to allow the party at that station to use his instrument.

In Fig. 330 is shown a six-party line, the equipment at each station being of a similar character to that shown in Fig. 329, but simplified for the purpose of clearer illustration. The two sides of the line terminate in the line springs of a spring-jack, *J*, which springs normally rest on anvils connected to the windings, 31 and 32, of a differentially wound switch-board drop. These two windings pass around the core of the drop magnet in opposite directions, after which they unite at the point, 60, and pass to ground through a battery, B^2. The relative direction of the windings on the drop is such that the current from this battery circulates around the core in opposite directions, and thus does not affect the drop. It then divides equally between the two main conductors, *A* and *B*, and finally returns by the ground connections, *G*, at each of the several stations. The current thus flowing to the two conductors from the battery, B^2, is in a negative direction, and thus tends to maintain the apparatus at the several stations in its unlocked condition.

When any subscriber removes his receiver from the hook, the short arm of the hook-lever, *L*, makes contact momentarily with the spring, *d*, which grounds the main line wire, *B*, and thus allows a heavy current to pass through the winding, 32, of the drop, *I*. This throws the drop and attracts the attention of the operator. The operator answers the call in the ordinary way by the insertion of one of the plugs, *P*, with which the ringing keys, *K*, in Fig. 328 are associated.

When a sub-station is to be signaled, the calling plug, *P*, is inserted into the spring-jack, which cuts off the annunciator and connects the keys, *K*, with that particular circuit. Key No. 7, which sends the plus current over both lines in parallel, is then operated to lock the apparatus at all stations without ringing any of the bells; and then the key representing the desired station is pressed which results in ringing the bell, and at the same time in releasing the telephone apparatus at that station by the means already described. At the close of any conversation Key No. 8, sending a minus current over both lines in parallel, is operated to release the apparatus at all stations, restoring the circuit to its normal condition.

We come, now, to the third general method of selective signaling pointed out in the beginning of this chapter wherein the selection from among the various stations is made by means of ringing currents of different frequencies. These systems, with one exception, make use of the fact that every pendulum or every vibrating reed has a natural period of vibration, and that it can be made to take up this vibration by the action of a succession of impulses of force occurring in the same frequency as that at which the reed or pendulum vibrates. A familiar example of this is found in one person pushing another in a swing. The swing has its natural period of vibration depending on the length of the ropes, and a gentle push applied at proper intervals by the person on the ground will cause the swing to vibrate with considerable amplitude. If the pushes are applied at intervals not corresponding to the natural period of vibration of the swing, many of them tend to retard rather than help its vibrations, so that a useless bumping results, producing but little motion.

The utilization of this principle has given inventors a very attractive field of work; but as in the case of the step by step systems, the results attained have, until very recently, proved of little practical value in telephony, save in so far as they have contributed to the general stock of knowledge on the subject.

This idea was used in telegraphy before the birth of telephony. A number of currents of different rates of vibration were impressed upon the circuit by as many different transmitters, each particular rate of vibration being capable of operating a reed in one of the receiving instruments, and producing no effect upon the others. By this means each receiving instrument was capable of picking out only those signals sent by the transmitter having the same rate of vibration, and thus all of the transmitters could be used simultaneously in the same circuit, producing a system of multiplex telegraphy.

The plan of harmonic signaling on party lines was proposed before the year 1880 by Messrs. Currier and Rice. They used magnets having armatures tuned to vibrate at certain fixed rates, one of these magnets being placed in series in the line at each station. All these magnets were therefore subjected to whatever current was flowing in the line. The armatures, or reeds, as they may be called, at the different stations, all having different rates of vibrations, did not respond unless the current on the line was of the corresponding frequency. Thus, by throwing a current of the proper frequency on the line, a reed at any one of the stations could be thrown into vibration. When so vibrated it served to close the circuit through a call-bell at that station, which was, therefore, operated.

Nearly every conceivable form of circuit arrangement was tried during the succeeding years until nearly the present date, the work of Messrs. Elisha Gray, Frank L. Pope and J. A. Lighthipe standing out in some prominence.

So far as the writer is aware, the only commercial application of the harmonic idea of selective signaling on party lines, prior to the year 1903, was made by the local Bell Telephone Company, of Sacramento, Cal., where a few lines were equipped and operated for several years on this principle. Although not an unqualified success, this single application served to show that the harmonic principle was feasible if it should ever be properly worked out. During the past two years Mr. W. W. Dean has applied himself to this problem with the result that a four-party selective system has been produced, operating on the harmonic principle, which has already been put into wide use by the Kellogg Company, notably in the system of the Frontier Telephone Company, of Buffalo, and which gives every indication of proving an entire success.

Nearly all previous attempts at the solution of this problem involved the use of relays with tuned armatures, so arranged that when an armature was thrown into vibration it would close the circuit of the bell, and thus in one way or another cause its operation.

The work of Lighthipe seems to have been one of the exceptions to this general rule, and he caused the tuned armature itself to play between the two gongs which were to produce the sound. Lighthipe bridged his bells directly across the circuit of the line, as in the bridging system, a condenser being included in circuit with each bell. The same general plan has been followed by Dean, but he uses one gong instead of two and a polarized responsive device instead of the usual non-polarized electro magnet. The circuits of Mr. Dean's system are shown in Fig. 331.

The cord circuit shown in this figure is a simplified Western Electric circuit, having four ringing keys, which are adapted to connect the different frequencies of alternating currents with the tip side of the line, at the same time grounding the sleeve side. The system is adaptable to any switch-board circuits. At each sub-

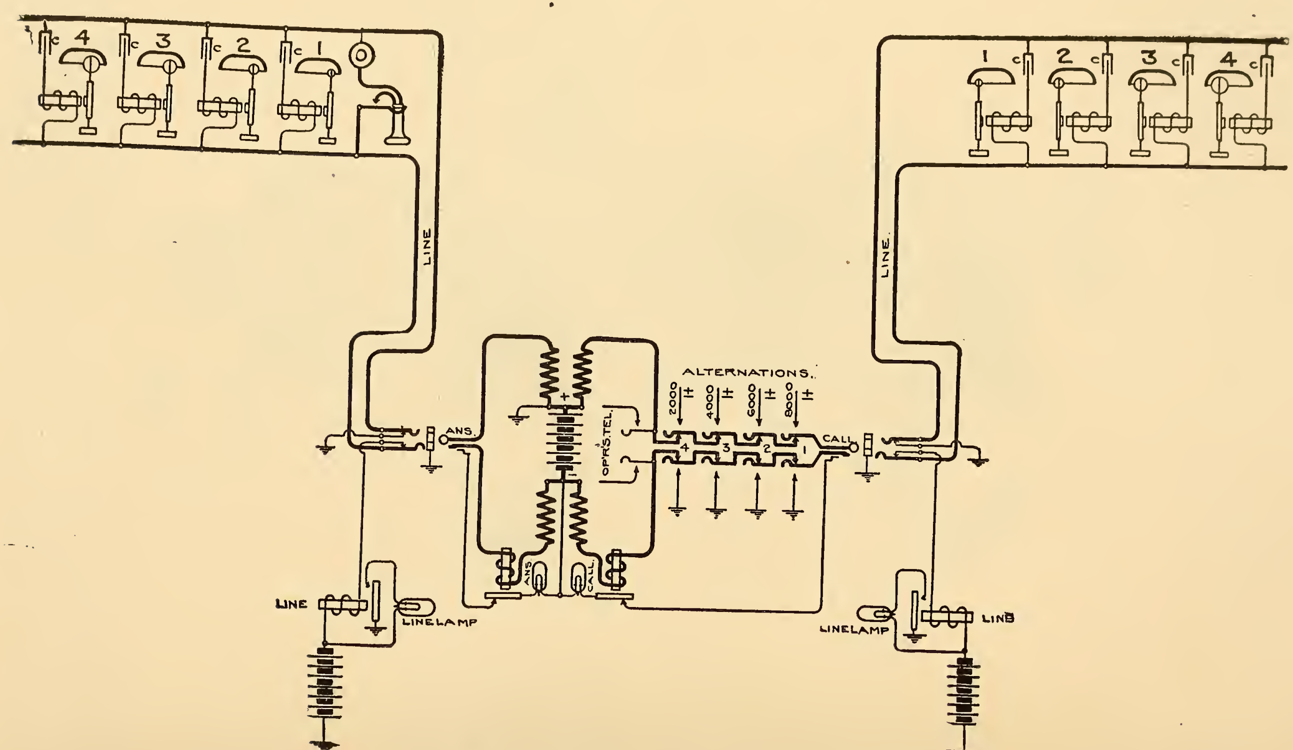


FIG. 331.—KELLOGG PARTY-LINE SYSTEM.

scriber's station, besides the usual talking apparatus, the bell magnet, with its tuned reed and bell tapper, is bridged across the line in series with a condenser, *C*. Currents of 2000, 4000, 6000 and 8000 alternations per minute are used, these currents being sup-

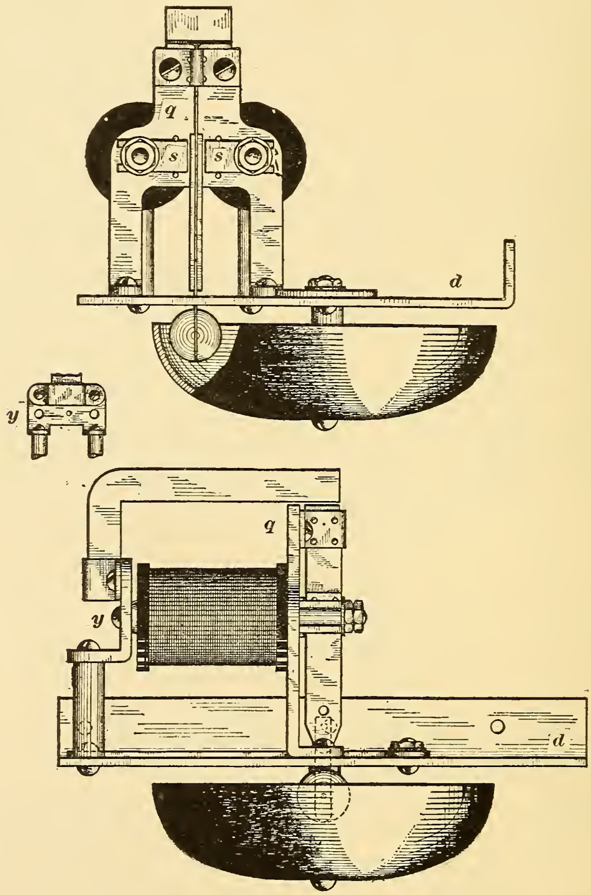


FIG. 332.—KELLOGG PARTY-LINE BELL.

plied by different generators properly governed to maintain a constant speed.

The bell mechanism is shown complete in Fig. 332, two views being given. The whole mechanism is mounted on a horizontal iron plate, *d*, the bell being mounted in a horizontal position below the plate, and adjustable toward or from the tapper in the usual manner by means of a pivot lever and set screw, as shown in the detail, Fig. 333. The polarized electro magnets consist of two bobbins of the usual form, mounted on a yoke-piece, *y*, at the rear, and having their forward ends supported firmly in a brass plate, *q*, secured at its lower end to the plate, *p*. Two slotted

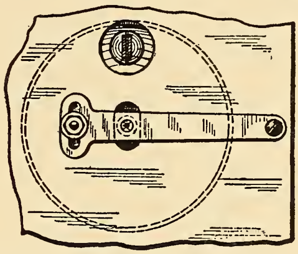


FIG. 333.—DETAIL OF KELLOGG PARTY-LINE BELL.

pole pieces, *s*, *s*, of soft iron are adjustably secured to the front ends of the cores of the magnets in such a manner as to allow the armature, *a*, to freely vibrate between them.

The vibrating part of the mechanism, including an armature, a ball-striker and two vibrating springs, are shown in detail in the right-hand portion of Fig. 334, together with their supporting

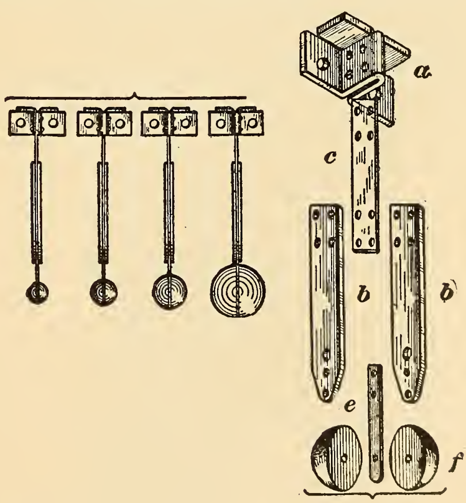


FIG. 334.—DETAILS OF ARMATURES AND STRIKERS, KELLOGG PARTY-LINE BELL.

pieces. In the left-hand portion of this figure four such armature units, having different sizes of ball strikers, are shown.

The armature proper is made of two pieces of soft iron, *b b*, riveted together and carrying between them a heavy spring, *c*, which is secured at its upper end to the metal support, *a*, and at its lower end a small spring, *e*, carrying a split-ball, *f*. This whole vibrating part is secured permanently together by riveting, and the support, *a*, is mounted on the upper portion of the vertical plate, *q*, as clearly shown. The heavy permanent magnet is secured to the iron yoke, *y*, at the rear of the magnets, and projects forwardly so as to impart its magnetism to the upper portion of the armature. It will be seen, therefore, that the magnetic design of the mechanism is along the line of the Siemans relay. By means of the permanent magnet the two pole pieces of the cores of the electro magnet are given one polarity and the armature is given the other. The currents passing through the two windings will strengthen one pole piece and weaken the other, thus causing the attraction of the armature toward one or the other of the pole pieces. The reversal of the current will cause an attraction toward the other pole piece. The armature will, therefore, tend to vibrate in unison with any vibratory current which is sent through the magnet, and would do so but for the fact that it is so designed as to have a certain distinct period of vibration of its own.

It will be seen that the ball-striker carried on the armature engages the inside of the signal gong rather than the outside, and that the gong is adjustable toward or from this striker by virtue of its being mounted on a lever carried on the upper side of the plate, *d*, as shown in detail in Fig. 333. The only difference in the various stations on the line is in the size of the ball-striker which engages the bell. The relative sizes of these balls for the four different stations are shown in the left-hand portion of Fig. 334. It is quite evident that a small ball so mounted will vibrate more rapidly than a large one, and the balls have therefore been proportioned so that in operation they will respond respectively to alternations taking place, 2000, 4000, 6000 and 8000 times a minute respectively.

Mr. Dean found that the placing of the bell or gong in such a position as to be struck by the ball changed the natural rate of vibration of the ball. For this reason he tuned the device so that the proper rate was secured when the bell or gong was in place, rather than tuning with respect to the vibration of the reed alone, as had been the case in most former efforts in this direction.

He also found that a polarized device was absolutely necessary in order to secure the proper promptness in response, and that a flexibility of connection between the armature and the ball was also necessary in order that the contact of the ball might not damp-

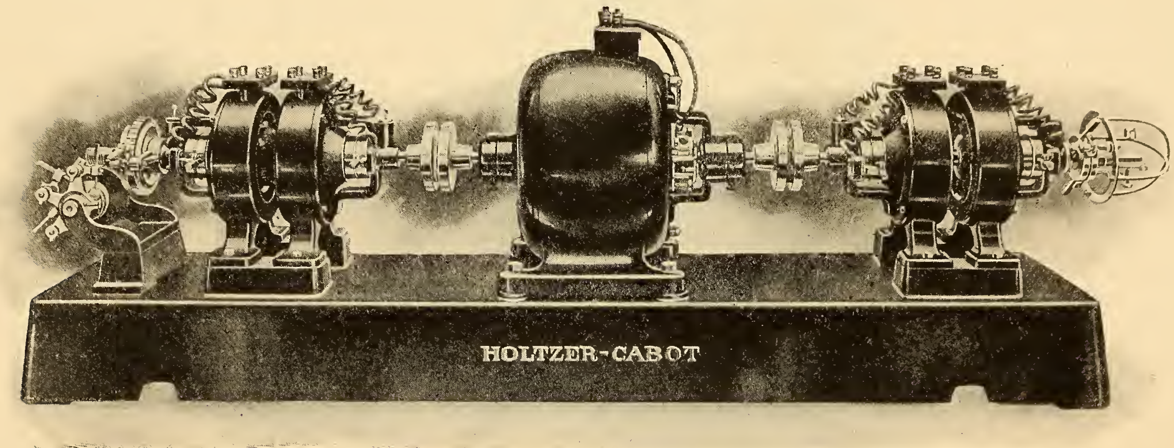
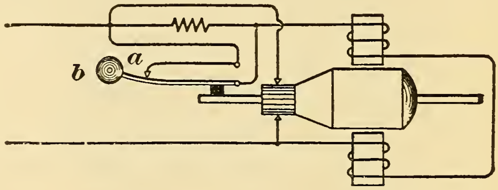


FIG. 335.—RINGING MACHINE USED WITH KELLOGG PARTY-LINE SYSTEM.

en and destroy the vibration of the armature. He used one gong instead of two because he found it impossible, when using two gongs, to make the ball strike more than one of them with any degree of certainty.

The machine for supplying the currents of the various frequencies in ringing in this system is shown in Fig. 335. In this four generators are directly coupled on the same shaft, all with a single



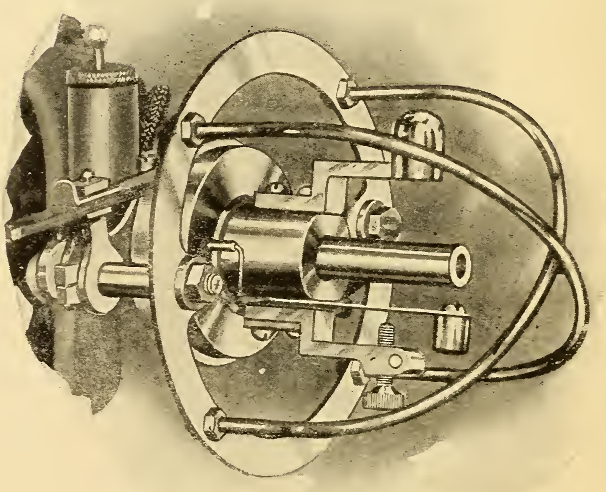


FIG. 336.—GOVERNOR FOR RINGING MACHINE, KELLOGG PARTY-LINE SYSTEM.

motor, this motor serving to drive all four generators. The motor is the center one of the machines shown. The generators are respectively of the two-pole, four-pole, six-pole and eight-pole type, and being driven at the rate of 1000 revolutions a minute, therefore produce currents having frequencies of 2000, 4000, 6000 and 8000 alternations per minute.

In order to properly govern the speed of the motor so that it will not fluctuate with changes in the primary voltage, a governor, shown in diagram and perspective in Fig. 336, is mounted upon the end of the motor shaft. This consists of a ball, *b*, mounted by means of a spring on the armature shaft. This spring is adapted to make contact with the point, *a*, when the ball is thrown outward by centrifugal force. The method of governing is as follows: With the desired rate of revolution, 1000 per minute, the motor was so constructed as to run at 900 revolutions on the highest voltage it could ever get. A resistance was then introduced in the field circuit of the motor sufficient to make it run at 1100 revolutions on the lowest voltage it could ever get. The connection was so made that the contacts on the governor would short-circuit this resistance when the ball is forced out so as to close it. It is evident, therefore, that normally a resistance is in circuit in the field, tending to make the motor run too fast. As soon as the contact is closed, however, by centrifugal action on the ball, the resistance is short-circuited, tending to make the motor run too slow. By adjusting the tension of the spring the motor can be made to regulate at within one per cent. of 1000 revolutions a minutue when subjected to a fluctuation in primary voltage of over 100 volts.

There is one other "frequency" system of party-line working which deserves attention. This is the Leich system, as put on the market by the American Electric Telephone Company, of Chicago. This system depends for its action on the fact that a high frequency current is more readily transmitted through a condenser than one of low frequence, while the reverse is true with respect to transmission through an impedance coil.

The circuits of a Leich four-party line and a central office cord circuit is shown in Fig. 337. In this two generators of ringing current are employed at the central office, one giving a frequency of 2400 alternations per minute and the other of 7200. Four ringing keys are so arranged as to connect either the high or the low frequency machine between either side of the line and ground. Two of the bells of the four sub-stations are bridged between one limb of the line and ground, the other two being similarly connected with respect to the other limb. Each bell has associated with it a retardation coil and a condenser, the arrangement being such that one of the bells on each side of the line will respond only to current from the high frequency generator, and the other only to that from the low frequency generator.

As will be seen from the circuit stations, 1 and 3 are high-frequency stations, and at each of these the bell is shunted by a low-wound impedance coil, this parallel circuit being placed in series with a one-microfarad condenser. The bells at stations 2 and 4 are adapted to respond to low frequency currents only, and therefore are placed in series with a two-microfarad condenser and a

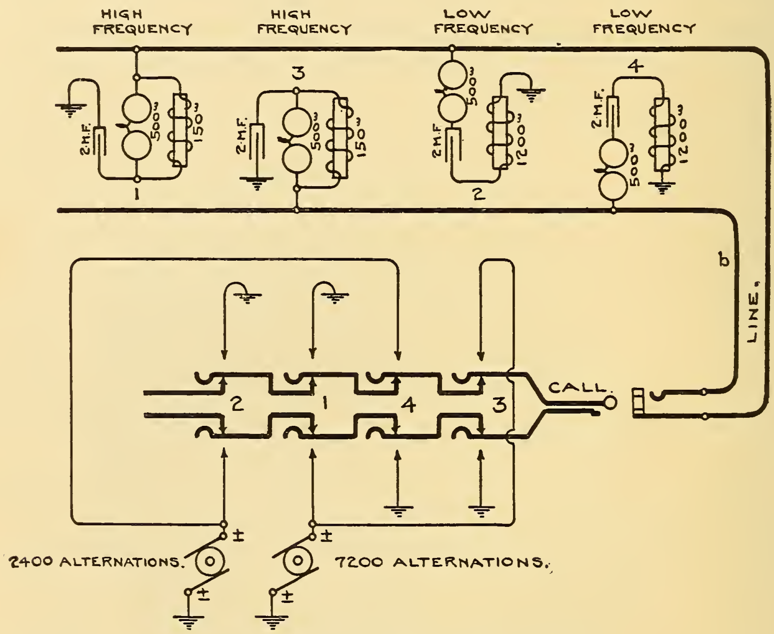


FIG. 337.—LEICH PARTY-LINE SYSTEM.

high-wound impedance coil. Each limb of the line carries one high and one low frequency station.

If the low frequency generator is connected with the limb, *a*, of the line, by throwing ringing key, 2, some current will pass to earth through the bell of both stations 1 and 2. Most of the current that passes to ground at station 1 will, however, pass through the shunt coil around the bell, and, moreover, the low-capacity condenser proves a somewhat serious barrier to the slowly fluctuating current. On the other hand, all of the current that passes to ground at station 2 passes through the bell magnets. This current is of sufficient magnitude to operate the bell, the larger capacity condenser allowing the low frequency current to pass through it more easily than that at the other station. The bell at station 2 rings, therefore, while that at station 1 does not.

If ringing key, 1, is thrown, the high frequency generator will be connected to limb, *a*, of the line, and, as before, some current will flow to ground through the bells of stations 1 and 2. In this case the combined impedance of the 1200-ohm coil and the ringer magnets at station 2 to the rapidly alternating current, will prevent enough current passing to ring the bell at that station. At station 1, the retardation coil will shunt enough current through the bell to cause it to ring, the one-microfarad condenser allowing the high frequency current to pass through it much more readily than the low. The operation of the two stations on the limb, *b*, of the line is the same.

The operation of the Leich system may be said to depend on a system of electrical tuning, the bell circuits at each sub-station being tuned to be responsive to either high or low frequency currents by means of the arrangement of condensers and impedance coils.

CHAPTER XXV.

MEASURED SERVICE.

METHODS of charging for telephone service are now the subject of much discussion, and it is not improbable that in the near future they will undergo general and radical changes. The plan that has been generally adopted is to charge the subscriber a fixed sum, payable monthly or quarterly, for the regular exchange service rendered, regardless of whether he uses his telephone much or little. Under this arrangement a subscriber who used his telephone once a day would be charged the same amount as one who used it fifty times a day. This is called the flat-rate plan, and its disadvantages have become more and more serious with the ever-increasing use of the telephone.

Besides being an inequitable arrangement, the flat-rate plan permits of the telephone being used for trivial purposes, which would not be the case if the subscribers knew that each message cost them a certain fixed amount of money.

Again, under the flat-rate plan people who have no telephone, and who cannot afford to pay the high rate usually charged for flat-rate service, make use of their neighbors' instruments, thus securing partial advantage of the telephone service without cost to themselves. This class of business, which has been properly termed "dead head," is disadvantageous to the operating company, because it is forced to supply operators and switch-board equipment for handling the increased traffic; and it is disadvantageous to those subscribers who do pay rental, on account of the time their line and instrument is used for handling business other than their own.

During recent years telephone companies have gradually awakened to the fact that to handle a telephone call and connection costs money; that the cost of operation increases with the traffic. Not only are more operators required when the average traffic on the lines increase, but a greater number of switch-board sections are made necessary in order to provide room for the increased number of operators. With a more complete realization of this condition, there has been a strong tendency toward supplying a different class of service under such conditions that the subscriber will pay in accordance with what he gets. This, of course, involves some plan of measuring the amount of service rendered the subscriber, so that the telephone business will be reduced to practically the same basis as to charge as that of gas and electric-lighting companies.

The problem of measuring telephone service is, however, a different one from that of measuring the number of cubic feet of gas, or the number of watt-hours used in electric lighting. The question to be solved first in the telephone business is, what is the proper commodity to measure. The simplest plan is to measure the number of times a subscriber makes a call, but this has the disadvantage of being inequitable, because many times the calling subscriber will not obtain a connection, owing to the fact that the subscriber called for is busy at the time, or that for some reason or other he does not answer. Seemingly a fair plan is to charge the subscriber for the number of successful connections obtained as a result of the calls he originates. This is the basis upon which most of the successful systems for measuring telephone service are based.

There have been those who contended that a subscriber should be charged not only for those calls he originates, but also for those calls he receives; but this plan does not work out to the satisfaction of the public, because a subscriber has no means of regulating the number of times he is called by the public, and there are few who would wish to place themselves in a position to pay for that over which they have no control. To charge on the basis of the number of calls received would be analagous to charging, in the postal system, for the number of letters received. Under certain circumstances, as in the case of a philanthropist, this might become a serious burden.

The first class of devices for measuring telephone service to be considered will be those which may be termed "coin-collecting devices," whereby the subscriber is made to pay as he goes, always depositing a coin in the collector before actually conversing with the party called for.

This has the advantage to the operating company of making collections in advance. Also, from the standpoint of the telephone company, and perhaps of the subscriber, it has the advantage of allowing the payments to be made in such small installments as not to appreciably burden even the poorest subscriber. Such devices are, however, subject to the disadvantage of requiring frequent visits to the premises of the subscriber to collect the money deposited, together with the incidental disadvantage due to the possibility of fraud on the part of the collectors and of the public.

Probably the simplest coin collectors are those which have no electrical connection whatever with the telephone or line circuits. These are, therefore, entirely mechanical in their operation, and are so arranged as to make a certain distinctive noise when a coin is deposited in the proper manner. This noise is transmitted to the head receiver of the operator at the central office through the transmitter at the subscriber's station in the same manner and over the same circuits as are used in speech transmission.

Among the strictly mechanical coin collectors is that manufactured by the Baird Manufacturing Company, of Chicago. An out-

FIG. 338.—BAIRD COIN-COLLECTING DEVICE.

side view of this is shown in Fig. 338. The box proper is of cast iron, provided on its lower front face with a door for allowing access to the coin box. Three slots appear in the upper front face of the box for the reception of 5, 10 and 25-cent coins, respectively. At the right of the box, adjacent to the slots, is a lever which, when pulled down after the insertion of a coin in a slot, sounds a gong or equivalent device, giving a significant noise, differing for each slot. By means of this the operator is notified by telephone that the coin of a certain denomination has been deposited. Pulling the lever down without depositing the coin does not make the required noise, the coin itself being necessary for the operation of the sounding device. In order to enable the operator to distinguish with as great a degree of certainty as possible, the sounds caused by the operation of the levers are made to differ as radically as possible. To this end the 5-cent lever when operated causes the striking of a deep toned gong, such as is used in cathedral clocks, this gong consisting of a coil of heavy steel wire. The 10-cent lever causes a rasping or buzzing noise due to the vibration of a steel spring, which strikes in its vibration against the side of the box. The operation of the 25-cent lever causes the striking of a high-toned gong, similar to those used in telephone ringers.

Should the coin be dropped by mistake into the wrong slot, as for instance, the nickel into the 25-cent slot, or the 10-cent piece into either the 5 or the 25-cent slot, or a penny into either of the last-named slots, no effect will be produced and the coin will pass through the machine and out at the pocket shown at the left-hand side of the cut where the depositor may reach it. All coins which are properly deposited are thrown by the operation of the lever into the coin box below, where they remain beyond the reach of the subscriber, and only accessible to the collector.

The door of the coin box is secured by an ingenious combination lock, requiring a very simple key for its manipulation, security being, however, dependent upon a proper knowledge of the combination rather than upon the shape of the key.

Several methods of attaching these collectors to telephone sets are shown in Fig. 339. At the right a heavy sheet-iron plate carrying the coin box is secured to the rear of the back board. In these purely mechanical coin collectors, care must be taken in installation to make as good as possible the conditions for conducting to the telephone transmitter the distinctive noises made by the deposit of coins. In the style of mounting shown at the right in Fig. 339 the conditions are improved by fastening the transmitter with machine screws passing through the wood of the telephone set and threaded directly into the iron plate holding the coin collector. In the center is shown a method of mounting, in which the transmitter, with a special bracket, is attached directly to the case of the coin collector. In this style of assembly, the noises are very plainly heard by the central office operator. An adaptation of this type of coin collector to desk portables is shown at the left of Fig. 339.

When one of these coin boxes forms a portion of a sub-station equipment the subscriber originates his call in the usual way, either by turning his generator crank in the magneto systems, or by removing his receiver from the hook in the case of a common bat-

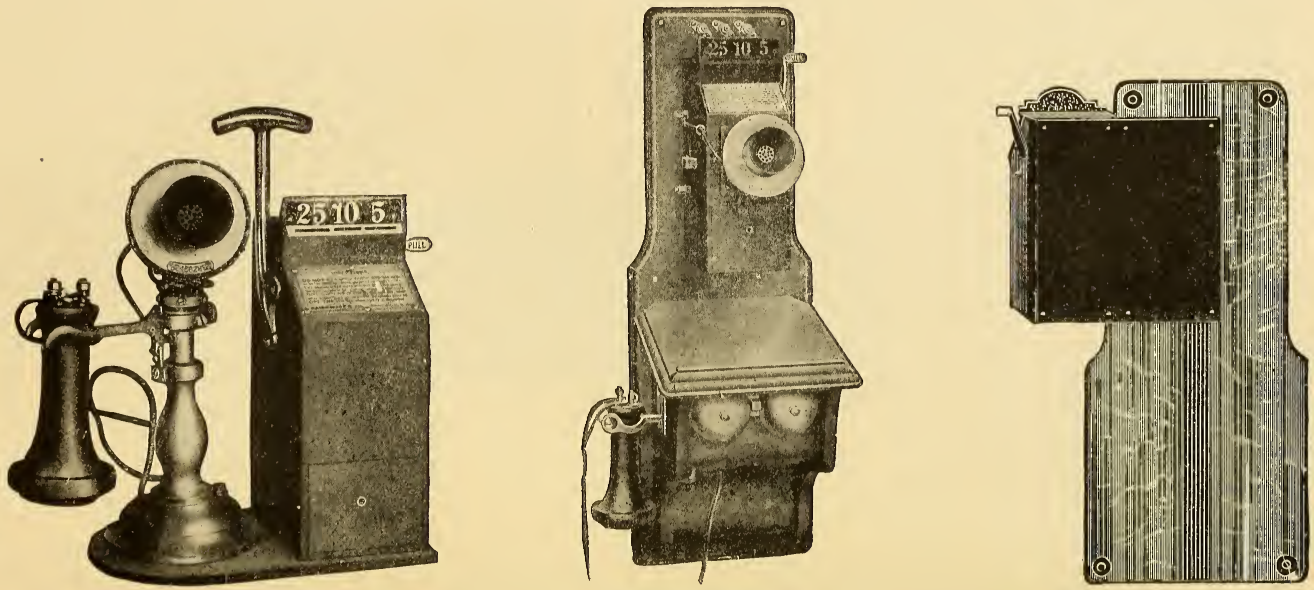


FIG. 339.—METHODS OF MOUNTING MECHANICAL COIN COLLECTORS.

tery system, and makes known to the operator the number of the subscriber with whom he desires a connection. The operator then makes the connection with the called subscriber, and upon securing his response notifies the calling subscriber to deposit a coin of the proper denomination. She is notified of his compliance by hearing the characteristic sound of that coin, after which she allows the conversation to progress.

An extensive line of purely mechanical coin-collecting devices is

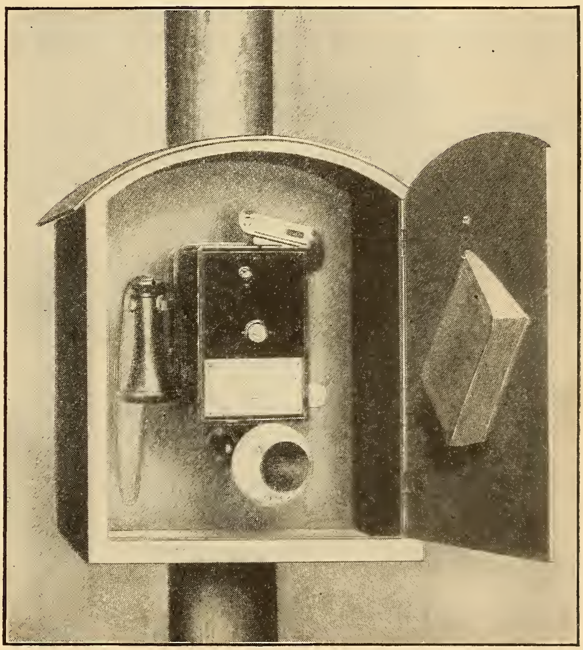


FIG. 340.—STROUD CONTROLLER FOR STREET SERVICE.

manufactured by the Gray Telephone Pay Station Company, of Hartford, Conn. In these, coins dropped through the slots are, if of the proper denomination, caused to strike against one or more gongs, the sound being transmitted to the operator as before. Some of these have been made with as many as five slots, corresponding to nickels, dimes, quarters, halves and dollars. Each coin when dropped through its proper slot strikes against the gongs underneath in such manner as to convey a distinctive signal to the operator. The code of signals in such boxes is: A single bell means a nickel; two bells a dime; one clock gong, 25 cents; two clock gongs, 50 cents, and a bell and rattle, $1.

Other devices have been used where the coin, after being dropped, closed a succession of electrical contacts, which, acting through the primary of the induction coil at the subscriber's station, caused a series of buzzes which may be distinguished by the operator.

In Fig. 340 is shown a public pay station, manufactured by the Controller Company of America. This is the design of Mr. Harold D. Stroud, and is adapted to street service, the box being of iron and weatherproof.

The coin-collecting devices so far considered have, as a type,

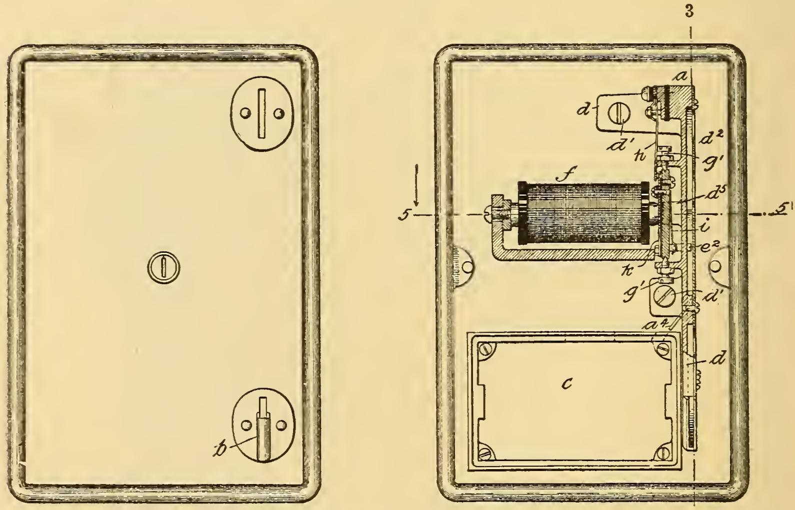
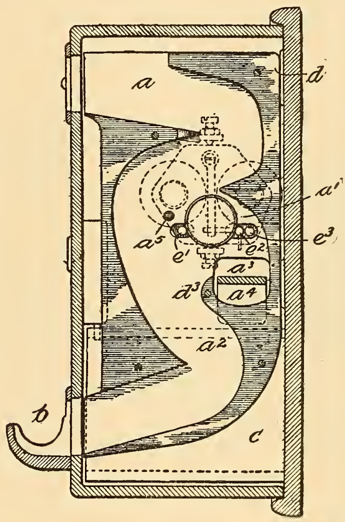


FIG. 341—SCRIBNER COIN-COLLECTING DEVICE.

the advantage of simplicity. All of these boxes, however, impose a duty upon the operator which necessarily tends to slow down her speed of working, thus producing what is called a "drag" on her work. The fact that the operator, after receiving a call, is required to obtain the proper connection, and then again place herself in communication with the calling subscriber before allowing the conversation to proceed, is a disadvantage which increases with the amount of traffic, and becomes a very serious matter in exchanges where the operators are already loaded with as much work as they can handle. More recent developments in the line of measured service have, therefore, aimed at a reduction in the drag on the operator. Without attempting to trace through the development by which coin-collecting devices for telephone stations have reached their present state of perfection, two systems and devices which are thought to represent the highest development in this class of work will be described.

The first of these is a box, designed by Scribner for the Western Electric Company, and used very widely among the Bell companies at present. The Chicago Telephone Company is now the foremost advocate of the measured service plan, and this company alone employs about 38,000 of these boxes in its Chicago exchange. While the particular box shown is the work of Scribner, many other

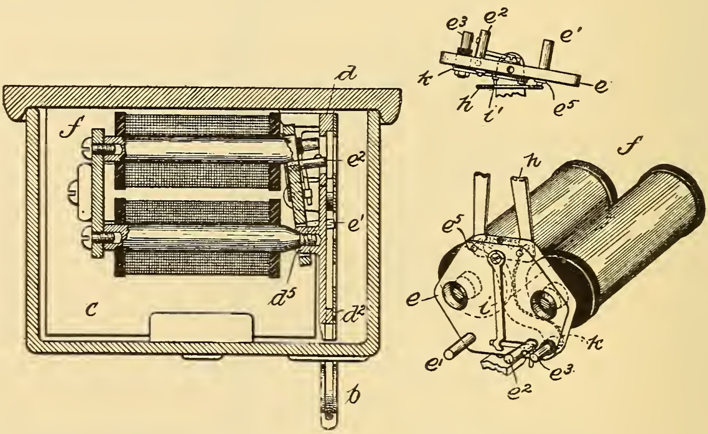


342.—SCRIBNER COIN-COLLECTING DEVICE.

of the Western Electric and Bell inventors did much of the preliminary work leading up to the type about to be discussed. Among these the work of O'Connell and Bullard is conspicuous.

The details of the Scribner box are shown in Figs. 341, 342 and 343. In the right-hand portion of Fig. 341 a front elevation of the box with its cover removed is shown, the cover with the deposit and return slots and key-hole being shown at the left of this figure. Fig. 342 shows a sectional view taken on the dotted line, 3-3, of Fig. 341. Fig. 343 is a sectional view looking from the top of the box, this being taken on the plane of the horizontal dotted line, 5-5, of Fig. 341. Fig. 343 also shows a perspective view of the coin-controlling magnets.

The upper slot in the cover of the box, shown in Fig. 341, leads into the portion, *a*, of the coin chute, shown most clearly in Fig. 342. The coin passes by gravity through the upper portion of this chute and is led to the rear of the box, and then, owing to the form of the chute, again toward the front of the box. Under normal circumstances it strikes against stationary pin, a^5, and rolls back into the positon shown in Fig. 342, resting between the pins, e' and e^2. These two pins are carried on the pivoted armature, *e*, of the electro-magnet, *f*, this armature being a flat piece of iron of approximately hexagonal shape, pivoted on its vertical axis by ordinary trunnion screws, which are shown most clearly in Fig. 341. The electro magnet, *f*, is polarized in much the same man-



343.—SCRIBNER COIN-COLLECTING DEVICE.

ner as an ordinary ringer, and therefore when its coils are traversed by a current in one direction the armature will be tilted so as to withdraw one of the pins, e' or e^2, from the chute and to push the other one further into it. A current in the reverse direction will tilt the armature the other way. As the deposited coin is supported in the chute under normal conditions by these two pins, it is evident, referring again to Fig. 342, that if the pin, e', is withdrawn, the coin will roll from its normal support and pass through the return chute, a^2, into the receptacle, *b*, on the front of the box. If, however, the pin, e^2, is withdrawn, the coin will roll in the opposite direction and will pass through the hole, a^3, and be guided into the cash box. It is obvious, therefore, that a current sent through the electro magnet, *f*, in one direction will return the coin to the user, while a current in the other direction will collect the coin.

If, while a coin remains lodged between pins, e' and e^2, a subsequent coin is dropped into the box, it will roll over the top of the first coin and thus pass over the pin, a^5, and to the left of that pin, as shown in Fig. 342, to the return chute. This prevents clogging of the box in case a coin remains undisposed of.

Referring now more particularly to the perspective view shown in Fig. 343, it will be seen that the pin e' is permanently fixed to the armature plate, *e*, while the pin e^2 is pivoted in the plate so as to swing sidewise. A spring, *i*, resting against a laterally projecting arm of the pin e^2 serves to keep this latter pin normally pressed toward the pin e'. When, however, a coin is lodged between the two pins, the pin e^2 is moved to the right so as to make contact with the pin e^3, which is insulated from the armature plate, but is in connection by the strip, *k*, with the spring, *h*, shown at the top of the figure. The spring, *h*, forms one terminal of the circuit, and the frame of the machine the other terminal, and this circuit is closed temporarily by the deposit of a coin.

The operation of this box will now be best understood by reference to Fig. 344, which shows the circuit of the subscriber's line, extending to a central office equipped with a multiple board of the well known Western Electric type. The only modification of the line circuit at the central office from that ordinarily employed is that the contact of the cut-off relay on the ring side of the line is left open and the contact on the tip side of the cut-off relay is connected to the line relay instead of being connected to ground. Two keys, *K* and *K'*, similar to ringing keys, are associated with the answering cord of each pair, as shown. At the subscriber's station, in addition to the ordinary common battery telephone set, the coin box is placed, the electro magnet, *f*, of this box being connected between the tip side of the line and ground. The circuit from the ring side of the line to the magnet includes also the pair of contacts, e^2, e^3, closed by the deposit of the coin.

A subscriber desiring to make a call does so, not by raising his receiver from its hook, but by dropping a coin of the proper denomination, usually a nickel, in the slot. This coin rests between the pins, e' and e^2, of the box, and closes the contact to ground through the magnet, *f*, as shown diagrammatically in Fig. 344. This completes the circuit through the line relay, using ground return, and the line lamp is lighted in the usual manner. The current flowing over the tip side of the line does not operate the magnet, *f*, in either direction because it is too feeble to do so.

In response to the line signal the operator inserts an answering plug, thus cutting off the circuit through the line signal by means of the cut-off relay. The operator then converses with the subscriber, calling in the usual manner, and completes the connection

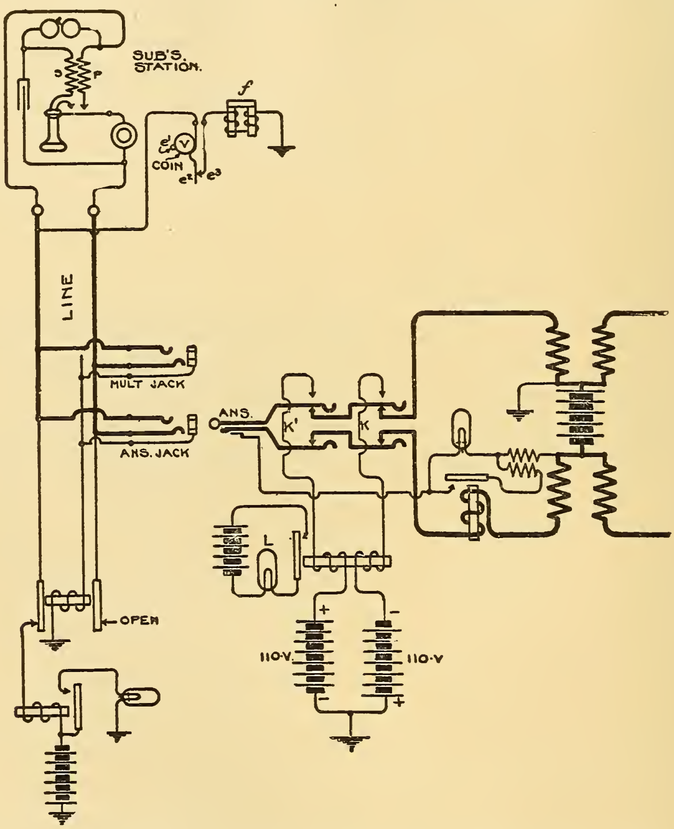


FIG. 344.—CIRCUIT OF SCRIBNER COIN-COLLECTING SYSTEM.

between his line and that of the called subscriber by means of the calling plug. When the called-for subscriber responds, the operator, noticing the going out of the calling supervisory lamp, presses the key, *K*, which interrupts the conversation between the two subscribers, if it has begun, and connects the negative pole of a 110-volt battery with the tip side of the line. The current thus flows from ground at central office, through this side of the line to ground through the magnet, *f*, of the coin device, which latter magnet is then actuated to withdraw the pin e^2 from under the coin, throwing the coin into the cash box. If, however, the called-for subscriber does not respond, or if his line is busy so that the operator cannot at the time make a connection with it, she depresses the key, K'' which connects the positive pole of the 110-volt source of current with the tip side of the line, thus causing current to flow through the magnet, f, in such direction as to withdraw the pin e' from

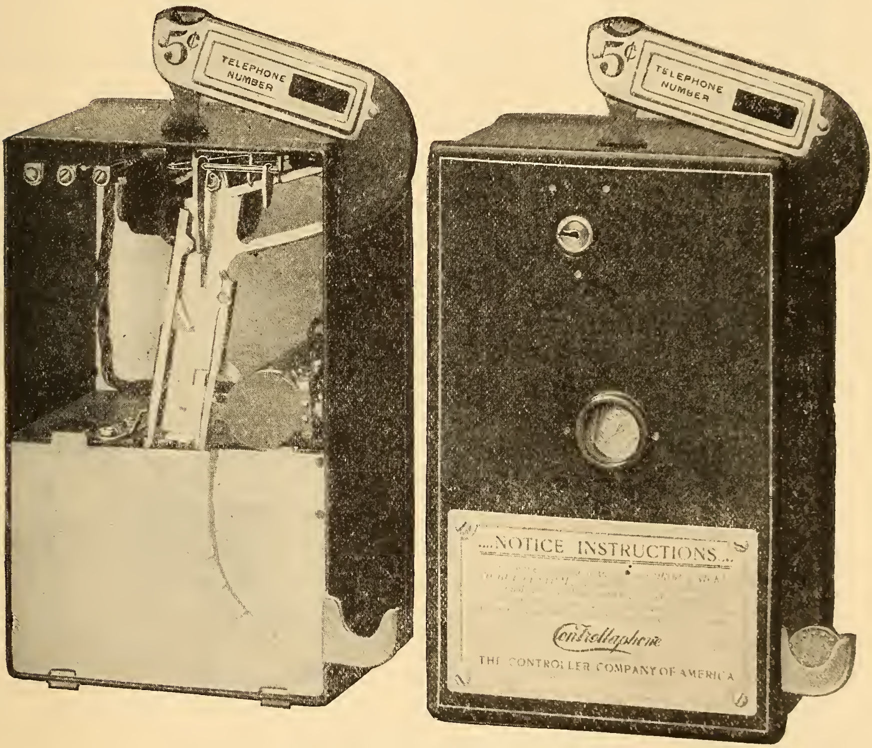


FIG. 345.—STROUD COIN-COLLECTING DEVICE.

beneath the coin, allowing it to roll into the return chute, and back to the depositor.

This device serves to measure the service on a strictly equitable basis, save for the fact that no discrimination is made between a long conversation and a short one, as a subscriber's money is returned to him in case he does not receive the connection for which he calls. The fact that the subscriber is forced to deposit his money before he can make the call is of great advantage from the standpoint of the operating company, for the operator knows that the coin has been deposited from the fact that a call was received. There is, therefore, a much less drag on the operator than if she were compelled to request the subscriber to deposit a coin. This device also insures the subscriber having the proper denomination of coin ready before he makes the call, which often causes much delay when the "request" plan of calling is employed.

As employed by the Chicago Telephone Company, however, the full advantages of this system do not seem to be obtained. As used by this company, the return side of the line is grounded at the cut-off relay, as usual, and therefore the subscriber calls central in the usual manner, that is, by raising his receiver from the hook. He drops his nickel when told to do so by the operator, immediately after telling her of the connection desired. After this the operation of returning or cashing the coin is the same as that already pointed out. The lighting of the lamp, L, when the operator presses in her key, K or K', shows the operator that the coin has been deposited, while its failure to light on subsequent pressure of the key, shows her that the circuit has been cleared.

In Fig. 345 is shown a coin-collecting device, designed by H. D. Stroud, of the Controller Company, which has the advantage over the Western Electric device of still further reducing the drag on the operator. In this the coin is deposited by the subscriber in order to make the call, and when so deposited it is arrested in its chute in front of a small glass window in the center of the cover. In this position the coin is held in view of the public until the next call is made. When the operator responds she completes the connection as called for by the subscriber in the usual way, and if the proper party is secured she has no duty other than would be imposed by the ordinary flat-rate service. The only contingency which may arise to require a special movement on the part of the operator is in case she does not secure the proper party, in which event she presses a key associated with the answering plug which operates the coin-controlling magnet to return the coin to the subscriber. In case the called-for party is secured, the coin is left in front of the window in the box, and is deposited by the falling of the next deposited coin. The electro magnet is not polarized, which is an advantage in the point of simplicity. The holding of the coin in front of the window also has a tendency to prevent the illegitimate use of slugs to operate the device, as the holding of the slug in view of the public until the next call is made is likely to expose the fraud. As by far the greater number of calls made are terminated successfully, it follows that in most cases the operator has no duties to perform in the operation of the Stroud device other than those imposed by ordinary flat-rate service. In the small percentage of calls, however, which are not successful, she presses the return button, which is the only extra duty imposed on the operator as the result of this service. This represents the highest

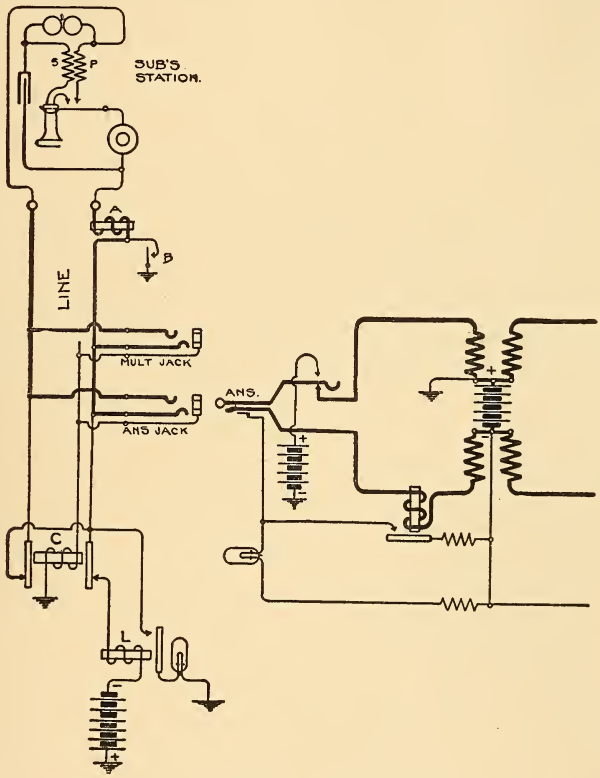


FIG. 346.—CIRCUIT OF STROUD COIN-COLLECTING SYSTEM.

development of coin-collecting devices that has been brought to the attention of the writer.

One form of circuit arrangement proposed by Stroud for use with his coin collecting device is shown in Fig. 346, this representing the system as applied to the Western Electric cord and line circuits. The restoring magnet, *A*, of the coin box is included in series in the line circuit at the sub-station, and for this reason it is made of low resistance and is provided with a heavy copper covering for the core and with heavy copper spool heads for the magnet winding.

By this construction the magnet is made to have a very low coefficient of self-induction so as not to materially interfere with the talking efficiency. A pair of contacts, *B*, is adapted to make a passing contact between the ring side of the line and ground when a coin is deposited in the slot.

At the central office the line circuit is so modified that the tip and ring side are normally connected together by means of the left-hand pair of contacts on the cut-off relay, *C*. The line relay, *L*, is connected permanently to the battery, the other terminal of its coil being connected to the ring side of the line through the right-hand pair of contacts of the cut-off relay. When the cut-off relay is actuated by the insertion of a plug by the operator the connection between the two sides of the line is broken, as is also the normal connection between the line and battery. The line relay is so connected as to have its coil included in its own local circuit with the line lamp and the right-hand pair of contacts on the cut-off relay. By this means the line relay locks itself up as soon as actuated by current flowing over the line, and then keeps the line lamp illuminated until the locking circuit is broken by the action of the cut-off relay.

In this system a subscriber may take his receiver off its hook without getting response from the operator until he has deposited his coin. The closing of the contact at *B* by the passing of the coin then completes a circuit from the live side of the battery through the line relay coil and thence over the two sides of the line in multiple to ground through the contact at *B*. Although the contact at *B* is immediately opened the line relay remains operated, thus keeping the line lamp illuminated until the response of the operator. If the subscriber desired is available and the connection made, the operator pays no more attention to the connection than she would in flat rate service, as she knows that the subscriber must have deposited his coin before he could light the line lamp. She knows also that the coin will be thrown into the cash box by the action of the next deposited coin. If, however, she cannot obtain the connection desired, she will depress the key, *K*, and thus by means of current from a 110-volt source cause the energization of the return magnet, *A*, at the sub-station. This magnet is too insensitive to be operated by current from the 24-volt storage battery.

In public telephone stations in a city, the traffic is well divided between city calls at 5 cents each, and suburban and long-distance calls involving larger amounts, which could be paid more conveniently in 10-cent and 25-cent coins. To use the simple mechanical machines described first in this chapter would entail an incidental delay and inconvenience on each local 5-cent call, while to use the electrical machines would require an attendant, say the druggist or clerk, to collect the larger amounts for toll line connections. Of the two conditions, the policy of the Chicago Telephone Company is to use the electrical machine generally, with exceptions in favor of the mechanical devices when an attendant for collecting the larger amounts is not available. For use at such stations Mr. David S. Hulfish has produced recently, for the Baird Manufacturing Company, models of coin collectors in which the electrical equipment for the rapid handling of local business is combined with the necessary slots and audible signal devices for collecting coins mechanically when required for suburban and toll line connections, the electrical features being such as to work indiscriminately with single-slot machines of the Western Electric or Stroud types described.

There is obviously another general method for charging for telephone service in proportion to the use of the telephone, than by the collection of coins or tokens at the subscriber's station. Meters may be employed which automatically keep a record of the number of times that the telephone is used, and these meters may be placed either at the subscriber's station or at the central office.

Considering first the placing of a meter at the subscriber's station, it may be said that the problem is very similar to that of collecting the coins, differing only in that some other function on the part of the subscriber than that of dropping a coin is used to operate the meter. A device has been produced by William Gray, of the Gray Telephone Pay Station Company, which operates on the same general plan as the Baird coin collector except that, instead of dropping a coin and pulling a lever as in the Baird and other similar devices, the subscriber, when told to do so by the operator, inserts a key into a keyhole in front of the box and turns it. The turning of the key not only operates the meter to register one count, but also trips a lever carrying a hammer which strikes a gong, and this notifies the operator by sound that the meter has been actuated. This meter has no electrical connection whatever with the system, its entire function being mechanical.

In another device manufactured by the Gray Company no key is required, the subscriber merely pressing a button on the front of the box when told to do so by the operator, this action ringing the bell and registering one count on the meter. One of these devices is shown in Fig. 347. The method of securing this to a portable desk stand is shown in Fig. 348.

These devices are simple and effective, but are subject to the same disadvantages as those coin collectors which have no electrical connection with the central office, the principal one of which is the amount of attention required by the operator to assure the proper registration of the meter. This fault is largely remedied in a class of meters which, like the Scribner and Stroud coin collectors, are partially controlled by the central office operator.

Prominent in this class is the device of H. V. Hayes, which

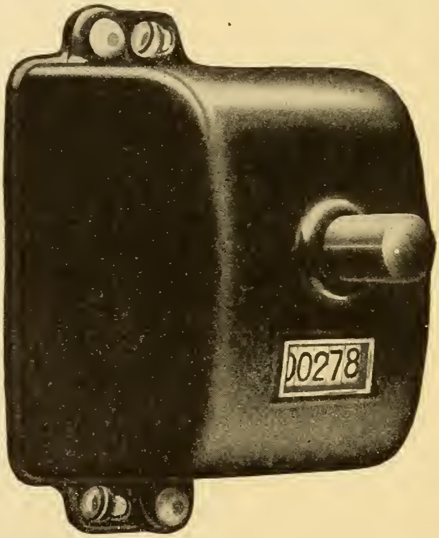


FIG. 347.—GRAY PUSH-BUTTON METER.

consists of an electro-magnetically operated meter placed at each subscriber's station, the operating coil of the meter being placed in a bridge of the telephone line which includes the talking apparatus. This device is adapted to use on common battery lines, and therefore the coil of the meter receives current whenever a subscriber removes his receiver from its hook for the purpose of sending a call. One impulse of the armature lever, however, will not affect the registration on the meter dial. In order to cause a registration, therefore, two impulses are required, one in one direction and one in the other, these impulses always occurring in the same order. For accomplishing this, the armature of the controlling magnet is polarized so as to move in one direction when the coil is traversed by a current of one polarity, and in the other when the current flows in the opposite direction. The source of current normally in the line which operates the line relay when a subscriber removes his receiver from its hook is of opposite polarity from that which is placed in the circuit with the line when a plug is inserted for completing a call. The first impulse received by the meter when a subscriber makes a call is therefore due to the current which flows through the line upon the raising of the receiver from its hook. This current places the meter into such position that a call will be registered when the

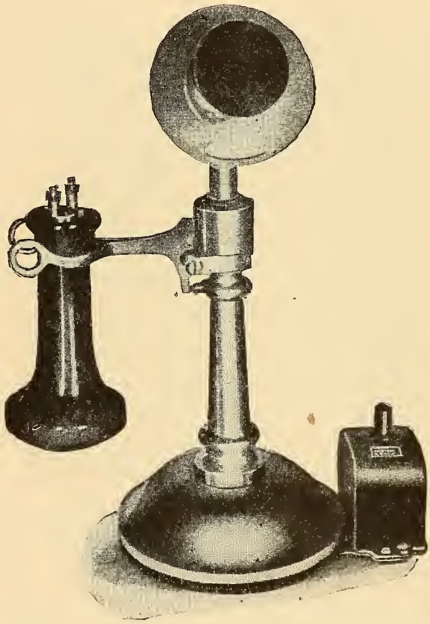


FIG. 348.—METHOD OF ATTACHING GRAY METER TO DECK-STAND.

meter lever is moved in the opposite direction, and this occurs when the operator answers the call in response to the signal, as current then flows from the cord circuit through the meter coil in the opposite direction. The meter does not operate on a called line because then only the current from the cord circuit battery flows through the meter coil, which cannot operate the meter because no preliminary current from the line battery has been sent through the coil.

This system of Hayes has the disadvantage of registering a count for every call that is answered by the operator, and thus all calls which are not successfully terminated on account of the called line being busy, or out of order, or on account of the non-response of the called subscriber for any reason, are charged. It has the advantage, however, of producing no drag on the work of the operator. Moreover, it is clearly adaptable to use on common battery party lines.

Later devices have been so arranged that only a successfully terminated call is charged for, this being accomplished by having the operator send the required second impulse through the meter by pressing a key after the subscriber called for had responded. This relieves the system from the defect of charging for calls other than those successfully terminated, but has the same disadvantage as to the drag on the operator as that found in the Scribner coin collector.

Mr. Stroud has in a large measure remedied this difficulty by having the meter register all calls whether successfully terminated or not. In order, however, to prevent false charges, each meter is provided with a magnet under the control of the operator which when energized serves to turn the meter back one count, thus crediting the call. This device has the advantage of requiring special work by the operator only when the call is not successful. With this scheme party lines could be indiscriminately equipped with Stroud meters, or coin collectors, and the operation, so far as the central office was concerned, would be identical in each case.

The external appearance of this meter is shown in Fig. 349, and its operation is as follows: In order to call the central office the subscriber pushes the button shown at the top of the meter-box, which performs the same function with respect to the line circuit as does the dropping of a coin in the slot of the Stroud Coin Collector—that is, it closes the circuit to ground which causes the line relay to pull up, thus lighting the line lamp. The coil of the line relay is included in the local circuit of the line lamp so closed, and therefore the line relay remains locked until released by the action of the operator in plugging into the jack in response to a call. The making of a call in this manner registers one count on the meter, the record being in plain sight of the subscriber. If the connection called for by the subscriber is obtained the operator has no other duties in handling it than in the ordinary flat-rate system. If, however, the call is not successfully terminated the operator presses the button in the answering cord circuit which operates the credit magnet in the meter-box, which subtracts one count from the registered number. A modification of this method of crediting for an unsuccessful call is employed by the later meters devised by Mr. Stroud. In this no arrangement is made to turn the counter back, but the equivalent result is accomplished by so arranging the mechanism that the register will not record a count when the subscriber makes his next call. In other words, after an unsuccessful call, the subscriber is entitled to a free call. In order to satisfy the subscriber on this point, a small round hole at the left-hand portion of the front of the box is provided, at which a white disc is displayed whenever the subscriber is entitled to a free call as the re-

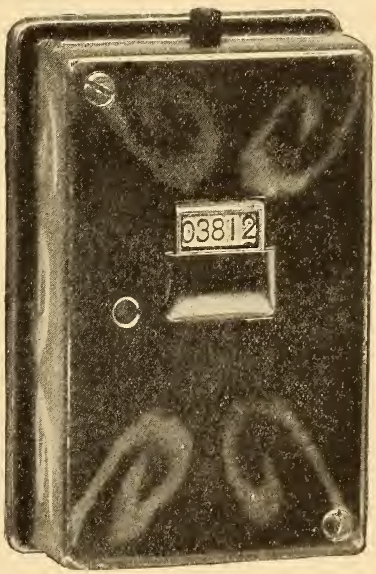


FIG. 349.—STROUD CREDITING METER.

sult of his last call having been unsuccessful. This free call attachment is, of course, controlled by a key in the cord circuit at the central office, used only by the operator in the case of an unsuccessful call.

Several methods of operating meters at the central office have been proposed. Probably the first was to provide in connection with each line an electro magnetic counting device, the coil of which was included directly in the line circuit or in the local circuit of the line relay, this being caused to record one count whenever a subscriber made a call. This has the obvious disadvantage of subjecting the subscriber to the condition of over-charging himself without being aware of so doing. For instance, the moving of his hook up and down in an attempt to attract the attention of the operator before a connection has been made with the line would record not one but perhaps many counts. As a remedy for this defect it has been proposed to operate the meter in connection with the cut-off relay at the central office. By this means it is evident that a subscriber by manipulating his hook can produce no effect upon the meter, which would be operated only when the operator inserted the answering plug in response to the display of the line lamp. In such cases the meter, in connection with the cut-off relay of the called line, could be prevented from operating by having the current in the calling cord of opposite polarity from that in the answering cord, the meter magnets being polarized. This practice, however, was subject to the same disadvantage as was pointed out in connection with the Hayes meter, as applied to sub-station apparatus, that is, that all calls answered by the operator were counted rather than the successful connections. Another disadvantage of less importance was that the meter, being entirely under the control of the operator, could be manipulated by her at will, and by inserting or withdrawing her plug a few times she could register more counts on the meter than should properly be charged.

Mr. George K. Thompson has proposed a system which has been put into operation to some extent by the Bell companies, which makes the action of the register dependent upon the conjoined action of the subscriber and operator. The method of applying this device to the ordinary Western Electric line circuit is shown in Fig. 350. The meter shown has two operating coils, *A* and *B*. The coil *A* is placed in parallel with the line lamp, *D*, in such manner as to be energized whenever the line relay, *C*, is energized to indicate a call. The coil *B* of the meter is placed in multiple with the coil of the cut-off relay, *N*, so as to be operated by current from the third strand of the cord circuit whenever a plug is inserted into a jack.

The meter is so arranged as to register a count only when the armature, *b*, of the magnet *B* is operated, and this armature cannot be operated until the armature, *a*, of the magnet *A* has been moved out of its way. If the magnet *B* is operated alone, as is the case when a plug is inserted into a jack of a called line, the meter, therefore, will not register a count because the armature *b* is prevented from moving by the presence of the armature *a* in its path. For this reason a call will not be registered on the meter of a called-for line. The armature *b* carries a pawl which engages a ratchet-wheel, properly connected with the train of counters, which wheel is moved one notch by every attraction of the armature, *b*, of the magnet *B*. In order to prevent the armature *a* from falling back into the path of the armature *b*, when the operator inserts the answering plug into the jack of a line upon which a call is being made (due to the opening of the circuit of the magnet *A* by the releasing of the line relay due to the action of the cut-off relay), the armature

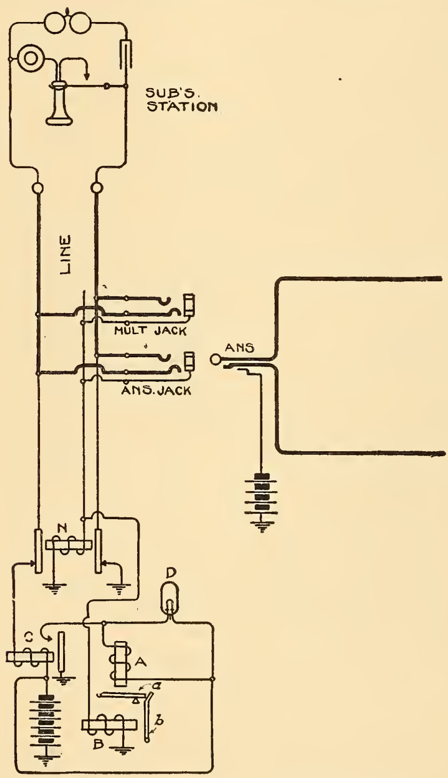


FIG. 350.—THOMPSON METER SYSTEM.

a is made sluggish in its movements, so that the armature *b* will always have time to complete its stroke before the releasing of the armature *a*.

This device, it will be seen, is subject to the defect that it records a count on the meter every time the operator inserts the plug in response to a call, whether or not the connection desired is finally secured. As a remedy for this defect, Mr. Thompson produced another system, using the same type of meter, but instead of making the operations of the magnet *B* depend on the insertion of the answering plug into a jack it was made to depend on the action of the calling supervisory relay of the pair of cords used, so that instead of registering when the answering plug was inserted in response to a call, as in the system shown in Fig. 350, the count would be recorded only after the calling plug had been inserted and the called subscriber had responded. This involved a somewhat com-

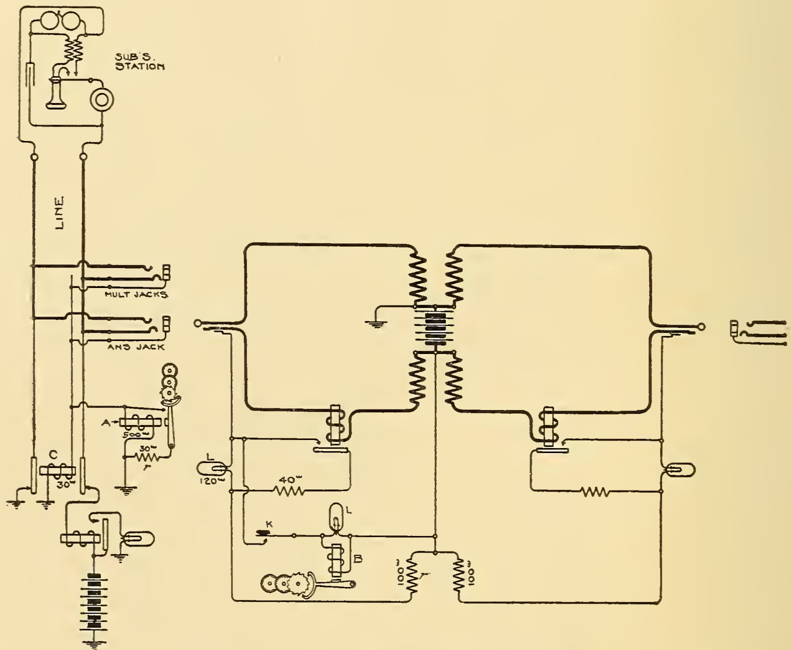


FIG. 351.—SCRIBNER METER SYSTEM.

plicated and probably unsatisfactory condition of circuits depending on marginal resistances for securing the operation of the meter, and has probably never been put into extensive practice.

The Bell companies are using, to some extent, a measured service device system, produced by Scribner, employing meters at the central office in connection with each line wherein the operation of the meter is secured by pressing a push button key associated with the answering cords. In this case the meter has a single magnet which is placed in multiple with the cut-off relay in the lead from the sleeve contacts of the jacks to ground. The circuits of this system are shown in diagram in Fig. 351. The line circuit will be recognized as that of the standard Western Electric Company's common battery system, with the exception that the meter coil, *A*, is placed in multiple with the cut-off relay, *C*. The meter armature when attracted is adapted to close the shunt circuit about the meter coil and about the cut-off relay coil, this circuit including the resistance coil, *r*.

The cord circuit is the same as that used in the ordinary Western Electric system with the exception that a push button key, *K*, meter coil, *B*, and a lamp, *L'*, have been added to the circuit of the answering cord. When the circuit, including the meter coil, *B*, and the lamp, *L'*, in multiple, is closed by pressure of the key, *K*, in the answering cord circuit, a shunt circuit is established around the regular supervisory lamp, *L*, and the usual resistance coil, *r'*, thus allowing a strong current to pass through the third strand of the cord to ground through the coil of the cut-off relay, *C*, and of the meter, *A*. In operation this system is as follows:

A call is made by a subscriber in the usual manner by the operation of the line relay and the illumination of the line lamp. In answer to such a call the operator will insert the answering plug, thus allowing the current to pass through the coil of the cut-off relay, *C*, to ground in the usual manner. A part of this current also passes through the magnet, *A*, of the line meter, but on account of the high resistance of this coil this current is not strong enough to cause the operation of this meter. The operator then proceeds in the usual way to obtain the called subscriber, and if successful presses the key, *K*, belonging to this cord circuit, thus allowing a strong current to flow through the third strand of the cord, which, in this case, is of sufficient strength to cause the operation of the line meter.

The meter, *B*, in the cord circuit is common to all the cords of an operator's position, and is of very low resistance. The shunt, *r*, around the line meter coil is for the purpose of reducing the resistance of the circuit through the meter, *B*, to a sufficient extent to allow the operation of this meter and of the lamp, *L'*, after the line meter has been actuated. This meter, *B*, is for the purpose of assisting in making peg counts and also in checking the records of the line meters. It is obvious that the sum of the meter readings of all the cord circuits should agree with the sum of the recorded counts on the line meters in a given time.

The meter used for this purpose is now manufactured by the

Western Electric Company as shown in Fig. 352. In this the coil, *A*, is wound on a long core which has a magnetic return through the side arms forming the meter frame. The armature is pivoted between these arms and has a long stroke. It engages by means of the small pawl and ratchet a train of gears belonging to the counter. The shunt coil, *r*, of Fig. 351 is wound on the same spool as the meter core, its circuit being completed by the pair of contacts

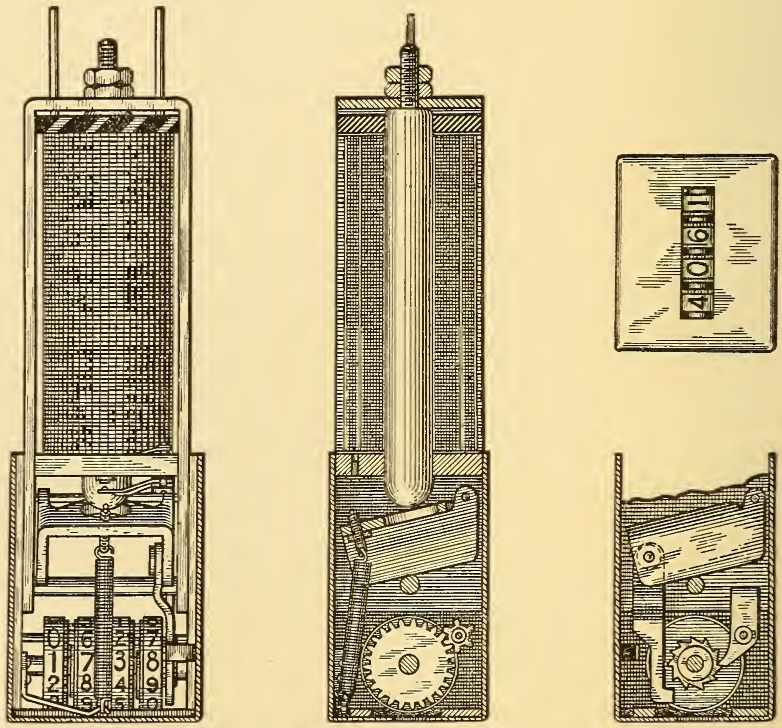


FIG. 352.—WESTERN ELECTRIC CONNECTION METER.

closed by the action of the armature. When the armature is attracted very little current is required to retain it, and therefore the armature does not fall back, even when the shunt circuit is closed about it.

This circuit seems to be extremely objectionable on account of its marginal action. It would seem better to use a higher voltage source of current than that of the 24-volt battery for operating the meter in order to reduce this defect.

CHAPTER XXVI.

TOLL SWITCH-BOARD SYSTEMS.

THE methods of handling switch-board connections over long-distance lines has undergone a radical change since the advent of common battery working, and it is only within the last few years that anything like standard practice in this line has been achieved. The problems involved are much more complex than those in making connections between the subscribers in a single city, as a greater number of operators are necessarily required to make a connection than when the connection is of a purely local nature. One great factor in efficient toll service is to keep the toll lines themselves effectively busy during as great a portion of the time as possible, and by *effectively* busy is meant busy in such a way as to enable their use to be charged for. In a toll or long-distance system the greatest investment, as a rule, is in the toll lines themselves, and as the revenue for any conversation depends, after a rate between points has been fixed, on the length of time the conversation lasts, it follows that the greater the use of the lines the larger will be the revenue. It is, therefore, of no little importance to so arrange a system that as little time as possible shall be lost in making up the connection between two subscribers in order to bring them into actual conversation, and after the conversation, in taking down the connection and leaving the lines free for other use.

Still another point in the design of toll systems is to so arrange the duties of the various operators that the work of the regular operators in the city exchanges shall be interfered with as little as possible. The work of these operators should be for all practical purposes standard, and their signals should be so arranged that when a toll connection is called for by a city subscriber, or vice versa, their operation will be interpreted by them in the same way, as far as possible, as if the connection were of a purely local nature.

As the duration of the connection determines the amount of charge for a conversation, it becomes necessary to accurately determine and record the time which elapsed from the moment the two subscribers were actually brought together for conversation until they finally released the line. This involves a duty not found at all in local work.

For all of these reasons it has become standard practice for the local operators, and by local operators is meant the A and B operator, in an exchange where trunking is used, to have as little to do as possible with the making up of toll connections, this work being assigned to special operators skilled in this particular work, and who have no responsibility whatever as regards purely local connections. Very briefly stated, the methods at present employed in handling toll connections in connection with large city exchanges are as follows:

A separate toll board is provided which may or may not, according to circumstances, be located in the building in which the city exchange is located. Two classes of operators are employed at the various positions of the toll board, which may be called "toll-line" and "toll-recording" operators. The various toll lines extending from the office to the offices of distant cities, and to the various toll stations scattered throughout the country, terminate in this toll board in much the same manner as subscribers' lines in the magneto multiple switch-board—that is, each line terminates in an answering jack and magneto drop in one section, and has a multiple jack in each section of the toll board. The answering jacks and drops are apportioned among the various operators in accordance with the amount of traffic on the various lines, the number handled by an operator, however, being very much smaller than in local work, ranging from 4 to 20 lines in accordance with the amount of traffic on these lines. The recording operators occupy other positions at the toll board, they being provided with no toll-line answering jacks or drops, but usually having in front of them multiple jacks of all the toll lines. The purpose of this is to make it possible for the recording operator to handle the entire toll business from her position at night. The recording operators' positions are provided with trunk lines, terminating in jacks and lamps. These trunk lines extend to the multiple switch-board, where they appear as multiple jacks in each section.

It is the duty of the recording operators to receive orders from local subscribers for long-distance connections, but they have nothing to do with calls coming in from toll stations for local subscribers or for other toll stations.

In order to enable connections to be made between toll and local subscribers one or more positions are provided on the local multiple board, in front of which the multiple jacks of subscribers' lines appear in the same manner as in front of the regular subscribers' positions. These are called "toll-switching" positions, or "toll-trunk" positions, and between them and the toll board extend trunk lines called toll trunks, by means of which the final connection between the local and the long-distance station is actually made, regardless of whether the connection originates at the toll or local station. These toll trunks are terminated at the toll-switching positions in plugs and cords, so that a toll trunk may be connected with any local line by merely inserting the plug into a multiple jack of that line. At the toll board the toll trunks terminate in jacks multipled generally once in each section. The arrangement in this respect is much the same as that between the outgoing trunk-jacks at the "A" operators' positions and the incoming trunk plug at the "B" operators' positions, in purely local work. When a local subscriber desires a long-distance connection his call is answered by the "A" operator in the ordinary manner. In response to his request for long distance, the operator connects his line with one of the recording operators' trunks leading to the recording operators' positions at the toll board. The "A" operator has nothing more to do with the connection until the supervisory signals tell her by the usual code to pull down the connection. The subscriber's line is now connected over a recording trunk to one of the recording operators' positions, and the recording operator at that position has her attention drawn to the fact by the lighting of the signal of that trunk line. She therefore plugs into the jack belonging to that line, and switching her telephone into circuit, obtains from the subscriber the number or whatever data is necessary, of the party with whom he wishes to converse, as well as his own number and name. It will be seen, therefore, that, aside from the fact that it is necessary for her to ring, the local subscribers' operator has nothing more to do with the connection than to connect the calling subscriber with the recording operator in the same manner as that adopted in connecting him with another subscriber in the same exchange.

The recording operator places the required data for connection on what is called a "ticket," which she passes to a toll operator, who proceeds to find the called-for party if the toll line with which the connection is to be made is not in use. Meanwhile, the local subscriber may be told by the recording operator to hang up his receiver and that he will be called, or he may be held waiting, as is deemed desirable. In case his line is released, the cord circuit is disconnected in the "A" operator's position, the act on the part of the subscriber of hanging up his receiver displaying the answering supervisory signal, while the act of the recording operator of disconnecting from the calling trunk will display the calling supervisory signal, the two signals conveying to the "A" operator the order to pull down the connection.

When the toll operator succeeds in obtaining a connection with the called-for party on the toll line she communicates by order-wire with the toll-switching operator at the local board and tells her the number of the subscriber's line with which connection is to be made. The switching operator in return designates the number of the trunk to the toll operator and inserts the plug of that trunk into the multiple jack of the subscriber who originated the call. At the same time the toll operator completes the connection between the toll trunk designated and the toll line by means of a pair of cords. Some systems are arranged so that the toll operator rings the local subscribers, while in others this work falls to the lot of the toll-switching operator at the local board. The former method is preferable. By means of an automatic time-stamp the time when the two subscribers are thus brought together is stamped on the toll ticket by the toll operator, and at the end of the conversation the time is again stamped on the ticket, thus showing accurately the duration of the conversation.

When the local subscriber hangs up his receiver at the termination of a conversation he either lights a lamp in the toll operator's cord circuit or throws the clearing-out drop, depending upon the system. The toll subscriber gives the clearing-out signal by turning the generator crank in his telephone, thus throwing the drop in the cord circuit. No signal whatever is conveyed to the toll switching operator until the toll operator pulls down the connection, which act lights a disconnect lamp in connection with the toll trunk, whereupon the toll trunk operator pulls down the connection and leaves the subscriber's line free.

Connections in the reverse direction, that is, connections wherein the call originates on the toll line for a connection with a city subscriber, are not participated in by the recording operator nor by any of the subscribers' operators. Such a call coming over the toll line is answered directly by the toll operator, who plugs into the line in response to the falling of the line drop. From the information obtained she makes out the ticket and then proceeds to order up the connection at the toll switching position in exactly the same manner as already described. The clearing out is, of course, done in the same manner as when the connection originated on the local subscriber's line.

This is a brief outline of the operation of the most modern toll system stripped of its details. There are many minor modifications of this plan, some of which will be pointed out in considering the actual circuits employed in toll work in the remaining portion of this chapter.

To give anything like a comprehensive description of the various toll circuits in use in this country as supplied by the various manufacturers, is totally out of the question and would, in fact, be largely useless, as the practice among many of the independent manufacturers is changing so rapidly as to call for a new system in every installation. The practice of the Bell companies may be considered as representative of the best thought on this subject, and from among the various systems installed by these companies during the past ten years, three stand out conspicuously. These three, which the writer has, for the sake of convenience, arbitrarily referred to as systems A, B and C, will therefore be described as typical of the development of toll system circuits since common battery work became well established.

System "A" differs from system "B" mainly in that only two wires are required in a toll trunk extending between the toll-switching operator's positions at the local multiple switch-board and the toll board. In system "B" three wires are employed in each of these toll trunks. In systems where the local board and the toll board are in the same building, it makes very little difference whether two or three wires are required in the trunks between the toll and local boards, but where these boards are widely separated, as is often the case, the toll board being in some outlying part of town in a position where the toll lines may be brought to it with a minimum use of underground cable, the requirement of three wires extending from the toll board to the local board would be a serious drawback.

System "A" requiring only two wires, was therefore designed for relieving this difficulty, while system "B," requiring three wires for the trunk, has been used only where the two boards were located in the same building or very close together. The circuit of the toll trunk line extending between the toll-switching operator at the multiple board and the various multiple jacks on the toll board is shown in Fig. 353. This circuit, it will be seen, terminates at the toll-switching operator's position in a cord and plug, being provided with the usual ringing keys which may be of any ordinary type for either manual or automatic ringing, according to the necessity of the case. This plug and cord circuit terminates in one half of a repeating coil, between the center points of which is bridged the battery for feeding current to the local subscribers' lines. The supervisory relay, *A*, is included in the ring strand of the cord, the function of this relay differing, however, from that of the usual cord circuit supervisory relay, as will be pointed out.

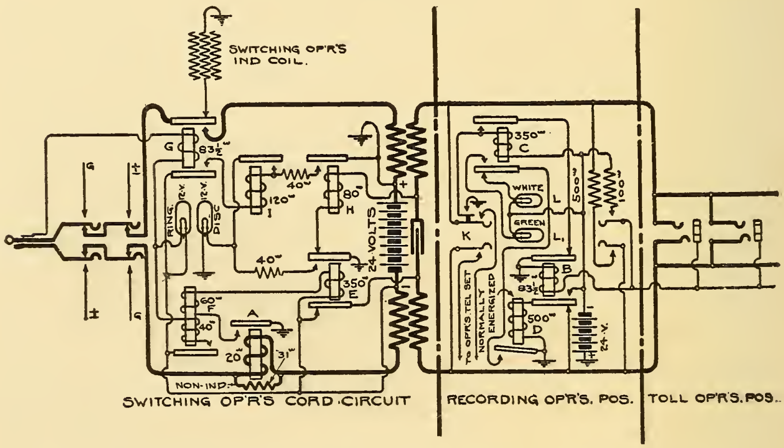


FIG. 353.—WESTERN ELECTRIC TOLL TRUNK LINE, SYSTEM A.

The two wires of the trunk line extending between the common battery office terminate in the second half of the repeating coil at the toll-switching operator's position. Between the center points of this half of the repeating coil is bridged a condenser which, however, under certain conditions, is adapted to be shunted by the action of several of the relays, as will be described. At the toll switchboard the trunk line passes through a multiple jack at each of the toll sections, but ordinarily no such jack is provided for the trunk line at the recording operator's positions. These jacks are provided with test rings which are connected to ground through the cut-off relay, *B*, in the same manner as the test rings of the jacks on the local line. When, therefore, a connection is made with a trunk line at one of the toll sections, this relay *B* is operated by the battery of the cord circuit and remains operated as long as the plug is so inserted in the jack. The test rings of the toll trunk line are thus made to test busy during such a connection in the same way as in a local line. The various relays and other apparatus associated with the two ends of the toll trunk line will be more fully described in connection with Fig. 354, which shows a local subscriber's line connected through the toll-switching operator's position, the toll trunk extending to the toll board, thence through the toll operator's cord circuit to the toll line which is shown at the right-hand end of the figure. Assuming that the local subscriber originates a call and desires a toll connection, this call will be answered by his "A" operator in the usual manner. Learning that a toll connection is desired, the subscriber's operator will press the button of an order-wire leading to the toll-switching operator's position and will order up the toll trunk connection specifying the number of the subscriber who made the call. Upon receiving this order the toll-switching operator will take up the plug of an idle toll trunk and insert it into the multiple jack of the called subscriber, disregarding the fact that this line tests busy on account of the presence of the "A" operator's answering plug in the answering jack of the line. The "A" operator, after this connection is made, will withdraw the answering plug from the jack and will have nothing more to do with the connection. The insertion of the toll trunk plug into the multiple jack of the subscriber's line will connect that subscriber's line through to the toll board, and since the calling subscriber still has his receiver off its hook, will cause the lighting of the lamp, *L*, having a white cap, at the recording operator's position. The means by which this is brought about may be described as follows: The circuit of the white lamp, *L*, at the recording operator's position is controlled at the back contact of two relays, *C* and *D*. The relay *C* is normally de-energized and therefore keeps its contact in the circuit of the white lamp closed. The relay *D* is, however, normally energized and therefore keeps the circuit of the white lamp open. The circuit over which the relay *D* is normally energized may be traced from ground at the recording operator's position through the coil of this relay, thence from the back contact of the relay *B* over one side of the trunk line to the toll-switching operator's position at the multiple board, and thence through one winding of the repeating coil through the back contact of the relay *E*, to the non-grounded side of the battery. This flow of current continues at all times except when the trunk

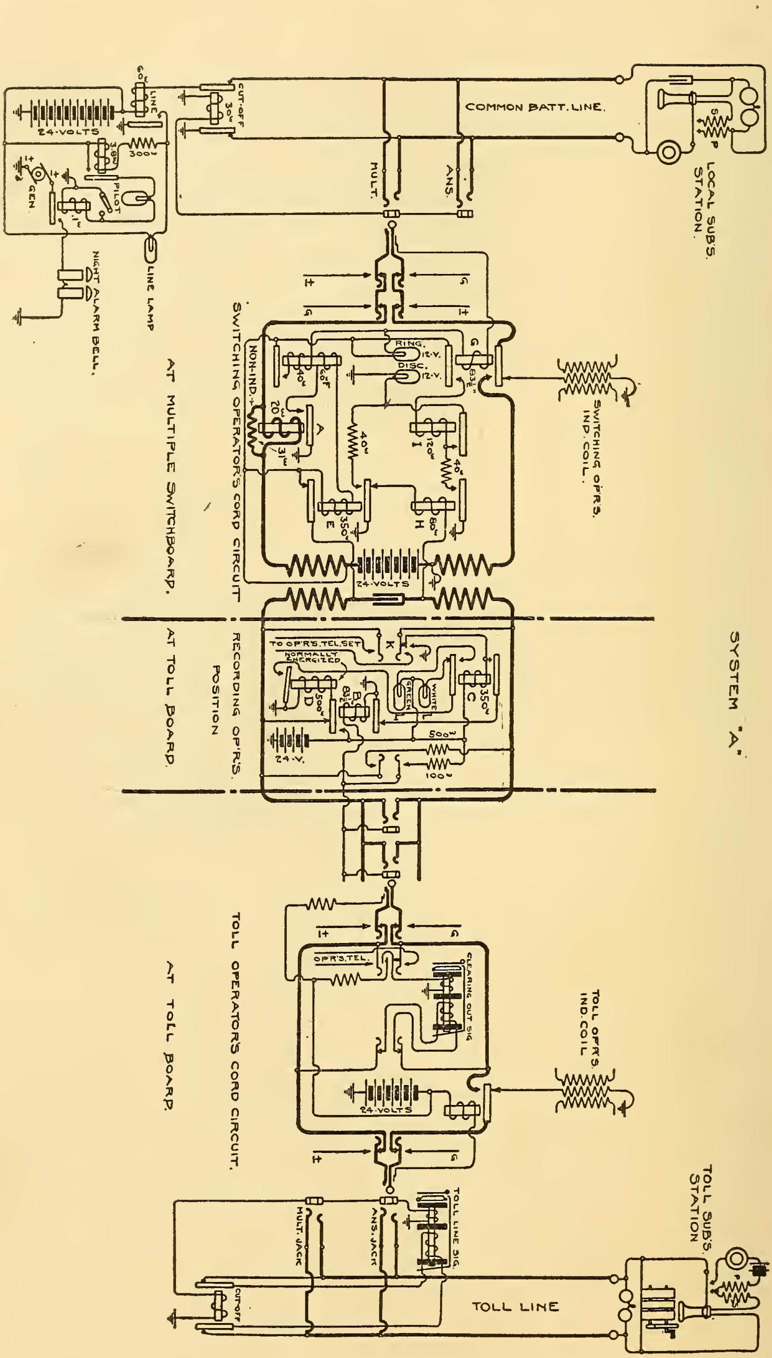


FIG. 354.—COMPLETE WESTERN ELECTRIC TOLL CIRCUIT, SYSTEM A.

line is in use and therefore the energization of the relay *D* normally holds the circuit of the white lamp open. When the toll-switching operator plugged into the multiple jack of the subscriber's line the flow of current took place through the relay *A* over the metallic circuit of the subscriber's line, since the calling subscriber had its receiver off its hook and thus caused this relay to attract its armature, thus closing the circuit through the relay *F* and the relay *E* from ground to battery. The operation of the relay *E*, which was thus caused, opened the normally closed circuit of the relay *D*, allowing its armature to drop back and thus lighted the white lamp. Upon seeing the white lamp lighted the recording operator will connect her telephone across the circuit of the trunk line by means of her listening key, *K*, and thus be enabled to converse with the calling subscriber over the combined circuit of the toll trunk line and the subscriber's line. From the information thus obtained the operator makes out the ticket, giving the proper data for completing the connection and passes it to a toll-line operator. The act of listening in on the trunk line on the part of the recording operator will cause the operation of the relay *C*, through the back contact of which the circuit of the white lamp extends. The operation of this relay therefore extinguishes the white lamp but lights in its place a green one, *L*, the circuit of which also passes through the back contact of the relay *D*. When the recording operator restores her listening key she will not extinguish the green lamp because the relay *C* is self-locking, it carrying an additional armature which, when closed, completes the circuit from the coil of the relay through the back contact of the relay *B*. The purpose of furnishing two lamps at the recording operator's position is to make it impossible for the recording operator, after she has answered the call and before the toll operator has taken up the connection, to forget that she has already responded to the lighting of the white lamp and again speak to the subscriber. If one lamp only were furnished, it would necessarily have to be arranged so that it would relight when the recording operator threw her listening key back into its normal position. Otherwise there would be danger that the trunk and the subscriber's line would be "held up."

The toll operator having received the ticket from the recording operator will insert the answering plug of the toll-cord circuit into the multiple jack of the toll trunk line. This will extinguish the green lamp at the recording operator's position by causing the operation of the relay *B*. The toll operator will then insert the calling plug of the cord circuit used into the multiple jack of the desired toll line, and after ringing on that line and securing the subscriber, bring the two subscribers together for conversation. When the toll-switching operator inserted the toll-trunk plug into the jack of the calling subscriber the relay *G* was caused to operate over a circuit extending from ground through the winding of the cut-off relay, the coil of the relay *G*, and the ringing lamp to battery and ground. This would cause the operation of the ringing lamp were it not for the fact that the calling subscriber has his receiver off its hook, and therefore the operation of the relay *A* had caused the operation of the relay *F*, which, when operated, had locked by virtue of its 40-ohm winding. This 40-ohm coil is, therefore, present as a shunt about the ringing lamp and prevents its lighting.

At the end of the conversation the clearing-out signal will be received at the toll board by the falling of the drop in the cord circuit. This drop may be made to fall either by generator current coming in over the toll line in an obvious manner, or by the hanging up of the receiver of the local subscriber. The means by which the hanging up of the calling subscriber's receiver causes the falling of the clearing-out drop bridged across the toll operator's cord is rather obscure, but it may be traced as follows:

The hanging up of the called subscriber's receiver opens the metallic circuit of the line, thus de-energizing the relay *A*, allowing the relay *E* to become de-energized. The falling back of the two armatures of this relay closes a circuit at two points, which may be traced from ground through one back contact of relay *E* and the winding of the relay *H*, one winding of the repeating coil, over the tip side of the trunk to the tip side of the multiple jacks in the toll sections, thence to the toll operators' cord and through the clearing-out drop to the sleeve side of the multiple jacks, thence back over the sleeve side of the trunk through a second winding of the repeating coil, through the second back contact of the relay *E* to battery. Receiving this signal, the toll operator will pull down the connection, and in removing the plug from the toll-trunk jack she will light the disconnect lamp of the toll-switching operator at the multiple board. This will be accomplished by the following means: The relay *H*, it will be remembered, was operated when the local subscriber hung up his receiver, owing to the de-energization of the relay *E*. When the relay *H* was energized it caused the energization of the relay *I*, also the circuit through this latter relay being from ground at the relay *H*, through the front contact of that relay, thence through the 40-ohm coil and the winding of the relay *I*, through the front contact of the relay *G*, to the live side of battery. The pulling up of the armature of the relay *I* causes that relay to lock, since the path was thus established from the live side of the battery through the front contact of the relay *G*, the coil of the relay *I*, and from the front contact of this latter relay through the disconnect lamp to ground. This disconnect lamp was not, however, operated by the current which thus flowed through it because of the presence of the 40-ohm shunt to ground between the contacts of the relays *H* and *I*, both of which relays are now operated. When, however, the toll operator withdrew the plug from the multiple jack of the toll-trunk line the relay *H* was de-energized, thus breaking the 40-ohm shunt around the disconnect lamp and causing the illumination of that lamp. Upon seeing the disconnect lamp lighted, the toll-switching operator will pull down the connection, thus restoring all apparatus to its normal position.

When a toll subscriber desires to converse with a multiple board subscriber the toll line operator will be signaled in the regular manner by the falling of the toll-line drop at the toll board. The toll operator will then insert the answering plug of a pair of toll cords into the toll-line jack, and after throwing the listening key and finding out the number of the common battery line with which the connection is to be established, speak over an order-wire to the toll-switching operator, telling her that a toll connection is to be established with a certain common battery line. The toll-switching operator will designate a trunk for use, and with the plug of this trunk test the multiple jack of the local subscriber's line. If the line is busy she will insert the trunk plug into the busy jack (not shown in figure), which will notify the toll operator by "tone" that the line is busy. In case, however, the line is free she will insert the trunk plug into the multiple jack, whereupon the ringing lamp associated with the trunk plug at the toll-switching operator's position will light immediately, and the toll-trunk operator will ring the subscriber. The illumination of the ringing lamp will be brought about by current flowing from the live side of battery through this lamp, the coil of relay *G* to the sleeve contact of the jack, thence to ground through the cut-off relay of the subscriber's line. When the subscriber answers the call the ringing lamp goes out and cannot be relighted until the trunk plug has been withdrawn from the jack, this state of affairs being brought about primarily by the operation of the relay *A*, due to the flow of current from the subscriber's telephone. The operation of this relay will cause the operation of the relays *F* and *E*, the closing of the contact of the relay *F* serving to close the circuit through the locking coil of this relay, which coil forms a 40-ohm shunt about the ringing lamp, thus extinguishing it. This locking coil remains effective in holding up the armature of the relay *F* until the connection is finally broken by the withdrawal of the trunk plug from the multiple jack.

At practically the same time that the toll-switching operator inserted the trunk plug into the jack of the subscriber's line the toll operator completed the connection between the toll line and the multiple jack of the toll trunk, thus bringing the subscribers into talking relation, the connection between the two subscribers being exactly the same as that shown in Fig. 354, except that the answering plug of the toll operator's cord circuit is now inserted in the toll-line jack instead of in the toll-trunk jack. The toll operator's cord circuit used in this system is adaptable without change to use in making connections between toll subscribers or between toll and local subscribers.

The clearing-out drop used in the toll operator's cord circuit is, as will be seen from the diagram an electrically-restoring drop of the type shown in Fig. 178. This is restored whenever the toll operator throws the listening key. This is accomplished by an extra pair of contacts which close when the key is operated and completes the circuit from the live side of battery through the restoring coil of the drop. Frequently, also, the coil of this drop is wired through an additional key so that it may be cut out of circuit in the case of a very long distance connection over which talking is difficult, in which case the bridge afforded by the drop would, if left permanent, effect to a slight extent the talking efficiency.

The circuits of the American Bell Telephone Company's system "B" complete, from a local subscriber's line on the left to a toll line on the right, are shown in Fig. 355.

In this system the repeating coil which separates the common battery line from the toll line is included in the cord circuit itself instead of in the trunk line. One-half of each cord circuit, in this case, at the right of the cut, is wired the same as half of a cord circuit at the local multiple board, the other half being wired substantially, as in ordinary magneto practice, with a self-restoring,

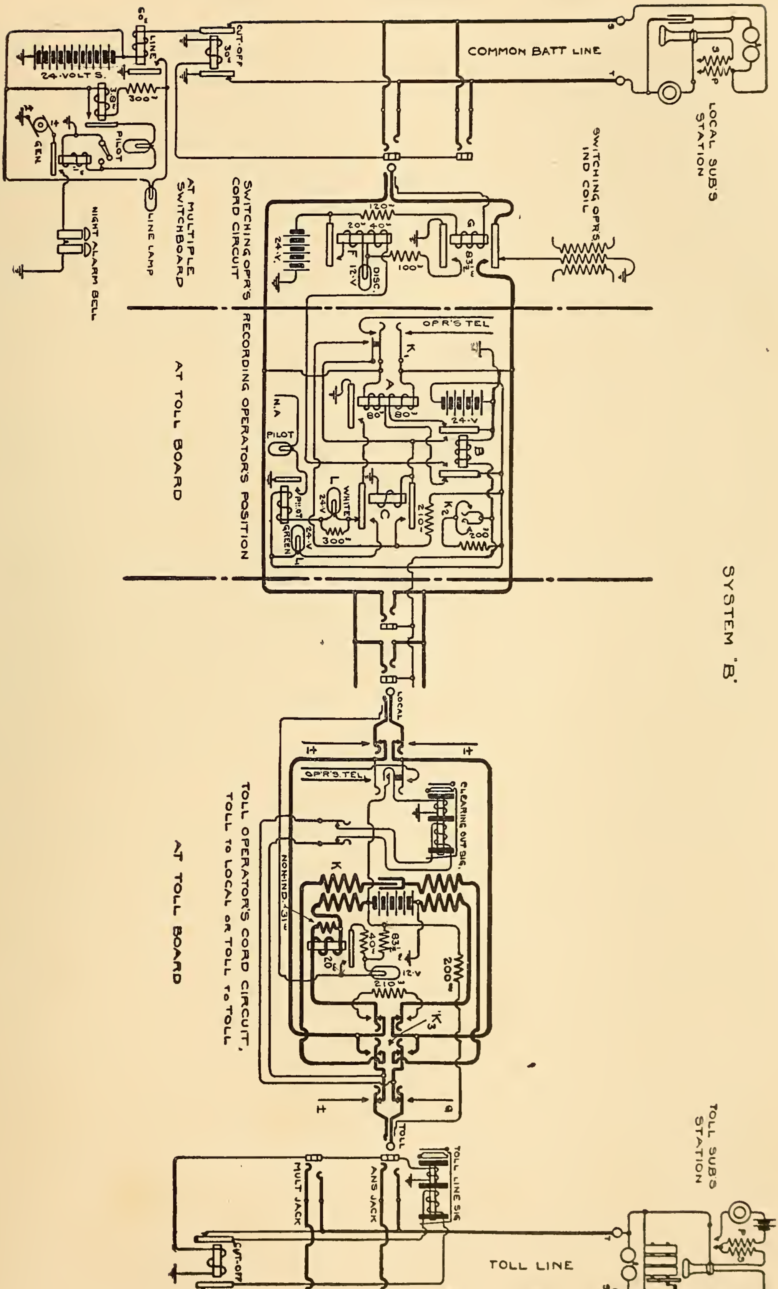


FIG. 355.—COMPLETE WESTERN ELECTRIC TOLL CIRCUIT, SYSTEM B.

clearing-out drop bridged across the tip and ring strands. Each cord circuit is equipped with a repeating coil key, K_3, which is so wired that when thrown the repeating coil, *K*, is cut out of circuit and a straight circuit obtained between the two plugs, so that the same cord circuit may be used for establishing toll-to-toll connecnections as is used for establishing connections between a toll and a local line, the only difference being in the position of the repeating coil key at the time of use. When key, K_3, is thrown in this manner a 210-ohm resistance coil is thrown across the common battery part of the cord circuit, and the 40-ohm shunt is placed around the supervisory lamp.

In this system a disconnect lamp appears at the toll-switching operator's position at the local multiple board, but no ringing lamp. The absence of a repeating coil in the toll-trunk circuit makes it possible for the toll-line operator to ring the bell of the local subscriber instead of having the toll-trunk operator do this, as in system "A." This is, of course, an advantage, as it enables the operator to be the true master of the situation and to more completely supervise the call than in cases where the toll-trunk operator is compelled to do the ringing. As will be noticed, the toll-trunk circuit, extending between the toll-switching position at the local board and the multiple toll board, contains three wires, thus practically limiting this system to use in exchanges where the toll and multiple boards are in the same building.

The operation of establishing a connection when a call is originated by a local subscriber is practically the same as far as the work of the operators is concerned, as that described in system A. The operation of the apparatus required to bring about the same signaling results is, however, somewhat different, and is as follows: The "A" operator upon receiving a call for long distance will communicate by order-wire to the toll-switching operator who will, as in system "A," insert the toll trunk plug into the multiple jack of line designated. This will cause the operation of the relay *G* which will cut off the test circuit and complete the connection between the tip strand of the trunk plug and the tip side of the trunk line. The operation of this relay will also connect a ground to one side of the disconnect lamp, which lamp will not, however, be operated because of the inactivity of the relay *F*. No change on the aspect of the signals will therefore take place at the switching operator's position. Since, however, the calling subscriber has his receiver off its hook, the double-wound relay *A* will be energized over a path which may be traced from the live side of the battery through the back contact of one lever of the relay *B*, through the coil of the relay *A*, to the ring side of the trunk, thence out over the ring side of the subscriber's line and back to the tip side of the line and trunk, through the other coil of the relay *A*, and the second back contact of the relay *B*, to earth. It will be seen that when the relay *B* operates it opens both windings of the relay *A*, thus rendering it inert. The operation of the relay *A*, when the toll-switching operator made the connection with the subscriber's line, illuminated a lamp, *L*, with a white cap at the recording operator's position over a circuit which may be traced from ground through the contact of the relay *A*, to the back contact of the relay *C*, the lamp and the pilot relay to the live side of the battery. The illumination of the white lamp is a signal for the recording operator to come in on the circuit, which she does by throwing a listening key, K_1, thus connecting her telephone with the circuit and enabling her to communicate with the subscriber. From the information thus obtained she makes out the ticket and passes it to a toll operator. The extra pair of contacts carried on her listening key closed the circuit energizing relay, *C*, which carries a contact which closes a locking circuit for this relay. The relay *C* carries an additional lever which, when operated, switches the circuit from the white lamp to a green one, *L*, so that when the recording operator listens in the white lamp goes out while the green lamp is lighted. The 300-ohm shunt around the white lamp is provided so that in case this lamp burns out the pilot will light and call the operator's attention. When the toll operator receives the ticket she inserts the toll plug of a cord circuit into the multiple jack of the toll trunk line. This will extinguish the green lamp at the recording operator's position because the relay *B* will be operated over the third strand of the toll operator's cord and the sleeve of the toll trunk circuit. The operation of this relay, as before stated, opens both sides of the circuit through the windings of the relay *A*, which, when de-energized, breaks the circuit through the green lamp at the recording operator's position, thus putting it out. The relay *C* which was operated when the recording operator listened in, and locked in that position, is, at the same time, de-energized because short-circuited, this short circuit existing between the winding of the relay and ground through the front contact of the left-hand lever of the relay *B*. All apparatus at the recording trunk operator's position, except the relay *B*, is thus restored to its normal condition, and this relay, *B*, which will be energized as long as the connection exists with the trunk line at the toll board, will thus prevent the subsequent operation of any apparatus at the recording operator's position.

The operation of the relay *B* has another function in that when operated it holds the disconnect lamp at the toll-switching operator's position in such position as to enable this lamp to be operated when further changes are made. The operation of the relay *B* closes the circuit from battery through the third strand of the trunk line, the 40-ohm coil of the relay *F*, and thence to ground through the contact of the relay *G*. The relay *F* is thus energized and the contact it closes serves to close a circuit through a locking coil on this relay and the disconnect lamp. The relay *F* is, therefore, held energized until its locking circuit is finally broken by the de-energization of the relay *G*, which takes place when the final disconnection is made. Although this locking current passes through the disconnect lamp, this lamp is not illuminated because of the presence of the 40-ohm shunt about it, this shunt being the 40-ohm coil of the relay *F*. The toll operator having inserted the local plug into the multiple jack of the trunk line designated, will proceed to call the toll station by inserting the corresponding toll plug into the jack of the line and ringing.

The connection is now established between the toll line and the subscriber's line, all signals at all positions being de-energized. It will be noticed that the supervisory signal on the common battery side of the toll operator's cord circuit will be placed under the control of the common battery subscriber in the same manner as if that cord were connected directly to the common battery subscriber's line. At the end of the conversation a double clearing-out signal will be received at the toll board due to the falling of the drop on the toll side of the cord and the lighting of the supervisory lamp on the common battery side. The toll operator will then throw her listening key, thus restoring the clearing-out drop, and listen in to satisfy herself that a second connection is not desired. If no connection is desired, the operator will withdraw the plugs from the toll trunk and toll-line jacks. The act of withdrawing the plug from the toll-trunk jack will de-energize the relay *B*, which will open the circuit through the 40-ohm coil of the relay *F*, at the switching operator's position, thus removing the 40-ohm shunt about the disconnect lamp and causing its illumination. This is the signal for the toll-switching operator to pull down the connection; which act will restore all apparatus to its normal condition.

A toll-to-local connection is established in practically the same way as in system "A." As in that system, the "A" operator and the recording operator play no part in the connection. The means by which the signals are made to operate, however, is different, although practically the same results are produced. The toll subscriber signals the toll board in the usual manner, and the operator inserts the plug belonging to the toll side of one of her cord circuits into the answering jack of the calling line. After finding out that the call is for a local subscriber, and making out the ticket, she will order up the connection at the toll-switching position at the multiple board by the order-wire, and the toll-switching operator will test the line in the usual manner. If she finds it free she will insert the toll-trunk plug into the multiple jack of the local subscriber called for, and thus complete the connection between the local subscriber and the toll operator, who by this time has inserted the plug on the common battery side of her cord circuit into the toll-trunk jack designated by the toll-switching operator. As the called-for subscriber has his receiver on its hook, the supervisory lamp in the common battery side of the toll operator's cord circuit will be lighted. Thus this lamp serves as a ringing signal for this operator who, by means of the ringing key, will call the local subscriber. When the subscriber responds, the supervisory signal will go out and the two subscribers will be in position for conversation.

The insertion of the toll operator's plug into the toll-trunk jack operated the relay *B*, at the recording operator's position. No effect is produced on the signals at the recording operator's position, as, due to the fact that the relay *B* is energized before the subscriber answers, relay *A* is not operated. The operation of the relay *B* placed the disconnect lamp at the switching operator's position in proper position to be operated when the relay *B* is again de-energized, as above pointed out. The disconnect signals are received in the same manner as when the call originated at the local subscriber's end.

The method of making connections between the toll subscribers in these two systems, "A" and "B," is almost identical. In both cases a toll subscriber signals the toll board by turning his generator crank and thus throwing the line drop at the toll board. The operator will insert an answering plug, and after throwing her listening key speak to the subscriber and find out that a connection is desired with some other toll station. In system "A" the cord circuit can be used for making either a toll-to-toll or toll-to-local connection without change, but in system "B" the cord circuits are normally suited for making connections between toll and local subscribers. On this account it is necessary for the toll operator in system "B" to throw a key associated with the cord circuit before this cord circuit can be used for connecting the toll subscribers. Having done this, the remainder of the operation is the same as in system "A." After testing, the operator will insert the calling plug associated with the answering plug in use into the multiple jack of the desired line, and ring. Until the subscriber answers, it is necessary for the operator to listen in at short intervals so as to know when the call is answered. The operator who has charge of the calling toll line will make out a ticket and record on it the duration of the conversation, the number of the calling and the number of the called toll stations, and the names of the calling and called parties.

Neither system "A" nor "B" seems to have been considered satisfactory by the engineers of the Bell telephone interests, and therefore what the writer has called system "C" was devised. This system embodies the advantages of both systems "A" and "B," with as few as possible of their disadvantages. The toll-trunk circuit requires but two wires, thus making the system adaptable to cases in which the toll board is in the same building with the local board, or at some distant point. The feature of having the toll operator ring the local subscriber in a toll-to-local connection is obtained, although a repeating coil is associated with the trunk line instead of with the toll operator's cord circuit.

The advantage of system "A" over system "B"—that the toll operator's cords are universally adaptable without change to either local-toll or toll-to-local or through connections—is retained, as is also the advantage of a two-wire trunk circuit, but it must be stated that these various desirable features have been attained at the expense of great complexity in the toll-trunk circuit, this circuit having no less than seven relays. Several features of advantage not found in either systems "A" or "B" are present, the general method of operation being quite different. In this system, when a local subscriber calls for a long-distance connection, the "A" operator who answers the call, instead of ordering up the connection at the toll-switching operator's positon, as in systems "A" and "B," simply completes the connection between the calling line and a recording operator's trunk by means of a special pair of cords. Aside from the fact that she does not ring in this case, she makes this connection and obeys the subsequent supervisory signals in the cord circuit in exactly the same manner as if the connection were between two local subscribers. The recording toll operator communicates with the subscriber over this trunk and then either orders up the connection herself at the toll-switching position, or allows the toll operator to do this after receiving the ticket, as will be described. Upon receipt of a call for long distance, the "A" operator will insert the answering plug of a special pair of cords, which are termed "tone-test" cords, into the multiple jack of the calling line, withdrawing the answering plug with which she answered the call from the answering jack of that line. With each plug of the "tone-test" circuit is associated a lamp, the plug adapted to connection with the jacks of the common battery line being associated with one having a white cap, and the lamp associated with the other plug, which is adapted to connection with the recording toll trunk, having a red cap. The white lamp in the tone-test cord circuit will remain unlighted when the answering cord is thus connected with the calling subscriber's line, since this subscriber has his receiver off its hook. With the remaining plug of the pair the "A" operator will test the multiple jacks of the recording toll trunk lines which terminate in multiple jacks on the local multiple board, and upon finding one which is not busy, complete the connection by inserting this plug into it. The red lamp associated with this plug will also remain unlighted, but a lamp at the recording operator's position associated with the particular recording toll trunk used will light, and the recording operator will plug into the corresponding jack of this trunk, thus connecting her telephone with the calling subscriber, from whom she will take the necessary information for making out the ticket. The cord circuit, by which the recording operator is enabled to communicate with the local subscriber, is provided with two lamps and terminates in a single plug. One of these lamps, the holding lamp, is placed under the control of the calling subscriber when the plug with which it is associated is connected through the toll trunk with the line of that subscriber. The second lamp is a disconnect lamp. The operation of both of these lamps will be described further on. After making out the ticket the recording operator has two courses of action opened to her, her decision between them depending on whether or not she has reason to believe that the connection called for may at once be obtained. If she thinks it will be some time before it will be possible to establish the connection desired, as in case the subscriber must be hunted up in some large and distant city, she will tell the calling subscriber to hang up his receiver and wait until called. The hanging up of the subscriber's receiver will light the white lamp of the tone-test cord used in making the connection, but the subscriber's operator will pay no attention to this, her signal for taking down the connection being the lighting of the red lamp. Having told the calling subscriber to hang up his receiver, the recording operator will first pass the ticket to the toll-line operator and remove her plug from the recording toll-trunk jack, which act will light a red lamp in the tone-test cord at the "A" operator's position. The lighting of this lamp gives a signal to the subscriber's operator to take down the connection, and she, therefore, removes both plugs, leaving the subscriber's line free for other business. The recording operator has now nothing further to do with the connection, the ticket being in the hands of the toll operator, who supervises all further work in connection with it.

If, after making out the ticket, the recording operator had reason to believe that the connection could be at once obtained, she would, by means of an order-wire key, speak directly to the toll-switching operator at the multiple switchboard and give her the number of the line with which the connection is to be made. In response to this the toll-switching operator will designate to the recording operator the number of the trunk to be used, which number the recording operator will place on the ticket, together with the other information. The toll-switching operator will then test the multiple jack of the subscriber's line and receive the special busy test due to the presence of the tone-test plug in the multiple jack at the section in which the call originated. She disregards this signal and plugs into the jack with the plug of the toll trunk designated to the recording operator.

After the toll-switching operator has inserted the plug of the designated trunk into the multiple jack of the calling line the recording operator will withdraw her plug from the recording trunk-jack, thus giving a signal to the "A" operator to disconnect with the tone-test plugs, and insert it into the multiple jack of the toll-trunk line. These trunk lines are multipled in all toll and recording sections. This enables the toll-recording operator to communicate again with the subscriber over a different route, and convince herself that the connection so far is complete and that the subscriber has given his proper number. She will then pass the ticket to the toll operator who has charge of the toll line with which connection is to be established. The calling subscriber cannot now signal the "A" operator, who has removed the tone-test cord from his jack, but he is enabled to signal the recording operator by means of the holding lamp in that operator's circuit, the path over which this signal is thus communicated to the recording operator being through the multiple jack of the subscriber's line at the toll-switching position, and thence over the toll trunk to the recording operator's position.

We have now traced the operation of this system to a point where the toll operator takes up the work, she having received a ticket which in one case was provided with information as to what trunk should be used, in which case she would know that the connection was already ordered up at the toll-switching position, and that she had only to connect that trunk with the proper toll line. In the other case, the ticket not being provided with the number of the trunk, she would know that the calling subscriber was not waiting and that the toll trunk had not been ordered up.

Taking the case where no trunk is designated, the toll operator will first insert the calling plug into the multiple jack of the desired toll line and ring in order to secure the party desired. After she has secured this party she will give the switching operator, over an order-wire, the number of the line of the subscriber who made the call, and will receive in return the designation of the trunk, whereupon she will insert the answering plug into the multiple jack of the designated line and call the desired subscriber by ringing, the toll-switching operator having made the connection between the multiple board end of the trunk and the subscriber's line.

If, on the other hand, the toll operator finds that the trunk line is designated on the ticket, she will know that the recording operator has already ordered up the connection, and that the subscriber is waiting. Under this circumstance she will first insert the answering plug into the trunk of the jack designated on the toll ticket. This act will light the disconnect lamp in the cord circuit of the recording operator. The lighting of this lamp will be the signal for the recording operator to pull down the connection at her position. The toll operator will then make the connection between the jack of the trunk line used and the toll line and call the toll station by ringing. Connection is now established between the toll station and the common battery subscriber. The wiring of all the circuits over which conversation takes place is shown in Fig. 356.

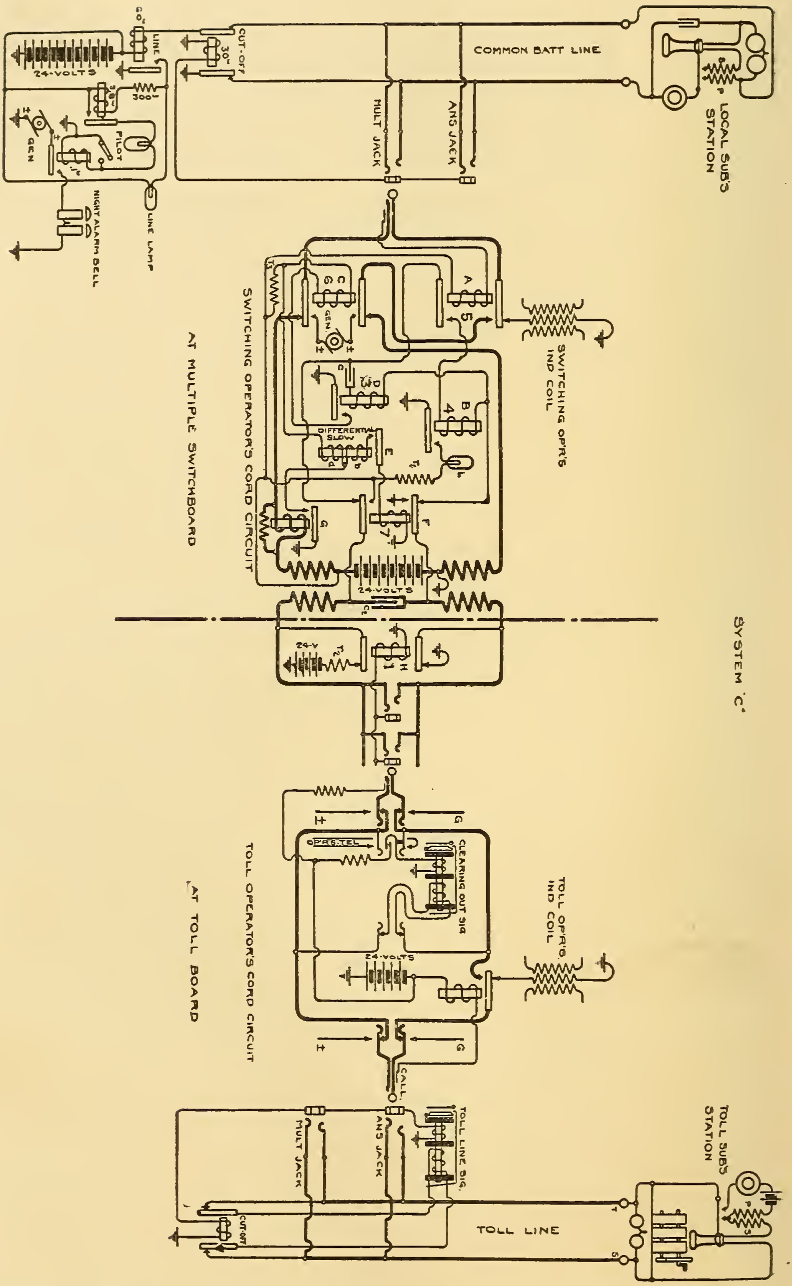


FIG. 356.—COMPLETE WESTERN ELECTRIC TOLL CIRCUIT, SYSTEM C.

The toll-trunk circuit shown in this figure shows it in the form which was patented, but differs in one or two respects from the circuit which the Bell companies are now using. Relay *E* has been replaced by one of a different type, but the method of operation, as described above, has not been changed.

When the trunk plug was inserted by the toll-switching operator into the multiple jack of the calling subscriber's line in response to the order received from the toll-recording operator or from the toll operator, the relay *A* at the toll switching position was energized. This severed the normally completed test circuit belonging to the trunk plug and completed the circuit from the tip of the plug to the tip side of the trunk line. The operation of this relay also closed a circuit from the grounded side of battery at the toll board through the upper contact of relay *H* over the trunk line to the common battery exchange, then through one winding of the repeating coil, the back upper contact of relay *F*, winding of relay *B*, the contact of relay *A*, the second back contact of relay *F*, a second winding of the repeating coil, thence back over the trunk line to the toll board through the second back contact of relay *H*, and resistance, r_2, to the non-grounded side of battery.

Current flowing over the circuit will at once operate relay *B* and illuminate the disconnect lamp, *L*, in the toll trunk circuit. However, as soon as the toll operator inserted the toll plug into the toll trunk jack (this would happen at practically the same instant in which the switching operator inserted the trunk plug into the multiple jack and hence this lamp in actual practice would seldom do more than flash), relay *H* was operated and the circuit above traced out opened in two points at this relay, thus extinguishing the disconnect lamp and removing the battery connections from the toll side of the trunk line. The method by which the toll operator is able, by throwing her ringing key, to ring the bell of the common battery subscriber is as follows: When the ringing key is thrown, current from the ringing generator will pass out over the ring side of the trunk line, one winding of the repeating coil, one back contact of relay *F*, through condenser, *C*, the winding of relay *D*, and back through the second set of springs of relay *F*, the second winding of the repeating coil, the tip side of the trunk line to the other side of the generator. It will be noticed that relay *B* acts as a shunt to the condenser and relay *D*, but as relay *B* is of high resistance, it will have no appreciable effect upon the operation of relay *D*. Relay *D* will then be energized and de-energized very rapidly and battery current will flow from ground through its armature, the winding of relay *C*, and resistance, r_3, to the non-grounded side of the battery. This will operate relay *C*, and thus close a circuit for ringing current from the generator at the common battery board out over the subscriber's line and through the bell. When the subscriber answers, relay *G* will be operated and battery current will then flow from ground through the contact of this relay, winding *a*, of relay *E* and resistance, r_3, to the non-grounded side of battery, thus energizing relay *E*. It will be noticed that when this relay, *E*, is operated, there will be a circuit from ground through the winding of relay *F*, contact of relay *E*, both windings of relay *E*, and resistance, r_3, to battery. However, as long as relay *G* is operated, relay *F* and winding, *b*, of relay *E* will be short-circuited and hence no current will pass through either of these windings. Relay *E* is a slow-acting differential relay arranged mechanically so that a small period of time will elapse after current has been withdrawn from the winding before it will release its armature. When current flows through both of these windings in series, the magnetism set up by these two windings will neutralize each other and release the armature. Hence, at the end of conversation, when the common battery subscriber hangs up his receiver, thus de-energizing relay *G*, the short circuit which has been placed around relay *F* and winding *b* of relay *E* will be removed and current will pass through both windings of relay *E* and the winding of relay *F*. Relay *F* will be energized immediately, before the differential action of relay *E* gets in its work, so that, for an instant, or before relay *E* is demagnetized, relay *F* will pull up its armature, thus closing a circuit from ground back over the trunk line through the clearing-out drop in the toll operator's cord circuit at the toll board, back on the other side of the trunk line to the negative or non-grounded side of battery at relay *F*. Thus, the clearing-out drop will fall and give a signal to the toll operator to disconnect. When the clearing-out drop has fallen and before the toll operator has withdrawn the plug, all of the relays in the multiple-board end of the toll trunk circuits, excepting relay *A*, are in their normal position. When the toll operator withdraws her plug, she will de-energize relay *H* and allow battery to pass over the trunk line and through winding of relay *B*, thus lighting the disconnect lamp in front of the switching operator. The toll-switching operator will then take down the connection.

When a call is received over a toll line at the toll board and the toll operator upon answering finds that a local connection is desired, she will speak over an order-wire to the switching operator at the multiple board. The switching operator will designate the trunk and insert the plug of this trunk into the multiple jack of the desired local line. The toll operator at the same time will insert the calling plug into a jack of the trunk line and ring. Clearing-out signals are in this case received in exactly the same way as when the connection is made from local-to-toll.

The methods which the Bell Telephone companies use for

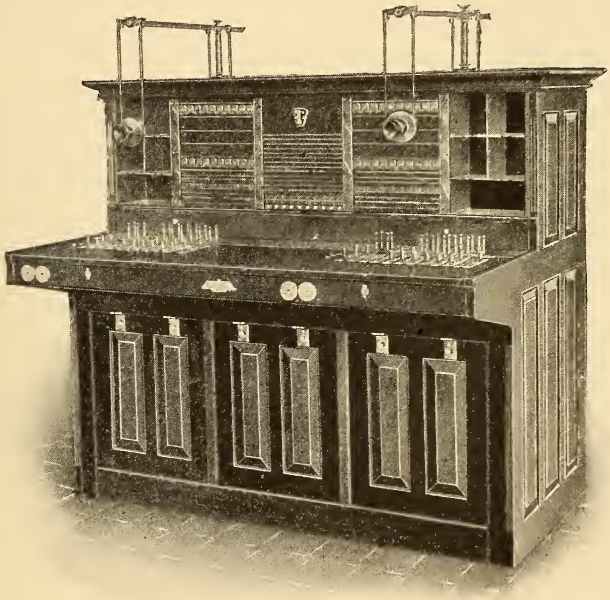


FIG. 357—SECTION OF TOLL BOARD.

handling connections between toll stations are numerous, but in many cases one or more separate positions are provided, called "through positions."

In a case having these through positions, if the toll operator receives a call from a toll line for another toll line, she will make out a ticket for it in the same manner as if the call were for a local line and, on completing the ticket, will establish the connection herself if it is possible to do so at once. If, however, the called for line is in use, she will pass the ticket to a through operator who has in front of her a multiple jack of each line, and in some exchanges a multiple lamp which remains lighted as long as that line is busy. This operator, as soon as she finds out that both lines are free, either by noting that the lamps of both are extinguished, if her position is provided with lamps, or by testing, in case she has none, will establish the connection. At the end of the conversation on such a connection the clearing-out drop will fall in the ordinary manner when either of the toll subscribers turns his generator crank.

The tendency among Bell companies seems to be to use lamps and locking relays for line and clearing-out signals in toll boards instead of drops, but as this scheme has advanced but little beyond the experimental stage, all of the circuits shown in connection with this description have been drop circuits.

The design of toll board sections has, during recent years, become fairly well standardized, a single typical section being shown in Fig. 357. The framework is nearly always of wood instead of iron, as in the case of multiple boards, and the woodwork as a rule is of mahogany, although oak has been used in some cases. The sections are usually of the two-position type with much wider key-shelves than it is customary to furnish on sections used for local work. This allows the toll operators more space for making out tickets and does not hamper their work as, due to the comparatively small amount of equipment in a toll board, the "reach" is never great. In the face of the board and within the reach of each position is also usually provided a number of pigeon-holes in which the toll tickets and various other memoranda may be readily filed away.

Room is usually left on the key-shelf in the middle of each section for the mounting of an instrument known as a calculagraph, this containing the time-stamping mechanism by which the elapsed time is recorded on the toll tickets. As one calculagraph is furnished for each section it is used by the two operators at that section, and such double use of the machine is not found to practically interfere with its proper working.

CHAPTER XXVII.

DETAILS OF MULTIPLE SWITCH-BOARD APPARATUS.

THE designing of the various pieces of apparatus which form parts of that wonderful complex whole—the modern multiple common battery switch-board—requires attention to an infinite number of details. In this chapter some of the most important parts of apparatus employed in practice to-day will be illustrated and discussed, but on account of the great variety and almost numberless types of such apparatus a complete treatment of the subject will be impossible.

The spring-jack is perhaps the most important of all pieces of switch-board apparatus. This is certainly true in point of numbers, as in the multiple board the spring-jacks increase almost as the square of the number of subscribers, and are often numbered by hundreds of thousands.

It is now almost the universal practice to build up spring-jacks in strips, usually of 20, the framework of these strips being formed for the most part of hard rubber, sometimes stiffened by strips of brass. The multiple jacks are almost always mounted in strips of 20, a few cases being on record where strips of 25 have been used. This, however, is not to be recommended for several reasons. The answering jacks may be mounted in strips of 10 or 20, 20 being common in boards where the jacks are not made closer together than on ½-inch centers. Where, however, the spring-jacks are made smaller than this, it is better to mount the answering jacks 10 per strip rather than 20, thus giving more room between them and preventing undue crowding among the answering plugs, which, besides being inconvenient for the operator in handling, may also serve to hide the signals from her view.

A jack used to a large extent by the Western Electric Company is made on ⅜-inch centers, both horizontal and vertical for the multiple. The answering jacks are spaced on ¾-inch centers, horizontally, the strip itself being ⅜-inch high.

The construction of this jack is shown clearly in Fig. 358, which needs little description. The "tip" and "ring" contacts consist of the two springs which register with the tip and ring contact on the plug. The test or sleeve contact of the jack is of German silver, provided with a rearwardly-extending shank projecting from the rear of the jack strip for the purpose of allowing the soldering of the wires. This jack represents the highest development in the construction of a three-contact jack for multiple switch-board work. There are no make-and-break contacts between the jack springs, all contacts being normally insulated from each other and adapted to engage only with the plug contacts during use. On account of considerations as to mechanical strength, and as to the proper insulation between the parts, it has not been found expedient up to the present time to build three-contact jacks closer to-

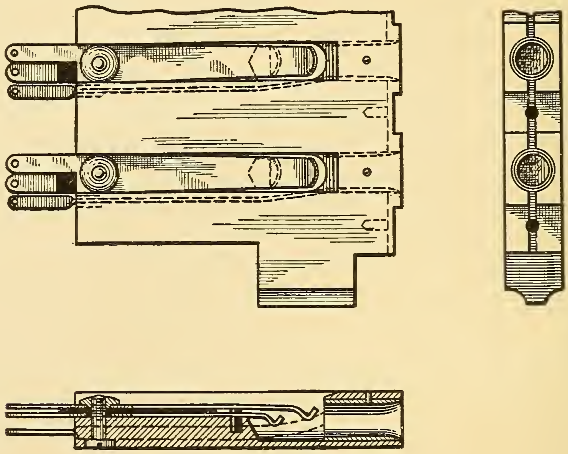


FIG. 358.—WESTERN ELECTRIC JACK.

gether than on $\frac{3}{8}$-inch centers, and, in fact, considerable difficulty was experienced in securing the design of a jack with three contacts which would be mechanically and electrically reliable when made as small as this. The jacks of Fig. 358 are those forming a portion of a strip of 10 answering jacks, and are therefore mounted $\frac{3}{4}$-inch apart horizontally. The notches in the front of the strip are for the insertion of designation plates by means of which the answering jacks may be identified.

This will be recognized as the spring-jack which is used in connection with nearly all of the Western Electric common battery circuits.

In Fig. 359 is shown a strip of two-point jacks, which is of the type used in nearly all of the two-wire switch-boards installed by the Kellogg Company.

Detail views showing the construction of this jack are shown in Fig. 360, from which it will be seen that the contacts of the jack consist merely of a tip spring and a sleeve contact, these two hav-

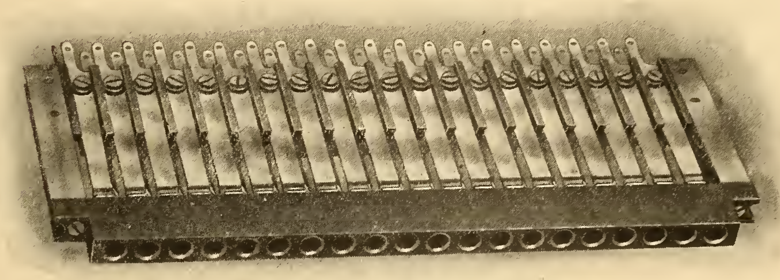


FIG. 359.—STRIP OF TWENTY KELLOGG JACKS.

ing rearwardly-projecting portions for facilitating the soldering of the wires. The framework of this jack is composed mainly of two hard-rubber strips, the front strip being drilled to receive the tubular portion of the sleeve contacts, while the rear strip is slotted on its upper side to receive the tip springs, and on its lower side to

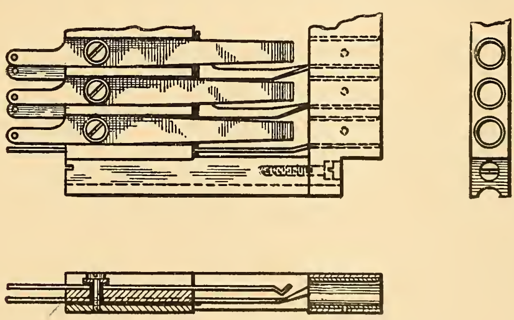


FIG. 360.—DETAIL OF KELLOGG JACKS.

receive the shanks projecting from the sleeve contacts. Underneath this rear rubber strip is secured a heavy brass strip into which the screws binding the tip springs in place pass. A thin rubber strip is placed between the slotted rubber back strip and the brass strip, this serving to prevent the sleeve contacts from short-circuiting against the brass strip. Grooved end lugs of brass secured to the upper face of the back strip and the rear face of the front strip serve as a means for fastening these spring-jacks into the framework of the board.

This jack of the Kellogg Company is made in three sizes, the largest of which is ½ inch between centers in a horizontal direction and 7-16 inch in a vertical direction. This size is used by the Kellogg Company on all switchboards having an ultimate capacity of not over 7200 lines. There is another size—⅜ inch between centers in each direction—which is used for exchanges having an ultimate capacity of not over 12,000 lines. The smallest type yet put in practice is mounted on 3-10-inch centers in each direction, this being embodied in the large multiple boards of the Frontier Telephone Company of Buffalo, N. Y., and of the Home Telephone

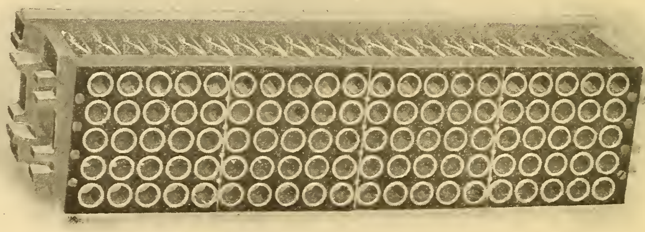


FIG. 361.—STROMBERG-CARLSON MULTIPLE JACKS.

Company of Los Angeles, Cal. The ultimate capacities of these switch-boards in each case is 18,000 lines.

The Stromberg-Carlson Company have recently made a somewhat radical departure from what is generally considered standard construction by mounting their multiple jacks in banks of 100 instead of in strips of 20. A good idea of one of these banks is afforded in Fig. 361, it being seen that the front strip, which is of a solid piece of rubber, carries 5 rows of jack sockets, there being 20 jacks in each row. The rear strip forms a support for the various springs and terminals and is secured to the front strip by means of heavy brass end lugs, which also form the means of securing the bank into the framework of the board. Even in their two-wire multiple boards the Stromberg-Carlson Company use three contacts in each jack. The jack has a ring contact and two springs, the ring contact and the forward spring being permanently tied together in the jack, thus making one contact of the two. Their idea in doing this is to afford what they consider a more secure contact between the sleeve of the plug than would be afforded by a tubular contact alone.

All of the jacks shown, it will be seen, are arranged in horizontal rows of 20, as that number has been adopted as a universal unit for the interior wiring of telephone exchanges. Twenty jacks form a convenient unit and a bank of 100 is usually formed by piling 5 strips together in the board. The arrangement for the numbering of the jacks brought about by this method makes easier the selection of any number in a bank of 100 than would be the case with any other available unit. Mounting the jacks in strips of 25 has been tried, notably by the Sterling Electric Company, in an exchange installed by them in Toledo, Ohio, in which case 4 strips are used for each bank of 100. With this arrangement, however, the operators cannot as readily select a number in the bank, be-

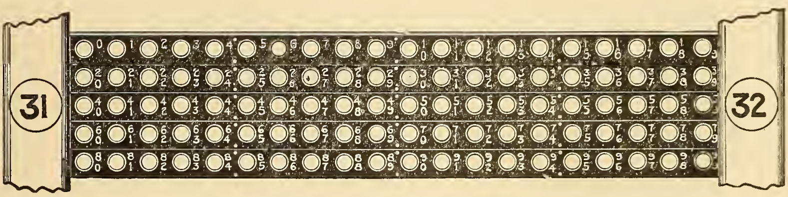


FIG. 362.—NUMBERING OF MULTIPLE JACKS.

cause, since the strips are not in multiples of 10, a given final figure of a number will occupy different positions in the various strips forming a bank of 100. In the numbering adopted in practice with 5 strips, 20 jacks to a strip, the first strip, beginning at the top, is numbered from 0 to 19, the second from 20 to 39, and so on, the last being from 80 to 99, thus making the jacks in a bank of 100 appear as shown in Fig. 362. In the multiple, however, the first hundreds are placed in the lowest row, with higher hundreds above.

In order to facilitate the work of the operators in selecting a number quickly, it is customary to divide off each strip of jacks into four equal parts by means of either dots between the 5th and 6th, 10th and 11th, 15th and 16th jacks in each strip, or else by vertical lines, as is clearly shown in the cut of the Stromberg-Carlson jack in Fig. 361.

A multiple cable, in the case of the 3-wire jack of the Western Electric Company, is made from 63-wire cable, this consisting of 21 twisted pairs and 21 single wires, the twisted pairs, of course, carrying the tip and ring contacts forming the talking circuit, and the single wire carrying the test or sleeve contacts. In the case of the Kellogg Company's 2-wire system the multiple cable is formed of 21 pairs (42 wires). In each of these cases a separate cable feeds each strip of 20 jacks.

In the Stromberg-Carlson 2-wire system, where the multiple jacks are mounted in banks of 100, the multiple cable is formed of 102 pairs of wires, a separate cable thus feeding each bank of 100 jacks.

The answering jacks in nearly all systems are the same as the multiple jacks in individual construction, but they are frequently mounted in strips of 10 instead of 20, the length of a strip being the same in each case, but the space between the jacks being twice as great in the former case as in the latter.

A form of lamp jack, used very largely until recently, was shown

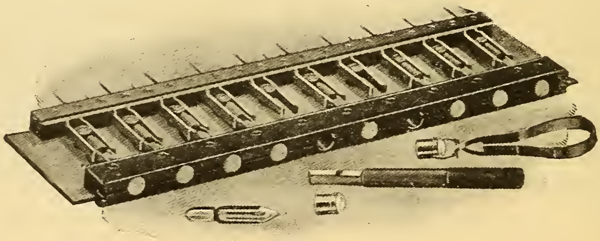


FIG. 363.—NORTH ELECTRIC COMPANY'S LAMP JACK.

in Fig. 245. This particular strip is one of 20 jacks as formerly manufactured by the Kellogg Company, a strip being formed of a single piece of hard rubber, milled and drilled as shown. The main portion of this strip is slotted from above and beneath for the purpose of securing in place and affording room for the contact springs for the lamp. After a lamp is put in place between the springs a small lens of opalescent glass, which is carried in a brass bushing, is pushed into place in front of the lamp.

Recently nearly all of the manufacturing companies have adopted a lamp strip constructed with a metal framework, a good example of which is shown in Fig. 363, which represents a strip of 10 lamp jacks as manufactured by the North Electric Company, of Cleveland, Ohio. This strip, as will be seen, is partly of metal, but is provided with a hard rubber face through which the lamps are inserted into the jack, and into which the lamp caps are afterwards pushed. The lamp terminals and springs are in this case mounted on edge in a rear strip, secured to the front by means of a brass plate underneath, which stiffens the whole structure. This cut also shows views of the lamp, the lamp extractor and the cap and cap extractor in common use.

The Stromberg-Carlson Company have recently introduced a combined answering jack and lamp strip, as shown in Fig. 364. This feature is one of apparent merit, as lamp jacks are always associated with answering jacks, and there is therefore no good reason why they should not be built together.

As will be seen, the answering jacks are beneath the lamp jacks, the two having a rubber face in common.

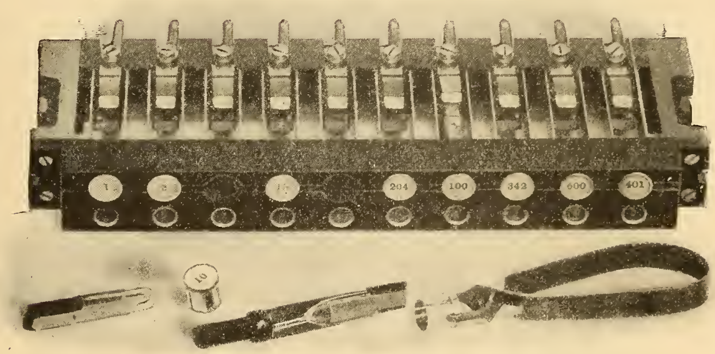


FIG. 364.—STROMBERG-CARLSON COMPANY'S LAMP AND ANSWERING JACK.

Both the Kellogg Company and the Stromberg Company, in their recent exchanges, have adopted the scheme of discarding the opalescent lens in front of the line lamp, using in its place a thin, flat glass disk, behind which and on a piece of paper is printed the number of the line. As will be pointed out in a later chapter, changes on the intermediate distributing board often destroy all significance as to the numbers of the answering jacks. By having the lamp cap carry the number, the number of the answering jacks may, with very little trouble, be made to conform with that of the line. This method of numbering is quite clearly shown in Fig. 364. The Bell companies use a separate designation plate for the answering jacks, these plates being made removable in order that changes may be made in the numbering.

Fig. 365 shows the relations between the answering jacks and lamps, and between these and the multiple jacks as mounted in a Stromberg-Carlson multiple board. In the panels just above the plug shelf are seen the pilot lamps, these being provided with large

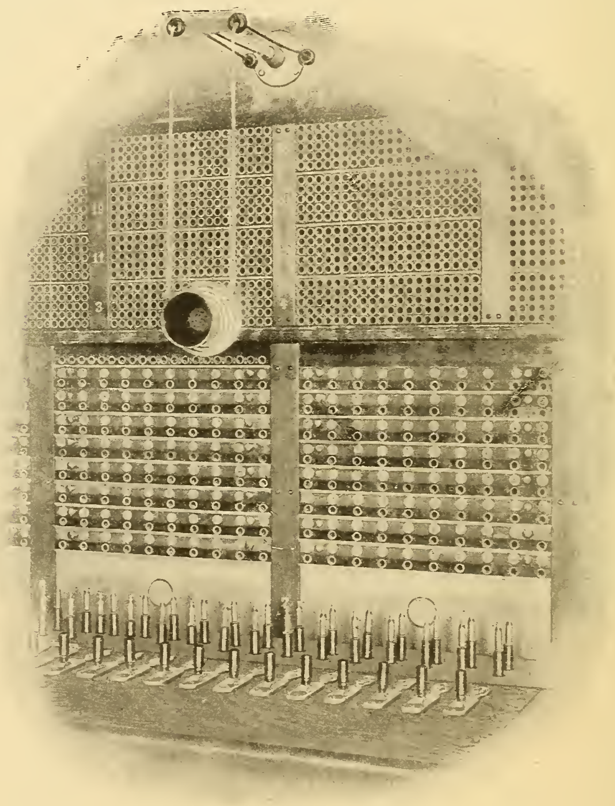


FIG. 365.—RELATION BETWEEN ANSWERING AND MULTIPLE JACKS.

lenses in order to give a more brilliant signal. This cut also shows well the mounting of the answering and calling plugs, together with the ringing and listening keys of each cord circuit. The supervisory lamps are mounted just back of the ringing keys in the metal plate there shown, there being one of these for each plug. It will be noticed that in this cut the dividing lines, or stile strips, between the multiple and answering jacks do not correspond. This is not in accordance with the usual and best practice, in which the strips of answering jacks and lamps are made to be of the same length as those of the multiple jacks, thus allowing stile strips, which divide the spaces between the jack strips, to run continuously from the keyboard to the top of the multiple jack space. This is, of course, desirable from the standpoint of rigidity of construction.

As there are usually three operators' positions to each section, the practice of making the panels in which the answering jacks are mounted the same width as those in which the multiple jacks are mounted prevents the answering jack panels from being evenly apportioned among the operators, unless it happens that the number of panels in a section is an exact multiple of three. The number of panels in the multiple is usually determined by the size of the section, as limited by the reach of the operators and by the length of the jack strip, as limited by the size of the jacks. It is found that the best length for a section is in the neighborhood of 67 inches, 65 inches being perhaps the minimum, and 70 inches the maximum, as allowed by good practice. Coming within these dimensions for the length of the section when jacks are mounted on ½-inch centers, there are usually six panels to a section; when jacks are mounted on ⅜-inch sections there are usually eight panels to a section, and when mounted on 3-10-inch centers there are usually ten panels to a section. When, therefore, the jacks are mounted on ½-inch centers giving a six-panel section, the stile strips accurately divide the positions between the operators; in that case there are two panels to each position. This apparently affords a slightly better arrangement in regard to the answering jacks and lamps, as the operators' field of operation with respect to these jacks and lamps is somewhat better defined. This advantage, however, is more apparent than real, for, as a matter of fact, the work of the operators in answering calls "laps over" to a considerable extent, as sometimes an operator in one position will be very busy, while the one adjacent to her will have little to do, in which case the latter operator may reach across with her plugs and cords and help the busy operator to handle the work. It is therefore thought that the practice of dividing the answering jack panels in a different manner from the multiple jacks, in order to make them conform more closely to the operator's positions, is not desirable, as it has the obvious structural disadvantage of breaking up the stile strips, and thus making the face of the board less rigid.

In Fig. 366 is shown the iron framework of a multiple switch-board section, this being a view of the same section, stripped of its apparatus, which is shown in detail in Fig. 365. As is seen, the frame is built of structural iron. Much of the woodwork shown in place in this figure is used as a medium on which to mount some of the apparatus and wiring. This represents about the condition of the multiple switchboard section when shipped from the factory,

FIG. 366.—FRAME OF MULTIPLE SECTION.

most of the apparatus and the enclosing woodwork being, as a rule, fitted to the section before leaving the factory, but afterward taken off and shipped separately.

In Fig. 367 is shown in detail the mounting of the supervisory lamps in the Stromberg-Carlson switchboard, this being in conformity with good modern practice. The lamp-jack itself is screwed to the under side of the key shelf, the lamp projecting upwardly from a hole bored in the shelf, the cap carrying an opalescent lens screwed into place in the woodwork above the lamp.

In the case of supervisory lamps it is found necessary to afford some means of protecting the lenses from breakage due to possible

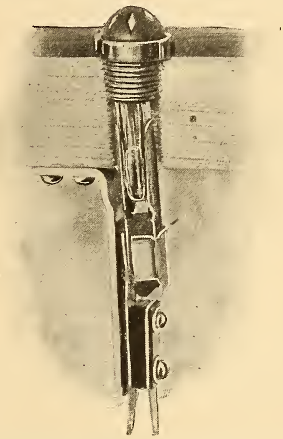


FIG. 367.—SUPERVISORY LAMP MOUNTING.

impact from the plugs, and for that reason a perforated metal shield is arranged in connection with the brass portion of this cap, as shown in this cut.

It has been said that the same type and size of lamp is used for pilot lamps as for line and supervisory lamps, but that in order to

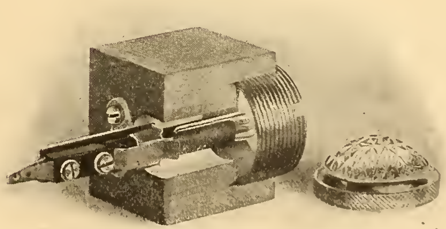


FIG. 368.—PILOT LAMP MOUNTING.

make a more luminous signal a larger and better lens is provided. The construction of the pilot lamp mounting, as used by the Stromberg-Carlson Company, is shown in Figs. 368 and 369, which shows the mounting assembled and in its various parts. The lamp jack itself in this case mounts on the rear face of the wood panel at the lower portion of the jack space, while the large brass bushing which serves to carry the lens screws into the face of the board from the front.

The construction of switchboard cords and plugs has been taken up to some extent in previous chapters, and the practice in this does not differ materially as applied to multiple boards from that as ap-

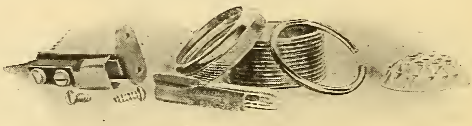


FIG. 369.—DETAILS OF PILOT LAMP MOUNTING.

plied to small boards. It, of course, "goes without saying," however, that a two-conductor cord will give less trouble than a three-conductor cord, and a two-conductor plug less trouble than a three-conductor plug. Moreover, it is possible to make a stronger two-conductor plug than a three-conductor when the sizes are kept the same. So far as the consideration of the cords and plugs *per se* is concerned the advantages are all in favor of the use of the two con-

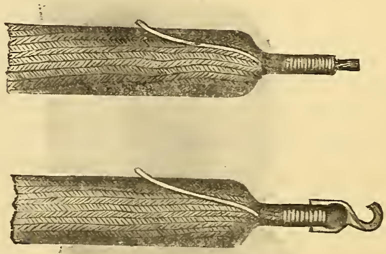


FIG. 370.—PLUG END OF CORD.

ductors, and this is one of the important advantages of the two-wire multiple board systems.

The method of preparing the terminals of the cord for attachment to the plug is shown in Fig. 370. In this the upper cut shows the cord itself before the small hook-shaped tip in the lower cut is applied. The tip strand of the cord is, it is seen, wound with wire, leaving a small portion of the tinsel conductor projecting through it, and to this wire wrapping is clamped a small hook connector, shown in the lower portion of the cut. After this a drop of solder is applied at a high enough temperature to make it run, but not high enough to burn the tinsel. This secures permanently the electrical connection. The end of the sleeve conductor of the cord is lapped back outside of the outer braiding, and this when screwed into the shank of the plug makes a firm connection between the sleeve contact of the plug and the sleeve strand of the cord. The connection between the tip conductor of the cord and the tip contact of the plug is made by means of a screw engaging the hook-shaped terminal of the tip strand, this being more clearly shown in Fig. 166.

In order to prevent the short-circuiting of the tip and sleeve contacts of the jack when the plug is inserted, a plug constructed as

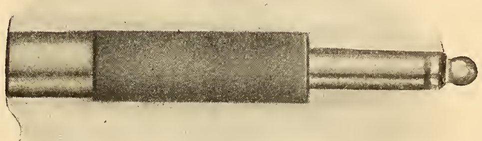


FIG. 371.—TWO-CONDUCTOR PLUG FOR MULTIPLE SWITCH-BOARD.

shown in Fig. 371 is used by the Kellogg Company. In this between the tip and sleeve conductors of the plug there is a small metal ring, insulated from both tip and sleeve conductors. Electrically this ring exercises no function as a conductor, and might be of insulating material. It is found, however, that insulating material in this place will not stand the wear of the constant insertion and withdrawal of the plug, therefore an insulated metal ring is used.

The end of the cord opposite the plug end is usually provided with some metallic clip or terminal, such as shown in Fig. 372, this particular cut representing the Kellogg method. The method of applying this terminal is similar to that described in applying the tip strand terminal to the plug end, as shown in Fig. 370, but in this case the metal terminal is fork-shaped and is squeezed tightly around the wrapping of wire on the outside braid of the cord.

The tinsel projects through this and is soldered to the terminal, as is clearly shown. The switchboard cord, where this is of the two-conductor type, forks at the end opposite the plug end, and at this fork the braid is usually extended in the form of a loop, which may

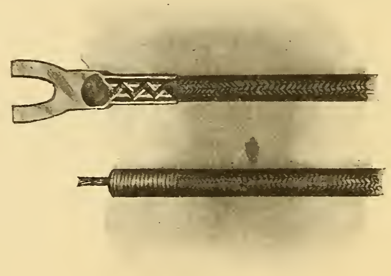


FIG. 372.—RACK END OF CORD.

be hooked on to the cord-connecting rack to form a support for the cord, which will relieve the conductors from strain due to the cord weights.

The method of connecting the cord to the connecting rack is shown in Fig. 373, which shows two stationary terminals secured to the rack, to which are secured by screws the fork-shaped cord ter-

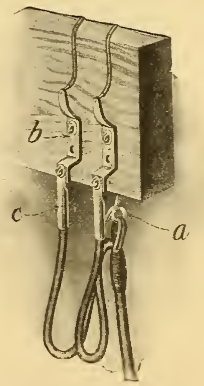


FIG. 373.—CONNECTION OF CORD ON CORD-RACK.

minals shown in Fig. 372. The hook and loop supporting the weight of the cord are clearly shown underneath this rack. The wiring leading to the other portions of the cord circuit terminates in a soldered connection at the upper portion of the stationary clips, this arrangement affording a ready means for changing the cord in case of defect, without disturbing any of the other wiring.

This brings us logically to the question of cord weights, a typical form of which is shown in Fig. 374. This consists of a weight composed of a hard alloy of lead cast about the lower portion of the brass punching, in which is secured a pulley through which the cord runs. The weight of these cord weights is, as a rule, about 8 ounces, that amount of weight being required to restore the cords properly to their places when the plugs are withdrawn from the jacks. The weights should not be much heavier than this, on

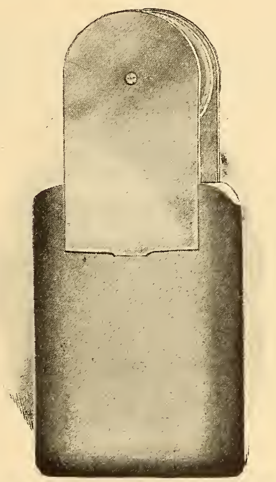


FIG. 374.—CORD WEIGHT.

account of the obvious disadvantage of subjecting the cord to too great strain and to consequent wear.

It is thought that there has been no more difficult type of telephone apparatus to properly design than that comprising the various ringing and listening keys, by which the operator is enabled to bring her telephone and generator into connection with the various cord circuits. Something has been said of these keys in an earlier chapter, but several of the types in most common use will be shown here, this forming an important part of multiple switchboard work.

In Fig. 375 is shown one of the best and most substantially constructed types of keys yet produced, this being that of the Western Electric Company. Nearly all of the keys of this company are of this general type, the particular one shown being adapted to two-party line ringing and listening.

The two operating levers, *L* and *L'*, are pivoted in a heavy brass casting, *A*, upon which the several sets of contact springs are mounted. The button or wedge of insulating material (rawhide) carried on the lower end of the lever, *L*, plays between the listening group of springs, shown at the left of the figures, and a set of ringing springs, which is the middle group on the key. When, therefore, the key lever, *L*, is thrown to the right, as seen in the cut, the operator's telephone set will be connected with the cord circuit. When

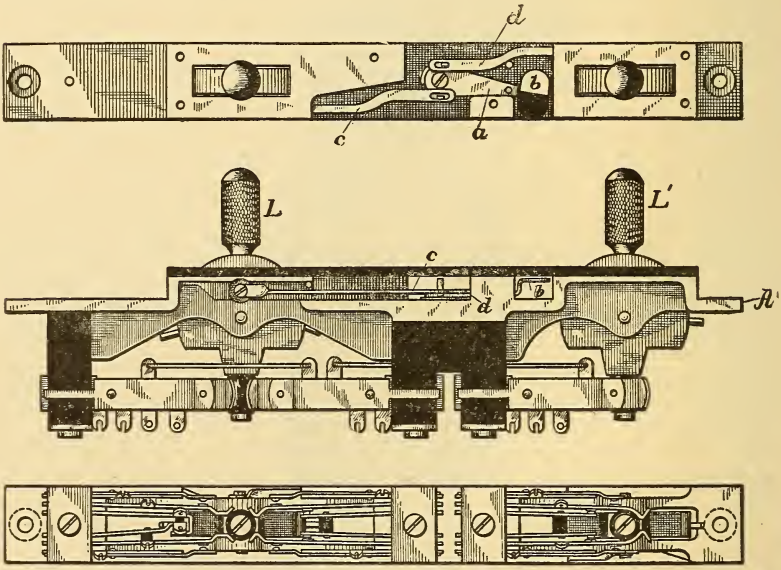


FIG. 375.—WESTERN ELECTRIC RINGING AND LISTENING KEY.

this lever is thrown in the opposite direction the calling plug is disconnected from the rest of the cord circuit and is placed in proper relation with the calling generator terminals to effect the ringing of the bell of one of the parties on the line with which the calling plug is connected. The wedge of the lever, *L'*, plays between one set of springs only, this lever when thrown to the right being adapted to serve as a ringing key for the other party on the line.

The operation of the springs themselves will be obvious from what has already been written of the cord circuits of the Western Electric Company. The small hook-shaped spring on the inside of the group of listening springs is that used for completing the circuit of the restoring coil of the clearing-out drop when the listening key is thrown.

The upper cut in Fig. 375 shows a top view of the key with its upper hard rubber finishing strip removed. This discloses a top view of a lever, *a*, carrying a white and red target, *b*. This target is displayed to the view of the operator through a hole in the rubber finishing strip. The lever, *a*, is so arranged as to be moved by the slotted link rods, *c* and *d*, pivoted respectively to the key levers, *L* and *L′*. By virtue of the pin and slot connection between these links and the lever, *a*, the target will be moved into the position shown (and will therefore appear white) when the lever *L* is thrown into its ringing position. It will not be moved by subsequent operation of this lever, but if lever L′ is thrown the target will be

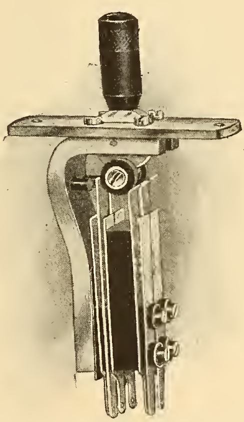


FIG. 376.—KELLOGG RINGING AND LISTENING KEY.

moved by means of link, *d*, so as to have its red portion visible to the operator. This target, therefore, always shows to the operator which one of the ringing keys was last operated, so that if required to ring a party a second time she will not press the wrong key.

It is obvious that this key may be modified to meet almost any requirements of service, as for instance, by leaving off the right-hand cam with its group of springs, and also the indicating device, the key becomes merely a combined ringing and listening key for ordinary single-party work. This key is secured in the key shelf in an iron framework, the various keys being mounted close together side by side and secured in this framework by machine screws. Eighteen of such keys may be placed side by side in an ordinary key shelf without unduly crowding, and at the same time leaving enough room for order-wire keys, if such are required.

The type of key used by the Kellogg Switchboard and Supply Company in nearly all of their work is shown in Fig. 376.

In Fig. 377 is clearly shown how two or more of these keys may be associated on a single mounting strip for the purpose of securing any desired combination of keys. The means by which this key is made into a two-way ringing key for two-party line service deserves attention. No separate indicator is used, but a knuckle joint is provided in the handle of the key at the point where it joins the cam. This joint, by means of a spring-pressed contact, moves with considerable friction, but always moves when the operator presses the

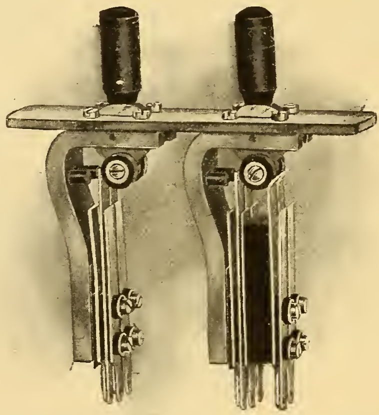


FIG. 377.—TWO KELLOGG KEYS ON SINGLE PLATE.

key into the ringing position in one direction or the other. The handle of the key is always left leaning in the direction in which it was last pressed, thus serving as an indicator to the touch, as well as to the vision, of the operator.

The four-party line ringing key of the Western Electric Company is shown in Fig. 378. The operation of this key in its relation to four-party line signaling will be apparent from the circuits already given in the chapter on Party Lines. The fifth ringing key at the left in the figure is for ringing on individual lines where no selective signaling is required. The cam-key at the right is the listening key. The indicating feature for the ringing keys in this is interesting, consisting as it does of four slidable plates adapted to be moved in one direction or the other by the operation of any one of the plungers. As these plates all bear against each other except for the slight space which may be left between any pair of them, and since there is only room enough in their slide-way for one such space between them as is produced by the movement of the plunger when

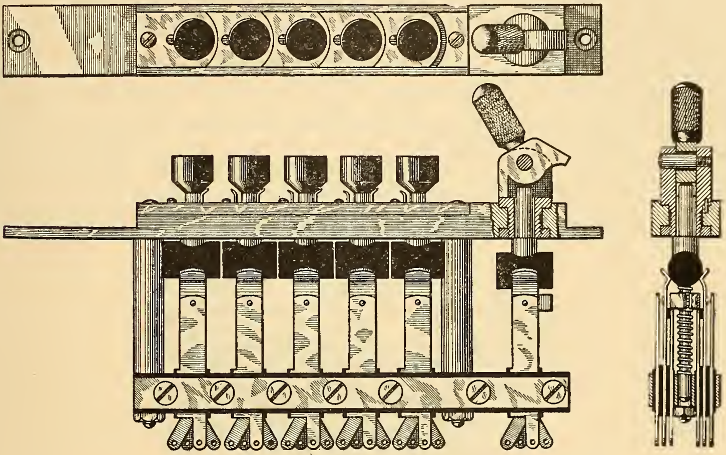


FIG. 378.—WESTERN ELECTRIC FOUR-PARTY-LINE KEY.

operated, it follows that an opening will always be left between the pair of plates corresponding to the plunger last depressed. The surface below the plates is painted a bright red, and this showing

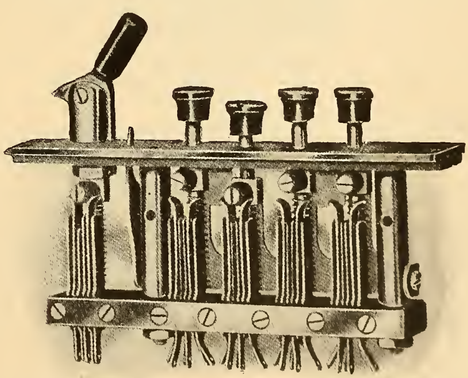


FIG. 379.—KELLOGG FOUR-PARTY-LINE KEY.

through the opening between the plates serves to indicate to the operator what key was last depressed.

The Kellogg four-party line ringing key is shown in Fig. 379. In general form, circuits and use this key is similar to the Western

Electric Company's key just described, but it has an additional advantage in recording the last party rung. In the figure, a metal locking plate will be observed, pivoted with screws to the vertical pillars uniting the top and bottom portions of the key, extending along beside the ringing plungers, and with a small tip projecting through the upper finishing plate of the key just between the listening cam and the first ringing plunger. This locking plate engages a projection on each ringing plunger which prevents a depressed plunger from returning to its normal position of rest, and holds it slightly below the level of the other plungers of the key, but the pressing of any plunger so engages and moves the metal locking plate as to release any plunger previously held, thus permitting all plungers to re-

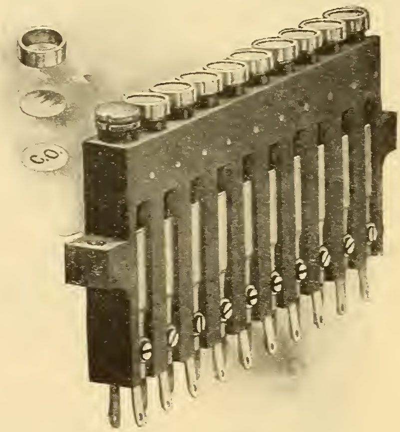


FIG. 380.—STRIP OF ORDER-WIRE KEYS

turn to their full height, except the one last used. The operator thus may learn by touch, as well as by sight, which station on a line was rung last. By pressing the locking plate tip projecting near the listening cam, all plungers may be released. In this key, as in any key having separate plungers for the separate stations, the push-buttons may be made of different colors and may be identified by their color as well as by their location on the keyboard.

Order-wire keys are usually operated in the same manner as push-buttons, the plunger when depressed serving to press the two contact springs with which the terminals of the order-wire line are connected into contact with the two springs forming the terminals of the operator's telephone set. Such keys are usually mounted in strips of ten. One of these strips, as manufactured by the Kellogg Company, is shown in Fig. 380.

In this the framework is formed of a solid piece of hard rubber, polished on its upper face. The springs are of German silver, platinum pointed. Such a strip of keys is usually mounted crosswise on the left-hand portion of the key shelf of the multiple board, the face of the rubber block coming flush with the upper face of the key shelf. If more than ten order-wire keys are needed, then more than one strip is provided, several strips being mounted side by side. The approximate dimensions of such a strip as this is 5 inches long by ½ inch wide.

Sometimes it is desirable to mount order-wire keys individually,

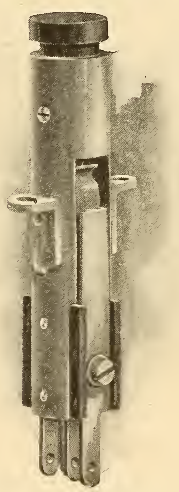


FIG. 381.—INDIVIDUALLY MOUNTED ORDER-WIRE KEY.

and in this case the key shown in Fig. 381 is used, this extending up through a circular hole on the key shelf and secured thereto by screws passing through the side lugs on the key into the shelf. The working parts of this key are mounted in a metal frame supporting the hard rubber block on which the several springs are mounted.

The push buttons or heads of the order-wire keys are usually provided with removable caps containing a mica or thin glass top, under which may be placed the number or other designation of the key or circuit.

On the front rail supporting the key shelf at the left-hand portion of each position of modern multiple boards are mounted one or two operators' cut-in jacks. These jacks afford means for instantly connecting or disconnecting the operator's head telephone, the free end of the cord of which terminates in a plug adapted to enter the jack. Besides the tip and sleeve contact for completing the talking circuit, these jacks are usually provided with an extra pair of springs, open when the plug is not inserted, but closed by the insertion of the plug, these springs serving to open or close the circuit which supplies current to the operator's telephone transmitter. In this way a waste of current through these transmitters at idle positions is prevented. Such a jack and plug are shown in Fig. 382, this being a type now manufactured by the Stromberg-Carlson Company. This type was originated by the Kellogg Company, and has the advantage of taking up very little room under the key shelf, the U-shaped springs extending a very much less distance back under the key shelf than if the springs were straight. When two such jacks are

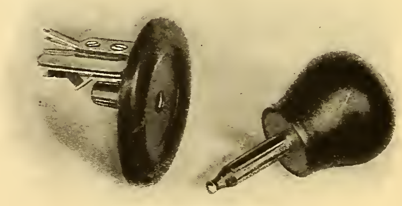


FIG. 382.—CUT-IN JACK AND PLUG.

mounted side by side they are wired together in multiple, the object being to provide a ready means for the instruction of new operators, and also for the repair men or inspectors to listen in without interfering with the work of the regular operators.

The support of the operators' transmitters in telephone switchboards has been the subject of much thought, and opinion and practice are now divided between two general methods. One of these, used to but a comparatively slight extent in this country, although finding considerable favor in Europe, is to support the transmitter directly on a plate carried on the operator's breast, this plate being suspended by a band passing around her neck. A long mouth-piece is provided extending to a point within a few inches of the operator's lips. Such a type has the advantage of not obstructing the view of the operator of the face of the board and of automatically following the operator in her motions. It, however, has the drawback of being in the nature of additional "harness" for the operator to wear, of not securing as good transmission, because of the long curved mouth-piece, and of requiring that the operator's cut-in plug and jack carry four contacts instead of two, two for the transmitter and two for the receiver. It is also found rather difficult to prevent these transmitters from becoming foul, due to the constant breathing of the operators into the mouth-pieces.

The other method of supporting transmitters which, in modified forms, is the most largely used in this country, is shown in Fig. 194. The board upon which the stand is mounted is the roof board

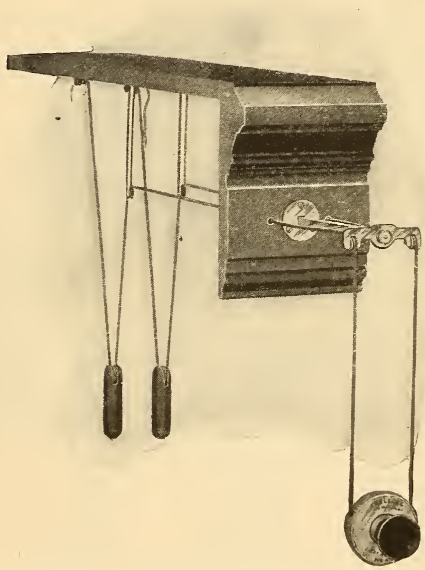


FIG. 384.—OPERATOR'S TRANSMITTER MOUNTING FOR MULTIPLE BOARDS.

of the switch-board section. As will be seen, the horizontal arm from which the transmitter is suspended is, by means of a thumb-screw, carried on the top of a vertical post, adjustable in or out, that is, toward or from the face of the jack space. The transmitter itself is adjustable up and down at the will of the operator, the transmitter cords passing over pulleys as shown. Counter-weights hanging on the cords within the switch-board section serve to balance the transmitter so that it will remain in any position.

Fig. 384 shows a transmitter suspension best adapted to large multiple boards. In this the upright post is abandoned, the horizontal arm passing through a brass bushing in the frieze-board above the multiple jacks.

The relays in telephone work assume an almost endless variety of forms. There has been a gradual evolution in these from the type used in telegraphy, commonly known as the Morse relay, one of which is shown in Fig. 385. For a quick-acting relay and a very sensitive one this type is still used in telephony where there is no particular need to economize room. The evolution spoken of, however, has been made necessary primarily on account of the necessity for the economy of room, and also in order to produce a somewhat cheaper design than that of the old Morse relay. Of course, other factors enter into the problem also. In particular cases, some relays

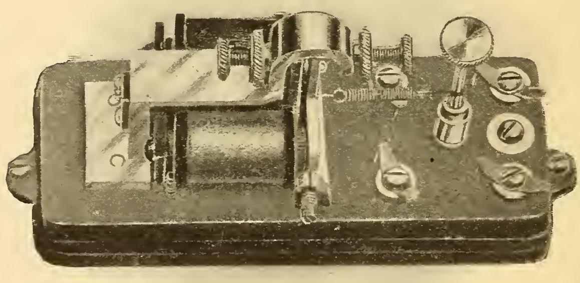


FIG. 385.—MORSE RELAY.

must be of such design as to enable them to be mounted closely together without producing cross-talk between them; some relays must be polarized so as to operate on current in one direction only; others must be differentially wound; some must be designed for maximum impedance; others for no impedance under certain conditions; some relays, as is the case with the old Morse, are required to make one contact only; others are sometimes required to make three contacts and break three; sometimes the order in which the contacts are made and broken is an important factor in the design. From all of this it will be seen that the design of a telephone relay must be made with a view to the particular use to which that relay is to be put, and that a relay adapted to one purpose in a telephone system will perhaps be totally unfit for use in some other portion.

Taking up first the matter of supervisory relays, one of the first of these to be developed is of the type shown in Fig. 386, this type having been widely used in Bell exchanges.

The coil, *b*, of this relay was in the earlier types enclosed in a heavy iron shell, the armature, *d*, serving when attracted to completely close this shell. The armature itself is in the form of a truncated cone, and has no support save that it rests within the cup-shaped cap which fits over the front end of the shell and protects the working

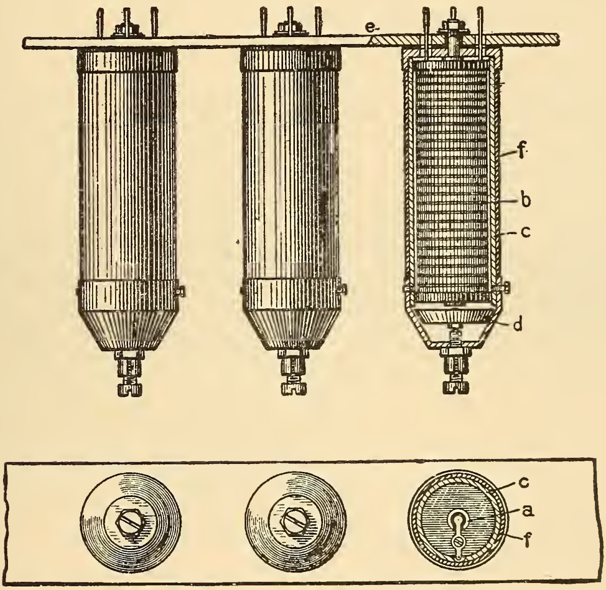


FIG. 386.—OLD BELL SUPERVISORY RELAY.

parts of the relay from dust. When the coil is not energized the armature falls back by gravity against the adjustable stop carried in the cap, while, when attracted, it merely rocks on its knife-edge support and completely closes the shell. This is a single-contact relay, the stationary contact being carried on the front end of the core, this end of the core being hollowed out, as at *a*, and provided with an insulating bushing carrying a brass clip, upon which is mounted the platinum contact. The armature itself carries at its center point a screw which is platinum pointed and adapted to make contact with the stationary contact point when the armature is attracted. Such relays were mounted on suitable iron strips on about $1\frac{3}{4}$-inch centers, such a strip of ten being shown in Fig. 387.

In later types of this relay, the heavy iron shell was abandoned, and the structure of shell specifically shown in Fig. 386 adopted. The primary object of the iron shell is to prevent cross talk by confining the lines of force set up in the coil of the relay, within the structure of the relay. It was later found by McBerty that a copper shell was effective for this purpose, and therefore a thin iron tube, *c*, Fig. 386, merely bent up from sheet iron, was used as a return circuit for the magnetic lines of force set up in the core, while cross talk was prevented by the outer shell, *f*, of thin copper. The application of the McBerty copper shell to coils of various kinds used in telephone work, was an important step in the art. It allows a much greater latitude of design of coils for various purposes.

This type of relay, while effective and efficient, is not now largely

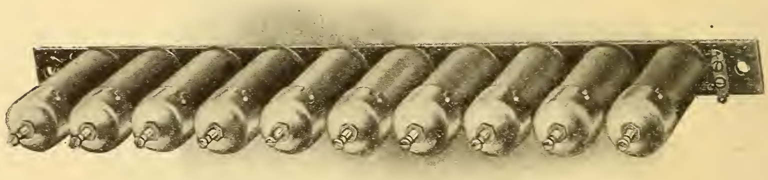


FIG. 387.—STRIP OF SUPERVISORY RELAYS.

used except in comparatively few installations of the Bell companies. It had one serious fault in that the knife-edge contact between the armature and the inside of the case formed a part of the local circuit to be closed by the relay, which contact was not reliable. It was made so, however, by bridging the contact with a little spiral of wire soldered at one end to the shell and at the other to the armature, but this was a nuisance, and was bad mechanically. Moreover, this type of relay was adaptable only to the operation of a single "make" contact, being useless when it became necessary to provide for both making and breaking one or several contacts when energized.

The type of relay now used for line and supervisory work by the Western Electric Company in the switch-board they manufacture for the various Bell companies is shown in Fig. 388.

This is a modification of the tilting armature type shown in Fig.

386, and needs little explanation. For supervisory purposes where it is important to prevent cross talk, the outer shell, *g*, of this relay is made of copper about 3-32 inch thick. This type of relay is also used as a line relay for lighting the line lamp, but in this case the copper shell is omitted, and all of the relays on the strip are enclosed in a common dust-proof case.

The type of relay now largely used by the Bell companies for their cut-off relay, or, in general, where several contacts have to be made and broken, is shown in plan, elevation and section in Fig. 389.

In this, *m*, is the mounting strip to which is secured the core, *a*, carrying at its rear end an angular pole-piece, *d*, and at its front end

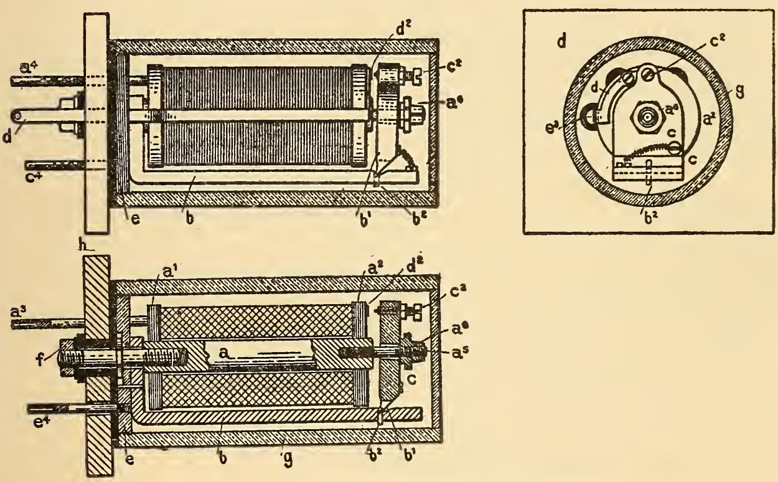


FIG. 388.—WESTERN ELECTRIC LINE RELAY.

a similar piece, *d'*; secured to the under side of the pole-piece, *d*, by a spring, *e'*, is an armature, *e*, projecting forwardly under the horizontal portion of the angular pole-piece, *d'*. This armature is therefore raised by the magnetic pull of the two pole-pieces when the coil is energized. The armature thus serves to complete the magnetic circuit between the two pole-pieces. The downward movement of the armature is limited by the adjustment screw, *f*, against which it rests when not attracted. The range of movement of the armature may be adjusted by means of this screw, as is readily seen. Carried on the upper face of the pole-piece, *d*, are two pairs of contact springs, *i* and *g*, *i'* and *g'*, these springs carrying platinum contact points at their forward ends, and are so arranged that the upper spring will normally make contact with the lower one. The lower spring, *i*, in each case rests on a rubber bushing on the front pole-piece, *d'*, thus affording a permanent support for these springs, which have a downward tension against these bushings. The movable springs, *g*, also have a downward tension, which serves to keep their platinum contacts in engagement with the lower springs. Two rubber plugs, *k* and *k'*, are carried by the armature, *e*, and one of these extends through each of the lower contact springs, *i* or *i'*, the holes in these springs through which these plugs extend being considerably larger than the plugs themselves. When

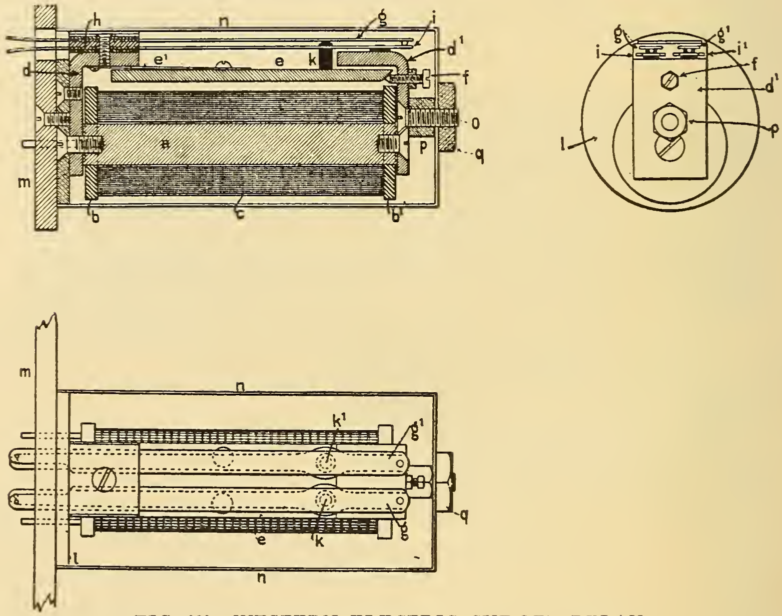


FIG. 389.—WESTERN ELECTRIC CUT-OFF RELAY.

the armature is attracted the plugs, *k*, serve to raise the springs, *g*, thus breaking their contact with the springs, *i*.

It is easy to see that the springs, *g*, in their upward movement might also be made to make contact with other springs above them when the armature is attracted. In order to shield the entire relay from dust a sheet-iron shell, *n*, slips over the entire structure and is held in place by a nut, *q*, permanently secured to the shell which engages a screw, *o*, carried on the frame of the relay. This is the type of relay now used by the Bell companies as a cut-off for their line circuits in common battery work.

A type of relay used by the Kellogg Company for both its line and cut-off relays is shown in Fig. 390.

In this it will be seen that the springs are mounted in a group or groups on an iron plate carried on the top of the coil, this plate being bent downwardly at its rear end and engaging the rear of the core. Resting on the knife-edge on the front of this plate which extends to the front of the relay coil is an angular armature which, when its lower end is attracted, raises the long spring out of contact with the lower spring and into the contact of the upper one. The lower spring

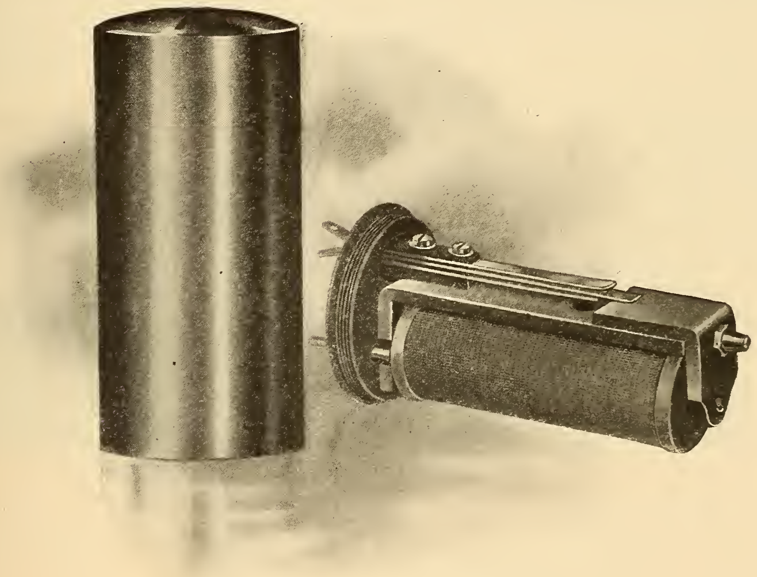


FIG. 390.—KELLOGG LINE RELAY.

rests on the shoulder of a hard rubber post, upon the top of which is also supported the upper springs, both of these springs having a normal tension downward. The hard rubber post passes through a large hole in the long spring, so as to allow its free movement up and down. By mounting three groups of springs on these relays as many as three make and three break contacts may be secured.

In the Kellogg line relay but a single "make" contact is required, there being one group of springs mounted on the center of the upper plate, these being adapted to make contact when the armature is attracted.

In the Kellogg cut-off relay, as used in the line circuit of the Kellogg multiple switch-boards, there are two groups of three springs, each having one make and one break contact. This relay, in whatever type made, is enclosed in a drawn iron shell about 1-16 of an inch thick, this shell being screw-threaded on the circular washer forming the base upon which the relay parts are mounted.

A group of twenty line and cut-off relays, ten of each mounted on a single strip of cold drawn steel, is shown in Fig. 391. This illustrates a feature of modern practice as adopted by nearly all companies, that of mounting the line and cut-off relays in such proximity as to enable much of the wiring to be done with short, stiff, bare jumper wires extending between the terminals of the relays themselves on the strip. The other side of this strip has the relay ter-

FIG. 391.—STRIP OF TWENTY LINE AND CUT-OFF RELAYS

minals so connected that all wiring is open and ready for inspection, the use of cable being very largely eliminated.

The Kellogg Company is also manufacturing a somewhat cheaper and more compact relay, which it terms its "minor" relay, which embraces the same mode of operation as its major type of relay just described, but embodies some very unique features in point of construction.

These relays are of the tubular type, but the method of construction differs radically from that of the ordinary tubular relay, for a single iron casting is drilled out to take the place of ten tubular shells. The various contact springs are arranged directly on top of this iron casting, being secured thereto by screws passing through rubber bushings and blocks for the purpose of insulating

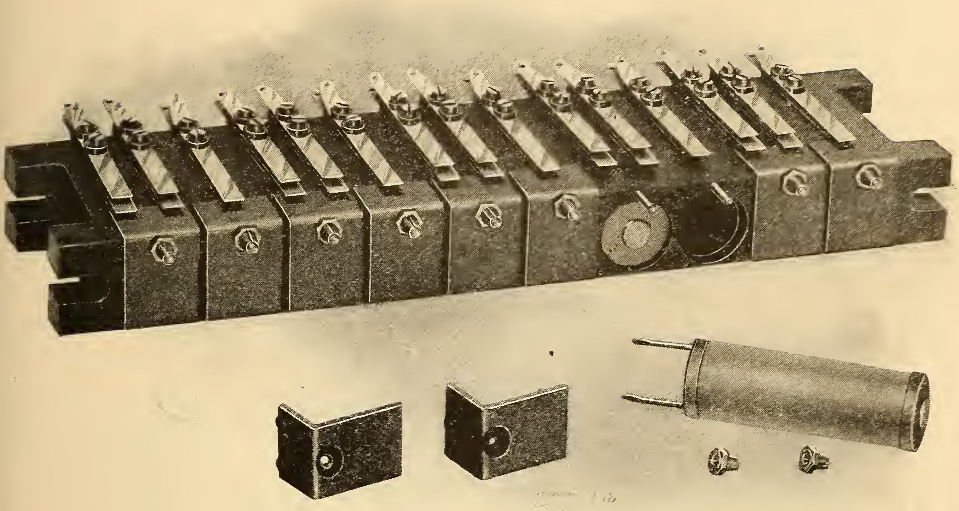


FIG. 393.—STRIP OF TEN KELLOGG MINOR RELAYS—FRONT VIEW.

FIG. 394.—STRIP OF TEN KELLOGG MINOR RELAYS—REAR VIEW.

them from each other and from the iron block. The coils are placed directly in the holes bored in the face of the block, their terminals extending through small bushed holes in the rear. The angular armature hangs over the front upper corner of the block in such position that when attracted by the core of the coil within, its rear leg will serve to raise the contact springs. In the block shown the relays are alternately line and cut-off. Fig. 393 shows the front and Fig. 394 the rear of such block of relays, the latter figure making clearer the arrangement of the various terminals. These relays, as will be seen, are not in themselves dust proof, and when therefore this type is used they are either mounted on a rack contained in a glass case or each strip of relays is provided with a sheet-iron dust-proof box, which slips over the entire strip.

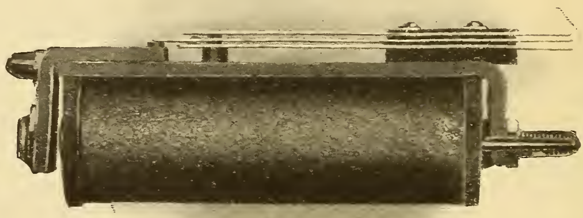


FIG. 395.—STROMBERG-CARLSON RELAY.

The Stromberg-Carlson Company are using a relay almost identical in design with the major type of Kellogg relay, the only difference being that they provide an adjustable iron screw on the lower end of the armature by means of which the air gap may be varied. One of their relays without its shell is shown in Fig. 395.

In the design of pilot relays, which are used in the common portion of a circuit extending from the battery to a number of different circuits, it becomes necessary to design a relay which will be of low enough resistance to allow sufficient current to be supplied to a number of such circuits in multiple. When such circuits contain lamps the pilot relay must be of great enough carrying capacity and low enough resistance to prevent causing enough drop through its coil to appreciably diminish the voltage of the lamps. At the same time it must be sensitive enough to be operated by current through one lamp only. It must have as another requirement a capacity to carry the current required by the greatest number of lamps that will have to be lighted through it without undue heat. As comparatively few of these relays are required, the heating effect may be taken care of by making the relay of large dimensions, so as to have a large radiating surface. This also affords greater winding space, so that the required number of turns may be put on the coil with comparatively large wire. Such relays usually have a resistance of from one to three ohms.

In Fig. 396 is shown the pilot relay of the Kellogg Company,

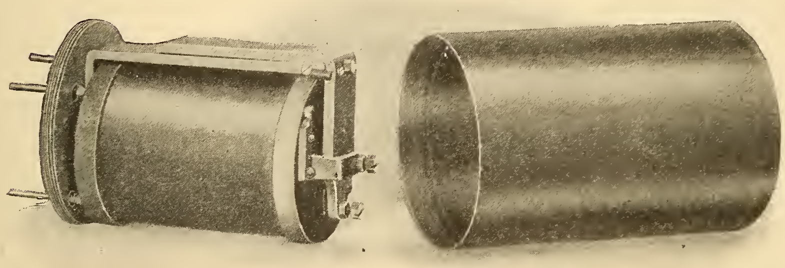


FIG. 396.—KELLOGG PILOT RELAY.

this being of the same general type as its major relay, except that the contacts are carried on the front leg of the armature and on the front head of the core. This relay has a gravity-actuated armature. It is about two inches in diameter and 3½ inches long. When wound to .022 ohm resistance it will operate with a current of ½ ampere, and will stand a maximum current of 45 amperes. When wound to a resistance of 1.5 ohms it will operate on about 1-20 of an ampere, which is amply sensitive for use as a pilot relay, since a single lamp requires a current of at least 1-10 ampere to operate it.

CHAPTER XXVIII.

POWER PLANTS FOR COMMON BATTERY SYSTEMS.

THE power plant required in an old magneto exchange was an insignificant portion of the equipment, and consisted, as a rule, of nothing more than one or a few ringing generators driven by some constant source of power, and adapted to produce alternating currents of the desired voltage and frequency to properly actuate the bells at the subscribers' stations. Frequently these machines were merely magneto generators provided with exceptionally strong fields, and adapted to be driven by the source of power available rather than by hand.

In the old magneto exchanges it was customary in most cases to equip each operator's position with a hand generator, to be used in case of a break-down of the power ringing machines, so that, aside from causing some inconvenience to the operators, the temporary disability of the power machines was of little importance. In modern exchanges, however, where the switch-boards are of large size, and, in fact, in common battery *multiple* switch-board work in general, the hand generators are not provided, so that entire reliance must be placed on the power machines. This, and the fact that the operation of the system is also dependent on the proper supply of direct current for signaling and talking, greatly increases the necessity for absolute reliability in the power plant, without which the continuous operation of the exchange cannot be effected.

The most convenient source of primary power for a telephone exchange is the mains of some municipal or private power plant, when these are available for service at the telephone central office. It is not, however, well to place sole reliance for power on a single source of such current supply, for a fire in some portion of the city or some other catastrophe may result in shutting off the power from the mains to the telephone office for a considerable period, and as a result render the giving of telephone service to the community an impossibility. It is therefore advisable, when possible, to secure two entirely independent sources of power, as, for instance, from two different power companies, where such are available, or from one power company and from an auxiliary power plant operated by a gas or steam engine, owned or controlled by the telephone company. Many telephone companies, therefore, arrange for two such sources of power, one of them being usually power mains from the outside, and the other a plant operated by a gas or steam engine in the telephone plant. In such cases the question as to whether the gas or steam engine should be used as the regular source of power, and the street mains as a reserve, or *vice versa*, depends entirely on the question of relative cost. This is usually dependent, in large measure, on the size of the telephone plant and on the terms the telephone company is able to secure from the company supplying the power.

Where electric power is available motors are used usually directly connected to the charging generators for delivering direct current to the storage batteries and to the smaller alternating current dynamos or ringing machines adapted to deliver the proper current for ringing the subscribers' bells. In case a gas engine or other prime mover is employed, this is generally belted directly to the charging machines, which may be of the same type as before, and, in fact, the same charging dynamo may be alternately belted to the gas engine or driven by an electric motor, according to whether outside or local power is being used.

On account of the necessity for absolute reliability good practice dictates that the charging machines, and also the ringing machines, should be in duplicate. When two sources of primary power are used, each charging machine should be adapted to being driven from either source of power. It is customary, in common battery offices, to employ two ringing machines, and to drive one of them from the street mains or other source of primary power, and to drive the other one by a motor deriving current from the discharge leads of the storage battery. In this way, in case of a complete break-down of all sources of primary power, the telephone plant may still be continued in operation as long as the storage battery retains a sufficient amount of charge. In a well-designed telephone plant the storage battery should be of sufficient capacity to run the entire exchange for a period of twenty-four hours without receiving any additions to its charge. When all of these precautions have been taken, it is seen that the chance of a complete shutdown of the telephone plant, due to any failure on the part of the power plant, is extremely remote, and it is a fact that there are very few cases on record of a common battery telephone plant of any size ever having been forced to suspend service from this cause.

As a rule, nothing short of a serious fire in the switch-board can bring about a cessation of service in a telephone office.

It may be said in general, therefore, that most telephone power plants for common battery work comprise at least two direct current machines of suitable voltage and capacity for properly charging the storage batteries, and two alternating or pulsating current ringing machines for operating the subscribers' bells, and that in the case of the ringing machines one of them is driven from the same source or sources of power which drives the charging machines, while the other should be driven by a motor taking current from the discharge leads from the storage battery.

The question as to the source or sources of primary power to be used in any exchange is one to be decided only after a careful consideration of the local conditions in the city in question. Practice must necessarily differ widely in this respect, but it may be considered as fairly well standardized with respect to the apparatus and circuits employed in generating, measuring and controlling the charging and ringing currents, as well as the current in the discharge leads of the storage battery.

For the purpose of discussing such circuits and apparatus a specific case will be taken in the standard power plant and equipment furnished by the Western Electric Company for most of its modern Bell exchanges. The arrangement of this is shown diagrammatically in Fig. 397.

The power leads from whatever source are shown entering the switch-board apparatus in the left-hand side of this figure. In this case the available power is direct current at 500 volts, and the mains pass first through fuses of sufficient carrying capacity, thence through the main switch adapted to cut off the entire power back of all apparatus, and thence through arresters for the protection of the power apparatus. These consist of an air-gap and a choke-coil of low resistance, but high impedance, in each side of the power circuit. Each lead then passes through another fuse, and thence to the power switch-board proper. An ammeter and a wattmeter are here shown for measuring the total current, and the total energy delivered to the power board. It is not the practice of the independent companies, as a rule, to furnish the wattmeter on the power board, for the reason that this is usually supplied by the company furnishing the current, and is mounted by them in some portion of the power circuit outside of the power board.

At the point *A* the main circuit divides into three separate leads,

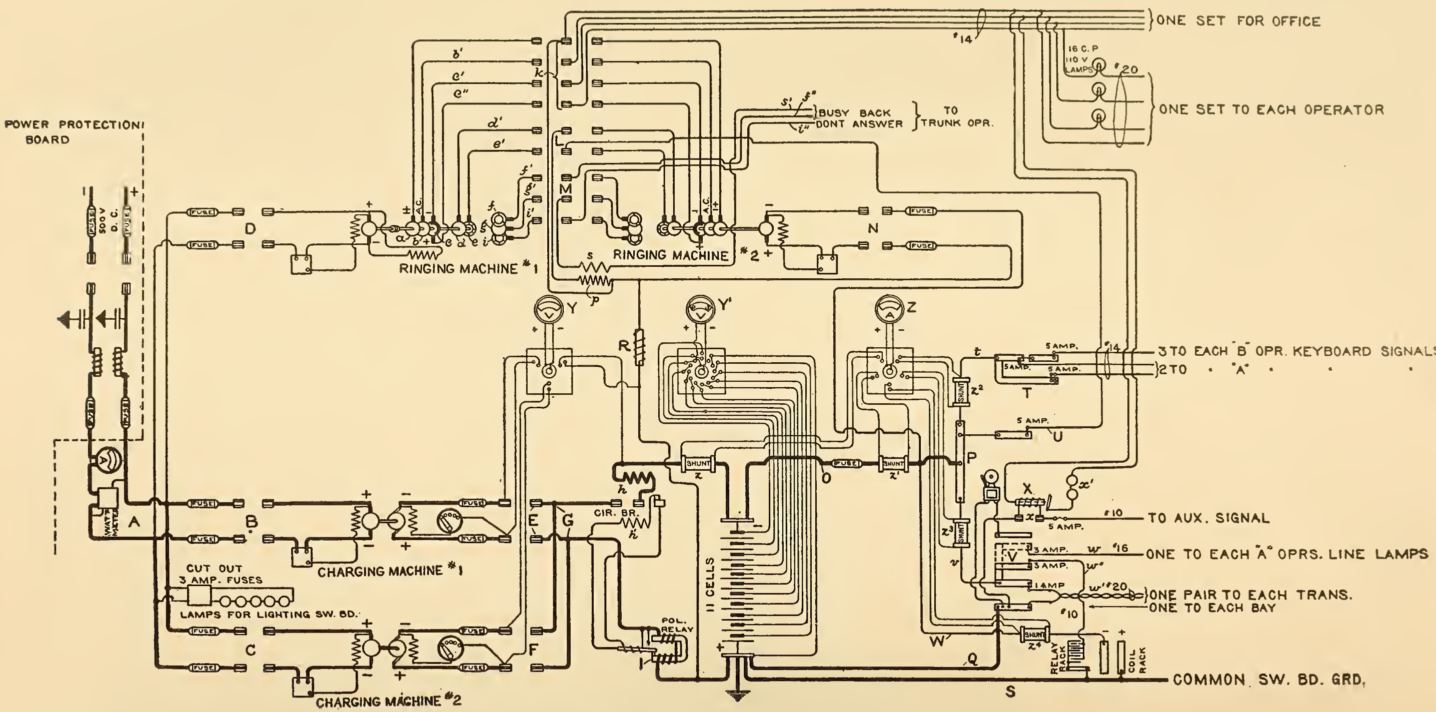


FIG. 397.—CIRCUIT OF POWER PLANT.

two of which extend through separate pairs of fuses to the single-throw, double-pole knife switches, *B* and *C*, controlling respectively the motors of charging machines, Nos. 1 and 2, the generators of which supply direct current for charging the storage battery for the supply of all direct current to the exchange. The third branch of the main power lead extends to the knife switch, *D*, which controls the motor side of ringing machine No. 1, used for supplying alternating and pulsating current to the subscribers' lines for ringing, and also for other minor purposes, which will be pointed out later.

Bridged across the main power leads are the lamps for lighting the power switch-board, these being arranged in any suitable manner, in accordance with the voltage across the power mains. In this particular case, where 500 volts direct current is used, five 100-volt lamps are placed across the circuit in series, and these are controlled by a double-pole cut-out of the snap-switch type.

It is seen that the motors of the charging machines and of ringing machine No. 1 are provided with ordinary starting boxes, which, with their respective switches, *B*, *C* and *D*, control the motor sides of any of these machines. The generator sides of the charging machines are shunt-wound, and in the shunt circuit is provided a field rheostat, having a sufficient number of points to allow for a very close regulation of the output of the machines at widely different voltages. Of course, under normal circumstances the voltage of the charging machines should be that necessary to deliver the proper charging current to the storage battery as a whole. In the treatment of a defective cell, however, it is often necessary to charge that cell separately, and it is of great advantage if the charging generator may be run at the low voltage then required, without the use of external resistance.

The generator leads from each of the charging machines extend through fuses, as shown, and through knife switches, *E* and *F*, from which switches the circuits of the two machines join at the point, *G*, forming the charging circuit of the battery. One side of this circuit passes through the switch of an over and under load circuit-breaker to the negative pole of the battery, while the other side passes through a coil of a polarized relay to the positive or grounded pole of the battery.

The functions of the circuit-breaker and of the relay are as follows: Current passing from either of the charging machines to the negative pole of the battery passes through the heavy wire coil, *h*, of the circuit-breaker, and if this current rises above a certain predetermined value the electro magnet, of which this coil forms a part, attracts its armature and trips the circuit-braker switch, so as to open the circuit, preventing any damage which might arise from an excess of current from the machines. The circuit-breaker has another winding, *h'*, of comparatively high resistance and greater number of turns, which winding is in the local circuit of a polarized relay, *I*. When the local circuit of the polarized relay is closed, therefore, the coil, *h'*, takes current from the charging leads and operates its armature to trip the circuit-breaker in exactly the same manner as when the heavy wire coil, *h*, operated. The polarized relay, *I*, is provided with a heavy winding, placed in series in that side of the charging circuit which connects with the grounded pole of the battery. The charging current flowing from the machines to the battery passes through this polarized relay in such a direction as to hold the local circuit of this relay open. If, however, through any cause whatever, the voltage of the charging machines becomes lower than that of the storage battery, current will tend to back up from the storage battery through the armature and field of the charging generator and run it as a motor. This current would pass through the coil of the polarized relay in the opposite direction from the normal, and would therefore cause it to close the local circuit and open the circuit-breaker by the action of the coil, *h'*.

By the means so far discussed, the batteries may be charged to any degree desired, and at the same time any damage due to the excess charging current, or to a reversal of current in the charging circuit, is guarded against.

The control of ringing machine No. 1 is the same, as far as its motor side is concerned, as that of either of the charging machines. On the shaft of the ringing machine are provided three collector or commutator rings, *a*, *b* and *c*. Rings *a* and *b* are continuous throughout their circumference, but ring *c* is split, one-half of it being of insulating material and the other half of conducting material. Separate brushes bear against rings *a* and *b*, while two such brushes bear against ring *c*, these latter brushes being placed 180° apart. There are therefore four brushes on these three collector rings, and from these extend four wires, *a'*, *b'*, *c'* and *c''*. These wires extend to the contacts on one side of the four-lever, double-throw switch, *K*. The leads *a'* and *b'* carry alternating current used in work on single-party lines. The lead *a'* may also be used in connection with *c'* or *c''*, to deliver negative pulsating current or positive pulsating current, as required. The blades of the four-lever switch, *K*, are connected with a four-conductor cable of No. 14 rubber-covered wire, from which the distribution of ringing current is made to each operator's position in the office.

The armature shaft of the ringing machine carries two other disks, *d* and *e*, against which brushes bear, which are connected by wires, *d'* and *e'*, to the left-hand contacts of the double-pole, double-throw knife switch, *L*, from one of the blades of which extends a wire through the primary coil, *p*, of an induction coil, and through an impedance coil, *R*, to the grounded pole of the storage battery. From the other blade of the switch, *L*, extends a wire which passes through a five-ampere fuse to the discharge lead from the ungrounded side of the battery. The contact, *d'*, upon the ringing machine shaft is continuous as to its conductivity, while the contact wheel, *e*, has its circumference divided up by interposed strips of insulating material into a number of segments. The conducting segments on the circumference of the disk, *e*, are in electrical connection with the wheel, *d*, and therefore the rotation of the ringing machine serves to alternately break and make the circuit between the leads, *d'* and *e'*, as many times during each revolution as there are segments in the wheel, *e*. As a result, when the switch lever, *L*, is thrown to the left, and ringing machine No. 1 is running, a pulsating current flows from the storage battery through the contact maker on the ringing machine shaft and through the primary, *p*, of the induction coil, thus inducing in the secondary winding *s*, of the induction coil, a periodic electromotive force for the production of what is known as a "tone" used in various forms of signaling in the exchange.

Associated also with the ringing machine shaft is another set of contact disks or wheels, *f*, *g* and *i*, which revolve with varying rates of speed. The brushes of these are connected by wires, *f'*, *g'* and *i'*, to the left-hand contacts of the triple-lever, double-throw switch, *M*. The secondary, *s*, of the induction coil is connected between the middle lever of the switch, *M*, and one conductor, *s'*, of the three-wire cable leading to the various incoming trunk operators' posi-
f, on the ringing machine is connected when switch, *M*, is thrown to the left, one terminal of this secondary coil is connected to the disk, *g*, the surface of which is a continuous conductor. The disk, *f*, on the ringing machine is connected when switch, *M*, is thrown to the left, with the conductor, *f''*, also in the three-wire cable leading to the trunk operators' positions; and with the switch in the

same position the disk, *i*, is similarly connected to the conductor, i'', in the same cable. The disk, *f*, is divided in its circumference into a small number of divisions and revolves slowly, and therefore when the conductors, s' and f', are used as a pair, in connection with a talking circuit, a slowly interrupted tone is heard. The tone itself is due to the interruption of the circuit passing through the primary coil, *p*, of the induction coil which induces current in the secondary winding, *s*, of this same coil, and the slow interruptions of the tone are due to the interruptions in the secondary circuit, *f*. It is thus that the busy back signal, consisting as it does of a slowly interrupted tone, is placed at the disposal of the connecting trunk operators, the wires, s' and f'', terminating in the conductors of the busy back jacks at each trunk operator's position. The "don't answer" signal is similarly placed at the disposal of the trunk operators by leading the wires, s' and i'', to "don't-answer" jacks on these operators' positions. In this case, owing to the greater rapidity of interruptions caused by the contact wheel, *i*, the tone heard in the receiver connected with the "don't-answer" circuits is more rapidly interrupted than in the case of the busy back.

It will be seen that the connections from the secondary side of ringing machine No. 2, including all of the disks carried on or operated by its shaft, are made in the same manner as those of ringing machine No. 1, all of the leads of ringing machine No. 2 being led to the right-hand, instead of the left-hand, contacts of the switches, *K*, *L* and *M*. By throwing these switches to the right instead of to the left, the various ringing currents from these machines, together with the busy back and "don't-answer" currents, will be obtained from ringing machine No. 2, instead of from No. 1.

Instead of being driven directly from the outside mains, as is ringing machine No. 1, ringing machine No. 2 derives its current from the discharge leads of the storage battery. This motor side is therefore wound for the voltage available from the storage battery. By throwing the switch, *N*, the motor of ringing machine No. 2 may be connected across the discharge leads of the storage battery, thus placing that machine in operation after the proper manipulation of the starting box. The retardation coil, *R*, is placed in the circuit leading from the storage battery to the motor of ringing machine No. 2, in order to prevent the fluctuations in the current drawn from the storage battery when this machine is running, due to the commutation on the motor from "throwing a noise on the battery." This term, "throwing a noise on the battery," means the causing of the potential at the battery terminals to vary periodically in such manner as to render all currents delivered from the battery fluctuating rather than steady, which, of course, would produce an audible effect in all receivers drawing current from this source.

It seems strange, at first thought, that it should be necessary to introduce an impedance coil in the circuit of the motor driving the ringing machine to prevent the fluctuations due to commutation from causing rapid periodic fluctuations in the battery voltage, when no such coils are placed in circuit with the charging generators which supply current to the battery. The reason for this is that manufacturers of these machines have devoted their attention to the designing of charging machines that would deliver a current practically free from "noisy" fluctuations, while no such result has been attempted with regard to motors driven from batteries. If the same precautions were taken in designing and constructing the motor with this end in view as are taken in the case of charging generators, the impedance coil would be unnecessary.

The distribution of current from the discharge leads of the storage battery to the various parts of the exchange may be varied in accordance with the size of the exchange, the circuits employed in the switch-board and also with respect to the ideas of the engineer as to how great an extent the various discharge circuits should be subdivided.

It will be seen that the main discharge lead, *O*, from the negative side of the battery, terminates in a bus-bar, *P*, from which the various supply wires leading to the different parts of the switchboard apparatus are led. The return side of the different discharge circuits are connected either to bus-bars connected to the grounded discharge lead, *Q*, or to the common switch-board ground wire, *S*. Considering the distribution from the negative or ungrounded side of the battery, the conductor, *t*, is led from bus-bar, *P*, to the busbar, *T*, from which No. 14 rubber-covered wires supply current to the keyboard signals of the A operators, and to those of the B operators. Two wires in each case lead to each A operator's keyboard and three to each B operator's keyboard. Each of these wires from the bus-bar, *T*, is connected to this bus-bar by 5-ampere fuses, these fuses being mounted on the face of the power board, so as to be readily replaced in case of burning out. In some cases it is desirable to separate the leads to the keyboard signals of the A operators from those to the keyboard signals of the B operators, and to accomplish this the bus-bar, *T*, may be divided as shown, the wires extending to the B operators' positions leading from one portion of it, and those to the A operators' positions to the other. These two sections are strapped together by a heavy enough conductor, usually a fuse, to carry whatever current is required, but if at any time it is desired to measure the current consumed by the A operators' keyboard signals separately from those of the B operators', or *vice versa,* this can be accomplished by separating the two portions of the bus-bar, *T*.

The lead, *U*, is tapped off from a bus-bar connected to the bus-bar, *P*, and is protected by a 5-ampere fuse. This lead, as before stated, supplies current to the local circuit controlled by the contact makers of the ringing machine shafts for the production of the tone. The E-shaped bus-bar, *V*, is connected to the bus-bar, *P*, by the lead, *v*, and serves to supply current to the A operators' line lamps, to the operators' transmitters, and to the relay racks for the operation of the line relays. For the first of these purposes a lead, *w*, extends from the bus-bar, *V*, to each A operator's position, where it supplies current for the operation of the line lamps. A separate No. 16 rubber-covered wire leads from this bus-bar through a 3-ampere fuse to each operator's position, and the blowing of one of these fuses, therefore, affects only the line lamps of that particular position. Similarly, a separate twisted pair, *w'*, of No. 20 rubber-covered wire has one of its wires leading from the bus-bar, *V*, and the other from the bus-bar connected with the discharge lead, *Q*, from the positive pole of the battery to each operator's transmitter. These are protected by 1-ampere fuses. These wires are arranged in twisted pairs, in order to prevent the possibility of cross talk between the operators' sets.

Another lead, *w''*, extends from the bus-bar, *V*, through a three-ampere fuse to each bay of relays on the relay rack. It will be remembered that the relays, both line and cut-off, are mounted together on the relay rack, usually in strips of 20, and it is customary, for the sake of convenience, to have a separate battery lead serve each separate bay of relays, a "bay" being the space between any two of the uprights which serve to support the relays. One such bay of the relay rack is shown in the lower right-hand portion of the figure, and, unfortunately, somewhat resembles the ordinary diagrammatic representation of a condenser.

A heavy conductor, *W*, extends from the main discharge lead, *O*, from a point back of all bus-bars, to the repeating coil rack shown in the lower right-hand portion of the figure. Through this is supplied all current to the repeating coils, and therefore all current used by the subscribers in talking, in the Western Electric system.

The common night alarm relay, *X*, has its coil placed in the lead running from the ground discharge lead, *Q*, to all of the pilot circuits of the various positions. The coil of the relay, *X*, is, however, adapted to be shunted by the knife-switch, *x*, when it is not desired to have the night alarm bell sounded. It will be seen that the night alarm bell, *x'*, which is an ordinary magneto bell, is placed in the circuit extending from the alternating current leads of the ringing machines, and including the local pair of contacts of the relay, *X*, so that whenever this relay is operated, the bell, *x'*, will sound, The night alarm switch, *x*, is not, as a rule, placed on the power board proper, but generally on one of the panels of the switchboard, so as to be available to the chief operator.

The bell shown at the immediate left of the night alarm relay, *X*, is of the ordinary vibrating type adapted to use with direct current. It is wired between the grounded discharge lead, *Q*, and a contact strip or bus-bar placed in proximity to the bus-bar, *V*. Whenever one of the line lamp fuses on bus-bar, *V*, blows, it releases a spring which completes contact between this bus-bar and the bus-bar to which the bell is connected, thus causing the bell to sound.

All the circuits and apparatus of the power-board have now been considered with the exception of those by which the measurements of the voltage and current of the different portions of the circuit are accomplished. As a rule, two voltmeters and one ammeter are placed on the power board, although instead of having two voltmeters a single one with a double scale is sometimes used. In the case shown, where two are used, the voltmeter, *Y*, has a scale somewhat higher than that required to register the maximum voltage of the secondary sides of the charging machines, and these machines are usually adapted when used with eleven cells of battery to produce a potential of about 30 volts at the generator terminals. Just below the voltmeter, *Y*, is placed a voltmeter switch having three pairs of stationary contacts, and that voltmeter, by the manipulation of this switch, may be connected with any one of these pairs. It will be seen that one pair of contacts is connected across the discharge circuit of charging machine No. 1; another pair across the discharge circuit of charging machine No. 2, and a third pair directly across the bus-bars of the battery. By this means the voltage of either charging machine may be taken, when running on an open or closed circuit, and also that of the battery may be measured.

The voltmeter, Y', is adapted to measure with great accuracy low voltages, the scale usually reading up to five volts, although a three-volt scale would be ample for the purposes required. It will be seen that the voltmeter switch just below this meter has a pair of contacts leading to the terminals of each cell of the battery, so that by manipulating this switch the voltage of any cell may be measured separately. This feature is of great value in that it enables the battery attendant to watch the behavior of the individual cells, as well as of the entire battery. By means of voltmeter and hydrometer readings a faulty cell may be readily detected and treated.

The ammeter, *Z*, should have a scale adapted to record the maximum current that will occur in any one of the various charging or discharge leads on the power board. These meters are in reality extremely low-reading voltmeters, and serve to measure the drop of potential around the shunts placed in the various leads carrying current which it is desired to measure. By means of proper calibration of the shunt and the conductors leading from it to the voltmeter, the voltmeter is made to register the number of amperes passing through the shunt. It will be seen that the shunt, z, is placed directly in the main charging lead extending from the charging generators to the negative pole of the battery. When the ammeter switch is thrown so as to connect the ammeter with this shunt, the total amount of current being delivered from the charging machine may therefore be measured. Another shunt, z', is placed in the main discharge lead, *O*, and enables the voltmeter to measure the total current being delivered by the battery alone, or by the battery and machines together, to the exchange. Practice differs to a considerable extent as to what degree means should be provided for measuring the various branch discharge leads, but the arrangement shown in this figure (397) is thought to be fairly representative of standard practice. A shunt, z^2, is provided in that discharge lead which supplies the keyboard signals for both A and B operators, but if it is desired to measure the keyboard signal current of the A operators separately from that of the B operators, this may be done by dividing the bus-bar, *T*, as already pointed out, and placing the shunt in circuit with each of the leads to the bar so divided.

Another shunt, z^3, is placed in the discharge lead, v', which supplies the bus-bar, *V*, from which the line lamps, the operators' transmitters and the line relays are supplied with current. Still another shunt, z^4, is placed in the lead from the live side of the battery to the repeating coil rack, and as all current for talking purposes is fed

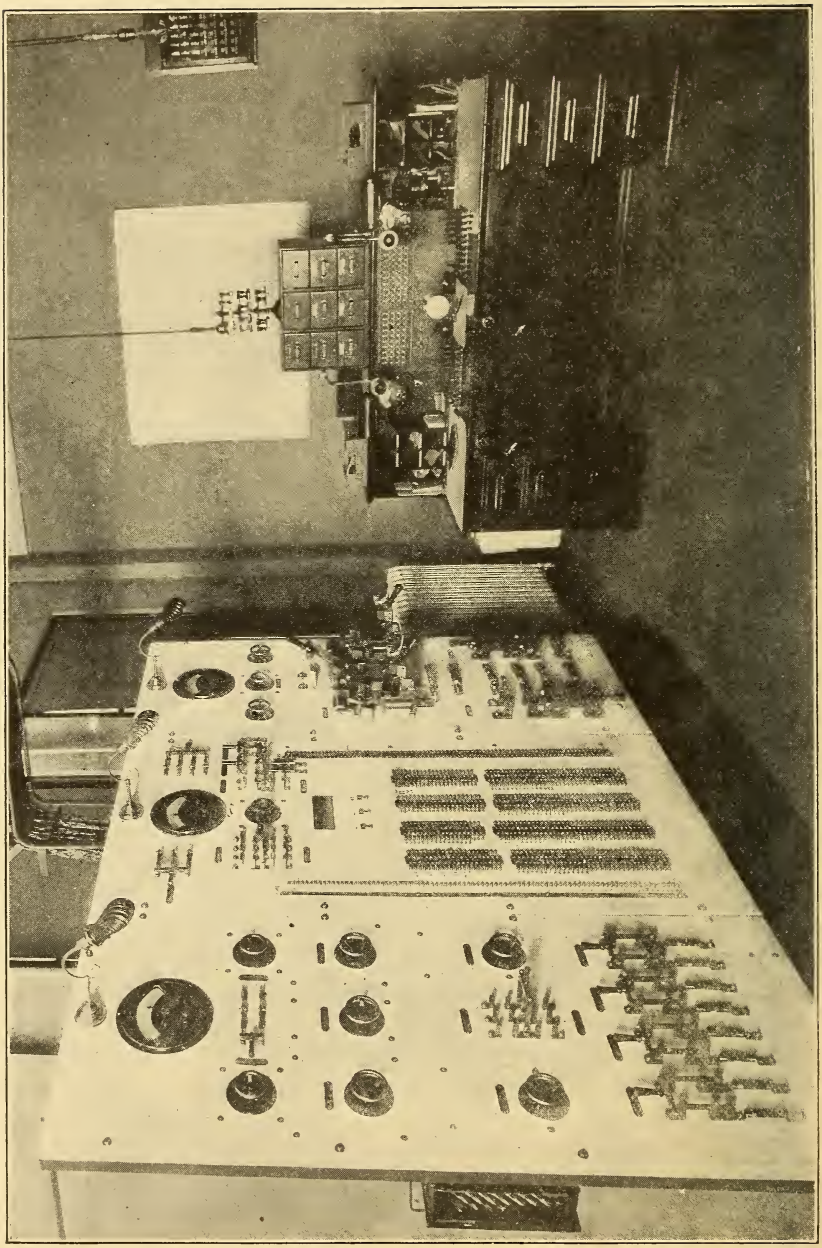


FIG. 398.—POWER BOARD.

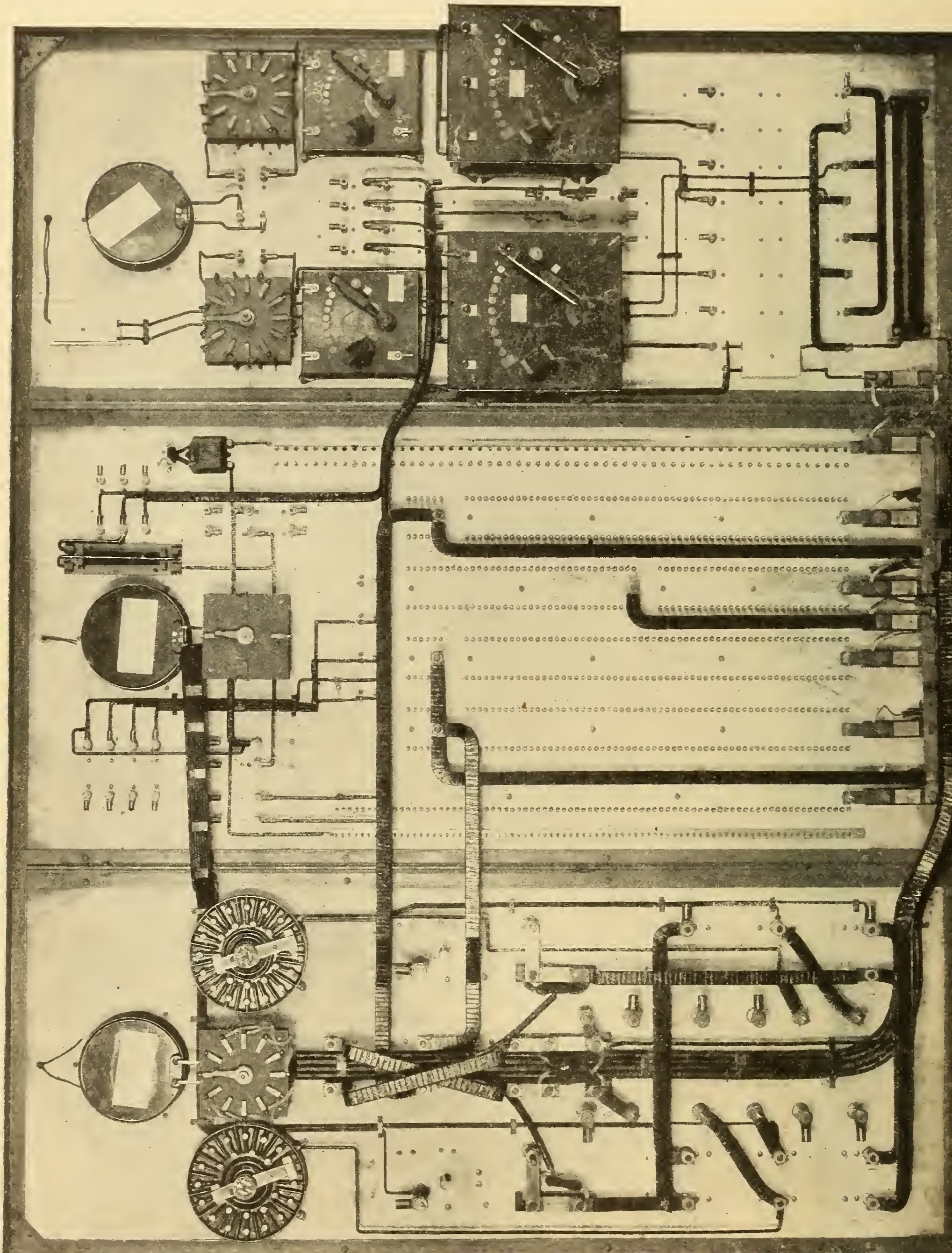
through the repeating coils, this shunt serves to measure the entire current consumed by the subscribers' lines in talking.

Of course, it is possible to effect a greater subdivision of the current, as for instance, a shunt might be placed in each of the leads, w, w' and w'', instead of having a single shunt to measure the current consumed by all of these leads. There is very little advantage, however, to be gained by too great subdivision in this respect, as it merely serves to complicate matters unduly, and very often the current in one set of leads alone would be so small as to render its measurement on the ordinary ammeter provided, almost an impossibility.

Coming now to the actual construction of the power board, Fig. 398 gives a good idea of a modern board furnished by the Kellogg Switch-Board and Supply Company in one of the large central office equipments of the Keystone Telephone Company in Philadelphia. This board is of marble, and all apparatus is so mounted upon it as to be handled from the front of the board, while the circuits are all accessible from behind. This and many other power boards are of white Italian marble, but a later and perhaps better practice is to make the boards of a fine quality of slate, to which an oil finish is given by smearing it with a heavy coat of oil, which is afterwards burned in. By this means a velvety black finish is imparted to the slate, against which the burnished copper instrument and switches present a handsome appearance, so that when such a board is properly constructed, its appearance is not less attractive than that of marble. Slate of the proper quality has an advantage over marble in that it is less liable to be traversed by metallic streaks which sometimes afford conductive paths from one part of the power board to another, and thus cause much trouble. There is but little difference between the cost of the best slate and ordinary Italian marble. Poor slate is more likely to be defective than marble.

The rear view of such a switch-board is shown in Fig. 399, which well illustrates the method of wiring and connection furnished in large modern telephone plants.

A full discussion of power machinery for telephone plants, that is, of the charging and ringing machines, would involve most of the points which have to be considered in the design and construction of dynamo electrical machinery in general. There are, however, a few points in which the dynamos and motors used for telephone work are peculiar. The condition met with in telephone work, which is not found to an equal extent in any other field of electrical



engineering, is that the current delivered by the charging generators or consumed by any motor deriving its current from the central battery, must be as nearly as possible absolutely "smooth." The fluctuations of electromotive force and current due to commutation at the brushes, or to the entrance of the various armature conductors into, or their passage from, the field of force of the machine, should be eliminated to such an extent that no noise whatever will be heard in the talking circuits deriving currents from the terminals of the battery during the use of the machines. Obviously, if the voltage across the terminals of the storage battery were subject to rapid periodical fluctuations due to the action of the charging machines, or motors driven from the battery, a noise would be heard in all receivers connected across lines fed by the battery.

It was formerly necessary, with the then available charging ma-

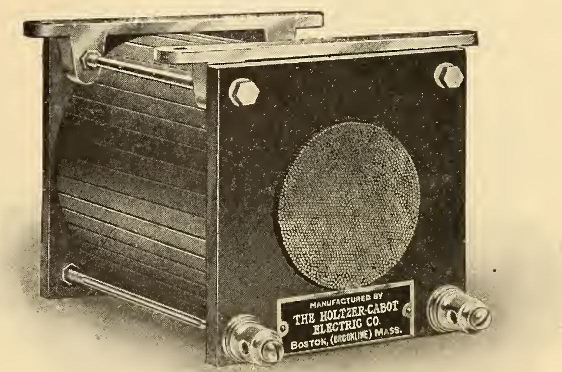


FIG. 400.—IMPEDANCE COIL.

chines, to place a heavy impedance coil in the charging leads to reduce the fluctuations in current and consequent noise in the talking circuits, and even with this it was often necessary to charge only in such hours as the exchange was least busy, that is, at night. By means of the machines now available, however, this is not necessary; the machine may run in the daytime or whenever necessary, and the objectionable impedance coil, which, of course, consumes a certain amount of energy, is done away with. An impedance coil for use with machines not suitable for giving sufficiently smooth current is shown in Fig. 400.

Probably the principal factor in the design of charging machines accomplishing this result is the use of a much greater number of commutator bars than would be required for almost any other type of direct current machine. The brushes on such machines with the very narrow commutator bars used cover approximately three complete segments on the commutator. The armatures are of the smooth core type, the winding being continuous and employing a greater number of conductors than would ordinarily be the case. It is found that with the slotted armature type of construction, wherein the conductors are bunched in groups between the teeth of the armature, a sufficiently smooth current cannot be produced. Another important factor is that the machine should be as nearly as possible magnetically and electrically balanced, which can only be attained by great care in its mechanical design and construction.

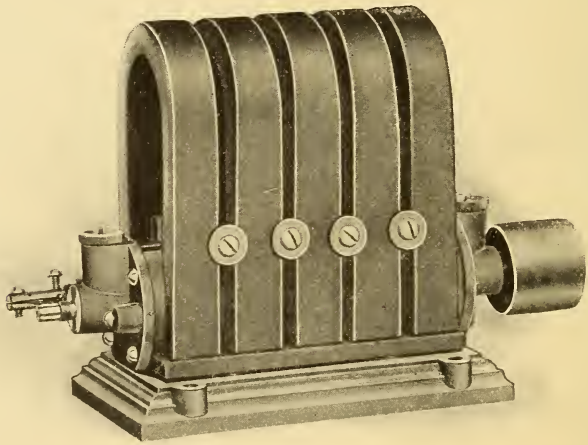


FIG. 401.—MAGNETO POWER RINGER.

The Holtzer-Cabot Company, of Brookline, Mass., which makes an excellent line of telephone charging and ringing machines, employs diamond-shaped pole faces on their charging machine pole pieces, the object of this being to cause the armature conductors to enter into and retire from the magnetic field as gradually as possible, so as to prevent any sudden fluctuation in the voltage.

As stated earlier in this chapter, the same care in the design of motors used in the battery ringing machines as is exercised in the case of modern charging machines would make those machines capable of drawing a current from the battery sufficiently steady to prevent noise without the use of impedance coils in the discharge lead to the motor. This is a matter of subsidiary importance, however, as the battery ringing machine is in most cases used only as a reserve, and manufacturers have not yet seen fit to construct special small motors for this purpose.

Considering now some specific examples of telephone charging and ringing machines, Fig. 401 shows a five-bar magneto generator for ringing purposes in small exchanges, adapted to be driven by belt from any available source of power. A similar generator belt connected to a direct current motor is shown in Fig. 402.

In more recent practice the magneto generator in all but the smallest exchanges is discarded, alternating current generators with

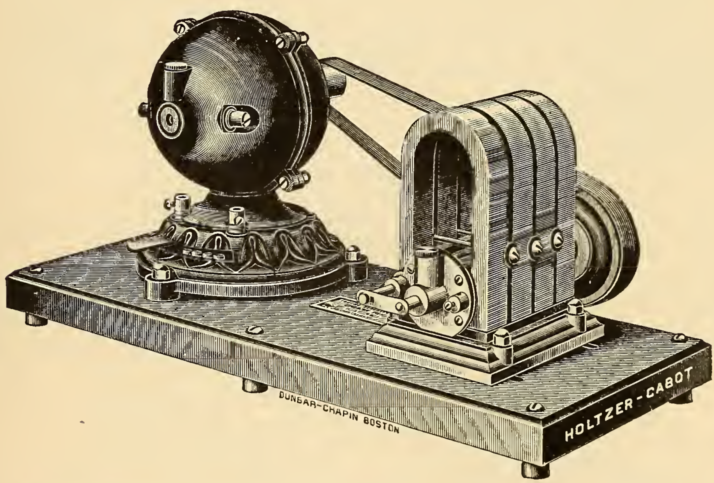


FIG. 402.—MAGNETO GENERATOR BELTED TO DIRECT-CURRENT MOTOR.

fields electro magnetically excited being used. Where low voltage (not over 220) direct current is available, the dynamotor is often used for ringing purposes. In this the motor and the generator windings occupy the same armature core, which revolves in a field common to both windings. Such a machine is shown in Fig. 403, this being of approximately one-sixth horse-power. For higher direct current voltages, the motor generator type of ringing machine is best adapted to furnishing ringing current in telephone exchanges.

The reason why it is not well to use dynamotors when only a high potential direct current is available for driving it is that in such cases there is always a liability that the insulation between the primary and secondary windings of the machine will break down under the stress of the greater electromotive force, thus impairing the action of the machines. Of course where the motor generator is used the two armatures are entirely separate, and this danger does not exist. It may be said in general that the dynamotor is not an efficient machine for any but ringing purposes in a telephone exchange under any conditions. When used for charging much trouble is had due to inefficient regulation. The fact that a single field serves for both the generator and the motor side of the machine makes it impossible to regulate the two sides independently.

Inasmuch as one or the other of the ringing machines are, in a modern exchange, driven during twenty-four hours of each day,

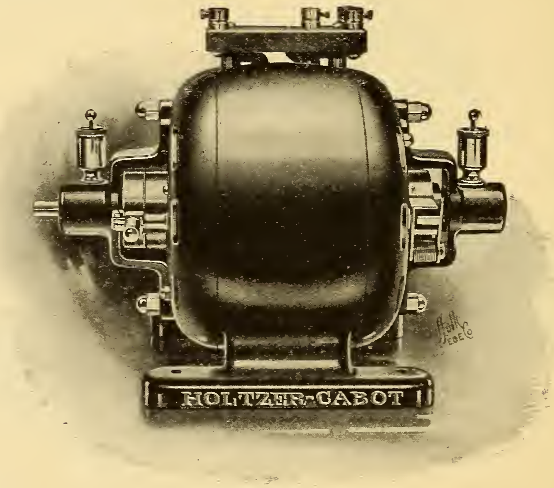


FIG. 403.—SMALL DYNAMOTOR FOR RINGER.

these machines become the most available for driving the busy-back and tone-test attachment already referred to in connection with Fig. 397. A dynamotor for ringing purposes adapted to be driven by direct current is shown in Fig. 404, and this has permanently attached to it a busy-back of obvious construction.

Until recently trouble has been experienced in applying alternating current motors to the direct driving of ringing machines. The reason for this was that all alternating motors available ran at such high speed that when direct-connected to ringing machines the frequency of the alternating current generated thereby was too great for properly actuating the bells. As a result of this direct-connected machines were not used in such cases, the ringing generator being belted to an alternating current motor in such manner as to run at lower speed. A ringing machine equipped with busy-back

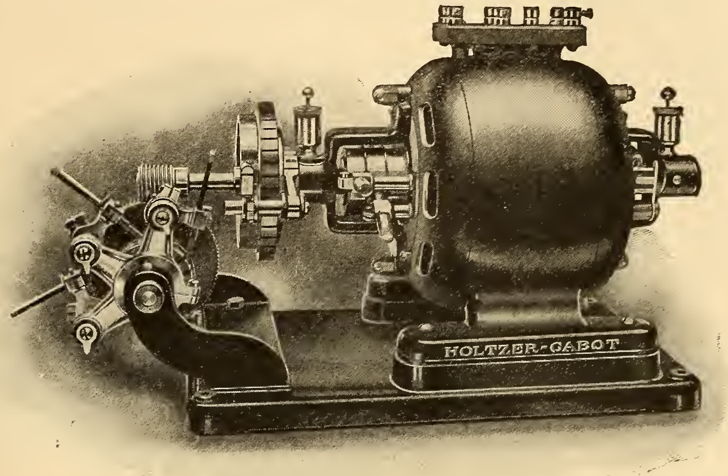


FIG. 404.—SMALL DYNAMOTOR WITH BUSY-BACK ATTACHMENT.

and don't-answer attachment and belted to an alternating current motor is shown in Fig. 405, this being a set used by the Stromberg-Carlson Company in one of their exchanges. Recently the Holtzer-

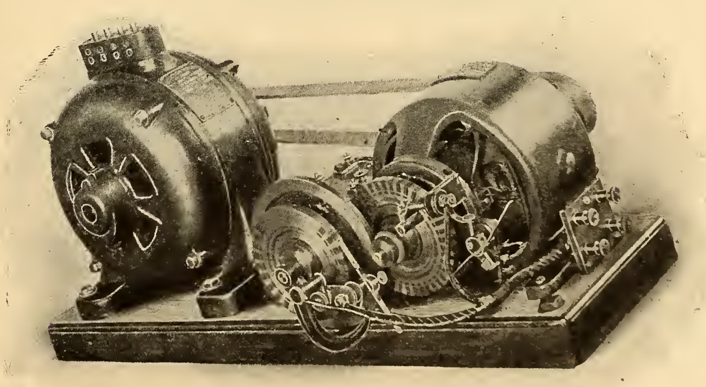


FIG. 405.—RINGING MACHINE WITH BUSY-BACK ATTACHMENT BELTED TO ALTERNATING-CURRENT MOTOR.

Cabot Company have perfected a low speed alternating current motor built specially for this purpose, so that the ringing machine will run at the proper speed to give the required number of cycles per minute.

It has frequently been found expedient to attach busy-back devices to old ringing machines, originally furnished without them, and for this purpose the Holtzer-Cabot Company has built a busy-back outfit as a separate unit so arranged that it may be fitted to the shaft of almost any ringing machine. One of these devices is shown in Fig. 406.

A modern charging machine is shown in Fig. 407, this consisting of a four-pole direct current motor of standard construction direct-connected to a specially constructed telephone charging generator.

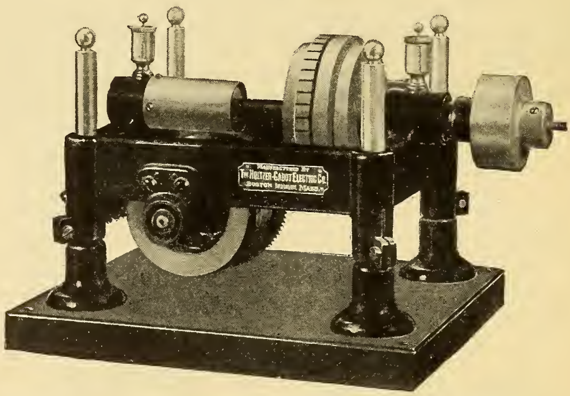


FIG. 406.—SEPARATE BUSY-BACK ATTACHMENT.

As is seen, the two machines are mounted on a heavy castiron sub-base common to both so as to maintain a permanent alignment of the bearings. In Fig. 408 a similar charging set is shown, the generator being direct-connected to an alternating current motor, thus making alternating current mains available for power purposes.

As a rule, the power machines, including both charging and ringing generators and their motors are mounted in close proximity to the power switch-board, which latter includes all devices for controlling the action of the various machines. It has been the practice of some companies to mount the ringing and charging machines on a table or bench of wood with perhaps an iron framework. Such an arrangement is shown in Fig. 409, where two special telephone motor generators and two ringing motor generators are mounted compactly on a table. The primary of one of the ringing machines is wound for the external power circuit and that of the other for the battery circuit.

The mounting of the power machines on a wooden table with in-

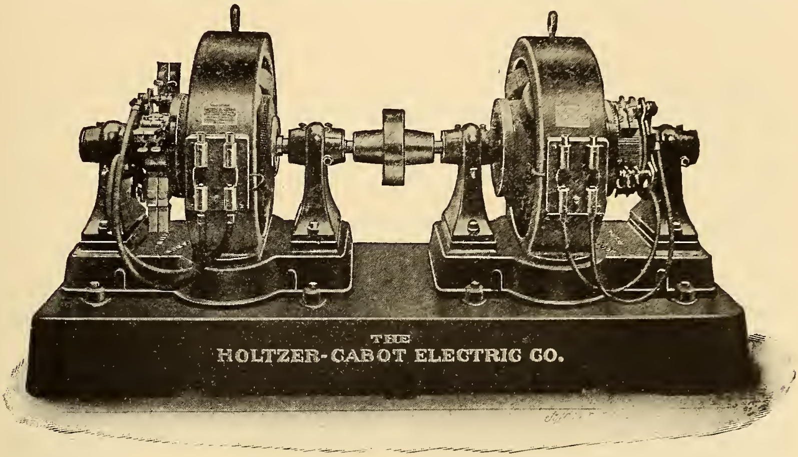


FIG. 407.–CHARGING MOTOR GENERATOR—DIRECT-CURRENT MOTOR.

closing panels of wood, as shown, is faulty in one respect; the table and its inclosing panels serve to enhance any noise that may be made by the machines, and for obvious reasons they should run as quietly

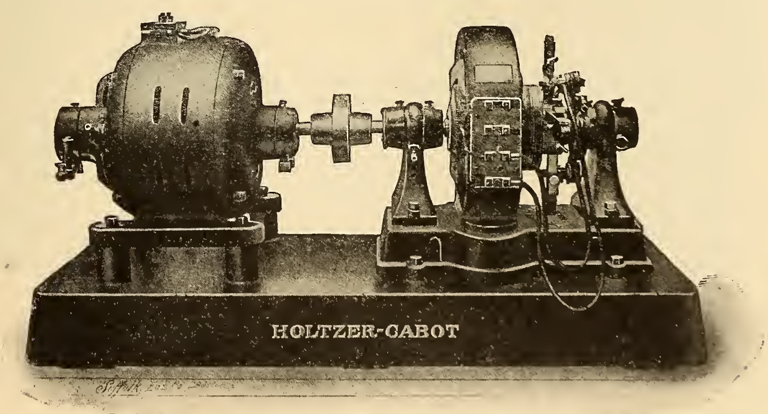


FIG. 408.—CHARGING MOTOR GENERATOR—ALTERNATING-CURRENT MOTOR.

as possible. A better practice is to build up a pier of brick from the floor of the power room and to provide this with a heavy slate top. This tends to greatly reduce the amount of noise of the machines, and this may be still further decreased by resting the sub-base of each machine on a heavy piece of felt.

Such a brick pier and with a slate top is shown in Fig. 410, which represents a power table equipment installed by the Kellogg Switchboard and Supply Company in one of the large exchanges of the

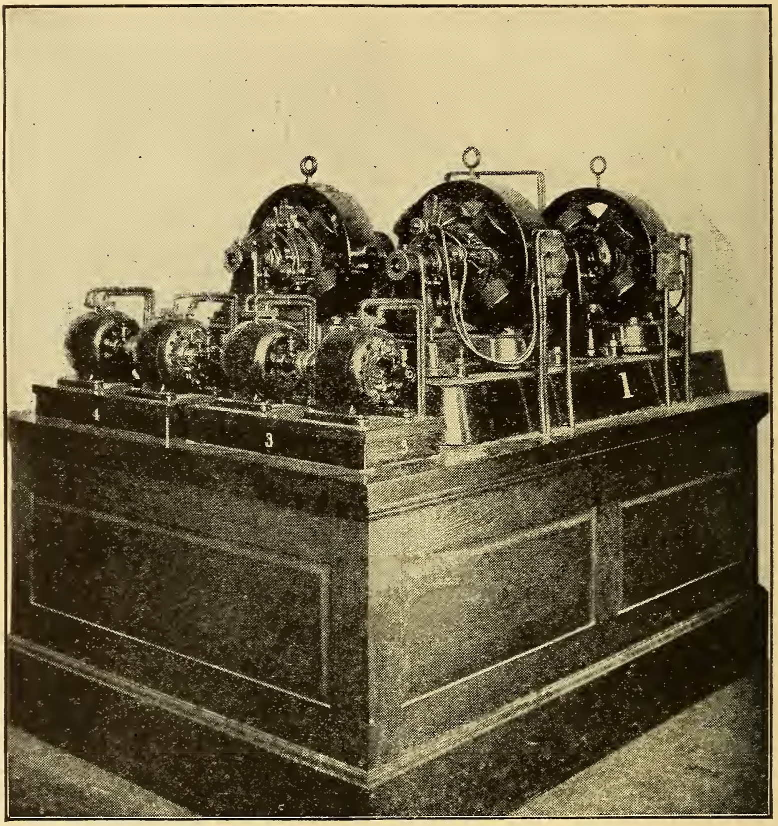


FIG. 409.—POWER TABLE—WOOD BASE.

Keystone Telephone Company of Philadelphia. All of these machines are made by the Holtzer-Cabot Company. The two charging machines are of $7\frac{1}{2}$ horse-power each on their motor sides, and are identical in construction with those shown in Fig. 407. In this plant three ringing machines were used owing to requirements made by the Keystone Company, two of them being adapted to use on the outside power mains (one as a reserve for the other) and one to run from the current of the storage battery.

It is customary in most modern work to build the pier for the power table of white enamel bricks highly glazed and to provide a top of heavy slate with a burnt-oil finish. By this means a construction exceedingly handsome, durable and effective is secured.

The range through which it is sometimes necessary to regulate the output of charging machines is, as has been stated, very wide. It is desirable to be able to reduce the voltage from that necessary to charge the whole battery to that necessary to charge a single cell. The field rheostats of ordinary commercial practice in other lines of electrical work do not have a sufficient range of resistance for this purpose, nor a sufficient number of steps between its maximum and its minimum resistances to enable the regulation to be effected with

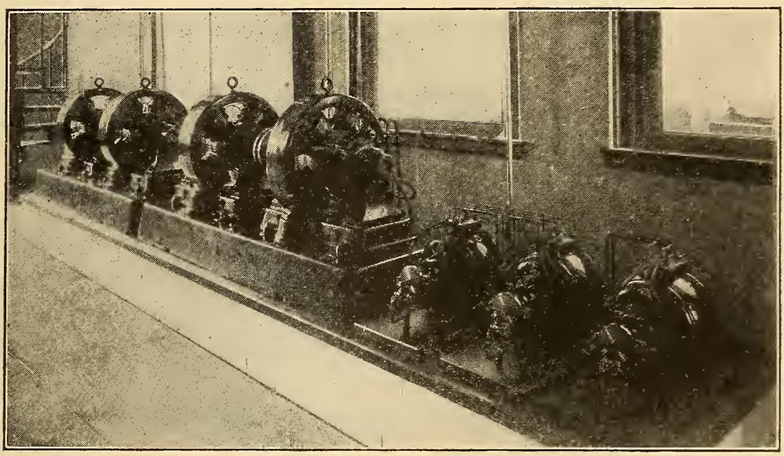


FIG. 410.—POWER TABLE—BRICK AND SLATE BASE.

great enough nicety. The remedy for this is more contacts on the rheostat and therefore more steps. Frequently, however, a sufficient number of contacts for the desired result cannot be placed on the rheostat face without making it of prohibitory size. The Holtzer-Cabot Company has again come to the rescue of telephone men in this difficulty by producing a rheostat consisting of two discs with a certain number, say fifteen, contacts each, each disc being provided with a separately movable rheostat arm or wiper adapted to move over all the contacts on its disc. The resistance coils on the front disc are of sufficient resistance to give the required range of action of the machine, while the coils on the rear disc are of such resistance that the entire fifteen of them equal the resistance of one coil on the front disc. The field resistance may then be adjusted roughly on the front disc, and then by manipulating the lever of the rear disc increments may be added until the desired resistance is obtained.

In the double-faced rheostat shown in Fig. 411, a total of 225 steps is obtained on a rheostat of the diameter of an ordinary fifteen-point rheostat.

The same general rules that apply to the care of dynamo electrical machinery in general will apply to charging and ringing machines in telephone work, but on account of the nicety with which these machines are made and adjusted, if of the proper type, an even greater amount of attention should be paid to their care. In telephone work special stress should be laid on the necessity of maintaining the commutator brushes in good order, as carelessness in this matter is one of the most prolific causes of disturbing noises

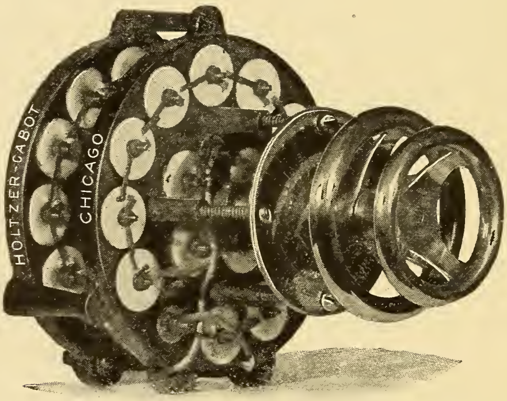


FIG. 411.—HOLTZER-CABOT RHEOSTAT.

caused by machines in the telephone lines. The brushes when properly set on a properly designed machine, will not cause noise in the lines even when no choke coils are placed in the charging leads. It has been stated that the brush should be wide enough to bear on about three complete segments on the commutator, and they should be fitted to the commutator in such manner that the entire surface of the brush makes contact with the commutator surface.

A good way to fit a brush after the brush-holder is properly placed is to lay fine sand-paper on the commutator, rough side out, and then draw it under and brush in the direction of the rotation of the armature, the brush being pressed against the sand-paper by the spring of the brush-holder. During the first rough adjustment of the brush in this manner, no harm will be done if the sand-paper is pulled back and forth under the brush, and to facilitate the securing of the approximately proper surface of the brush quickly, extra pressure may be placed on the brush-holder. In putting the final touches on the wearing surface of the brush, however, no additional pressure than that of the spring in the brush-holder should be applied, and the direction of the motion of the sand-paper should be the same as that of the motion of the armature, great care being taken to keep the sand-paper closely pressed against the surface of the commutator.

In multipolar machines the brushes should be equally spaced around the commutator.

The number of commutator bars between each two adjacent sets of brushes should be equal. After the brushes are all properly set, the rocker upon which all of them are mounted may be moved in one direction or another until a position is reached in which no sparking at the brushes will occur on all loading of the machines, from no load to full load. It is sometimes found that after careful adjustment all brushes will behave properly except one, and when this is the case, it should be carefully resurfaced, and if it still sparks, may be adjusted back and forth separately, leaving the other brushes as they are. This condition, however, in a properly designed machine, and with uniform and suitable brushes, is not liable to occur.

A properly working commutator presents a rather dark, glossy appearance. A commutator in this condition seems to be glazed, the general color being considerably darker than that of freshly cut copper. The appearance, therefore, of bright streaks, which are sometimes rather rough, indicates that some or all of the brushes are cutting, and this should be remedied.

The best lubricant for the commutator is probably vaseline, but it should be very sparingly used. It should be applied with a small clean rag into which vaseline has been thoroughly, but sparingly soaked, so that no lumps of vaseline will come off on the commutator.

As a rule, telephone central offices, when first installed, are equipped for only a portion of the number of lines that it is thought it will be eventually called upon to serve. The switch-board and most of the auxiliary apparatus are equipped to a sufficient extent to meet the present requirements, and arrangements are made whereby they may be added to in future as the number of lines increase. This is not the case, however, with most of the power plant apparatus, which must be installed at the outset with sufficient capacity to serve the ultimate number of lines which it is thought will eventually enter the office. The only exception in this regard, in connection with the power plant, is the storage battery, as it is possible and feasible to provide only enough plates to serve for present requirements, room enough being left in the tanks, however, for the addition of subsequent plates to meet the demands of the extended service. In most power plants, therefore, the full load current output of the charging machines is in excess of the normal charging rate of the battery.

The greatest efficiency in the operation of the power machines is obtained when the machines are run at approximately full load, and therefore it is more economical to charge during the period of the day when the traffic is greatest. At this time there is a heavy discharge from the battery, and the current delivered to the battery through the charging leads may be greatly in excess of the normal charging rate of the battery. Obviously, however, at such times the effective charging current which the battery is absorbing, is the difference between the current in the main charging leads and that in the main discharge leads; in other words, it is the difference between the ammeter reading around the shunt, z, and that around the shunt, z', Fig. 397.

In case of sudden demands on the service by virtue of which traffic becomes so great as to exceed the maximum discharge rate of the battery, the charging machines may be called into service to help the battery out, in which case the battery and the charging machine are both delivering current to the discharge leads.

The length of the daily run is determined by the traffic, and should be continued each time until the batteries indicate full charge. The charging rate should be limited either by the capacity of the battery or of the machine, which ever has the smallest capacity. On account of the fact before mentioned, it is usually true that the battery has less capacity than the machines. It is desirable that the batteries should be fully charged each day, and preferably that this full charge should be reached at a time after the period of heaviest traffic in the day. This is true because in the case of a complete disability of all charging machines, the battery would act as a reserve and should be able to run the plant for twenty-four hours without additional charge. It is also true because the welfare of the battery itself depends on its being fully charged at frequent intervals, and on its remaining discharged as short a time as possible.

It is obvious that the ringing machine, which derives its power from the main power leads, should be used regularly, and that the one which runs from the battery current should be used only as a reserve.

CHAPTER XXIX.

STORAGE BATTERIES.

If two plates of lead are immersed in a weak solution of sulphuric acid, no difference of potential will be established between them, because the acid, if it acts on them at all, does so to an equal extent on each plate. If now an electric current, as from a battery or a direct-current dynamo, is sent through the two plates and the solution between them, a redistribution of materials will take place in the cell. The electrolyte will be decomposed, the oxygen in it forming, with the plate to which the positive terminal of the charging force is connected, lead peroxide; while hydrogen is liberated at the plate to which the negative terminal is connected. On disconnecting the source of current, the cell, which was before incapable of producing a difference of potential, is found able to drive a current through a circuit formed by connecting its poles together by a wire or any other conductor. The combination has become a voltaic couple.

The cell, consisting of two lead plates in a solution of sulphuric acid, was devised by Gaston Planté, and is the prototype of all storage batteries or accumulators that have come into general use up to the present time. Nearly all commercial cells, of which there are many, have the plates coated with, or in close mechanical contact with, some compound of lead, rich in oxygen. This is changed by the charging current into lead peroxide on the positive plate, and to spongy lead on the negative. In this condition the cells will give an electromotive force of slightly over 2 volts, the pressure remaining nearly constant during the greater portion of the time while the cell is being discharged through some external circuit. The direction of the current flowing from the cell while discharging is always opposite to that of the charging current. A charged storage cell behaves exactly like a primary battery, but it has the advantage that after being discharged it can again be made useful without the addition of any material whatever, by merely sending a current through it in the proper direction.

In all but the smallest storage cells more than two plates are used, all the positive plates being connected by a heavy strip of lead, and likewise all the negative plates by another similar strip. There is usually one more of the negative than of the positive plates, the arrangement being such that the plates are alternately positive and negative.

The extremely low internal resistance of storage batteries, and the fact that their voltage is high (2 + volts per cell) and constant and that they are not subject to polarization, make them, all things considered, the ideal source of current for telephone work. They are much more economical in operation than any form of primary cell, inasmuch as there is practically no consumption whatever of the materials in the cell itself, it depending of course

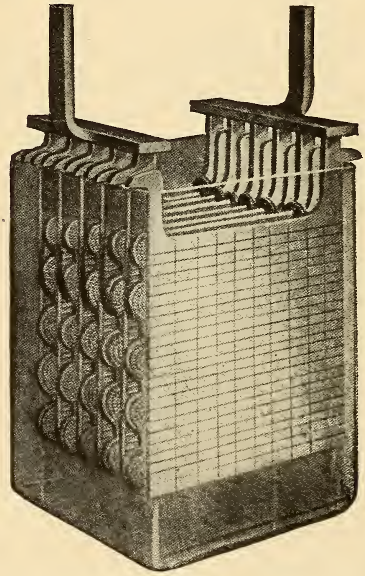


FIG. 412.—ELEVEN-PLATE CHLORIDE CELL.

for its energy on some outside source. Their ease of manipulation and general cleanliness and reliability are also strong points in their favor. They have long been used for supplying the operators' transmitters in large central offices, but the recent developments leading to the almost universal adoption of the various common battery systems have vastly increased their field of usefulness, since they are now called upon to furnish current for subscribers as well as operators.

Among the several good storage batteries on the market, the chloride accumulator made by the Electric Storage Battery

Company of Philadelphia may be mentioned first on account of is being more widely used than any other. In this the negative plate is composed of a number of small square blocks of spongy lead held together by a grid of lead with a small amount of antimony added for hardness. The blocks are made by fusing together zinc chloride and lead chloride, after which they are placed in a mold and the grid cast around them under pressure. Afterwards by an electro-chemical process all traces of zinc are removed, leaving the composition of the blocks pure spongy lead. The positive plate consists of a lead-antimony grid in which circular holes are molded. These holes are filled with buttons

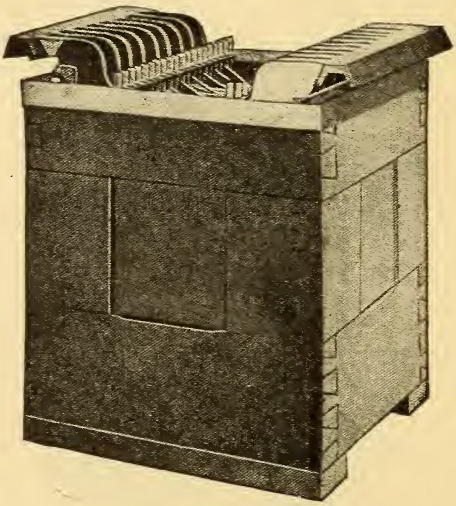


FIG. 413.—NINETEEN-PLATE CHLORIDE CELL WITH WOODEN TANK.

made by rolling up a crimped lead ribbon in the form of a spiral, of a size to fit tightly in the holes. The plates are then treated electro-chemically in order to form the proper oxide from this ribbon.

The positive and negative plates so formed present a large surface to the electrolyte for it to act upon, the negative plates on account of the porous, spongy, lead blocks, and the positive plates on account of the crimped lead ribbon. The plates are held apart by long hard-rubber washers hung over each end of each negative element. These are placed in a vertical position to prevent forming a shelf upon which loose particles from the plates might lodge and form a short-circuit. These cells have amply demonstrated their adaptability to telephone use by long service in this and other fields.

The electrolyte for these cells is a mixture of sulphuric acid and water in the proportion of about five parts of water to one of acid. The proper specific gravity of this mixture, as specified by

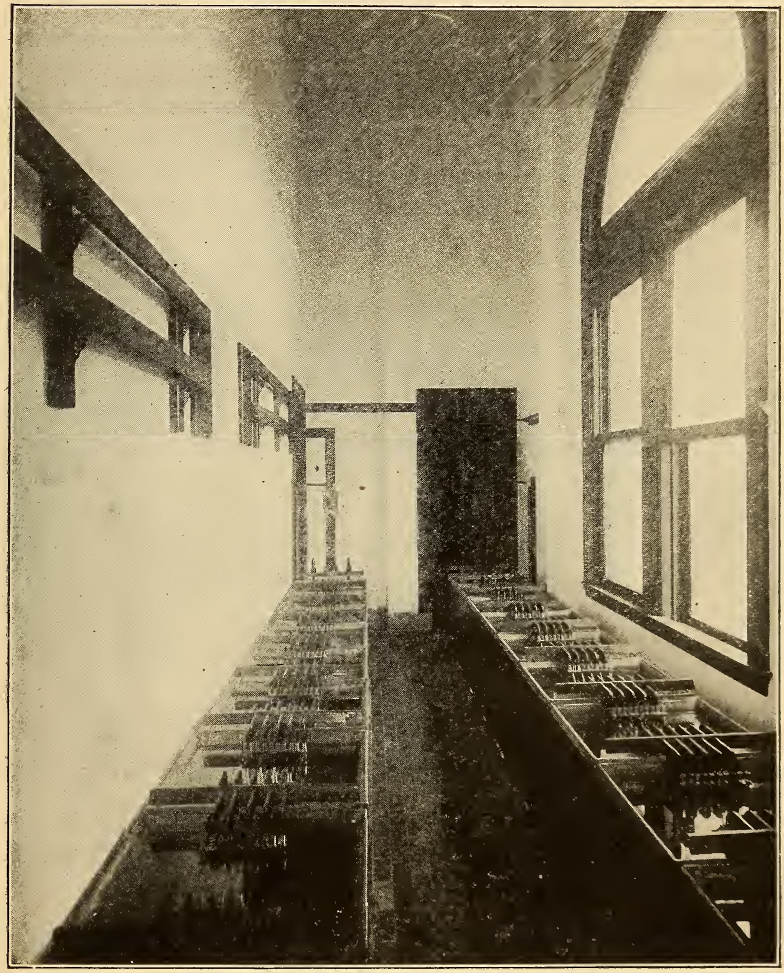


FIG. 414.—BATTERY PLANT.

the manufacturers, is from 1180 to 1190, as indicated on an ordinary hydrometer.

In Fig. 412, the general appearance of one of these cells having six negative and five positive plates is seen. Fig. 413 shows a larger cell having ten negative and nine positive plates mounted in a lead-lined wooden tank. Lead-lined wooden tanks are preferable to glass jars in large batteries, on account of the liability of glass to breakage. In small capacity batteries, glass cells are used in most cases, one of their advantages being that they allow of free inspection of the plates more than would lead-lined tanks of small size.

In Fig. 414 is shown a portion of two batteries of chloride accumulators as installed in one of the large common battery exchanges of the Kellogg Switch-Board and Supply Company. These batteries have eleven cells each, thus giving approximately twenty-four volts each. They are used for supplying all current for talking and signaling in the entire exchange, except that used for ringing the bells

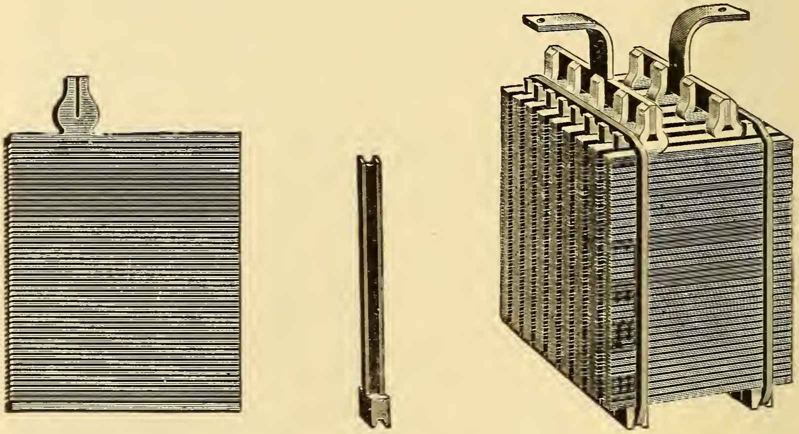


FIG. 415.—DETAILS OF AMERICAN CELL.

of the subscribers, which is, of course, alternating or pulsating in character.

Another type of storage battery used to a less extent is that made by the American Battery Company of Chicago. In this battery the plate is made from a solid sheet of pure rolled lead deeply grooved on both sides so as to leave projecting ribs, one-twentieth of an inch apart, affording a very large surface for the electrolyte to act upon. The form of a single plate is quite clearly shown in Fig. 415. The ribs are slightly upturned in order to better retain the active material carried in the grooves between them. The active material in the plate is electro-chemically formed in a strongly oxidizing solution, filling the grooves and covering the surface of the ribs with an adherent peroxide of lead coating. The positive and negative plates are alike in construction, the active element, spongy lead, in the negative, being reduced from the peroxide of lead of the positive. Hard-rubber insulators, shown in Fig. 415, serve to separate the plates as well as to hold them clear of the bottom of containing jars. The insulators are held rigidly in place, being firmly keyed to the plates and surrounded by heavy rubber bands as shown in Figs. 415 and 416.

Instructions for Installation, Care and Maintenance of Storage Batteries.

Setting Up and Connecting.

The elements, before being placed in the glass jars, should be examined carefully, and any foreign substance which may have

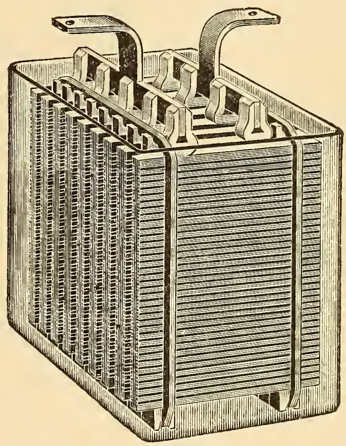


FIG. 416.—COMPLETE NINE-PLATE AMERICAN CELL.

lodged between the plates should be removed. See that the hard-rubber insulators are in position and that the positive plates do not in any way touch the negatives. After the elements are placed in the jars, connect the terminals—the positive of one element to the negative of the next and so on.

The best method of connecting the cells permanently is to burn the terminal strips together, or when it is not practicable to do this solder them together, using a hot iron or soldering torch, first scraping bright the surface to be soldered. For a soldering flux it is best to use ordinary pure tallow. Under no circumstances should muriatic acid or soldering salts be used. For temporary connections the connectors usually sent with the elements will answer. To prevent corrosion, these must be painted with some protective paint and well covered with okonite tape.

The best method to thoroughly insulate the cells is to place each one on a separate wooden base painted with good insulating paint, this base resting on glass or porcelain insulators; or to place them on shelves or tables covered with sheet glass. Care should be taken to place cells in a cool, well-ventilated place, where each cell is readily accessible, so that elements can be removed when necessary with the least possible trouble.

When lead-lined tanks are used, the cells should be placed on the floor if the available space permits.

Lead-Burning.

As stated under the preceding heading, the best way to permanently connect the lugs or terminal strips of the separate cells

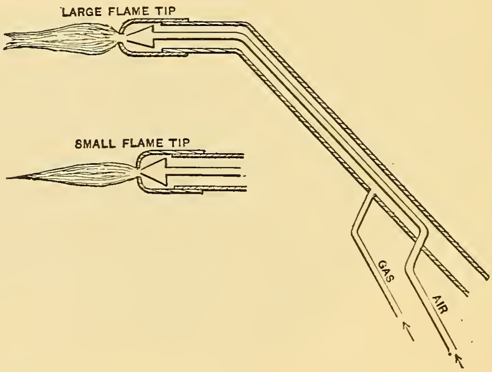


FIG. 417.—BURNER FOR LEAD BURNING.

is to burn them together. This process is not difficult to carry out if well understood, but of course the beginner should first experiment on lead strips that do not form the terminals of storage cells.

The best flame to use for lead burning is the hydrogen flame, as this can be used without flux and in general produces cleaner work. A hydrogen generator is necessary for this, this usually consisting of two lead chambers, one above the other and connected by a lead pipe. The pipe leads from a point near the bottom of the lower chamber, out of the top of this chamber, and into the bottom of the upper one. Equal parts of zinc and sulphuric acid are put in the bottom chamber. The acid in attacking the zinc forms zinc sulphate and liberates hydrogen gas. As the gas is generated the acid solution is forced up into the upper chamber, thus maintaining a fairly constant pressure, which is usually from 6 to 8 pounds per square inch. A rubber tube serves to lead the gas from the top of the lower chamber to the burner tip.

The acid used for this purpose should be free from arsenic and most other impurities. Arsenic will make a white deposit on the lead, and thus may cause a poor connection.

The burner used for this work is usually of a form shown in Fig. 417, having two leading-in tubes, one for air and one for gas. These are provided with several tips having different sized holes for obtaining different sizes of flames. Air must be supplied to the burner by an ordinary form of foot-bellows or by any other available means.

Lead burning may often be successfully done by using ordinary

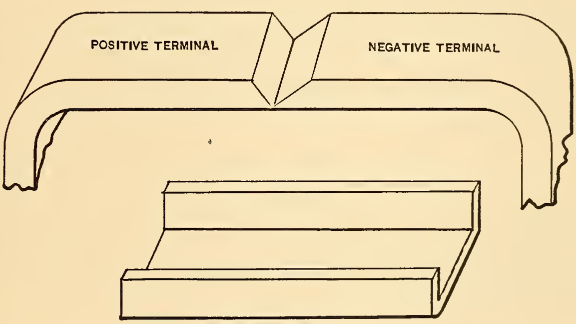


FIG. 418.—METHOD OF BURNING SMALL TERMINALS.

illuminating gas instead of hydrogen, but this depends largely on the quality of the gas. Natural gas is sometimes used, but this is likely to prove unsuccessful. In any case the work is somewhat more difficult to perform than when hydrogen is used.

The method of procedure will depend somewhat on the form of terminals to be jointed. On comparatively small cells the terminals are usually of the form shown in Figs. 412 and 416. With these, the terminals should be bent down and beveled off as shown in Fig. 418, and the surfaces to be jointed should be scraped perfectly clean and bright. A scraper made by securing a triangular piece of steel with sharp edges to a suitable handle, as shown in Fig. 419, is very convenient for this purpose. A small sheet-iron trough, as shown in the lower portion of Fig. 418, and having an interior cross-section equal to the cross-section of the terminals, should be slipped over the two lugs from beneath and secured in place by a wooden clamp or in any other convenient manner. A chamber is thus formed into which the melted solder may be run as described later.

If the battery is of large size, it will usually have a number of lugs, which will be joined to a cross bus-bar when two cells are connected. This form is clearly shown in Figs. 413 and 414. When burning such lugs and bus-bars together, a pair of lead burning tongs made of iron, and of a form shown in Fig. 420, should be used. The front surfaces of these are beveled to an angle accurately corresponding to that of the bus-bar, so that they will fit snugly against the bus-bar when in place. The inner surfaces of these tongs should be parallel when opened just wide enough to fit the lug on the cell. The lug after being properly beveled and scraped is brought into position almost touching the bus-bar, the surface of which has also been scraped, after which the tongs are applied in

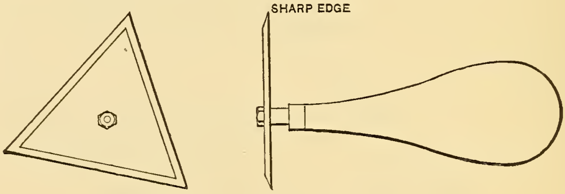


FIG. 419.—SCRAPER FOR LEAD TERMINALS.

such manner as to form a chamber in which to run the melted solder.

Having proceeded thus far according to either of the methods described, the blow-torch, using either hydrogen or illuminating gas, may be brought into play. The solder should be pure lead. No flux will be needed with the hydrogen, but tallow will be required with the other gas. The solder should be melted off the stick and allowed to drop into the chamber, and at the same time the surfaces to be joined should be kept just at the melting point by a judicious application of the flame. The chamber may thus gradually be filled, and if all goes well the solder will unite perfectly with the lead surfaces, thus making a continuous piece of metal.

The melting point of lead is not far from 610° F., and in burning the lugs to a bus-bar of a large cell great care must be taken not to entirely melt the lugs before the bus-bar is sufficiently hot—it requiring, of course, more heat than the lugs. In the flame of the burner there will be noticed an outer bluish-red and rather scattering flame, and an inner flame blue and well defined. The best results are usually obtained by holding the point of this inner blue flame on the surface to be burned. In burning lugs it is usually better to use a comparatively large flame, as shown in the upper portion of Fig. 417. In burning seams, however, the small flame shown in the lower portion of that figure is more desirable.

After the metal has thoroughly set, the tongs or clamps may be removed and the joint trimmed up a little if necessary for appearance. It is always well to leave the joint of slightly larger cross-section than the lugs.

Electrolyte.

After the cells are connected up, and the terminals of the battery led to the switch-board so that the charging current is ready to be

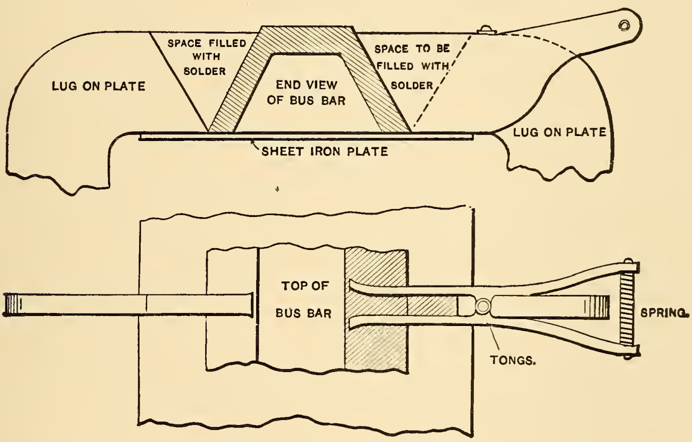


FIG. 420.—METHOD OF BURNING LUGS TO BUS-BARS.

turned on, the electrolyte may be added. It is important that this should not be done before.

The electrolyte, consisting of a mixture of pure sulphuric acid and water, preferably distilled, should indicate a specific gravity of 1190 on the ordinary specific gravity hydrometer or 23° Baumé scale. This solution should be mixed in stone jars in about the proportion of five parts water to one of concentrated sulphuric acid, by volume, pouring the acid slowly into the water. It is very dangerous to pour the water into the acid, and one cannot be too careful on this point. The electrolyte becomes hot after mixing, and it should be allowed to cool for at least four hours before using. Under no circumstances allow the glass jars to be used for mixing purposes. River and well water usually contain impurities and should be avoided, as the least quantity of chlorine or ammoniacal salts present in the electrolyte will seriously affect the life of the plates.

Charging.

Great care must in all cases be taken that the batteries are so connected that the charging current passes through them in the proper direction. The positive pole of the battery must be connected to the positive pole of the generator. The positive pole of the generator leads may be determined by the use of a direct-current volt or ammeter. A simple test, and the most convenient one when neither ammeter or voltmeter are available, for determining which is the positive pole of any source of current is to dip wires leading from both terminals into a small vessel containing slightly acidulated water. Bubbles of gas will be given off from each wire, but at a very much higher rate from the wire leading to the negative pole than from that leading to the positive. The poles of the charging dynamo should always be determined with absolute certainty before connection is made to the terminals of the storage battery, for a reversal in the connections is very likely to ruin the battery.

As soon as possible after the electrolyte has been poured into the glass jars, seeing that the plates are covered with at least one-half inch of the fluid, the elements should receive their first charge. It is well to begin at about half the normal rate of charging, but after making sure that all is going well the charging may proceed at the normal rate, which is always given by the manufacturers, but which may be found by dividing the normal rated capacity of the cells in ampere hours by eight. Thus for a cell the rated capacity of which is 400 ampere hours the normal charging rate would be 50 amperes. The manufacturers of the American cell advocate the continuance of the first charge for 30 hours, while the chloride people advocate 20 hours.

During the last hours of the first charge the solution will appear to boil. The specific gravity of the electrolyte which fell much below 1200 shortly after it was first poured into the cells should have risen to 1225 by this time. If it is higher than this, water should be added until the solution indicates uniformly 1225; on the other hand, add dilute sulphuric acid if specific gravity does not show 1225. A lower charging current than the normal may be used if it is not convenient to obtain that rate, but the time of charging must be continued proportionately longer. A 10 per cent. or even 20 per cent. overcharge will not injure the elements in any way; excessive overcharging, however, if practiced often, seriously shortens their life. Even though for any reason the battery is only slightly used, it should, nevertheless, be charged fully about once in two weeks.

Determination of Amount of Charge.

By means of an accurate low-reading voltmeter the state of charge may be ascertained quite closely, providing that the same rate of charge be employed regularly. In charging at the normal rate when the pressure at the cell terminals indicate 2.5 volts it may be assumed that the cell is charged within 90 per cent. of its rated capacity, so that when this point is reached the charging operation may be discontinued. On the other hand, when the voltage falls as low as 1.8 or 1.9 the cell may be considered discharged, and recharging should begin as soon as possible.

The hydrometer may be used with a fair degree of accuracy to show the condition of a cell, inasmuch as the density of the solution varies between full charge and discharge. As this variation is a function of the ratio of the area of plate surface to the volume of electrolyte, it is difficult to state a definite rule, inasmuch as there is no constant relation between plate surface and electrolyte in the various sizes of cells. The specific gravity of the electrolyte may be noted at full charge,—*i. e.*, when the voltage is 2.5,—and that indication made a basis for the determination of future full charge. Another reading of the specific gravity made when the voltage is 1.9 per cell may be made a basis for future determination of the discharged condition of the cell. A little careful observation will soon enable the one in charge of battery to determine approximately its condition by means of the hydrometer alone.

Batteries may be charged from a direct-current, incandescent lighting or power circuit, depending on the charging current wanted. The resistance used may consist of lamps in parallel or iron-wire coils conveniently arranged as in the ordinary motor-regulating rheostat. Where the best efficiency is desired it is advisable to use a motor generator, the generator end being wound to suit the number of cells to be charged. This method is the only practical one for 500-volt direct or alternating-current circuits. In charging from any source of electricity, an automatic under and overload circuit-breaker should be used, so as to prevent current from the battery passing back over the line in the event of a shutdown at the power house.

Discharging.

At least 75 per cent. of the energy in a good storage cell is obtained before the voltage falls below 1.9 volt. It is advisable not to discharge beyond this point ordinarily, although a discharge to 1.8 is allowable. A cell may be considered discharged at 1.8 volt.

Never under any circumstances completely exhaust the battery. If a battery is allowed to stand discharged for a period exceeding two or three days, the capacity of the cells may be found on subsequent discharge to be materially lessened, due to conversion of the lead oxides into inert sulphate of lead.

Replacing of Electrolyte.

The boiling of the electrolyte when charging causes a fine spray to arise, by which some of the fluid is carried off, so that diluted acid must sometimes be added to replace it. All spilled solution should be replaced by solution of like density. Evaporation loss should be replaced by the addition of water only. The electrolyte must be maintained at all times over the tops of the plates and each cell individually inspected at least once a week, when the strength of the electrolyte should be tested, and if the density is below 1200° when other indications point to the full charge of the cell, dilute acid should be added until the density reaches that figure. Never under any circumstances pour pure acid into a cell in order to bring the electrolyte up to the proper density. A portion of the old fluid should be siphoned off and fresh acid in a diluted form added. When water is added to replace loss due to evaporation, it should be added at the bottom of the cell either by a glass or rubber tube or syringe.

Defective Cells.

If for any reason one or more of the cells should act strangely, —that is, show a marked difference in color, voltage, or specific gravity indications from the others,—they should be examined at once and the cause of the trouble ascertained. Should a nail or other foreign substance, or any material scaling from the plates themselves, lodge between the plates, it will cause a short-circuit, and this will be indicated by low voltage and low specific gravity, and should be at once removed. Its most probable cause is the lodging between the plates of some foreign article, but it may also be due to the depth of sediment in the bottom of the cells reaching the bottom of the plates. If the short-circuit is due to a foreign body, it should be removed; if to a loosened portion of the plates, it may be forced to the bottom of the cell; if to sediment, the cell should be cleaned out. A strip of hard rubber that will go between the plates is convenient for use in this work. If the short-circuit is removed promptly, no harm will result; on the other hand, if the cause of a short-circuit is allowed to remain, the plates may be seriously affected, injured possibly beyond repair.

It is important to use only glass, rubber, or wood in reaching into the cells. Metals will be attacked by the electrolyte, and thus impair its purity. Moreover, they are likely to short-circuit the cells and thus damage the plates.

Treatment of Short-Circuited Cell.

A cell that has suffered a short-circuit will need more than its usual amount of charge after the trouble has been removed. This may be obtained in various ways. First, by overcharging the whole battery, a bad practice if done too frequently, but it may be occasionally resorted to without evil effects. Second, by cutting out of circuit the cell in trouble on one or two discharges and replacing it on the charges. This can be most conveniently done on small cells with bolted connections, but not very well with cells permanently connected. Third, by giving the cell in trouble an individual charge during the discharge of the battery. Current for this may be obtained from the regular charging dynamo, working through a resistance if necessary. The third method is the best one, and is easily carried out.

Color of Plates.

The color of the plate is a valuable indication as to the condition of the cells.

The positive plate should have a dark brown, velvety appearance. Any lightness in color indicates insufficient charging. The negatives should have a clear bluish lead or light slate color.

Cells that have not been sufficiently charged for a continued period, or that have been left standing uncharged too long, are liable to what is termed sulphating. This is indicated by a white deposit on the plates due to the formation of lead sulphate which is insoluble in the electrolyte, and is deleterious to the action of the cells. When it occurs between the lead of the plate and the active material it is liable to loosen the latter, causing it to drop off, or, if it remains on the plate to increase the resistance of the cell. The remedy for sulphating is to continue the charging current at about half normal value for several hours after the cells give indication of being fully charged.

A whitish deposit sometimes appears on the surface of the plates in spots, even when the cells have not been subject to undercharging. This, the manufacturers claim, need not give alarm. It usually disappears after the battery has been in service some months. It is probably a mild form of sulphating, occurring only on the outer surface of the active material.

Taking a Battery Out of Service.

Charge the battery fully at a rate not higher than the normal. Siphon off the acid (which may be used again) into convenient receptacles, preferably thoroughly clean carboys, and immediately refill each cell with water. Then discharge the battery at the normal rate down to less than one volt per cell.

The elements should then be removed from the water and allowed to dry. They may then be replaced in the empty tanks or jars, previously dried and cleaned, or stored in any dry place.

CHAPTER XXX.

PROTECTIVE DEVICES.

PROTECTING telephone apparatus from the damaging effects of currents other than those which properly belong on telephone lines, and guarding the users of such apparatus against accidents and their property from fire, caused by such currents, has claimed the attention of telephone engineers in no small degree.

The problems involved have been numerous and varied because of the widely different conditions which may, and often do, arise to make protection necessary. To-day the protective apparatus used in a telephone exchange forms an important part of the entire equipment, as on it depends not only the safety of the lives of the operators and users, but of the physical property of the telephone company and that of its customers.

The devices used for this purpose are broadly termed "arresters," this being a shortening of the term "lightning arresters," which was universally used when the currents due to lightning were practically the only extraneous currents to be dealt with. The term arrester now has significance with respect to all kinds of damaging currents, whether they be due to lightning, or to any other source, natural or artificial.

The advent of the street railway and electric lighting and other systems in the allied fields of electrical engineering, and of the common battery system now largely used in the telephone industry itself, has placed before the telephone engineer more complex conditions than were present in the days when the old "saw tooth" arrester afforded what was thought to be adequate protection for telephone apparatus.

There are broadly three elements against which apparatus must be protected: lightning, high tension currents, such as may be caused to flow on a telephone line by a cross with electric light or power wires; and *sneak currents*, which are currents too small to do instantaneous damage, but which, if they persist, may, by the accumulation of heat, cause damage to the apparatus. Of course, only the first two causes need be considered in regard to the danger to human life.

The lightning arresters found on nearly all telephone instruments up to within a few years ago, were of the saw tooth type, and usually of the general form shown in Fig. 421. This was an adaptation of the lightning arrester frequently used on single telegraph lines at intermediate stations where the two wires, which looped into the office, terminated respectively in the binding posts on the plates, *A* and *B*, between which posts the local instruments were also looped. The plate, *C*, was connected directly with earth. By inserting a conducting plug in the hole, *e*, the local instrument would be short-circuited and the line left connected through. If the plug were inserted in the hole, *g*, that end of the line terminating in plate *A* would be grounded, while the local instruments would be connected in circuit with that end of the line terminating in plate *B*. Similarly, inserting the plug in hole, *f*, would ground the end of the line connected with the plate *B*, and leave the instruments connected

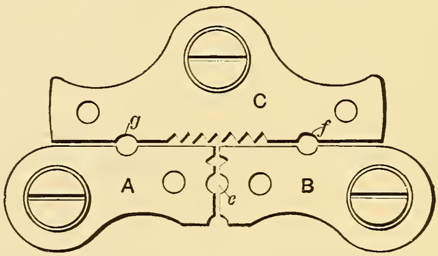


FIG. 421.—SAW-TOOTH ARRESTER.

in operative relation with the end of the line terminating in the plate *A*.

When applied to a telephone instrument, or more properly, to a sub-station equipment, the plates *A* and *B* form the terminals of the instrument and also the terminals of the line, the plate *C*, as before, being grounded. When telephone instruments are connected in series in a party line, as was the common practice in the early days, either end of the line could be cut off and grounded, leaving the instrument in operative relation with the other end in exactly the same manner as described in connection with the telegraph line. This formed a convenient means of cutting out a defective end of the line when comunication was desired with the other end. On a telegraph line, or on a series telephone line this device, therefore, served admirably as a switch, in addition to its functions as a lightning arrester. The latter functions may be described as follows: When the line was subjected to a high potential charge of electricity, this charge would seek the most available path to earth, and this would usually be across the air gap between the ground plate and the plates *A* or *B*. The current, as a rule, would take this path rather than pass through the high impedance coils within the telephone.

In lightning discharges, and, in fact, high tension discharges from other causes across an air gap, the current is often of an oscillatory nature of inconceivably high frequency, and, therefore, the impedance of the coil even though it consists of but a few turns, presents more of a barrier than would an air gap of considerable length. It is on this principle that the action of the air gap arresters are based. It is frequently true, however, that a shorter air gap than that afforded by the arrester is found between the wire of a coil and its core, and from the core to the ground. For this reason, telephone apparatus which has grounded cores is, as a rule, defective, and it may be stated further that when the core is grounded it is better to have the line wire connected with the outside layer of winding rather than the inside layer.

The old saw tooth arrester, besides being inefficient, has serious drawbacks, from a practical standpoint. The subscriber would often, on the approach of a thunder storm, short-circuit his instrument by inserting a plug in the hole, *e*, or connect it directly to earth by inserting a plug in one or both of the holes, *f* and *g*. This would afford the instrument as perfect protection as could be given, but he would frquently forget to remove the plug after the storm, therefore leaving his instrument out of service; and if the line used bridging instruments the insertion of the plug in the hole, *e*, would also leave most or all of the other instruments on the line out of service; also, if it were a series party line, the insertion of the plug in one of the ground plate holes, would sever the connection between the two ends of the line.

A lightning arrester much more efficient than the one shown in Fig. 421, but based on the same general principles, consists of a pair of carbon blocks held apart by a thin disc of mica. One form of this which has come into wide use is shown in Fig. 422, which has two pairs of blocks, one for each side of a metallic circuit line. One block of each pair is connected to the line wire it is to protect, while the other block of each pair rests on a metal ground plate. These pairs of blocks are usually arranged as in this figure, to slip between rather strong springs and the ground plate, the springs forming the line terminals. By this arrangement the blocks may be easily removed when desired. The thin mica strip between the pairs of blocks is perforated so as to allow a small air gap between the blocks, over which the high potential charge may jump with much greater ease than between the comparatively widely separated plates of the old saw-tooth arrester. The length of the air gap as determined by the thickness of the separating mica strip usually varies from .005 inches to .007 inches. Carbon block arresters of this general type are now almost universally used for protection against lightning, and against all currents such as might produce potentials of 300 volts or over between the line and ground. With a distance of .005 of an inch between the carbon blocks a pressure of 300 volts across the blocks will break down the insulation of the air gap between them.

This kind of an arrester, of course, operates by grounding the line either temporarily or permanently; and in the case of a lightning discharge, which persists for only a minute period of time, no

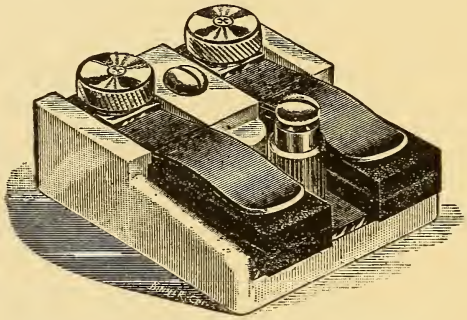


FIG. 422.—CARBON BLOCK ARRESTER.

other protection is necessary. However, a high potential current due to a cross with a high tension wire is likely to persist after being grounded, and thus cause a very large current to flow over the conductor so grounded, which may be injurious to the line wire or cable itself. For this reason it becomes desirable to provide some means for opening the circuit after it has been grounded in case the current allowed to flow by the grounding is of sufficient magnitude to become dangerous. The most simple means of accomplishing this consists of a fuse wire of limited carrying capacity. Such a wire is usually made of some low-fusing metal having comparatively low conducting power, such as lead, the object being to make it the weakest link, electrically speaking, in the chain of conductors.

In Fig. 423 is shown in diagrammatic form the combination of fuse and carbon arrester as they are associated together on telephone lines, with a view to first protecting the instrument from the current to which a high tension cross might subject it, and second, to protecting the line from the current which would flow after the line was grounded at the carbon arrester. In this, *A* represents the air gap between the two plates of the carbon arrester, and *F* the fuse wire, it being obvious that if a high tension cross occurs on the line the arcing across the air gap will protect the telephone instrument, after which the current flowing over the now grounded line will, if it becomes dangerous, cause the fuse, *F*, to blow thus entirely opening the line and preventing all flow of current.

The general principles governing high tension and strong current protection have now been dealt with, but none of the means so far pointed out are sufficient to cope with the sneak current, against which an entirely different means of protection must be employed.

Sneak currents may be caused by a low potential cross somewhere on the line, or by comparatively high potential cross through

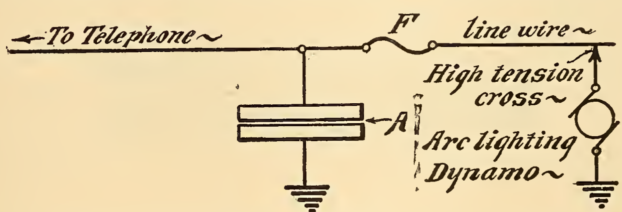


FIG. 423.—DIAGRAM OF FUSE AND CARBON ARRESTER.

a very high resistance. Cases have been known where they were caused entirely by induction from some wire carrying high potential alternating current in the operation of a lighting or power circuit. In common battery work still another very common cause of sneak currents is due to the grounding of one of the telephone wires or the crossing of two wires, in which cases, even though the lines are not subjected to any outside electromotive force, the current flowing from the common battery may, in some systems, persist to such an extent as to cause ultimate damage to the apparatus.

The most simple means of protecting against these small currents is to employ a fuse wire of very small carrying capacity. These wires may be made sufficiently small to fuse when subjected to the passage of a current of $\frac{1}{8}$ ampere, and fuses supposed to blow at $\frac{1}{8}$ ampere have been widely marketed. These small capacity fuses are usually mounted on mica strips to which they are secured usually by varnish or shellac, the ends of the strip being provided with some form of terminal to which connection may readily be made without subjecting the fuse proper to mechanical injury. Such a fuse is shown in Fig. 424, the terminals in this case being of heavy tin-foil wrapped around the ends of the mica strip, the fuse wire being electrically securely connected to the terminals at each end. Such forms of fuses are adapted to slip between spring clips mounted on insulating blocks and provided with binding posts for securing the terminals of the circuit to be protected. These fuses play a very important part in telephone and telegraph work, particularly in small installations. Frequently, in combination with carbon block arresters, they form the only protection afforded to the line, the apparatus and the user. They are not, however, efficient forms of sneak current arresters, for the reason that they cannot be depended upon to open the circuit when traversed by current of predetermined strength. It is frequently found that a fuse supposed to blow on being traversed by a certain current will safely carry four times that. Another disadvantage is that they are, on

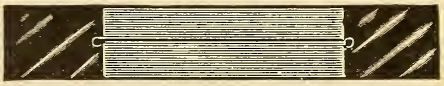


FIG. 424.—POSTAL-TYPE FUSE.

account of their small size, very frail and liable to mechanical injury.

On account of these objections an entirely different type of sneak current arrester has come into use, depending for operation on the thermal effect of the current. In these the heat generated by the passage of the current in a small body, usually a coil of low conductivity, closely confined, melts not the coil itself, but a particle of low-fusing solder in close proximity to it. These devices are commonly termed heat coils.

The idea of the heat coil was, so far as the writer is aware, first introduced by Mr. H. V. Hayes, of Boston. His device consisted of a flat coil, through the center of which projected a pin fixed in place by a drop of low-fusing solder. Against this pin rested a spring which bore against the pin with considerable force tending to push it through the coil. When a sufficient current passed through the coil to generate enough heat to melt the solder, the pin would give way and allow the spring to come in contact with the ground plate which would throw a dead ground on the line.

Another pioneer in this line was Mr. F. B. Cook, of Chicago, whose arresters are now widely known and used. The construction of one of Cook's heat coils is shown in Fig. 425. In this *c* is a hard rubber cylinder having a tapped hole extending throughout its length, into one end of which is screwed a flanged brass piece, *a*,

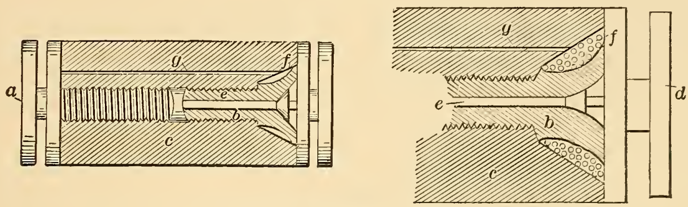


FIG. 425.—HEAT COIL.

and into the other a brass plug, *b*. A flanged piece, *d*, carries a wire rod, *e*, which extends through a hole in the plug, *b*, and is soldered therein by a low-fusing solder. In the chamber, *f*, which surrounds the enlarged portion of the plug, *b*, is contained a coil of German silver wire wrapped about this plug. One end of this wire terminates in the plug itself, to which it is soldered, and the other extends through the small hole, *g*, in the hard rubber block and is soldered to the piece, *a*.

The heat coil is slipped between the terminal springs as is shown

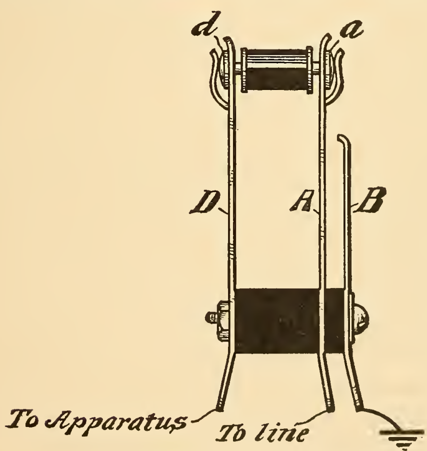


FIG. 426.—HEAT COIL AND HOLDER.

in Fig. 426, the springs, *A* and *D*, being the terminals respectively of the line wire and the wire leading to the instrument to be protected. The circuit may be traced from the line through the spring *A*, thence to the flanged head, *a*, through the German silver wire in the hole, *g* (Fig. 425), through the heat coil proper, and to the plug, *b*, and other coil head, *d*, to the spring *D*. The springs *A* and *D* are held together by the coil, their tension being such as to tend to pull the coil apart. When, therefore, a current of sufficient strength to melt the solder passes through the coil, the pin, *e*, attached to the head, *d*, is released, allowing this head to be withdrawn from the plug, *b*, thereby opening the coil and allowing the spring *A* to come in contact with the ground spring, *B*, thereby shunting the line current to ground.

All of the general types of protective devices that are in common use have now been discussed, but before passing to the consideration of these devices in detail, it will be well to consider what is at present regarded the proper degree of protection for telephone apparatus and lines. This may be discussed by reference to the diagram of Fig. 427. In this figure is shown a line extending from the central office to a subscriber's instrument, this line passing directly from the office through a section of underground cable, thence to a section of overhead cable, and thence through bare wires on poles to the subscriber's premises. The underground cable, it is understood, runs directly into the central office, being terminated either in potheads or their equivalents, or directly on the line side of the distributing frame, so that there is practically no danger of a cross occurring between one of the telephone wires and a power wire at any point between the central office and the outer end of the underground cable.

At the point in the office where the conductor emerges from the cable, is provided a combined carbon and sneak current arrester, the carbon arrester being shown diagrammatically at *A* and the heat coil of the sneak current arrester at *B*. This latter coil is so arranged that when released it will allow the line spring, *b*, to make contact with the ground connection, thus grounding the line and either opening the circuit to the switch-board, or merely grounding it while leaving it closed. The latter has the advantage that the ground applied by the heat coil spring will light the line lamp, if the wire in trouble leads to the line relay, and a notice of the action will so be given; this is not true if the line wire is merely opened. At the outer end of the underground cable at the point, *C*, where connection is made with the overhead cable, a fuse should be placed, but this connection is frequently made with no protective device whatever. A fuse should always be placed at *D*, the junction point of the overhead cable and the bare wire, and still another fuse at *E*, the point where the line wire enters the subscriber's premises. Sometimes a carbon lightning arrester is also added at *D*, as shown in dotted lines. Within the subscriber's premises, and frequently forming a part of the telephone equipment, is placed the carbon arrester, *F*, and in some instances a heat coil is also used at this point.

Most engineers prefer to place a fuse between the underground and overhead cable, as at the point, *C*. It is undoubtedly an additional protection and might prevent serious loss where a heavy cross existed between the sheath of the overhead cable and a high tension wire. Such a cross might easily cause the current to arc to the sheath, and, melting a hole in this, to the conductors within the overhead cable, in which case the fuse at *C* would probably save the conductor in the underground cable. If a cross with a potential of over 300 volts occurs on any of the conductors, a flow of current will probably take place through the carbon arrester at *A*, or *F*, or both, and the consequent flow due to

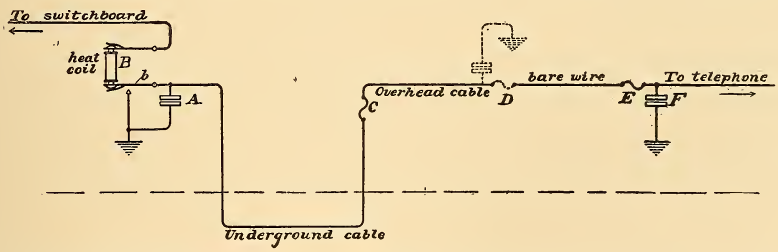


FIG. 427.—DIAGRAM OF COMPLETE PROTECTION FOR TELEPHONE LINE.

the low resistance path thus established would cause sufficient current to flow to blow one or more fuses at *C*, *D* or *E*. If, on the other hand, a comparatively low potential cross existed not of high enough potential to cause the carbon arrester at *A* or *F* to act, and not causing a current of sufficient strength to flow to blow the fuses at *C*, *D* or *E*, the heat coil, *B*, would receive the current and would operate, throwing a dead ground on the line, and thus effectually prevent any current entering the exchange apparatus. The low resistance path thus leading to the ground would, if the current were of sufficient strength to affect the conductors in the cable, cause the blowing of one or more of the fuses.

The placing of combined heat coils and carbon arresters at the exchange of the line fuse at *C* or *D* and *E*, and of the carbon arrester at *F*, represents well established practice. The sensibility of the various protective devices and also the questions as to whether a fuse, or carbon arrester or both should be placed at *C*, whether a carbon arrester should be added to the fuse at *D*, and whether a heat coil should also be added to the protective devices at the subscriber's station are all subject to discussion.

There is a difference of opinion among exchange engineers as to whether it is desirable or not to secure absolute protection. Protection that is to all intents and purposes absolute may be secured by putting in all of the devices mentioned and by making them sufficiently sensitive. Under this condition, however, the heat coils may be frequently operated by the normal currents of the exchange; again, if the line fuses are made of too low carrying capacity very slight currents which might injure nothing would also cause their operation. If the gaps in the carbon arresters are made too small, the liability of short-circuiting the line to ground by the accidental contact between the carbons, or the presence of a small amount of carbon dust, would exist.

The blowing of a heat coil or the short-circuiting of the carbon arrester at the exchange is not a matter of much importance, because it is an easy matter to quickly replace them, men being always present in the exchange for that purpose. However, all such unwished for occurrences at the office arrester, even though remedied within a few moments, are likely to cause interruptions in the service which, from the subscriber's standpoint, is not desirable. The blowing of a fuse or the operation of a carbon arrester or heat coil at some point in the outside construction or at the subscriber's station is, however, much worse, as the interruption to the service is of longer duration and the cost of repairing is much greater.

It is seen, therefore, that there is such a thing as overdoing protection, as too perfect a system, considered from the standpoint of protection alone, brings about an increased cost for maintenance and frequent interruptions of service. For this reason a middle course is usually pursued, aiming to give sufficient protection to the apparatus and property to prevent the possibility of any far-reaching disastrous results, at the same time keeping in mind the minimizing of the cost of maintenance and of service interruption.

With these general ideas in view the various questions as to best protection in the typical case shown in Fig. 427 may be discussed. That the central office protection should consist of a heat coil and carbon arrester is a matter concerning which there is little dispute; although there are those who maintain that a line when entirely underground from the central office to the subscriber's premises has no need of any protection whatever. In the case shown in Fig. 427, however, where a portion of the line circuit is aerial, the force of this contention is removed.

The degree of sensitiveness of the heat coil cannot be specified for all cases, as the apparatus of some switch-board systems is very much more susceptible to damage by excessive currents than others. In other words, currents which would be excessive for the electro magnets of some systems would be carried readily without danger of harm by those of others. It may be said in this connection that the best switch-board designers are making the coils of electro magnets, as far as possible, self-protecting; so that they would not be damaged by any current due to the voltage of the central office battery which might flow through them, even on a short circuit.

The electro magnets of some switch-boards are wound with such fine wire as to render the following requirements of the heat coil necessary: That it shall carry .1 ampere indefinitely and operate on .2 ampere within 5 minutes. To meet these requirements the heat coil is generally wound to about 20 ohms resistance. In other cases the requirements are that the coil shall stand .2 ampere indefinitely and that it must operate on .25 ampere within 3 minutes, and that the resistance of the coil shall not be more than 7½ ohms. These latter figures are now perhaps the most commonly adopted, and with such a coil when the current is in excess of ¼ of an ampere but less than .4 of an ampere the coil will operate in from 1 to 1¼ minutes; and with currents in excess of .4 of an ampere they are operated practically instantaneously.

In a letter from Mr. Frank B. Cook to the writer on this subject, Mr. Cook says: "My own personal opinion is that in view of the constantly increasing number of high tension circuits (10,000 to 30,000 volts) that all telephone apparatus should be made to stand .3 ampere for an indefinite period, and to operate on, say, .35 ampere within 2 minutes. This would admit of the heat coil having a resistance of 5 ohms or less. This is simply my opinion and not what is practiced."

The air-gap between the arrester blocks at *A*, Fig. 427, is now fairly well standardized at .005 inch, and with such an air-gap and with carbon of ordinary grade the insulation between the blocks will break down when subjected to a tension of about 300 volts.

The question as to whether a fuse should be placed at *C*, Fig. 427, or not, that is, at the point where an underground cable joins an aerial cable, is a mooted one, but it is thought that the chance for trouble, due to omitting the fuse at this point, is far too great to warrant the risk of omitting it. In other words, practice has proved in general that the occasional loss due to damaged cables caused by the omission of fuses at these points is of more importance than would be the maintenance of fuses at all points where the underground and aerial cables join.

The propriety of putting fuses in all wires in the cable at the point, *D*, where the overhead cable joins the bare wire or where an underground cable is connected to a bare wire without the intervention of an aerial cable, is very questionable. There are, however, many who prefer to use carbon arresters also at this point, and many exchanges are so equipped. It is sometimes desirable to put carbon arresters at the point, *D*, to protect the cable against lightning discharges from long lines. Where this is done, the fuse is necessary in order to protect the pole equipment from currents which may flow, due to arcing at the carbon and consequent fires therefrom. As the office of carbons at *D* is to arrest lightning and not stray currents of lower potential, the separation of carbons at this point should be made about 1-10 inch or greater.

Mr. Cook's views on this subject are as follows: "I have noticed for some time past that the use of the combined fuse and carbon arrester is increasing at a very rapid rate, and now I think a majority of good construction companies are following the plan of using the combined fuse and arrester. I also notice that there are many complaints of damage to cables at points where the fuse alone is used, and in many instances, well-managed telephone companies who were formerly using simply a fuse for protection to their cables, have replaced the fuses with the combined fuse and carbon arrester, all of which indicates that they have learned by experience that fuses are not good lightning arresters, and this is true, of course, regardless of their carrying capacity." The carrying capacity of the tubular fuses used in outside construction work varies from about 1 to 7 amperes. Probably in the various Bell companies the 7-ampere fuse is most commonly used, while most of the Independent companies are using somewhat smaller carrying capacity, averaging perhaps 2½ or 3 amperes. Where, however, a carbon arrester is used in connection with the line fuse the usual carrying capacity of the fuse is 5 amperes. It would perhaps be safe to say that as far as standardization has progressed, the various Bell companies use the 7-ampere on practically all outside construction work, while the Independent companies use fuses adapted to blow 2½ or 3 amperes.

Probably all telephone engineers agree that a fuse should be placed at the points where the line wire enters the subscriber's premises, as at E_3 in Fig. 427. Most complete telephones are now also equipped with fairly efficient forms of carbon lightning arresters, these latter forming integral parts of the telephone as produced. The combination of the fuse and the arrester, therefore, forms a very efficient protection for the instrument, the premises, and in fact for the line conductor itself. Some companies, however, add a heat coil to the protective device at the subscriber's premises, but this is thought to be not in accordance with the best practice. The cost of burnt-out telephones which would have been saved by the presence of a heat coil would probably prove much less than the cost of time and labor of replacing heat coils at the subscriber's stations.

One of the difficulties met in solving the problems of adequate and economical protection may be realized when it is considered that in any common battery exchange there must be a certain flow of current over the lines for the operation of the signals, and for furnishing talking current to the subscribers. The heat coils, of which there are at least two in each line circuit, must be so made as not to be affected by these currents, even though they sometimes approach very close to what is considered the dangerous limit, yet they must operate with certainty on slightly heavier current, particularly if it persists for any length of time.

The question has often arisen relative to the efficiency of carbon as a sparking or discharging surface for lightning, and as to its possessing qualities for this purpose superior to those offered by metals. The reason for its alleged superiority for this work is probably the fact that in carbon small particles of material on its roughened surface often become detached and lie in a loose state, in which they may possess the qualities of the coherer, maintaining an open circuit until cohered by the lightning discharge. After storms much trouble is often experienced from line grounds due to the presence of this dust, it being necessary to remove these grounds before service is restored. Schemes have been tried by which the carbon may be prevented from giving off this dust; one of these being to soak the carbon block in resin or paraffin. The object desired was thus undoubtedly attained, but unquestionably at the sacrifice of the sensitiveness of the sparking surface. The use of certain metals as a substitute for carbon in the usual carbon block arresters is being experimented on, and developments in these will be of general interest.

Coming now to a discussion of the actual devices and apparatus used in the protection of telephone equipments and lines, the matter of fuses will be first considered. One of the usual forms of sneak current fuses is that shown in Fig. 424, this being known as the Western Union type. Another common fuse differing only in the style of its terminals is shown in Fig. 428, this being known as the Postal type.

The salient points of difference between the Western Union and the Postal fuses is that the former is adapted to insertion between spring clips, while the latter is secured in place on its clips by cross screws extending through the slots in its ends. These fuses are, as a rule, adapted to inside construction only. If, therefore, they are placed outside, they should be inclosed in weatherproof boxes of substantial character.

Such fuses are often mounted in conjunction with carbon arresters so as to form protection against both low potential and high potential currents, the theory of such operation and connection with the

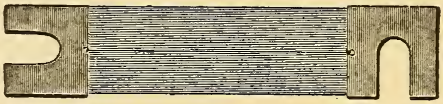


FIG. 428.—WESTERN UNION FUSE.

line circuit being the same as described in connection with Fig. 423. Such a combination adapted to a single line wire is shown in Fig. 429, which, as will be seen, employs the Postal type of fuse. The two carbon blocks of this figure are adapted to be held in the spring clips shown at the upper portion of the porcelain base, the mica washer serving to keep them from actual electrical contact. For metallic circuit lines these devices are usually made up in pairs, mounted on porcelain blocks, there being one fuse and carbon arrester for each side of the line. In Fig. 430 such a device for a metallic circuit adapted to use with Western Union fuses is shown, while that in Fig. 431 employs the same combination adapted to Postal type fuses. In Fig. 432 is shown one of these combined carbon and fuse arresters applied to a line circuit entering an ordinary magneto-telephone. This practice is used in many country exchanges, and as a cheap form of protection is fairly efficient.

For use on outside line construction in such portions of the line as are shown at *C*, *D* and *E*, in Fig. 427, a form of fuse generally known as the tubular line fuse has come into wide use. One of these is shown in sectional and in perspective view in Fig. 433. In this a long fuse wire is inclosed in a tube of either wood or

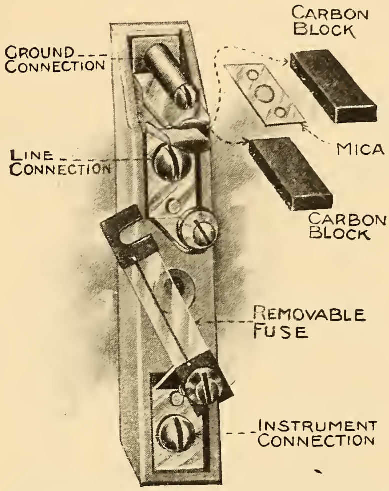
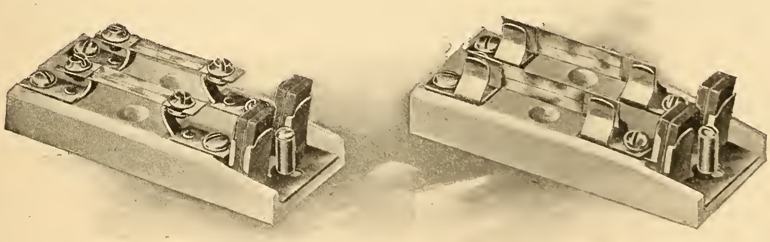


FIG. 429.—COMBINED FUSE AND CARBON ARRESTER SINGLE CONDUCTOR.

fibre, this tube being closed at its ends by heavy brass terminals provided with ready means for attaching the line wires. The fuse wire within the tube is secured to the terminal at each end by solder, the fuse wire extending entirely through the terminal at each end,



FIGS. 430 AND 431.—POSTAL AND WESTERN UNION TYPES OF CARBON AND FUSE ARRESTERS.

so that its ends may be accessible for soldering. The fuse is made in this general form for two reasons, one of which is to give a substantial case in which the comparatively delicate fuse may be held safe from mechanical injury. The second reason is that experiment has shown that the incasing of a fuse in a tube, whether it is hermetically sealed or not, tends to prevent the arcing of a heavy current across the terminals after the fuse has blown. In case the fuse is hermetically sealed, the forming of gas prevents the arc from being maintained, and sometimes the casing explodes as a result. When there is an opening in the casing, the expansion within due to

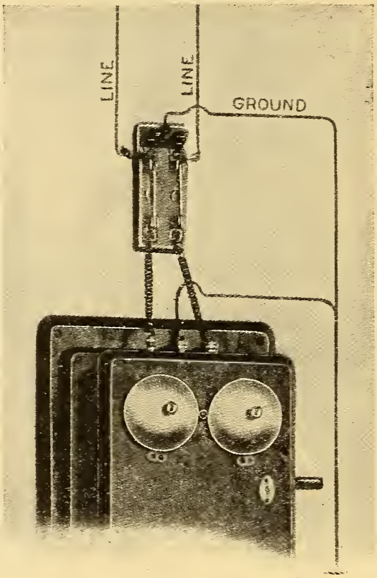


FIG. 432.—FUSE AND CARBON ARRESTER AS APPLIED TO MAGNETO TELEPHONE

heat and gas that is formed, tends in passing through the opening, to blow whatever arc is formed.

The method of clamping the wire at each end of the fuse, shown in Fig. 433, is obvious, one end of the line wire being clamped between the parallel jaws at the right hand end of the cut, and the other end between the brass terminal block and the inside nut at the left hand end of the cut. In each case the outside nut serves as a lock nut. This particular fuse is one made by the American Electric Fuse Company, of Chicago. It is particularly adaptable to clamping directly on the line wire outside of the subscriber's premises as at the point, *E*, in Fig. 427, the parallel jaws serving to grip the line wire usually at or near the insulator, while the wire leading to the subscriber's premises is clamped by the nuts at the other end.

When used on a cable pole, as for instance at the point, *D*, in Fig. 427, these fuses are usually placed in boxes and mounted in banks for economy of room. In this case the line wires leading from the cable and from the bare wires are permanently soldered to spring

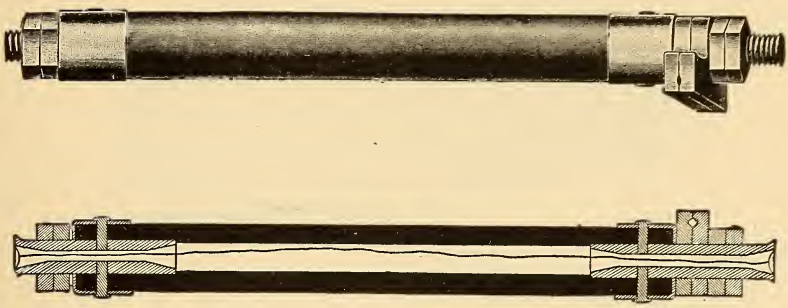


FIG. 433.—TUBULAR FUSE.

clips between which the fuse proper is adapted to slip. Such a construction is shown in Fig. 435, the fuses in this case being held in place between the clips by clamping nuts at their ends, as clearly shown, Fig. 434 giving detail of the unmounted fuse. Fig. 436 shows a similar arrangement, but in this case each fuse has associated with it a carbon arrester, thus affording additional protection against high-tension charges.

A complete equipment for subscribers' stations protection consisting of tubular fuses, heat coils and carbons all mounted on a single porcelain block in a very compact and convenient form, is shown in Fig. 437. This device was designed by Mr. F. B. Cook to meet

FIG. 434.—TUBULAR FUSE.

the requirements of those who prefer this complete protection at the subscriber's premises.

It has been said that most complete telephone sets are now equipped with carbon block arresters, and one of these, as manufactured by the Kellogg Switch-Board and Supply Company, is shown in Fig. 438. The method of associating this with the line circuit and with the circuit of the instruments which terminates in the line binding posts is clearly shown in Fig. 439. This arrester consists merely of two brass discs of approximately semi-circular form, one being permanently connected to each of the line binding posts of the instrument. Over these fit a perforated mica washer of circular form, and over this is clamped, by means of a centrally

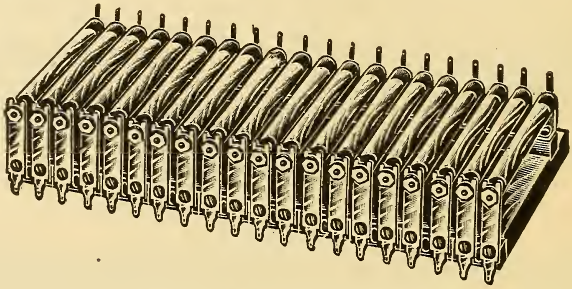


FIG. 435.—BANK OF TUBULAR FUSES.

disposed screw set, a carbon plate, covering both the semi-circular brass plates. The screw holding this carbon in place is permanently connected to the ground binding post, these connections being shown in Fig. 439.

The lightning arrester usually furnished by the Stromberg-Carlson Company on their telephone sets is shown in Fig. 440, in which the binding posts shown are those of the telephone instrument.

Coming now to the question of heat coils and the associated devices used for protection at the central office, it may be said that the

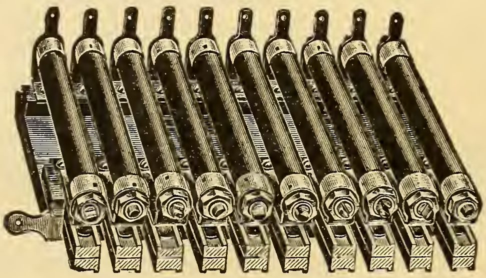


FIG. 436.—BANK OF TUBULAR FUSES WITH CARBON ARRESTERS.

coil shown in Fig. 425 is typical of standard practice in heat coil construction, it being the type almost universally used until a very recent time.

As two heat coils and two carbon arresters are used in connection with each line circuit in a modern central office, economy of space and in the amount of wiring between them, has brought about the association of the carbon arrester with the heat coil device in such manner as to form virtually one piece of apparatus. These combined carbon and heat coil arresters are, in order to further economize space, usually mounted in groups or banks of twenty pairs, on long

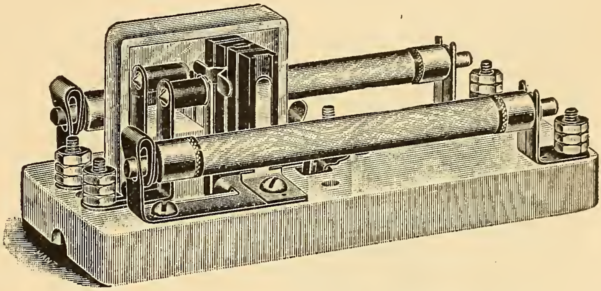


FIG. 437.—PROTECTIVE APPARATUS FOR SUBSCRIBERS' STATIONS.

heavy strips of cold rolled iron, a single strip containing from five to twenty banks, each bank containing twenty pairs; each strip therefore contains from 100 to 400 pairs of arresters, according to the requirements of the available space and of the cable distribution within the office. A view of a single pair of office arresters as designed by Cook, and manufactured by himself and by the Sterling Electric Company, is shown in Fig. 441, this view showing a horizontal section through a part of the

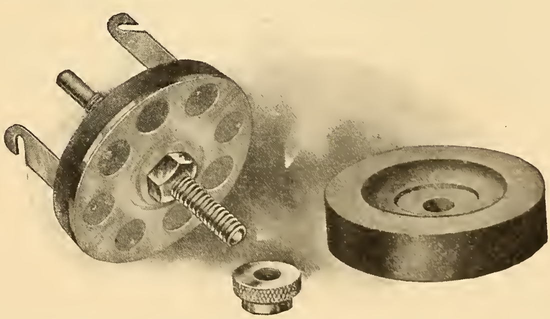


FIG. 438.—KELLOGG CARBON ARRESTER FOR TELEPHONE SETS.

arrester strip, heat coils and carbons. The heat coil in the left hand portion of this figure is shown in proper relation to its springs, as in normal use. That at the right hand portion, however, shows the heat coil after it has been operated, thus allowing the springs to separate, opening the line circuit and closing it to ground. The circuit through these arresters may be traced by following the arrows marked *a* and *b*, these arrows leading from the wires extending to the switch-board to the wires extending to the outside line. Following arrow *a*, it will be seen that the circuit extends from

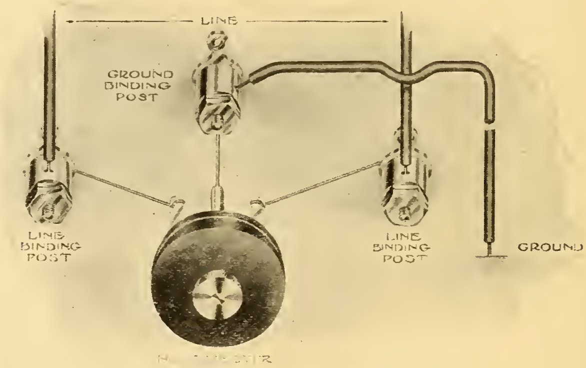


FIG. 439.—CONNECTIONS OF KELLOGG CARBON ARRESTER.

the spring connecting with the removable head of the coil, thence, when the coil is intact, through the winding of the coil and through the spring which holds the other end of the coil through which the circuit is led, to one of the left hand terminals of the arrester, through the insulated tube of brass surrounding the bolt which holds the entire structure together. Ordinarily this circuit is entirely insulated from all other portions of the arrester, but when the heat coil is traversed by too great a current, it is pulled apart by springs,

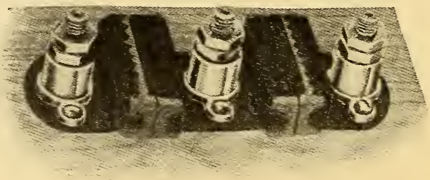


FIG. 440.—STROMBERG-CARLSON CARBON ARRESTER FOR TELEPHONE SETS.

thus allowing the spring which connects the line to become grounded by virtue of an extension of the line spring which then presses against the strip upon which all the arresters are mounted; this strip is in all cases well grounded at the central office. The circuit through the left hand arrester may be traced by following arrow *b*, from the switch-board wire through the bolt, and thence from the outside spring of the left hand heat coil through this coil and to the line spring as shown. The two pairs of carbon plates are normally held between the ground plate and two springs which are permanently in contact with the line springs carrying the heat coils. These springs are not, however, normally grounded because of the

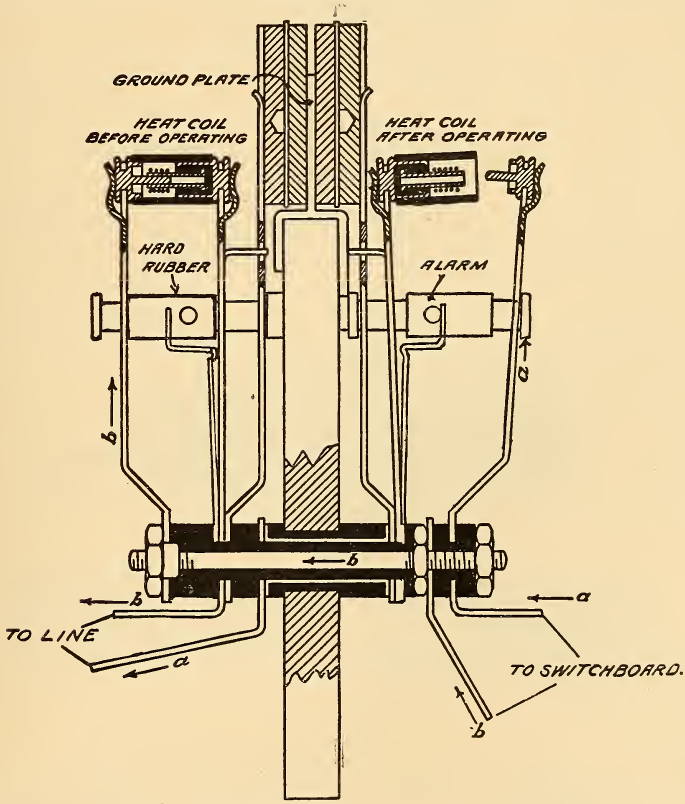


FIG. 441.—COOK COMBINED HEAT COIL AND CARBON ARRESTER.

presence of the mica strips between the carbon blocks. The ground plate or strip is usually of German silver or brass, and is supported by and in electrical contact with the heavy iron strip upon which all of the arresters are mounted. The various springs are guided in their respective movements by means of two hard-rubber posts, which pass through each of the springs and which also carry conducting pins for the purpose of completing the alarm circuit when the heat coil operates. For this purpose there is an additional spring on each arrester, adapted, when the heat coil releases the springs, to close the alarm circuit and thus indicate to the attendant that the line has been opened at the heat coil. Frequently each of these alarm circuits is made common to a single strip of arresters and an annunciator placed in the circuit, so that by a glance at the annunciator-board the attendant may tell on which strip of arresters the coil has been operated, thus saving time in effecting its repair.

Sometimes an added feature of protection is provided by inserting in one of the carbon blocks of each pair a small drop of solder or easily fusible metal. If an arc occurs between the two blocks this metal will melt, thus establishing a more or less perfect connection between the two and affording a better grounding of the line.

As will be shown in a subsequent chapter the arresters in central offices are usually mounted on the switch-board side of the main

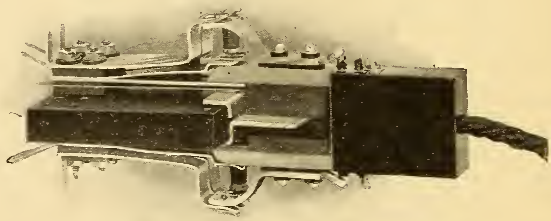


FIG. 442.—KELLOGG ARRESTER WITH TEST PLUG INSERTED.

distributing frame, and when so mounted they afford the most convenient place on the line circuit within the office at which to make electrical tests as to the condition of the line both outside or within the office.

In the general form of arresters shown in Fig. 441, such tests are usually made by removing the heat coils of the pair of arresters belonging to the line to be tested, and inserting in their place a four-contact plug, so arranged as to make contact with the two-line springs and with the two springs connected with the switch-board circuits. By means of the conductors leading from this plug, the party making the tests has access to both ends of the line for testing purposes, that is, to the two line wires leading from the central office to the subscriber's premises and to the two wires leading to the arresters from the switch-board.

Fig. 442 shows such a test plug as applied to a pair of arresters;

this figure also incidentally showing the type of arrester put on the market by the Kellogg Switch-Board and Supply Company. The general plan of operation of this arrester is the same as that described in connection with Fig. 441, but the "heat coil" is peculiar and merits attention. Instead of using a German silver wire as a

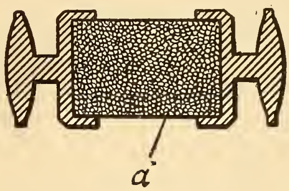


FIG. 443.—KELLOGG HEAT COIL.

heat-producing medium, a small cylindrical block or carbon, *a*, Fig. 443, is used, and to this is soldered the brass terminals which serve to engage the springs of the arrester holder. The size and general appearance of this device is not unlike that of the ordinary heat coil of the type shown in Fig. 425, and although it is not in any sense a coil, it is ordinarily called by that name. This device depends for its operation on the heat generated by the passage of a current through the carbon, which is made of suitable resistance to produce the desired degree of heating. Before soldering the brass terminals on the ends of the carbon block the ends of the latter are copper

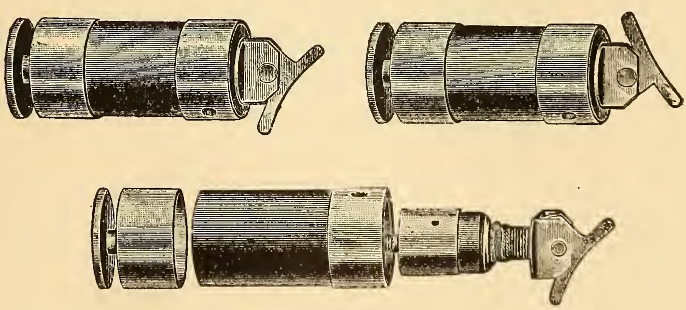


FIG. 444.—AMERICAN ELECTRIC FUSE COMPANY'S SELF-SOLDERING HEAT COIL.

plated and the terminals then soldered in place. The solder used in this and other heat coils is usually of such alloy as to melt at about 160° F.

All of the heat coils mentioned are subject to one objection, which, however, has been brought to notice only in view of an ingenious improvement recently made. This objection is that when once used it was necessary to throw the coil away or to go to some expense to put it in proper condition to be used again.

In Fig. 444 are shown three views of a type of coil embodying this improvement. This is manufactured by the American Electric Fuse Company, of Chicago, and was designed by Mr. C. A. Rolfe, of that company. In this, the movable part, instead of entirely separating from the body of the coil when the solder melts, is merely moved from one position to another, and in so moving releases the spring which grounds the line. As soon as the spring has been so released the circuit through the coil is broken and the parts immediately begin to cool. The movable part as soon as sufficiently

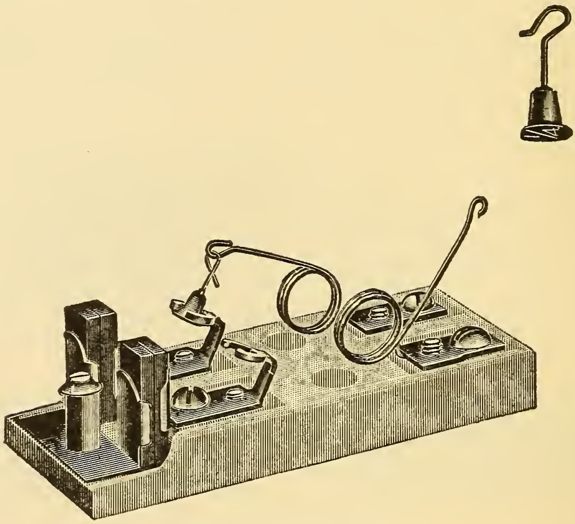


FIG. 445.—ROLFE ARRESTER.

cooled is thus automatically resoldered into its new position in which it is, by its other end, again adapted to hold the spring as before.

Referring particularly to Fig. 444, the only movable part of this device is a small lever shown at the right-hand end of the coil. When it is in the position shown in the upper left-hand view of this cut, the spring of the arrester holder is adapted to be caught under the lower leg of this lever and thus retained in place. When the solder holding this lever in this position is softened the spring forces the lever into the position shown in the upper right-hand view of this cut and the spring is thus released. After the coil is cooled it is only necessary to turn it around in the holder in order to bring the other end of the lever in connection with the spring, as that end is now in such position as to retain the spring. This device may be operated many hundreds of times without showing any appreciable deterioration, and as a result the only expense caused by the blowing of the heat coil is that of the time necessary for the attendant to again set the springs which it released by this operation.

Another type of thermal arrester or heat coil which deserves passing mention, is that also designed by Rolfe and shown in Fig. 445. In this the heat coil assumes the form shown in the upper portion of this figure, it consisting of a little metallic capsule having embodied within it a coil of German silver wire held in place and insulated by a plastic material resembling sealing-wax. A hook projects from the small end of this capsule, thus forming one end of

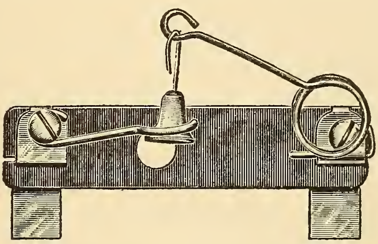


FIG. 446.—ROLFE ARRESTER.

the coil, the capsule itself forming the other terminal. This device is held between a coiled spring and a forked clip, as clearly shown in Fig. 445, the heat coil being thus subjected to tension and also forming a link in the circuit to be protected. When traversed by too heavy a current the hook pulls out of the capsule, due to the softening of the plastic material, and the circuit is broken by the retraction of the coiled spring.

These arresters are manufactured by the American Electric Fuse Company, and so made as to adapt them to service in place of the ordinary Western Union fuse, the working parts of the arrester being mounted on a fibre strip provided with clips adapted to slide into the fuse holder in place of the ordinary fuse. This arrangement is quite clearly shown in Fig. 446 as applied to the Western Union style of fuse holder.

CHAPTER XXXI.

DISTRIBUTING FRAMES.

In every central office it is necessary to provide some means for distributing the various line wires which enter the office to their proper numbers on the switch-board and switch-board apparatus, and to afford means for changing this distribution as required. To do this in any manner without a proper regard for systematic arrangement would lead to endless trouble by producing the tangle of wires commonly and well-termed "rat's nest."

In order to provide means for the systematic arrangement of wires and for the proper handling of subsequent changes in their distribution, what is called the distributing board or frame is used. These two terms are at present used indiscriminately. The boards or frames assume a great variety of forms, but the principle on which they are designed is as follows: On one portion of the distributing frame are placed clips or connectors, suitably arranged, in which the wires of the cables leading from the lines may terminate. On another portion of the distributing frame is arranged another set of clips, in which another set of wires leading to the switch-board apparatus may terminate. All conductors from the lines, and all conductors from the switch-board apparatus are wired in a permanent manner to the various connectors or clips on the respective portions of the distributing frame. The gap between the terminals of any pair of wires on the line portion of a distributing frame, and those of the corresponding pair leading from the switch-board apparatus, is filled by means of bridle or jumper wires, the latter term being the most commonly used. The distributing board is so arranged that the jumper wires may lead from any pair of connectors on the line portion to any pair on the switch-board portion, and if the distributing frame is a good one these jumper wires may be led with perfect order and may be changed as often as desired.

In Fig. 447 is shown a distributing board, which is, happily, a relic of the past, but which, in its day, was distinctly superior to others, and may be said to have served its purpose well. It is of interest here from a historical standpoint. This picture was taken

FIG. 447.—OLD ST. LOUIS DISTRIBUTING FRAME.

from the inside of the distributing frame, which was in the form of a hollow square, one corner of which is shown. It accommodated about 4,000 lines entering the old office of the Bell Telephone Company, at the corner of Fourth and Pine streets, in St. Louis, Mo. The lines were practically all aerial and were brought to a large tower at the top of the central office building; they were then led down in cables, shown in the picture, these cables being fanned out for attachment to the clips on the upper portion of the frame. In the same manner the switch-board cables were led up to the lower set of clips on the distributing board shown at the bottom of the

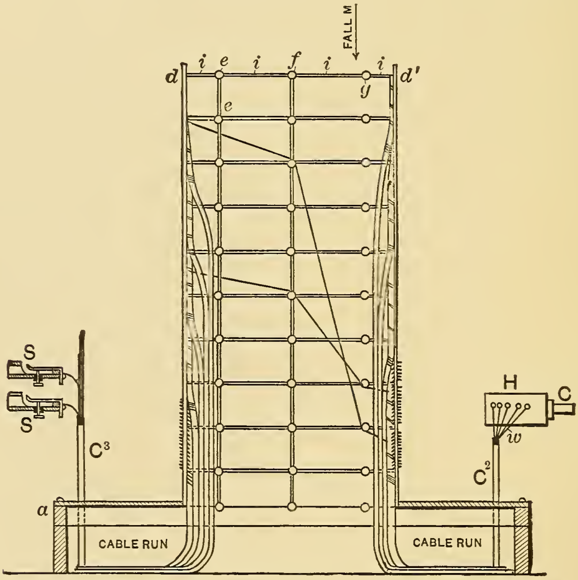


FIG. 448.—END VIEW HIBBARD DISTRIBUTING FRAME.

picture. Connection between any line wire and any switch-board wire was then completed by means of a jumper wire, as readily seen.

A later form of distributing frame which at one time was widely used by the Bell companies, was the design of Mr. Angus S. Hibbard, and is illustrated somewhat in detail in the accompanying figures.

The frame is built up entirely of iron pipes, extending in three directions and mounted upon a hollow platform, *a*, shown in Figs. 448 and 449. These two figures represent respectively the end and side elevations of the complete framework, a plan view being shown in Fig. 450. Vertical pipes serve as supports for the structure, and are intersected at short intervals by transverse pipes, *i*, and longitudinal pipes, *e*, *f*, and *g*, extending the entire length of the frame-

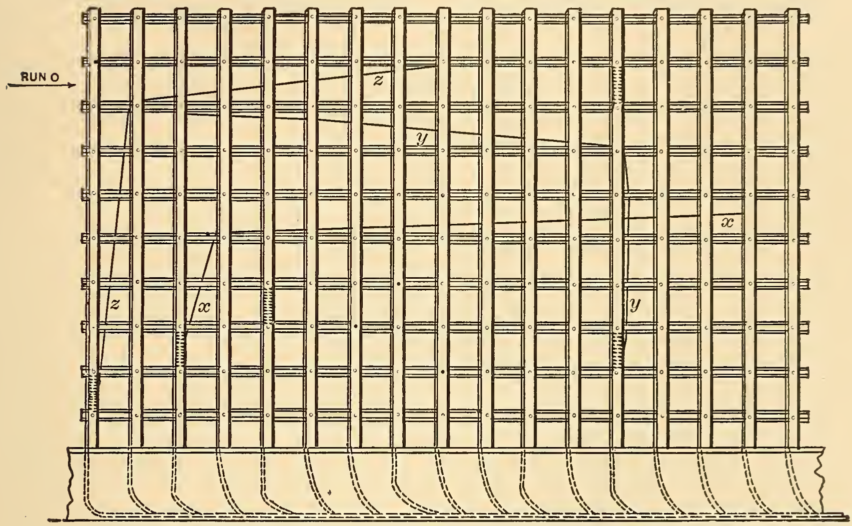


FIG. 449.—SIDE VIEW HIBBARD DISTRIBUTING FRAME.

work. As a result of this arrangement channels or horizontal runs are formed for the jumper wires between the vertical and lateral bars, and vertical channels or falls between the sets of intersecting horizontal bars. On the ends of the lateral bars, *i*, are vertical strips, *d* and *d'*, of insulating material, upon which are arranged the terminals for the various wires in the cables and the jumpers.

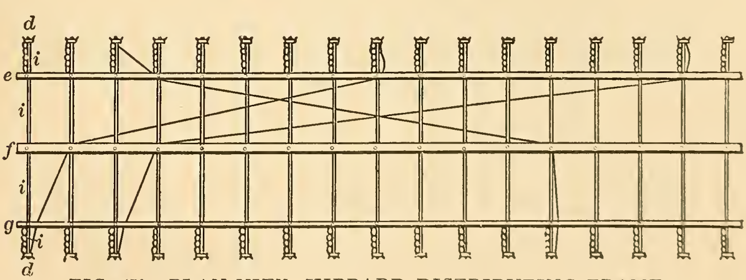


FIG. 450.—PLAN VIEW HIBBARD DISTRIBUTING FRAME.

The general plan by which the wires in old magneto exchanges were led from the cable heads to the switch-board is shown quite clearly in Fig. 448, where *H* represents the cable head carrying the terminals of the line cable, *C*. The various wires, *w*, leading from the cable head are bunched into a cable, C^2, which enters the cable run in the box beneath the frame, and after passing in a horizontal direction to the proper insulating strip, *d'*, is led upward

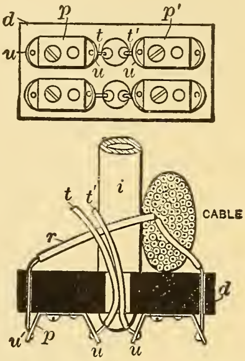


FIG. 451.—DETAIL OF CONNECTING STRIPS.

and fanned out, the various pairs of wires being soldered to the outer ends of the terminals on the insulating strip.

The details of these strips and the methods of attaching the wires of the cable are shown in Fig. 451, in which *p* and *p'* are the connectors screwed to the strip, *d*. These connectors have outwardly bent lugs, *u*, to which the wires may be soldered.

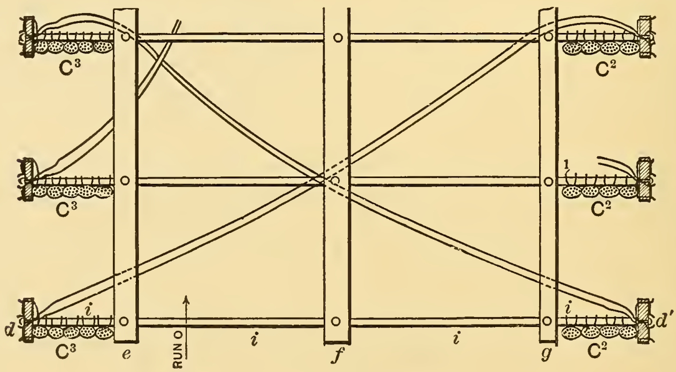


FIG. 452.—ENLARGED PLAN HIBBARD FRAME.

The ends of the jumper wires are shown at *t t'*. In a similar manner the wires leading from the switch-board jack are bunched into a cable, C_3, which is then led through the cable run to the proper strip, *d*, of the distributing board, where it is fanned out and connected to similar terminals. The vertical portions of the cables, which are to be fanned out on the distributing board, are supported by the lateral horizontal rods, *i*, by being laced thereto, this being shown quite clearly in the enlarged plan view of Fig. 452.

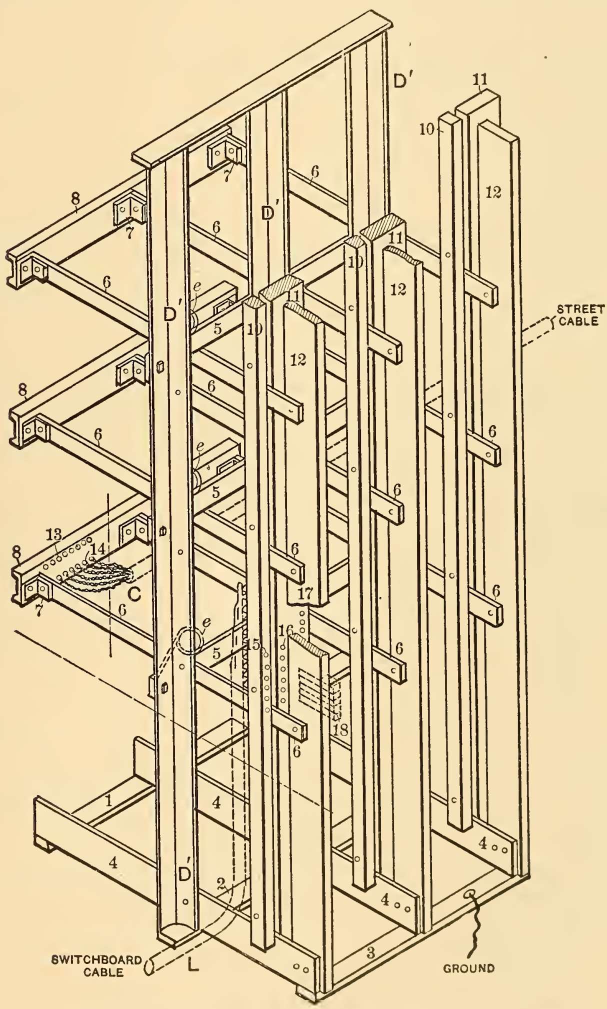


FIG. 453.—FORD & LENFEST DISTRIBUTING FRAME.

The jumper wires, which are usually of tinned rubber-covered wire in twisted pairs, are attached to the inner ends of the terminals on the line side of the distributing board and led through a hole in the strip and through the proper channels in the framework to the desired terminals on the switch-board side, where they are secured in the same manner.

This arrangement serves to keep the wires fairly open and easy of access. It has several great distadvantages, however, the principal one of which is that it is too cumbersome. It has been almost en-

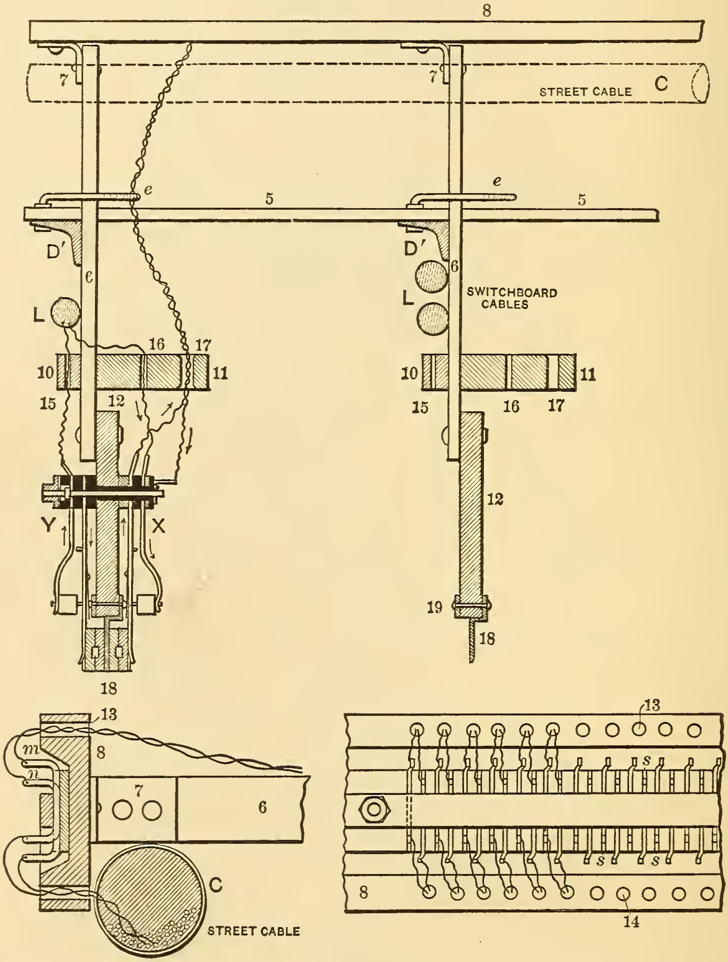


FIG. 454.—DETAILS OF FORD & LENFEST DISTRIBUTING FRAME.

tirely superseded in the practice of the Bell companies by a frame designed by Messrs. Ford & Lendfest, some of the details of which are shown in Figs. 453 and 454. This, like the Hibbard frame, is in the form of an open framework built almost entirely of iron so as to be practically fireproof. Iron bars, 1, 2 and 3, to which are bolted plates, 4, form the foundation of the frame. To the face of the plates, 4, are bolted the supporting columns, *D'*, of angle iron, to which are secured all the other portions of the frame. Horizontal bars, 6, are bolted to the columns, *D'*, and carry upon one side of the frame horizontal strips, 8, of hard wood, upon which are secured the terminals for the wires of the street cables. A detail of these terminals is shown in Fig. 454, the metallic connectors, *m* and *n*, being secured in place in transverse saw-cuts in a thin strip of hard rubber by another strip bolted over them. Supported upon the other end of the horizontal bars, 6, are the vertical pieces, 10 and 11, of hard wood and the flat bar, 12, which is of iron. Upon this bar of iron are mounted the arresters, *X* and *Y*, as shown in Fig. 454. These arresters, which are of the combined static and sneak-current type, will be recognized as similar to those shown in Fig. 441.

In wiring this distributing frame, the street cables, *C*, are led in a horizontal direction under the strips, 6, as shown in Figs. 453 and 454. These cables are then fanned out, the various pairs of wires passing through holes, 14, in the under side of the horizontal wooden strip, 8, and secured to the lower ends of the connectors, *m* and *n*. The switch-board cables, *L*, shown in Figs. 453 and 454, are led from beneath up along the sides of the bars, 6, between the supporting bars, *D'*, and the wooden strips, 10 and 11. They are supported in this position by being laced to the horizontal bars themselves. These cables are fanned out, the various pairs passing through holes, 15 and 16, in the wooden strips, 10 and 11, and to their appropriate terminals on the arresters. The connections of the street and switch-board cables are thus as far as possible made permanent. The jumper wires are each led through a hole, 13, in the upper part of the horizontal wooden strip, 8, its ends being secured to the upper portion of the connectors, *m* and *n*, as shown in Fig. 454. The pair is then led in a horizontal direction along the top of the bars, 6, on the line side of the frame until a point is reached opposite the vertical strip on which the desired switch-board terminal is located. It is then led through an eye or ring, *c*, and through holes, 17, in the vertical strip, 11, and attached to the proper pair of terminals on the arrester through which the connection is made with the switch-board wires.

A distributing frame built upon this general plan is shown in Figs. 455 and 456, these being views of the frame in the main exchange of the Bell Company at St. Louis, Mo.

The line cables approach the frame under a false floor, and are

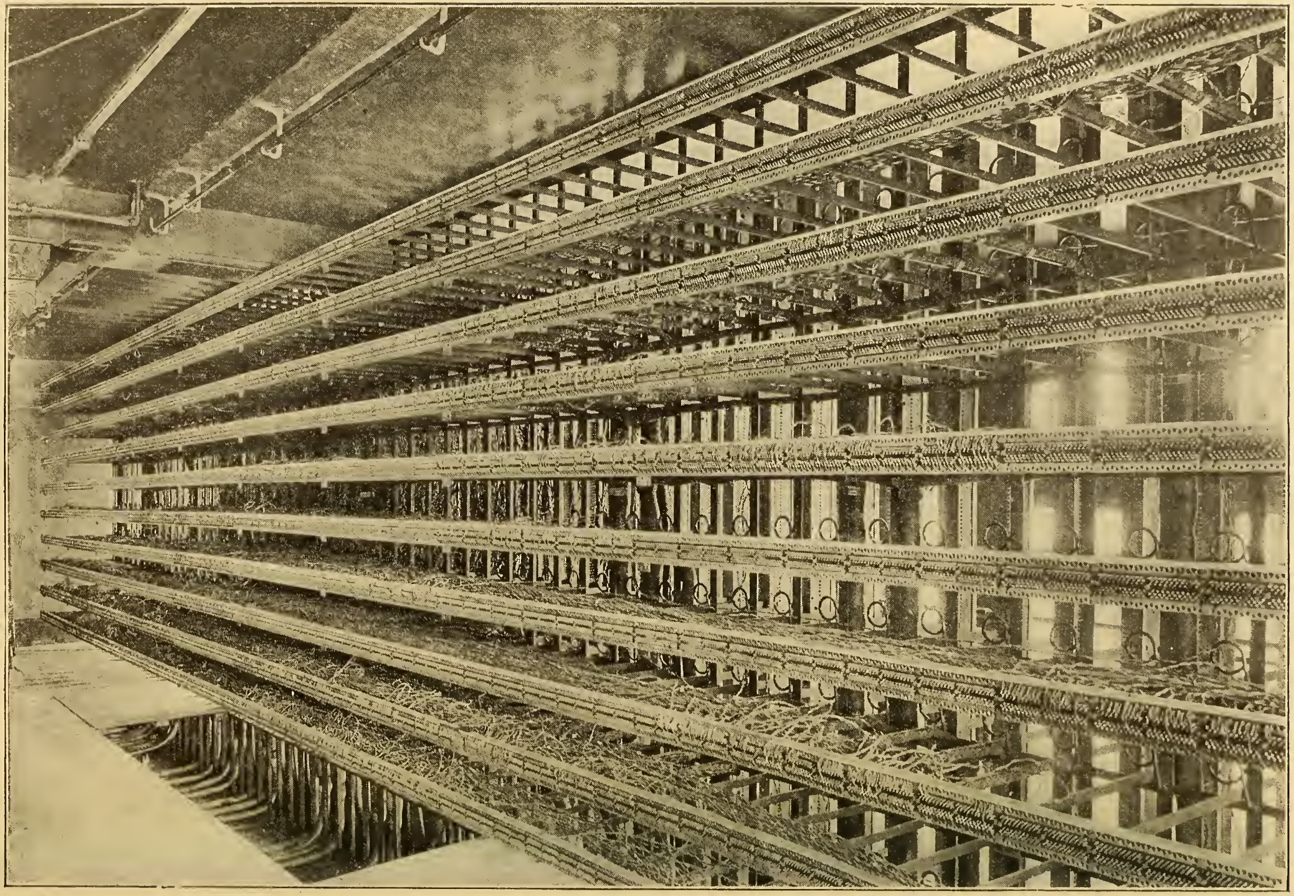


FIG. 455.—PRESENT DISTRIBUTING FRAME IN ST. LOUIS BELL EXCHANGE.

accessible through trap-doors, as may be seen in Fig. 455. They are fanned out on the horizontal side of the distributing frame, as shown in this figure. The terminals on the line side are numbered with respect to the wires in the cables to which they belong. On the vertical side of this board, which is shown in Fig. 456, are placed the arresters, to which lead the wires from the switch-board cables. The jumper wires connecting the horizontal with the vertical sides are arranged as already described.

In the Independent field a distributing frame has recently come into extensive use similar to the Ford & Lenfest frame, but differing from it in that the line side terminals are mounted in vertical instead of horizontal rows, and are divided into short lengths, thus affording arm space between them for reaching into the horizontal jumper runs. A single section of this frame with its line strip divided into five short strips of twenty terminals each is shown at the left in Fig. 457. This frame is manufactured in large quantities by Frank B. Cook, of Chicago, for the Stromberg-Carlson and other manufacturing companies. A complete distributing frame built on this plan with four sets of uprights is shown at the right in Fig. 457.

The distributing frame largely used by the Kellogg Switch-Board and Supply Company differs from any of those yet considered in that the line terminals and the switch-board terminals are mounted on alternate vertical strips arranged on the *same* side of the frame instead of on opposite sides, as on all other modern frames. Thus, when the arresters are mounted in conjunction with the switch-board terminals, as is usually done, there are alternate vertical rows of arresters and of line terminals. The jumper wires lead from their respective line terminals through iron rings such as those used in the Ford & Lenfest and Cook boards, to the opposite side of the frame, and then pass through horizontal runways similar to those shown in Fig. 453, to a point opposite the proper vertical strip of arresters, and then through another ring back to the terminal side of the frame. The construction is similar to that of the Ford & Lenfest and of the Cook frames.

Up to this point only those distributing frames have been considered by which changes may be made with respect to the connection between outside lines and lines leading to the switch-board apparatus. Such frames are termed *main distributing frames*, to distinguish them from *intermediate distributing frames*, which have an entirely different function

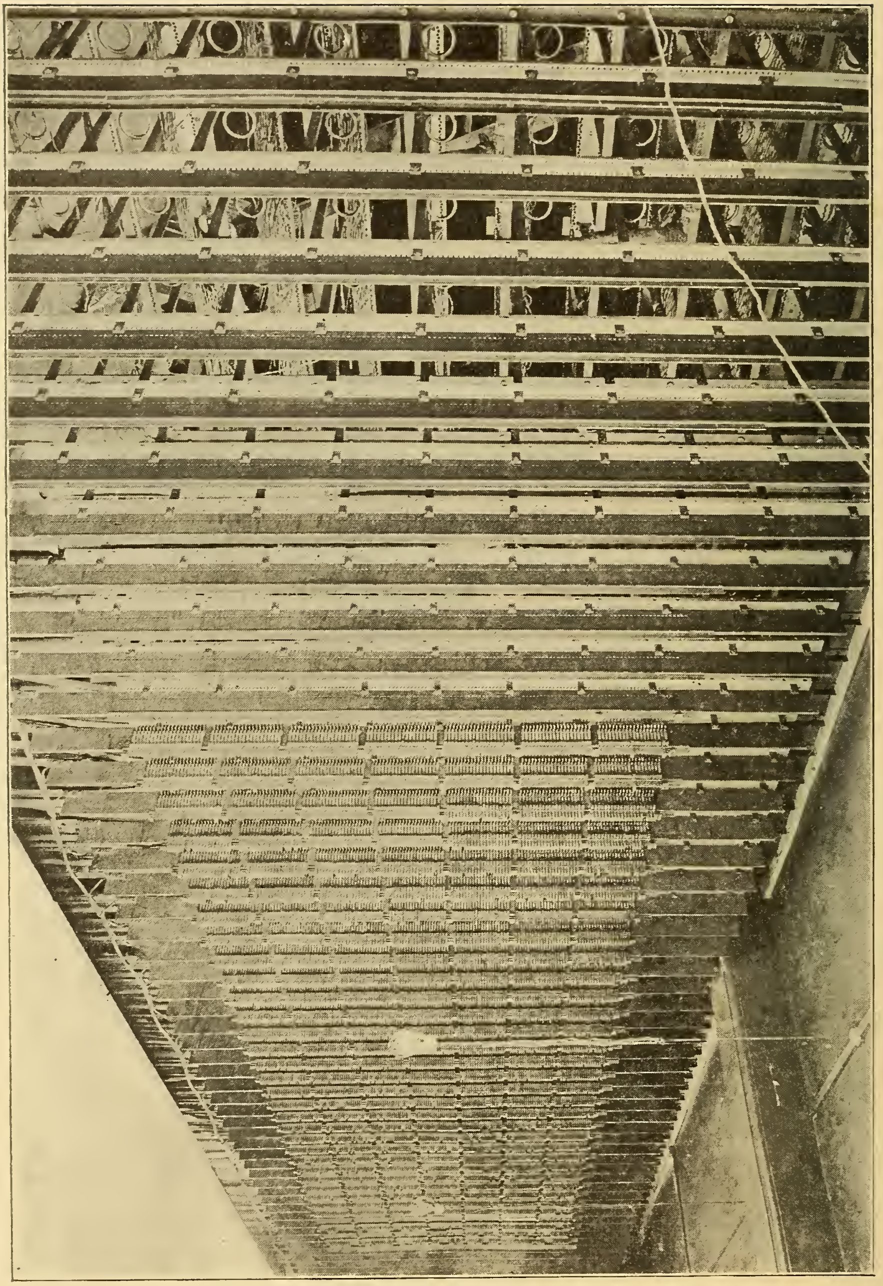


FIG. 456.—PRESENT DISTRIBUTING FRAME IN ST. LOUIS BELL EXCHANGE.

In modern exchanges of sufficient size to employ multiple switch-boards an intermediate distributing frame should be provided, and the circuits leading from the switch-board side of the main frame should lead through this before passing to the switch-board proper.

The function of the intermediate distributing frame is this: It affords means for changing the relation between the answering jack with lamp and the multiple jacks on any line. Unless a change is

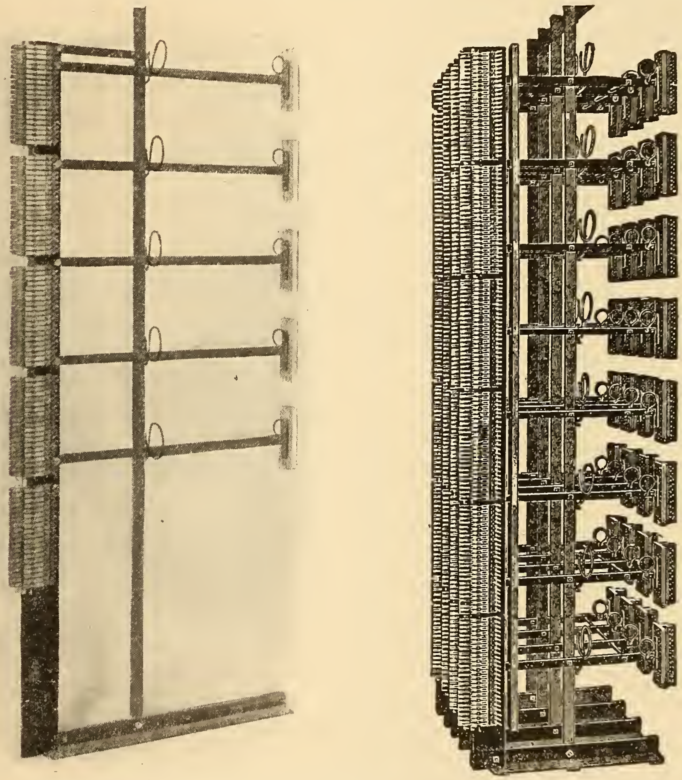


FIG. 457.—COOK DISTRIBUTING FRAME.

made at the main distributing frame, a certain line entering the exchange is always definitely associated with a certain number in the multiple jacks. Furthermore, the number of a subscriber's line must of necessity always correspond with the number of the multiple jacks to which it is connected. When a change is made at the main distributing frame affecting the relation of an outside to an inside line, the number of an outside line must of necessity change to correspond with that of the multiple jacks of the inside line to which it is connected. This is not necessarily true, however, with respect to the answering jacks. A little thought will show that it is never necessary for an operator to know the number of an answering jack, or for her answering jacks to be in numerical order, for the only time that she plugs into such a jack is in response to the lighting of the line signal immediately below it. For this reason, therefore, it is not essential that the answering jack and its lamp shall bear a permanent relation to the multiple jacks, and in fact, the reverse is quite true.

The load of any subscribers' operator is determined by the number of answering jacks and lamps placed before her and on the amount of traffic on the lines served by those answering jacks. On an average, in modern common battery exchanges, perhaps 120 lines may be handled by an operator; but on account of the great difference between the traffic on different classes of lines it may be necessary to reduce the number of answering jacks on some operator's position to one-third or one-quarter of this, while on the other hand, other operators, no more skillful, may be able to handle the answering jacks of 300 or 400 lines. As just pointed out, it makes no difference on what position an answering jack is located so long as it has associated with it the proper line lamp and so long as the number on the multiple jacks corresponds to that of the line served. By means of the intermediate distributing board an answering jack and lamp on any position of the board may be made to serve any line and its multiple jacks; so that if a certain operator is overloaded, some of her lines may be disconnected from her answering jacks and lamps and connected with those of another operator at a new position or at some old position at which the operator is not overworked.

The method of making changes at the intermediate frame varies somewhat by reason of the requirements of the particular line circuit used. In no system, however, should the relation of the multiple jacks to the main line be changed at the intermediate distributing board, while in all systems changes at the intermediate board should alter the relation of the answering jack and lamp with respect to the multiples and the outside line. In some systems the arrangement works out better if the line and cut-off relays occupy a permanent relation to the outside line and the multiples, and are therefore not subject to change at the intermediate boards. In other cases each line and cut-off relay occupies a permanent relation with respect to the answering jack and lamp, and therefore their relation with the line is changed whenever a change is made at the intermediate board. To express this in a different way: In some systems, as for instance, that of the Kellogg Company, a line and cut-off relay always stay with a particular number in the multiple jacks regardless of changes at the intermediate frame, and therefore the line and cut-off relays always bear the same number as the multiple to which they are connected, and therefore the same number as the line. In the Western Electric system, however, a given line and cut-off relay always stay connected to a particular answering jack and lamp, and therefore these relays change with relation to the multiple jacks and the outside line whenever a

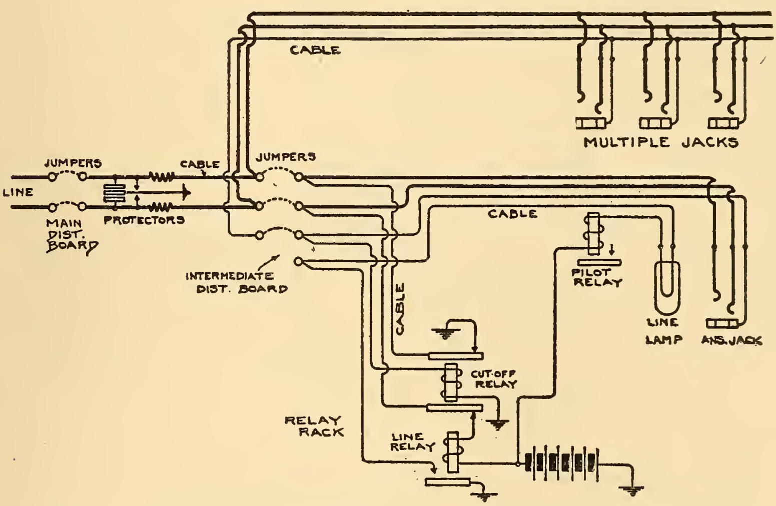


FIG. 458.—DIAGRAM OF CONNECTIONS THROUGH INTERMEDIATE DISTRIBUTING FRAME—WESTERN ELECTRIC SYSTEM.

change is made at the intermediate board. The line and cut-off relays are therefore given numbers of their own, and do not bear the same numbers as the multiple jacks and subscribers' lines which they serve.

To make this clearer, reference is made to Fig. 458, which shows the part that the intermediate frame plays with respect to the line circuit of the Western Electric multiple switch-board system.

The line will be seen entering at the left and passing through the two sides of the main distributing frame, the jumper wires on this frame being indicated in dotted lines. From the main distributing frame the two sides of the line are continued to two clips on the intermediate distributing frame to which same clips are run, the

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tip and sleeve sides of the multiple jacks, the test wires on the multiple jacks being run to a third clip on the same side of this frame. All of the connections to the line and cut-off relays, also to the answering jack and lamps are made to four clips on the opposite side of the intermediate distributing frame, all of these connections being permanent, therefore allowing of no changes in the relation between the answering jack and the line and cut-off relays. By means of a three-strand jumper wire, shown in dotted lines, it will be seen that the connection between any outside line and its multiple jacks and any group comprising an answering jack,

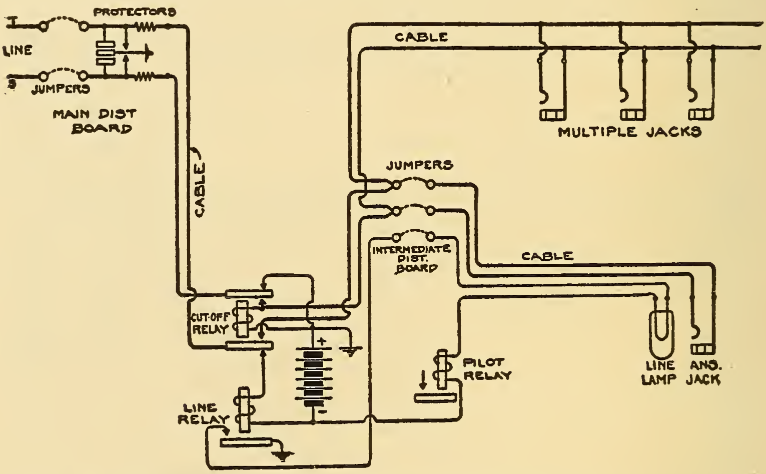

FIG. 459.—DIAGRAM OF CONNECTIONS THROUGH INTERMEDIATE DISTRIBUTING FRAME—KELLOGG SYSTEM.

lamp and relays, may be altered by changing the connection of the intermediate wires.

In Fig. 459 is shown the method of accomplishing the intermediate distributing board changes when applied to the two-wire systems of the Kellogg Company.

In this it will be seen that the line and cut-off relays are both permanently wired to the multiple jacks and to the arrester side of the main distributing frame. The tip and sleeve side of the circuit leading from the cut-off relay and also from the multiple jacks terminate in two clips on the line side of the intermediate distributing frame, while the lamp circuit, extending from one of the contact springs of the line relays, terminates in the third contact on the same side of the intermediate frame. No change in the relation between the multiple jacks, the arrester, the line and cut-off relay is therefore possible with this form of circuit, all of the wiring between them being permanently done. The opposite side of the distributing frame has three clips for each line, two of these leading to the tip and sleeve strands of the answering jack, the other leading to the line lamp, the opposite terminal of which is grounded. The answering jack and line lamp may, therefore, be made to occupy operative relation with any number in the multiple and, therefore, with any outside line, by changing the three-strand jumper wires on the intermediate frame.

It is thought that the latter method, by which the answering jack and line lamp alone are affected by changes at the intermediate frame is the better. It has the advantage of allowing the numbers of the line and cut-off relays to correspond with those of the multiple jacks which are permanent. This seems to offer a practical advantage in the facility with which cases of trouble may be handled. Again, when answering jacks and lamps are furnished in excess of the number of lines in the multiple, as is frequently done to afford latitude in the use of the intermediate frame, the addition of a corresponding number of line and cut-off relays is not required with the former method, it being only necessary to provide one of each for each line in the multiples.

CHAPTER XXXII.

CHIEF OPERATOR'S AND MONITOR'S EQUIPMENTS.

THE apparatus and circuits by means of which such employees as the chief operator, wire chief, monitor and service clerks are enabled to perform their various duties are usually mounted in the desks at which these employees sit. An intelligent arrangement of these desk equipments with respect to the needs of a central office force, will do much toward economy and good service in general.

Practice concerning desk equipments varies widely among the different operating companies, but in recent years that of the more progressive Bell companies and some of the larger Independent companies seems to have settled into channels well enough defined to be called standard.

The principal employees, directly or indirectly concerned, in the giving of service, and who rank above the regular operators, are the chief operator, monitors, supervisors, and wire chief. All of these except the supervisor are, as a rule, provided with desk equipments. The duty of the supervisors, in most exchanges, is to walk up and down behind the regular operators, watching the service and helping out where occasion require. Since the nature of their duties keeps them on their feet, they require no desks.

It is perhaps the more common practice to place the chief operator's and monitor's equipment in the same desk, this being large enough to allow both the chief operator and monitor to occupy it at once. During the least busy time either alone may attend to the duties of both.

The chief operator, being in charge of the entire operating force, is usually given the following facilities for directing, supervising and inspecting the work of this force, as well as for giving personal attention to those subscribers who may require it:

For observing the service given on any subscriber's line about which there has been complaint, the chief operator is usually provided with a number of lines terminating in jacks and lamps on her desk, and at normally open clips on the intermediate distributing frame. When persistent or serious complaint is received from a subscriber as to the service he is obtaining, one of these lines for observing service may be connected at the intermediate distributing frame with that subscriber's line, and left so connected for a period sufficient to allow the chief operator to make a thorough diagnosis of the case. When a subscriber's line is so connected, a lamp will be lighted on the chief's desk, simultaneously with the lighting of the line lamp on the regular switch-board in response to the call of the subscriber. The chief operator, who is provided also with a telephone set terminating in a plug, may, in response to this signal, plug in on the line and thus observe the response of the A operator, noting the time and the method of the response. The chief may also, during the conversation, observe the language and demeanor of the subscriber in asking for a connection, and determine any irregularities which may exist at either end of the line. In connection with each one of these lines for observing service is another lamp on the chief's desk which lights whenever the subscriber on a line that is under surveillance is called by an A or B operator. The chief operator noticing the lamp, may go in on the line with a plug for the same purpose as before. These lines, therefore, which are called "service observation" lines, afford means for the chief operator to personally investigate the justice of complaints as to service by surreptitiously watching the behavior of the subscriber and of his operator in answering his call, and of any operator in calling him up.

The chief operator is also provided with several lines terminating in her desk in jacks and lamps, and multipled through the main switch-board as regular subscribers' lines. (One or more strips of jacks at each section, are usually set aside in the multiple in the main board for accommodating lines leading to the various desks.) By means of these lines leading to he chief operator's desk, the chief operator may be called by an A or B operator in the same manner as a subscriber would be called, and if need be, the chief operator be put in communication with any subscriber over these lines. In this way the A or B operators are enabled to refer any subscriber whose business demands it, directly to the chief operator, thus relieving these operators from all duties which might detract from their regular work.

When the chief operator and monitor occupy the same desk, this is usually equipped with lines called "monitor's taps." There is one of these for each regular operator in the office, each leading from a jack on the desk to the head telephone of an operator. By inserting a plug into any one of these jacks the chief operator or monitor is enabled to listen to the conversation of a regular operator without her knowledge. When the chief operator's or monitor's desks are separate, these taps terminate in the monitor's desk.

In addition to the different circuits mentioned, the chief operator's desk is usually provided with lines leading to various local points in the exchange, such, for instance, as a line to each of the other desks, a line to the traffic manager's office, and lines to the office of any other official who may have need for direct communication with the chief operator.

It is the custom of many of the independent companies, but as a rule not of the Bell companies, to provide on the chief operator's or monitor's desks, a lamp for each position on the main switch-board, this lamp being wired so that when the calling pilot lamp at any position of the switch-board lights, a corresponding lamp on the desk will light. In those systems where the supervisory signals at the main board are also provided with pilots, this feature is

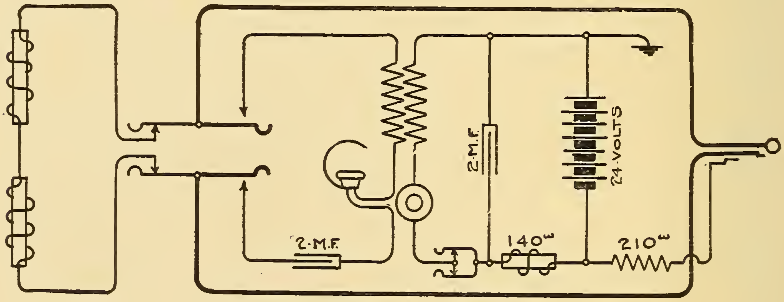

FIG. 460.—CHIEF OPERATOR'S TELEPHONE CIRCUIT.

usually extended also to the chief operator's and monitor's desk, the arrangement being such that two lamps are provided for each position on the main board, one adapted to light whenever the line pilot at that position lights, and the other whenever the supervisory pilot at that position lights. For convenience in distinguishing between the monitor's lamps, those corresponding to the line pilot are made white, and those corresponding to the supervisory pilot are made red. By this means the chief operator or monitor, seated at the desk, may, by noting the length of time that any one of the monitor's lamps remains lighted, determine the promptness with which calls are being handled on various positions of the board. If it is seen that a certain operator's work is dragging, she may be communicated with over one of the circuits leading to that position, and if found in need of help it may be provided.

An almost endless variety of desk equipment circuits might be given, these, of course, differing for each general exchange system, and also with the ideas of the various operating companies. Modern Bell practice may be taken as typical, and therefore all of the diagrams in this chapter will, unless otherwise specified, illustrate the latest obtainable ideas of the Bell companies on this subject. These circuits are all adapted to use in connection with the standard common battery system supplied by the Western Electric Company.

Fig. 460 is the chief operator's telephone circuit, adapted to connect by means of its plug with any line terminating at the chief's desk. A retardation coil bridged across the cord circuit is for the purpose of affording a comparatively low resistance path for direct

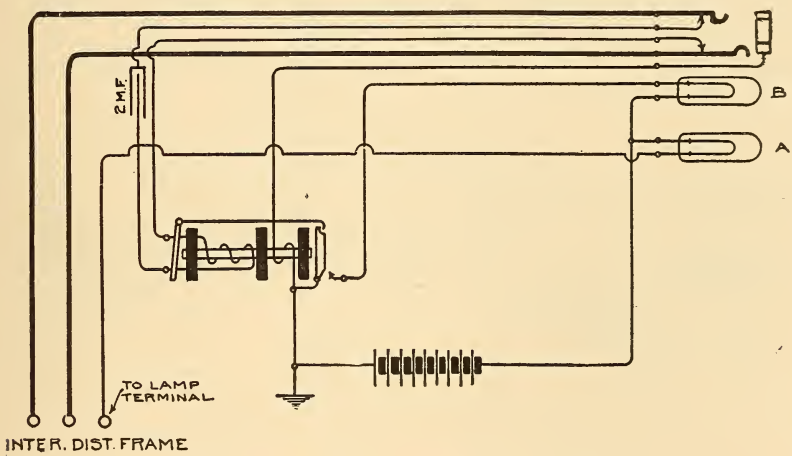

FIG. 461.—SERVICE OBSERVATION LINE.

current, so that when the chief operator plugs in on a line terminating as a subscriber's line in the main switch-board, the effect will be to light the lamp of that line in the same manner as if the subscriber had removed his receiver from its hook. This retardation coil may be cut out by means of a key, as shown. Besides the regular listening key by which the chief operator may associate her talking set with any one of the plugs with which she is provided, there is another key which, when operated, serves to cut out the chief operator's transmitter only. The object of this is to prevent the subscribers' operators from knowing when the chief operator listens in on their circuits. Operators become very skilled in noticing any changes in the sound of their circuits, and would at once observe the effect of any other transmitter being connected with their telephone sets.

As illustrating the astute methods sometimes employed by the regular operators to ascertain whether or not they are being watched, it may be mentioned that in some cases where nickel-plated fronts have been provided for the operators' transmitters, these have been kept carefully polished and used as a mirror, by which the operator could observe the actions of the chief, seated behind her. This is one reason for the usual black finish of the operators' transmitters.

In Fig. 461 is shown one of the chief operator's service observation lines. These lines are normally terminated at open clips on the

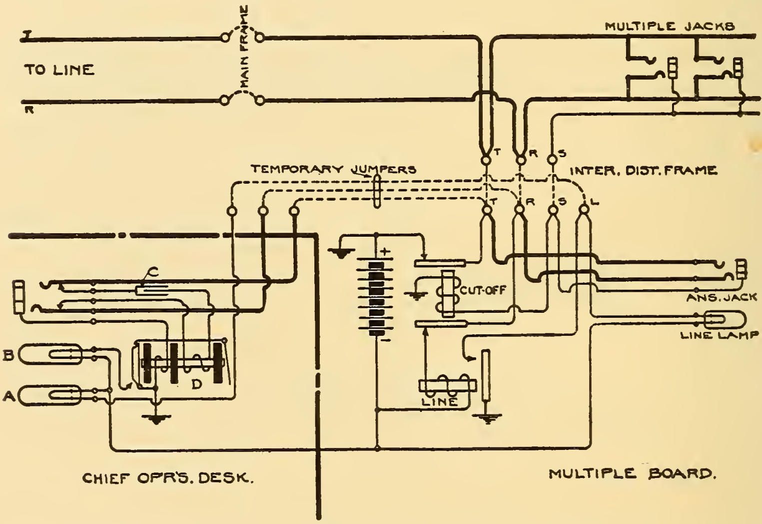

FIG. 462.—METHOD OF CONNECTING LINE FOR OBSERVING SERVICE.

intermediate distributing frame, and by means of three-wire jumpers, any one of them may be connected to any subscriber's line. A regular Western Electric line circuit so connected by means of a temporary jumper wire to a service observation circuit on the chief operator's desk is shown in Fig. 462.

When the subscriber on such a line calls the lamp, *A*, will be lighted, that lamp being connected between the live side of battery and the regular line lamp terminal on the intermediate frame, the two lamps thus being lighted in multiple by the action of the line relay. The chief operator, by inserting the plug of one of the circuits shown in Fig. 460, will place her telephone in a bridge of the subscriber's line, cutting off the remaining portions of the observation circuit apparatus at the cut-off jack, but not putting out the lamp, *A*. This lamp will go out when the A operator answers the call. When a regular operator rings out on such subscriber's line, the restoring drop, *D*, at the chief's desk is thrown through the condenser, *C*, thus allowing the lamp, *B*, to light. The drop is restored in the usual manner by the insertion of the chief operator's plug, thus putting out the lamp. The circuit over which this drop is restored includes the third strand of the chief operator's plug and the sleeve contact of the jack.

The circuit by which the chief operator may be brought into connection with any subscriber through the main board, or by which any operator may put herself into communication with the chief

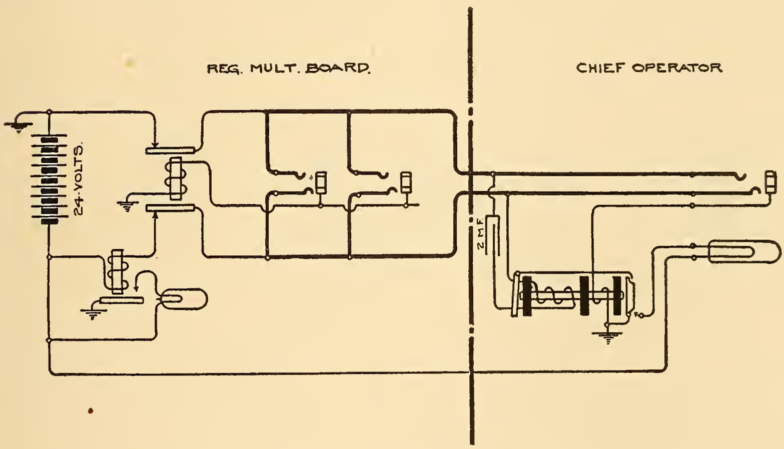

FIG. 463.—CHIEF OPERATOR'S LINE TO MULTIPLE BOARD.

operator, is shown in Fig. 463. The apparatus of the chief operator's board is shown at the right-hand side of this figure, the apparatus to the left-hand side being that of any regular common battery subscriber's line. The chief operator, by inserting one of her plugs (Fig. 460), into the jack of such a line on her board, may, by means of the retardation coil in her cord circuit, call the A operator at the position where the line lamp of this line is placed. On the other hand, any regular operator, by going in one of the multiple jacks and ringing, will throw the self-restoring drop on the chief operator's desk, lighting the lamp belonging to this line. This lamp will be put out by the restoring of the drop over the third strand of the cord of the chief operator's plug.

The monitor's taps from the chief operator's desk to the various positions of the regular board shown in Fig. 464, need no explanation in view of what has already been said.

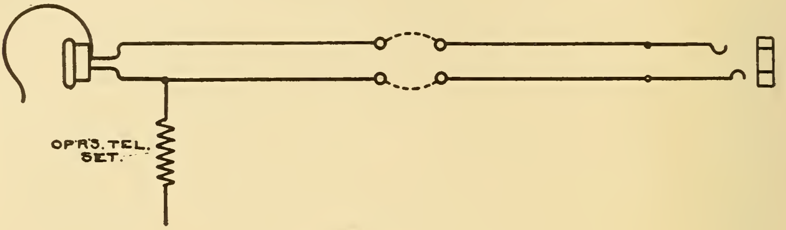

FIG. 464.—MONITOR'S TAP.

In Fig. 465 is shown the circuits of one of the lines leading from the chief operator's desk to the various local points, as, for instance, to the local telephone set of the traffic manager. At the right of this figure is shown the line leading to the local telephone equip-

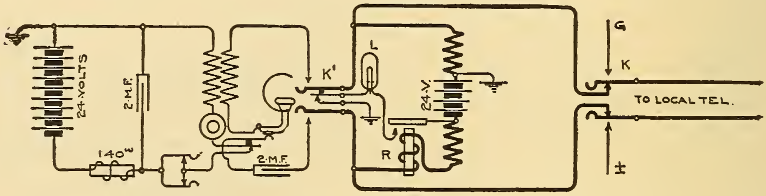

FIG. 465.—CHIEF OPERATORS' LINES TO LOCAL POINTS.

ment. At the chief's desk this passes first through a ringing key, *K*, thence normally through retardation coils and a relay, *R*, to the common battery. When the user of the local telephone connected to this circuit removes his receiver from its hook, the lamp, *L*, associated with this line on the chief operator's desk will light. It will be put out when the operator responds by throwing the key, *K'*, which will connect her telephone set with the line calling. The two may thus converse. When, on the other hand, the chief operator wishes to call up a party on one of these local lines, she has only to throw the corresponding ringing key, *K*, to ring the bell of such subscriber, after which the operation is as before.

CHAPTER XXXIII.

WIRE CHIEF'S EQUIPMENT.

THE wire chief, by the aid of his desk equipment, exercises one of the most important functions in an exchange, his duties relating largely to the determination of the electrical conditions of the various outside and inside lines, this information forming the basis for the proper repair and maintenance of the lines and line equipments. The wire chief's desk may be equipped with one or more positions, according to the size of the office and the number of persons likely to be required in the performance of the wire chief's duties.

Extending from the wire chief's desk are, as a rule, a number of testing trunks leading to a certain position on the main switchboard, where they terminate in plugs. It is customary in order not to thus take up room on a position that is available for operating, to terminate these testing trunks on one of the end positions of the local multiple board, from which position by the use of long cords an entire section may be reached by these plugs. Any testing plug may thus be inserted into the multiple jack of any subscriber's line. Besides these testing trunks leading to the multiple board there are other testing trunks leading from the wire chief's desk to the main distributing frame, where each terminates in a plug adapted to be connected at the arrester with any subscriber's line. By means of these testing trunks any subscriber's line may be continued to the wire chief's desk for the purpose of testing.

Lines are also usually extended from the wire chief's desk to one or several jacks on each section of the main board, these being multipled through the sections in the same manner as the jacks of the chief operator's lines. The wire chief's desk is also equipped with suitable testing apparatus by means of which the complete electrical condition of any subscriber's line may be ascertained in the most convenient manner.

The methods of performing the various tests on the wire chief's desk have changed radically during recent years. The old practice made use almost entirely of Wheatstone bridge methods, while more recent practice uses almost exclusively various voltmeter methods.*

* Those not familiar with bridge and voltmeter methods of testing are referred to Chapter XLII. on Testing, at the end of this book.

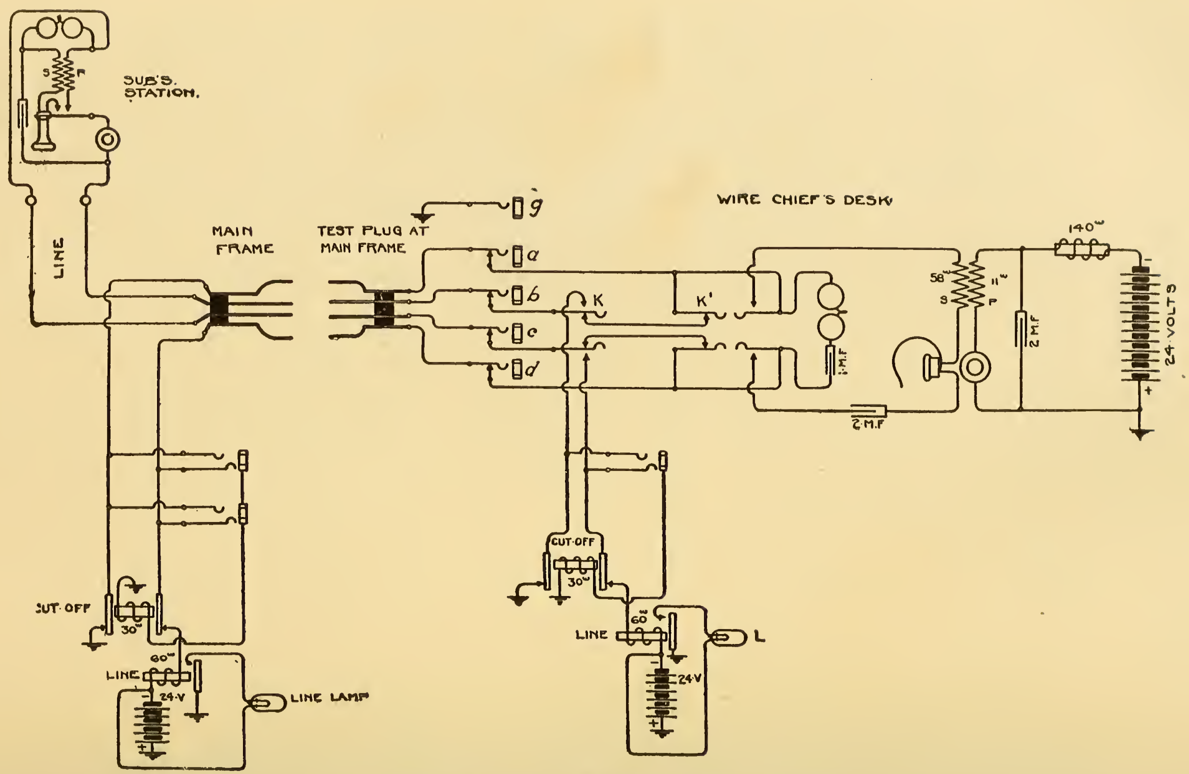

FIG. 466.—WIRE CHIEF'S TESTING TRUNK.

Although the Wheatstone bridge method is not in accordance with what is now considered the most advanced practice for wire chief's use, it will be described briefly, as it is in use in a large number of exchanges.

In the right-hand portion of Fig. 466 is shown a testing trunk leading from the main distributing frame to the wire chief's desk. In the left-hand portion is shown the circuit of a subscriber's line leading from the subscriber's station to the switch-board apparatus at the central office through the arrester clips at the main board, the heat coils having been removed.

The removal of the heat coils and insertion of the test plug divides the line at the distributing frame into two portions, one extending *out* from the arrester to the sub-station and the other extending *in* from the arrester to the switch-board apparatus. The two portions so divided may be called the "outside" and the "inside" lines respectively. The four limbs (two each) of the two divisions of the line are led to the wire chief's desk by means of the testing trunk, the plug in which this trunk terminates being so arranged as to make connection with the proper arrester springs connected with the outside and inside lines.

By means of the jacks, *a*, *b*, *c* and *d*, on the wire chief's desk, plugs in which the testing instruments terminate may be inserted and a test made on tip or ring side of either the outside or the inside line. When no plug is inserted in any of the jacks and when keys, K and K', are in their normal positions as shown in Fig. 466, the subscriber's station is connected through to the switch-board with the addition of the ringer and condenser within the wire chief's desk bridged across the circuit. By throwing the key, K', to operate its right-hand springs, the wire chief may place his telephone equipment upon the circuit of the line. When testing the outer line by use of jack *b* or *a*, or both, the ringer is left upon the inside line where it will signal the wire chief in case the line under test be called in the regular way by any A or B operator. When testing the inner line, the key, K, is thrown so that a subscriber attempting to call upon the line under test would have his call received by the lamp, L, upon the wire chief's desk. With the key, K', thrown to operate its left-hand springs, ringing signals from the switch-board are kept off of the line under test, and are received at the wire chief's desk instead.

In Fig. 467 is shown the test plug circuit. By means of these plugs and the jacks, *a*, *b*, *c* or *d*, the Wheatstone bridge may be connected between any two of the four limbs of the inside and outside line, or, by inserting one of the plugs in the ground jack, *g*, between any one of the limbs and ground.

As will be seen the two testing plugs in Fig. 8 are normally connected in series through a battery of five cells and through a relay and key, the purpose of which is to ascertain whether or not the relay will be operated when the key, *K''*, is closed over whatever resistance is connected between the circuit of the two plugs.

When, however, the key, K''', is thrown into its alternate position, whatever resistance is between the two plugs represents the unknown resistance on the Wheatstone bridge arrangement, and may be measured accordingly. The voltage of the battery supplied to the Wheatstone bridge may be varied by inserting the plug, *p*, into one of the several jacks connected with the cells of the battery.

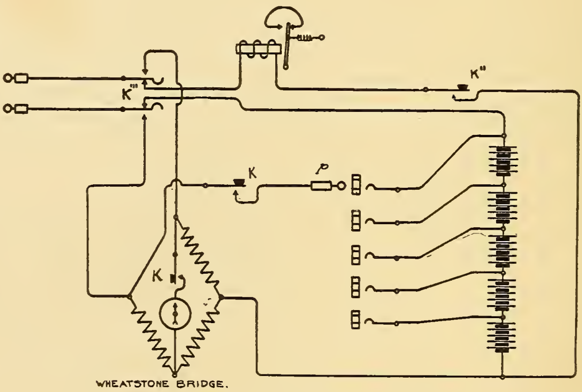

FIG. 467.—TESTING PLUG CIRCUIT.

It is evident that if it is wished to measure the resistance between the ring side of the outside line and ground, one of the bridge plugs will be inserted in the jack, *c*, while the other will be inserted in the ground jack, *g*.

The more modern wire chief's desk equipment used by many of the Bell companies are shown in Figs. 468, 469, 470, 471 and 472. In Fig. 468 is shown the test trunk leading from the wire chief's desk to the test plug adapted to connect with the arrester springs at the main distributing frame. Remembering that the two outside springs of the arrester lead to the switch-board end of the line, while the two inside terminals lead to the outside line, it will be seen that when the connection is thus made with a line, the jack, *J*, affords means for connecting directly with the switch-board line circuit, while the jack, *J'*, affords means for connecting with the outside line circuit.

For the purpose of avoiding, as far as possible, any interruptions in service while connection is made with a subscriber's line, the

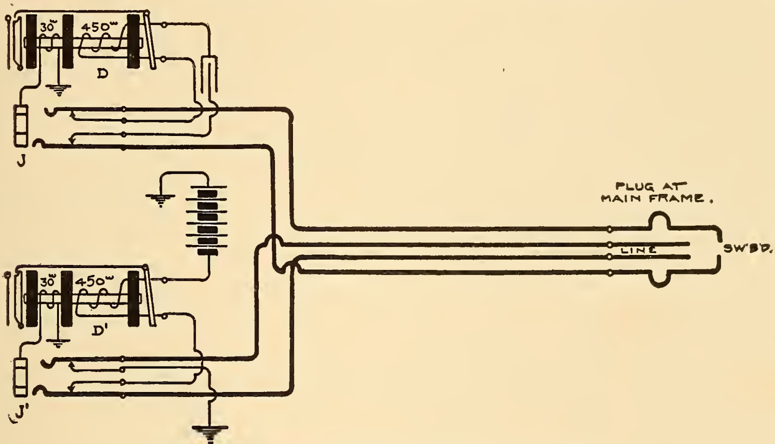

FIG. 468.—WIRE CHIEF'S TESTING TRUNK.

drops, *D* and *D'*, are provided, which are under control of the inside and outside lines respectively. Thus, while such a connection is up at the main distributing board, if the operator at the switch-board sends calling current out on the line, the drop, *D*, will fall, the ringing current passing through the coil of this drop and the condenser.

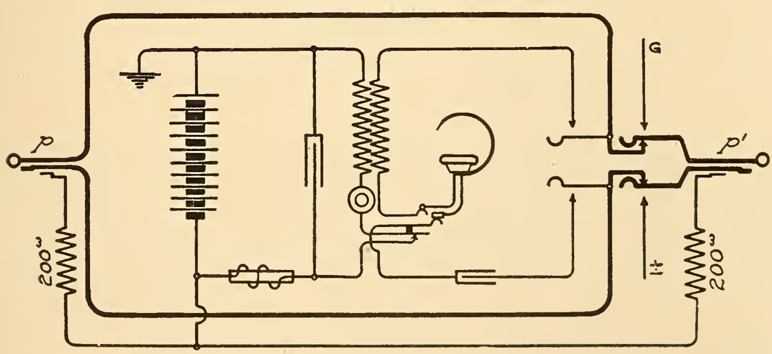

FIG. 469.—WIRE CHIEF'S THROUGH CONNECTING CORDS.

If, on the other hand, a subscriber attempted to call the exchange the drop, *D'*, would fall. In either case the wire chief could answer by plugging into the jack, *J* or *J'*, with the plug, *p*, of the "through connecting cord circuit" shown in Fig. 469, and throwing his listening key. If he so desired and the condition of his line permitted, he could then complete the connection by inserting the corresponding plug, *p'*, in the other jack, either *J* or *J'*. As soon as the conversation was finished, which fact he could ascertain by listening in, he would pull down the plugs and resume testing.

As the jacks, *J* and *J'*, are of the cut-off type, plugging into either of them cuts off the drops and all other apparatus from the line, leaving a straight connection to either the outside or the inside line. The shutters of the drops are restored in the usual manner upon plugging into the jacks, through the third strand of the cord.

One of the testing trunks leading to the multiple board is shown in Fig. 470. This terminates on the wire chief's desk in a drop,

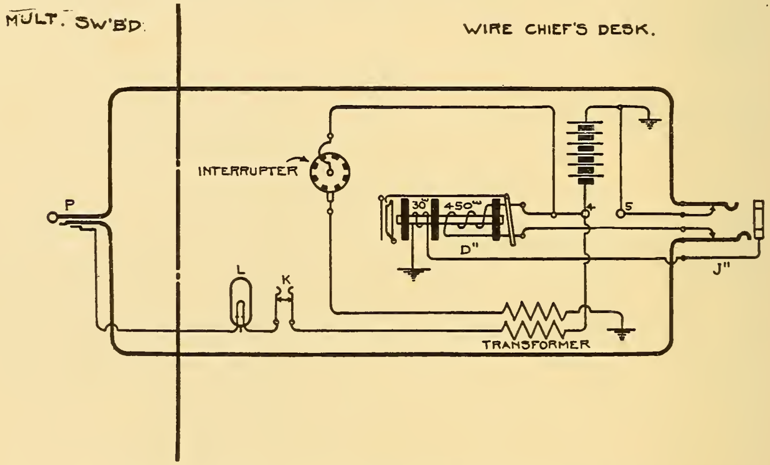

FIG. 470.—TESTING TRUNK TO MULTIPLE BOARD.

D", and jack, J", the arrangement being exactly the same as that of the drop, *D*, and the jack, J', in the testing trunk to the main distributing frame, the circuit of which is shown in Fig. 468. At one position of the multiple board these trunks terminate in plugs, *P*, so that any line may be extended to the wire chief's desk by inserting this plug in its multiple jack. The circuit of the third strand of this plug passes through a lamp, *L*, and key, *K*, located at the wire chief's desk, and thence through the secondary of a tone test transformer to the live side of battery. By means of interruptions in the primary of the transformer a tone is put on the test rings of a line thus plugged up for test. The cut-off relay of such a line is operated in the usual manner, thus rendering the line signal inoperative. By pressing the key, *K*, however, the wire chief may at any time release the cut-off relay of a line thus held. By means of a plug and cord circuit, shown in Fig. 471, he may then establish connection between the tip and ring sides of the test trunk and thus flash the line lamp to attract the attention of the A operator. After this he may converse with the operator by the talking set of Fig. 471.

In Fig. 472 is shown the test circuit by means of which the wire chief is enabled to perform all the necessary tests to ascertain conditions of any line. The circuit is equipped with the following apparatus:

A ringing key, 1, to enable the wire chief to ring out over any testing trunk.

A reversing key, 2, to be used for transposing the two sides of

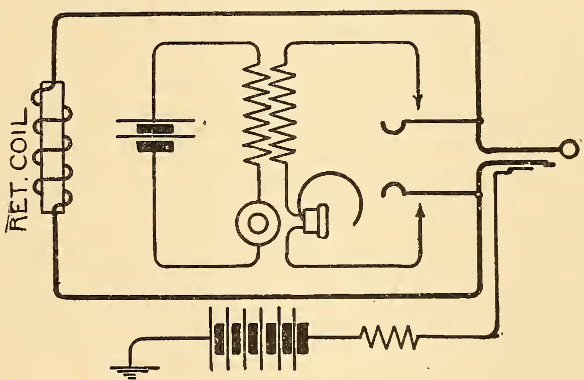

FIG. 471.—WIRE CHIEF'S TELEPHONE CIRCUIT.

a line undergoing test with respect to the testing apparatus, as will be described.

A grounding key, 3, to ground one side of the line under test. By means of this and the reversing key the two sides of the line may be alternately grounded.

A volt-meter key, 4, to be operated in connection with: First, a battery cut-off key, 8, which disconnects the testing battery from the volt-meter, and at the same time connects the high-reading coil of the latter to the volt-meter key for use in measuring external voltages; second, a battery-switching key, 9, which, in its normal position, connects the 40-volt testing battery to the high-reading coil of the volt-meter, and when thrown, connects the 4-volt battery to the low-reading coil; third, a volt-meter shunt key, 10, arranged to reduce the effective low-resistance winding of the volt-meter from 10,000 ohms to 1,000 ohms, for use in measuring comparatively small resistances.

A relay key, 5, used to connect a relay and sounder to a line under test, when audible signals are desired, or when a test with a current of greater volume than that allowed by the volt-meter is desired.

A continuous ringing key, 6, to switch the calling generator on the line and hold it there while continuity tests through condensers or repeating coils are being made.

A spare key, 7, for the connection of any special apparatus desired. This is often used for the attachment of a "howler" current designed for calling subscribers in case of failure to replace the receiver upon the hook.

A listening key, 11, to be operated in connection with a retardation coil key, 12, which normally bridges a retardation coil, R_2, across the talking set, and when thrown disconnects it; the retardation coil is used as a means to cause the subscriber's operator's supervisory signal to be extinguished when the wire chief or inspector responds to a call from the multiple switch-board. It is also used to attract the attention of an A operator over any line or test trunk running to the main switch-board. The listening key is also to be used in connection with a battery key, 13, which, when thrown, supplies battery current to the two sides of the cord circuit; this combination is provided in order to enable a subscriber who has been called up for test to converse with the wire chief.

The various tests commonly employed by the wire chief in locating trouble on common battery lines are divided by the Bell Company in its specifications for testing with its standard wire chief's equipment as follows: First, tests for grounds; second, tests for the continuity of currents; third, tests for crosses; fourth, ballistic tests; fifth, tests for continuity through condensers and repeating coils; sixth, tests for determining the presence and magnitude of foreign currents; seventh, tests for locating trouble in the switch-board; eighth, miscellaneous tests. These will be briefly taken up in their order.

Tests for grounds may be made in two ways, by means of the volt-meter, or by the use of relay, *R*, connected through key, No. 5. In order to make clearer the methods of volt-meter testing for grounds, and of measuring the resistance of a circuit to ground or

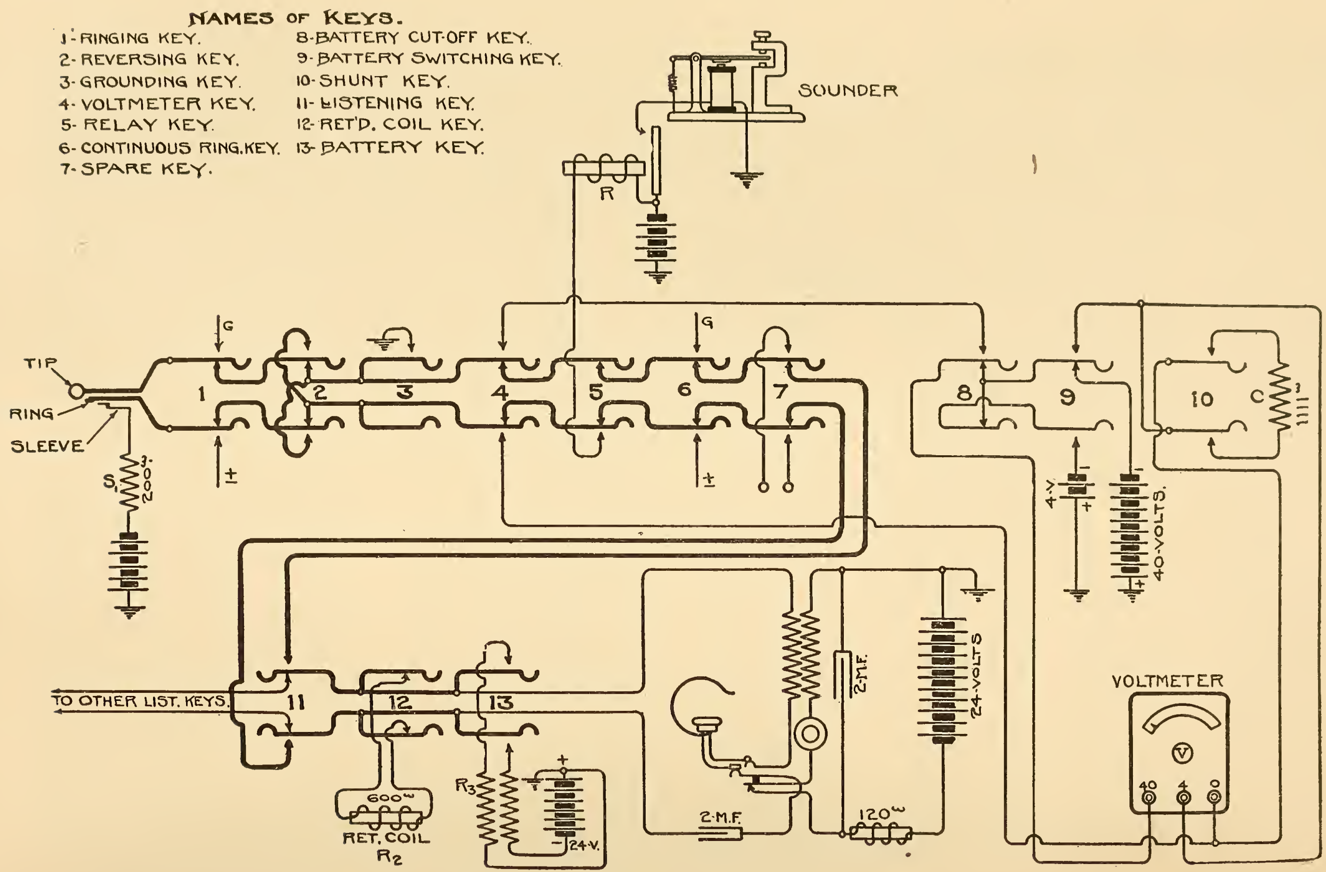

FIG. 472.—WIRE CHIEF'S TESTING CIRCUIT.

of any other circuit by means of the volt-meter, the cord circuit of Fig. 472 has been redrawn in part in Fig. 473, all parts not directly concerned in volt-meter tests being omitted.

In making tests for grounds, throw the volt-meter key, No. 4, leaving the other keys in their normal positions. This will place the 40-volt coil of the meter in a circuit between the ground and the ring side of the line under test, the circuit including the 40-volt battery. If a ground exists on the sleeve side of the line, the volt-meter will be deflected, owing to the passage of current through it. The same test may be made with respect to the tip side of the line by throwing the reversing key.

The resistance of the ground may be measured by noting the amount of deflection. In the arrangement shown, the 40-volt coil of the volt-meter has a resistance of 100,000 ohms, and the 4-volt coil, 10,000 ohms. The shunting key, when closed, places a shunt of 1,111 ohms around the 4-volt coil, thus reducing the effectiveness of the volt-meter coil to one-tenth its original value. The volt-meter, therefore, has three effective resistances, 100,000, 10,000 and 1,000, the first adapted to use with the 40-volt battery, and the other two for use with the 4-volt battery.

If there is no external resistance in circuit with the volt-meter, the needle should show a full scale deflection when the 40-volt battery is connected across the terminals of the 40-volt winding, when the 4-volt battery is connected across the terminals of the 4-volt winding, or across the 4-volt winding in parallel with the 1,111 ohm shunt coil.

When the voltage is such as to give a full scale deflection with no external resistance, and the zero position of the needle is at the left-hand end of the scale, then when the needle is deflected by current through the external resistance the external resistance is to the volt-meter resistance as the scale reading to the right of the needle is to the scale reading to the left.

To determine then the value of the unknown resistance, it is only necessary to consider that the scale divisions from the zero point to the needle in its deflected position represent the volt-meter resistance, while the scale divisions from the needle to the point at which the needle comes to rest when the volt-meter is connected directly across the terminals of the battery, will represent the external resistance. For instance, if the volt-meter needle comes to rest at a point one-quarter of the way across the scale, the remainder of the scale (three-quarters) will represent the value of the unknown resistance; hence, if the 100,000-ohm winding has been employed, the unknown resistance will be 300,000 ohms; if the 10,000-ohm winding has been employed, it will be 30,000 ohms; and if the 10,000-ohm winding has been shunted by the 1,111-ohm resistance coil the unknown resistance will be 3,000 ohms.

It is evident by referring to Fig. 473 that leaving all keys except the volt-meter key in their normal positions, the 100,000-ohm coil and the 40-volt battery will be brought into service. Leaving the volt-meter key No. 4 thrown and throwing the battery switching

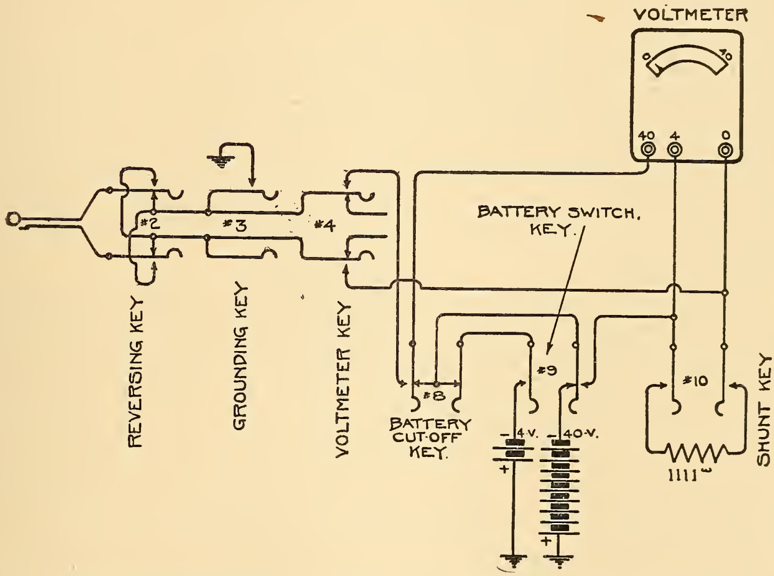

FIG. 473.—VOLTMETER CONNECTIONS OF TESTING CIRCUIT.

key No. 9, brings the 4-volt battery with the 10,000-ohm volt-meter coil into circuit. Throwing these two keys together with the shunt key leaves the same combination in service, and shunts the volt-meter scale. For greatest accuracy the volt-meter combination to be used in making a resistance determination should be that which gives a volt-meter resistance nearest to the resistance to be determined.

The grounded or non-grounded condition of a line should not be decided finally by means of a volt-meter test only; for, if the ground happens to be of an intermittent character the swing of the volt-meter needle would be a most unreliable indication and might in extreme cases be scarcely perceptible. In that event the relay and sounder should also be used. This has the advantage that the comparatively large amount of current flowing may be great enough to permanently break down the insulation at the fault and make the ground of a permanent character.

The method of testing for a ground with a relay and sounder may best be described in connection with Fig. 472. By throwing the relay key No. 5 and leaving all of the other keys in their normal positions, a ground on the sleeve side of the line will cause the relay to become energized and the sounder to be operated. If, now, the reversing key, No. 3, be thrown, this will test for a ground on the other side of the line. Tests for grounds with the relay depend, of course, on the resistance of the ground being low enough to allow current to flow through it to operate the relay. By testing the relay over a known resistance the greatest resistance through which it will be operated may be determined. With this resistance known, a line which tests clear under a relay test will be known to have no ground on it of a less resistance than that through which the relay will operate.

Continuity tests of a line may be made as in testing for grounds, the only difference being that the subscriber's receiver must be off its hook and that a ground must be applied to the return side of the circuit by throwing the grounding key, No. 3. If there is no break in the circuit, the volt-meter will show a deflection. Of course, the fact that the subscriber's line is normally open to continuous currents at the sub-station must be taken into account in making this test. A test for the continuity of a circuit should always be preceded by a test for grounds, for if the line is grounded it might be broken on the other side of the ground, and still give the proper test for continuity. A good order, therefore, in making these tests in routine work is to first throw the volt-meter key, then the reversing key, and then, if no deflection occurs due to a ground on the other side of the line, throw the grounding key.

As the resistance of a line is usually comparatively low with respect to the coils of the volt-meter, continuity tests should as a rule be made with the low reading scale of the volt-meter using the shunt. If it is seen that the reading will not go beyond the range of the instrument, the low reading scale without the shunt or the high reading scale may be used. Of course, continuity tests may also be made with the relay.

In making tests for crosses between two lines, the grounding cord shown in Fig. 474 is useful, and a few of these cords are usually added to the wire chief's equipment. If the two lines are free from grounds, a cross between them may be determined by grounding one of them with the grounding cord, and testing for a corresponding ground on the other.

To test for a cross or a short circuit between two limbs of a line, it is desirable to know the normal resistance of the line. It is well, therefore, to have a record of the resistance of each line when it is in good condition, and when the receiver is off the hook. This record should be kept in a card index, and any subsequent variation from the recorded resistance of a line should be taken as an indication of trouble.

The lifting of a subscriber's receiver off its hook sometimes gives an indication which is mistaken for an actual cross on the line. A cross on the line is usually of a non-inductive nature, while the path between the two limbs of the line through the subscriber's talking apparatus contains a considerable amount of retardation.

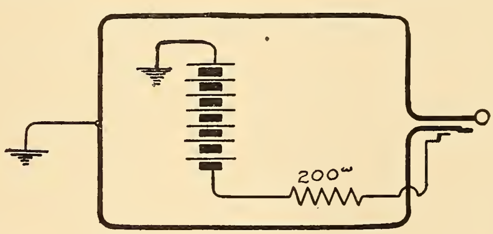

FIG. 474.—GROUNDING CORD.

This difference may often be made use of to determine whether or not the indicated cross is due to the subscriber's receiver being off its hook. If the ringing current is applied to the line by means of key No. 1, an audible discharge due to the self-induction of the circuit will take place when the key is released, when the subscriber's receiver is off its hook. If the subscriber's receiver is on its hook, and the indicated cross is due to another cause, this discharge will not take place. Another means of determining whether or not the cross is due to the subscriber's receiver being off its hook may be made by depressing the circuit-opening button on the testing trunk (Fig. 11), thus lighting the line lamp. The operator will respond and an attempt at conversation will give some indication as to the condition of the line, for if the trouble is in the form of a non-inductive cross, conversation will be scarcely audible.

Ballistic methods of testing involve the reading of a sudden throw of the volt-meter needle, due to a momentary rush of current as from the discharge of a condenser or the kick of an impedance coil. Ballistic methods are used by the wire chief in those tests involving the capacity of the line and attached condensers. To test an ordinary one-party, metallic circuit, common battery line, first throw the volt-meter key, No. 4, then the grounding key, 3; next throw the reversing key quickly back and forth, causing a throw of the needle at each reversal.

Consideration of Fig. 473 will show that at the closing of the volt-meter key a rush of current will take place from the live pole of the 40-volt battery, through the 40-volt coil of the meter to the ring side of the line. This side of the line will thus receive a negative charge, while the tip side of the line will receive by induction a positive charge. When the reversing key is thrown, the tip side of the line will be connected to the volt-meter and a current will flow from the battery through the volt-meter until the charge on this side of the line is changed from positive to negative. There is naturally, therefore, a double discharge at each reversal, it being necessary for the current flowing through the volt-meter to neutralize one charge and build up one in the opposite direction. The momentary rushes of current through the volt-meter coil will be in the same direction, and the deflection of the needle may thus be readily noted. By comparison with the double discharge from a known capacity at a known voltage the capacity of the line as indicated by these readings may be readily determined.

In case of very large capacities the 4-volt scale without the shunt should be used.

When the extension bell is used in connection with a subscriber's line, it may be connected either in parallel with the bell associated with the subscriber's set, or a separate condenser may be placed in series with the extension bell, and bridged directly across the line. The former arrangement will have no appreciable effect on the capacity of the line, while the latter arrangement will increase it considerably.

Party lines having alternating current relays or magneto bells bridged across the line in series with condensers, will give an increased throw for each added instrument. Party lines having the bells connected to ground on either side of the line will give a throw for the bells on the ring side of the line when the reversing key returns into its normal position, and a throw for the bells on the tip side of the line, when the reversing key is thrown out of its normal position. In case the bell is connected from one side of the line to ground through a condenser, the throw of the needle of the volt-meter, when a ballistic test is being made, will be equal to about one-half of the throw occasioned when the bell and condenser are bridged directly across the line. This is due to the fact that in the former case the charging current alone is measured, while in the latter case, both the charging and the discharging currents are measured.

The distance from the exchange of a break in a long line which has a high insulation resistance may be approximately located by observations taken of the throw of the volt-meter needle.

It is often necessary to determine the continuity of a circuit which contains a condenser, thus rendering continuous current methods unavailable. To make a test of this character throw the continuous ringing key, No. 6 (Fig. 472), and if necessary, the reversing key. The continuity of the circuit for alternating currents may thus be determined by connecting the ends of the circuit beyond the condenser through a magneto bell. This method may also be applied when the two ends of a circuit are separated by a repeating coil.

Tests for foreign currents which may be present, due to a cross between some other line and a telephone line, may be made by throwing the battery cut-off key, No. 8, and the volt-meter key, No. 4. This bridges the 40-volt coil of the volt-meter across the line to measure the voltage present. The grounding key, No. 3, and the reversing key, No. 2, may be used as occasion demands.

The tests for switch-board troubles are perhaps the most varied of all, and methods may be often devised to meet the particular case in hand. A convenient way of locating breaks in the multiple wiring is to employ an ordinary head telephone attached to a switch-board plug, which may be inserted into the jacks of the line undergoing test at the multiple switch-board. With the Western Electric line circuit, or any other circuits, where the tip and ring conductors of the jack are permanently in contact with the tip and sleeve sides of the line, the continuity of the circuit to any jack will be indicated by the lighting of the line lamp when the plug is inserted in that jack. As soon as the plug is inserted in a jack beyond the break, the line lamp will not light, and the break may therefore be located between the last jack through which the lamp will be lighted and the first one through which it will not.

In those boards, as for instance those of the Kellogg and Stromberg Companies, where the line jacks are not normally connected with the line, a similar test may be made by placing a battery and a buzzer across the tip and sleeve strands of the multiple at the first section of the board, and then plugging into the successive jacks of that line with a receiver bridged across a plug. The noise will not be heard, except perhaps faintly, beyond the break.

Under the heading of miscellaneous tests, almost an infinite variety might be mentioned, these varying in accordance with the nature of the trouble, the nature of the circuit and apparatus, and the ingenuity of the person making the test.

CHAPTER XXXIV.

THE LAY-OUT AND WIRING OF CENTRAL OFFICE EQUIPMENTS.

A VISIT to a modern central office containing a large common battery multiple switch-board, is apt to impress one with the fact that the wiring of a central office equipment is one of the fine arts. On account of the great multiplicity of circuits, the systematic and neat arrangement of the various wires connecting the different pieces of apparatus in their proper circuit relations is of great importance, and the really artistic work which is seen in a large central office is not the result of a desire to merely "make things look pretty," but is brought about by necessity.

It is not unusual in any line of work that good workmanship, when applied in carrying out good design from the standpoint of utility alone, will result in what will be called an artistic product. Nowhere is this more apparent than in the interior arrangement of a telephone central office.

The function of the wiring is, of course, to connect the different parts of apparatus in proper working relation. It is necessary, for several reasons, to place these various pieces of apparatus in different parts of the office, in accordance with a certain classification governed largely by the functions each class of apparatus is to perform. Thus all those parts necessarily within reach of the operators, such as signals, jacks, plugs, keys and the like, are placed in the operating room, and form, when assembled with their proper mounting, the switch-board proper. Those parts individual to the line circuits, including line terminals, arresters, relays and distributing means, are placed on racks in a separate room or rooms and arranged with particular reference to convenience in maintenance and repairs. Those parts concerned in the generation or control of the various currents necessary for the operation of the exchange form another distinct group, known, as a whole, as the power plant.

While all of these parts must be arranged primarily with regard to the most efficient performance of their various functions and to convenience of maintenance, proper regard must be had in the lay-out to the securing of an economical arrangement with regard to the wiring, extending between the various pieces of apparatus in each class, and between those in the different classes. This matter deserves much careful attention from the standpoint of first cost, as the cable and wire is in itself expensive, and much may be saved by a proper relative location of apparatus of the different classes.

In order to make clear the arrangements necessary from the wiring standpoint, the wiring of a line circuit will first be considered. The line circuit of the Western Electric Company, shown in Fig. 264, will be taken as an example. The circuit of one line, as actually wired, is shown in Fig. 475, this being an elaboration of the conventional circuit shown in Fig. 264. Such a circuit as this is usually called a wiring diagram, because in it the various connections, as they actually exist in practice, are indicated, together with other information as to the makeup of the cables, sizes of wire, location of the apparatus, etc. Taking this circuit as a basis, the progress of a line will be traced from the place where the lines enter the office building through the two distributing frames to the switch-board and other portions of the equipment.

It will be seen that the line after entering the office building is first led to the line side of the main distributing frame, and is there connected by means of duplex jumper wire to the arresters on the switch-board side of the main distributing frame. From this the two sides of the line continue to two of the three clips on the line or multiple side of the intermediate distributing frame. Up to this point in the circuit shown, all wires have been in twisted pairs, there being only two wires to each circuit. There are, however, three clips on the line side of the intermediate frame, and from these three lead three wires to the three contacts on the multiple jacks, two of these being simply a continuation of the tip and sleeve conductors of the line, the third being a lead to the test rings on all the jacks. The two line wires take the names "tip" and "ring," and the third wire the name "sleeve," these being derived from their plug contacts; hence the designation of their various distributing frame terminals, "T," "R" "S."

The wires leading from the main to the intermediate distributing board are usually grouped in 21-pair cables, 20 pairs being the unit of wiring throughout the exchange from the arrester side of the main distributing frame. The cables leading from the main to the intermediate distributing frames are termed the "main to intermediate" cables.

In order to accommodate the three wires leading from the inter-

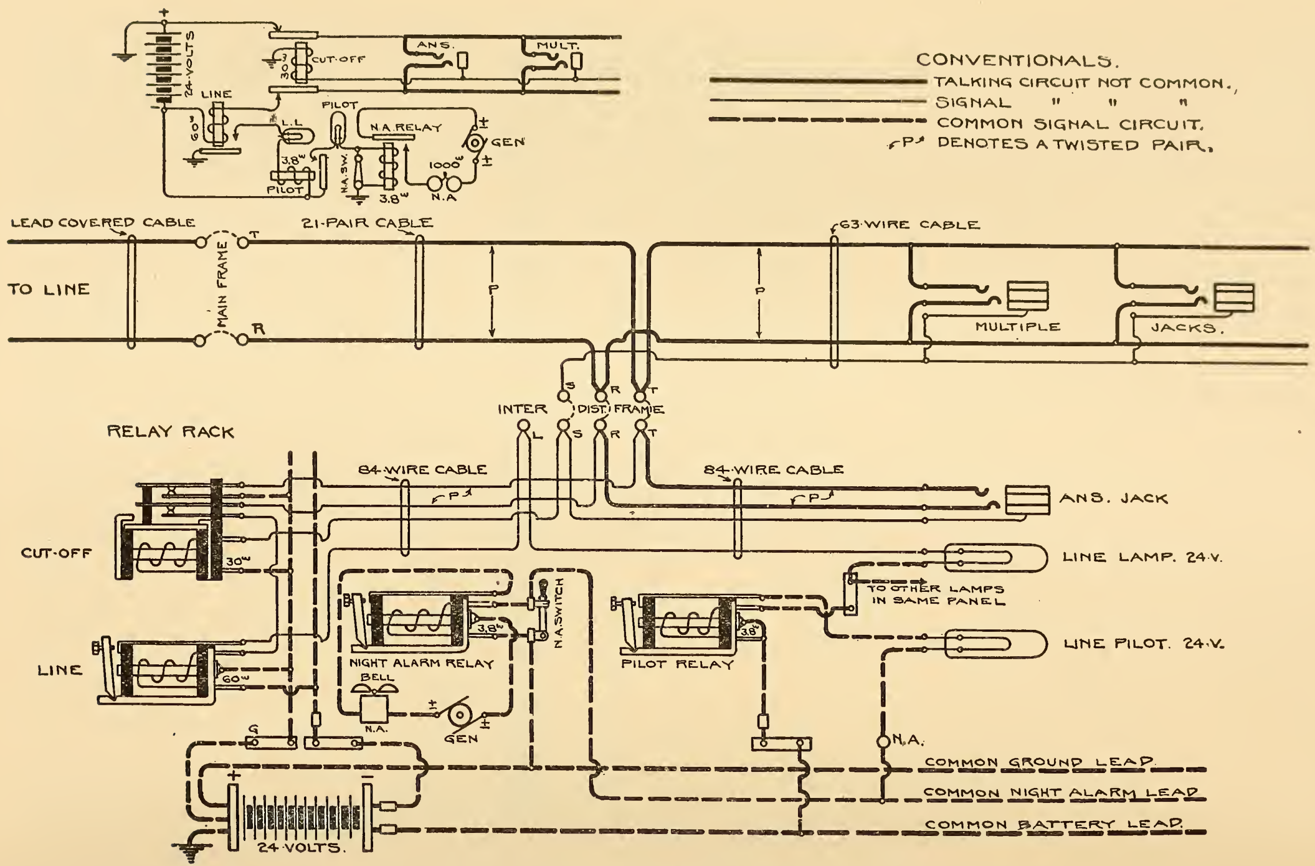

FIG. 475.—WIRING DIAGRAM—WESTERN ELECTRIC LINE CIRCUIT.

mediate distributing frame to the first multiple section of the switch-board, the wires serving the 20 lines are grouped into a 63-wire cable, this cable consisting of 21 twisted pairs serving the tip and ring contacts of the jacks, and 21 single wires serving the sleeve contacts. These are the "intermediate to multiple" cables, sometimes called "long multiple cables."

On the opposite side of the intermediate distributing frame the conditions are more complex. All of the relays associated with the lines are mounted on what is called a relay rack, and from the four clips on the answering jack side of the intermediate distributing frame to the relay rack, four individual conductors for each line extend. One of these is that which connects the line lamp clip *L*, on the intermediate frame with the lamp contact of the line relay. Two others connect the tip and ring contacts, *T* and *R*, respectively, on the frame with the long contact springs of the cut-off relay. The fourth connects the sleeve of the answering jack and those of the multiple jacks to the coil of the cut-off relay. These four wires, serving 20 lines, are bunched into a cable, forming with four spare wires, an 84-wire cable. This cable is termed "the intermediate to relay rack cable." The four wires belonging to any line in this cable consist in each case of a twisted pair, "tip" and "ring," and of two straight wires, "sleeve" and "lamp."

Another group of cables extends from the same clips on the answering jack side of the intermediate frame to the answering jacks, and these are termed "intermediate to answering jack cables." There are also four wires in this cable for each line, these being the wires extending to the three contacts in the jack and to the lamp. These as in the intermediate to relay rack cables consist in each case of a twisted pair and two straight wires.

Besides the cables so far considered there are the "short multiples" leading from section to section of the switch-board, each cable connecting a strip of multiple jacks in one section with the corresponding strip in the next. There are therefore for each line one less short multiple cables than there are sections of the switch-board.

In a three-wire system like that of the Western Electric Company under consideration, the cable in the short multiples consists of 63 wires in all, 21 pairs and 21 individual wires.

Various leads, such as those extending from the live side of the battery or from ground are made of okonite or similar wire of sufficient carrying capacity to supply the maximum current demanded. It is common practice to run the principal common battery and ground wires bare, unless the particular place in which they are used makes it safer to insulate them. Much of the common wiring is shown in the diagram of a power plant, Fig. 397.

In order to facilitate the work of properly forming the cables and bringing the corresponding wires out at such points as to reach the corresponding terminals at the two ends of the cable, the wires in the cable are arranged in accordance with a certain color scheme, or, as it is more often called, a color code. The outer wrapper of cotton of the different wires is, with this end in view, dyed so as to be of a distinctive color. The colors by which the various pairs of wires in a 21-pair cable are distinguished, are composed of the following, always used in the same order: Blue, orange, green, brown and slate. One wire of each pair always has its cotton covering formed of one of these colors, or a combination of two or three of

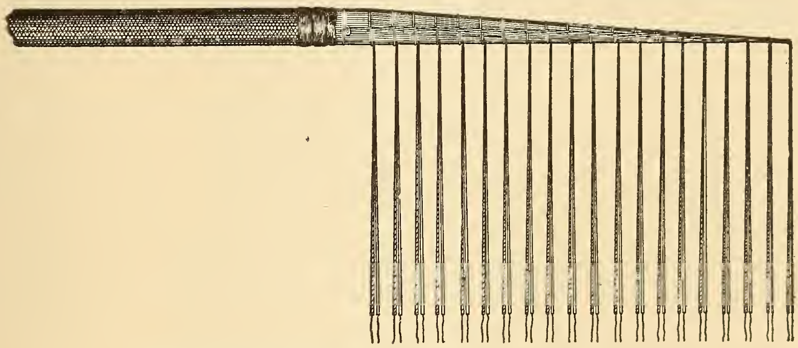

FIG. 476.—METHOD OF FANNING OUT CABLES.

them. Such a wire when forming part of a pair usually has a white mate. When there are three wires associated together, as in a 63-wire cable, the third has the same code as the colored wire in the pair, but also has a thread of red running with the other colors in each case. The color code for a 21-pair cable, therefore, is as follows: Blue, orange, green, brown, slate, blue-white, blue-orange, blue-green, blue-brown, blue-slate, orange-white, orange-green, orange-brown, orange-slate, green-white, green-brown, green-slate, brown-white, brown-slate, slate-white. The spare wire in a twisted pair is solid red, its mate being solid white. When there is a third wire associated with the spare pair it is red-white-blue.

The method of forming the end of a cable so as to facilitate the soldering of its component wires is shown in Fig. 476. This figure applies to machine cables, that is, to cables made up by machinery in continuous lengths, and afterward cut to length before forming. Each cable is stripped at its end, and butted with tape at the point where the covering of the cable ends. The wires leading from the cable are then formed and laced in the manner shown in Fig. 476, the various pairs being led out at intervals corresponding to the intervals between the terminals in the strip to which they are to be attached.

The method of wiring the multiple cables is shown in Fig. 477, which shows a single strip of jacks with the ends of the cables leading to the two adjacent sections soldered to it. A two-point jack only is shown in the figure.

The lay-out of a telephone exchange building involves not only the floor plan of the operating room, of the terminal room, and of

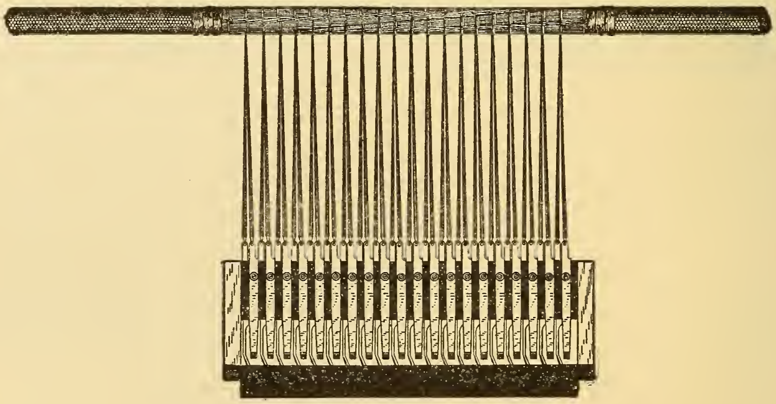

FIG. 477.—MULTIPLE JACK WIRING.

rooms occupied by other portions of the equipment, but in modern practice the primary design of the building itself. It is a matter for which few general rules may be laid down, it being necessary to solve the various problems arising, in view of the conditions in each case. It may be said, however, in general, that except in comparatively rare cases, the space available for an operating room usually makes it desirable to arrange the board in horseshoe form, the various sections being arranged in a line facing inward around the operating room. The reasons for facing the boards inward instead of outward are several. The direct light from the windows does not then fall on the face of the board, which might prevent the lamp signals from being distinctly seen by the operator when lighted. Moreover, the light from the windows in the walls of the room may shine behind the board, which is an advantage from the standpoint of repairs. When the operators are on the inside rather than the outside of the curve of the board, they are within sight of the chief operator and other officials of the operating room. The operators at the angles of the boards are, by reason of being within the angle, enabled to reach the entire section of multiple jacks, which would not be the case were they on the outside of the curve. Lastly, there is a distinct advantage from a constructive standpoint in that more room is afforded at the boards in which to make the multiple cable connections when the cables are on the *outside* rather than the inside of the curve.

As a rule, all cables entering the switchboard, whether multiple, answering jack or other, are led into one end of the board through what is usually called the turning section, the cables being led up from beneath or down from above, usually the former, and assuming a horizontal direction after passing through what is called a cable support, within the turning section. Most of these cables run from the end of the intermediate distributing frame, and it is therefore obvious that the end of the intermediate distributing frame should be as close to the turning section of the multiple board as possible, in order to save in the amount of cable required between them.

It is also important that the arrangement of the distributing frames and the relay rack be such that a minimum amount of cable shall be required in the main to intermediate and in the intermediate to relay rack runs. The length of these two runs, however, is not of as much importance as that of the run between the intermediate frame and the turning section on the switch-board, because this run always includes the intermediate to multiple cables and usually also the intermediate to answering jack cables.

A point of not less importance is that the distance from the main cable vault of the office to the main frame should be as small as possible, so as to shorten the run of the street cables to the main frame. In modern construction these are usually lead covered and therefore more expensive.

It is necessary, especially in large exchanges, to provide separate room for the storage batteries for the purpose of isolating them from all other portions of the equipment, particularly on account of their fumes. Such a room should always be provided with ample ventilation, particularly with a vent near the top of the room, and if necessary, with forced draft. The room should, moreover, be light, in order to afford ready means for inspection of the plates. A concrete floor is perhaps most common in the battery room, but several exchanges have been installed using a rough glazed tile floor, with the binding between the tiles resembling tar. Such a floor has the advantage of tending to prevent the workmen from slipping when handling the acid and also of not being attacked by the acid when spilled upon it.

The power plant should be located as close to the battery room as possible, and preferably in the terminal room containing the distributing frames and relay racks.

The wire chief's desk is usually placed in the terminal room, and where this room also contains the power apparatus, the supervision of the wire chief may extend over this portion of the apparatus as well.

There is still some controversy in regard to the best method of arranging the cables and line terminal apparatus between the cable entrance and the switch-board apparatus in central station offices. Two general methods are now practiced, either of which is subject to many modifications. One of these consists in terminating the street cables in pot-heads or their equivalents, and running directly from these to line clips on the main distributing frame, the switch-board side of this frame carrying the arresters. From the arresters the various cables run to the relay rack or intermediate distributing frame, and thence to the switch-board proper. The other method is to terminate the cables in iron terminal heads placed on a separate rack, these terminal heads carrying the arresters, from which cables then run to the main distributing frame and thence to the intermediate frame and relay rack, and to the switch-board.

The former method, that is, of terminating the street cables in pot-heads or their equivalent devices and of placing the arresters on the switch-board side of the main distributing frame, is growing in favor and has been the practice of most of the Bell operating companies. Some of the advantages of this method may be outlined as follows:

First, it brings about a considerable saving of expense over the construction using the iron terminal heads. This is so, principally because where the pot-head construction is used the number of arresters provided need be equal only to the number of lines in use on the switch-board; rather than equal to the number of cable pairs in the street cables, as may be required where the iron terminals are used. The number of pairs in the outside cables is usually greatly in excess of the actual working capacity of the switch-board, and the providing of an arrester for every pair in the street cables involves a considerably greater investment than would be required where only one for each switch-board line is needed. Furthermore, the price of the iron cable heads with arresters is considerably more than the price of the arresters without the heads, and there is an additional cost in the rack upon which the iron terminals are to be mounted, as well as in the additional amount of wiring and soldering to be done where the iron terminals are used. This additional wiring and soldering is brought about by the fact that cables must be led to the iron arresters to which they are soldered, and other cables led from the arresters to the line side of the distributing frame; whereas, in the case where the iron terminals are not used, the cabling is carried directly from the street cables to the line side of the main switch-board.

Second, the method of using pot-heads requires less floor space than the other, no cable rack being required.

Third, it is more convenient to associate the arrester with the switch-board line than it is to associate it with the outside line. When the arrester is mounted directly on the switch-board side of the main distributing frame it may be said to become a part of the line circuit of the switch-board, and in the exchange is associated definitely with the particular line and cut-off relay, as well as certain other portions of the apparatus on the main switch-board. When, however, the arrester is mounted on a separate cable head outside of the main distributing frame, it becomes more properly a part of the line equipment, inasmuch as any arrester must then always be associated with any particular line. Inasmuch as the arrester is a part of the central office apparatus, it seems better to consider it as belonging to a certain switch-board line rather than to an outside line. This is particularly true in case of trouble needing quick action, for, when the arrester is mounted on the switch-board side of the distributing frame, no jumper list need be consulted to get at the arrester belonging to any switch-board line.

Fourth, the iron cables are supposed to hermetically seal the lead-covered cables entering the office. They are frequently not moisture-proof, however, and are liable to be left open at any time by workmen. Furthermore, the interior arrangement of the conductors in these heads whereby the wires in the cables are attached to the wires in the switch-board cable, is always extremely awkward, because it is necessarily crowded. Pot-heads, when properly made, afford a much better protection to the cable insulation than can with certainty be afforded with the iron cable heads. These latter are always necessarily punctured full of holes through which the terminals must pass, and therefore depend for their air-tight condition upon the successful plugging of these holes with the rubber insulation.

On the other hand, there are several features which may be cited as disadvantages in connection with the practice of terminating the cables in pot-heads or equivalent devices and carrying the arresters on the main distributing frame.

There is a considerable amount of soldering always necessary at the distributing frames due to the constant changes of the jumper wires. From this viewpoint the placing of the arresters on the distributing frame is disadvantageous in that drops of solder are likely to fall down through the arrester strips and short-circuit some of the springs or connectors. The arresters are necessarily closely bunched, and a drop of solder falling through them may introduce several cases of trouble in different lines. This is not as likely to happen where the arresters are mounted on the outside of cast-iron terminal boxes, because in this case most or all of the soldering is necessarily done on the inside of these boxes.

Another disadvantage often pointed out by advocates of the iron terminal head is that when the arresters are mounted on the switchboard side of the distributing frame no protection is afforded for th line side of the distributing frame or for the jumper wires. This, in the old methods of construction where beeswaxed or paraffined jumper wires were used, and where the distributing frame was built largely of wood, was a very serious drawback. Now, however, it is of less importance, because the use of flameproof jumper wire and structural iron frameworks has rendered the liability to damage by fire in the distributing frame itself very slight.

This brings us logically to still another method of construction which in some circles is growing in favor. In this pot-heads or some equivalents are used for protecting the outside cable insulation, and the cables from these are terminated in arresters on a separate arrester frame. In this case the arresters are mounted on iron bars and are entirely open, as when mounted on the distributing frame. From the arresters the cables then lead to the line side of the distributing frame. The switch-board side of the distributing frame in this case consists only of ordinary clips for connecting the cables leading to the intermediate and relay racks and the switchboard.

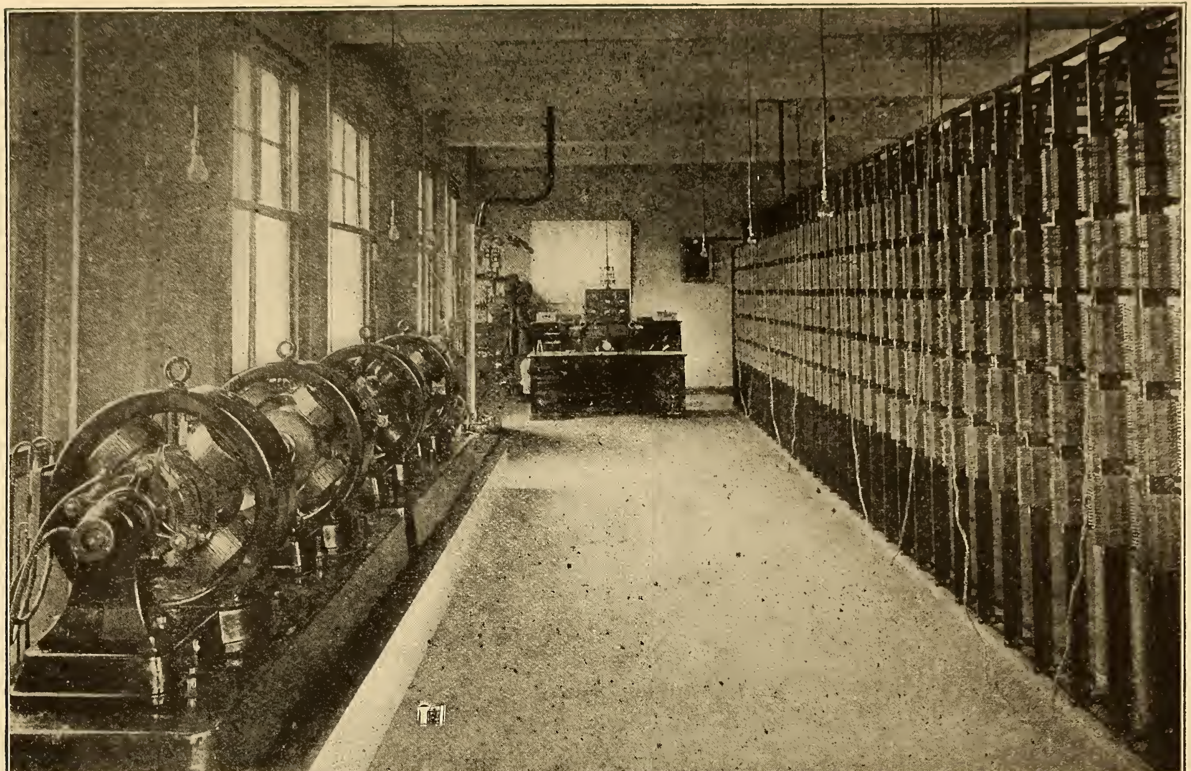

FIG. 478.—ARRESTER SIDE OF MAIN DISTRIBUTING FRAME—KEYSTONE TELEPHONE COMPANY.

FIG. 479.—MAIN DISTRIBUTING FRAME AND RELAY RACK—KEYSTONE TELEPHONE COMPANY.

By this construction protection is afforded to the whole of the main distributing frame and the cables leading to it, as in the case where the arresters are mounted on iron terminal heads. Also the advantages concerning the use of solder are secured. The running of the jumper wires on the main distributing frame is made somewhat more convenient, because of the absence of the arrester strips, which are often of such nature as to somewhat crowd the work of soldering the jumper wires.

Of course, this latter method has the disadvantage of requiring more arresters—that is, one for every street conductor. It also requires more room on account of the extra rack for mounting the arresters.

Although each of the three methods has its advocates among competent engineers, the consensus of opinion seems to be strongly in favor of the method wherein the arresters are carried on the switch-board side of the main distributing frame.

Practice differs to a considerable extent when this latter arrangement is used as to the method of connecting between the street cables and the line side of the main distributing frame. One method, and under certain circumstances a good one, is to end the street cables within the exchange in pot-heads, running from these pot-heads small regular switch-board cables to the main distributing frame. It is common in this case to use 20-pair switch-board cable, and where the condition of the portions of the building through which these cables are to pass is such as to be depended upon for absolute dryness there seems to be no reason why this cable should be lead-covered. They are, however, frequently lead-covered, although when this is done larger cables than 20-pairs are commonly used. The dividing up into small cables at the pot-head is of distinct advantage in distributing the wires of the large cables properly to the terminals on the distributing frame, and is to be preferred to bringing the larger cable to the distributing frame and having to split it up so as to accommodate it to several strips.

Another method, and one widely used, is to use in the place of pot-heads a considerable length of wool-insulated cable, lead-covered, this being spliced directly onto the street cable and serving in itself to keep moisture out of this cable.

In the Western Electric system (see Figs. 458 and 475) the arrangement of the line circuit is such that the cables naturally pass directly from the main frame to the intermediate and thence to the relay rack. In the Kellogg system (see Fig. 459) the cables from the main frame pass first to the relay rack and then to the intermediate frame. In plants installed by the Western Electric Company, therefore, the frames are arranged on the floor in this order, main distributing frame, intermediate distributing frame and relay rack. In Kellogg plants the order is main frame, relay rack and intermediate frame. In all cases, however, all of the cables involving the line circuits pass directly from the intermediate frame to the switch-board.

The cables leading from one frame to another, or from the intermediate frame to the switch-board, are usually carried in iron channels or runways secured either to the frames themselves or to the building. The cables are piled in the runways in systematic fashion, thus economizing space and rendering them accessible for repairs.

In the Western Electric plants the cables leading from one rack or frame to another lie in runways extending between the ends of the racks, whether the racks are mounted side by side or end to end. Thus, in the case of the intermediate to relay rack cables, they are run in a trough extending along the upper side of the intermediate frame to one end of this frame, thence across to the top of the relay rack and down its entire length. All cables were thus led through this trough at the end of the two racks, requiring much more cable than would be necessary if the cables were laid straight across from the intermediate frame to the relay rack in case the frames were mounted side by side.

In the later plants of the Kellogg Switch-Board and Supply Company the three frames are mounted side by side, the relay rack being between the main and intermediate frames. This construction involves the placing of a horizontal lattice-work extending between the top of the main frame and the top of the intermediate frame, upon which all cables extending between the three frames may be led in the most direct manner. In order to prevent the criss-crossing and consequent tangling of the cables on this horizontal rack, the distributing frames are so proportioned with respect to each other that a bay of relays will be made just as wide as the interval occupied by three arrester strips on the main frame, and this bay will be provided with the same number of relays as there are arresters on a corresponding space on the main frame. This makes it possible to extend all cables straight across between the frames, thus securing a systematic arrangement without piling up the cables in a compact mass. The open construction thus secured is advantageous in case of repairs or changes, while the saving of cable is enormous.

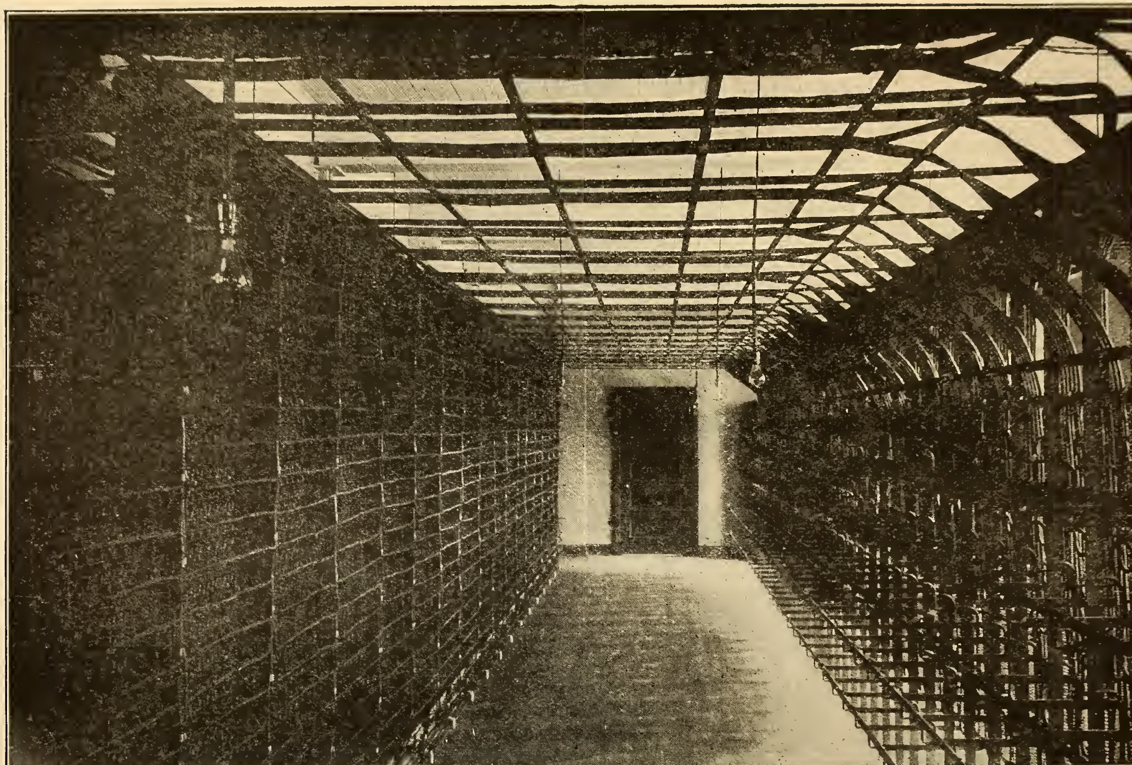

FIG. 480.—RELAY RACK AND INTERMEDIATE DISTRIBUTING FRAME—KEYSTONE TELEPHONE COMPANY.

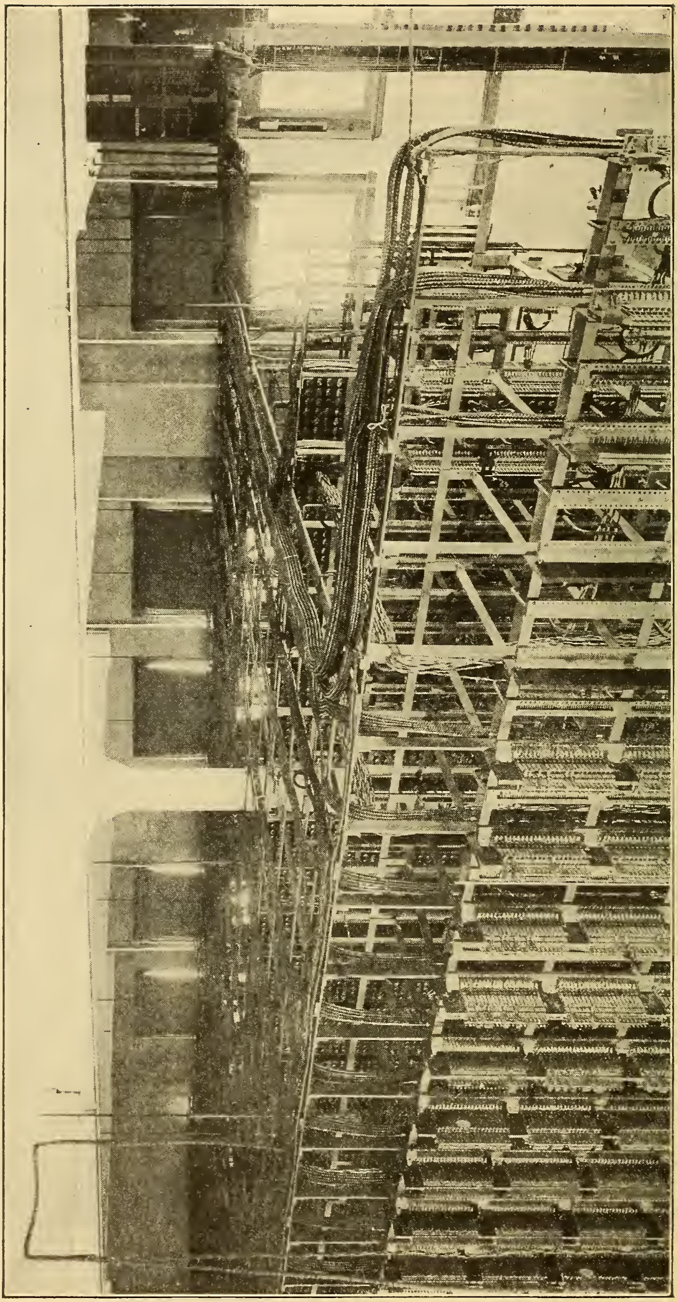

FIG. 481.—RACK ON TOP OF FRAMES—KEYSTONE TELEPHONE COMPANY.

Such construction is well shown in Figs. 478 to 481, inclusive, these being views of the terminal room in one of the large offices of the Keystone Telephone Company, of Philadelphia, Pa. This work is that of the Kellogg Switch-Board and Supply Company.

Fig. 478 shows a view of the terminal (line and switch-board) side of the main distributing frame. The charging machines, power switch-board and wire chief's desk are also plainly shown. Fig. 479 is a view taken in the opposite direction from that of Fig. 478, showing the jumper side of the main frame and the relay side of the relay rack. The other side of the relay rack, upon which all wiring is done, is shown in Fig. 480, this view showing on the right the jumper side of the intermediate frame.

The general overhead construction is shown quite clearly in Fig. 481, which is a view of the tops of the main frame, relay rack and intermediate frame.

In all modern common battery multiple systems the main body of cables leading to the switch-board extend from one end of the intermediate distributing frame in an iron runway between the end of this frame and the turning section of the multiple board.

One end of such a cable run is shown in Fig. 482, which is a view of the end of the intermediate distributing frame of the new Cortlandt Street exchange of the New York Telephone Company. The horizontal or multiple side of this frame is that toward the observer in this view, and from this side the cables lead through the diagonally mounted runway, as shown, to a horizontally disposed runway which passes to the turning section at the end of the multiple board. From the vertical or answering side of this frame lead the intermediate-to-answering-jack cables, and these pass into another horizontal runway, where they may be seen in the upper left-hand corner of Fig. 482. The other end of these horizontal cable runs is shown in Fig. 483. This view shows the rear of the turning sections of both the subscriber's multiple board and the incoming trunk boards. The multiple cables to these switch-boards turn right and left through ninety degrees in a horizontal plane, and then downward into the turning sections at the ends of their respective boards, as shown. Behind the panel work shown in the lower part of this figure the multiple cables again turn into a horizontal direction into the switch-boards behind the multiple jacks.

The method of arranging the multiple cables always involves serious attention. The practice is now almost universal to lay the multiple cables on a shelf directly back of the jacks which they serve, the thickness of the cables being so arranged that they will build or pile upon each other at the same rate as the strips of jacks in the face of the board; thus, the cable serving any particular strip

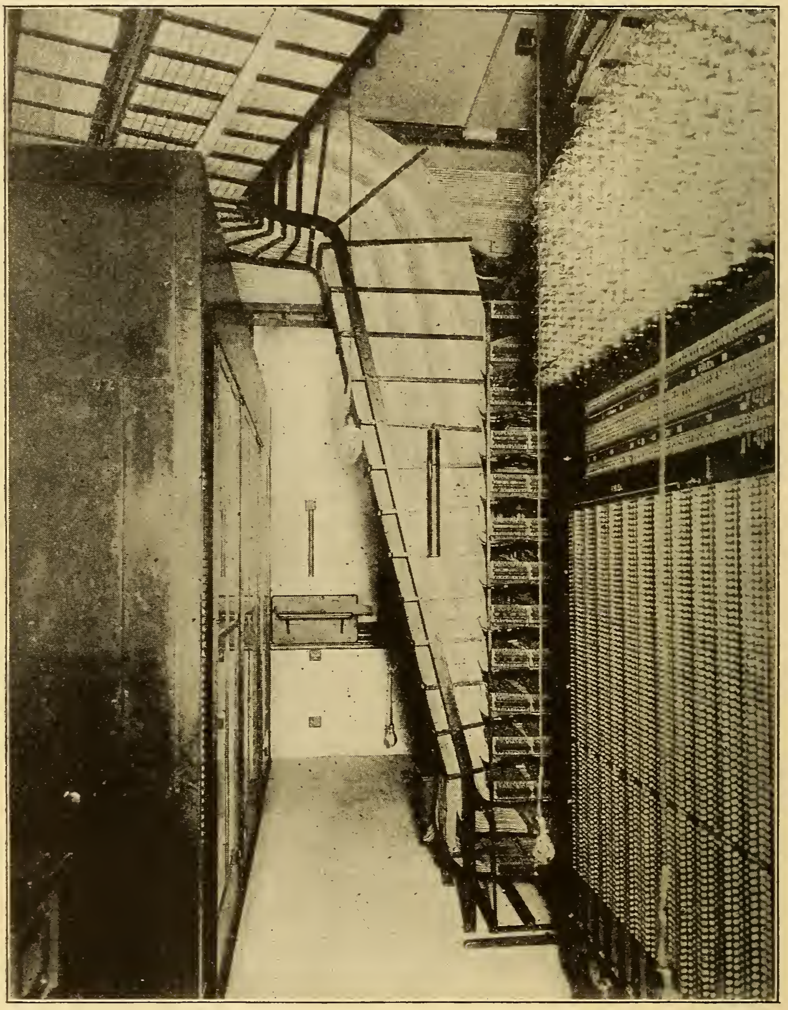

FIG. 482.—END OF INTERMEDIATE DISTRIBUTING FRAME—CORTLANDT STREET OFFICE.

of jacks will always lie on the same level as that strip of jacks. It is evident that if the cables are thicker than the jacks so that they will build up more rapidly, the available space for the cables will be filled before all the jacks required by the ultimate capacity of the exchange are put in place. Furthermore, the "skinners," as the individual wires leading from the cables to the terminals of the jacks

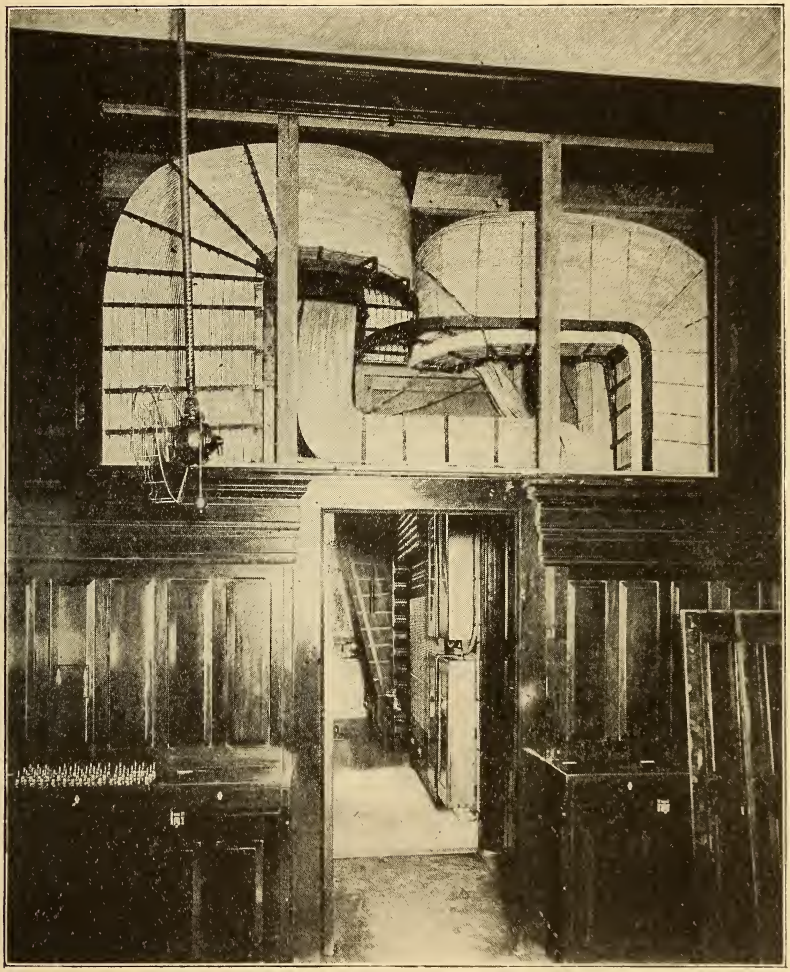

FIG. 483.—TURNING SECTION—CORTLANDT STREET OFFICE.

are called, would have to be longer than would be necessary where the cables build up at the same rate as the jacks.

A rear view of a portion of the large multiple board of the Cortlandt Street exchange of the New York Telephone Company is shown in Fig. 484. This shows the appearance of the multiple cable when piled in place back of the multiple jacks.

In Fig. 485 is shown an excellent rear view of the wiring of a common battery multiple board, this being that in the main office

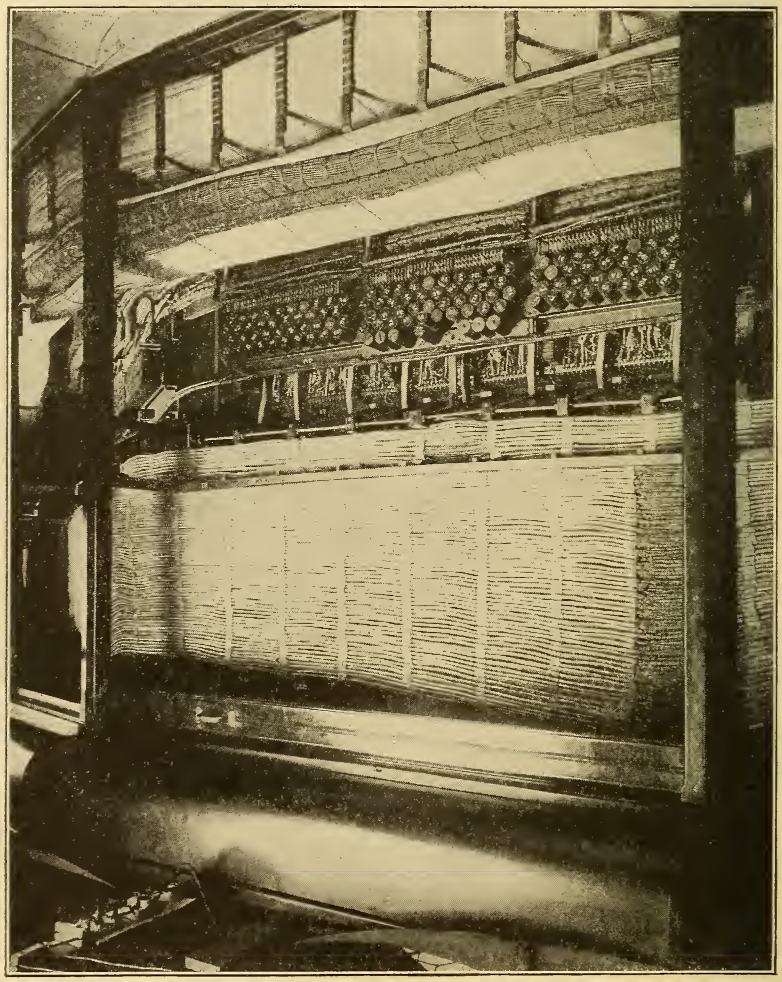

FIG. 484.—VIEW OF MULTIPLE CABLES—CORTLANDT STREET OFFICE.

of the Bell Telephone Company at St. Louis, Mo. A general view of the front of this board was shown in Fig. 284. In the upper portion of Fig. 485 may be seen the mass of multiple cables connecting with the multiple jacks. Below these are the cord terminal jacks

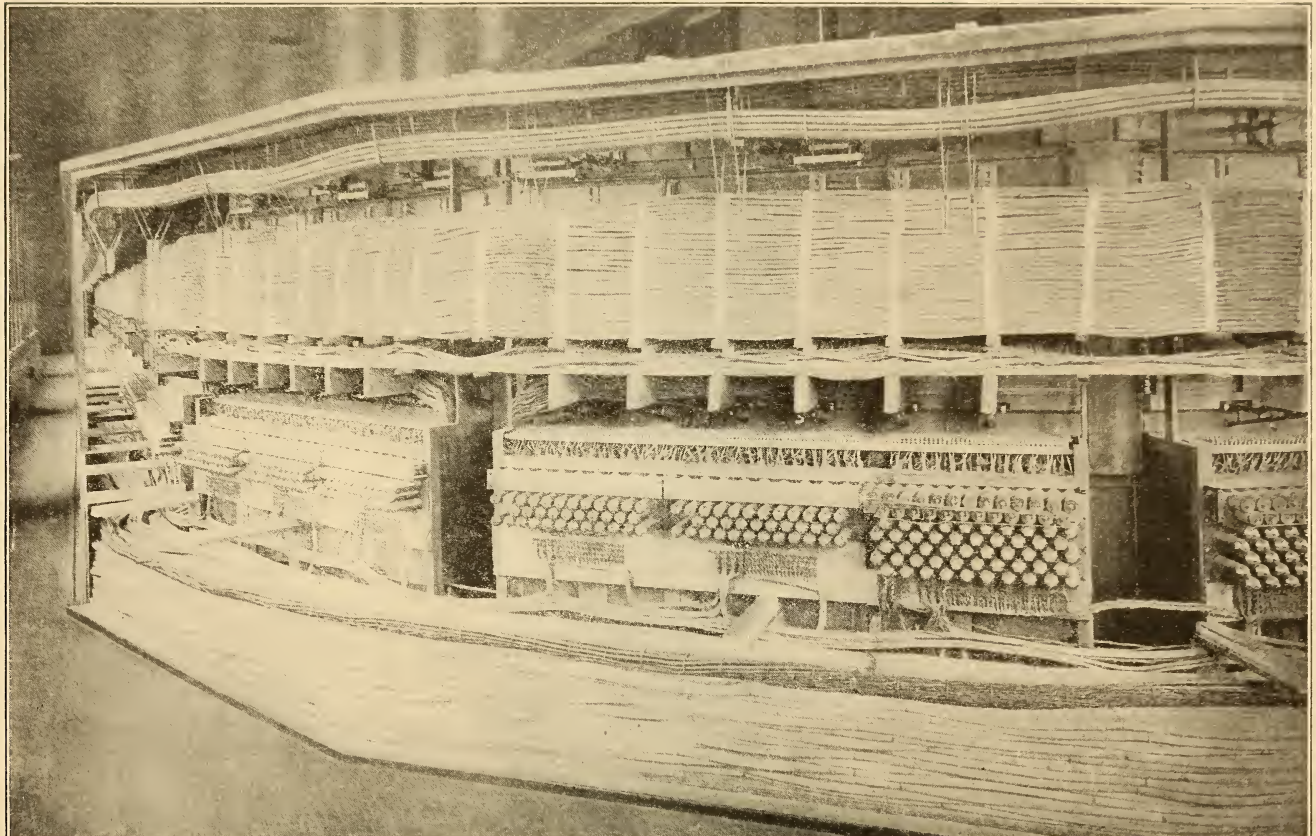

FIG. 485.—REAR OF SWITCH-BOARD—BELL EXCHANGE IN ST. LOUIS, MO.

and supervisory relays, and at the bottom of the view is the mass of intermediate-to-answering cables, these cables lying in a running box on the floor, a portion of which is removed in this view for the purpose of giving a better view of the cables themselves.

The pile of multiple cable is always as many cables high as there are horizontal rows of multiple jacks in the board. It is as many cables deep (front to rear) as there are panels in the switch-board section. From this it is evident that the skinners of the cables leading to the jacks in the first panel of each section are the shortest, those leading to the second panel a little longer and so on to those leading to the last panel, which are longest. This is well shown in Fig. 486, which is a horizontal plan of the arrangement of jacks and cables in any one layer of the multiple.

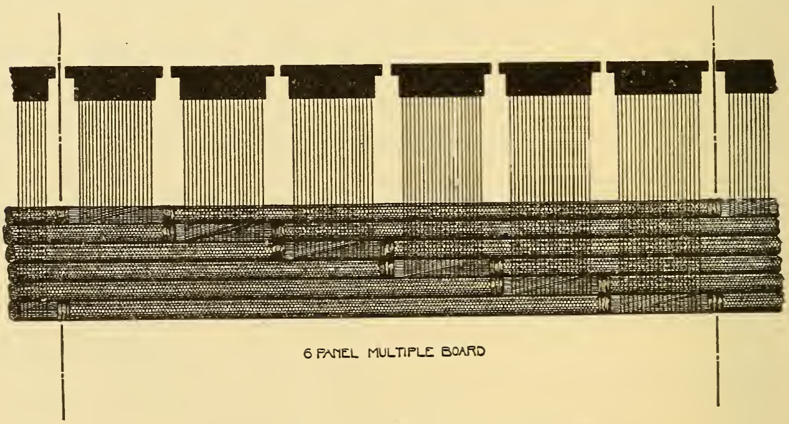

FIG. 486.—PLAN OF MULTIPLE CABLING.

The forming up of the multiple cables and soldering them to their jacks should always be done in the factory. In this way a vast amount of soldering may be accomplished before the apparatus is shipped to its destination, and in fact, the multiple jacks and multiple cables should all be tested out for transpositions, crosses, open wires, etc., before they leave the factory. The premises in which a large multiple board is being installed is no place for the performance of the almost endless task of soldering the multiple cables. The work may be done much more cheaply in the factory, where skilled labor is kept on hand for that purpose. It is therefore difficult to see why the practice still exists in some quarters in shipping the cables in lengths to be cut up, formed and soldered on the premises in the installation. There is, moreover, no reason, if proper engineering

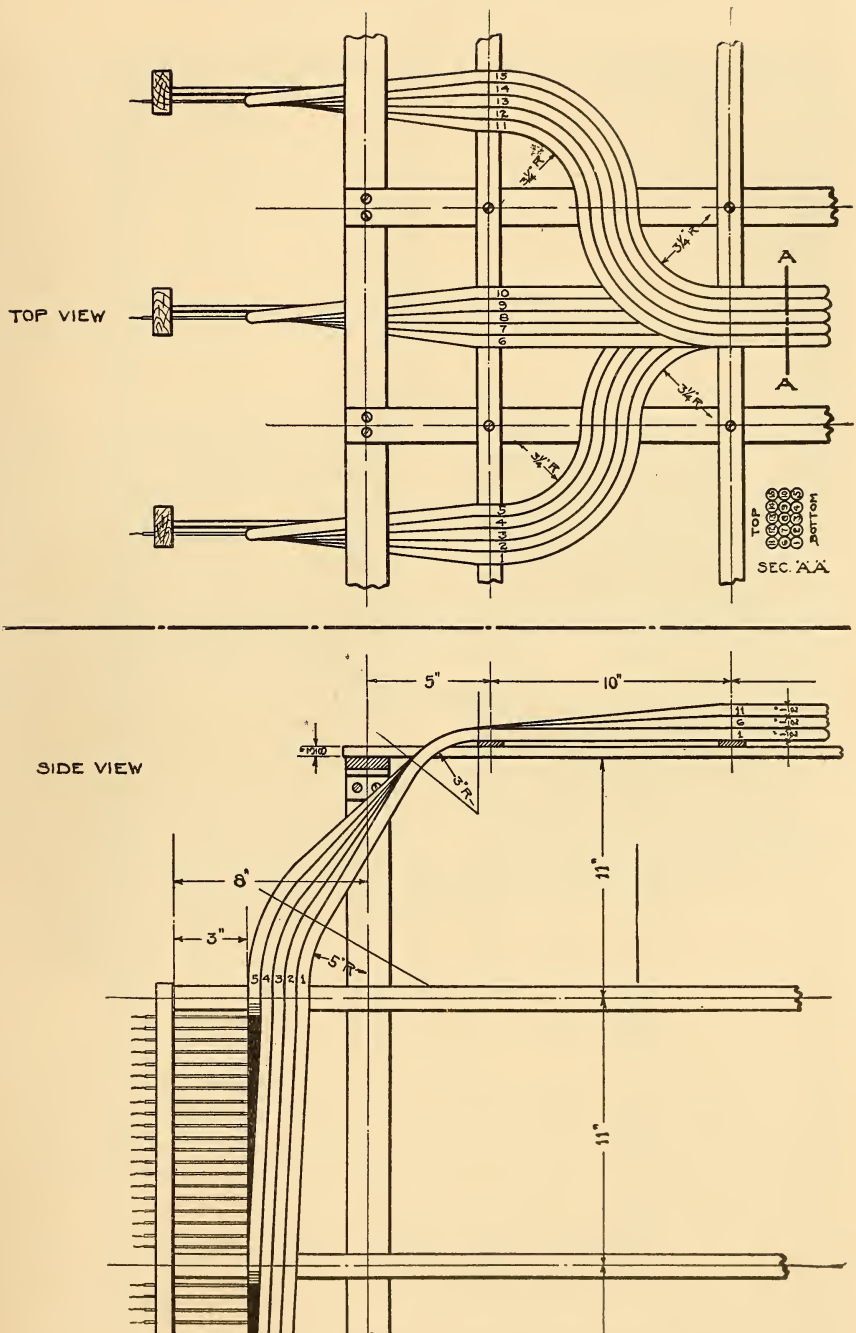

FIG. 487.—DETAILS OF CABLE LAY-OUT.

work is done in designing the wiring, why practically all of the cables, both long and short, should not be prepared, cut to length, formed, and in some cases soldered to their terminals in the factory rather than doing it at the installation. To do this, however, requires the utmost nicety in the laying out of the various details of the plant.

The scheme of cabling down to the running of each individual cable must be worked out at the draughting table on as large a scale as possible, after which the various cable runs are scaled and cable

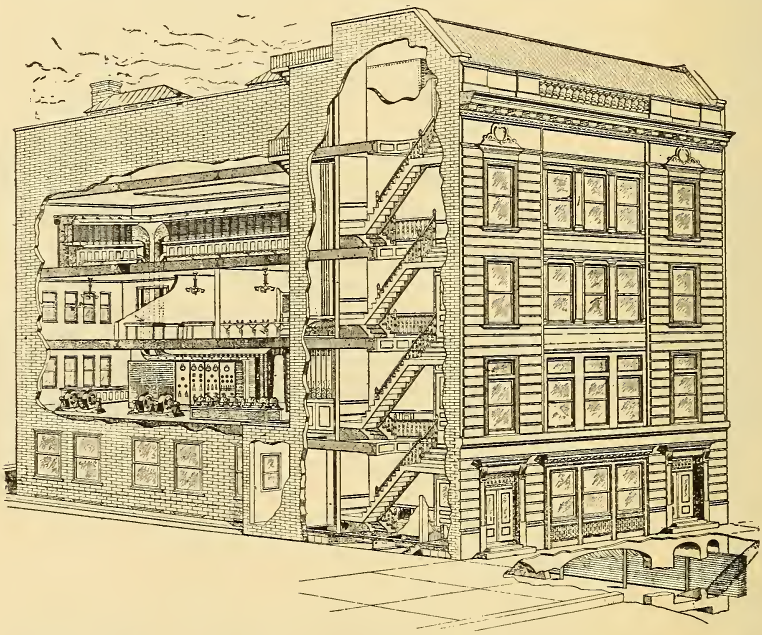

FIG. 488.—PLAZA CENTRAL OFFICE BUILDING.

cut to length and formed. Modern methods applied in this direction permit practically all cable forming being done before the apparatus is shipped; even the longest cables being cut to length and formed to such a nicety as to fit exactly and without waste into the various cable runs in which they are to be placed.

When it is considered that sometimes many hundred cables must be placed in a single runway, and that these cables must be piled in compact forms, a certain number in a layer and a certain number of layers deep; that they must often in going from room to room or from floor to floor be led around rather complex curves so that

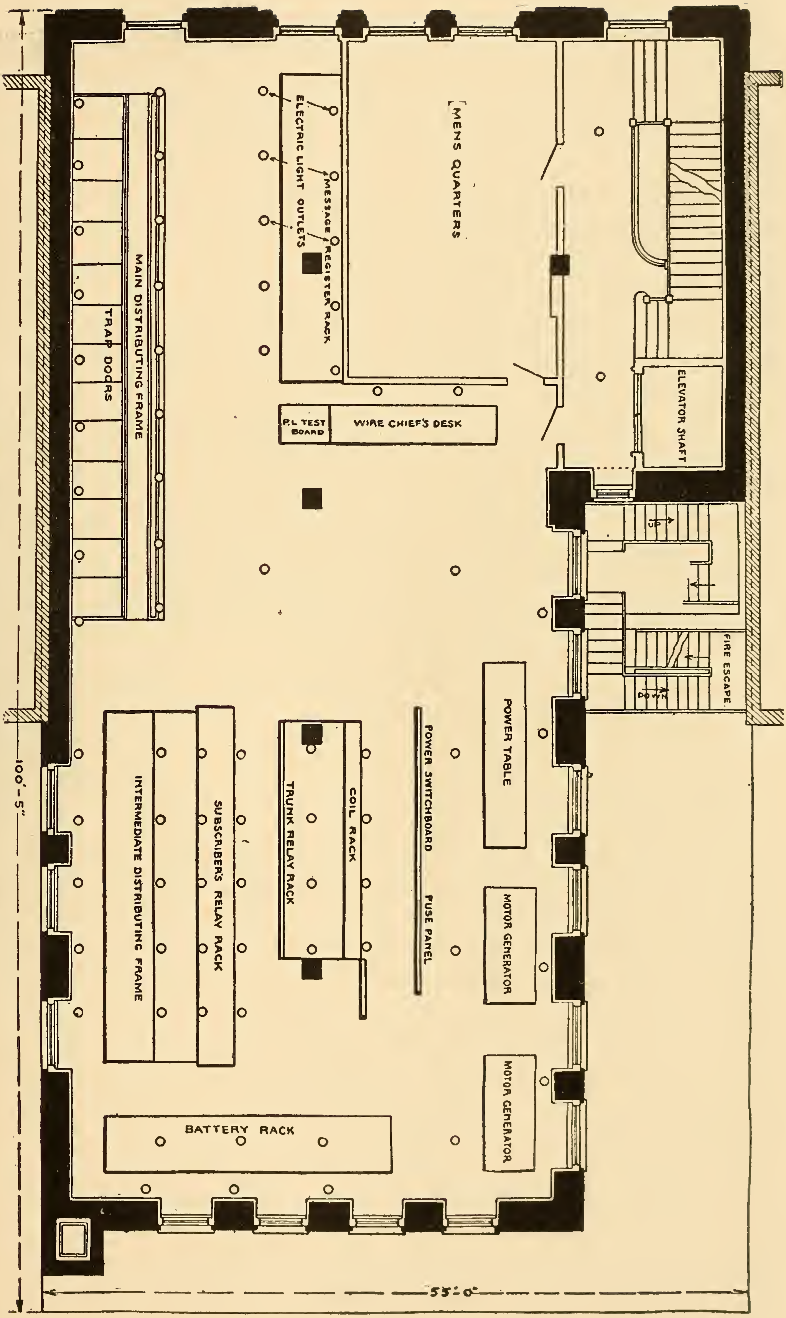

FIG. 489.—PLAN OF SECOND FLOOR—PLAZA OFFICE.

some will be bent on a short radius and some on a long, the nicety of detail in this work will be appreciated. A portion of a detail sheet showing the manner in which these cable plans are made is given in Fig. 487, this being taken from a drawing made for actual practice.

As already stated the various problems relating to the lay-out of a large telephone central office equipment must be solved with regard to the conditions of each individual case. As it is impossible to discuss in the space available all of the factors in such a problem, this chapter will conclude with a brief description of two modern central office equipments which are thought to represent present good engineering practice.

In Fig. 488 is shown a view of the Plaza central office building of the New York Telephone Company, this office having been put into commission about two years ago. This view, while showing the general appearance of the building, shows also much of its interior arrangement by virtue of portions of the wall being cut away.

A plan view of the second floor of this building is shown in Fig. 489. This floor is devoted entirely to the distributing frames, the relay racks and the power plant.

Fig. 490 shows a plan of the fourth floor, which is devoted entirely to the operating room containing both the subscribers' and trunking sections.

Fig. 491 shows a plan of the third floor, which is devoted to the operators' quarters and offices.

Referring to Fig. 488, the underground cables may be seen in the lower right hand corner of the picture, these entering the basement of the building from the subways. These cables are each led into the building and up to the second floor through an individual iron duct, thus doing away with the ordinary cable shaft for leading these cables from the cable vault to the terminal room. At about the floor line of the second floor the underground cables are connected, by means of pot-heads, to rubber covered cables leading to the distributing board. These pot-head joints are concealed under a false floor in that portion of the room.

The doing away with the open cable shaft and substituting therefor the individual iron ducts is a great advantage from the standpoint of fire hazard, and also is advantageous from a mechanical standpoint, there being much less liability to damage the cables than there is with the use of an open cable shaft with its numerous cable clamps. These iron ducts are built into the wall of the building

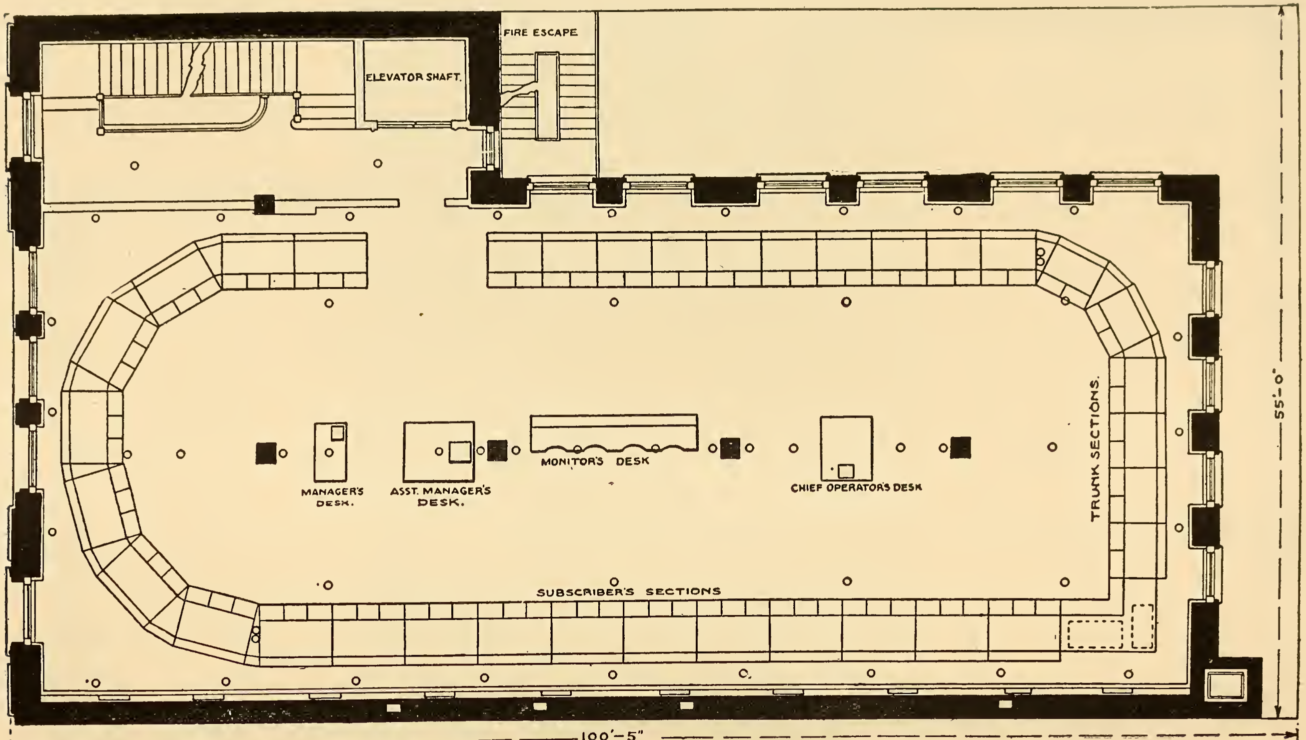

FIG. 490.—PLAN OF FOURTH FLOOR—PLAZA OFFICE.

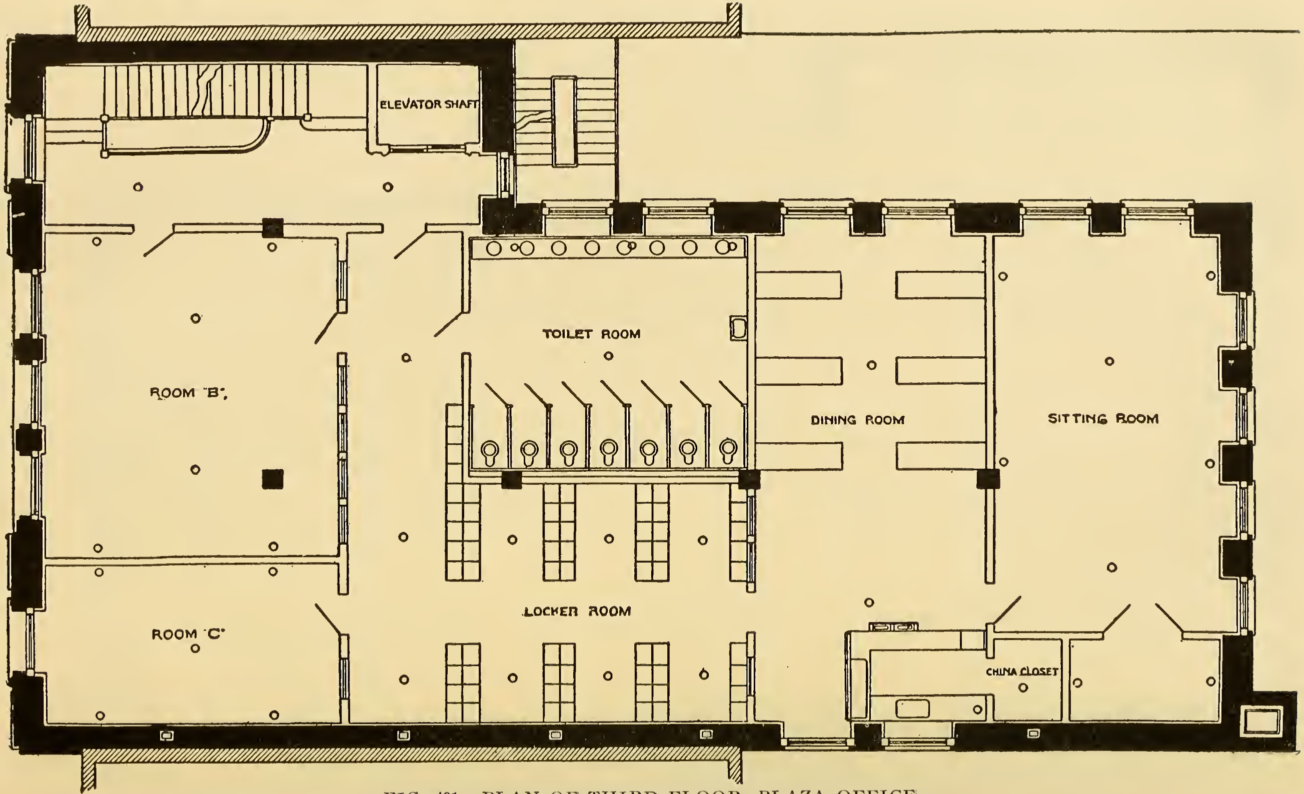

FIG. 491.—PLAN OF THIRD FLOOR—PLAZA OFFICE.

thus reducing still more the fire risk. In order to prevent the empty ducts from forming flues in case of fire, all unused ducts are plugged at both ends.

The main distributing frame cannot be seen in Fig. 488, as it is behind the stairways in that figure. Its position, however, is well shown in the plan of 489. As will be seen from this floor plan the intermediate distributing frame is arranged at the end of the main frame; and the relay rack for the subscribers' lines runs alongside of the intermediate frame. The trunk relay and repeating coil rack

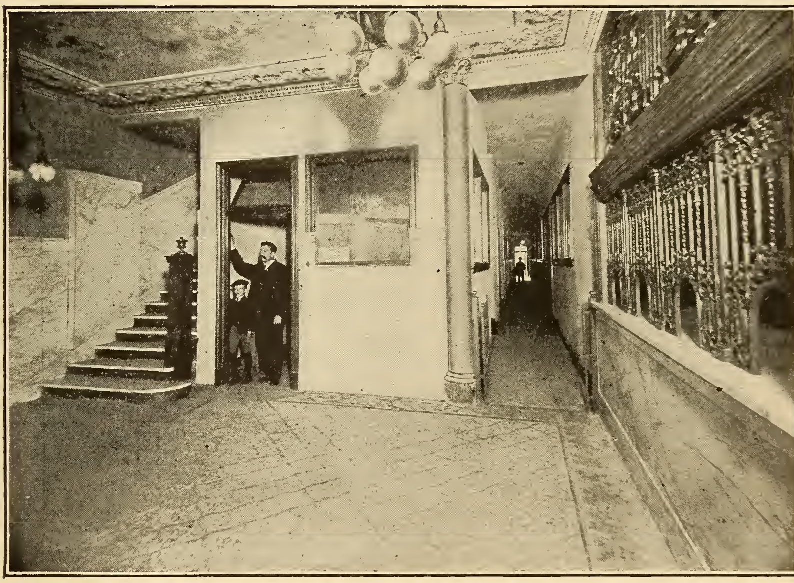

FIG. 492.—FOYER-HOME TELEPHONE COMPANY, LOS ANGELES, CAL.

are mounted in parallel lines with the subscribers' relay rack and intermediate frame. In a separate rack extending in a line parallel with the main distributing frame are mounted the service meters, these being used to a large extent in this exchange to determine the proper charge to the subscribers for service.

The power plant, consisting of the power board, battery, two charging motor generators and three ringing machines, are arranged as clearly shown in this view, all of them being in the same room with the various terminal apparatus.

The wire chief's desk is so located in the central portion of the room as to afford from it a comparatively clear view of all parts of the apparatus on this floor.

From the left hand end of the top of the intermediate distributing frame extends a cable shaft leading to the fourth floor or operating room. This runs up in the rear corner of the building, and is best shown in the plan view of the third floor in Fig. 491, where it may be seen between the operators' china closet and the chimney. All cables leading to the switch-board pass up through this shaft to the third floor, where they enter the turning sections, respectively, of

FIG. 493.—CABLE VAULT—LOS ANGELES OFFICE.

the subscribers' sections and the trunking sections, these two turning sections being located adjacent to each other at the point where the subscribers' sections and the trunking sections come together at a right angle.

The arrangement of the operating room needs little description, as it is clearly shown in the plan of Fig. 490. The capacity of this switch-board, as provided for in multiple jack space and in the number of sections, is 9,600 lines. As room is provided for only nineteen subscribers' sections, this indicates an average of about 500 lines per section, which would be considered high in a city of the size of New York, save for the fact that this office serves to a great extent a residence district.

The operating room has a hard-wood floor over which rubber tiling is laid, this being advantageous in point of the degree of quiet which it affords, and also in the ease with which it may be kept clean.

In the lay-out of this building it would have been more economical, from the standpoint of first cost, to have devoted the third floor to the operating room, and the fourth floor to the operators' quarters. By making the terminal as close to the ground as possible

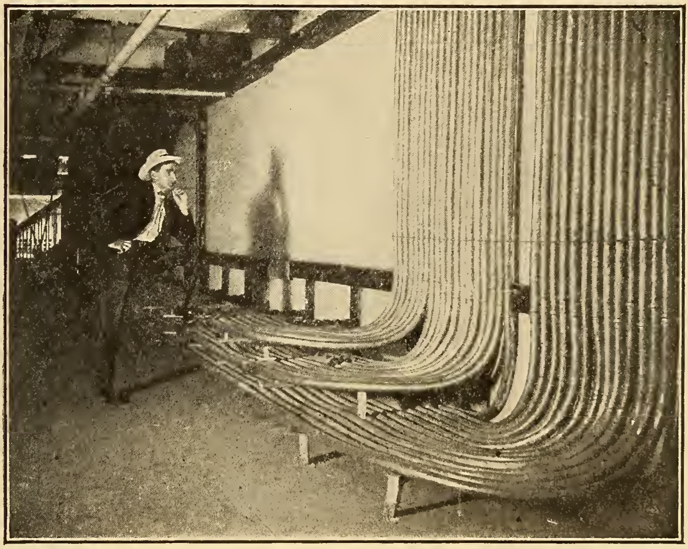

FIG. 494.—ENTRANCE TO CABLE SHAFT—LOS ANGELES OFFICE.

and by placing the main distributing board as nearly in a line above the cable vault as possible, as has been done in this case, much is saved in length, and therefore in the cost of the lead-covered cable leading from the subways to the distributing frame. By placing the operating room on the third floor, so as to be immediately above the terminal room a considerable amount would have been saved in the cables leading from the intermediate frame to the multiples and from the intermediate frame to the answering jacks. This latter advantage, however, was sacrificed, undoubtedly, because of the fact that the top floor of the building was more adaptable

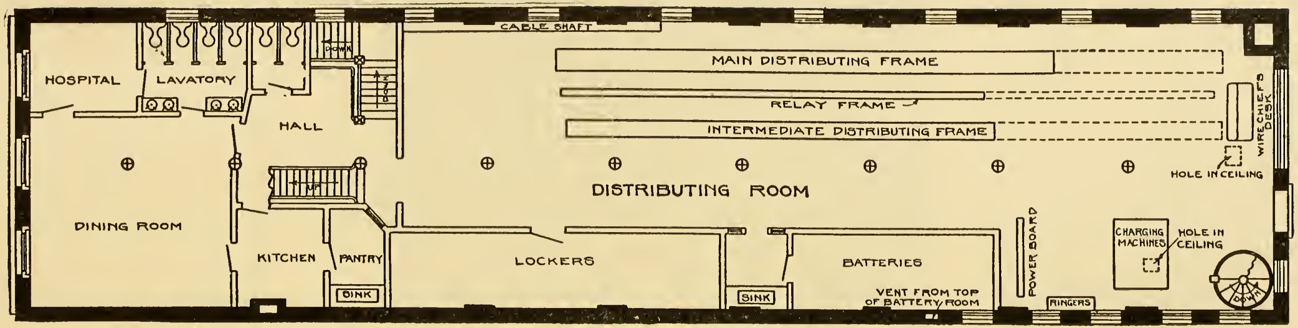

FIG. 495.—FLOOR PLAN TERMINAL AND POWER ROOM—LOS ANGELES OFFICE.

to the purposes of the operating room on account of light, air and a greater degree of quiet.

The floors of this building, as in the other late central office buildings of the New York Telephone Company, are designed to support a maximum load of 200 pounds to the square foot, this being about double that usually provided for in office buildings. The building is as nearly fire-proof as possible, the walls are of smooth finished cement, and instead of the ordinary wood trimming metal window frames and marble surbases are provided.

One of the most complete telephone central office equipments

FIG. 496.—VIEW OF DISTRIBUTING FRAMES AND RELAY RACK—LOS ANGELES OFFICE.

in the Independent field, and one with which the writer happens to be very familiar, is that of the Home Telephone Company, of Los Angeles, California. The plant is unique in that it is believed to be the largest multiple board (present equipment 9,160 lines), in the United States, and that there is but one other board having the same ultimate capacity (18,000 lines). This board and the entire central office equipment was installed by the Kellogg Switch-Board and Supply Company. The building was erected specially for the purpose, and is used by the telephone company exclusively. It is a three-story structure, fire-proof throughout.

The basement of the building contains a large room for storage besides the usual heating and ventilating apparatus and other equipment found in a modern building of this size. The first floor is devoted entirely to the general offices and reception rooms of the company, and nothing has been spared to enhance its architectural beauty.

In Fig. 492 is shown a view of the foyer on the main floor, showing the windows leading to the cashier's office on the right hand, and the main stairway on the second floor to the left. In one

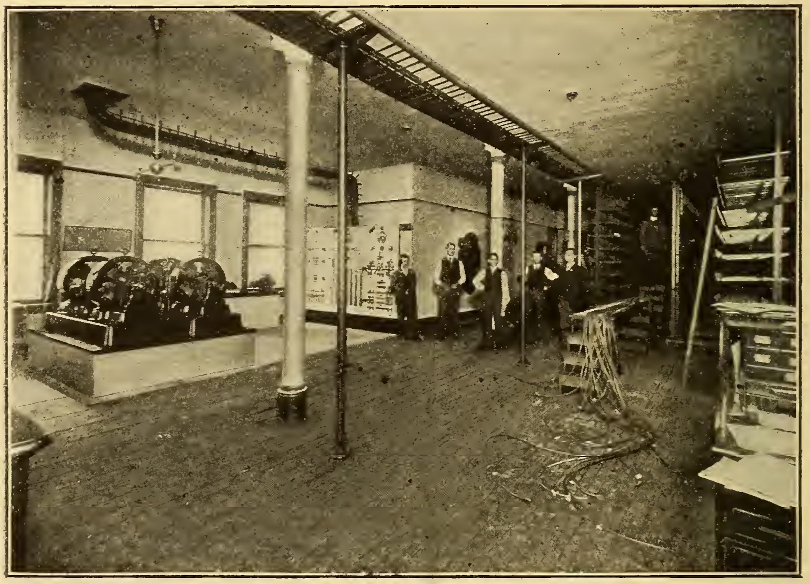

FIG. 497.—GENERAL VIEW OF TERMINAL AND POWER ROOM—LOS ANGELES OFFICE.

corner of this room is placed a row of long-distance booths serving as a public long-distance station.

In Fig. 493 is shown the cable vault by means of which all the underground cables enter the exchange. This picture was taken before all the cables were drawn in. This vault is under the sidewalk in front of the building, and communicates directly with the main cable run leading to the second floor.

Fig. 494 shows a view of the cable run at a point where the cables turn from a horizontal to a vertical direction, after which they extend through a narrow cable shaft to the second floor, this shaft being approximately 20 feet long by 8 inches wide. There were at the time this view was taken thirty-two 300-pair cables in this run, thus giving a cable capacity of 9,600 lines.

The floor plan of the terminal room is shown in Fig. 495, and from this it will be seen that the main distributing frame and relay rack and the intermediate frame are mounted side by side in accordance with the method of construction already referred to. The main frame occupies a position alongside of the cable shaft, and the line cables, after being terminated in pot-heads, are extended to

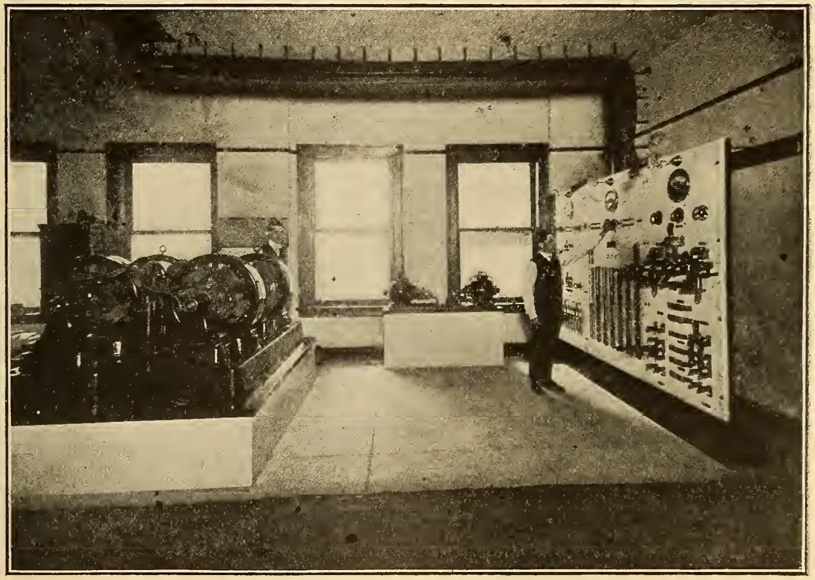

FIG. 498.—POWER PLANT—LOS ANGELES OFFICE.

the various line terminals of the main frame. The lead-covered cables leading up through the shaft are bent around a quarter-round grooved beam at the level of the terminal room floor. This supports the cables in the shaft, and from this support the cables extend in a horizontal direction to the main distributing frame terminals.

A good idea of the arrangement of the frames may be had from Fig. 496, the main frame being on the left, the intermediate frame on the right and the relay rack in the middle.

This view is taken from the front end of the building looking toward the rear.

In Fig. 497, the opposite ends of the distributing and relay frames are shown, this view also showing a general view of the power plant and power switch-board. In the center of this view, supported by iron posts, is shown a cable run leading from the end of the intermediate distributing frame, by means of which a part of the intermediate to answering jack cables are taken to the switch-board, all answering jack cables, from the 1st to the 17th section, being fed through the main cable run at the other end of the intermediate frame while those for sections beyond the 17th are fed through this cable run. By this means a saving in cable was made possible.

In the rear left hand portion of this view (Fig. 497) is also shown

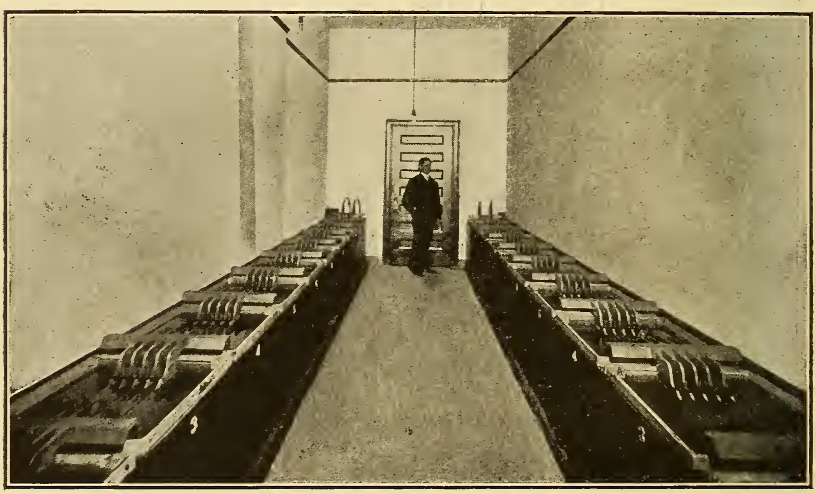

FIG. 499.—BATTERY ROOM—LOS ANGELES OFFICE.

a cable run leading from the power switch-board and fuse-board to the floor above and through this run is fed all power and battery wires to the switchboard.

In Fig. 498 is given a general view of the power plant. All wiring between the machines and the power board is in ducts imbedded in the cement floor. The machines, both charging and ringing, are of the Holtzer-Cabot type.

In Fig. 499 is shown the battery room, this containing two batteries of ten cells each of chloride accumulators, each cell having eleven plates. Sufficient capacity is provided in the tanks for adding plates enough to supply the future growth of the switch-board up to its ultimate capacity.

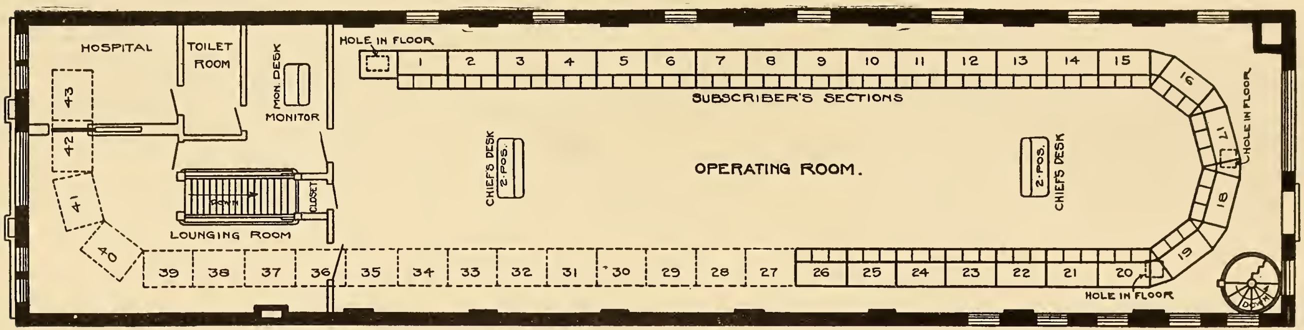

FIG. 500.—FLOOR PLAN OPERATING ROOM—LOS ANGELES OFFICE.

FIG. 501.—GENERAL VIEW OF OPERATING ROOM—LOS ANGELES OFFICE.

In Fig. 500 is shown a plan of the operating room. The turning section at the end of the first section is placed over an opening in the floor, through which passes a cable run leading from the intermediate distributing frame below. The present arrangement of the switch-board is in accordance with ordinary practice, except that on account of the narrowness of the room it was necessary to make a slightly shorter turn than is usually the case. The turn was made on four sections instead of five, there being 36° angles between the sections on the turn, instead of 30°, as is usual.

This switch-board is arranged with a trough plug shelf. The

FIG. 502.—LOCKER ROOM—LOS ANGELES OFFICE.

front of the key shelf is of the ordinary height, thus allowing sufficient knee-room for the operators, but the key-shelves slope downwardly toward the rear, so that the plug shelves are about 3 inches below the level of the front of the key-shelves. In this way the jack space is made to extend lower than would be the case were the flat key and plug-shelf used, and a greater multiple jack space is thereby attained. A general view of the operating room is shown in Fig. 501, this view having been taken before the work of installation was fully finished.

In Fig. 502 is shown a view of the operators' locker room. There is nothing particularly instructive about this view, except that it illustrates the modern practice of using lockers composed entirelv of iron lattice for the operators' clothes and effects. By this construction the lockers are made much more hygienic, always being properly ventilated. On account of the open construction of the lockers, inspection of their contents is also facilitated.

CHAPTER XXXV.

AUTOMATIC SWITCH-BOARD SYSTEMS.

In an early edition of this work this statement is made concerning the subject of automatic telephone switch-boards: "It is with the idea of following briefly, though not completely, the growth of an interesting phase of telephone work, rather than of attempting to chronicle any really practical developments, or of giving any hopes of its future practicability that this chapter is written." During the last few years, and particularly within the years 1903 and 1904, conditions have greatly changed, and the automatic switch-board, or more particularly the so-called automatic exchange, has come into such prominence through the efforts of its developers and promoters as to make it appear a decidedly important factor at the present date, and one that will be of increasing importance in the future.

The main idea of the automatic system is to dispense with the central office operator, switches being so arranged at the central office that they will, without the aid of human hands, perform the necessary acts of connecting lines for conversation, and afterwards disconnecting them at the will of the subscribers. The central office switches are governed in their movements by the actions of the subscribers or users who desire connections and subsequent disconnections; the subscriber doing his own work, manipulating the apparatus before him in such a way as to cause the switches at the central office to select, connect with, and afterwards disconnect from, the line of the subscriber desired.

As early as 1879, Messrs. Connelly & McTighe, of Washington, D. C., conceived the broad idea of having machines perform the entire work of switching lines; and they worked out a set of apparatus for the purpose that, while somewhat crude in design, nevertheless embodied the generic principle of modern automatic systems. Connelly & McTighe's system consisted essentially of a line leading from each subscriber's station to the central office, and provided at the sub-station end with a switch whereby it could be connected to a make and break impulse-sending device, or to the telephone set. With his switch turned to connect his make and break device with the line, the subscriber would cause current impulses to affect the magnets belonging to his line at the central office and thereby control the step by step devices which would continue his line into connection with any other line in the exchange.

Connelly & McTighe's patent, No. 222,458, was granted December 9, 1879, and is well worth reading by those interested in this first of all automatic systems.

It will be obvious, even from a casual inspection of the figures of the Connelly & McTighe patent, that a limit would soon be reached in the number of subscribers who could conveniently be handled by the machines described; and a little thought will show that the difficulties caused by the ever-increasing number of subscribers, even in the development of the manually operated switch-board, will be much sooner reached and apparently harder to overcome when dealing with the problem of automatic switching.

Some years after Connelly & McTighe devised their first system, Almon B. Strowger made a number of inventions which were probably the first steps toward a practical realization of the ideas advanced by Connelly & McTighe. The most important operation in all of Strowger's work was that of simplifying the contacts for the different line wires, and arranging them on plain or curved surfaces so that the selecting arm or point under the control of the stepping magnets, operated by the subscriber, would, instead of making a continuous forward progress from the beginning to the end of the whole series of contacts, be moved relatively to said contacts in one direction to select a given *series* of contacts from among a number of such series, and then in a given direction at right angles to the first, to select the particular *one* of the series that might be desired. In an early embodiment of this idea by Strowger, a glass cylinder was employed, having embedded in it a number of rows of contacts, each contact connected to its own line wire and all adapted to be swept over by a contact arm on the inside of the cylinder. The shaft on which the contact arm was mounted had a vertical movement within the cylinder, so that the arm might be brought into line with any required circular row of terminals. Such movement was imparted to the shaft by a magnet operating a pawl, engaging a ratchet in such manner as to step the shaft in the direction of its length. Beside the longitudinal motion of the shaft, a rotary motion was made possible, this being controlled by a pawl, engaging the ratchet wheel, the pawl being adapted to receive successive movements imparted to it by another electromagnet, and thus cause the ratchet wheel with its shaft and contact arm to rotate in its bearings, thus causing the contact arm to pick out any one contact of the series opposite which it had been brought by the action of the first mentioned pawl.

This system was of value only in that it contributed an apparently important idea to the art, the idea of moving the selecting point first in a longitudinal and then in a rotary direction. The defects of the system are obvious and great. A very heavy battery, strong enough to operate the central office switches over the lines, was required at each subscriber's station, and moreover, not less than five wires were necessary from each sub-station to the central office. Like the Connelly & McTighe patent, this early Strowger patent is interesting, if only from an historical standpoint. It was granted March 10, 1891, its number being 447,918.

In 1894 a system was produced by Messrs. Keith, Lundquist, J. and C. J. Ericson, which was tried in commercial use, and although abandoned, served as an impetus to further effort on the part of the same gentlemen. In this a series of wires were tightly stretched on a rack, parallel to each other, there being one such wire for each line going into the office. Each telephone line also had a mechanism consisting of a shaft carrying contact arms or "wipers," the shaft being adapted to be moved in a longitudinal direction, and also to be given a rotary movement in a manner not unlike that employed by Strowger in his work. A common battery was used at the central office to supply the energy needed for the switch-moving magnets, current from this battery flowing over the lines to the subscribers' stations in response to the closure of the switches at these stations. The number of wires was reduced from five to two, the rotary movement of the shaft being imparted by a magnet adapted to respond to currents in one of the line wires with ground return; and the vertical movement being similarly imparted by a magnet responding to currents in the other wire with ground return.

The parallel wires at the central office were divided into groups of ten, and each shaft had as many arms as there were groups of ten wires, the arms being differently set on the shaft with respect to their angular placement, so that but one arm at a time could engage any of the wires.

Four keys were placed on each subscriber's instrument marked "H" (hundreds), "T" (tens), "U" (units), and "R" (release). If a subscriber desired to call No. 143, he would press the hundreds key once, the tens key four times, and the units key three times, which would bring one of the contact arms on the shaft into engagement with one of the parallel wires forming the terminals of line No. 143. This system was apparently adapted to serve one hundred lines only, as a maximum.

In the present Strowger system, as it is now manufactured by the Automatic Electric Company, of Chicago, the parallel wire method of switching has been abandoned; but the switches having both longitudinal and rotary motions have been retained, this idea forming the basis of the entire system. The idea of trying to make the switch contacts of any line play over a large number of the contacts, in order that the selecting contacts of any line may be brought directly into contact with the stationary contacts of the line wanted, has also been abandoned, and in its stead a system of trunking has been brought into play. By this means what are called primary switches, or first selectors, and secondary switches, termed "second selectors" and "connectors," are used, and through their action the connection between any two lines is built up, a section at a time, rather than by a single connecting link, as was the idea of all the early inventors.

In order to understand the system as it is at present installed in a number of large offices, it may be said that each line terminates in a switch known as a first selector, the circuit of the line passing through certain magnets of this switch and terminating under certain conditions in the selecting contact points or wipers of this switch. Mounted upon the framework of the switch and within range of the wipers, are what are called "banks of contacts," there being 100 sets of the contacts for each bank, the contacts being arranged in ten rows of ten each. The construction of the switch is such that for each step in the longitudinal direction of the shaft, which is vertical, the wipers in which the line wires terminate, are brought opposite a different horizontal row of bank contacts, and after the shaft is brought to the required height, that is, opposite the required row of bank contacts, it may be given by another magnet a rotary movement which causes the wipers to engage any particular contact in that row.

Assuming that the exchange is adapted to accommodate 10,000 lines, or more properly, is adapted to accommodate lines numbered up to 9999, each row, or "level," as it is sometimes termed, in the bank contacts of the first selector switch, will represent trunk lines leading to a group of second selectors for a particular thousand. That is, the bank contacts in the first row or level of the first selector, will be connected by trunks to second selectors adapted to extend connections to subscribers having numbers beginning with 1000. The second row of bank contacts will be connected by trunks to second selectors adapted to continue the connections to lines bearing numbers in the two thousands, and so on. In order not to unduly multiply the number of trunks thus leading from the first to the second selectors, the first selectors are divided into groups, in later exchanges of a thousand each, and all of the corresponding bank contacts of the first selectors in this group are multipled together after the manner of multipling spring jacks in a multiple switch-board. For the present understanding it is sufficient to say, therefore, that the first contact in the first row of all the first selectors in a given thousand, are connected together, and to a trunk line, this trunk line terminating in a second selector in practically the same manner as does a subscriber's line in a first selector. As there are contacts for 100 trunk lines on each first selector, it follows, therefore, that there are, for each thousand first selectors, 100 trunk lines leading to 100 second selectors. These 100 second selectors belonging to any group of 1000 first selectors, are divided into 10 groups of 10, it being remembered that the trunk lines leading from the bottom row of contacts on the first selectors are ten in number, and leading to ten second selectors in the first thousand. There are, therefore, for each thousand first selectors, 10 groups of 10 second selectors, each group of second selectors corresponding to a given row or level of contacts on the first selectors, and each representing a possible connection from any one of its group of first selectors to any wanted line in a particular thousand.

The action of the first selector with respect to the trunks of the second selectors is this: A series of impulses sent over one side of the subscriber's line and ground causes the shaft of the first selector to move up a step at a time until it gets opposite the row of contacts containing trunk terminals of the proper thousand in which the called-for subscriber's number exists. The switch arm is then given a rotary motion until it picks out a trunk line leading to a certain selector in that thousand that is not busy. It is obvious since the bank contacts of the first selectors are multipled, that unless special arrangements are made to guard against it, the wipers on different first selectors might stop on the same trunk in the same manner as, without a busy test, two operators in a manual system might plug into different multiple jacks of the same line at the same time. This difficulty is met by so arranging the circuits

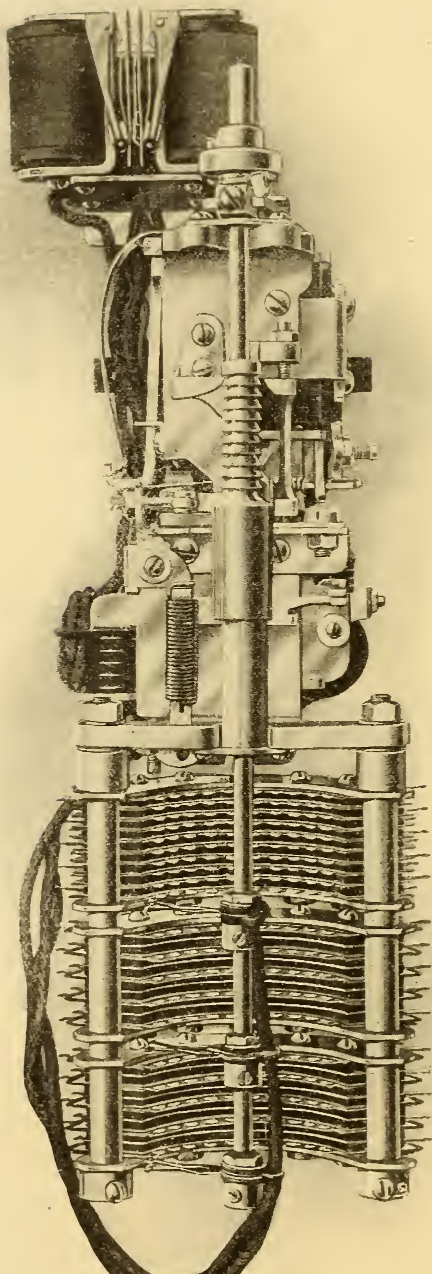

FIG. 503.—SELECTOR SWITCH, FRONT VIEW.

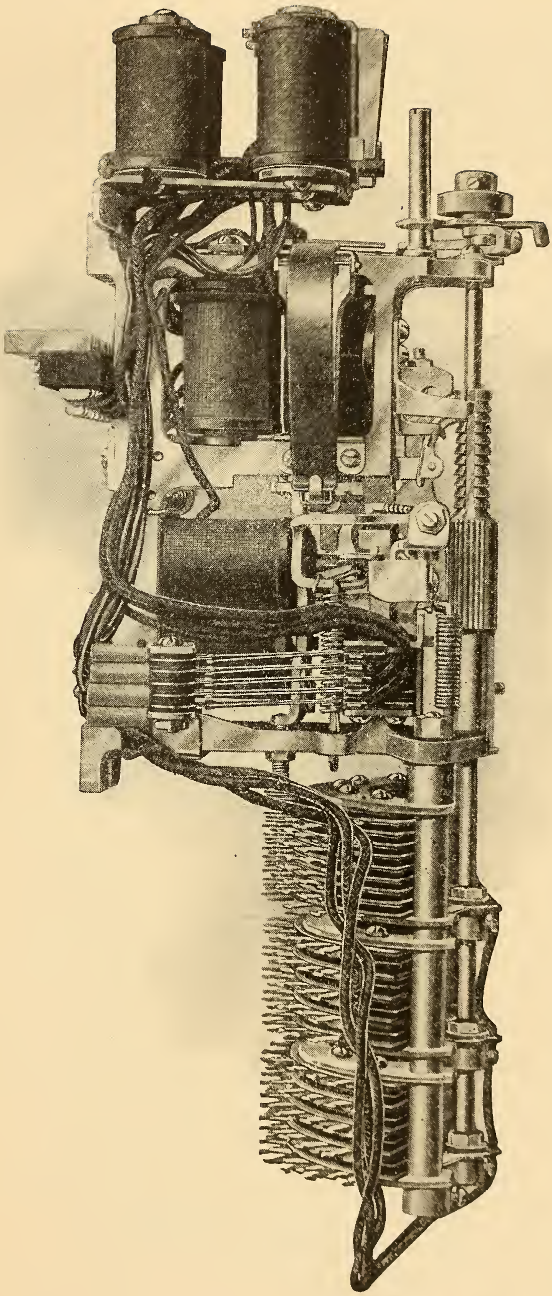

FIG. 504.—SELECTOR SWITCH, SIDE VIEW.

that the rotary movement of the wipers will continue until the wipers engage a trunk line that is not in use.

By this means, that is, by the first series of impulses sent over the subscriber's line in making a call, the line of the subscriber is extended through the first selector to a second selector belonging in that group of a thousand lines in which the called-for subscriber's line terminates.

The next series of impulses that is sent over the subscriber's line operates in a like manner on the second selector, to cause it to pick out a trunk line extending to the connector belonging to the particular group of 100 lines in which the called-for subscriber's line exists. In order to accomplish this, the bank contacts on each group of 10 second selectors are multipled together, and these extend by trunk lines to the wipers of the connectors, the relation between the connectors and the second selectors being the same in this respect as that between the second selectors and the first selectors. The second series of impulses sent by the subscriber, therefore, moves the shaft of the second selector until it is opposite the row of contacts in which terminate the ten trunks leading to the connectors of the particular hundred desired, and after that a rotary impulse is imparted to the shaft of the second selector, which causes it to revolve until an idle trunk contact is engaged; whereupon the connection is continued from the subscriber's line through the first and second selectors to the connector. The connector is a switch that is identified with a particular group of 100 lines. There may be, and usually are, 10 connectors for each 100 lines, and the bank contacts of these connectors are multipled together in the same manner as are the bank contacts on the first and second selectors. Instead, however, of these multiple bank contacts forming the terminals of trunk lines, they are connected directly with the lines of the subscribers in the group of 100 to which the particular ten connectors are assigned. There being 100 sets of bank contacts on each connector, all these being multipled together on the entire group of connectors belonging to that hundred, it follows that each line has one contact in the bank of each of the ten connectors belonging to that group. The second series of impulses sent by the subscriber serves, as has been said, to continue his line to an idle connector within the 100 to which the line of the called-for subscriber belongs.

The third series of impulses sent by the subscriber will merely move the shaft of the connector up until it is opposite the row or level of contacts in which the line of the called-for subscriber belongs.

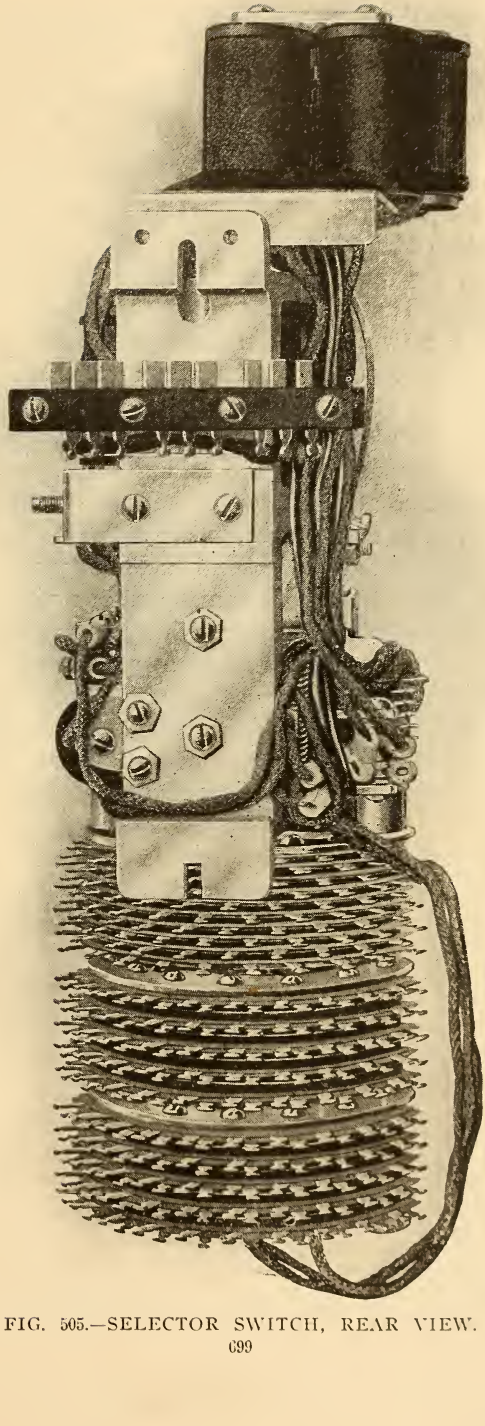

FIG. 505.—SELECTOR SWITCH, REAR VIEW.

The remaining selection, therefore, is only one of ten, and the fourth series of impulses merely gives the wipers of the connector a rotary motion of as many steps as are necessary to bring the wipers into engagement with the bank contact on the connector belonging to the line of the subscriber called for.

The calling subscriber then, by means of pressing the ringing button on his telephone, completes such a circuit condition as to cause the operation of a relay on the connector, which in its action performs exactly the same functions as does the ringing key in a manual exchange. That is, it cuts off the line behind it and establishes connection between the terminals of the calling generator and the line of the subscriber called. If the called subscriber's line were already in use, or busy, the connector would not have connected with it, but would have dropped back to its normal position. Under this circumstance, when the calling subscriber presses his ringing button, immediately afterwards he receives the well-known buzz in his receiver, indicating that the line is busy.

Having now considered the general method by which the connections are established in the automatic exchange, consideration may be given to the details of the switching apparatus, and to the various circuit arrangements by which they are connected and enabled to perform one of the most remarkable series of actions and interactions that has ever been attained by mechanical structures. A good idea of the structure of the first selectors may be obtained from an examination of Figs. 503, 504 and 505. Of these, 503 shows a front view of the switch, the shaft being clearly shown, and on it near its top, the series of notches in which the pawl engages to actuate it in its vertical movements. At the bottom of this figure the bank contacts are shown, these being arranged in three sections. The two lower sections, consisting of five double rows each, carry the talking contacts of this switch. There are 100 pairs of these contacts, the lower five rows of these being adapted to be engaged by the lower pair of wiper contacts on the shaft, and the upper five rows—that is, those in the bank of the section in the middle—being adapted to be engaged by the second pair of wiper contacts on the shaft. These 100 pairs of bank contacts might, so far as their switching function is concerned, be arranged in a single section; but in order that the vertical steps by which the shaft moves might not be too long, or the insulation between the rows of contacts too thin, they are divided into two sections, as shown. The lower pair of wipers is brought into engagement with the lower row of the lower section by the first vertical movement of the shaft. The second vertical movement of the shaft brings the second pair of wipers into engagement with the lower row of the upper section of the line contacts, the lower pair of wipers then occupying a space half way between the first and second rows of the lower section. The third vertical movement brings the lower wipers into engagement with the second row in the lower section, and the fourth vertical movement the second pair of wipers into engagement with the second row of its section. The two lower pairs of wipers on the shaft are connected in multiple, and thus the same result electrically is secured as if the whole 100 pairs of bank contacts were engaged by a single pair of wipers rather than by two pairs. According to this arrangement, the five rows of bank contacts in the lower section form the levels for the first, third, fifth, seventh and ninth thou-

FIG. 506.—BANK CONTACTS.

sand. The rows in the second section form the levels of the second, fourth, sixth, eighth and naught thousand.

So far, no mention has been made of the upper section of bank contacts, and this, it may be stated, is called the "private" or "busy" bank. It consists of ten rows of ten contacts, each adapted to be engaged by the wiper carried by the same shaft as that on which the wipers for completing the talking circuit are carried, and moving in unison therewith. The function of these private or busy contacts will be pointed out when the circuits are considered.

A side view of the switch shown in Fig. 504 gives some idea of the details of what is termed the "side switch." This is composed of five springs shown just below the lower magnet in this cut. Fig. 505 shows the rear view of the switch, the terminals of the bank contacts being clearly shown denuded of multiple wiring.

In Fig. 506 is shown the method of building up the banks of contacts, a complete bank being shown in one view of this figure, and a single row of multiple contacts in the other. The contacts in these banks are clamped between layers of fibre, and bolted together as shown, in a way that is at once ingenious, reliable in point of permanency, accuracy and insulation, and, moreover, not unduly expensive to construct.

The telephone or subscribers' equipment is shown in Fig. 507.

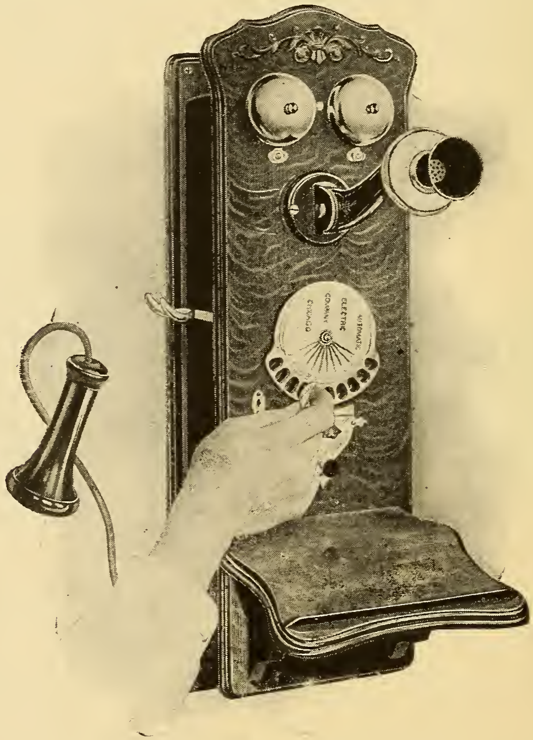

FIG. 507.—AUTOMATIC TELEPHONE.

The only part of this that is of special interest is the impulse transmitting device, of which a front view is shown in Fig. 508, a rear view in Fig. 509, and a side view in Fig. 510. The dial, shown most clearly in Fig. 508, is mounted on the front of the telephone box, as shown in Fig. 507. It has in it a series of ten holes, into which the forefinger of the subscriber is adapted to fit. In order to send the proper impulses to the central office to secure a connection with a line of any desired number, the finger of the subscriber desiring the connection is first placed in the hole corresponding to the first digit in that number, and the dial is pulled

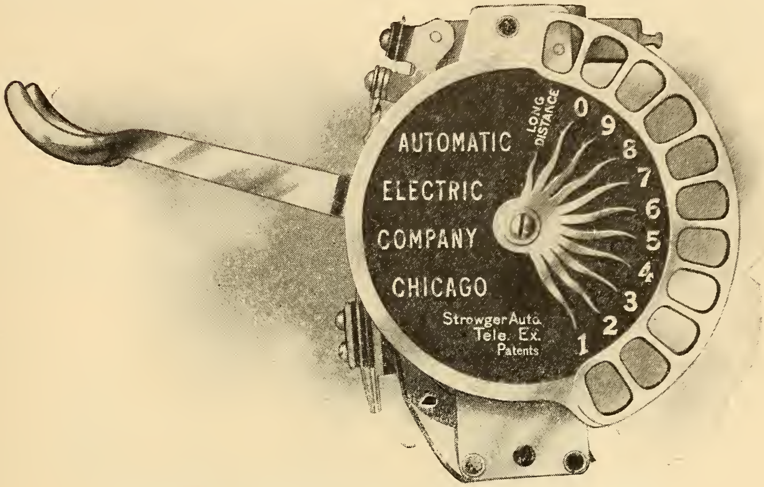

FIG. 508.—TRANSMITTING DEVICE, FRONT VIEW.

around, as shown in Fig. 507, until the finger strikes a stop mounted on the front of the telephone box, as is clearly shown. The dial is

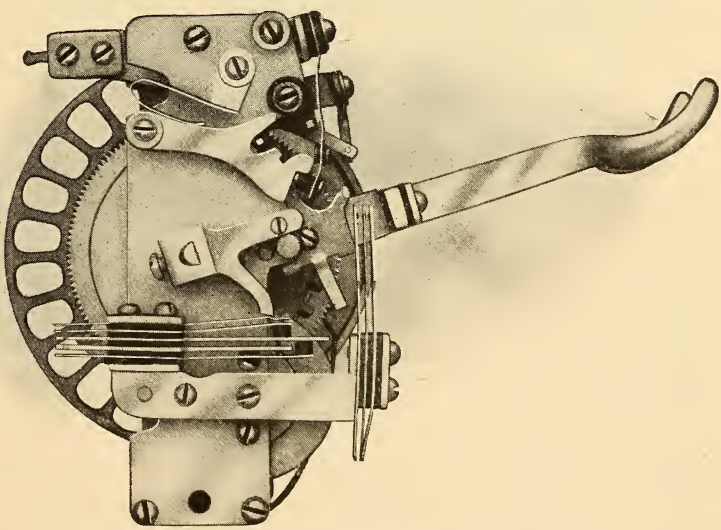

FIG. 509.—TRANSMITTING DEVICE, REAR VIEW.

then released and returned to its normal position by a retractile spring, and in so doing the notched wheel within the box causes a pair of springs to make a series of contacts, serving to impart a vertical movement to the first selector of the subscriber calling. The operation is then repeated for the second, third and fourth digits in the number, the second movement of the dial imparting to the second selector the required vertical motion, the third doing the same for the connector, and the fourth serving to rotate the arm of the connector into engagement with the line wanted, as already described.

The circuit and some of the mechanisms of the subscriber's instrument diagrammatically arranged are shown in Fig. 511. This is typical of the latest desk-stand telephone of the Automatic Elec-

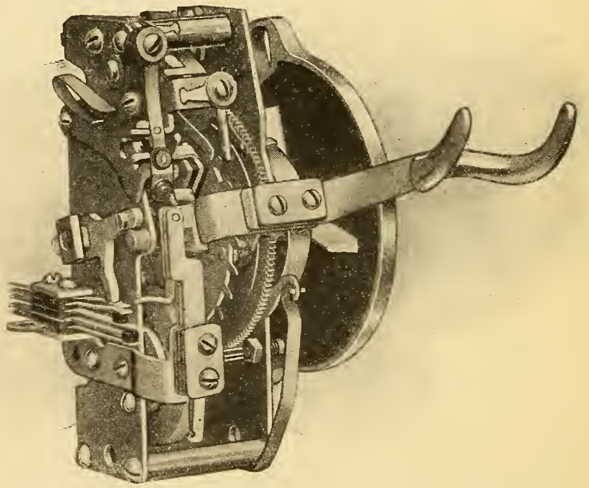

FIG. 510.—TRANSMITTING DEVICE, SIDE VIEW.

tric Company, this being somewhat more simple than is the wall set, although its electrical functions are identical therewith.

The two sides of the line which, in manual practice, are designated by such terms as "tip" and "sleeve," or "tip" and "ring," are, in automatic practice, designated as "vertical" and "rotary." These names are given the limbs of the line because over the vertical side of the line are sent those impulses which impart to the switch its vertical motion, and over the rotary side of the line single impulses are sent, as a result of which the various switches are started in their rotary movements. The letters, "V" and "R," will be used throughout this discussion as designating the vertical and rotary sides of the line, respectively, or such extensions thereof as may be brought about at the central office as a result of the movements of the switches.

The two limbs, *V* and *R*, are shown in Fig. 511, and in all positions of the switching mechanism these lead directly to the two

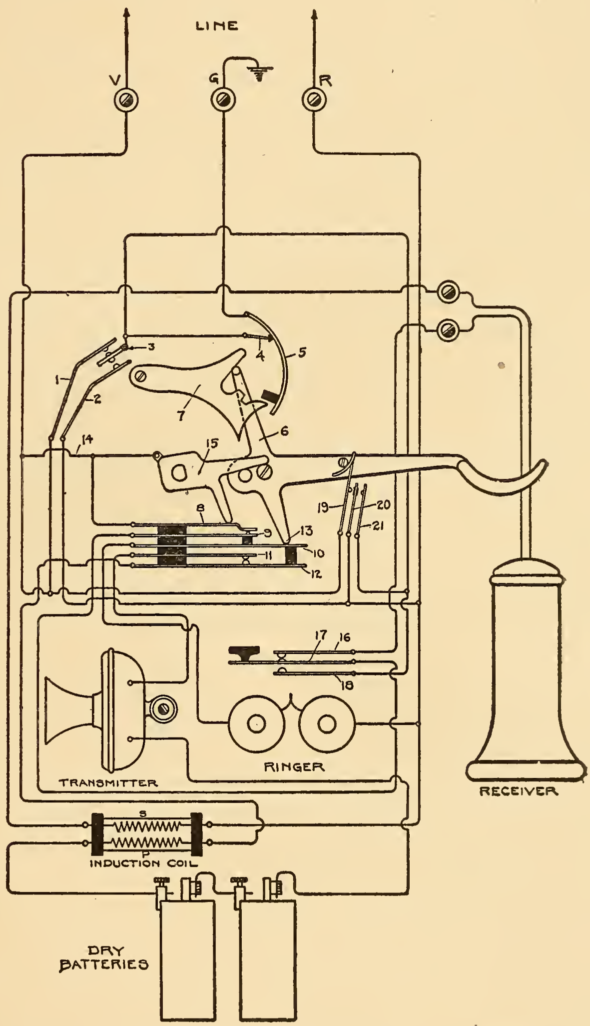

FIG. 511.—CIRCUITS OF SUBSCRIBER'S INSTRUMENT.

impulse-sending springs, 1 and 2. These two springs are so moved by the dial of the impulse transmitter, the action of which has already been explained, that upon the return movement of the dial the spring, 1, makes as many contacts with the ground spring, 3, as will correspond to the digit in the number of the called subscriber which is at that time being selected. Immediately after this series of impulses, which result in the flow of current over the vertical side of the line, a single contact is made at the end of the return movement of the dial by forcing the spring, 2, into engagement with the ground spring, 3, this resulting in a single impulse over the rotary side of the line. To make this clear, if the number of the called subscriber is 5692 the subscriber would first, after removing his receiver from the hook, put his finger in the hole marked 5 (as shown in Fig. 507) and pull the dial down to the stop. Upon releasing the dial five impulses of current would flow over the vertical side of the line, followed by one over the rotary side. He would then repeat the motion, using the holes 6, 9 and 2, respectively, in the order mentioned, the corresponding number of impulses being sent over the vertical side of the line upon the return of the dial in each case, each series of vertical impulses being followed by a single rotary impulse.

This succession of vertical and rotary impulses must be firmly rooted in one's mind before a proper understanding may be had of the automatic system, as at present developed. It must be borne in mind that no series of vertical impulses may be sent without being immediately followed by one rotary impulse, and one only.

Returning now to consideration of Fig. 511, it will be noted that there is a pair of contacts, 4 and 5, controlling the circuit from the spring, 3, to ground. This pair of contacts is normally open by virtue of spring, 5, being held out of engagement with the contact, 4, by the upwardly extending arm, 6, on the hook. When the hook is raised the spring, 5, is prevented from making engagement with its contact, 4, by the presence of the dog, 7, which lies within the path of an insulated bushing on the spring, 5. This dog, 7, is moved out of engagement with this bushing as soon as the dial is moved off its normal position. It is, therefore, not until the hook has been raised and the dial started that any ground connection is secured at the subscriber's station. It may be also said in connection with the dog, 7, that it serves as a lock for the dial, preventing any movement of the dial until the hook has been relieved from the weight of the receiver.

When the hook is down the circuit through the magneto bell of the station is completed from the rotary side of the line through the bell magnets to the spring, 10, thence through the contact, 13, on the hook and the wire, 14, to the vertical side of the line. This circuit is broken in an obvious manner when the hook is raised. The primary circuit containing the transmitter, battery and primary winding of the induction coil, is closed in the ordinary manner when the hook is raised at the contacts, 11 and 12. The secondary circuit, including the receiver and secondary winding of the induction coil, is closed when the hook is up by the engagement of the springs, 8 and 9, but this circuit is opened by the movement of the dog, 15, which is mounted on the shaft of the dial and turns therewith; the arrangement being such that as long as the dial is "off normal" the arm of the dog, 15, will not press the spring, 8, into engagement with the spring, 9. This is to secure the disconnection of the two sides of the line during the transmission of the impulses as described, and this arrangement is necessary to prevent impulses from being sent over both sides of the line at once when the springs, 1 and 2, are in action.

The circuit over which voice currents pass when the hook is up and the dial not in motion is traced from the rotary side of the line through the secondary of the induction coil and the receiver to the spring, 16, of the ringing key, thence through the spring, 17, of this key to the springs, 9 and 8, of the hook, the latter spring being connected to the vertical side of the line.

When the ringing key is pressed the spring, 17, engages the spring, 18, thus breaking the talking circuit and grounding the vertical side of the line.

The springs, 19, 20 and 21, are so disposed with relation to the hook lever that they will not be forced into engagement by the upward motion of the hook, but will be brought into engagement momentarily while the hook is being depressed. These springs are normally out of engagement with each other in either position of the hook, their only time of engagement being while the hook is returning to its normal position. When they are caused to thus engage each other it is obvious that both the vertical and rotary sides of the line will be grounded, if the contact at 4 and 5 has been previously closed by the movement of the dial. This condition is that which causes the restoration of all the switches at the central office, which are connected with this line at the time, to their normal position.

If the salient points in the operation of the subscriber's mechanism be borne firmly in mind an understanding of the very complex sequence of events at the central office will be made easier. A recapitulation of these points is as follows: *Each movement of the dial causes a series of impulses to flow over the vertical wire, followed in each case by a single impulse over the rotary; each pressure on the ringing key opens the talking circuit at the subscriber's station and grounds the vertical side of the line; each depression of the hook after the dial has been moved causes both the vertical and rotary sides of the line to be grounded for clearing out purposes.*

Passing now to the central office, the circuits of the first selector are shown in some detail in Fig. 512. In this the two wires, *V* and *R*, leading from the subscriber's station just described, and shown in Fig. 511, may be seen entering at the left. These terminate in the first and second levers of the side switch, these levers being numbered for the purpose of easy description from 1 to 5 as shown. It must be remembered that all of the levers of the side switch move in unison; that their normal position is on the left-hand contacts as shown in the various figures; and that their position during conversation is that in which they engage the right-hand contacts, this being the position in which they are shown in Fig. 512. It must further be remembered that *the side switch levers are controlled in their movements by the action of the private magnet, P M.* This method of control is peculiar: a spring tends to hold the side switch in its right-hand position; it is normally held, however, in its left-hand position by an escapement mechanism on a lever controlled by the private magnet. When the private magnet is energized and de-energized once, the escapement allows the side-switch arms to move one step, thus engaging their middle contacts. A subsequent attraction and release of the private magnet armature will result in the release of the side-switch levers one more step, thus bringing them into engagement with their right-hand contacts. The arrangement by which this action of the side switch is brought about is partially shown pictorially in the diagram in connection with the private magnet, *P. M.* The forwardly projecting arm on the armature of this magnet is notched as shown, and these notches serve to retain an arm, 22, of triangular cross section, rigidly attached to the side-switch levers. When the armature of the private magnet is attracted the arm, 22, tends to move toward the left, but is held by a notch in the spring lying just under this arm, and is only released therefrom when the private magnet armature is released. The arm, 22, is then engaged by the second notch on the private magnet armature, the side switch then being in its middle position. The subsequent attraction and release of the private magnet arma-

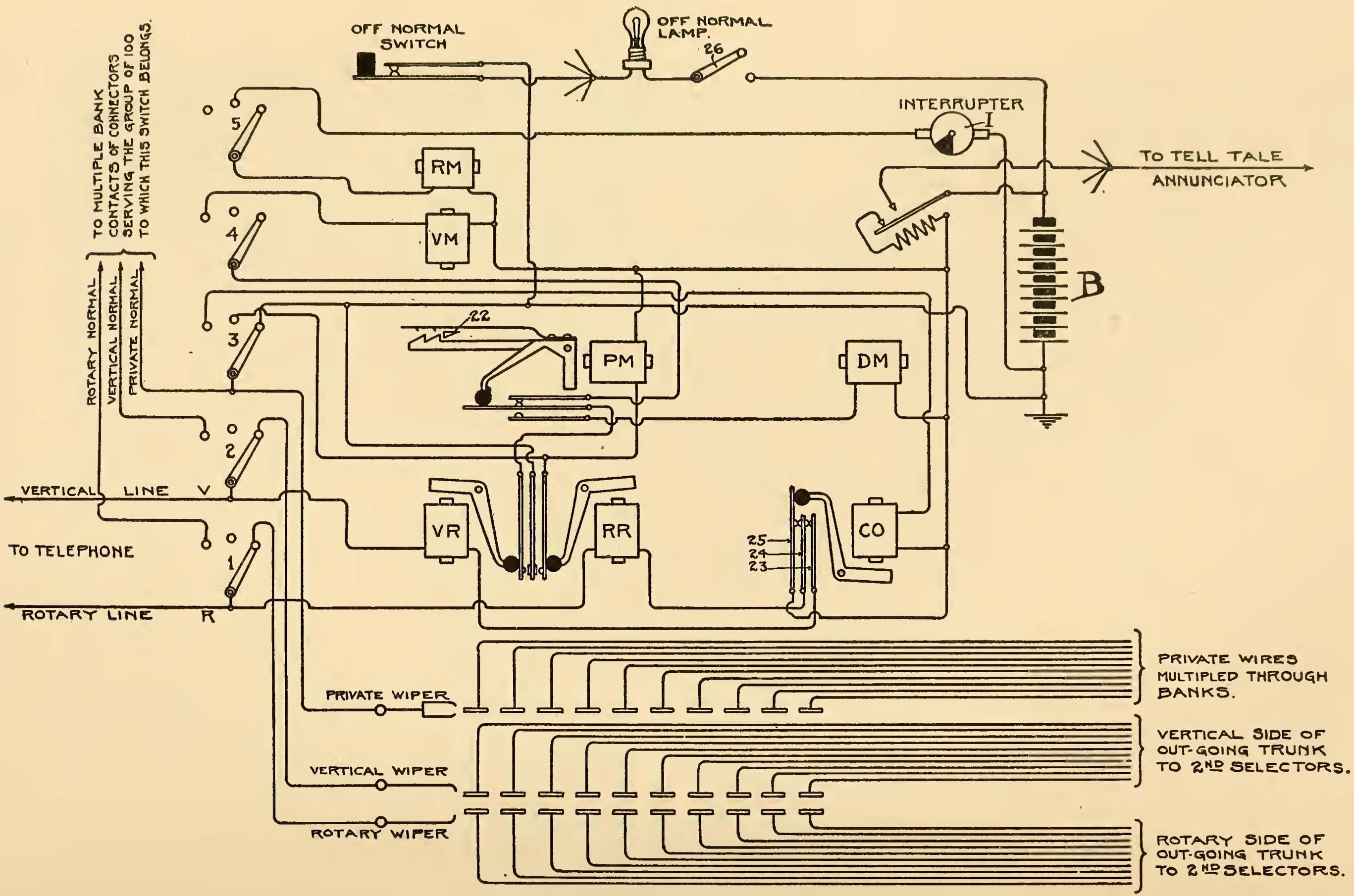

FIG. 512.—COMPLETE CIRCUIT OF FIRST SELECTOR.

ture will result in the moving of the side switch to its third position.

This action of the side switch, and its control by the private magnet, is one of the salient features in the operation, not only of the first selectors, but of the second selectors and connectors, and must be clearly kept in mind in following the actions of all these switches.

The two sides of the line pass from the side-switch levers to the vertical and rotary relay coils marked *V R* and *R R*, respectively, and from these the circuits of the two sides of the line are continued through the springs, 23, 24 and 25, of the cut-off relay, *C O*, to the live side of the battery, *B*. These relays are thus placed in such relation as to be actuated over their respective line wires when the grounding of these wires occurs in response to the movements of the dial and of the release springs at the subscriber's station. The function of the cut-off relay, *C O*, is to break the circuit under certain conditions through these two relay magnets, this function being pointed out in its proper place. *R M* and *V M* are, respectively, the rotary and vertical magnets which impart to the shaft of the switch its rotary and vertical movements. It will be noted that the vertical magnet can have its circuit completed only when the side switch is in its first position, while the rotary magnet can have its circuit completed only when the side switch is in its second position.

The disconnect or release magnet is shown at *D M*, and this is so connected that its circuit will be completed only when both the vertical and rotary sides of the line have been grounded at the subscriber's station, the conditions under which this occurs being more readily understood as this description progresses.

At the top of the diagram in Fig. 512 is shown what is called an off-normal switch and an off-normal lamp. The contacts of this switch are held apart by a collar on the shaft of the selector switch, the arrangement being such that as long as the selector shaft is in its normal position the off-normal switch will be open, while as soon as the shaft is moved upward one step or any number of steps the off-normal switch will be closed and a lamp common to a group of switches be lighted, if the small hand switch, 26, is closed. The object of this is to afford facility for the detection of any switch or switches in a group which may be, through some fault in the working of the system, left in other than normal position. At *I* is shown a constantly driven interrupter, the purpose of which is to afford to the rotary magnet periodically recurring current impulses from the battery, *B*, during the time while the side switch is in its second position.

Before passing to the operation of the selector switches under the various circuit conditions, attention should be called to the fact that

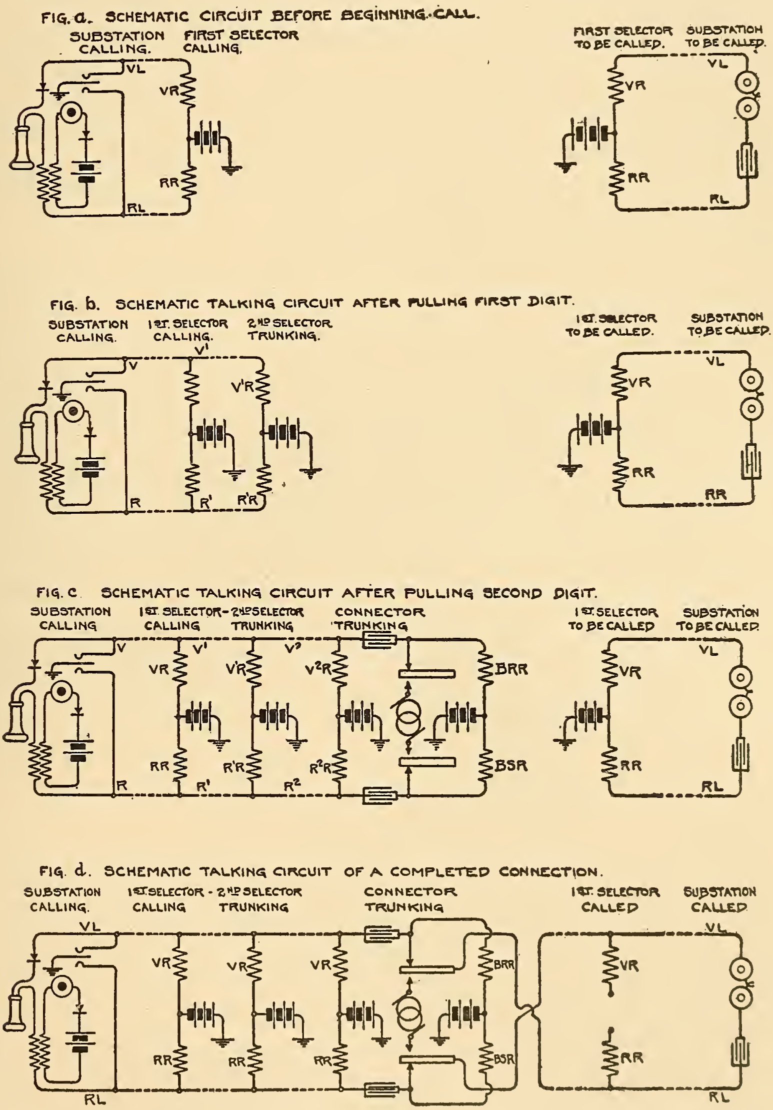

FIG. 513.—SCHEMATIC REPRESENTATION OF THE VARIOUS STEPS IN A CONNECTION.

the two left-hand contacts of the side-switch levers, 1 and 2, are connected by wires designated respectively as "rotary normal" and "vertical normal," to the multiple bank contacts of the group of connector switches, serving the group of subscribers to which this particular first selector belongs. The lever, 3, of the side switch is permanently connected by the "private normal" wire to the private bank contacts on the same connector switches. These normal wires form the path for the incoming calls to the line of this first selector, and it will be noticed that the contacts between the vertical and rotary line wires, *V* and *R*, and the corresponding vertical and rotary normal wires is severed as soon as the side switch of this first selector is moved out of its normal position.

At the lower portion of Fig. 512 are shown the wipers carried by the shaft and also the corresponding rows of private, vertical and rotary bank contacts over which these wipers are adapted to move when the shaft has been stepped to a certain vertical position. The bank contacts shown on this circuit are those of one level only of the first selector, and therefore one-tenth of all the bank contacts on this selector. The first selectors are divided into groups of one hundred and the bank contacts are multipled throughout this group, as has already been described. In addition to these multiple connections the vertical and rotary bank contacts are also connected by means of trunk wires to second selectors, these second selectors being grouped with respect to the groups of thousands they are to serve. The vertical and rotary bank contacts shown in this figure are each connected therefore to the second selectors serving some particular group of a thousand lines. The ten pairs of contacts in each of the nine other levels on the first selector would terminate in other second selectors serving respectively other groups of thousands.

Coming now to the actual description of the workings of the various parts of the first selector, reference will be made to the various diagrams in Fig. 513, in which the successive steps in building up a connection between a calling subscriber's station at the left, and a called subscriber's station at the right, are illustrated in a schematic way. At the top of this figure is shown the condition of the circuit of the called and calling lines before the beginning of a call. This condition with respect to the first selector of the calling line is shown more in detail in Fig. 514, some of those parts shown in Fig. 512 not operative at this time being omitted.

Referring particularly to Fig. 514, the two sides of the line, *V* and *R,* are shown, continued respectively to the vertical and rotary normals, *V N* and *R N*, thus being in a receptive condition for incoming calls from some connector. This is the telephone's condition of idleness, the side-switch levers 1, 2, 3, 4 and 5 of the first selector being at the left. The line wires, *V* and *R*, are continued to the live pole of the battery, *B*, through the relays, *V R* and *R R*, respectively.

It is evident that the first series of vertical impulses sent by the subscriber corresponding to the thousands digit in the number of the desired subscriber, will cause a corresponding number of attractions of the armature of the vertical relay. This will cause a corresponding number of current impulses to traverse the vertical

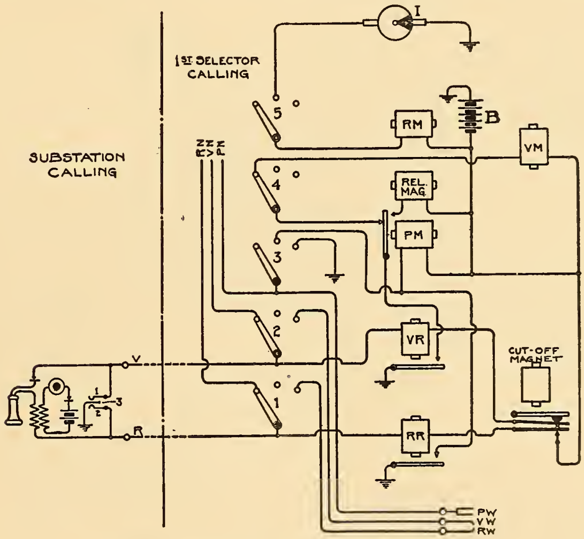

FIG. 514.—FIRST SELECTOR—NORMAL.

magnet, *V M*, this circuit being traced from battery, *B*, through the magnet, *V M*, to the left-hand contact point of the fourth side-switch lever, thence to the back contact of the private magnet to ground through the contacts of the vertical relay. The vertical magnet will therefore step the shaft up a corresponding number of points until the wipers, *P W*, *V W* and *R W*, are opposite their respective rows of contacts corresponding to the trunk lines leading to the proper group of second selectors. Immediately afterwards, the rotary relay, *R R*, will receive one impulse due to the grounding of the spring, 2 (Fig. 511), and as a result of the attraction of its armature the private magnet will operate to attract and release its armature once. The contacts carried by the private magnet will not in this case effect any circuit changes, since the circuit from its armature is open at the vertical relay. The movement of the private magnet armature will, however, through its escapement, allow the side switch to move to its middle point.

The circuit is now that of Fig. 515, and from this it will be seen that the circuit of the rotary magnet is completed through the fifth side-switch lever, the battery, *B*, and the interrupter, *I*. The rotary magnet thus receives a number of impulses in rapid succession, and

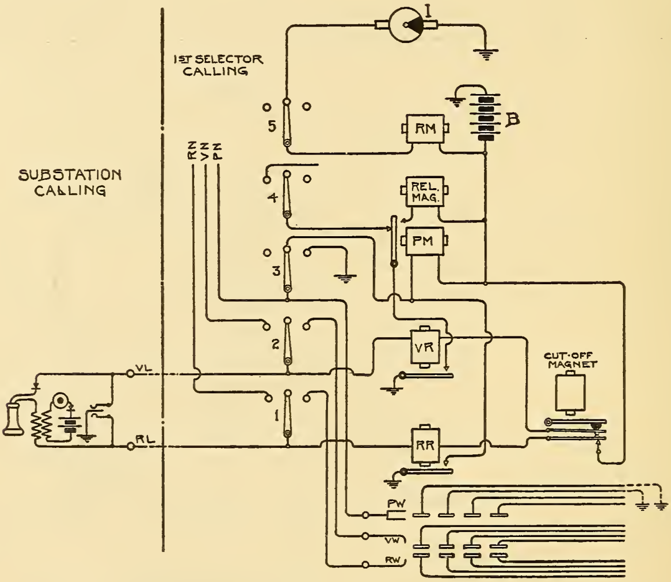

FIG. 515.—FIRST SELECTOR DURING TIME OF ACTION.

as a result of each one the shaft and its wipers are stepped around over the horizontal row of trunk line contacts.

In view of the fact that the wiper contacts connected with the trunk lines are multipled to other switches, it is evident that some of the trunk lines, represented by the contacts over which the rotary magnet is now causing the wipers to sweep, may be busy at other switches. It is the function of the rotary magnet, therefore, to move the wipers until they engage the contacts of the first idle trunk, and for the purpose of illustration let it be assumed that the first two trunk lines of the selected horizontal row are busy at this time. When a trunk is busy its private bank contacts are grounded at the switch at which the trunk is made busy in a manner that will be explained. The first two private wiper contacts of the switch that is being rotated are therefore in Fig. 515 shown as grounded. The private wiper, *P W*, when it engages the first private contact, will complete a circuit from the live side of the battery, *B*, through the private magnet, side-switch lever, 3, to ground through the private wiper. This will serve to hold attracted the armature of the private magnet, while another impulse is given the rotary magnet through the interrupter. The rotary magnet is thus again attracted to move the private wiper and other wiper contacts into engagement with the second contacts, where another ground is found by the private wiper, resulting in the private magnet being still held attracted and another impulse being given the rotary magnet. The private wiper now finds in contact 3 no ground, and the private magnet is therefore released, which results in the movement of the side switch to its third contact point which primarily accomplishes the result of cutting off the interrupted current through the rotary magnet and stopping the wipers on the third contact. It will be seen that the rotation of the shaft depends on the continued action of the rotary magnet, and this depends on the side switch being in its second position. This in turn depends on the private magnet not being released while the private wiper is sweeping over busy trunk contacts, for as soon as it is released it causes the movement of the side switch to its third position. In order that the private magnet armature may not fall back while the private wiper is passing, in its rotary movement, to the first private multiple contact or from one private contact to another, a certain mechanical relation exists between the armature of the rotary magnet and that of the private magnet. The rotary magnet armature carries a finger which projects in front of the private magnet armature and results in the private magnet armature being held up, as though attracted, during the attraction of the rotary magnet armature. It may, therefore, be stated that while the wipers are sweeping over a series of busy trunk line contacts the private magnet armature is held attracted electromagnetically while the private wiper is on a busy trunk line contact, and during the interval while the wiper is passing to the first contact, or from one to another, the private magnet armature is held up by the rotary magnet armature, which is then in operation. This interaction between the private magnet armature forms an important link in the chain of actions in all the selector switches.

The movement of the side switch into its third position brings about the state of affairs shown in Fig. 516. Beside cutting off the circuit through the rotary magnet, the movement of the side switch into its third position causes other important circuit changes which are indicated in Fig. 516. The first of these is the grounding of the private wiper at the right-hand contact of side-switch lever 3. Since this private wiper now engages the private contact of the trunk line to which the vertical and rotary wipers have been connected, it follows that all of the private contacts of that trunk on other switches are grounded, and this trunk line will therefore be held busy to other incoming calls in the same group of subscribers. This explains how the ground connections are put on busy trunks, as was referred to in conection with Fig. 515. The movement of the side switch into its third position also connects the vertical and rotary sides of the line with the vertical and rotary wipers, *V W* and *R W*,

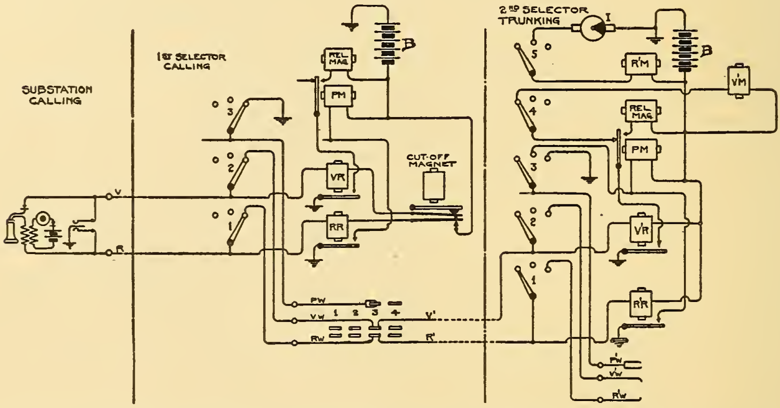

FIG. 516.—FIRST AND SECOND SELECTORS AFTER PULLING FIRST DIGIT.

and the connection is therefore continued from the line to the trunk line formed by the two wires, *V'* and *R'*, leading to a second selector.

The first step in securing the desired connection is now accomplished, and the conditions with respect to the talking circuit are those shown in the second schematic diagram of Fig. 513. The bridge formed by the vertical and rotary relay magnets, *V R* and *R R*, of the first selector still exists, while another bridge has been added at the second selector in the coils, *V' R* and *R' R*. The selection of the thousands group has been performed and the line of the calling subscriber has been brought one step closer to the terminals of the called subscriber.

The action of the second selector is identical with that of the first selector; a horizontal row of trunk line contacts being selected by the vertical magnet of the second selector in accordance with the number of impulses sent over the vertical side of the line in response to the second movement of the subscriber's dial. The impulse over the rotary side of the line, immediately following, operates the rotary relay, which in turn gives the private magnet one impulse, and this in turn releases the side switch of the second selector which moves to its second position. This brings into play the rotary magnet which, as long as the private magnet armature is held attracted by virtue of the private wiper engaging busy contacts, continues to operate, until the private wiper strikes a non-busy and therefore non-grounded contact, which moves the side switch to its third position by virtue of the release of the private magnet armature. The movement of the side switch to its third position cuts off the interrupted current from the rotary magnet, grounds the private wiper and continues the trunk line wires, V' and R', to the wipers, $V'W$ and $R'W$, respectively, and therefore to the trunk line leading to the proper connector.

As a result of the second movement, therefore, the circuit of the calling subscriber's line is continued to a connector serving the group of one hundred subscribers in which the called-for subscriber's line exists. The connection thus established is shown in Fig. 517, and the schematic diagram of the talking circuit is shown in the third diagram of Fig. 513. The calling subscriber's line is now extended, as shown in this latter figure, by the addition of the trunk line wires, V^2 and R^2, and a third bridge is added by the vertical and rotary magnets V^2R and R^2R of the connector switch. It now only remains for this connector switch to pick out by its vertical movement the row of ten contacts in which the called subscriber's line exists and then by its rotary movement to pick out the terminal of that line from among this ten.

Upon pulling the third digit of the number being called the series of impulses sent over the vertical line will operate the vertical relay, V^2R, of the connector switch as in the case of the first and second selectors. This, as before, will cause the vertical magnet, V^2M, to step the shaft up a corresponding number of steps, the side switch of the connector being at the time at the left. The wipers of the connector are thus moved to a position opposite that row of multiple contact points on the connector bank, which form the terminals of the ten subscribers' lines containing the desired subscriber.

The rotary impulse following the third movement of the dial energizes the rotary relay, R^2R, which, as before, energizes the private magnet, $P^2 M$, this in turn releasing the connector side switch to its middle point. This action in the first and second selectors, it will be remembered, served to start the rotary magnet in its work of stepping the shaft around in its rotary movement. In the case of the connector this is not true, but instead, the lever, 4, of the side switch merely places the rotary magnet, $R^2 M$, under the control of the vertical relay in place of the vertical magnet. This action is clearly shown in the diagram of Fig. 517, where it will be seen that with the side switch in its first position the vertical magnet, $V^2 M$, is in the local circuit closed by the vertical relay, $V^2 R$. When the side switch shifts to its middle position the rotary magnet, $R^2 M$, is placed in the same relation with respect to the vertical relay

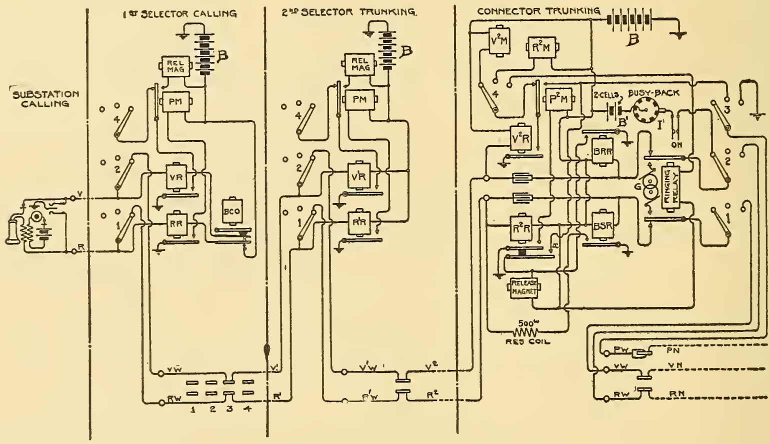

FIG. 517.—FIRST AND SECOND SELECTORS AND CONNECTOR AFTER PULLING SECOND DIGIT.

as was the vertical magnet before. As a result of this when the fourth and last movement of the dial is made the series of impulses coming over the vertical side of the line will actuate the vertical relay as usual, but its action will be to cause the rotary magnet of the connector to attract its armature a corresponding number of times, thus moving the wipers around into engagement with the contacts of the line of the subscriber desired.

Assuming for the present that this line is not busy, the connector wipers will remain on these contacts during the conversation which is to follow. The final impulse over the rotary side of the line following the fourth movement of the dial will actuate the rotary relay, $R^2 R$, which will close the circuit of the private magnet, $P^2 M$, and release the side switch to its third position. The connection is now completed, as this last movement of the side switch brought the levers, 1 and 2, of this switch into engagement with the right-hand side-switch contact, thus continuing the vertical and rotary sides of the line from the connector trunks, V^2 and R^2, through the condensers to the vertical rotary wipers, which already rested on the bank contacts connected with the vertical and rotary normals, *V N* and *R N*, of the desired line.

The complete connection and all parts involved at the central office in making it is shown in Fig. 518. It will be seen at the right of this figure that the first selector of the called subscriber's line is involved in the connection, since the bank contacts of the connector employed in making the combination of circuits are connected by the vertical and rotary normals, *V N* and *R N*, to the side-switch of the first selector, the levers of which are in their normal position. It is now that the function of the bridge cut-off relay, *C O*, may be understood. It is seen that this relay of the first selector of the called line will, under the conditions just brought about, be energized, the circuit being traced from the live side of the battery through the coil of this relay to the switch-lever 3 of the side switch of this first selector, thence over the private normal to the private wiper of the connector in question and thence to the lever 3 of the side switch of this connector to ground. The bridge cut-off relay is thus energized, and as a result the vertical and rotary relays of this first selector are cut off, and no bridge is formed by them across the now completed circuit.

The condition with respect to the talking circuit is now that shown in the lower schematic diagram of Fig. 513, and it only remains to accomplish the ringing of the called subscriber's bell. To do this the calling subscriber presses his ringing button which, as before stated, grounds the vertical side of the line at his sub-station, and thus energizes the vertical relay, V^2 *R*, at the connector in the usual manner. When the connector side switch moved into its third position, the coil of the ringing relay was brought into the local circuit of the vertical relay of the connector. Pressing the ringing button at the calling sub-station at this time therefore causes the energization of the ringing relay. These circuits are most clearly shown in Fig. 517.

The action of the ringing relay is exactly the same as that of an ordinary ringing key in a manual switch-board. It cuts off the line behind it and establishes connection between the limbs of the

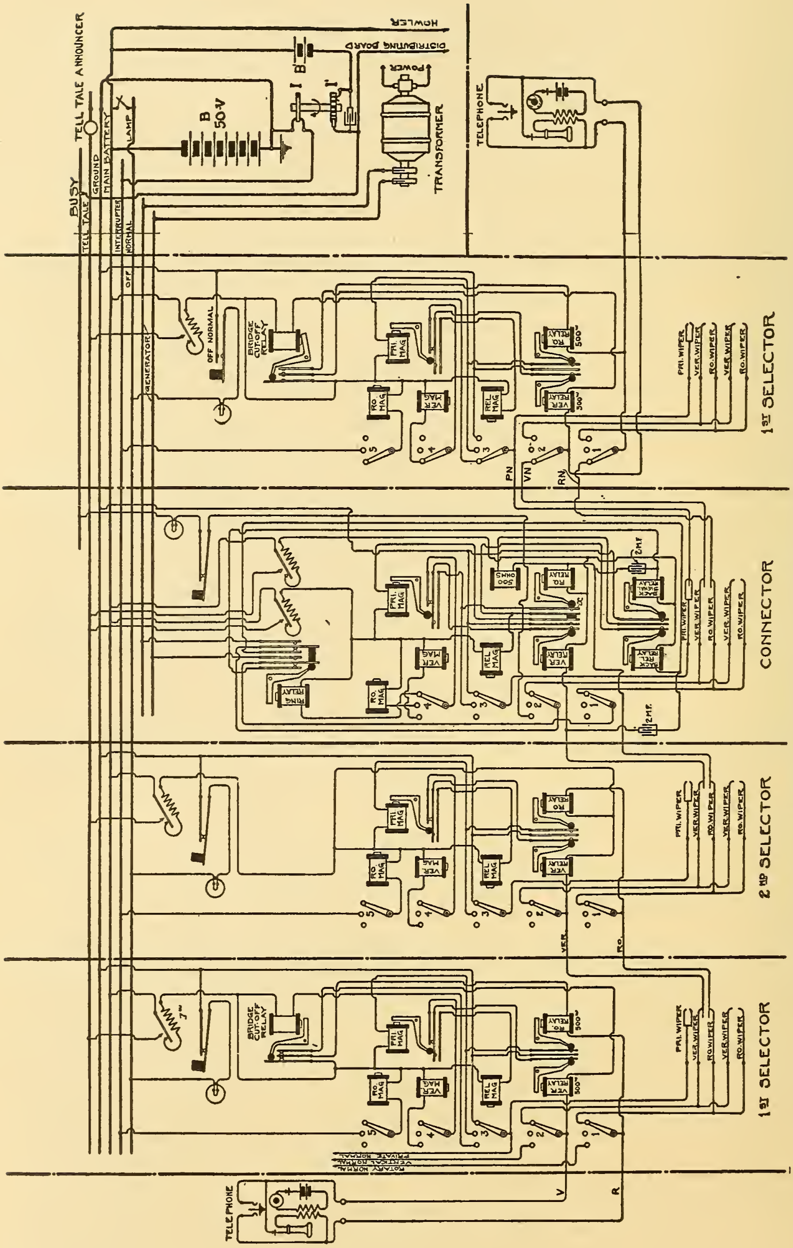

FIG. 518.—COMPLETED CIRCUIT BETWEEN TWO SUBSCRIBERS.

called subscriber's line and the calling generator, *G*. The bell of the called subscriber is thus rung, and when he responds the conversation ensues over the circuit shown in the lower diagram of Fig. 513.

No mention has yet been made of the back signal relay, *B S R*, and the back release relay, *B R R*. The action of the back release relay may be best understood when the question of releasing the line is discussed later on. It may be said, however, concerning the back signal relay, that its function is to enable a subscriber who has been called by a toll operator to signal this operator if desired by means of his ringing button.

If the called line had been busy at the moment when the connector wipers moved upon its bank contacts in seeking to connect with it, then its private normal would have been grounded. A line may be busy from two causes: either because it may have been sought out and connected with by another line, or it may have sought out and connected with another line through its own first selector. In the first case the private normal would have been grounded because the wipers of some other connector would be in contact with the multiple bank contact of this line, and as that connector would have its side switch in its third position all of the private bank contacts of that line would be grounded through the private wiper of that connector. In the second case, when the line was busy on account of its having originated a call, the side switch of its first selector would be in its third position, and therefore the private normal and all of the corresponding bank contacts on the group connectors grounded.

As a result of this engagement by the private wiper of a connector that is seeking to connect with a busy line, a circuit is established which places a ground on the spring, *x*, of the rotary relay of the connector, it being remembered that the side switch of the connector has not yet moved out of its second position. The rotary impulse which comes over the line immediately after the final set of vertical impulses operates the rotary relay as usual, which by virtue of the ground upon the spring, *x*, completes a circuit through the release magnet of the connector, which withdraws both the vertical and rotary holding pawls from the connector shaft and restores it to its normal position. When in this position the act of attempting to ring by the subscriber will, by grounding the vertical side of the line at the ringing button, step the shaft of the connector up one notch, or as many notches as the number of times the ringing key is pressed. This closes the off-normal switch of the connector and establishes a circuit from the busy test apparatus to the vertical side of the line, thus throwing a tone upon the talking circuit. The circuit by which this tone is given to the calling subscriber may be best seen in Fig. 519. In this, *B′* is a test battery of low voltage connected in series with an interrupter wheel, *I′*, and a lamp, this circuit terminating on one side in the main battery lead, *L*, and on its other side in the off-normal switch, *O N*, of the connector. When this switch is closed and the side switch of the connector is in its normal position the test circuit is completed, as shown in Fig. 519, with the result that a certain amount of interrupted current passes to the receiver of the calling subscriber, causing the buzz which signifies to him that the called line is busy. It is true that this circuit is bridged in several places by the various relay magnets, but

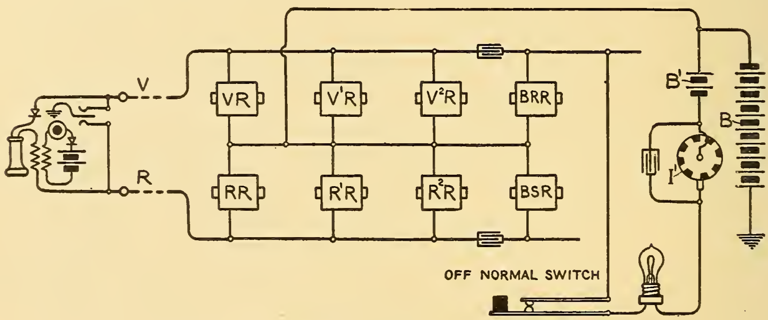

FIG. 519.—DETAILS OF TEST CIRCUIT.

sufficient current is received at the subscriber's station to produce the required signal.

The clearing-out operation may be best understood from this figure or from Fig. 517. When the calling subscriber hangs up his receiver at the close of conversation both sides of his line are connected momentarily to earth, as has already been described. The vertical and rotary magnets of the first selector of the calling line, the second selector and the connector involved will, as a result of this, receive simultaneous current impulses which will cause the attraction of the armature of each. The releasing action is the same for all of the switches, and will therefore be described in connection with the first selector only. The closure of the contacts of the rotary magnet causes operation of the private magnet in a manner already described, and this closes one pair of contacts in the circuit of the disconnect magnet. The vertical relay, which is at the same time operated, serves to close another pair of contacts in the circuit of the disconnect or release magnet, this circuit now being traced from the live side of battery, through the release magnet, to the springs of the private magnet, thence through the springs of the vertical magnet, and to ground at the opposite pole of battery. As a result the disconnect magnet for the first time in the operation that has been described receives current and withdraws the holding pawls from the shaft so as to allow it to return to its normal position in both vertical and rotary movements.

The same action takes place at each of the other switches that are off normal, and both calling and called lines are thus ready to receive or make other connections.

Unless means were provided to prevent it, the line of a subscriber might be connected with by another subscriber and left "tied up" by the failure of the subscriber who made the call to hang up his receiver and thus release the line. To guard against this occurrence the back release relay on the connector is provided and connected between the rotary side of the called subscriber's line and battery in such manner as to be under the control of the called subscriber's instrument. When, therefore, a subscriber who has been called and not released by the calling subscriber, moves his dial to make a call, the back signal relay will be energized and thus close the circuit through the disconnect magnet of the connector switch only. As a result this switch is restored to its normal position, leaving the called subscriber's first selector free.

The circuits and apparatus here described are those installed by the Automatic Electric Company, of Chicago, in the 6000-line exchange of the Citizens' Telephone Company, of Grand Rapids, Mich. Practically the same circuits are installed in a plant of similar size at Dayton, Ohio, the system of these two plants being a later development and a considerable improvement over the systems installed at Fall River, Mass., New Bedford, Conn., Chicago, Ill., and other places.

A later development has been made, by means of which all of the relays at the first and second selectors are cut off from the line after they have served to operate their switches, this severing of their connections being accomplished in each case by the last movement of the side switch. Only the relays at the connector are left across the circuit during a connection, and the release of the other switches is accomplished at the end of the conversation by means of a circuit established over the private wire connecting the bank contacts of one set of switches with the wipers of the corresponding selector. By this means a much more positive action of the various switches is secured, as there are fewer of them to be operated in multiple, and besides this a better talking circuit is afforded.

The switch room of the Citizens' Telephone Company, of Grand Rapids, is shown in Fig. 520, and a closer view of the various racks containing the switches in Fig. 521. The switches are mounted on iron racks, as shown, there being one hundred first selectors on each

FIG. 520.—SWITCH ROOM IN GRAND RAPIDS AUTOMATIC EXCHANGE.

rack, these occupying the first four rows. Above these are mounted the corresponding second selectors and connectors, these occupying the upper two rows. All cabling is done on iron racks overhead, in much the same manner as is practiced in the cabling between the distributing frames in the manually operated plant.

The giving of toll service in automatic exchanges presents an interesting problem, and it may be said that the most approved method up to date is that employed at Grand Rapids, the exchange in this city having a very large relative amount of toll work. All lines, after passing through the distributing frame are led to a toll switching section, where they terminate in cut-off jacks. From the inner contacts of these jacks the two sides of the line lead to the automatic apparatus, where they terminate in first selectors, as already described. Under normal conditions, therefore, the line

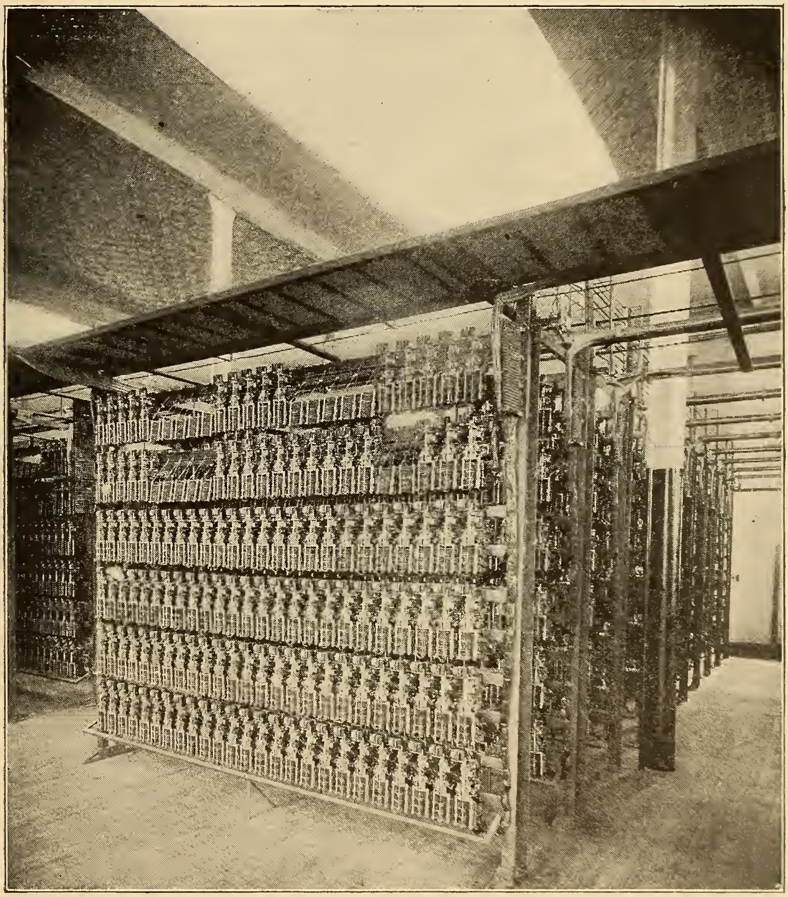

FIG. 521.—SECTION OF AUTOMATIC SWITCH-BOARD, GRAND RAPIDS EXCHANGE.

extends directly to the automatic apparatus, but when a jack is plugged at the toll section the portion of the line extending to the automatic apparatus is cut off, and connection is made with the line at the toll board as in ordinary practice.

In this exchange the numbers from 0 to 1000 are not used, and the connection through the automatic apparatus is such that when the subscriber desiring to call toll places his finger in the o hole and pulls the dial once, his line will be continued to a recording operator in the toll room, and a signal displayed before that operator indicating that her attention is required on the corresponding line terminating before her in a jack. In order not to confuse the subscribers, an extra hole is placed in the dials of their instruments, this being just above the o hole. This is marked "Long Distance" and is used instead of the o hole in calling for toll, although the effect produced is exactly the same at the central office as that of pulling the o hole. The recording operator will take the instructions of the subscriber as to the toll connection wanted, make out the ticket and will tell the subscriber to hang up his receiver. After the required toll connection is secured by the toll operator who receives the ticket, the connection is ordered up in the usual manner at the toll switching section, and connection is thus completed between the line of the subscriber who made the call and the toll trunk leading to the position of the toll operator who is handling the connection. It will be seen that this method obviates the possibility of fraud on the part of the calling subscriber in giving a wrong number to which the connection is to be charged, for the connection over which he originates the call is destroyed and connection is afterwards made with his line through the multiple jack in the toll switching section.

Incoming toll calls are handled in exactly the same manner as in manual practice, the local connection being ordered up through the switching section, thus cutting off the extension of the called subscriber's line to the automatic apparatus.

With this method of handling toll service practically all the complexity of the automatic apparatus is eliminated, so far as toll work is concerned, and the presence of the automatic apparatus, which might be considered injurious to the talking efficiency in a really long distance connection, is thus entirely avoided.

Some work has been done, and it seems probable that more will follow, in the line of applying common battery advantages to automatic systems. The works of Messrs. Malcolm C. Rorty and Albert M. Bullard, of the American Bell Telephone Company, of Boston, stand out prominently in this line. The system that they have perfected is at present applicable, however, only to comparatively small exchanges, that is, to those exchanges small enough to allow each selector directly controlled by a line to make connection within itself with any other line in the exchange without the intervention of second selectors and connectors.

Much has been done in the line of automatic telephony that might be described here, but attention has been given to a complete description of the only automatic system that has gone into wide commercial use rather than to several systems which, while promising, have as yet achieved little commercial prominence. It is to be expected that the near future will bring forth many developments in this newly aroused field of telephone activity, and the advent of an effective party line system of working as well as of measured service working in its various branches, is to be confidently expected.

It is difficult at the present time to form an accurate opinion as to the relative merits of the so-called automatic and manual systems. The writer's views on this subject, so far as formulated at the time, are shown in a paper entitled "The Automatic vs. The Manual Telephone Exchange," delivered by him before the International Electrical Congress at St. Louis, September, 1904. The remaining portion of this chapter is quoted from that paper:

"In the manual system in its highest development, the telephone user has only to place his receiver to his ear and make his wants known, the desired connection being made at the central office by operators. This system may be assumed to be highly developed, as it has been almost universally used since the advent of telephony, a period of nearly thirty years. The manual system, in its present form, represents the consecutive work of a large number of men in a field of the most intense and constantly increasing activity, all these men striving for the best possible means of accomplishing a desired result.

"In the automatic system, the central office switches are governed in their movements by the actions of the subscribers or users who desire connections and subsequent disconnections. The subscriber does his own work, manipulating the apparatus before him in such a way as to cause the switches at the central office to select, connect with, and afterwards disconnect from, the line of the subscriber desired.

"Unlike the manual system, the automatic cannot be assumed at the present time to have reached a relatively high development. While the automatic switch-board has been in the minds of inventors since the year 1879, it is not true that it has been put into considerable use until very recently. Instead, therefore, of its development being paramount in the minds of a large number of practical telephone workers, it has been fostered till lately by but few men, some of whom were unfamiliar broadly with the details of the telephone business. With a courage that must excite the admiration of all, a very few of these men have persisted, and as a result the telephone engineer, the operator of telephone companies, and last, but most important, the general public, are confronted with what I think is the greatest problem that has been recently before the telephone world: The problem of the automatic vs. the manual switch-board.

"It is not the purpose of this paper to attempt to solve this problem. The unequal degree of development of the two systems makes impossible a final satisfactory solution at the present time. It is rather to state some of its phases as they appear to me, and to make comment on them wherever my study of the situation has led to more or less positive convictions that this paper is offered.

"A fundamental question affecting the entire problem is this: is it possible to make a machine serve to effect the electrical connection of any line, in a large or small group, with any other line in the group, for the purpose of telephonic communication, and afterwards to effect a disconnection when required? There can be, even at the present early stage of development, but one answer to this question. That it is. The automatic switch-board at Grand Rapids, Mich., recently selected for me 100 different lines chosen at random from among approximately 5000 lines centering at that office. Some of the subscribers called did not respond, which will occur in any system; and some of the lines were automatically reported busy, which is to be expected; but in no single case was the wrong line chosen, and in but one case was the disconnection improperly effected. The verdict of a large number of subscribers interviewed by me in that city is practically unanimous to the effect that they uniformly secure their connections and disconnections promptly, accurately and satisfactorily.

"I conclude, then, in view of present achievement and of that future progress which this must stimulate men to make, that it is possible for the automatic switch to perform these functions satisfactorily.

"If, then, the automatic switch-board may be made to accomplish the commonplace connection and disconnection of lines, which form the great bulk of the work in a telephone exchange, is not the system so inflexible in its method of operation as to preclude the possibility of its performing the great multitude of special duties which, while not constituting the bulk of the work, are of constant occurrence and of hardly less importance? I refer to such matters as toll connections, private branch exchange work, and to a number of subordinate but necessary classes of service.

"A prominent telephone engineer has recently remarked to the effect that if some of the people enthusiastic on the subject of automatic switching in telephone exchanges were to visit the school for telephone operators maintained by the New York Telephone Company, they would be discouraged in their efforts, as no machine could ever be made to perform the many and varied functions that it was necessary to teach these young ladies before they became proficient telephone operators. This seems to be a statement that has very little to do with the real automatic problem. It should never be required that the machine shall do the same work that is demanded of the girl, nor do it the same way. That is manifestly impossible, for no machine can ever be endowed with intelligence. (It may be that you will say that there are some telephone girls similarly affected.) Since the very reason for the existence of the automatic exchange is to do away largely with the operator, it follows logically that whatever intelligence is to be applied to the making of the ordinary connection between two lines, it shall be that with which the subscriber desiring to make the connection is endowed. Here is a fundamental difference between the two systems which must always lead to different modes of operation.

"The real functions that the automatic switch-board should be required to do automatically are those relating to the ordinary routine work of connecting and disconnecting subscribers' lines under the control of the calling subscriber. When some act needing intelligence at the central office is required, then let an operator supplement the work of the machine. To condemn the automatic switch because it will not perform all of the special requirements without the aid of human intelligence, is just as unfair as to condemn a linotype machine because it cannot digest one of Steinmetz' equations. My mind has gradually changed upon this point until the doubt now exists as to whether the automatic system, wisely supplemented by operators, is not even more flexible than the manual. It is the ease with which the personality of the operator may be introduced into the automatic system, and also the ease with which certain of the purely automatic functions may be varied by mere changes in the circuit, or in the mechanical relation of the parts, that makes this doubt exist.

"Of course, there are many phases of traffic and service that are yet to be worked out for the automatic system, but apparently the longer one studies the problem the more nearly he becomes convinced that the automatic system is sufficiently flexible, with the interjection of human intelligence when necessary, to make possible the solution of practically all of the problems of service.

"So far as I am aware, selective-signal party line working has never been accomplished commercially with automatic systems. I believe that the reason for this is solely the fact that automatic telephony is yet new. I have recently seen a plan whereby any ordinary number of stations can be selectively operated on a party line with practically no other added complication either at the central office or at the subscribers' stations than that which is added to the apparatus of an individual line manual system to adapt it to the same class of party line work. While the automatic party line is not yet developed to the extent of actual commercial use, it is entirely feasible, and will not be one of the controlling factors in the solution of the problem: automatic vs. manual.

"I have looked into the subject enough to believe that what is true of the party line problem is true of the common battery problem, and also of the measured service problem, whether the measuring of the service is accomplished by collecting coins or tokens at the subscribers' stations or by operating counting devices either at the sub-stations or at the central office. There is undoubtedly a vast amount of work yet necessary before these features are commercially incorporated in working apparatus in an entirely satisfactory manner. I merely say that my study has shown me that no insurmountable obstacles exist that would prevent the successful establishment of party line, common battery and measured service working.

"These statements do not greatly help the man who is to-day casting about in making a choice between the automatic or the manual system for present use. It is not, however, with the present alone that we are concerned. We must plan and build for the future; and the remarks just made are given merely as bits of contributory evidence as to what developments may be expected.

"Having seen that the thing is possible, that it seems from a technical standpoint to be able to do what is wanted, another question is: do the subscribers like it?

"The evidence all seems to point in one direction. They do. At Grand Rapids, Mich., ninety-five per cent. of a large number of subscribers interviewed by me liked it better than common battery manual service; four per cent. did not care much one way or the other, and one per cent. liked the manual system better. At Fall River, Mass., where the system has been in use for a much longer period, the verdict was quite the same in effect. Evidence from other cities where automatic service is being tried seems to agree. It must be said in fairness, however, that at Grand Rapids the mass of subscribers is leavened by the presence of a large number of stockholders in the local company. Again, there is in that city much civic pride in the system, as telephone people come from all parts of the country to inspect the plant. Still again, the delight of the subscribers may be similar to that of a child with a new toy, but this can hardly be true, because of the fact that the exchange at Grand Rapids has been in service for a period of nearly nine months and is carrying a very large business load, so that if the people were not actually getting satisfaction they would probably know it. The new toy idea is also apparently disproven by the condition at Fall River and New Bedford, where the service has been maintained for several years and seems to be much liked.

"The question also naturally arises: is not the automatic switch-board and necessary subscribers' mechanism too complex to be maintained in proper working order without undue cost? It is perhaps too early to decide this question. There is not enough evidence one way or the other. Judging from the past, however, the tendency of industrial achievement seems to be toward automatic methods. As examples, take the arts of printing, of weaving and the use of machine tools.

"Summing up, therefore, the statements already made, the automatic system is not only a possibility, but is actually here. With the interjection of human intelligence to supplement it in performing certain functions, it seems to be as flexible as the manual. Party line, common battery and measured service working, while not yet achieved commercially, so far as I am aware, seem to be well within the grasp of those who are doing the development work. The public seems to like it, and we do not know whether it is too complex or not.

"It will be noted from the foregoing that the idea of having the central office apparatus perform *all* the phases of telephone service is apparently not tenable. Many of those who have advocated it in the past have abandoned it and are introducing human aid in the performance of some of the functions. This being true, a certain number of operators are and will be needed in automatic exchanges. This tends to destroy in some degree the primary object of the automatic system—the doing away with operators. We have seen many papers bearing on each side of this question, to the effect that the salaries of the operators were or were not to be eliminated; that retiring rooms, matrons, operators' luncheons, etc., were or were not to be done away with. These items of expense will probably exist to some degree in all large automatic exchanges. That they will be greatly reduced is without question, but whether or not they are reduced to such an extent as to offset other sources of expense introduced by the employment of automatic apparatus, is a problem yet to be solved.

"What are some of these sources of expense that tend to offset the reduction in operators' salaries and expenses coincident therewith? Taking the automatic system as a whole, we find that it is considerably higher in first cost than the manual system, and assuming that interest and depreciation are at the same rate in each case, this shows to considerable disadvantage for the automatic system in the annual charges due to these items alone.

"For an exchange of 5000 lines served by one office, the cost of automatic equipment, including telephones, may be taken at $35 for each individual line. In manually operated exchanges the corresponding cost is not far from $25 per line. The difference becomes greater, that is, more in favor of manual, for smaller offices, and smaller or less favorable to the manual in larger offices.

"Whether or not the depreciation on automatic apparatus should be taken at a higher rate than that on the manual, is a question that we have not at present sufficient data or information to determine. It is true that in the automatic switch-board the flexible cord nuisance found in all present forms of manual switch-board apparatus is largely eliminated. It is also true that the automatic apparatus is more complicated and requires greater care in its maintenance; but whether, if both systems are maintained with reasonable care, the automatic will show a greater rate of depreciation than the manual, I am not at all certain. Much of the depreciation in manual telephone apparatus is due, not to the fact that the apparatus wears out, but rather to the fact that it is rendered obsolete by new inventions. That the same will be true in the case of automatic apparatus cannot be doubted, but it is a good point to bear in mind that if telephonic development should point toward automatic apparatus to the exclusion of manual, and should prove the superiority of automatic, then the highest developed and newest manual apparatus will depreciate greatly in value by that fact alone. It does not seem unreasonable, therefore, to place the rate of depreciation on both manual and automatic apparatus at about the same figure.

"In point of maintenance the advantage must be conceded to the manual. This is certainly true at present with regard to both the central office and the subscriber's station apparatus. No good reason is apparent why it should not always be true. Automatic apparatus is especially at a disadvantage at the subscriber's stations, and it is really at this point that the automatic system seems to involve a poor engineering feature. The tendency of telephone development in regard to sub-station apparatus has been until lately along what seemed to be unquestionably good engineering lines. The sub-station equipment has been gradually simplified, the battery has been removed, as has also the magneto generator, and the instrument has been reduced to the simplest fundamental parts.

"Automatic telephony as at present developed for large work takes a step backward by reintroducing the local battery. That this is disadvantageous no one can deny, but on the other hand, it must be pointed out that the disadvantage is by no means as great as it would have been several years ago because of the fact that dry batteries have recently come into almost universal use for this kind of work, and are far superior, all things considered, to anything heretofore available.

"The disadvantage of local batteries, while mitigated, is still present, and is real; but, taking the automatic system as we have reason to believe it will exist in the future with no local batteries, it will still possess, as far as we are able to see, a more or less complicated impulse transmitting device, by means of which the subscriber will be able to direct the movements of the switches at the central office. Complexity, not only of mechanism, but of function, is thus introduced at the subscriber's instrument, and this seems to be an inherent disadvantage to all present schemes of automatic exchange working. This, of course, is another factor that must be weighed in considering the relative economies of the two proposed methods.

"There is a point that I have not yet seen mentioned in print, which, under certain cases, seems to be of great importance. This is the matter of trunking between two or more automatic offices in such cities or communities as naturally demand, by the distribution of their subscribers, more than one office. It is true that the present automatic switch-board seems to be capable of properly handling this condition if the requisite number of trunk lines between the offices are provided. At first thought it seems that the number of trunks required between offices for a given amount of traffic might be somewhat less in the case of the automatic than in the case of the manual system, on account of the immediate disconnection and release of the trunks; in the automatic, upon the hanging up of the receiver of the calling subscriber. Further consideration, however, will show that there is very little difference in the time the trunk is held busy in the two systems, the length of actual conversation being assumed to be the same in each case. The reason for this is that, while the automatic gains in this respect in the release, it loses something in the making of the connection, because in the case of the automatic, the trunk is selected with the first movement of the dial by the subscriber, and the length of time that the trunk is held busy, therefore, must include the time during which the subscriber is setting up his own connection; whereas, in manual boards a trunk line begins to be busy at the time when the B operator picks up the incoming trunk plug and designates its number to the A operator.

"So far there seems to be little difference between the systems in this respect.

"The bearing on the trunking problems of the relative efficiencies of different sized groups of trunks between offices does not, however, seem to have been weighed by many in considering the question of automatic vs. manual exchanges. When sufficient trunks are provided between offices to handle business on the so-called 'no delay' basis, it is known that a large group of trunks will handle very much more business per trunk line than a small group. For instance, when there are only ten trunks in a group between offices, it is a well-established fact that slightly less than eighty calls per trunk per day may be handled. If, however, the group be increased to 100 trunks, as many as 145 calls per trunk per day may be handled. This is an increase of considerably over eighty per cent. in actual trunk efficiency. In the present automatic system, group the trunks as you may, it is inherently true that the efficiency of the trunks is reduced to that of a group of ten. I do not mean by this that it is not possible to place as many trunks as desired between any two offices, but that any subscriber has access to ten trunks only in order to secure a connection to any other office. It is true that some other subscriber may have access to another ten, or to the same ten, but no one subscriber can reach more than ten.

This seems to be a grave objection to the use of automatic systems as at present developed, in those communities where several offices must be employed and where traffic is such as to demand a large number of trunks between offices. The remedy to this is obviously that of giving the subscriber the chance to select his trunks from larger groups. This, I take it, is one of the problems that need serious consideration in adapting the automatic system to very large communities. It does not enter seriously in single office work.

"In all that I have said I have attempted to take the very practical view of the engineer, and fundamentally that view must always compare systems with the intent of selecting a means of doing what is required well enough for the smallest price. From the strictly engineering view one does not take into account relative popularities of mere ways of accomplishing results. But this is necessary in such a case, for there are features of the automatic system which may make it so popular as to force upon the owners or prospective owners of telephone industries a serious consideration of the doctrine of expediency. This is by no means the least of the important things to consider.

"I expect to be criticised because I have not solved the problem. It cannot now be solved any more than the question of alternating versus direct-current transmission could be decided when we first were brought to realize that there was an alternating versus direct-current transmission problem. My object has been to state the problem as I see it, and I hope that in doing this something may have been accomplished toward clarifying it."

CHAPTER XXXVI.

INTERCOMMUNICATING SYSTEMS.

Two general plans of installing interior telephone systems for giving service between the various departments of a business establishment may be followed: One of these is to install a switch-board at some central point to which all the lines radiate, and at which they are connected as desired by an operator. In following this plan the switch-boards and instruments used may be of any of the types already outlined for use in small exchanges. The second plan involves the use of what is called an intercommunicating or house system, in which the instrument at each station is placed on a separate line, the line belonging to each station passing through all of the other stations. By means of a simple switching device arranged in connection with each telephone, the party at any station may at will connect his telephone with the line belonging to any other station and call up the party at that station without the intervention of an operator. This involves the necessity of running at least one more than as many wires as there are instruments in the exchange through each one of the stations; and the simplest way to do this is to run a cable having the requisite number of conduits through each of the stations, all of the conductors in the cable being tapped off to the switch-contact points on each telephone. The connections for a system having four stations is shown in Fig. 522. Each of the telephone sets embraces the ordinary talking and calling apparatus switched alternately into circuit by the ordinary form of hook-switch. These instruments differ in no respect from the ordinary magneto exchange telephone.

Connected with one of the binding posts, *b*, of each instrument is the pivot of the lever, *L*, which lever is adapted to slide over the buttons, 1, 2, 3, and 4, arranged in the arc of a circle beneath. Each button on each telephone is connected with a line wire, 1, 2, 3, or 4, bearing the same number as the button. The binding post, *b′*, on each instrument is connected with the common-return wire which runs through the same cable as the line wires. During the idle periods of each instrument the lever is kept on the button bearing the same number at that station. This button is usually called the home button, and is for convenience placed at the extreme left of the row of buttons on each instrument. The apparatus as shown represents the condition when station I. is about to call station IV. For this purpose the party at station I. has moved the lever, *L*, from its home button to button No. 4, thus connecting the instrument at station I. with the line belonging to station IV. When the generator at station IV. is operated, the current flows from binding post, *b*, to the common-return wire to the binding post, *b′*, at station IV., thence through the generator and call-bell at that station to binding post, *b*, and to lever, *L*, whence the return is made by line wire, 4, to the lever, *L*, and the binding post, *b*, at station I. When the receivers at both stations are raised the talking apparatus is thrown

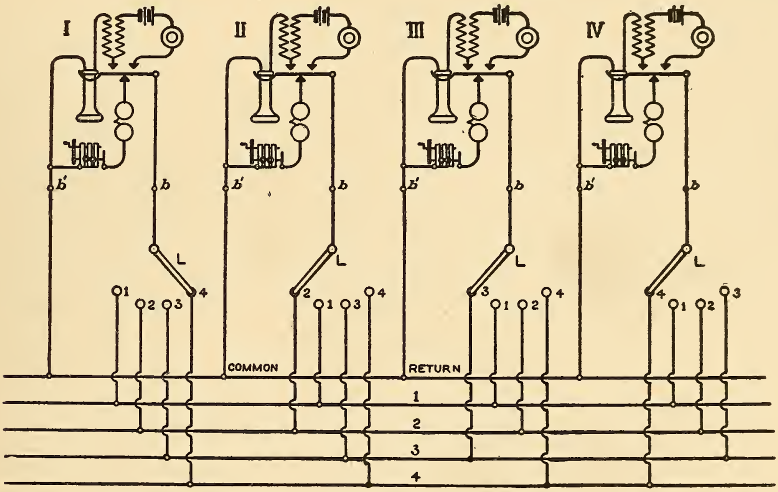

FIG. 522.—CIRCUITS OF ORDINARY HOUSE SYSTEM.

into the circuit over which the calling current was just sent, and the parties converse over the common-return wire and line wire No. 4. Had station IV. called station I., then the talking and ringing would have been done over the common-return wire and line No. 1.

The great drawback to the system of wiring shown is, however, that the lever at the calling station must always be moved back to the home button when a conversation is finished. If this is not done the instrument at that station will be left switched upon the wrong line, and will not respond to a call sent over its own line from another party. Moreover, when anyone calls a party on the line to which these two stations are left connected, both bells will ring, thus producing much confusion. To illustrate this: if after station I. had called station IV. he had left his switch lever, *L*, in the position shown, station II. could not call station I. because the instrument at station I. would no longer be connected with line No. 1. Should station II. attempt to call station IV., the bells at both stations I. and IV. would ring because both of those instruments are connected with line No. 4.

Frequently, instead of using a rotary switch, an ordinary plug and cord are used in place of the switch lever, while the buttons are replaced by simple spring-jacks into which the plug may be inserted. In Fig. 523 is shown such a system, where plug, *P*, in each case takes the place of the lever, *L*, in Fig. 522. Ten line wires are shown in this figure, each connected with ten spring-jacks on each of the telephone instruments; the wiring of but five instruments is shown, this being a sufficient number, inasmuch as all are connected to the circuits in the same manner. This system is for common battery work, a single battery located at any convenient point being used for supplying both talking and calling current to all of the stations. This battery is connected across the common-return and battery wires, which are common to all of the stations, and which are placed in the same cable as the line wires. Connected between the common return wire and the line wire bearing the same number as its station is an ordinary vibrating bell, the circuit through which is broken when the receiver is removed from its hook. By pressure upon the key, *k*, at any station, circuit may be completed from the common-return wire through the battery to plug, *P*, of that station, and therefore if this plug is inserted into the jack belonging to any other station the pressure upon this key will cause the bell to sound at that station. In this way a call may be received or sent. When the hook-switch is raised the transmitter of a station is connected between the battery wire and common-return wire, so that all of the transmitters at the stations in use take current from the same battery in multiple.

In order to reduce cross-talk between two or more pairs of stations which happen to be communicating at the same time, the small impedance coils, *c c*, are placed in each side of the transmitter circuit at each station, and between their terminals, as shown, is bridged at each station a condenser, *C*, so as to afford a local circuit for the vibratory currents set up by the transmitter. The coils, *c*, tend to prevent the fluctuations in current produced in any transmitter from backing up through the battery wire and common-return wire into the local circuits of the other transmitters. Fluc-

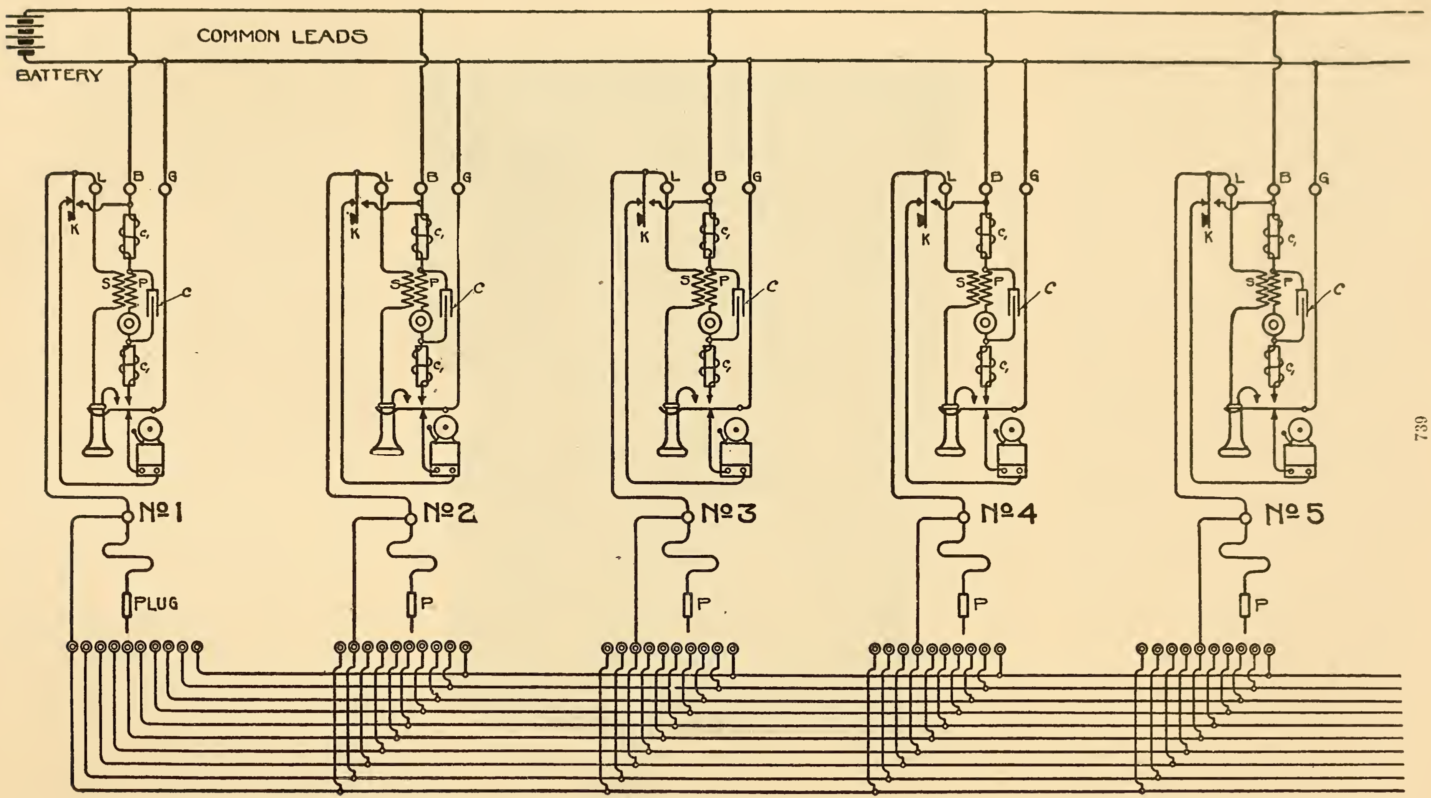

FIG. 523.—COMMON BATTERY HOUSE SYSTEM.

tuations produced in the local circuit of any transmitter act inductively through the induction coil, *I*, upon the talking circuit containing the receiver, the circuit being completed between two stations by the common-return wire and the wire of the station that has been called. This arrangement necessitates the removal of the plug when through talking, as otherwise both of the stations connected would be rung up when either of the stations was called.

The Holtzer-Cabot Electric Company has overcome the difficulty due to the subscriber calling leaving his switch lever in the wrong position, by the apparatus shown in Fig. 524, this device being the

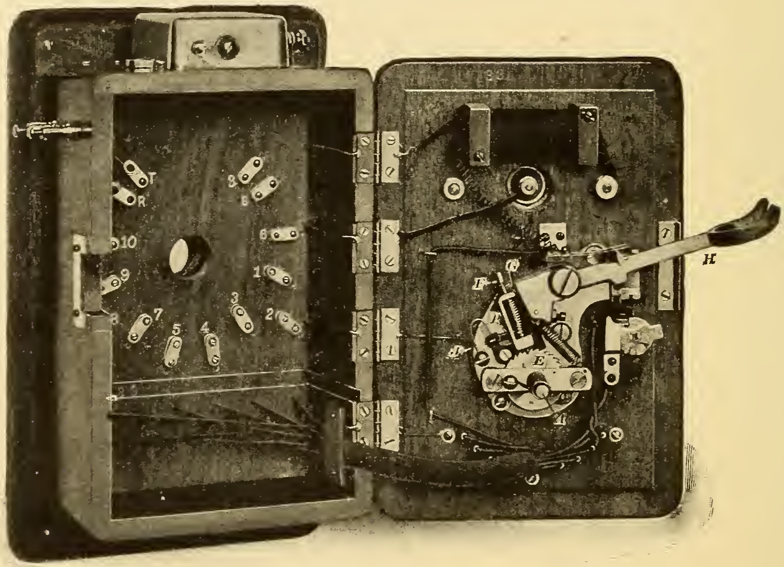

FIG. 524.—NESS AUTOMATIC SWITCH FOR HOUSE SYSTEMS.

invention of Mr. T. W. Ness. The arrangement is such that when the subscriber hangs up his receiver the switch arm, which is under the influence of a spring, will be automatically released and will fly back to the home position without his volition. In the figure the switch-restoring mechanism is mounted on the inside of the cover of the box, the switch lever itself being mounted on the opposite side. The lever, *L*, at each station, shown in diagram in Fig. 525, is adapted to slide over the buttons, 1, 2, 3, and 4, as in the systems already described. The curved contact-piece, *D*, is so arranged that the lever will not normally engage it, but by pressure upon the handle of the lever it may be brought into engagement with the contact.

Referring again to Fig. 524, *H* is the hook-switch adapted to perform the ordinary functions of connecting the calling and talking apparatus alternately in the line circuit. The switch lever is mounted upon the shaft, *A*, which may be seen passing through the front board of the box and which carries a ratchet-wheel, *E*, of hardened steel. A coiled spring around the shaft tends to rotate it so as to bring the lever always to the home position. *F* is a sliding pawl normally held in its lower position by a coiled spring surrounding it. This sliding pawl serves to hold the lever, *L*, in any

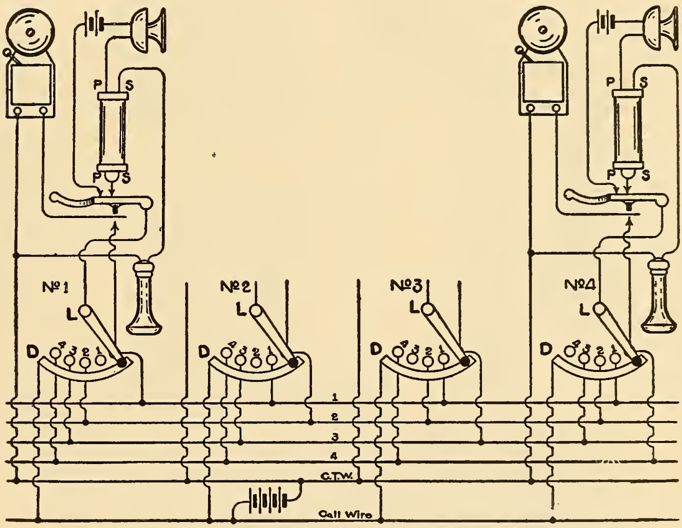

FIG. 525.—CIRCUITS OF HOLTZER-CABOT SYSTEM.

position to which it has been rotated, by the engagement with the teeth of the ratchet-wheel, *E*. Upon the short arm of the hook-switch is pivoted a dog, *G*, adapted, when the receiver is placed upon the hook to engage a notch in the pawl, *F*, and lift it out of engagement with the ratchet-wheel. This allows the spiral spring to return the switch lever to its right-hand position in contact with the home button. After raising the pawl out of the notch on the ratchet-wheel the dog slips out of the notch on the pawl, thus allowing the latter to return into contact with the ratchet-wheel, in order to be ready for the next use of the telephone. In order, however, that the pawl may not engage the ratchet before the lever, *L*, has fully returned to its normal position, a second dog, *J*, is provided, which is pressed by a spring so as to occupy a position under the pin, *p*, carried on the pawl, thus holding it out of engagement with the ratchet-wheel until the rotation of the lever is nearly completed. At this point a cam on the under side of the ratchet-wheel pushes the dog, *J*, out of engagement with the pin, *p*, and thus allows the pawl to drop into position against the ratchet-wheel. It will be seen that this device accomplishes with certainty what the memory of the telephone user could not be relied upon to do. This entire

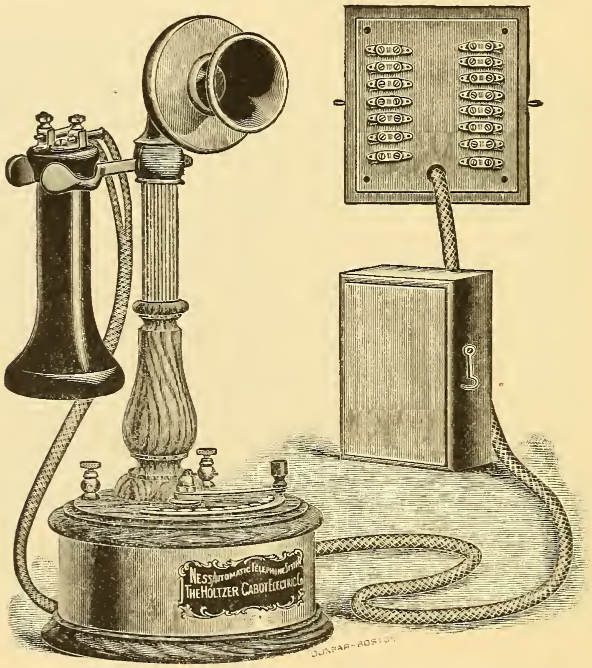

FIG. 526.—HOLTZER-CABOT DESK SET.

mechanism is well constructed, all of the parts subject to wear being of hardened steel.

The diagram of circuits given in Fig. 525 shows a system of wiring for four stations equipped with this automatic return switch, this system being operated with the common calling battery and with local batteries at each station for talking purposes.

Fig. 526 shows such a device applied to a desk telephone and also shows a method of wiring adopted in such systems. A cable having a sufficient number of conductors is run through each of the stations to be served, and each conductor is brought out to a connector in a terminal box, as shown. To these terminals are also secured the conductors of the cable leading to the telephone instrument and switch.

There is another way than by the use of the spring-actuated return switch, of obviating the difficulty mentioned in regard to subscribers forgetting to switch their instruments in connection with the home line after use. This involves no mechanical complications whatever, the circuits being so arranged that it makes no difference whether the subscriber leaves his switch lever or plug in connection with some line other than his own or not. This is accomplished by

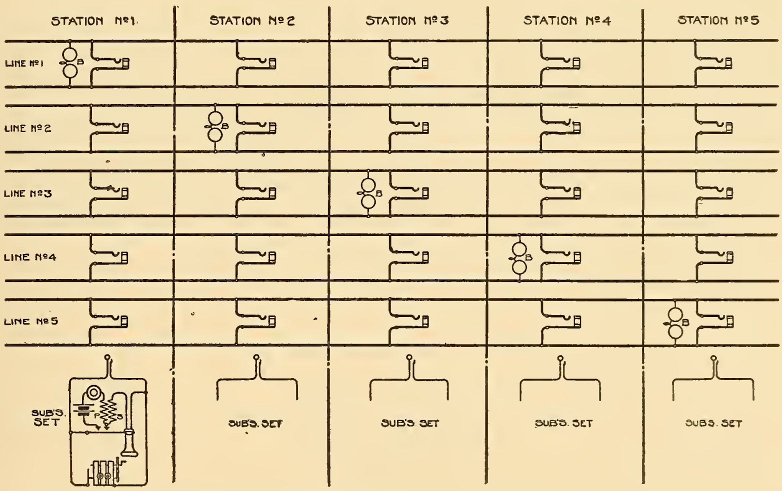

FIG. 527.—MAGNETO INTERCOMMUNICATING SYSTEM, METALLIC CIRCUITS.

bridging the call-receiving bell, which in this case should be high wound directly across the line circuit belonging to the station at which the bell is placed. This bell remains permanently so connected, the subscriber's switch arm or plug serving only to connect the talking and call-sending apparatus with the line of the party with whom it is desired to talk. An arrangement of this kind using individual metallic circuits for each line is shown in Fig. 527. In this there are five lines running through five separate stations and the call-receiving bell, *B*, of each line is permanently bridged across the line at that station bearing the same number as the line. Two-point spring jacks are provided at each station for each line, and the subscriber's telephone set and generator may be switched into the circuit of any line by means of the plug in which the set terminates. Thus, if a party at station No. 1 desired to call station No. 5 the plug at station No. 1 would be inserted in jack No. 5 and the generator operated. This would ring the bell at station No. 5, and the subscriber at that station would respond by inserting the plug in his own home jack. When through talking if the subscriber at station No. 1 left his plug in connection with line No. 5 no harm would be done, as other parties could operate the call bells of either line No. 1 or No. 5 just as well with the plug inserted as if it were withdrawn.

The system of Fig. 527 shows individual metallic circuit lines for each station, and this practice is one that is well to follow in the installation of house systems, especially if a considerable length of cable is involved. By this means, and this means only, complete freedom from cross-talk may be obtained. The expense of running two wires instead of one to each station is not as serious in point of cost as might be supposed. For interior work it is common to use ordinary switch-board cable for the wiring of such systems, the color code in the cabling being of great convenience in connecting up the station when originally installed.

As a rule, about twenty stations have been considered the greatest number that may be satisfactorily served by an intercommunicating system, and when a greater number of stations is to be installed it has been thought better to use a central office provided with a switch-board with an operator in attendance. There is no inherent reason, however, why the number of stations should be limited to twenty, and where stations are close enough together so that the cost of wiring is not prohibitive, a much greater number than this may be used.

CHAPTER XXXVII.

THE TELEPHONE RELAY OR REPEATER.

One of the most attractive fields of research and invention in telephony has been that of the telephone relay or repeater. It has been very natural to suppose that the principle of repeating now used so successfully and extensively on long telegraph lines could be used with equal advantage on long telephone lines. The idea is very simple, and involves merely the placing of a microphone contact in operative relation with the diaphragm of a receiver connected in the first line circuit, and causing the changes produced in the resistance of this contact, when acted upon by the receiver diaphragm, to vary the strength of a current in a local circuit, which circuit would in turn act inductively on the second line wire with reinforced energy.

This method is outlined in Fig. 529, where *A* is the transmitting station, being provided with a transmitter, *T*, battery, *B*, and in-

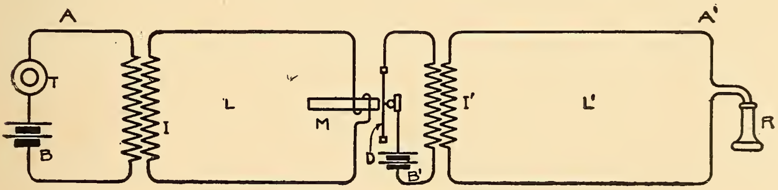

FIG. 529.—SIMPLE RELAY CIRCUIT.

duction coil, *I*. *L* is the transmitting line, having connected in its circuit the coil of a receiver, *M*. *D* is the vibrating diaphragm of this receiver against the center of which rests a pair of microphone contacts, which may be the same as those in the Blake transmitter, or of any other type. This microphone contact must be so arranged with respect to the receiver diaphragm that any vibrations of the latter will be imparted to the former, thus causing them to vary their resistance in exactly the same manner as if acted upon directly by sound waves. The microphone contact, *C*, serves to vary the resistance of a local circuit containing a battery, *B'*, and the primary of an induction coil, *I'*, at the relay station, and the receiver, *R*, at the receiving station, *A'*. Any changes in current in the local circuit at the station, *A*, produced by the operator at the transmitter, *T*, will induce alternating currents in the line, *L*, in the ordinary manner, which will cause the diaphragm, *D*, to vibrate as in everyday practice. The vibrations of *D* will be imparted to the microphone contact, *C*, which will produce changes in the current flowing in the local circuit at the relay station corresponding to those taking place in the local circuit at station, *A*. These changes will act inductively on the line circuit, *L'*, in the ordinary manner, the receiver, *R*, finally reproducing the sound.

Such an arrangement as this will do its work well, but it is quite evident that the transmission may be affected only in one direction. When it is desired to transmit from station *A'* to *A*, a separate circuit would ordinarily have to be used. Much difficulty was experienced in making a two-way repeater, for no automatic switch could be arranged which would bring about the changes of circuit required when the transmitting station desired to become the receiving. Many attempts were made to associate two relays with the line circuits in such manner that no interference would occur. The difficulties involved in this were, however, great; and chief among them was the fact that two relays when associated with the same pair of lines would almost invariably set up a singing sound, due to the mutual action between the two; for instance, a slight vibration of the diaphragm of one relay would produce changes in current in the local circuit, which would act upon the diaphragm of the other relay, producing another change of current, which would in turn react upon the first relay. This action is somewhat analogous to that produced by holding the earpiece of a telephone receiver directly in front of the mouthpiece of a good granular-carbon transmitter; the singing or shrieking noise set up when a proper adjustment is obtained in this case being due to the fact that the sound waves set up by the receiver diaphragm act upon the transmitter diaphragm, which in turn causes currents to flow through the receiver coil, causing its diaphragm to vibrate still more strongly. This defect, however, was finally overcome, several inventors having produced two-way relays which were successful in so far as they would operate in either direction with equal facility, and with a fair degree of clearness.

One of these systems, devised by Edison, is shown in Fig. 530, in which *A* and *A'* are the telephone stations, each arranged in the ordinary manner. *M* is the magnet of the relay receiver, the coil of which is included in a local circuit containing the secondary, 3, of an induction coil. The primary winding of this coil is divided into two parts, 1 and 2, these parts being connected together in one side of the combined circuit of the two lines, *L* and *L'*. Between the juncture of these two primary coils and the opposite side of the line is connected the secondary coil, 4, of an ordinary induction coil. The primary coil, 5, of this latter induction coil is connected in a local circuit containing the relay microphone contact, *C*, and the local battery, *B''*. Assuming that station, *A*, is for the time being the transmitting station, currents set up in the line circuit, *L*, will divide at the relay station, part passing through the coils, 1 and 4, and back to the transmitting station, and the other part passing through the primary coils, 1 and 2, in series and to the receiving station direct. The current passing through the coil, 4, will, however, under ordinary circumstances, be by far the greater on account of the high resistance of the long line, *L'*. The current passing through the coils, 1 and 2, however, will act inductively upon the coil, 3, thus causing currents to flow through the

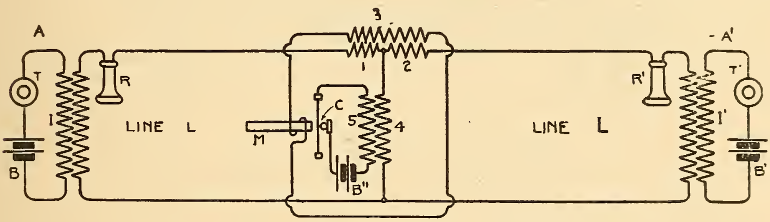

FIG. 530.—TWO-WAY RELAY CIRCUIT.

coil on magnet, *M*, and produce changes in the contact resistance of the microphone. These changes will cause fluctuations in the current in the local circuit, which fluctuations will act through the primary coil, 5, upon the secondary coil, 4, and cause currents of considerable comparative strength to flow in the line circuit, *L'*, to the receiving station, *A'*. It is obvious that as the various circuits at the relay station are symmetrically connected with respect to the two lines, *L* and *L'*, the station, *A*, may in turn serve as the transmitting station. No reactive effect between the relay transmitter and receiver will in this case be produced, and the means for preventing this forms the most interesting portion of this invention. Whatever currents are set up in the coil, 4, by the action of the microphone contact, *C*, will divide equally between the primary coils, 1 and 2, passing through them in opposite directions. These coils will therefore act differentially upon the coil, 3, and their effects will be neutralized. No current will be caused to flow in the circuit containing coil, 3, and the relay magnet, *M*, and therefore no reactive effect will be produced upon the transmitter. In other words, any current flowing in either line circuit will induce currents in the local circuit containing the magnet, *M*, while currents set up in the coil, 4, by virtue of currents flowing through the magnet, *M*, will produce no effect in turn upon the coil, 3.

A great many improvements have been made in the mechanical construction of the telephone relay, but with few exceptions they have embodied only the idea of combining an ordinary transmitter with an ordinary receiver. In 1897, however, a relay was

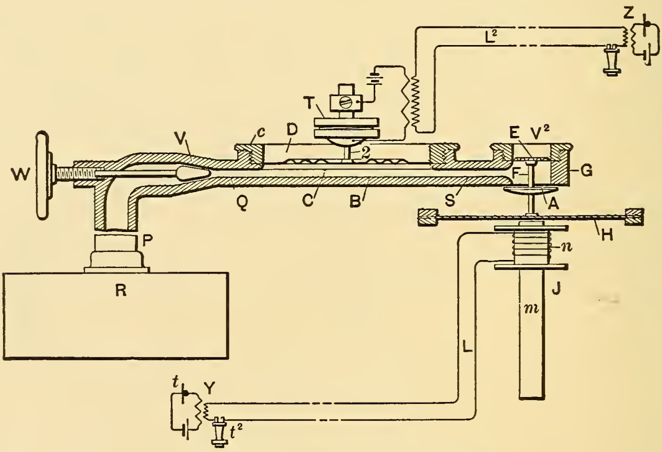

FIG. 531.—ERDMAN REPEATER.

devised by Mr. A. W. Erdman, and is shown in Fig. 531, and embodies probably the most radical departure in the structure of telephone repeaters of all since the first was produced. In this figure *L* is the transmitting line, and L^2 the receiving line. *H* is the diaphragm of the receiving instrument and is used to operate the balanced valve, V^2, which by its motion to and fro varies the flow of an otherwise constant stream of air flowing through the chamber, *C*. This chamber is covered by a flexible diaphragm, *D*, which is caused to vibrate by the changes in pressure within the chamber produced by the motion of the valve, V^2. The diaphragm, *D*, serves to operate a microphone, *T*, which in this case consists of the variable resistance button of the solid-back transmitter. *R* is a reservoir containing compressed air, and *V* a reducing valve by which the amount of air escaping through the chamber may be regulated. In the balanced valve, V^2, E is a flexible diaphragm and A a movable portion which controls the outlet. The centers of the diaphragm, E, and of the valve plate, A, are connected by the rod, F, to the center of the receiving diaphragm, H. The balancing of the valve, V^2, renders it extremely sensitive, so that it may be set in motion by the delicate movements of the diaphragm, H. In operation, the vibrations of the diaphragm, H, caused by currents in the transmitting line, L, cause the balanced valve, V^2, to vary the opening of the air outlet. This produces changes in pressure within the air chamber under the diaphragm, D, which cause that diaphragm to vibrate and thus actuate the microphone in the usual

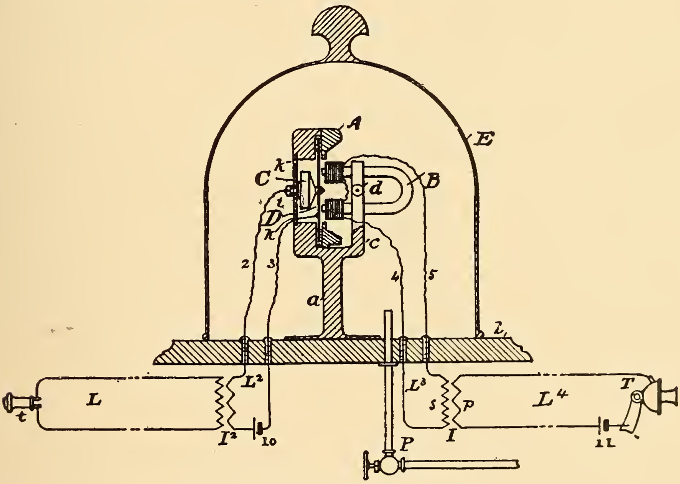

FIG. 532.—STONE REPEATER.

way, thus causing currents to flow in the receiving line, L^2, in the usual way. No reports have been made public concerning the results obtained in actual practice with this repeater, but it seems that it may be a step toward the solution of this difficult problem. Instead of employing the mechanical connection commonly used between the diaphragms of the transmitting and receiving mechanisms, Mr. Erdman has, in his current of air or gas, chosen one of the most delicately subtile mediums known.

Another relay, devised by Mr. John S. Stone of the American Bell Telephone Co., is shown in Fig. 532. This relay differs in the essentials of its construction from those of the older type only in that its entire working parts are inclosed in a vacuum chamber. The repeater, together with the circuits of the two connected lines, is shown in this figure, in which T is the transmitter of the sending station and t the receiver of the receiving station. These are connected with the repeater by lines, L^4 and L, respectively, the line circuits being associated with the repeater circuits by induction coils, I and I^2, in the usual manner. B is a polarized electromagnet whose poles are in proximity to the diaphragm, D. C is the variable resistance button of a solid-back transmitter, the front electrode of which is rigidly secured to the center of the diaphragm, D, while the back electrode is rigidly secured by means of a cross-piece to the frame, A, which also supports the diaphragm, D, and the electromagnet, B. E is a bell jar closely fitted to the base, b, by an air-tight joint. The air from within the chamber may be withdrawn by the pipe, P, attached to an air pump. It is

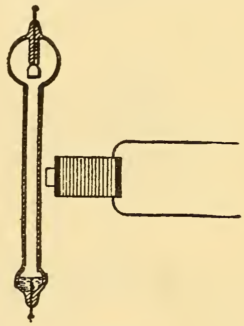

FIG. 533.—COOPER-HEWITT REPEATER.

said that the removal of the air from within the chamber brings about a decided improvement in the operation of the repeater. Concerning the results obtained, Mr. Stone says, "The messages automatically transferred by it from one circuit to another are reproduced in the receiving telephone of the second circuit with a well-defined gain in volume or loudness, and without any substantial distortion or offsetting loss in clearness of articulation." If this claim is borne out in practice, the production of this relay should prove a step of some importance in the matter of long-distance telephony.

It has seemed plausible that very feeble currents received at the relay station would, by virtue of the delicate action of the microphone, be able to produce comparatively large changes in resistance of the local relay circuit associated therewith, and that these changes in resistance would produce correspondingly great changes in the current of the local battery at that station, which changes would act inductively on the second line wire with perhaps as much energy as that imparted to the original circuit. As a matter of fact, however, no gain in the volume of transmission has ever been commercially effected by this method. The telephone repeater may be made to work perfectly on ordinary lines, but it has not shown its ability to transmit speech between two distant points any better than or quite as well as could be done by direct transmission without the use of the relay at all. The amount of energy received by the electromagnet of the relay is so exceedingly small that it does not seem capable of producing the desired mechanical effect upon the microphone contact. Something more subtile in its action than the microphone contact, a medium devoid of all mechanical inertia, is evidently needed.

A step that is apparently in the right direction has recently been made by Mr. Peter Cooper Hewitt, of mercury lamp fame. He has found that the resistance of the mercury vapor column is extremely sensitive to changes in the magnetic flux within which it lies. He therefore brings the mercury vapor tube, *A*, Fig. 533, within the field of an electromagnet, *B*, so that changes in the field set up by the latter will produce changes in the resistance of the mercury tube. The magnet, therefore, forms the receiving device and the tube the resistance-varying device, when connectd as a telephone repeater. This is certainly of great scientific interest.

CHAPTER XXXVIII.

WIRE FOR TELEPHONE USE.

THE wires in use in telephone work are, at present, of copper and iron exclusively. Aluminum will probably, as the price of its manufacture is cheapened, come into extensive use, and it will not be surprising if it eventually supersedes both copper and iron for all except very long distance service. Iron possesses a slight advantage over copper on account of its tensile strength, and a very decided advantage in point of first cost, but in all other respects copper is vastly superior.

The tensile strength of a wire is its ability to resist a pulling stress and the amount of tensile strength is usually expressed in the number of pounds necessary to break a given wire. The breaking stress varies, of course, in the same metal with the size of the wire, that is, with the area of its cross-section. The weight of a given wire varies also in the same ratio, and, therefore, in order to have a convenient method for designating the breaking strength applicable alike to all sizes of wire of a certain grade, the breaking stress is frequently expressed in the number of times the weight per mile of the given wire necessary to break it.

Thus, knowing that a certain grade of wire has a breaking strength equal to two and one-half times its weight per mile, all that we have to find out in order to know the breaking strength of any size of this same grade, is the weight per mile of that size. For example, a No. 12 iron wire weighs 165 pounds per mile. This we find out by consulting any table giving the weight of wire, or by weighing a known length of wire. Knowing that the breaking strength of this wire is $2\frac{1}{2}$ times its weight per mile, we may at once arrive at the conclusion that the breaking strength of this particular size is $2\frac{1}{2}$ times $165 = 412\frac{1}{2}$ pounds.

The most important electrical property of line wire is its conductivity per unit area of cross-section. A conductor of iron may be made to have a resistance as low as that of a copper conductor, by giving it about seven times the cross-sectional area. In doing this, however, we make its inductive capacity greater, and, as has been shown, this is a disadvantage. Besides this, the greater weight of an iron wire of the same conductivity as that of a copper wire is a very objectionable feature, in that it gives the insulators and poles or other supports, a far greater burden than is necessary.

The resistance of a conductor varies, of course, inversely as the conductivity, and therefore inversely as the cross-sectional area of a uniform wire. Since the weight also varies with the cross-section, it follows that the resistance of a wire varies inversely as its weight per mile. A very convenient method of comparing the relative resistance of various grades of metal used in making wire is to take as the standard of conductivity the *weight per mile-ohm.* The weight per mile-ohm of a conductor is the weight of a conductor a mile long, and of such uniform cross-section as to have a resistance of one ohm. Evidently the better the conductor, the smaller such a wire would be, and therefore a low value of the weight per mile-ohm will indicate a high conductivity. The relative conductivities of any two metals may be determined, knowing the weight per mile-ohm of each. Thus, if the weight per mile-ohm of pure copper is 873.5 and that of a sample wire is 896, then calling the conductivity of pure copper 100 per cent. the conductivity of the sample will be

$$\frac{873.5}{896} \times 100 = 97 \text{ per cent.}$$

In making conductivity tests, the resistance of the sample tested is measured, and from it is calculated the weight per mile-ohm for that sample. This value can then be compared with the weight per mile-ohm of pure copper as in the above example. By doing this the trouble of calculating the resistance of a pure copper wire of the same dimensions as that of the sample is saved.

The diameter of wire for electrical purposes is usually expressed according to some gauge, and there are, unfortunately, a number of such. Most of the different gauges have been brought into existence by various wire manufacturers and used in connection with their particular products only. In these gauges the sizes of wires are referred to by numbers, and in nearly every case the smaller numbers refer to the larger wires. A better way, and one which is coming into more common use, is to refer to the diameter in thousandths of an inch or in mils, as thousandths of an inch are called. A very convenient way of expressing the area of a wire is to give its cross-section in circular mils; a circular mil being the area of a circle, the diameter of which is one mil, or 1-1000 of an inch. This is better than expressing the area in square inches, because the area in circular mils is obtained simply by squaring the diameter of the conductor in mils. This very simple relation between the area in circular mils and the diameter in mils is true, because the area of two circles are to each other as the square of their diameters. To reduce the area expressed in circular mils to square inches, multiply it by .7854 and divide by 1,000,000.

It is a matter of importance, when purchasing wire in any quantity, to measure its diameter accurately, so as to be sure of obtaining the size ordered. It is not an uncommon thing to order a wire in one gauge and have your order filled in another, and the latter gauge usually happens to be smaller than the former.

Circular wire gauges, such as is shown in Fig. 534, are obtainable and serve their purpose well, but are subject to the disad-

FIG. 534.—CIRCULAR WIRE GAUGE.

vantage that a separate gauge is necessary for each particular set of gauge numbers. These gauges are used by inserting the wire into the notches in its periphery until one is found which it just fits; the number corresponding to that notch is then the gauge number of the wire. A far better gauge, although one which is at first a little puzzling to use, is that shown in Fig. 535 and known as the micrometer. It consists of a yoke of tempered steel, in one side of which is mounted a graduated thumbscrew. The wire or other object to be measured is placed between the end of the thumbscrew and the anvil on which it rests when closed, and the screw turned until it makes light contact with the object on both sides. These screws are arranged with forty threads to the inch, so that one complete turn of the screw in a left-handed direction will open the micrometer 1-40 of an inch. The edge of the collar carried by the screw is divided into twenty-five equal parts, so that a turn of the screw through one of these divisions will open the micrometer 1-25 of 1-40, or 1-1000 of an inch. The shaft on which the collar turns is divided into tenths of an inch, and each 1-10 is subdivided into four parts. Thus a rotation of twenty-five divisions on the collar will equal one division on the shaft, or .025 inch. If the collar is turned so as to expose the first division on the shaft and thirteen divisions on itself, then the distance which the jaws have opened will be equal to $.025 + .013 = .038$.

The Brown & Sharpe gauge, usually abbreviated B. & S., is probably used more for copper wire than any other gauge, while the Birmingham Wire Gauge, abbreviated B. W. G., is used to a greater extent for iron wire.

A decided advantage in the B. & S. gauge over any of the others

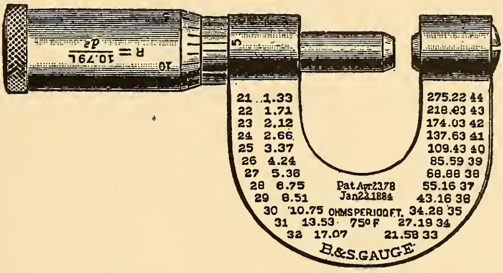

FIG. 535.—MICROMETER.

is that the areas of the cross-sections of the various sizes of wire diminish according to a geometrical progression as the gauge number increases. The ratio in this progression is 1.26, or more accurately the cube root of two. From this it follows that when we have increased three sizes we have doubled the sectional area of the wire; and, on the other hand, when we have diminished three sizes we have reduced the cross-section one-half. A very convenient thing to remember in the B. & S. gauge in connection with copper wire is that the diameter of a No. 10 wire is 1-10 of an inch, and that the resistance per thousand feet of this wire is one ohm. These figures are not perfectly accurate, but enough so for most practical purposes. If one desires to make an approximate calculation regarding the size of any wire, he may do so by remembering these figures, which is readily done because of the number of times the number ten occurs in them. For example, suppose it were desired to find the resistance of a No. 13 B. & S. gauge copper wire. Inasmuch as 13 is three sizes smaller than 10, the area of a No. 13 wire will be one-half that of the No. 10, and its resistance per thousand feet double that of the No. 10, or 2 ohms. If the resistance of a No. 14 instead of a No. 13 were desired, it could be found by finding the resistance of a No. 13, as before, and multiplying by 1.26, thus obtaining the result 2.52 ohms.

Table III. gives the relative sizes of various numbers of wire in several of the gauges which are or have been in use in this country.

IRON WIRE.

Iron wire corrodes so rapidly that it would be utterly useless for outdoor work were it not possible to protect it to some extent from the action of the weather. This is done by a process called galvanizing, which consists in coating wire with a thin film of metallic zinc. The process of manufacturing iron wire is briefly as follows: the iron, after being brought into the proper condition by various processes of rolling and purifying, is rolled into small rods, after which it is subjected to the process of "drawing." This process consists in pulling the rods through a series of dies, made of steel, each die being smaller than the one preceding it. This is necessarily done while the iron is cold and is termed "cold drawing." The successive drawings of the wire through the dies serves not only to reduce its cross-section, but also to render it excessively hard and brittle, and it is necessary, therefore, to anneal it frequently between the drawings. After the wire has been drawn to the proper size it is annealed and inspected and is then ready for galvanizing. The wire, in order to thoroughly clean its surface, is "pickled" in diluted sulphuric acid for a considerable length of time, after which it is thoroughly washed in order to remove all traces of acid. It is then immersed in hydrochloric acid. The wire is then rolled from one reel to another and between these reels it passes first through a furnace heated to a very high degree, immediately afterward through a vat containing a solution of hydrochloric acid which cools the wire and removes any oxides that have formed during the drawing, and then through a second vat containing molten zinc maintained at a constant temperature by a furnace underneath. The time between the immersion in the last acid bath and the zinc bath is short, because these vats are placed very close together, and the metal therefore has no chance to oxidize.

As the proper galvanizing of iron wire is, all things considered, the most important step in its manufacture, it is very essential that

TABLE III.—Table Showing Difference Between Wire Gauges in Decimal Parts of an Inch.

No. of Wire Gauge.	American or Brown & Sharpe.	Birmingham or Stubs'.	Washburn & Moen Manufacturing Co., Worcester, Mass.	Trenton Iron Co., Trenton, N. J.	New British, or Standard.	Old English from Brass Manufacturers List.	No. of Wire.
000000	....	....	.46	.....	.464	....	000000
00000	....	...	.43	.45	.432	....	00000
0000	.46	.454	.393	.4	.4	....	0000
000	.40964	.425	.362	.36	.372	....	000
00	.3648	.38	.331	.33	.348	...	00
0	.32495	.34	.307	.305	.324	....	0
1	.2893	.3	.283	.285	.3	....	1
2	.25763	.284	.263	.265	.276	....	2
3	.22942	.259	.244	.245	.252	....	3
4	.20431	.238	.225	.225	.232	....	4
5	.18194	.22	.207	.205	.212	....	5
6	.16202	.203	.192	.19	.192	....	6
7	.14428	.18	.177	.175	.176	....	7
8	.12849	.165	.162	.16	.16	....	8
9	.11443	.148	.148	.145	.144	....	9
10	.10189	.134	.135	.13	.128	....	10
11	.090742	.12	.12	.1175	.116	....	11
12	.080808	.109	.105	.105	.104	....	12
13	.071961	.095	.092	.0925	.002	....	13
14	.064084	.083	.08	.08	.08	.083	14
15	.057068	.072	.072	.07	.072	.072	15
16	.05082	.065	.063	.061	.064	.065	16
17	.045257	.058	.054	.0525	.056	.058	17
18	.040303	.049	.047	.045	.048	.049	18
19	.03589	.042	.041	.039	.04	.04	19
20	.031961	.035	.035	.034	.036	.035	20
21	.028462	.032	.032	.03	.032	.0315	21
22	.025347	.028	.028	.027	.028	.0295	22
23	.022571	.025	.025	.024	.024	.027	23
24	.0201	.022	.023	.0215	.022	.025	24
25	.0179	.02	.02	.019	.02	.023	25
26	.01594	.018	.018	.018	.018	.0205	26
27	.014195	.016	.017	.017	.0164	.01875	27
28	.12641	.014	.016	.016	.0148	.0165	28
29	.011257	.013	.015	.015	.0136	.0155	29
30	.010025	.012	.014	.014	.0124	.01375	30
31	.008928	.01	.0135	.013	.0116	.01225	31
32	.00795	.009	.013	.012	.0108	.01125	32
33	.00708	.008	.011	.011	.01	.01025	33
34	.006304	.007	.01	.01	.0092	.0095	34
35	.005614	.005	.0095	.009	.0084	.009	35
36	.005	.004	.009	.008	.0076	.0075	36
37	.004453	....	.0085	.00725	.0068	.0065	37
38	.003965	....	.008	.0065	.006	.00575	38
39	.003541	....	.0075	.00575	.0052	.005	39
40	.003144	....	.007	.005	.0048	.0045	40

reliable tests are made before purchasing wire for outdoor use. Fortunately such a test is a very easy thing to make. Several samples of the wire should be selected at random. Each should then be immersed in a saturated solution of sulphate of copper for a period of seventy seconds. It should then be withdrawn and wiped clean with a cloth. This process is repeated in all four times. If, at the end of the fourth immersion, the wire appears black, as it did at the end of the first immersion, the zinc has not all been removed and the galvanizing may be said to have been well done; but if the wire has a copper color, either as a whole or in spots, it shows that the zinc has been eaten away and that copper has deposited itself upon the iron wire. In this case the wire should be rejected.

Iron wire which is thoroughly well galvanized is at best rather short-lived, and poor galvanization may result in the total loss of the wire within a year. Well galvanized iron wire has been known to last twelve years, but the conditions were very favorable. Four to six years probably represents a fair average for the life of wire of this kind, but cases are frequent where wires have been so corroded within a year as to make their replacement necessary. In factory districts and in railroad yards where the gases from furnaces come in constant contact with the wire, the life of the zinc coating is comparatively short.

The grades of galvanized iron wire as used by the manufacturers are, if not well understood, very misleading. They are referred to in the following terms: Extra Best Best, Best Best, Best, and Steel, the first three in this list being abbreviated E. B. B., B. B., and B.

Extra Best Best wire is of a very soft, high grade material, having the highest conductivity of all. It has sufficient tensile strength for all ordinary purposes, while its conductivity is far superior to that of the other grades. It has a breaking strength of three times its weight per mile, and the weight per mile-ohm varies from 4500 to 4900, 4700 being a good average.

Best Best is less uniform and tough than the above, but is somewhat better mechanically. It has a breaking strength of about 3.3 times its weight per mile, and its weight per mile-ohm varies from 5300 to 6000.

Best should undoubtedly have been called worst, for as a rule it is a rather poor quality of wire, and before accepting it it should be very carefully tested. It is harder and less pliable than the preceding grades, and has a weight per mile-ohm of about 6500.

Steel wire, which is in reality a rather low grade Bessemer process wire, is much stronger than any of the above grades, but is greatly lacking in conductivity. It has a breaking strength of about 3.7 times its weight per mile, and its weight per mile-ohm varies between 6000 and 7000 pounds.

Steel wire is largely used for telephone work on very short lines, and if well galvanized serves its purpose admirably. In short city lines no difference can be noticed so far as talking results are concerned between an iron or steel and a copper circuit. The steel wire is, as a rule, cheaper than an Extra Best Best or the Best Best, and has the additional advantage of greater mechanical strength.

The following specifications are in substance those used by the Western Union Telegraph Company in selecting their iron wire:

(1) The wire shall be soft and pliable, and capable of elongating fifteen per cent. without breaking, after being galvanized.

(2) Great tensile strength is not required, but the wire must not break under a less strain than two and one-half times its weight in pounds per mile.

(3) Tests for ductility will be made as follows: Pieces of wire shall be gripped by two vises six inches apart and twisted. The full number of twists must be distinctly visible between the vises on the six-inch piece. The number of twists in a piece six inches long shall not be under fifteen.

(4) The electrical resistance of the wire in ohms per mile at a temperature of 68 degrees Fahrenheit must not exceed the quotient arising from dividing the number 4800 by the weight of the wire in pounds per mile. This is equivalent to saying that the weight per mile-ohm must not exceed 4800. The coefficient .003 will be allowed for each degree Fahrenheit in reducing to a standard temperature.

(5) The wire must be well galvanized and capable of standing the test of dipping into sulphate of copper as stated above.

The British Post Office Specifications require a value of the weight per mile-ohm of 5323.

Table IV., taken from Roebling, gives the weight, breaking strength and resistance of the various sizes and grades of galvanized iron wire:

TABLE IV.—GALVANIZED IRON WIRE.

Numbers B. W. G.	Diameters in Mills.	Weights, Pounds.		Breaking Strengths, Pounds.		Resistance Per Mile in Ohms.		
		1000 Feet.	One Mile.	Iron.	Steel.	E. B. B.	B. B.	Steel.
0	340	304	1607	4821	9079	2.93	3.42	4.05
1	300	237	1251	3753	7068	3.76	4.4	5.2
2	284	212	1121	3363	6335	4.19	4.91	5.8
3	259	177	932	2796	5268	5.04	5.9	6.97
4	238	149	787	2361	4449	5.97	6.99	8.26
5	220	127	673	2019	3801	6.99	8.18	9.66
6	203	109	573	1719	3237	8.21	9.6	11.35
7	180	85	450	1350	2545	10.44	12.21	14.43
8	165	72	378	1134	2138	12.42	14.53	17.18
9	148	58	305	915	1720	15.44	18.06	21.35
10	134	47	250	750	1410	18.83	22.04	26.04
11	120	38	200	600	1131	23.48	27.48	32 47
12	109	31	165	495	933	28.46	33.3	39.36
13	95	24	125	375	709	37.47	43.85	51.82
14	83	18	96	288	541	49.08	57.44	67.88
15	72	13.7	72	216	407	65.23	76.33	90.21
16	65	11.1	59	177	332	80.03	93.66	110.7
17	58	8.9	47	141	264	100.5	120.4	139.
18	49	6.3	33	99	189	140.8	164.8	193.8

COPPER WIRE.

Copper wire is practically indestructible by exposure to ordinary climatic influences. After it is first put up it acquires a thin coating of oxide, and after that no change whatever takes place, so far as can be ascertained. The process of manufacturing copper wire is similar to that for iron wire, with the exception that no galvanizing is necessary. The process of drawing copper wire has been so greatly improved recently that the old fault, lack of mechanical strength, has been almost, if not quite, overcome. Copper wire is now drawn so as to possess a breaking strength of 60,000 pounds per square inch, which is quite equal to that of some grades of iron wire. The difference between hard-drawn copper wire and soft wire is due entirely to the fact that the hard-drawn wire is not annealed as often between the drawings. The value of the weight per mile-ohm is, for good commercial wire, 882 pounds, the wire having a tensile strength equal to about three times its weight per mile. For hard-drawn wire the percentage of elongation is not nearly so high as that for iron wire, being only about one per cent. before breaking.

The value in pounds per mile-ohm of pure annealed copper is 859, this being based on the international ohm.

In the following table, taken from Roebling's "Wire in Electrical Construction," the weights and resistances of the various B. & S. gauge numbers of copper wire are given:

TABLE V.—COPPER WIRE TABLE.

Numbers B. & S. Gauge.	Diameters in Mils.	Areas in Circular Mils.	Weights Per		Resistance Per 1000 Feet in International Ohms.	
			1000 Feet.	Mil.	At 60° F.	At 75° F.
0000	460.	211600.	641.	3382.	.04811	.04966
000	410.	168100.	509.	2687.	.06056	.06251
00	365.	133225.	403.	2129.	.07642	.07887
0	325.	105625.	320.	1688.	.09639	.09948
1	289.	83521.	253.	1335.	.1219	.1258
2	258.	66564.	202.	1064.	.1529	.1579
3	229.	52441.	159.	838.	.1941	.2004
4	204.	41616.	126.	665.	.2446	.2525
5	182.	33124.	100.	529.	.3074	.3172
6	162.	26244.	79.	419.	.3879	.4004
7	144.	20736.	63.	331.	.491	.5067
8	128.	16384.	50.	262.	.6214	.6413
9	114.	12996.	39.	208.	.7834	.8085
10	102.	10404.	32.	166.	.9785	1.01
11	91.	8281.	25.	132.	1.229	1.269
12	81.	6561.	20.	105.	1.552	1.601
13	72.	5184.	15.7	83.	1.964	2.027
14	64.	4096.	12.4	65.	2.485	2.565
15	57.	3249.	9.8	52.	3.133	3.234
16	51.	2601.	7.9	42.	3.914	4 04
17	45.	2025.	6.1	32.	5.028	5.189
18	40.	1600.	4.8	25.6	6.363	6.567
19	36.	1296.	3.9	20.7	7.855	8.108
20	32.	1024.	3.1	16.4	9.942	10.26
21	38.5	812.3	2.5	13.	12.53	12.94
22	25.3	640.1	1.9	10.2	15.9	16.41
23	22.6	510.8	1.5	8.2	19.93	20.57
24	20.1	404.	1.2	6.5	25.2	26.01
25	27.9	320.4	.97	5.1	31.77	32.79
26	15.9	252.8	.77	4.	40.27	41.56
27	14.2	201.6	.61	3.2	50.49	52.11
28	12.6	158.8	.48	2.5	64.13	66.18
29	11.3	127.7	.39	2.	79.73	82.29
30	10.	100.	.3	1.6	101.8	105.1
31	18.9	79.2	.24	1.27	128.5	132.7
32	8.	64.	.19	1.02	151.1	164.2
33	7.1	50.4	.15	.81	202.	208.4
34	6.3	39.7	.12	.63	256.5	264.7
35	5.6	31.4	.095	.5	324.6	335.1
36	5.	25.	.076	.4	407.2	420.3

Abbott gives the following specifications, which contain much information governing the requirements to be made of manufacturers in purchasing copper wire:

COPPER WIRE.

1. *Finish.*—Each coil shall be drawn in one length and be exempt from joints or splices. All wire shall be truly cylindrical and fully up to gauge specified for each size, and must not contain any scale, inequalities, flaws, cold shuts, seams, or other imperfections.

2. *Inspection.*—The purchaser will appoint an inspector, who shall be supplied by the manufacturer with all facilities which may be required for examining the finished product or any of the processes of manufacture. The inspector shall have the privilege of overseeing the packing and shipping of the samples. The inspector will reject any and all wire which does not fully come up to all the specification requirements. The purchaser further reserves the right to reject on reception any or all lots of wire which do not fulfill the specifications, even though they shall previously have been passed or accepted by the inspector.

3. *Apparatus.*—The manufacturer must supply at the mill the necessary apparatus for making the examination called for. This apparatus shall consist of a tension-testing machine, a torsion-testing machine, an elongation gauge, an accurate platform scale, and an accurate bridge and battery. Each of these pieces of apparatus may be examined by, and shall be satisfactory, to the inspector.

4. *Packing for Shipment.*—When ready for shipment each coil must be securely tied with not less than four separate pieces of strong twine and shall be protected by a sufficient wrapping of burlap so the wire may not be injured during transportation. The wrappings shall be placed upon the wire bundles, after they have been coiled and secured by the twine. The diameter of the eye of each coil shall be prescribed by the inspector, and all coils shipped shall not vary more than two inches in the diameter of the eye.

5. *Weight.*—Each coil shall have its length and weight plainly and indelibly marked upon two brass tags, which shall be secured to the coil, one inside the wrapping and the other outside.

6. *Mechanical Properties.*—All wire shall be fully and truly up to gauge standard, as per B. & S. wire gauge. The wire shall

be cylindrical in every respect. The inspector shall test the size and roundness of the wire by measuring both ends of each coil, and also by measuring at least four places in the length of each coil. A variation of not more than 1½ mil on either side of the specified wire-gauge number will be allowed, and the wire must be truly round within one mil upon opposite diameters at the same point of measurement. The strength of the wire shall be determined by taking a sample from one end of each coil, 30″ in length. Of this piece 18″ shall be tested for tension and elongation by breaking the same in the tension-testing machine. The samples should show a strength in accordance with the following table:

TABLE VI.—BREAKING WEIGHT OF HARD-DRAWN AND ANNEALED COPPER WIRE.

Size of Wire, B. & S. Gauge.	Breaking Weight of Hard-Drawn—Pounds.	Breaking Weight of Annealed—Pounds.
0000	9971	5650
000	7907	4480
00	6271	3553
0	4973	2818
1	3943	2234
2	3127	1772
3	2480	1405
4	1967	1114
5	1559	883
6	1237	700
7	980	555
8	778	440
9	617	349
10	489	277
11	388	219
12	307	174
13	244	138
14	193	109
15	153	87
16	133	69
17	97	55
18	77	43
19	61	34
20	48	27

A variation of 1½ per cent. on either side of the tabular limits will be accepted by the inspector. The elongation of the wire must be at least three per cent. for all sizes larger than No. 1; 1½ per cent. from No. 1 to No. 10, and 1 per cent. for sizes less than No. 10, for hard-drawn copper wire. The remainder of the sample selected will be tested for torsion. The torsion sample will be twisted in the torsion-testing machine to destruction, one foot in length being placed between the jaws of the machine. Under these circumstances hard-drawn copper wire shall show not less than 20 twists for sizes over No. 1; from 40 to 90 twists in sizes from No. 1 to No. 10; and not less than 100 twists in sizes less than No. 10. Should the sample selected from one end of each coil show failure to come up to the specifications, the inspector may take a second sample from the other end of the coil. If the average of the results from both samples shall be within the specifications, the coil shall be accepted; if not within the specifications, the coil shall be rejected. The weight per mile shall be determined by carefully weighing 2 per cent. of the number of coils called for in the contract, and the weight thus obtained shall correspond, within 2 per cent., on either side of the result given in the following formulæ.

$$\text{Weight per mile} = \frac{CM}{62.567};$$

$$\text{Weight per 1000 ft.} = \frac{CM}{330.353}$$

7. *Electrical Properties.*—The electrical properties of the wire shall be determined by the inspector selecting 3 per cent. of the coils, and from them taking lengths of 100 ft., 500 ft., or 1000 ft., at his discretion, and measuring the conductivity of the same with a standard bridge. For soft-drawn copper wire the following resistance per mil-foot will be assumed:

TABLE VII.—RESISTANCE OF COPPER WIRE AT VARIOUS TEMPERATURES.

Temperature in Degrees F.	Resistance, Legal Ohms.	Temperature in Degrees F.	Resistance, Legal Ohms.
0	8.96707	60	10.20253
10	9.16413	70	10.42083
20	9.36473	80	10.64268
30	9.56887	90	10.86806
40	9.77655	100	11.09698
50	9.98777		

For hard-drawn wire the resistance per mil-foot shall be 1.0226 times the foregoing figures. All wire shall be within 2 per cent. of the above figures.

So far in this chapter only bare wires such as are used in outside construction work have been considered. The subject of insulated wire is no less important, but is more difficult to treat of comprehensively owing to the great variety of such wires as well as the great number of uses to which they are put. Wire having a single, double or triple wrapping of either cotton or silk, unimpregnated with insulating compound, may be classified under the general heading of magnet wire, as it is used almost exclusively for the winding of magnets. In telephone work, single silk magnet wire, by which is meant a copper wire wrapped with a single layer of silk, is by far the most common, and for most purposes by far the best. Silk, even in cases where high insulation is not of great importance, makes a much more economical insulation in telephone magnet work than cotton, because, on account of the extremely thin insulation afforded by silk a much greater number of turns may be put on a given spool with the same length of wire than when cotton insulation is used.

The thickness of the insulation of wire is a point concerning which even manufacturers of telephone apparatus have been negligent as to their own interests. The difference between the cost of winding a given magnet with a given number of turns with fine wire (say No. 36) with a 3-mil insulation and with a 1½-mil insulation is astonishing. Not only is the amount of silk required per pound of wire much less with the thinner insulation, but the length of wire required to secure the requisite number of turns is also greatly reduced when the thinner insulation is used, on account of the smaller diameter assumed by the coil.

Manufacturers of thin insulated wire are experiencing some trouble in securing a perfectly uniform covering of a thickness of only 1½ mil, but it can be done at a somewhat increased expense for labor. The consumer, however, would convince himself with a little thought and experimenting that the thinnest covering which affords ample protection, so far as insulation is concerned, is cheaper even when the wire costs a considerably greater price per pound.

There is a class of wire commonly known as office wire, which is used largely for the interior wiring of houses for such work as the installation of electric door bells, annunciators, etc., and was at one time largely used in telephone work. This consists of a copper wire insulated with one wrapping of cotton in one direction and another wrapping of cotton in another direction, the whole being saturated with paraffin. This wire is unsatisfactory from many points; it is not moisture proof, its insulation is not high, and, furthermore, it is highly inflammable.

For interior wiring now in telephone work a wire which is heavily coated with a good grade of rubber and afterwards braided over with cotton is being used to a greater and greater extent. For outside construction, such as is required in running drop wires from telephone poles to subscribers' premises and similar work, the best possible grade of rubber-covered wire is rapidly supplanting the cheaper grades, and the old so-called weather-proof wire containing no rubber is almost a thing of the past for this work.

The following specifications for No. 18 rubber-covered wire have been used by the engineers of one of the large independent operating companies:

RUBBER-COVERED TELEPHONE WIRE

(NO. 18 B. & S. G.).

WIRE:

The wire to be furnished under these specifications is No. 18 B. & S. G. rubber-covered copper wire.

The copper shall be soft drawn and shall have a conductivity of not less than 98 per cent.

The wire shall be perfectly symmetrical, uniform in quality, pliable, free from scales, inequalities, flaws, splits, and other defects.

KIND:

There are four different kinds of wire to be furnished.

First. Plain rubber insulated wire, twisted in pairs.

Second. Twisted pairs, of which each wire is insulated with rubber and then the braid woven on; the two separately braided wires then being twisted.

Third. Single wire, plain rubber covered.

Fourth. Single wire, rubber covered and then braided.

INSULATION:

The rubber compound shall be of the highest grade and of such composition as to be thoroughly waterproof and insure a permanently tough and lasting form of insulation.

The insulation must show a resistance of one megohm per mile after two weeks' submersion in water at 70 degrees Fahrenheit, and three days' submersion in lime water, and after three minutes' electrification at 550 volts.

The thickness of the rubber insulation shall be such that the diameter of the finished wire shall not be less than 3-32 of an inch under the braiding.

The insulation shall be applied to the copper wire so that it will be concentric with the wire, and of equal thickness at all places.

For the braided wire a close braid of cotton shall be put on covering the wire, and in one pair of the twisted, braided wire, a differently colored thread, either green or red, shall be woven in the braid, so that the wires of the pair shall be distinctly marked one from the other.

The color of the braiding shall be brown of an approved shade, to conform with samples submitted with the proposal.

COILS:

The wire shall be put up in coils, which shall contain continuous lengths of not less than 2000 feet, in which no joints or splices of any kind will be allowed.

CHAPTER XXXIX.

POLE LINE CONSTRUCTION.

THE poles most used in the United States are of Norway pine, chestnut, cedar and cypress. Southern pine is not as durable as Northern pine, although it is used to a large extent in the South. Canadian or Michigan cedar is, however, all things considered, the best wood to use.

The average life of the various woods mentioned are, according to Maver, as follows:

Norway pine	6 years
Chestnut	15 "
Cedar	12 "
Cypress	10 "

In choosing the kind of pole to be used, the locality must always be considered, for obviously it might be poor economy to bring cedar poles from Michigan for the reason that they would last perhaps a few more years than cypress poles, which would be cut on the ground.

Poles should be well seasoned before setting in the ground. This is accomplished by natural process of drying. Before seasoning, however, the pole should be peeled and all knots trimmed. It is easier to do this while the sap is in them than afterwards, and, moreover, the drying takes place in a shorter time if the bark is removed. If the pole is not seasoned before setting or before it is painted, where it is to be painted, the sap is almost sure to cause a dry rot, which will eventually destroy the pole. The worst feature of this trouble is that the defect is not noticeable on the surface and therefore is likely to cause trouble when least expected. A pole may have all external appearances of being perfectly sound and yet be a mere shell, so that, when subjected to some heavy storm it goes down, perhaps carrying many other poles with it.

Practice differs to some extent concerning the size of poles. Money saved, however, in the purchase of light poles is usually saved at a great cost in the future. Table VIII gives a list of the sizes which in most cases meet the demands of the best practice to-day. There is now a growing tendency to use in the best work, even heavier poles than these.

TABLE VIII.

Length.	Diameter at Top.	Diameter 6 ft. from Butt.	Length.	Diameter at Top.	Diameter 6 ft. from Butt.
25 feet.	7 inches.	9 inches.	50 feet.	7 inches.	14 inches.
30 "	7 "	10 "	55 "	7 "	16 "
35 "	7 "	11 "	60 "	7 "	17 "
40 "	7 "	12 "	65 "	7 "	18 "
45 "	7 "	13 "	70 "	7 "	20 "

Telephone companies that have been in the field long enough have learned that the days of "fence-post" construction are over, and that in the long run poor construction is much more expensive than good. To be sure, in many of the Independent installations it is a matter of necessity to use a medium construction throughout on account of the first expense, and in such case if the dimensions of the poles given in the table above are too expensive, they will at least serve as a standard at which to aim.

The number of wires to be carried on any pole line is also a question that will largely determine the diameter of the poles. On the corners, or where a heavy lead is dead-ended, to make connection perhaps with an underground cable, the poles used should be in many cases much larger than those given. In fact, in such cases the heaviest poles that can be had will be none too large.

The question of the number of poles to the mile is one that must be decided to meet the particular conditions of the line to be erected. The greater the number of poles the lower the insulation, but this is of no importance, and is more than offset by the greater freedom from breakage of wires and consequent decrease in the expense of maintenance when the poles are set closely together. In this country on long-distance lines the best practice dictates the use of from forty to fifty to the mile, although many lines are operated with thirty or less. As a rule, the greater the number of wires carried, the closer and heavier the poles should be. The liability of any particular locality to heavy sleet and wind storms is another factor in determining the size and distribution of poles. In the long-distance lines of the American Telegraph and Telephone Company the standard distance between the poles is 130 feet, making approximately forty to the mile.

In the past the standard has been, on long-distance lines, to use no pole shorter than 35 feet, many of course being necessarily much longer. Recent practice, however, seems to tend toward shorter poles, bringing the wires closer to the ground.

In cities poles varying from 30 to 60 feet are, as a rule, used. These are generally of cedar. It is frequently necessary to use a

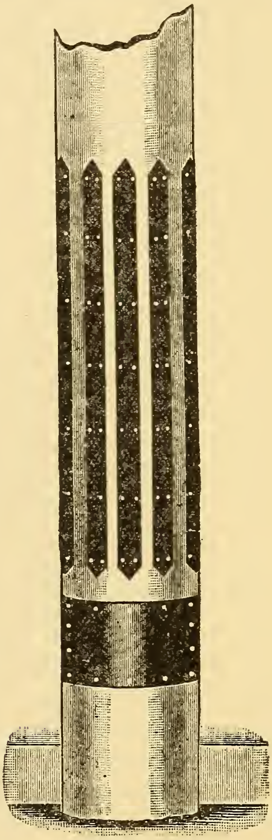

FIG. 536.—POLE STRIPS AND BUTT PLATES.

longer pole in city work in order that the line may be carried above electric light and power circuits.

It is often necessary to protect poles along the streets of towns and cities from the gnawing of horses hitched to them, and also from the wearing effects of wagon-hubs, which often greatly weaken the poles at a point where they are least able to stand it. Galvanized steel protecting strips are obtainable for the former purpose, and what are termed butt-plates, about 15 inches by 18 inches by 3-16 inch thick of the same material, may also be purchased from supply dealers for the latter purpose. A pole thus equipped is shown in Fig. 536. Attention has been recently called to the fact that butt-plates sometimes cause rotting of the pole by holding moisture. For this reason, ¼-inch strap iron, or, better still, regular 26-inch cross-arm braces fastened on with small lag screws and spaced about 1½ inches apart, seems better practice.

In Table IX. is given some useful information concerning the weights of poles of various sizes and the number to a single or double carload:

TABLE IX.—CEDAR POLES.

Single Cars.	Number in Load.
4 inches, 25 feet.	Not less than 175 and up to 225
5 " 25 "	" " 150 " " 200
6 " 25 "	" " 100 " " 125
7 " 25 "	" " 75 " " 100
6 " 30 "	" " 75 " " 100
7 " 30 "	" " 60 " " 80
7 " 35 "	" " 55 " " 75

Double Cars.	Number in Load.
7 inches, 40 feet.	Not less than 60 and up to 75
7 " 45 "	" " 50 " " 65
7 " 50 "	" " 40 " " 50
7 " 55 "	" " 35 " " 45
7 " 60 "	" " 25 " " 35
7 " 65 "	" " 20 " " 25

	Weights.	
	Green.	Seasoned.
4-inch top, 25 feet	200 pounds	155 pounds
5 " " 25 "	260 "	200 "
6 " " 25 "	325 "	250 "
7 " " 25 "	425 "	350 "
6 " " 30 "	425 "	350 "
7 " " 30 "	500 "	450 "
7 " " 35 "	750 "	650 "
7 " " 40 "	1,075 "	850 "
7 " " 45 "	1,150 "	1,000 "
7 " " 50 "	1,400 "	1,250 "
7 " " 55 "	1,875 "	1,650 "
7 " " 60 "	2,300 "	2,000 "
7 " " 65 "	2,800 "	2,500 "

Table X gives similar data regarding Norway pine poles.

TABLE X.—NORWAY PINE.

Length.	Top.	Weight in Pounds.	Number in Load.	Length.	Top.	Weight in Pounds.	Number in Load.
40 feet	7 inches	1,100	90	65 feet	7 inches	2,000	45
45 "	7 "	1,200	80	70 "	7 "	2,400	50
50 "	7 "	1,350	72	75 "	7 "	2,800	45
55 "	7 "	1,500	65	80 "	7 "	3,400	35
60 "	7 "	1,700	55	85 "	7 "	3,800	30

Twenty-five and 30-foot poles should be loaded on cars taking a minimum of 24,000 pounds; 35-foot poles on cars taking a minimum of 30,000 pounds; double loads (40 feet and longer), on two cars 30,000 each or 60,000 minimum for the double load.

All poles up to and including 7 inches—35 feet, will be loaded on single cars.

It is not customary in this country to treat poles with any preserving process, but it is always well to coat the pole for a distance of six feet from the butt with pitch before setting it. It is also well to give city poles two coats of good oil paint, and a very neat appearance is added if the lower portions are painted black or dark green to a distance of six feet above the ground, while the remaining portion is painted some light color.

In some quarters a process termed creosoting is meeting with favor for preserving telephone and telegraph poles. It is probably the cheapest of all effectual processes of this kind, and consists, briefly, in placing the pole in an air-tight cylindrical iron chamber, after which steam, at a pressure of about 100 pounds to the square inch, is admitted and the poles are subjected to this treatment for about four hours. This vaporizes the sap and wood acids, and completely sterilizes the poles throughout, killing all germs which might afterwards cause fungus and decay. When this is accomplished the steam is released and the chamber subjected to vacuum, by which all moisture and organic matter is extracted and the wood left in a porous condition. While in vacuum the chamber is kept hot by steam coils, thus aiding in the drying. The poles may now be called antiseptic, and are ready for the preserving fluid. After this dead oil of coal tar is forced into the cylinder under a heavy pressure, and it is found that it penetrates to the very heart of the poles, thus adding very materially to their lasting qualities. Cases are cited where poles treated by this method have been perfectly sound after having been in service for a period of twenty years.

A cheaper process involves the sterilization of the pole as above stated and then injecting into its pores a solution of chloride of zinc. This is sometimes followed by a treatment of dead oil of coal tar in order to prevent the subsequent dissolving of the chloride in moist climates.

Another process, termed vulcanizing, consists in heating the pole in a closed vessel for several hours to a temperature of about 500° F. The principle in this treatment is that the intense heat causes the sap in the wood to coagulate, after which it can produce no evil

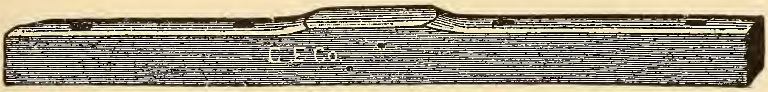

FIG. 537.—CROSS ARM.

effects. This would apparently be cheaper than creosoting, or the chloride of zinc process.

Several forms of structural iron or steel poles have recently been put on the market, for which are claimed low depreciation and low cost of maintenance as well as great strength and sightliness. They have not as yet been widely adopted.

The cross-arms carrying the insulators are preferably of sawed yellow pine, as shown in Fig. 537. The size in general use is $4\frac{1}{4}''$ by $3\frac{1}{4}''$. The lengths vary from 3 to 10 feet, according to the number of pins or insulators to be used. Table XI shows the lengths of the various standard cross-arms; also the spacings of the pin-holes.

TABLE XI.

Length.	Number or Pins.	End.	Spacings.	
			Center.	Sides.
3 feet	2	4 inches	28 inches	
4 "	4	4 "	16 "	12 inches
5 "	4	4 "	18 "	17 "
6 "	4	4 "	22 "	21 "
6 "	6	4 "	16 "	12 "
8 "	6	4 "	18 "	17½ "
8 "	8	4 "	16 "	12 "
10 "	8	4 "	17½ "	15¾ "
10 "	10	4 "	16 "	12 "

The standard size of pin, Fig. 538, for the above arm has a $1\frac{1}{2}$-inch shank, and arms of this size are usually bored accordingly. They are also bored, as shown in Fig. 537, with two $\frac{1}{2}$-inch holes for lag-screws used in attaching them to the poles.

Another size of cross-arm, called the telephone arm, once came into use to a considerable extent for cheaper installation, but has

FIG. 538.—INSULATOR PIN.

now been generally abandoned in good construction. The size of this arm is $2\frac{3}{4}$ by $3\frac{3}{4}$, being $\frac{1}{2}$ inch smaller in each dimension than the standard. These arms are usually bored for $1\frac{1}{4}$-inch pins and the length of a ten-pin arm is only $8\frac{1}{2}$ feet.

All cross-arms should be given two coats of good metallic paint, usually red, before setting in position. In order to attach them to the pole a gain is cut in the pole of such dimensions as to accurately fit the longest side of the cross-arm. The gain, as a rule, should

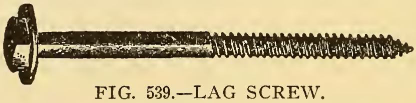

FIG. 539.—LAG SCREW.

not be more than one-half inch deep, however, for the reason that a greater depth is likely to weaken the pole unduly. The gain should be given two coats of good white lead before the cross-arm is put in place. The common way of attaching the cross-arms to the pole is by two lag-screws of the type shown in Fig. 539. These are of such length as to reach almost through the pole, and their threads are cut in such a manner that they may be driven part of

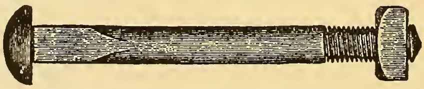

FIG. 540.—CARRIAGE BOLT.

the way home. A much better practice now is to attach the cross-arm to the pole by means of a single carriage bolt, or "through bolt," Fig. 540, extending entirely through the arm and pole, being secured by a nut and a washer. This method has an advantage over the use of lag-screws in point of strength and durability. The hole for the carriage bolt may be bored perfectly smooth and clean, and of such size as to accurately fit the carriage bolt, so there is little chance for rotting. Another way, not easy to follow on account of the varying sizes of pole tops, is to bore no hole whatever through the pole, but to attach the cross-arm by means of a U-bolt extending through the cross-arm and around the pole and secured from the front by means of two nuts. This is little used.

FIG. 541.—REINFORCED CROSS-ARM BRACE.

The arm is further braced in any case by the use of wrought-iron or steel strips, commonly termed cross-arm braces. These usually consist of straight flat bars not smaller than $1\frac{1}{4}$ inch wide by $\frac{1}{4}$ inch thick, and varying in length from 20 to 30 inches. A hole is usually punched in one end for the reception of a $\frac{1}{2}$-inch lag-screw and in the other for a $\frac{3}{8}$-inch carriage bolt. The two braces for each cross-arm are attached by single lag-screws to the pole at a distance varying from 16 to 18 inches from the bottom of the arm.

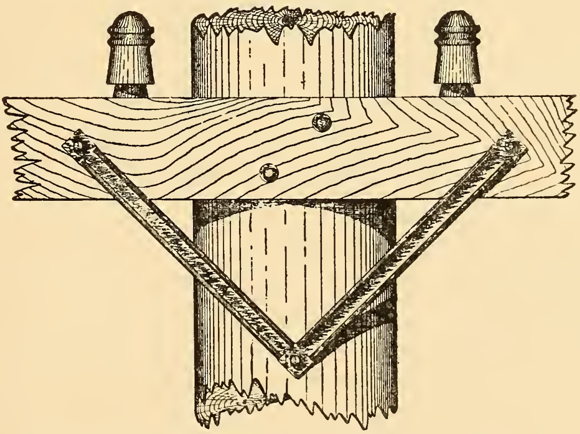

FIG. 542.—METHOD OF ATTACHING BRACES.

The other ends of the braces are attached by carriage bolts to the cross-arms at points about equal distances from the pole.

A new cross-arm brace has recently been produced, this being formed up of sheet steel with reinforced edges. The reinforcements are formed by rolling the metal into hollow cylinders along the edges of the brace. This seems meritorious in that it is lighter than the regular solid brace and is said to be stronger and cheaper. It would, apparently, however, be more liable to rust through. This brace and the usual method of using braces are shown in Figs. 541 and 542, respectively.

In all cases suitable washers should be used under carriage bolt nuts and heads, and under lag-screw heads where they are used in attaching an arm to the pole. All hardware to be used on poles, such as bolts, washers, braces, etc., should be thoroughly galvanized and should be made to stand the same test that is required on galvanized iron wire—that is, four successive plunges of seventy seconds each in a saturated solution of sulphate of copper without removing all of the zinc coating.

The pins most commonly used are of locust or of oak. The

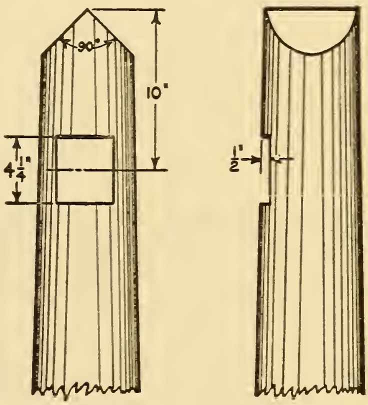

FIG. 543.—ROOFING AND GAINING.

former is by far the better, as it is stronger and more capable of resisting the action of the weather. It is, however, nearly twice as expensive as oak. The pins should be turned from split wood in order that they may not be cross-grained, and all pins should be given two coats of the same kind of paint that is used on cross-arms, or dipped in white lead just before driving them into the cross-arm. They should be nailed in the cross-arm with a sixpenny nail.

In some cases on corners, or in places where excessively heavy strain will be brought upon a pin, it is advisable to use wrought-iron or steel pins, but these must be used with caution, as in many cases they have proven inferior to wooden pins, being so soft that they bend to a horizontal position when subjected to the strain.

The top of the pole should be roofed as shown in Fig. 543. The center of the first gain should be about 10 inches below the peak of the roof. The spacing between cross-arms depends on circumstances. For city work 18 or 20 inches between centers is good practice. For toll line work this spacing should not be less than 20 inches, and in some cases the American Telephone and Telegraph Company use 24 inches.

The insulators used in this country are universally made of glass. Blown glass has been found to be much superior in insulating qualities to molded glass, but the latter is so very much cheaper that it is always furnished. Fig. 544 shows a form of insulator largely used in telephone work, called the "pony" insulator. There is another style, termed the "double-petticoat" insulator. It is so termed from the fact that it has two downwardly projecting flanges

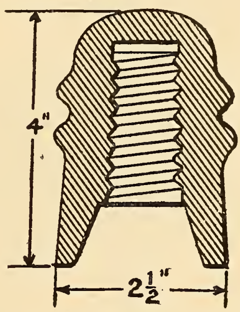

FIG. 544.—STANDARD PONY INSULATOR.

or "petticoats," the idea of this being that the path for leakage from the line to the pin is thereby rendered considerably longer, the leakage current having to pass up and down the surfaces of both petticoats in series.

For making transpositions a double glass insulator, Fig. 545, is used. This requires a longer pin than the standard.

In an interesting series of experiments described by Abbott, it was found that the insulating quality of glass insulators varied largely with the condition of the surface of the insulator. These experiments were conducted over a period of one hundred and fifty days, observations being made once a day. The general result indicated that the greatest loss in insulation occurred during foggy or misty weather. During heavy rainstorms the insulation was somewhat higher and after the storm, when the insulators had been dried, the resistance of the line was considerably higher, owing to the cleaner condition of the surface. In good weather the double-petticoat insulators gave much higher resistance than the single or corresponding size, but during a rainstorm a double-petticoat form was inferior to the single, although it was found to dry more rapidly after a storm.

The determination of the pole line route is a matter of no small importance. Right of way must be secured, and this usually calls forth all the ingenuity of the party unfortunate enough to be assigned to that duty. Before distributing the poles and other material the route should be thoroughly studied in every detail. Stakes should be driven marking the location of the poles. It should be borne in mind in locating these stakes that bends in the pole line should be avoided wherever possible, that the ground should be of such nature as to form as good a support as possible for the pole, that there shall be no interference from trees, houses or other poles, and lastly

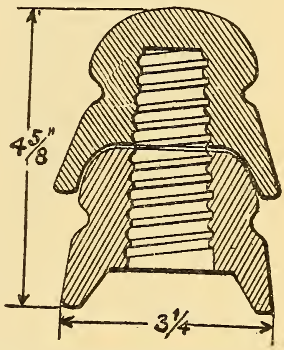

FIG. 545.—DOUBLE-GLASS TRANSPOSITION INSULATOR.

that the route shall be as direct as possible. When a turn must be made it should be so located, if possible, that the guy wire required to hold up the corner will have suitable anchoring ground. Lack of attention to these preliminary details too often brings an endless amount of trouble in the way of rehandling of poles, redigging of holes and similar useless labor.

When the ground is level or gently undulating, no provision need be made for grading the pole tops. Where, however, the country is hilly it is well to make a survey of the route with a level, placing the instrument between each successive pair of stakes and taking a front and back sight from each position to the adjacent stakes. A record of the data thus obtained will enable one to plat the vertical section of the route. The profile of the pole tops may then be platted, care being taken to smooth out all sharp bends in it. This is accomplished by putting the tallest poles in the hollows and the shortest on the hilltops. The same results may be accomplished, though not so well, without the use of the level, but it requires an experienced eye to do it to best advantage.

After having decided on the location of the poles, the length of

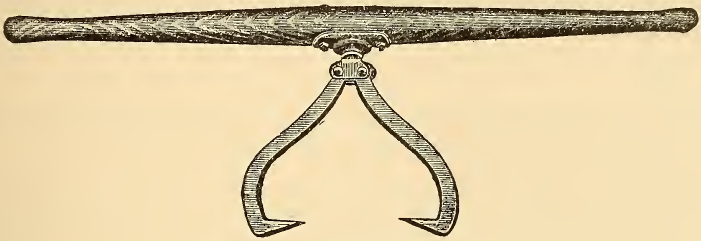

FIG. 546.—CARRY HOOK.

pole for each point and all other preliminary details, such as placing of heavy poles at the corners, the poles may be hauled and distributed along the route. They should be laid with the butt near the stakes and pointing down hill if on a grade.

The poles are distributed along the route by any available means. If the line runs along the railroad, they may be rolled from the flat car at the proper intervals and carried to their places by carrying hooks (Fig. 546). If the line is a long one and does not follow the line of a railroad, the poles should be unloaded from the cars at convenient points, and hauled to their proper locations by wagons.

Poles of medium length may, under ordinary circumstances, be raised with the cross-arms in place, and as they are much more

FIG. 547.—SHOVEL.

easily attached on the ground, this should always be done where possible. Where this is done the arms should not be permanently secured in place as they need to be levelled after the pole is set. Where the arms are not in place when the pole is raised it is convenient to nail a lath in the gain, in order that the proper alignment of the cross-arms may be secured.

In digging the pole holes long-handled shovels (Fig. 547) and spoon shovels (Fig. 548), having 7 and 8 foot handles, are used in conjunction with 8-foot steel digging bars, shown in Fig. 549. Sometimes the post-hole auger (Fig. 550) is used, but this is only where the conditions are very favorable. Dynamite, judiciously

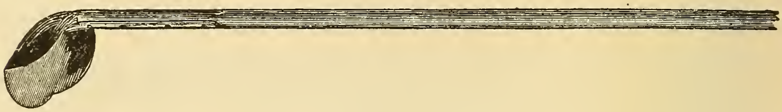

FIG. 548.—SPOON SHOVEL.

applied, is now being used successfully in digging holes, even where the soil is of such a nature as not to absolutely require its use.

No definite rule can be given for the depth at which poles should be set in the ground. The character of the soil, the distance between poles, the number of wires carried, the height of the pole and the sharpness of the turns made in the line must all be considered in

FIG. 549.—DIGGING BAR.

determining this question. For average work the data given in Table XII are believed to be in accordance with the best practice.

TABLE XII.

25-foot	pole,	5	feet	in ground		50-foot	pole,	7	feet	in ground	
30	"	"	5	"	"	55	"	"	7½	"	"
35	"	"	5½	"	"	60	"	"	8	"	"
40	"	"	6	"	"	65	"	"	8	"	"
45	"	"	6½	"	"	70	"	"	8½	"	"

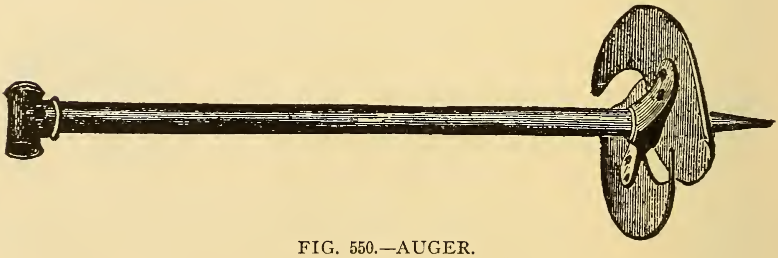

FIG. 550.—AUGER.

On curves or corners the holes should be dug from 6 inches to a foot deeper than is specified in this table.

After digging the holes the poles are carried or rolled by cant-hooks (Fig. 551) so that the butt of each is over its hole. A piece of scantling, or preferably a hardwood board, is placed in the hole to serve as a rest for the butt of the pole while it is being raised. The use of this butt-board prevents the crumbling of the earth which is sure to result and cause much trouble if this precaution is not taken.

The tools required in raising poles of the average length—from

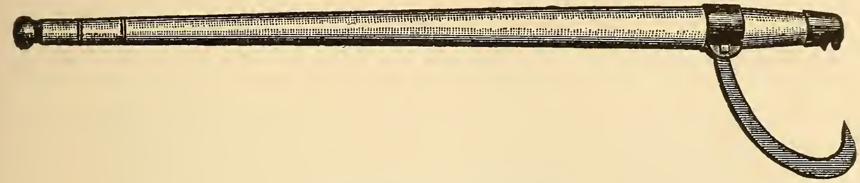

FIG. 551.—CANT HOOK.

30 or 50 feet—are five or six pike-poles (Fig. 552), ranging from 12 to 16 feet in length, and two dead men, or pole supports, of which two types are shown in Figs. 553 and 554.

The pole is raised slightly and its end slipped into the hole resting

FIG. 552.—PIKE-POLE.

all the while against the butt-board or scantling. The small end of the pole is then raised higher and the pole support placed under it, while the men obtain another hold. The pole is raised gradually, the support being each time moved closer to the butt. When too

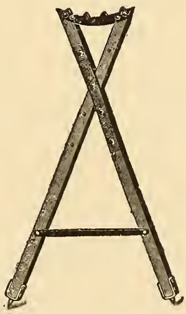

FIG. 553.—JENNY POLE SUPPORT.

high to be handled directly, the pike-poles are used on its upper part (Figs. 556 and 557), and in this way it is readily raised into a vertical position, slipping into the hole while bearing against the butt-board. It is then braced by the pike-poles, as shown in Fig. 558.

and turned by means of cant-hooks, so that the lath or cross-arms, if they were attached before raising the pole, are in proper position; it being remembered that the cross-arms should face each other on every alternate pair of poles. The hole is then filled in with the soil which was removed from it in digging, the soil being thoroughly tamped with tamping bars, shown in Fig. 555, from the bottom up. Great care should be taken that the shoveling in is not done so fast that the earth can not be properly tamped. This is frequently the

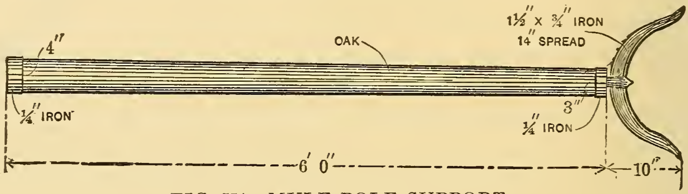

FIG. 554.—MULE POLE SUPPORT.

cause of much trouble, and, while it expedites the erecting of the poles, it causes much loss of time and money later, on account of the poles giving way when placed under strain.

A later and much more economical way of setting poles where large numbers are to be set, is by the use of a pole derrick wagon, which consists merely of a heavy wagon with low platform, upon the rear of which is placed a boom to be used in raising the pole. This boom is made adjustable with respect to the wagon, and is provided with guys extending from the forward portion of the truck. A block and tackle supported from the end of the boom serves as a

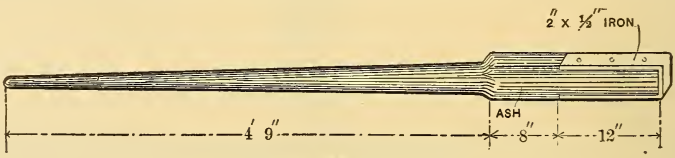

FIG. 555.—TAMPING BAR.

means for raising the pole, the necessary power being applied by horses operating through the intervention of a snatch-block. Figs. 559, 560 and 561 show such a derrick wagon, these cuts being made from photographs loaned by W. H. Anderson & Sons, of Detroit, Mich., who manufacture the wagon.

As will be seen, the platform of the wagon is very low, being supported beneath the axles. The boom is mounted on a trunion at the rear of the wagon, and is made of a piece of 8 inch steel tubing

FIG. 556.—RAISING POLE.

FIG. 557.—RAISING POLE.

17 feet in length into which a hardwood spar is inserted, so that a telescopic adjustment is afforded, thus giving a long boom suitable to raising different lengths of poles. By this means poles 70 feet in length are easily handled. On the front end of the wagon is mounted a hand-operated hoisting winch for adjusting the guys leading to the end of the boom. By this means the angular position of the boom may be adjusted to any degree even while subjected to the weight of the pole.

Steam or electric power has been proposed for raising the poles

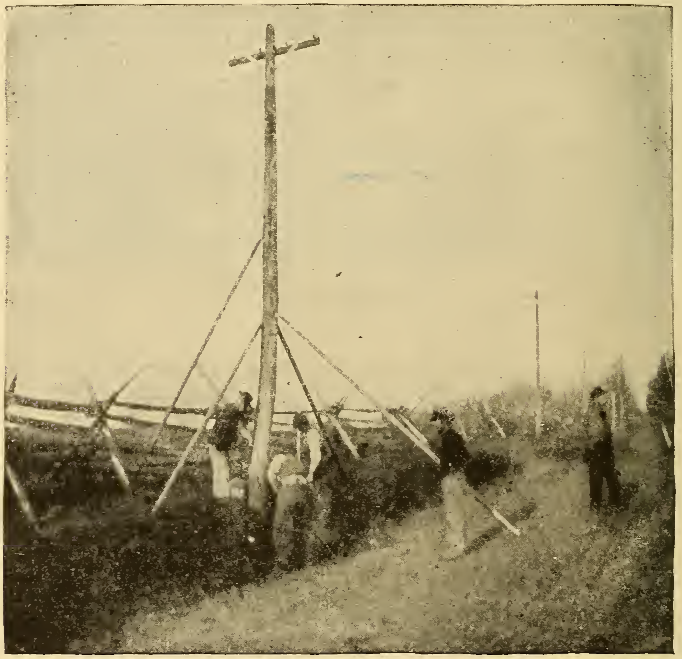

FIG. 558.—POLE RAISED.

when derrick wagons are used, but this is not thought to be economical, for the presence of horses is needed in any event to draw the wagon to the place of work and from pole to pole thereafter. With the wagon shown it is not necessary for the team to be hitched to the wagon tongue to move from pole to pole for arrangements are made whereby the team is hitched to the rear end of the wagon, and one of the crew, taking hold of the tongue, steers the wagon to its proper position while the team pulls it along backward.

The following statement is made by the manufacturer of this wagon as to the economies incident to its use:

"The majority of the telephone and construction companies are using eighteen men as a pole raising crew, and with a team of horses to pull poles into position, an average day's work is to set twenty to thirty-two poles; figuring the men at an average of $2 per day per man, gives $36 to set an average of twenty-six poles per day, or $1.83 per pole for wages of the crew.

"With the pole-raising derrick wagon some companies use eight

FIG. 559.—DERRICK WAGON—POLE PARTLY RAISED.

men in the crew and some prefer twelve, an average of ten men. An average day's work is to set forty-five to sixty-four poles. Figuring the average as $2 per day per man, gives $20 to set an average of fifty-five poles, or 36 1-3 cents per pole for wages of the crew, a saving of over $1.40 per pole.

"These figures are subject to considerable variation on account of varying conditions. On straight work where no wires interfere, as many as seventy-six poles have been set in a day with twelve men, and where wires are in the way and cause considerable trouble, the work is very much speedier than by the old method of pike poles, inasmuch as the pole is suspended in a manner that one or two men can have absolute control of the pole, moving it in any direction with comparatively little effort."

If the soil is soft a foot-plate should be placed under the butt of the pole. This can be made by fastening together two 2 inch by 12 inch pieces of oak or hard pine 2 or $2\frac{1}{2}$ feet long, at right angles to each other. In case the soil is very soft, as in marshy districts, more elaborate means will have to be taken. The hole should be dug in such places much larger than in ordinary instances, and a

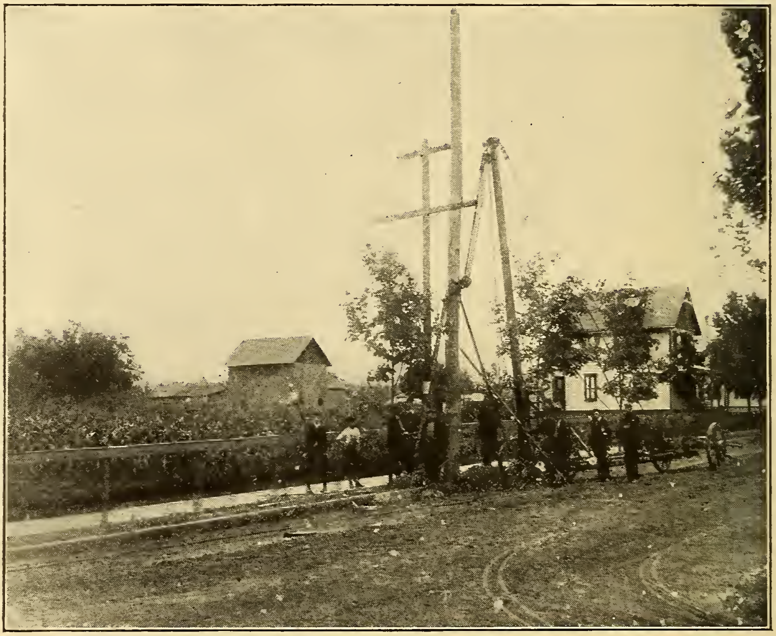

FIG. 560.—DERRICK WAGON—POLE RAISED AND BRACED.

larger foot-plate may be inserted. A good plan, under these conditions, is to place in the bottom of the hole a layer, 6 inches deep, of concrete, and, after raising the pole, filling in the center hole to the surface of the ground with the same mixture, thoroughly tamped into place. For this purpose, and for other cases where concrete is needed in line construction work, the following formulas are given:

Formula No. 1.		Formula No. 2.	
Natural cement	1 part	Portland cement	1 part
Sand	2 parts	Sand	3 parts
Broken stone	3 "	Broken stone	5 "

Broken stone is, as a rule, better than gravel, and stones of varying size, up to the size of an egg, are somewhat cheaper than stones of uniform size, because the small stones fill in the interstices between the large ones, and thus require less cement, while the concrete is just as strong.

On a straight line three different kinds of strain must be provided for, namely, the crushing strain, due to the weight of the wires; the side strain, due to wind pressure, and the strain in the direction of the wires. This latter is due to the tension in the wires

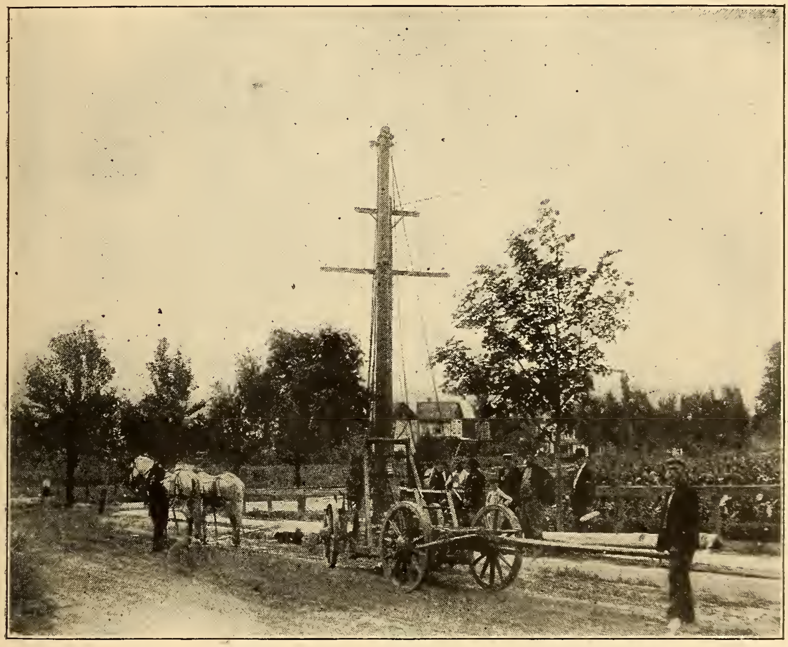

FIG. 561.—DERRICK WAGON—MOVING WAGON TO NEXT POLE.

at the end of the line, or to wind pressure in the direction of the line, or to the tension in portions of the line caused by the falling of a pole or the breaking of a number of wires. In hilly country also considerable strain is caused in the direction of the line itself on a long down grade, due to the actual weight of the wires. The first two strains, that is, the crushing strain and the side strain due to wind, are at times very great, both being augumented by the formation of a crust of ice on the wires and poles during sleet storms. Abbott cites cases where coatings of ice 6 inches in diameter have been formed on a No. 10 wire throughout its length. These, of course, are extreme cases, but coatings 2 inches in diameter are quite common. It is customary to provide for the crushing and side strains on a straight line by making the poles heavy enough to stand them without recourse to other methods, although on very heavy lines side guys are often used, even on straighway work. The sizes of poles given in Table VIII. is sufficient to insure against breakage in such cases under all ordinary conditions.

The strain in the direction of the wires should be provided for by a method of bracing known as head-guying. This consists in running a guy wire from the base of one pole close to the ground to the top of the next, etc., for several poles in succession. About three poles should be guyed from the top of one to the butt of the next, and in the next three the order should be reversed, thus bracing the line in both directions. This, if repeated at intervals of 1 mile, will greatly strengthen the line against vibration in the longitudinal directions caused by high winds or by the other causes mentioned. On a down grade the head-guys should extend from the butt of the pole on the highest ground to the top of the pole below it. The method of head-guying is illustrated in Fig. 562. When the line is dead-ended at the termination of a lead, or for the purpose of connecting with an underground cable, the last three poles should be head-guyed by running a guy wire from the bottom of the last pole to the top of the next, and so on for three poles. The last pole should be guyed by planting a guy-stub at as great a distance as possible beyond it, in the direct line of the poles, and firmly guying to it. It frequently happens in cities that sufficient room cannot be obtained for dead-ending a pole line in this manner, and under these conditions some sort of an anchor pole is necessary. Frequently room may be had by planting the anchor at a distance of perhaps 10 feet from the base of the pole. In this case the guy wire or rod should be made very strong in order to successfully stand the

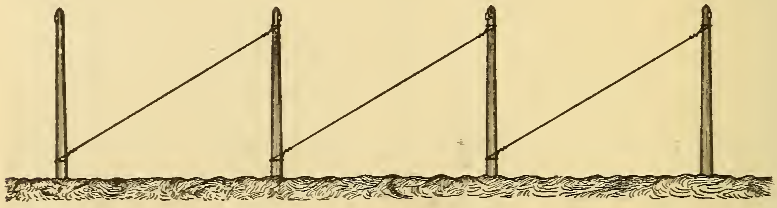

FIG. 562.—HEAD GUYING.

excessive strain, and the anchor should be buried to a depth of perhaps 8 feet and weighted by a mass of rock and concrete.

As an additional precaution a lattice-work of angle iron is in some cases used to reinforce the upper portion of the pole for the purpose of equalizing the pull on the guy rod without undue stress on any portion of the pole. In Fig. 563 is shown such a lattice-work, and also a method of anchoring a pole to be subjected to a severe

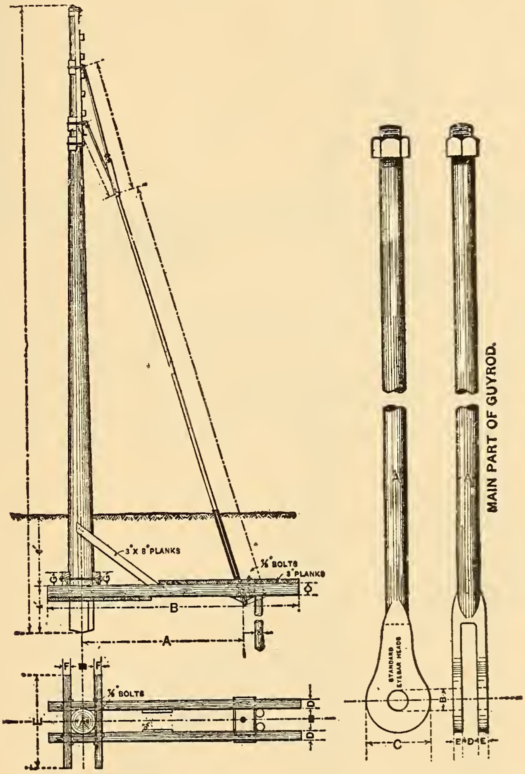

FIG. 563.—DETAILS OF ANCHOR POLE.

strain. Structural iron anchor poles are sometimes used for the termination of very heavy leads, and these offer the neatest solution of the problem, but have the disadvantage of being extremely expensive.

When a bend occurs in the line or when a branch lead is taken off at an angle, a side strain is exerted on the poles. These strains must be amply provided for by means of a system of braces which are capable of exerting an opposite pressure to that of the pull of the wires. This is usually done by means of guy wires, connected to the tops of the poles and extending in such direction as to bisect the angle of the bend which the line makes. On long curves a guy wire should be provided for each pole, and it is also well to head-

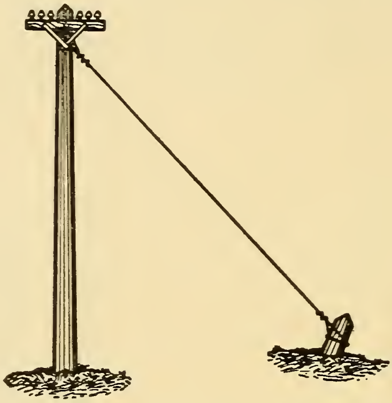

FIG. 564.—SIDE GUY.

guy each pole. Beginning at the center of the curve, head-guys should extend from the base of each pole to the top of the next pole in each direction from the center. The shorter the turn the greater

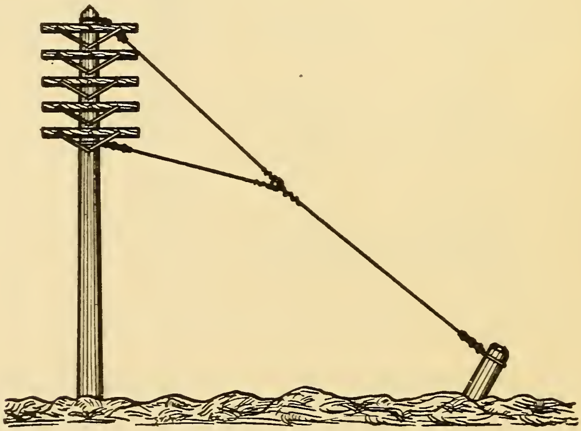

FIG. 565.—Y-GUY.

the strain, and the greater therefore must be the precaution taken to meet it.

In Fig. 564 is shown an ordinary side guy used in light lines where there are but few cross-arms.

Where more than four cross-arms are used a Y-guy (Fig. 565) should always be employed, as it takes the strain from both the

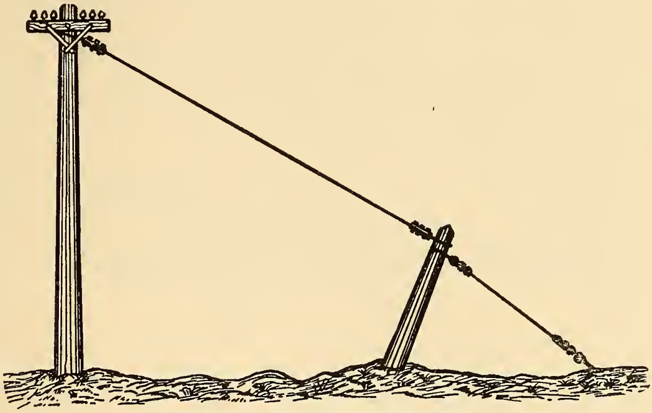

FIG. 566.—GUY AT CROSSING.

top and bottom arm. To guy from the top of the pole only, as is frequently done, causes the latter to bow toward the center of the

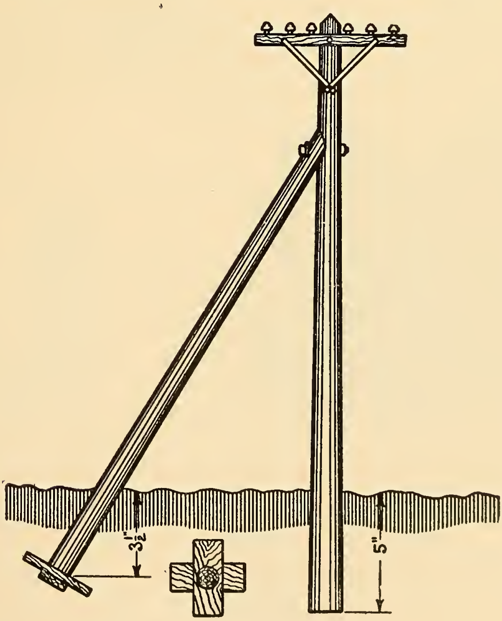

FIG. 567.—PUSH POLE BRACE.

curve at the lower cross-arm, and frequently causes the pole to break at that point, usually in the gain of the lower arm. On the other hand, to guy from the lower cross-arm usually causes a pole to bow in the other direction with the same result.

Where possible, the anchor should be placed 20 or 25 feet from the base of the pole. When it is necessary to set the anchor 10 feet or less from the base of the pole, the pole should have a foundation formed of two planks 2 inches thick by 12 inches wide and 30 inches long set at right angles.

To raise the guy wire to a considerable height in crossing a road a long guy-stub securely anchored may be used, as shown in Fig. 566.

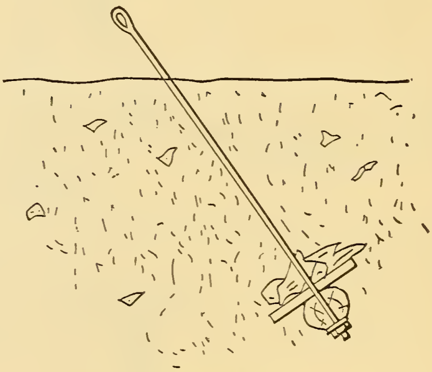

FIG. 568.—ANCHOR.

Where it is not convenient to guy, a "push" pole brace, shown in Fig. 567, may be used.

To properly anchor guy wires often requires a good deal of ingenuity, and it is hard to lay down any definite rule, as they frequently have to be planned to meet the existing conditions. One of the most common methods, and a very satisfactory one, is shown in Fig. 568. The anchor log should correspond in size to the depth of the excavation in accordance with the following table:

Depth of Excavation.	Anchor Log.	
	Length.	Diameter.
4 feet	4 feet	6 inches
4 "	5 "	6 "
	7 "	8 "
	5 "	12 "
3½ "	7 "	9 "
	9 "	7 "

When an excessive strain is to be met, an anchor of several logs bolted together crosswise may be used. The anchor rod should be of wrought iron, from 6 to 10 feet long and from $\frac{3}{4}$ to $1\frac{1}{2}$ inches in diameter, having an eye forged in one end and a heavy screw thread and nut on the other. The rod should pass directly through the anchor log and be secured by the nut, a heavy iron washer being placed between the log and the nut. All iron so used should be gal-

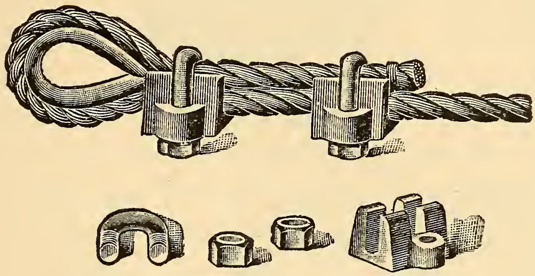

FIG. 569.—GUY CLAMP.

vanized. In extreme cases the log should be buried in a mass of concrete.

A common way of anchoring a guy wire is to a guy-stub, which is usually formed of the stub end of a pole from 8 to 12 feet long, set

FIG. 570.—GUY WIRE HOOK.

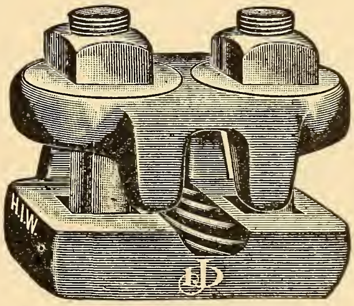

FIG. 571.—HALLETT CLAMP.

at an angle of approximately 90 degrees to the direction of the guy wire.

The guy rope should be fastened to the pole by passing it twice around and clamping it by means of a malleable iron guy clamp, of which one is shown in Fig. 569.

In order to protect the pole and to keep the guy wire from slipping down the pole, guy wire hooks are used such as are shown in Fig. 570.

Several good forms of guy wire clamps are on the market. These have from one to three clamping bolts according to the strain to

FIG. 572.—"CINCINNATI" CLAMP.

be borne. The single bolt clamp shown in Fig. 569 is known as the "Crosby" clamp. The Hallett clamp is shown in Fig. 571; the

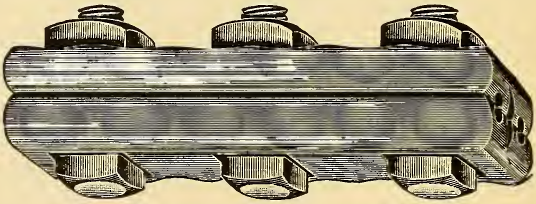

FIG. 573.—"A. T. & T." CLAMP.

"Cincinnati" in Fig. 572, a three bolt "A. T. and T." clamp in Fig. 573, and a three-bolt Cook clamp in Fig. 574.

Tests of various single-bolt clamps show that one bolt or single

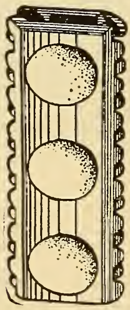

FIG. 574.—COOK THREE-BOLT CLAMP.

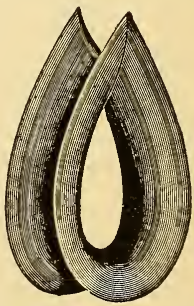

FIG. 575.—THIMBLE.

"U"-bolt clamps sustain loads of from 600 to 2000 pounds without slipping of the guy wire; two-bolt clamps from 1000 to 4500 pounds, and three-bolt clamps from 1100 up to 6000 pounds.

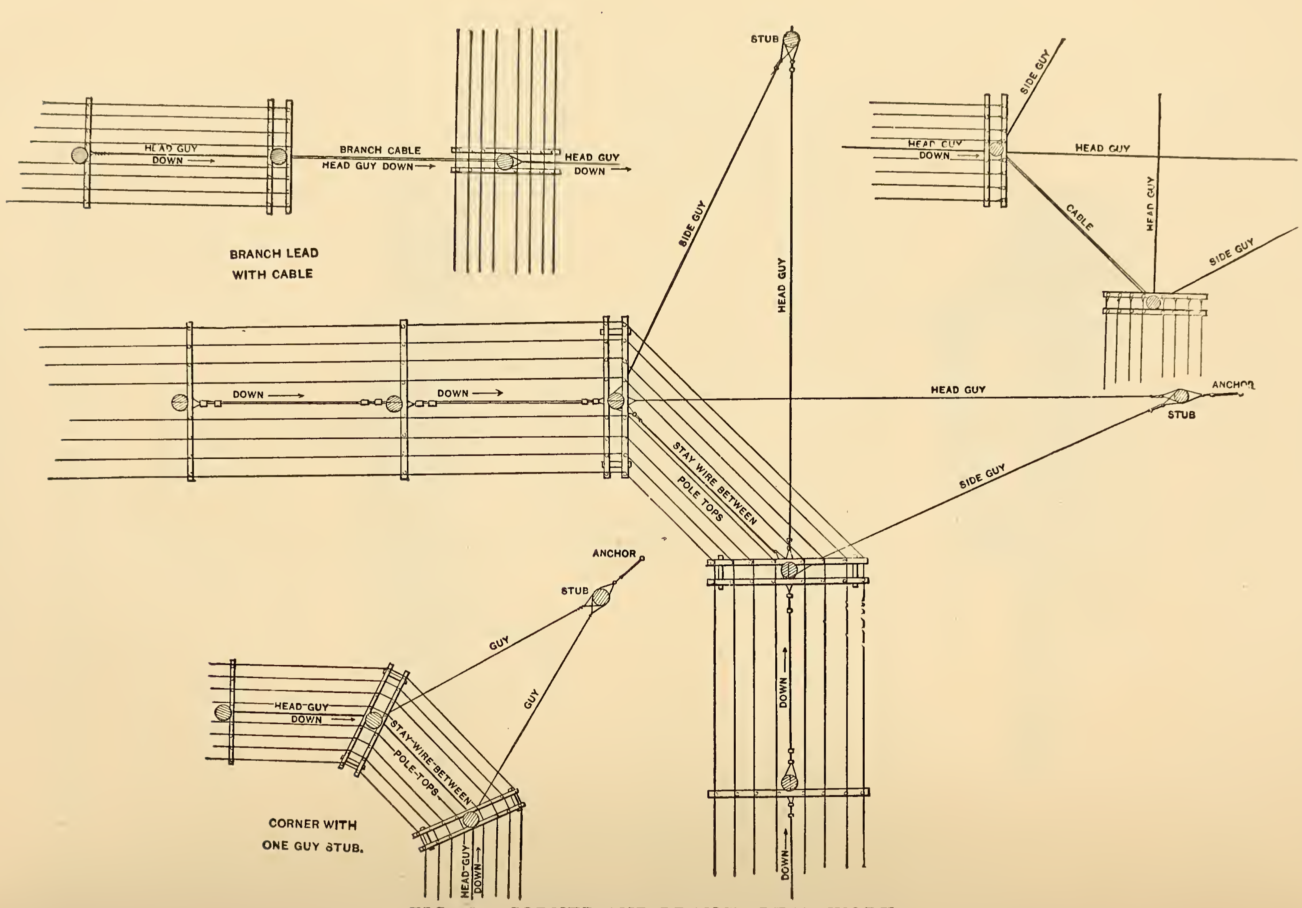

FIG. 576.—CORNER AND BRANCH LEAD WORK.

A thimble (Fig. 575) of galvanived steel is used for attaching the guy wire to the anchor rod, as shown in Fig. 569.

The wire used in guying may consist of one or more strands of No. 9 or 10 B. & S. steel wire twisted together, but a better plan is to use the regular steel cables, thoroughly galvanized, furnished by the several reliable wire manufacturers. This has the advantage of

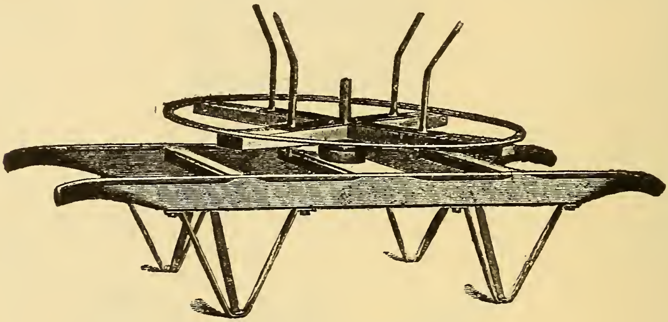

FIG. 577.—HAND BARROW.

being more flexible, more easily handled, and, at the same time, stronger for its weight than the single strands of larger wire. The cable usually consists of seven No. 12 steel wires laid up with a $3\frac{1}{2}$-inch twist.

In turning a sharp corner it is better to use two poles. Fig. 576 shows several styles of double-pole corners, and also a method of taking off branch leads that is sometimes, but seldom, used. On corner work the poles should be heavier than the standard used,

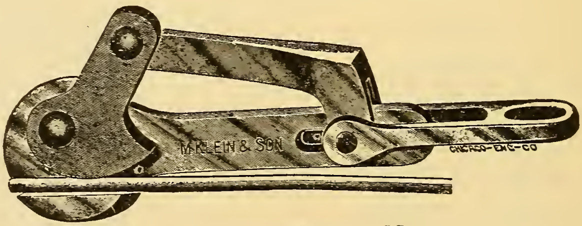

FIG. 578.—COME-ALONG.

and should be guyed in a manner that will effectually brace them in all directions. The large cut in Fig. 576 shows the best method of guying, but the method shown in the lower left-hand corner may be used where there is room for only one guy stub and anchor.

Sometimes instead of leading the bare wires around the bend, they are dead-ended on the corner poles in the same manner as at the end of a lead, and then connection made between the two leads by means of a lead-covered or rubber cable, suitable cable terminals

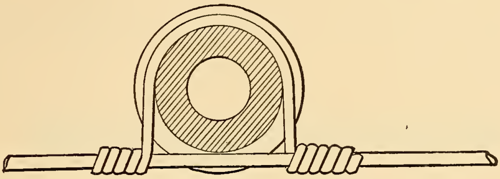

FIG. 579.—IRON-WIRE TIE.

(usually potheads) being used for connecting the cable wire with the bare wires. This construction is shown in the upper right-hand corner of Fig. 576.

The same method has been used in taking off a branch lead from a

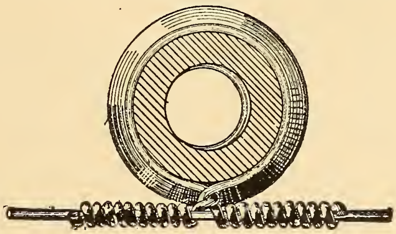

FIG. 580.—HELVIN TIE.

main lead. This is shown in the upper left-hand corner of Fig. 576. The use of cable for corner and branch work frequently saves much complexity in difficult places, leaving the work much more open and clean.

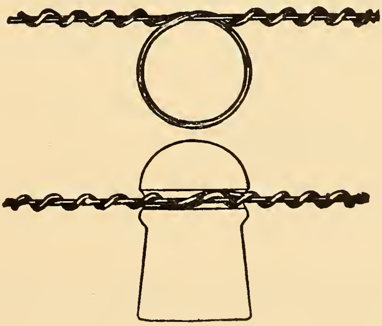

FIG. 581.—COPPER-WIRE TIE.

After about a mile of poles have been set and guyed, and the cross-arms, pins, and insulators put in place, the process of stringing, where but a few wires are to be run, consists in placing the reels on hand barrows, as is shown in Fig. 577, or on a cart, and paying them as they go, drawing the wire up to each pole separately.

When, however, a large number of wires are to be run, the method is briefly as follows:

Ten reels similar to that shown on the hand-barrow of Fig. 577,

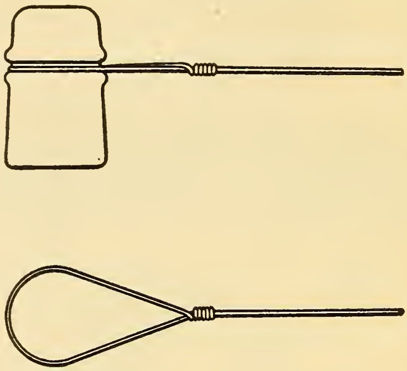

FIG. 582.—DEAD-ENDING IRON WIRE.

are mounted on a wagon, so that ten wires may be pulled off at once. A running rope is pulled over the top cross-arms the full length of the section to be strung, and this rope runs through a snatch-block at the end of the section down to the base of the pole, where it passes through another snatch-block. A team of horses is then hitched to the end of the running rope and draws this back towards the wagon. The ten wires are fastened to what is known as a running board made in the form of a triangular frame, to one corner of which the running rope is attached. This enables the running board to slip over and by obstructions more easily. The side of the triangular frame opposite the corner to which the running rope is attached,

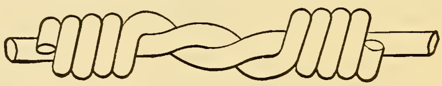

FIG. 583.—WESTERN UNION JOINT, FOR IRON WIRE.

is provided with ten snap hooks to facilitate fastening the wires to be strung. Linemen place each wire in proper relation to the pin to which it is to be secured.

A short hand line is usually fastened to one corner of the running board to keep it from turning over, and thus twisting the wires, and also to help it in passing trees and other obstructions.

When stringing wires on other than the top cross-arm the same method is followed, but as the running board passes each pole five of the wires are unsnapped and passed around the pole, and again attached to the running board after it has passed the pole. Another way, which prevents the unsnapping of the wires from the running

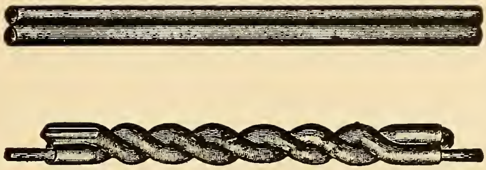

FIG. 584.—McINTYRE SLEEVE.

board, is to string on two cross-arms at once, five of the wires being utilized on one arm and five on the arm below it. After the wires are all in place each one is separately pulled up to the proper tension, and tied to the insulator at each pole.

After the wires have been dead-ended at one end, experienced linemen are set to work pulling up the slack, attention being given to getting the same tension in all of the wires. This is quite an art, and it is important that it be done properly. The force is applied by attaching a wire clamp, commonly known as a "come-along,"

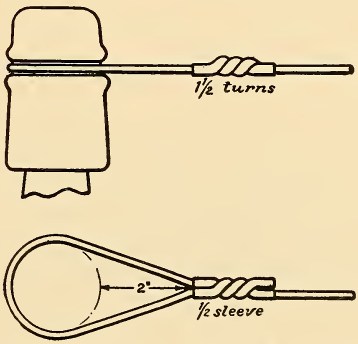

FIG. 585.—DEAD-ENDING WITH McINTYRE SLEEVE.

shown in Fig. 578, and pulling it up with a block-and-tackle or by hand. The tension depends on the kind and size of wire, on the distance between the poles, and on the temperature at time of the stringing. The amount of tension put on each wire is usually taken as about one-third the breaking strength of the wire, which may be found from the wire tables. The other method is to allow a certain sag or distance between the center of the span and the straight line between the points of support.

Table XIII., which is taken from Roebling's handbook on "Wire in Electrical Construction," gives the sag in inches for the various lengths of span at different temperatures, these figures being based on the use of good hard-drawn copper wire.

TABLE XIII.—AMOUNT OF SAG IN SPANS.

Temperature in Degrees Fahrenheit.	Spans in Feet.					
	75	100	115	130	150	200
	Sag in Inches.					
—30	1	2	2½	3⅜	4½	8
—10	1¼	2½	3	3¾	5	9
10	1½	2⅝	3½	4⅜	5¾	10¼
30	1¾	3	4	5⅛	6¾	12
60	2½	4¼	5½	7	9	15⅜
80	3⅛	5⅜	7	8⅝	11¼	18¾
100	4½	7	9	11	14	22¼

The tying of wires to the insulators is an important matter, and there are several different methods of doing it. The ordinary method used almost since the beginning of line construction is shown in Fig. 579. This is now used in the tying of iron wires only. The line wire merely passes along the side of the insulator and should not be bent, being held in the groove by a tie wire, twisted around it in opposite directions at each end, as shown. The tie wires are, as a rule, about sixteen inches long, and made of slightly smaller diameter than the line wire itself, especially in case of very heavy wire.

Another method, known as the Helvin tie, is shown in Fig. 580. This has been used with considerable success with hard drawn copper wire, but is not now used so far as known. In this the tie wire is first wrapped around the insulator and twisted once or twice on itself, after which the ends are twisted around the line wire as before.

Still another method of tying the wire to the insulator is shown in Fig. 581, this being now used exclusively in copper wire work. In this, as in the first method, the line wire is laid in the groove of the insulator, and the tie wire is passed entirely around the groove, one end passing down over the line and the other end up under it, the twist being made as shown.

Where an iron wire is dead-ended it is simply passed once around the insulator and twisted five times upon itself, the twist beginning at a distance of about two inches from the insulator. The method of making this tie is shown in Fig. 582. In the case where trans-

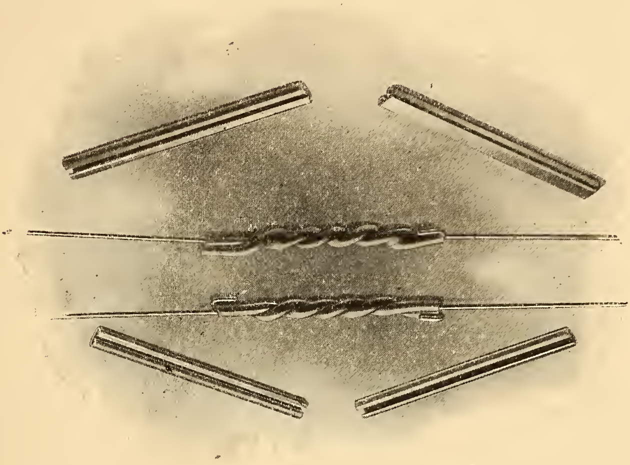

FIG. 586.—LILLIE JOINT.

positions are to be made the free end of the wire should be left long enough to pass over and make connection with the other side of the circuit.

The joining of wires is a matter which has received much at-

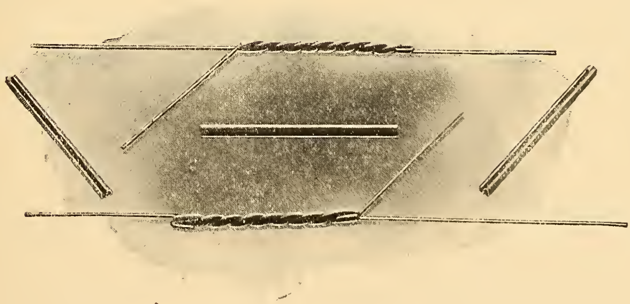

FIG. 587.—LILLIE JOINT.

tention. The old style of joint, and one which gives satisfaction for iron wire, is shown in Fig. 583. This is known as the Western Union joint, and is made by placing the two ends side by side and clamping them with a hand vise or with a heavy pair of pliers.

With another pair of pliers, the free end of each wire is twisted tightly around the other wire, as shown. This is used exclusively for joining iron wires.

Another method of joining wires, known as the McIntyre sleeve joint, is shown in Fig. 584, this being now almost universally used in joining copper wire. The sleeve for making this joint consists

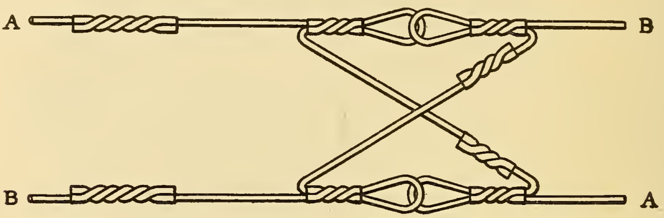

FIG. 588.—TRANSPOSITION.

of two copper tubes soldered together and having a bore corresponding to the sizes of the wire to be joined. The ends of the wire are passed in opposite directions through these tubes and are then grasped at each end with a special tool for the purpose, and given three distinct twists. This joint is now widely used in practice and is very convenient because the use of solder is not required in order to make it perfect.

In Fig. 585 is shown the method of dead-ending a copper wire with a half length of McIntyre sleeve.

Still another connector, not so well known, is the Lillie joint, this being shown in Fig. 586. The connector in this consists of a

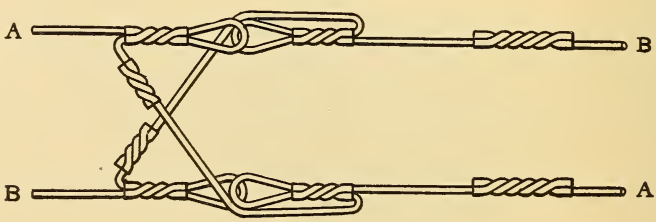

FIG. 589.—POLE-TRANSPOSITION.

sheet of copper curved longitudinally in opposite directions. The wires are slipped in each curve of the strip and twisted in opposite directions, as in the McIntyre joint. This joint has not come into such extensive use as the McIntyre sleeve, but should prove efficient. Fig. 587 shows how this sleeve may be applied in taking off branch wires, as in the case of attaching bridging telephones to a line. This joint is advantageous in this respect, in that it is not necessary to cut the line wire to apply it.

The method of making transpositions on copper wire is shown in Fig. 588. This is done by cutting the wires on the pole side about 20 inches from the cross-arm, and slipping on each a half McIntyre sleeve, with which the wires on the cross-arm are dead-ended, one in the lower groove and one in the upper groove, of the respective transposition insulators, leaving the ends projecting.

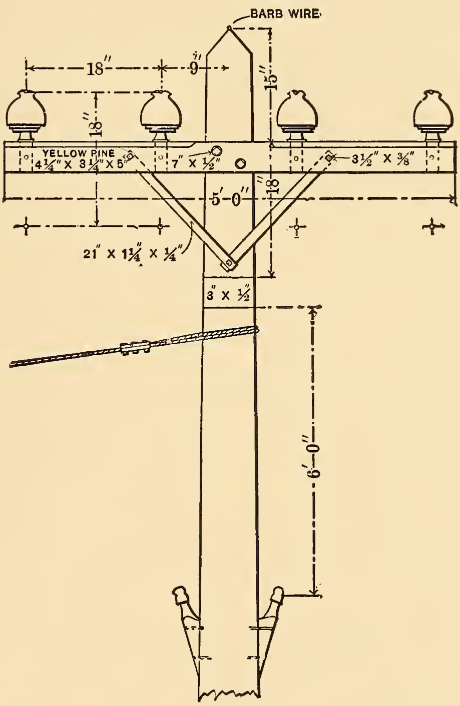

FIG. 590.—TELEPHONE AND POWER CIRCUIT.

About six feet of slack is then joined to the wires on the cross-arm side by using whole McIntyre sleeves. Half sleeves are then slipped on and the wires dead-ended in the vacant grooves of the transposition insulators. In dead-ending the stationary clamping tool should be held next to the insulator, so that the twists will be made in the long section. Fig. 389 shows the method of crossing over the wires where the two wires transposed are on the opposite sides of the pole. In making transpositions a good, though more expensive way, is to use double cross-arms at the transposition poles, dead-ending the wires on each and bridging across by bridle wires in much the same manner as shown.

It is frequently necessary to run a telephone line on the same poles with a high-tension power circuit. Induction from the power wires is of course under these conditions very likely to render conversation impossible, especially if the current in the power circuit is alternating. Fig. 590 shows the details of a pole thus equipped, the two insulators on brackets being for the telephone line. The latter should be of No. 12 B. & S. copper, and transposed every three poles. In this way a fairly quiet line may be obtained under the most unfavorable circumstances.

CHAPTER XL.

AERIAL CABLE CONSTRUCTION.

The tendency of telephone practice in cities is to bunch in the cables, the line wires following the same route, so that many wires may be placed in a very restricted space. It may be added that there is also a strong tendency toward the placing of these cables underground, this being due in great measure to the protests of the public against all overhead electrical construction, and to the decreased cost of maintenance of underground work. Overhead cables are however used to a large extent, and there probably always will be conditions under which it will be advantageous to use them.

The overhead or aerial cable presents many advantages over the use of bare wires. In many districts it would be absolutely impossible to handle the required number of wires without the use of cables on account of lack of space for one hundred or more wires, which alone would require the use of a pole line carrying at least twenty cross arms, may be crowded into a cylindrical space less than two inches in diameter. Besides this the cost of construction is in many cases greatly cheapened; the lines are rendered far more sightly; the danger of crosses from high tension or other wires is greatly reduced; the liability to injury in winds and storms is lessened; and much less obstruction is offered to firemen in the performance of their duties.

The use of cable brought new electrical problems, for obviously the placing of so many conductors in such a contracted space tended greatly to change the electrical properties of the circuits. The advent of cable rendered the use of smaller wires possible, and this necessarily brought about greater resistance per lineal foot. The bringing of the two sides of the line close together and close to many other line circuits tended to increase the electrostatic capacity of each circuit, thus bringing about a greater shunting effect on the voice currents. Again, the bringing of the wires so close together brought in problems relating to the insulating of the various wires from each other, making necessary a continuous solid insulator of such a nature as to be capable of holding the wires apart at all portions of their length. Obviously, also, the close spacing of wires rendered necessary greater precautions for the prevention of induction between them which would give rise to cross talk and similar trouble.

Briefly stated, the electrical problem in cable construction has been the production of a cable in which the conductors will be as low in resistance as possible, in which the electrostatic capacity between the various conductors will be as low as possible, in which the resistance between the various conductors shall at all times be as high as possible and in which the relations between the various conductors are such that inductive action between the various circuits will be practically nil.

Besides the electrical requirements there are certain obvious mechanical ones which will be dealt with more specifically later on.

In the earlier days of telephony rubber was considered the best insulating material for the wires in cables. Cables so constructed are now used only in special and comparatively rare cases. Rubber-covered cables give excellent results as to insulation and durability; but a serious objection to their use for telephone work is that their electrostatic capacity is very high. This is due to the fact that while rubber is a splendid insulator, its specific inductive capacity is much higher than that of some other insulators.

Table XIV. shows the diameter and weight of rubber-covered cables of various numbers of pairs, the conductors being in each case of No. 18 B. & S. G. wire, tinned, and double coated with rubber.

TABLE XIV.—Aerial Cable. Rubber-Covered Wires.

Number of Pairs.	Number of Conductors.	Diameter in Inches.	Weight per 1000 Feet in Pounds.
3	6	$\frac{9}{16}$	175
5	10	$\frac{11}{16}$	256
10	20	$\frac{29}{32}$	452
15	30	1	633
20	40	$1\frac{1}{8}$	813
25	50	$1\frac{1}{4}$	994

Dry air is the most desirable insulator with respect to electrostatic capacity and of course air is the insulator mainly used in bare wire work. The reason for this superiority is that the specific inductive capacity of air is lower than that of any other substance that is at all practical to use. At first it was not thought possible to rely upon air at all in cable construction, but a great improvement over rubber cable was brought about by the use of paper insulation between the individual conductors. In the earlier forms of cables so constructed the wires were wrapped with paper which was afterwards impregnated with some insulating material, such as paraffin, having relatively low specific capacity. Such cables were once largely used, being known as saturated paper cables.

It was found that by aerating the paraffin thus used in saturated cables with dry carbolic acid gas, the electrostatic capacity between the conductors was reduced as much as 15 per cent.

In order still further to reduce the capacity, what are known as dry core cables have been introduced and have been adopted almost universally in telephone work. These are usually formed in this

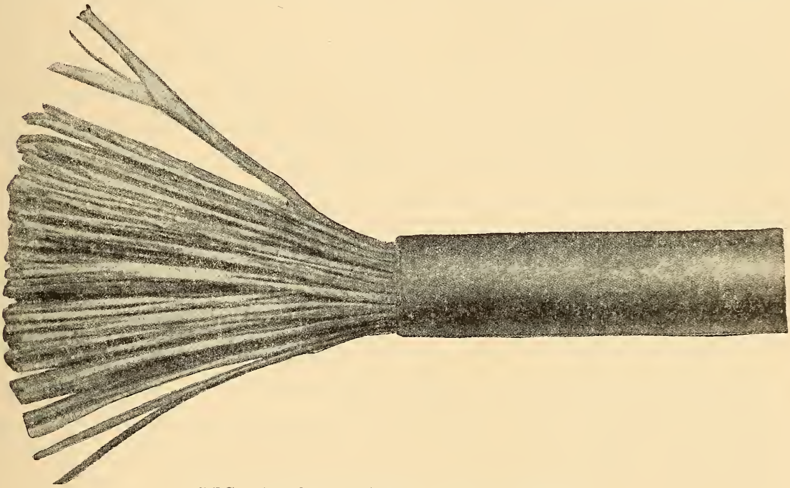

FIG. 591.—DRY-CORE PAPER CABLE.

country by wrapping the separate conductors with two layers of dry paper loosely laid on. Some times only a single wrapping is used. Two wires thus insulated are formed into a twisted pair, the length of a complete twist being about three inches. These pairs are formed into a core in layers, the twist in the successive layers being reversed in direction. The paper is very porous, which fact, together with the loose construction, allows the permeation of dry air throughout the structure.

After the core is formed it is served with heavy manilla paper and the whole is enclosed in a lead sheath, usually about one-eighth of an inch in thickness. A piece of such cable from which the lead sheath has been partially removed is shown in Figure 591.

The method of applying the lead sheath is an interesting feature of cable manufacture. In the earliest lead covered cables, the core was formed complete in as long a length as could be shipped on one reel when completed, then sections of lead pipe of proper diameter and about fifty feet long were slipped over the core and soldered together at their junctions. Later, the present method of applying the lead covering was adopted. This is to pass the core direct from its drying oven into a lead-press of the type used in making lead pipe, from which press, charged with just molten lead, the core and its covering pipe emerge as a finished thing. The exact way in which the lead gets formed around the core can be understood best by conceiving the core to pass through the bottom of a tank filled with just-flowing lead, and then passing out through the side of the tank through a ring-shaped die.

Another way of forming a twisted pair in cable work is to lay the two wires upon opposite sides of a strip of paper and then twisting the two together with the paper strip between them. The pair is afterwards served with a single wrapping of paper, forming a complete tube around it. This method is not widely used in this country, the separate wrapping or wrappings on each individual wire having come into almost universal use.

The saturated cable had the advantage of not being so susceptible to moisture as the dry core cable, but its electrostatic capacity was much higher, and principally on that account it has been abandoned. The capacity between a single wire and all of the other wires bunched together and connected to the sheath is for a certain type of dry core cable about .080 microfarads per mile. For a saturated cable of the same dimensions the electrostatic capacity would be from .15 to .20 microfarads per mile, or even higher. This illustrates well the difference in electrostatic capacity between a saturated and a dry core cable.

The sizes of conductors ordinarily used in telephone cables vary from No. 19 B. & S. G. down to No. 22 B. & S. G., Nos. 19, 20, and 22 being standard sizes. There has been recently a tendency in large work to use No. 24, but this has not as yet become well standardized in practice. Nos. 20 or 22 are most frequently used in aerial construction.

For toll line work where the lowest possible electrostatic capacity and resistance is required, and yet where the conditions are such that the wires must necessarily be bunched into cables, No. 16 B. &. S. G., or even as large as No. 13 B. W. G., are sometimes used in paper cables. In these cases, in order to further reduce the capacity, the wires in the cable are very loosely laid together, thus forming a very soft and yielding bunch over which the lead sheath is placed.

The American Telephone and Telegraph Company's specifications allow as a maximum conductor resistance per mile of cable for various sizes of conductor the following:

No. 22, B. & S. G.	95	ohms per mile.
" 20, "	60	"
" 19, "	47	"
" 16, "	23½	"
" 13, B. W. G.	$6\frac{2}{10}$	"

These figures are for a mile of single conductor, and they take into consideration the allowance for the increased length of conductor due to twisting the wires in pairs and to the twist of the pairs in the cable.

The use of two wrappings of paper on a conductor rather than one, and the loose bunching of wires in a cable rather than squeezing them tightly together, tends to produce higher insulation between the conductors and at the same time to bring about a lower electrostatic capacity. In the best cables two wrappings of paper are used and the wires are as loosely bunched as is compatible with the space they are to occupy and the size of the investment that it is desired to make. It is obvious that a considerable amount of money may be saved by squeezing the wires tightly together, thus making them go in smaller space and requiring less sheath to cover them. The sizes of the cable vary widely although the same amount of insulating material, the same size of conductor and the same thickness of lead sheath is used. With these factors fixed the size of the cable will be governed largely by the requirements as to electrostatic capacity and insulation.

The usual method of measuring insulation resistance is to measure the insulation between one wire and all of the other wires in the cable bunched together and connected to the sheath. The usual requirements specified for insulation resistance is that it shall be not less than 500 megohms per mile measured as stated above.

It is evident that this degree of insulation in a dry core cable can only be maintained by keeping the insulating material within the cable perfectly dry, and this is of course dependent upon the lead sheath being kept intact. This point will be considered later on in this chapter.

As already stated, the size of the cable may be largely governed by the requirements as to electrostatic capacity, other things being equal. The method of measuring capacity, therefore, becomes important. The old and until now standard method of measuring electrostatic capacity was, as has already been stated, to measure the capacity of each wire against all of the other wires bunched and connected with the sheath. A new method has recently come into vogue, which is a test for mutual electrostatic capacity, that is, the capacity between the two wires of a pair, these two wires being disconnected from all others, but all of the other wires being connected together and connected with the sheath. It is quite evident that the mutual capacity between a pair of wires will be less, under ordinary circumstances, than the capacity between any one wire and all of the others. The equivalent capacities according to these two methods of measuring are as follows, the capacity of the same cable according to each of the methods being given for several types of cable:

Capacity one Wire to all Others.	Equivalent Mutual Capacity.
.08	.054
.10	.066
.12	.08
.14	.093
.16	.107
.18	.12

Specifications usually state that the cable sheath shall be composed of an alloy of lead and tin, the amount of the latter being not less than 3 per cent. of the entire mixture. This requirement has been made because it has been found that such an alloy is not so susceptible to chemical action as lead alone, which is an important consideration in underground work. The Standard Underground Cable Company appears to advocate the use of pure lead sheath for all cases, the sheath being treated, after forming, with an external coating of pure tin. They argue for this that the tin when mixed with the lead makes the sheath brittle, and that the tin will be most advantageous if all of it is placed on the outside. This argument is given some further weight in view of the fact that it has been found difficult to secure an absolutely uniform alloy of tin and lead, resulting in some parts of the sheath having an excess of tin and being then unduly brittle.

The general practice at the present time is to use an alloy of 3 per cent. tin for underground work and pure lead for overhead work.

The use of a braiding saturated with a mixture, previously compounded, placed over the outside of the sheath was once advocated, and much of such cable was formerly used. It has been found, however, that the disadvantage of the outside braiding outweighed its advantages in either overhead or underground work. The locating of punctures in the sheath of aerial cables is made much more difficult by the use of this braid, for when the sheath is bare they may be located by mere external inspection. Very often the braiding considerably increases the cost of the cable, and its only advantage has been in tending to prevent abrasion, which need not occur if the cable is properly supported. In underground work the braiding effected but a poor protection for the sheath during the drawing-in process and practically none against chemical action. After the braiding rots, as it does, the pieces hanging from the cable present an unsightly appearance in the case of overhead work, and may serve to thoroughly clog up the conduit in underground work in attempting the subsequent withdrawal of the cable.

A new objection to the old external braiding for cables has recently developed. Mr. John Hesketh, electrical engineer for the State of Queensland, Australia, in a very valuable contribution to the proceedings of the International Electrical Congress at St. Louis, in September, 1904, entitled "A New Danger to Lead-Covered Aerial Cables," has shown that many of the formerly unaccountable punctures in lead cable sheaths is due to the work of certain insects, which, either for the purpose of finding a secure place in which to deposit their eggs, or in the hope of finding food, bore through the sheaths as they would through the bark of a tree. One form of these is developed from eggs laid on the cable sheath under the braid, and these insects as soon as hatched start at once to bore into the sheath. The danger to cables is thus much heightened by the presence of the braid, as it is found that the eggs are not so often deposited upon the bare sheaths. This accounts in a large measure for the mysterious presence of holes in cable sheaths immediately adjacent to or under the cable hangers, and as is well known, these holes have usually been attributed to some mysterious electrostatic action, or to an electrical discharge from the conductors to the hangers. The facts in Mr. Hesketh's paper merit the serious attention of all telephone men, as Mr. Hesketh states that the insects capable of this damage are many in kind and are by no means confined to Australia.

Table XV. gives the outside diameter and weight per thousand feet of the various sizes of lead covered paper cable each of 100 pairs manufactured by a prominent firm. The conductors are No. 19 B. & S. G., each served with two layers of paper. The average electrostatic capacity is .080 microfarads, each wire being measured against all the others and the sheath. The diameters and weights of such cable will differ largely with various methods of manufacture, and with different capacities, or other electrical properties.

TABLE XV.—Aerial Cable.

Number of Pairs.	Outside Diameter, inches.	Weights per 1000 Feet in Pounds.	Number of Pairs.	Outside Diameter, inches.	Weights per 1000 Feet in Pounds.
1	5/16	214	30	1 7/16	2,748
2	3/8	302	35	1 1/2	2,985
3	1/2	515	40	1 9/16	3,176
4	9/16	629	45	1 5/8	3,365
5	5/8	747	50	1 3/4	3,678
6	21/32	877	55	1 13/16	3,867
7	11/16	912	60	1 7/8	4,055
10	13/16	1,214	65	1 15/16	4,241
12	15/16	1,375	70	2	4,430
15	1	1,566	80	2 1/8	4,804
18	1 1/16	1,758	90	2 1/4	5,180
20	1 1/8	1,940	100	2 3/8	5 505
25	1 5/16	2,232			

Before passing to the methods of supporting aerial cable, it is well to state briefly some facts concerning the talking qualities of conductors in cables. Preece's famous K R law states in substance that when the product, K R, formed by multiplying the electrostatic capacity, K, of a circuit expressed in microfarads by the resistance, R, expressed in ohms, exceed 15,000, speech becomes impossible. And that for smaller values of this constant the talking quality of a circuit is in direct proportion to this product. This law has apparently been disproven so far as limiting value of K R is concerned, as there are many circuits in the United States in commercial use whose K R value is much over 15,000. For instance, the New York-Chicago circuits have a K R value of something like 25,000. Mr. Preece has, however, pointed out that the accuracy of the law when approaching the limiting values of speech transmission has not been disproved, and that in the case of the very long circuits which seemed to disprove the law, there was some question as to whether the electrostatic capacity was determined with accuracy. It may be said, however, on the other hand, that when the electrostatic capacity of 1000 mile line is measured a value is arrived at not greatly different from that secured by measuring one mile of the same kind of line and multiplying it by 1000. It is not, therefore, altogether clear why the measurements of the value of K on these circuits was not a true determination. It is very fair to say that with ordinary methods of measuring the value of K, the K R law does not hold as to the limiting values of speech transmission.

The K R law is very fairly accurate for other than limiting values, and it may be said that the talking value of a circuit is in inverse proportion to the K R value. With this in view it is easy, with a given standard of speech transmission in mind, to determine roughly the spcifications for a cable of given length which is desired to give this standard transmission. If it is desired to find out what length of No. 20 B. & S. G. cable with an electrostatic capacity of .10 m.f. per mile, will give the same transmission as 10 miles of No. 19 cable, having an electrostatic capacity of .08 m.f. per mile, it is only necessary to figure the K R value of the cable taken as a standard and to take such a length of the new cable as will produce the same K R value.

Consideration of this method will often throw much light on the size and kind of cable that should be used in specific cases.

There are other considerations than those of mere talking efficiency which may enter into the determination of the proper cable to use in any given place, and it is not improbable, in view of changes through which telephone apparatus proper is now going, that other considerations may prove to be of more weight. These other considerations are those relating to the operation over the cable circuit of exchange apparatus, such as relays. Particularly, the current supply necessarily involved in operating trunk apparatus may have some influence on the size of conductors. Again, the advent of the automatic telephone switchboard, using as it does rapidly recurring impulses of current for the operation of the switches, makes it more probable that not only the ohmic resistance of the line, but its electrostatic capacity as well, may prove an important factor in the proper operation of the switches themselves.

Aerial cables are supported on steel rope stretched tightly between poles or other supports. This is stranded wire, and has the trade name of messenger wire. The use of messenger wire is necessary because the cable has not the requisite strength to support its own weight. For the heavier cables the messenger wire is usually composed of seven No. 8 steel wires twisted together into a rope. Table XVI. gives the common sizes of two different grades of messenger wire together with their diameters, weights and breaking strengths.

TABLE XVI.

Diameter in 32ds of an inch.	Weights per 100 Feet, Pounds.	Estimated Breaking Strength, Pounds.	
		Ordinary.	Special.
16	51	8,320	16,640
15	48	7,500	15,000
14	37	6,000	12,000
12	30	4,700	9,400
10	21	3,300	6,600
9	18	2,600	5,200
8	11½	1,750	3,500
7	8¾	1,300	2,600
6	6½	1,000	2,000
5	4½	750	1,400
4	2¼	375	750
3	2	320	640

For first-class work the wires of special strength, as given in the right-hand column, should be employed.

Table XVII. is useful in determining the size of cable that any messenger wire may safely carry, for any given length of span. By referring to the table giving the weights per thousand feet of cable and knowing the maximum length of span the size of messenger wire may be determined. It is not customary or necessary, however, to compute the size of messenger wire separately for each cable. The one-half inch messenger is largely used for all but the lightest cables. A cable man may always ride this with safety, which is not the case with some of the smaller messenger wires.

TABLE XVII.—Ordinary.

Diameters of Strands in 32ds of an Inch.	Spans in Feet.								
	100	110	120	125	130	140	150	175	200
	Weights of 1000 Feet of Cable. Pounds.								
16	2,818	2,516	2,263	2,152	2,050	1,867	1,709	1,391	1,154
15	2,520	2,247	2,020	1,920	1,827	1,663	1,520	1,234	1,130
14	2,030	1,812	1,630	1,550	1,476	1,344	1,230	1,001	900
12	1,580	1,409	1,266	1,204	1,146	1,043	953	774	640
10	1,110	899	890	846	805	733	670	544	450
9	860	765	680	652	620	563	513	414	340
8	585	765	468	445	423	385	352	285	235
7	433	385	346	329	313	284	260	210	172
6	337	300	270	257	245	223	2 4	165	137

SPECIAL.

Diameters of Strands in 32ds of an Inch.	Spans in Feet.								
	100	110	120	125	130	140	150	174	200
	Weights of 1000 Feet of Cable. Pounds.								
16	6,146	5,482	5,036	4,814	4,510	4,244	3,928	3,292	2,818
15	5,520	4 974	4,520	4,320	4,134	3,808	3,520	2,948	2,520
14	4,430	3,994	3,630	3,470	3,322	3,058	2,830	2,372	2,030
12	3,460	3,118	2,832	2,708	2,592	2,386	2,206	1,848	1,580
10	2,430	2,008	1,990	1,902	1,820	1,820	1,550	1,298	1,110
9	1,900	1,710	1,540	1,484	1,420	1,306	1,206	1,008	860
8	1,285	1,157	1,051	1,005	961	885	819	685	585
7	953	857	778	745	712	655	607	507	473
6	737	663	603	577	553	509	472	393	337

The messenger wire may be supported in various ways, one of which is to bolt what is called a messenger wire clamp to the side of the pole, which in turn serves to clamp the messenger wire in place. This method is shown in Fig. 592. A form of messenger clamp,

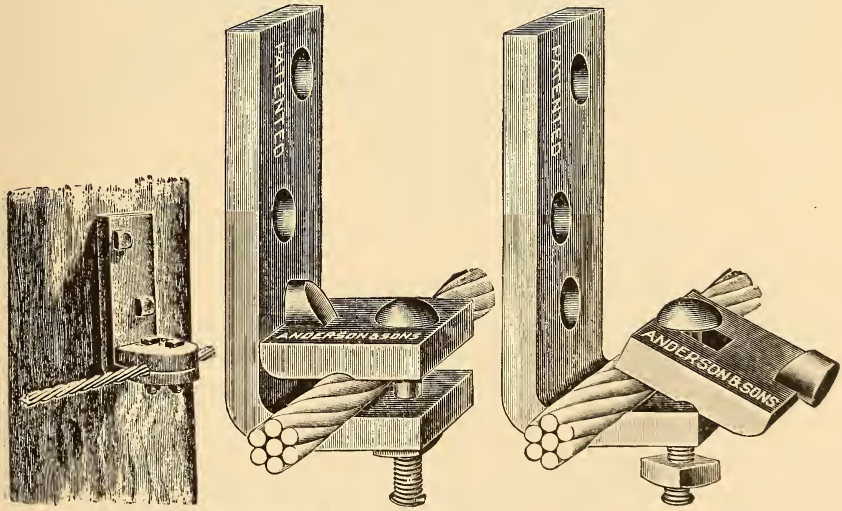

FIG. 592.—MESSENGER WIRE CLAMPS.

known as the Stroud clamp, shown in two views at the right of Fig. 592, has the advantage of requiring but one bolt to fasten the clamp block in place, a projection on the clamp block which passes into the main portion of the support serving in lieu of the second bolt. Another advantage of this type of clamp is that the bolt never need be taken entirely out, which prevents the separation and possible loss of the clamping block and bolt.

Where more than one or two cables are to be supported from a pole, cable cross arms are often used, these being of angle iron construction, bolted to the pole as an ordinary cross arm and braced by cross-arm braces in some such manner as is shown in Fig. 593. If it is desired also to carry one or more bare wires, wooden cross arms may be secured within the angle iron arm as shown in this Figure, on which wooden arm ordinary pins and insulators may be secured.

The cable is suspended from the messenger wire in several different ways. Sometimes it is suspended by binding it to the messenger wire by strong tarred marlin. The marlin is wrapped around both cable and messenger wire, usually in two directions to give it

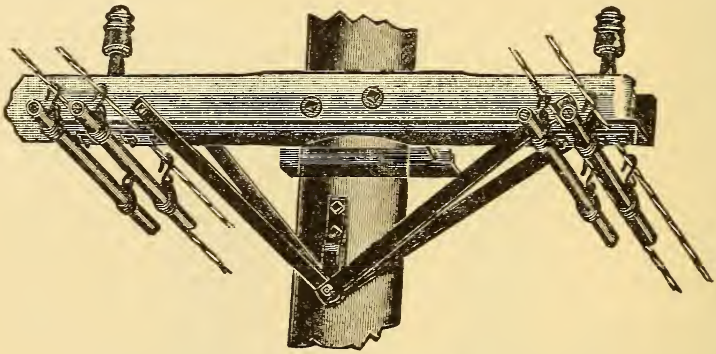

FIG. 593.—CROSS-ARM FOR MESSENGER SUPPORT.

greater security. This method is still largely used by the Western Union Telegraph Company in supporting its cables.

The method now most extensively used by telephone companies in supporting aerial cable is by means of cable hangers adapted to tightly encircle the cable sheath and provided with a hook to slip over the messenger wire. One of the best forms of cable hanger is that shown in Figure 594. This consists merely of a loop of marlin, to one end of which is attached a galvanized steel wire hook. The method of attaching this to the cable is clearly shown in the figure. The marlin hanger has been much criticized on the ground that it would subsequently rot and allow the cable to fall, and many forms of all metal hangers have been devised to take its place. Some of these involved the use of a zinc band which was placed around the cable and supported by the wire hook. They were very satisfactory, but the marlin is perhaps the standard of to-day, it having demonstrated its capability of withstanding the effects of the weather for many years.

It is well before hanging the cable to make tests for continuity of

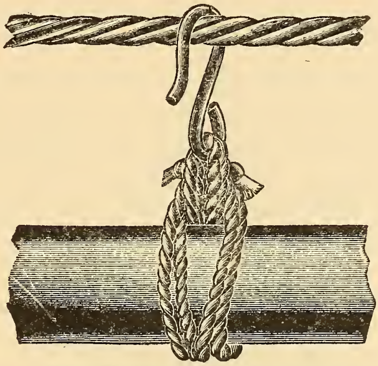

FIG. 594.—MARLIN HANGER.

the conductors and for insulation of its resistance and capacity before the cable is unreeled, so that any difficulty that may exist may be attributed to the fault of the manufacturer or to the transportation company. For facilitating such tests the cable is usually placed upon reels in such a manner that both of its ends are available for such tests.

When the cable arrives both of its ends are sealed to prevent the

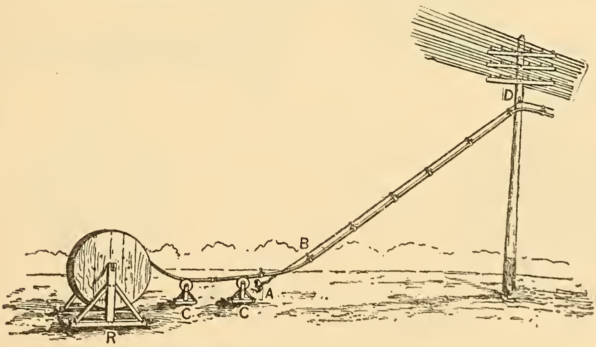

FIG. 595.—RUNNING UP CABLE.

entrance of moisture, and after testing, the ends should be carefully re-sealed in a manner that will be described later.

The method of hanging cables is shown in Fig. 595. The end of the supporting strand after passing over the last messenger wire, clamp *D* is firmly secured to a guy-stub set in the ground at *A*.

The reel on which the cable is coiled is placed in line with the messenger wire and a few feet beyond the stake as shown. One or more grooved pulleys, *C C*, mounted on suitable supports are placed between the reel and stake in such a manner as to support the cable when it is paid out. A stout rope, or better, a small wire cable, is previously hung on pulleys or hooks below the cross arms of the entire stretch over which the cable is to be drawn. One end of this it attached to the end of the cable, while the distant end is attached to a capstan or other form of windlass. As the cable passes over the rollers, *C C*, the hangers are attached and are placed one by one upon the inclined messenger wire as they reach the point, *B*. As the cable progresses, linemen stationed on each pole lift the hangers

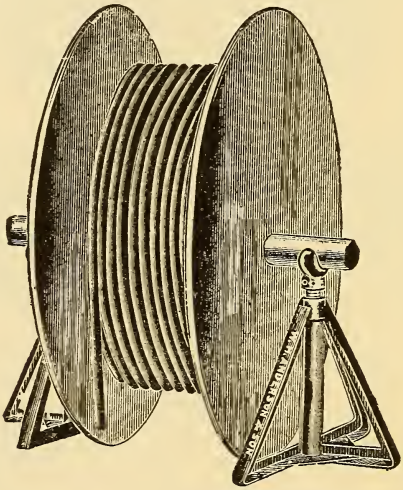

FIG. 596.—CABLE REEL JACKS.

over the messenger wire clamp or cross arm as they pass. In this way the entire length of cable is drawn up to and along the stretch without subjecting any portion of it to an undue strain. The hangers are usually attached at distances of from twenty-four to thirty inches, according to the size of the cable. The work is somewhat expedited if, during the drawing up of the cable, only about every fifth hanger is hooked over the messenger wire. This reduces the labor of the linemen in lifting the hangers over the support. When, however, the forward end of the cable reaches the beginning of the last span, the signal should be given to all linemen stationed on the poles to hook on all the hangers as they pass, and in this way all of the hangers will be secured in place throughout the entire stretch without going out over the line afterwards.

In Fig. 596 is shown a cable reel support, provided with screw actuated lifting jacks so that the reel may be readily lifted from the ground to allow its rotation.

The method of hanging cable shown in Fig. 595 is subjected to

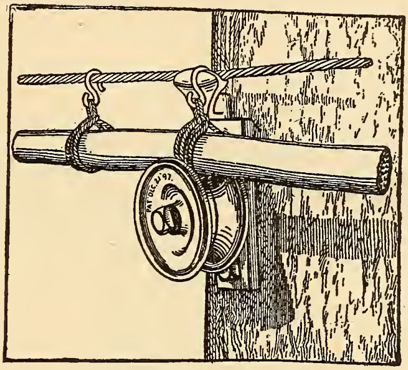

FIG. 597.—CABLE ROLLER.

a disadvantage when all-metal cable hangers are used, in that the sliding of the hanger hooks along the messenger wire tends to loosen the hangers on the cable, sometimes to such an extent that several of them become bunched at one point of the cable.

A modification of this method which does away with the necessity for a man on each pole to lift the hangers over the messenger wire

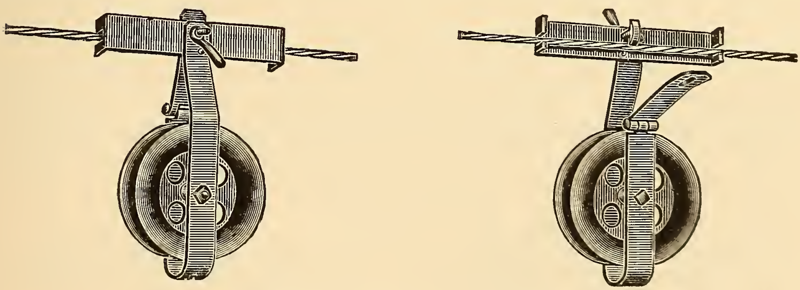

FIG. 598.—CABLE TROLLEY.

support involves the use of the apparatus shown in Fig. 596. A bracket, such as shown in this figure, carrying a grooved pulley and a temporary support for the messenger wire, is temporarily attached to each pole. As the cable passes each pole the pulley serves to raise the cable so that the hanger will readily pass over the temporary support. When the cable is in place the brackets are removed and the messenger wire secured to the pole in any ordinary manner.

Still another way of drawing up aerial cable is by means of so-called "cable trolleys." These consist of grooved pulleys such as are shown in Fig. 598, which may be secured to the messenger

FIG. 599.—CABLE SPLICING.

wire at frequent intervals, and over the pulleys of which cable is drawn, the hangers not being fastened to the messenger wire at all. After the cable is in place the ordinary hangers may be applied and the cable trolley removed.

When it becomes necessary to splice a cable, the greatest care should be taken that no moisture be allowed to enter while the splice is being made, and that the splice shall be so thoroughly sealed at the end of the operation that there will be no possibility of the subsequent entrance of moisture. A suitable staging should be erected on the pole where the splice is to be made if it is possible to bring the splice within reach of the pole. This can always be provided for in new cable, but sometimes in repairing a leak it is necessary to

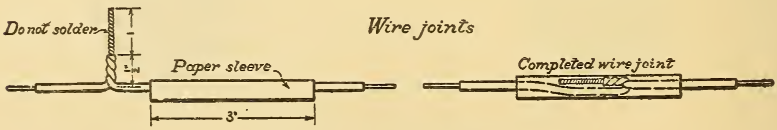

FIG. 600.—DETAILS OF WIRE SPLICE.

make these splices from a car suspended from the messenger wire. When all is ready the lead sheath of each end of the cable to be spliced should be cut away for a distance of about two feet, the ends of the cable having previously been cut off square. The cable ends then appear as in Fig. 599. The wires should then be bound tightly together where they emerge from the lead sheath, using cotton twine or wicking. This winding should be extended close up to the end of the sheath. This is to prevent paraffin applied in the next operation from following along the core of the cable within the sheath.

The next operation is to dip the end of the cable so prepared in hot paraffin, which must be heated above 212 degrees F. The cable ends should be held thus immersed until all bubbling ceases, when they should be taken off. This preliminary "boiling out" is to prevent moisture from getting into the cable while splicing, and should extend well over the cotton wrapping already applied.

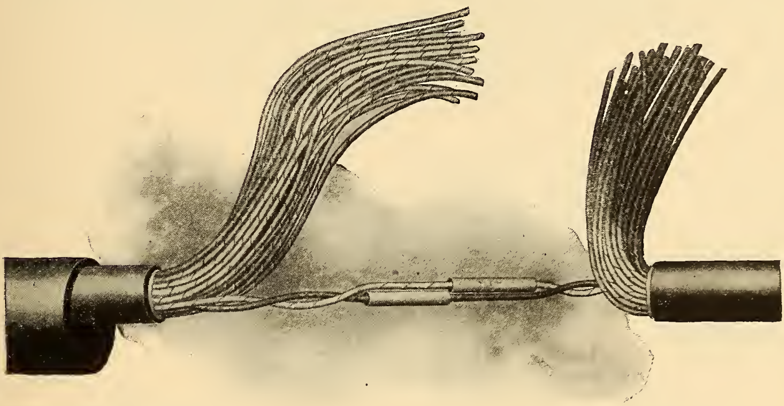

FIG. 601.—CABLE SPLICING.

A sleeve, consisting of a lead tube of the following dimensions for various sizes of cable, should then be slipped over one of the cable ends and back out of the way.

Lead Sleeves—Straight Joints.

150 pair cable	30 inches	× 3 inches	× $\frac{1}{8}$ inch
120 " "	28 "	× $2\frac{3}{4}$ "	× $\frac{1}{8}$ "
100 " "	28 "	× $2\frac{1}{2}$ "	× $\frac{3}{32}$ "
90 " "	28 "	× $2\frac{1}{2}$ "	× $\frac{3}{32}$ "
60 " "	28 "	× $2\frac{1}{4}$ "	× $\frac{3}{32}$ "
50 " "	28 "	× 2 "	× $\frac{3}{32}$ "
30 " "	28 "	× 2 "	× $\frac{3}{32}$ "
25 " "	28 "	× 2 "	× $\frac{3}{32}$ "

A paper sleeve should then be slid over each wire of a pair. The pairs in paper-covered cables are usually colored red and white, and as a matter of convenience the paper sleeve should be slid over the red wire on one end of the cable, and the white wire on the other.

The insulation of two wires of the pair should be removed and the wires so cut that they will overlap about four inches. Each wire should be stripped of its insulation for a length of about one and one-eighth inch, care being taken that the wire is not nicked in this process. The two ends of the white wires to be joined should then be twisted together, the twist extending through the entire length of the bare wire and so as to include about one-half inch of the insulation.

The details of the method of splicing the two wires together is shown in the left-hand portion of Fig. 600. The paper sleeve is to be then slid over the sleeve as shown in the right-hand portion of Fig. 600. The reason for including a portion of the insulation in the twist is merely to keep the insulation of the wire from sliding away from the joint when the paper sleeve is pushed over it. In no case should the joint be soldered.

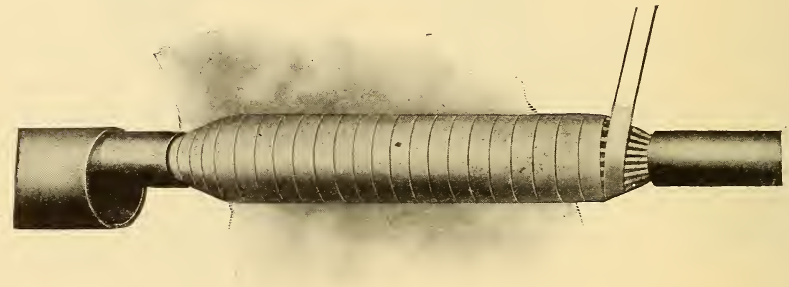

FIG. 602.—CABLE SPLICING.

The two ends of the cable with a single pair thus connected is shown in Fig. 601.

The joint in the wires should be so spaced that the joints in a pair will not be directly opposite each other, and the joints in the various pairs will be approximately evenly distributed throughout the entire length of the splice. After all wires are spliced hot paraffin should be poured over them, a ladle being used to dip the paraffin from the melting pot and pour it over the splice. The pot should be placed under the splice so that the surplus paraffin will drain back into it. This operation of boiling out should extend from the ends of the splices towards the middle of it and should be continued until every trace of moisture has been driven off as indicated by the absence of bubbles. The splice should then be thoroughly taped with a strip of muslin about one inch wide, as shown in Fig. 602. Some may prefer to omit this wrapping of tape. Where it is used, however, the splice should again be boiled out after it is in place, after which the lead sleeve should immediately be drawn in place as shown in Fig. 603. If the splice has been properly made the lead sleeve

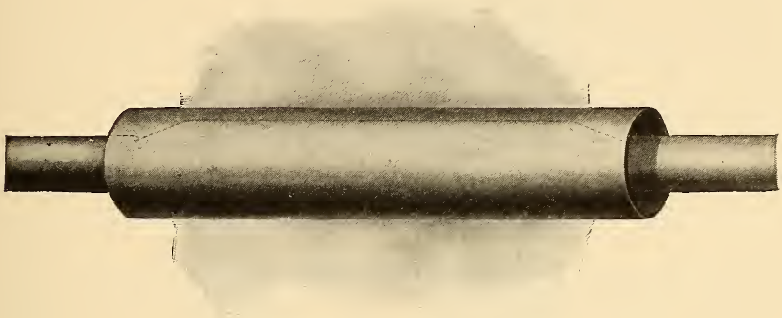

FIG. 603.—CABLE SPLICING.

will lap the cable sheath about two inches at each end. The lead tube should then be pressed down into close contact with the cable sheath at each end, and a wiped joint made carefully about each end.

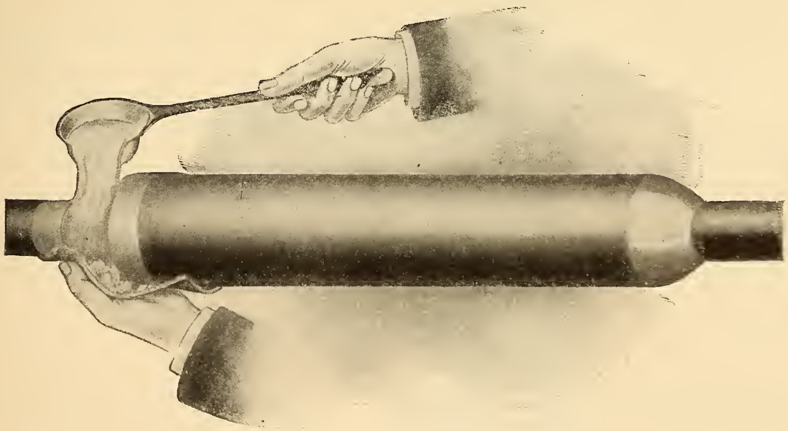

FIG. 604.—CABLE SPLICING.

Figure 604 shows the appearance of the finished joint and also the method used in making the wiped joint.

Where a cable terminates, means must be provided for distributing its various wires and connecting them to the wires which are to form connections of the same circuits. Means must also be pro-

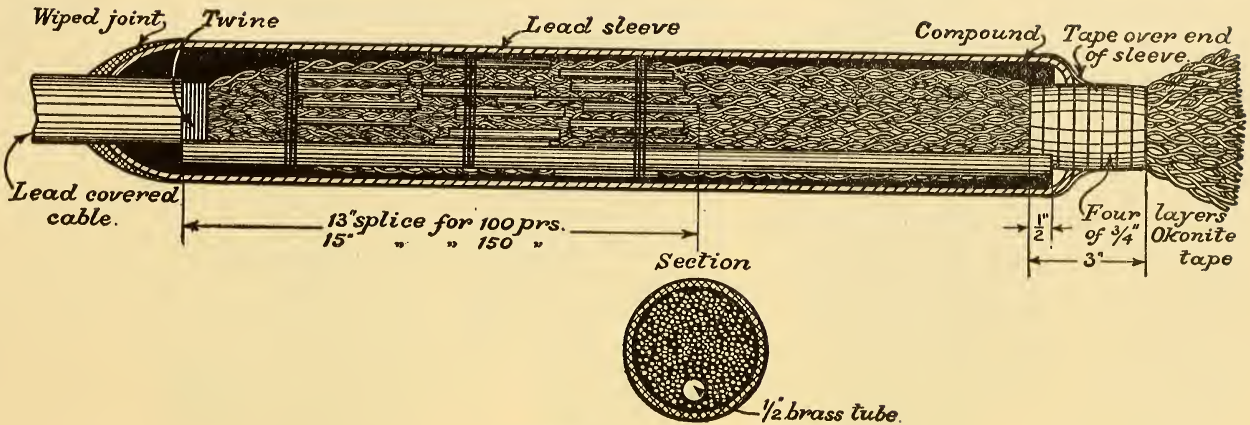

FIG. 605.—POT HEAD.

vided for protecting the cable core so as to prevent moisture from entering. The same is true at intermediate points on a cable wherever it is necessary to take out some of the wires making them available for use at such points.

There are two general methods of terminating or tapping cables, one employing what is known as a pothead or flexible terminal, and the other employing what are called box terminals. Potheads or flexible terminals are made by joining rubber-covered wires to the cable and hermetically sealing the metal tube, usually made of lead, to the cable sheath in such manner as to enclose all the joints between the paper insulated cable and the rubber insulated wires. This tube is then filled with a melted insulating compound which on cooling effectually seals the cable, the rubber-covered wires projecting beyond the end.

Box terminals consist usually of iron boxes provided at the lower ends with thimbles of brass to which the cable sheath may be soldered and through which the wires of the cable may be led to conveniently arranged terminals within the boxes. To these terminals the wires of the cable are soldered, and access is given to the conductors from the outside of the box by the fact that the terminals project through the walls of the box to the outside, they being insulated from the metal portion of the box by hard rubber bushings. After the completion of the connections within the box, the latter is hermetically closed by a lid which screws in place, a rubber gasket serving to prevent the entrance of moisture.

Potheads are perhaps, all things considered, the most reliable and most economical method of terminating cables. A pothead, however, to be effective, should be made with the greatest care, and the following are specifications governing their construction used by one of the various operating companies in this country.

POTHEAD TERMINALS.

Materials.

Lead sleeves, of unalloyed lead, 1-8 inch thick, of the following dimensions.

For	150	pair	cable,	length	26	inches,	inside	diameter	3½	inches
"	100	"	"	"	24	"	"	"	3	"
"	50	"	"	"	20	"	"	"	2½	"
"	25	"	"	"	20	"	"	"	2	"

Drift out the sleeve for one-half its length until its diameter is increased one-quarter of an inch.

Okonite Wire; twisted pair, red and black No. 20 B. & S. gauge, 3-32-inch insulation, without braid or outside covering.

Okonite Tape; $\frac{3}{4}$-inch wide.

Paper Sleeves; all moisture driven off by *dry heat* just before using.

Brass Tubing; thin, $\frac{1}{2}$-inch in diameter, length, $2\frac{1}{2}$ inches less than that of lead sleeves.

Heavy Cotton Twine, or wicking.

Wiping Solder; containing 43 per cent. tin.

Sealing Compound; of standard type as furnished for this purpose. Do not mix the compound with other materials.

Directions.

Remove the cable sheath for fifteen inches for all sizes except 150 pair cable, when the distance should be seventeen inches. Slip the lead sleeve over the cable, drifted end last, and splice the cable wires to the okonite wires in the usual manner, joining the colored wire of the cable to the red okonite wire of each pair. Cover each splice with a sleeve, and keep the splices within a limit of thirteen inches from the end of the cable sheath in all cases except when 150 pair cable is being used, when a distance of fifteen inches is allowable. Remove all pieces of paper or other debris, bind the cable wires as they leave the sheath tightly with several layers of twine to prevent the compound entering the cable, and tape all the okonite wires together for three inches in such a manner that one-half inch of the tape wire will be below the surface of the compound. Open up the spliced wires as much as possible to allow free spaces between, and bind the brass tube with twine alongside the wires with the lower end even with the end of the sheath of the cable, binding no higher than the wire splices. Draw up the lead sleeve until its lower end laps over the cable sheath $1\frac{1}{2}$-inch, and wipe it to the sheath. Secure the whole in an upright position, warm the lead sleeve until it can barely be touched with the hand, place a funnel in the brass tube, and slowly pour in the sealing mixture, previously heated to 350 degrees F., until it fills the sleeve to within one-half inch of the top. Then remove the funnel and allow the compound to settle and cool. Test the compound just before using by putting in a short piece of okonite wire for two minutes. If the okonite wire is not softened so as to readily come off the wire the compound is not too hot. Protect the open end and the wires leading therefrom against the weather. On the next day fill with hot compound to make up for the settlement. Three days later do the same if necessary. After this, and when thoroughly cold, dress the top of the lead sleeve into contact with the okonite tape wrapping, which at this point should consist of at least four layers. Place a cross on the outside of the lead sleeve at a point opposite the upper end of the brass tube. Do not boil out the cable end with paraffin. If dampness enters, the cable should not be used until this defect is

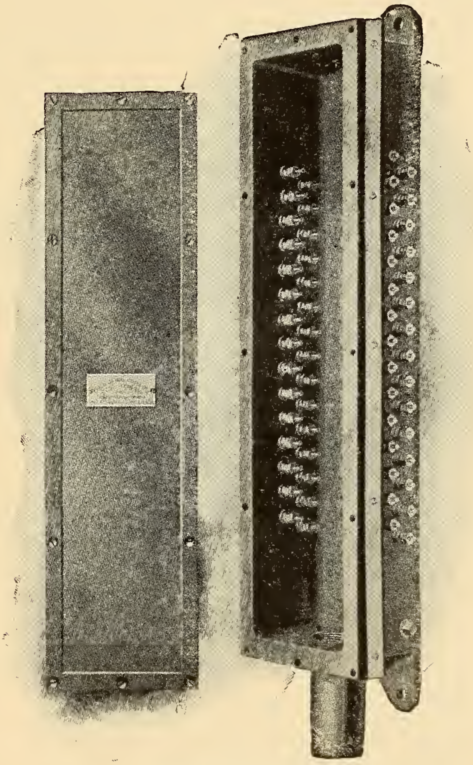

FIG. 606.—BOX HEAD.

remedied, or the part cut away. *Under no circumstances* may paraffin be used on okonite ends.

The completed pothead as made above is shown in sectional view in Fig. 605. Sometimes the brass tube is omitted and the sealing compound is poured directly into the top of the pothead. The formation of air bubbles and the incomplete sealing of the cable are very much more likely to ensue when this method is employed. When the brass tube is used the sealing compound is really introduced at the bottom of the splice, the compound gradually coming up from below and forcing all air out before it.

A typical iron box head is shown in Fig. 606, in which various wires are shown extending each from the cable entering the tube at the lower portion of the box to one of the terminals within.

There is an almost endless variety of box terminals adapted to be secured to the pole in various ways, and some of these are very reliable, but they are usually more expensive than the pothead.

The use of lime in hermetically sealed box terminals has been subjected to a good deal of discussion. The fact that the box terminal is sometimes open to perhaps moist air always tends to lower the insulation of the cable on account of the entrance of moisture. A little unslacked lime introduced into the cable head will serve to absorb what moisture is in the cable end, or within the terminal itself, and thus keep the insulation high. There are other such absorbent materials, but most of them are subject to one or more disadvantages, some of them being in themselves of a corrosive nature and others tending in themselves to lower the insulation. Lime thus used will actually raise the insulation where a small amount of moisture has been present, and will keep it high, and seems to offer no deleterious action upon the conductors or the insulation even after the lime is so fully slacked as to crumble in the bottom of the box.

In modern overhead cable work it is the practice to distribute the wires in a cable so as to make a single pair of wires available for use at more than one point. To do this single pairs of wires within the cable are brought out at intermediate points within the cable, the same pair extending on to the end of the cable, or to several other intermediate points. This is called multiple distribution.

In a telephone system, the wire plant is the part needing the most careful consideration and best judgment in view of the particular condition of the territory to be served. What part of the system should be underground, what part in aerial cable, and what part in open wire, constitute important fundamental elements; but the distribution of the lines from the cables may be done in many ways. Multiple cable distribution is a method of line construction in which the cable pairs of a system are available at more than one point; the object of forming such a system of distribution is to provide for the constant and unforseeable changes in the location of substations, and for the inevitable errors in estimating growth. In making the development of a telephone system, however, the best that can be done in the sparsely developed regions is to make a fair assumption

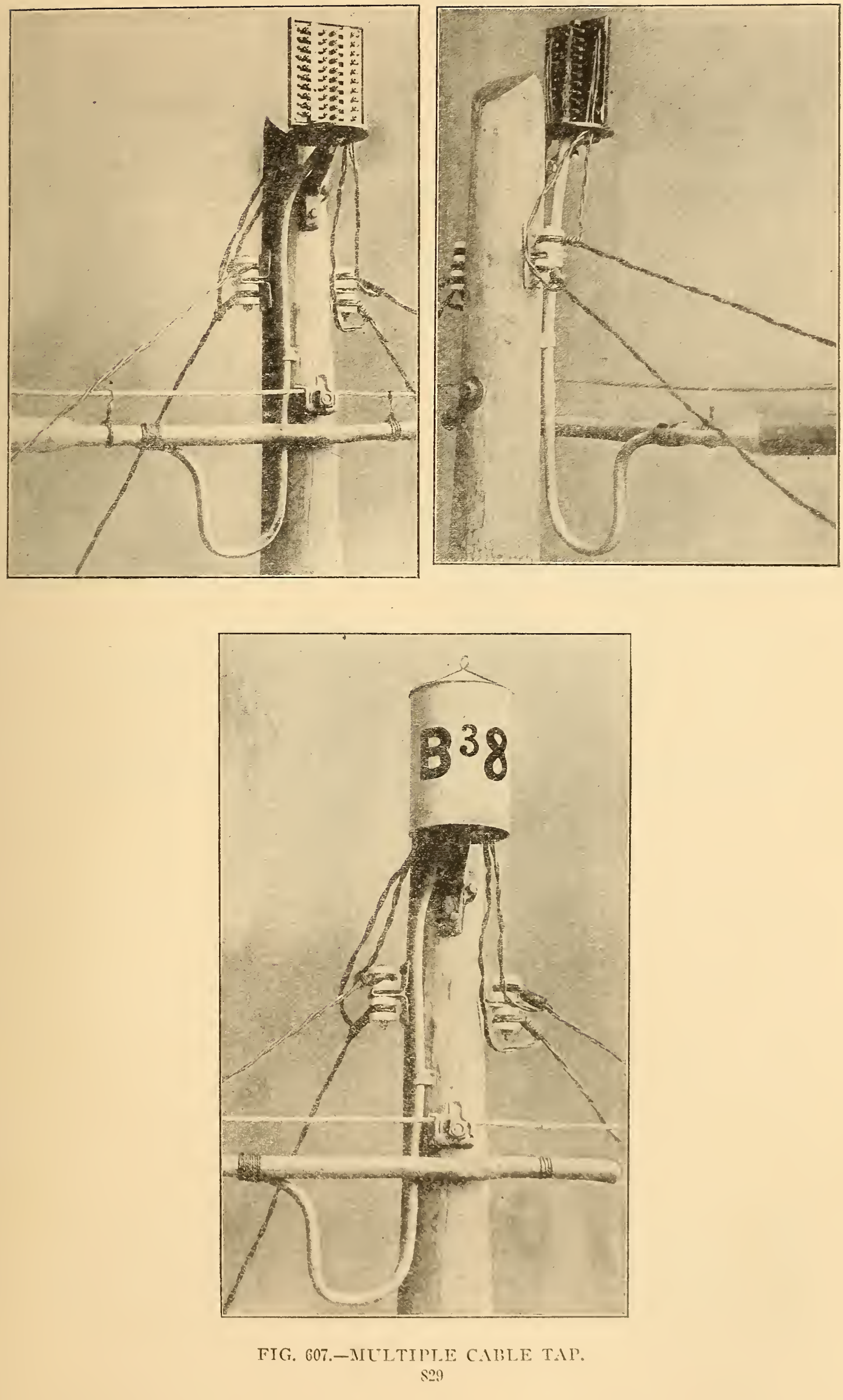

FIG. 607.—MULTIPLE CABLE TAP.

as to where the various densities of development will occur; and at the best this assumption can only be generally correct. It will vary in minor ways, even if the broad suppositions proved to be accurate. Multiple cable distribution is intended to provide a flexibility which

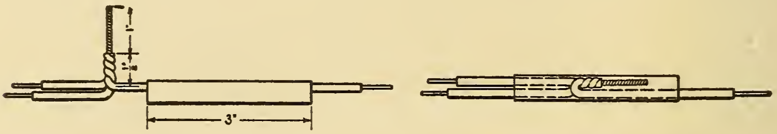

FIG. 608.—DETAILS OF WIRE JOINT IN Y SPLICE.

will offset these inaccuracies of assumption; and that system of multiple distribution is best which requires the smallest number of cable wires to serve a constantly increasing number of subscribers.

The method of bringing out a certain number of pairs from a cable consists in making a "Y" splice at the required point, a cable of the required number of pairs that it is desired to bring out being

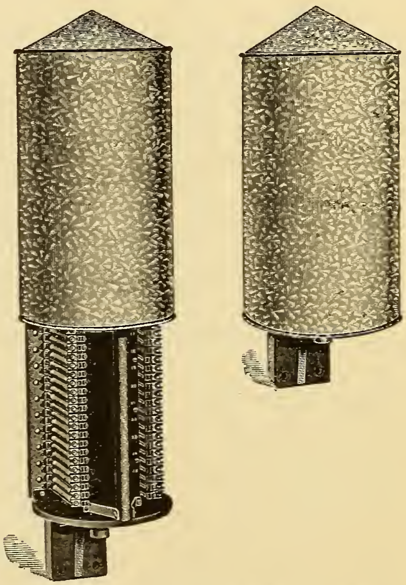

FIG. 609.—CABLE TERMINAL CAN.

tapped on the main cable, which may be of, say, 50 pairs, the joint being made on a lead sleeve with wiped joints after the fashion of the splice already described. One method of taking out multiple taps consists in the use of regular dry core paper cable for the tap cable which is then terminated at its upper end in a pothead as already described. A modification of this method consists in placing the required number of rubber-covered wires of No. 19 or No. 20 gauge in a lead tube, such as to very loosely hold the wires, and filling this tube with a compound of the same nature as that used in pothead work. This pipe cable is tapped on to the main cable with an ordinary "Y" splice, and moisture is prevented from entering the main cable by the sealing compound in the lead pipe. No other seal is then necessary for the cable. In Fig. 607 such taps are

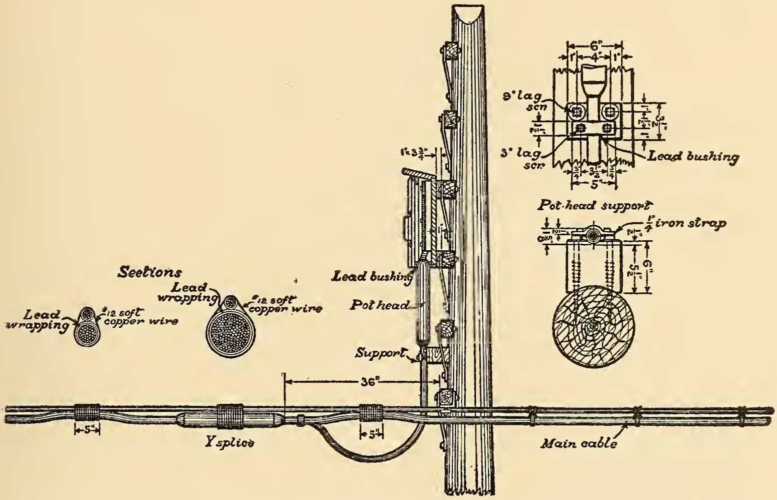

FIG. 610.—DETAILS OF CABLE TERMINAL.

shown, these being used by Mr. L. W. Stanton in some of his recent work.

The details of the wire joint used in making "Y" splices are shown in Fig. 608.

Where the cable is terminated by means of a pothead, or some form of box terminal, some housing must be provided for out-of-door terminals for the conductors to which the external circuits are to be joined. Sometimes this housing assumes the form of a cylindrical can of galvanized iron, as in the case shown in Fig. 607, and is better illustrated for a large terminal in Fig. 609. Where a pothead is used the general practice is to support it in an upright position on the pole, having its upper end extending into a wooden cable box containing conductor strips, to which the wires leading from the pothead and those leading to the outside circuits may be joined. This construction is applied to a multiple tap as shown in detail in Fig. 610, this being the standard construction of one of the large Bell companies.

In the case of Fig. 610 the wires leading to the subscribers' stations are taken off on insulators attached to cross arms, while in other cases what are called distributing rings or circle tops, of which one is shown in Fig. 611, are provided.

Methods of distribution from aerial cables to subscribers' prem-

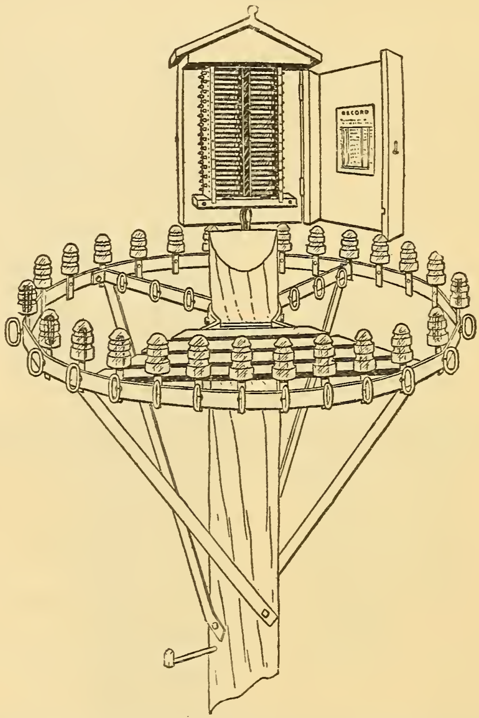

FIG. 611.—DISTRIBUTING RING OR "CIRCLE TOP."

ises differ greatly. The old method was to terminate the cable on a pole and then to continue the conductors as bare wires on cross arms until the destination of a pair was reached, after which "drop" wires were run from the pole nearest the subscriber's premises to his house. This bare wire distribution has largely gone out of use and plants have been constructed in this country in which hardly a foot of bare wire was used. This latter practice, however, is thought to be carrying the cable idea to an extreme. At present the best practice after terminating the cable by any of the methods described, is to run a No. 18 B. & S. rubber-covered braided wire from the terminal in the cable box to the distributing insulator on the same pole, and then drop off from its insulator with the drop wire to the subscribers' premises. Drop wires differ largely, both bare and insulating wire being used. Drop wire should be No. 14 hard drawn

FIG. 612.—TEN-PAIR TERMINAL DISTRIBUTING TO RESIDENCES.

copper if bare. If both are insulated, they should be not smaller than No. 16 rubber-covered and braided, unless they are twisted, in which case they may be as small as No. 18. Frequently one bare and one insulated wire is used, these being run separate in practically the same manner as two bare would be run. In this case both wires should be of No. 14 hard drawn copper.

In Figure 612 is well shown the methods of extending drop wires from a multiple tap terminated in a can to the various subscribers' houses. Figure 613 shows a can at the top of a pole feeding to a

FIG. 613.—TWENTY-FIVE-PAIR TERMINAL DISTRIBUTING TO BUSINESS BLOCK.

distribution ring from which the various drop wires are led. These cuts were loaned by Mr. L. W. Stanton, whose construction work they represent.

CHAPTER XLI.

UNDERGROUND CABLE CONSTRUCTION.

It is now settled practice to place all telephone wires underground in the business centres of large cities, and even to do so in the central parts of smaller cities. The primary requisite for this construction is that a suitable conduit shall be provided in which the conductors may be laid. It is usually necessary to provide conduits having a suitable number of ducts to meet the requirements for future as well as immediate use, and much judgment should be exercised in this respect in planning the system. Suitable openings are provided for the conduits at frequent intervals, these being in the form of manholes, from which sections of the cables may be drawn into the ducts and withdrawn when occasion requires, for repairs. The principal requirements of a good conduit may be outlined as follows:

The material of which the conduit is made must be durable, and this implies that it must be absolutely proof against decay or corrosion due to moisture, dry rot, gases, or the liquids present in the soil. It should, moreover, be fire-proof if possible, although this is a minor consideration.

The conduit should possess both tensile, shearing and crushing strength. Severe vertical strains are frequently imposed upon subway structures, due to the removal of the support from beneath them, caused by excavations in the streets or by the settling of the ground. Side strains are not so likely to occur, and their effects are usually slight; therefore, it follows that the conduit should be, if possible, strongest in a vertical direction. If the stress imposed upon the structure is such as to cause a fracture or undue settling, the alignment of the ducts is thereby destroyed, which may interfere with the drawing in or withdrawal of cables. Moreover, the grade of the duct is destroyed, so that the proper drainage cannot be effected. The ducts between the manholes should be straight, if possible, and where curves are necessary they should be very gradual and present no sharp corners which would interfere with the drawing in or seriously abrade the cable sheath. Slight turns in conduits are frequently made by joining together short straight sections, but where the nature of the conduit used permits it, it is better to form all bends of curved sections. It is desirable that the structure should be composed of insulating material and be moisture-proof. No dependence, however, for insulation of the conductors themselves must be placed on the conduits, as the cables must in all cases provide the means for keeping the conductors thoroughly insulated and free from moisture, even under the most adverse circumstances. No conduit system has yet been constructed which has been kept dry, and to do so means to seal each end of each duct at each manhole. As yet, it has not been found absolutely necessary to get such dryness.

It is very essential that the conduit must contain no chemical agents capable of exerting a deleterious effect on the cable sheath. As an example of this may be mentioned certain forms of wooden conduits, which in the process of decay liberate acetic acid, which in a short time totally destroys the cable sheath, changing it to lead acetate. This difficulty has been experienced with some forms of creosoted wood conduit, but in the later products in this line this difficulty is said to have been completely removed by the use of a better grade of creosote oil and improved methods.

Economy of space is often an important item in the selection of conduit to be used, and under crowded conditions that conduit which will place a given number of ducts within the smallest space is the most desirable, other things being equal.

The earliest form of conduit used in this country was the open-box conduit, which consisted merely in a trough made of inch-and-a-half or two-inch lumber and of sufficient size to accommodate enough cables to meet the existing demands, as well as the future growth of the system. These troughs were laid in a trench, the bottom of which was properly graded, the sections of the trough being about fifteen feet in length and butt-jointed—that is, laid together end to end. The joints were held in line by boards nailed on the outside and overlapping each end about a foot. The cable was laid in these troughs by driving the reel containing it slowly alongside of the trench, the cable being carefully laid as it was unwound from the reel. After all the cables were in place the trough was filled with hot pitch, when the cover was nailed in position and the trench refilled. This is probably the simplest form of underground cable construction, with the exception of a method, infrequently practiced, of laying the cable directly in the ground without any conduit whatever.

The cheapest and simplest form of conduit which permits the drawing in or withdrawal of the cables is that composed of creosoted wood tubes, or "pump logs," as they are commonly and appropriately termed. These are usually made in eight-foot lengths, having a square external section $4\frac{1}{2}$x$4\frac{1}{2}$ inches, with a 3-inch bore. A tenon joint one and one-half inches long is used for securing proper alignment of the joint. Several views of this tube are shown in Fig. 614.

The wood is usually treated with creosote or dead oil of coal tar in the following manner: The lumber is laid on cars and run into a large steel cylinder six feet in diameter, which is closed by a heavy iron door. It is first subjected to live steam at a temperature of 250° F. until the timber is heated through and through, the purpose of this being to coagulate the albumen in the sap. A vacuum

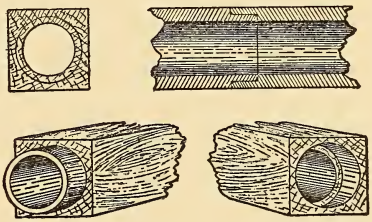

FIG. 614.—"PUMP LOG" CONDUIT.

pump is next applied to the tank, exhausting all air and steam, the pump maintaining a vacuum of about twenty-six inches. This evaporates practically all of the sap and water from the wood, thus seasoning the timber. The next step in the process is to pump creosote oil previously heated to a temperature of 100° to 125° F. into the tank until it is full. This is then placed under a pressure of about eighty pounds per square inch and the amount of creosote which is forced in after the filling of the tank is carefully measured, this being the amount that is taken up by the pores of the wood. Specifications for the treatment require that from eight to twenty pounds of the oil shall be absorbed by each cubic foot of timber. Twelve or fifteen pounds is the average amount required for electrical purposes. As has been stated before, much trouble has existed owing to the liberation of acetic acid from conduit treated with creosote. It is claimed, however, that by using a proper quality of creosote oil, and by using the method of impregnation just described, that this trouble has been entirely eliminated. The life of creosoted wood conduit is, to say the least, problematical, but there seems to be good reason to believe that when properly treated and laid it will last an ordinary lifetime, if not longer.

In laying this conduit the trench is dug, and after its bottom is properly graded so as to have a gradual slope either from an intermediate point toward both man-holes or an uninterrupted slope

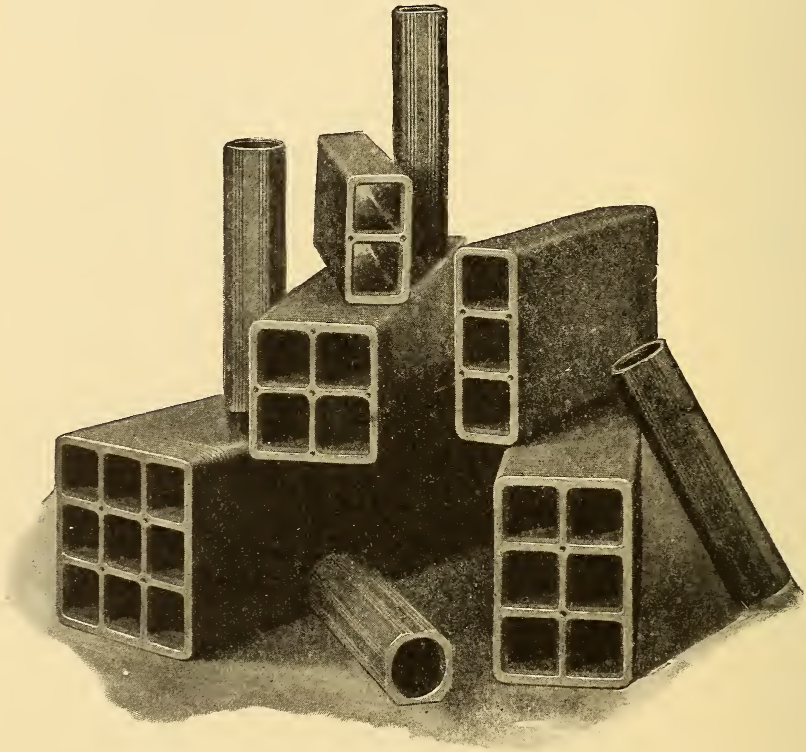

FIG. 615.—SINGLE AND MULTIPLE-DUCT CONDUIT.

from one man-hole to the other, a creosoted wood plank two inches thick is laid as a foundation. The ducts are then laid on this plank side by side and in as many different layers as are necessary to give the required number. They should be so laid that the separate ducts break joint in order to give strength to the entire structure. Over the upper layer is then laid another creosoted wood plank two inches thick, after which the trench is filled in with earth. The great point in favor of this conduit is its cheapness, this being greatly enhanced by the fact that no concrete is employed for a foundation.

Conduits of clay or terra-cotta, burned hard and with vitrified surface, are being extensively used and are giving unqualified satisfaction. These are made up in a number of forms which may be divided into two classes, namely, multiple duct and single duct. The multiple duct conduit is made up in a variety of ways, some of which are shown in cross-section in Fig. 615, loaned by the H. B. Camp Company. For telephone purposes, the duct opening is either round and 3½ to 4 inches in diameter, or square with round corners and of the same dimensions both ways.

The earliest form of clay duct, which was used at all, generally was one having a square outer form in section, about 12 by 12 inches,

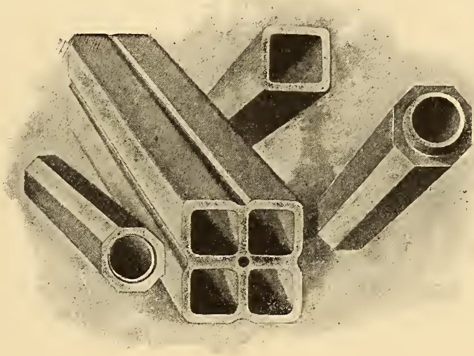

FIG. 616.—SINGLE AND QUADRUPLE TILE.

walls of one inch, and a horizontal shelf across the middle, one inch thick. This divided the pipe into two ducts, one above the other, each about 4½ inches high by 10 wide. Into each duct were drawn three cables, two side by side, and one on top of these two. Economy of duct space was gained at a sacrifice of safety, as it was found impossible to draw out one of three, if it became necessary, without tearing the sheath off in doing so.

Single-duct tile then came into existence, and still later the multiple-duct type, but these latter, as Figs. 615 and 616 show, had one duct opening for each cable. Fig. 616 is loaned by Field Clay Conduit Company.

The single-duct class of tiles possesses some advantages over the multiple-duct tiles, chief among which are the greater flexibility and the increased ease of handling. The form shown in Fig. 617 has come into very wide use and has proven its adaptability to meet almost any conditions that may arise. These tiles are $4\frac{5}{8}$ inches square by 18 inches long, and have a $3\frac{1}{4}$-inch bore. By it curves are easily made, short curved lengths being provided, or curves of long radius may be made with the regular tiles, the lengths being so short as to form a practically smooth interior surface. This conduit is laid in much the same way as ordinary brick, and in order to insure proper alignment a mandrel (shown in lower portion of Fig. 617), three inches in diameter and about thirty inches long, is laid in the duct and pulled along through it by the workmen as each additional section is laid on. The rear end of this mandrel is provided with a rubber gasket a little larger than the diameter of the

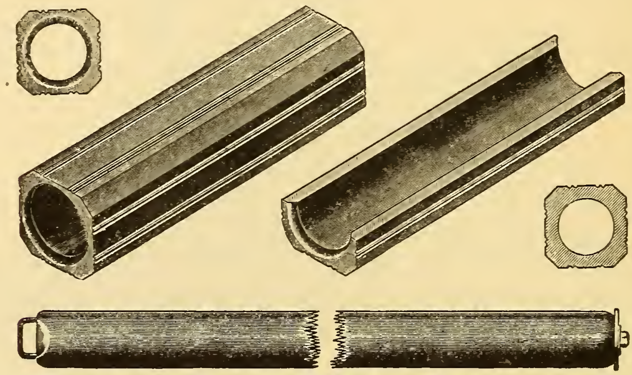

FIG. 617.—SINGLE-DUCT CONDUIT AND MANDREL.

conduit, which effectually smoothes the inner surface and prevents the formation of lips which might prove injurious to the cable sheaths in drawing in. On the front end of the mandrel is provided an eye which may be engaged by a hook carried by the workmen in order to move it forward. Fig. 618 shows two examples of single-duct subway in process of construction.

In laying vitrified clay tile the process used is as follows: The trench is dug to such a depth as to allow at least two feet of earth above the top of the entire structure. Some specifications call for as great depth as three feet, but this is necessary only where there is a probability that new ducts may be added to the conduit in the future. The width of the trench should be about six inches in excess of the actual width of the number of ducts which are to be laid side by side. In the bottom of the trench is laid a concrete foundation to a depth of from three to six inches—the former under ordinary circumstances is sufficient. The tiles are then laid in place in cement mortar, and as each layer is finished the sides of the trench should be filled to the top of that layer with the same concrete as that used for the foundation. The space between the tiles in a layer and between the layers should be carefully filled with good cement mortar mixed thin enough to readily fill the interstices. After the required number of layers are in place the top is covered with a mass of concrete not less than four inches in thickness.

The concrete used in this work should be composed of one part of

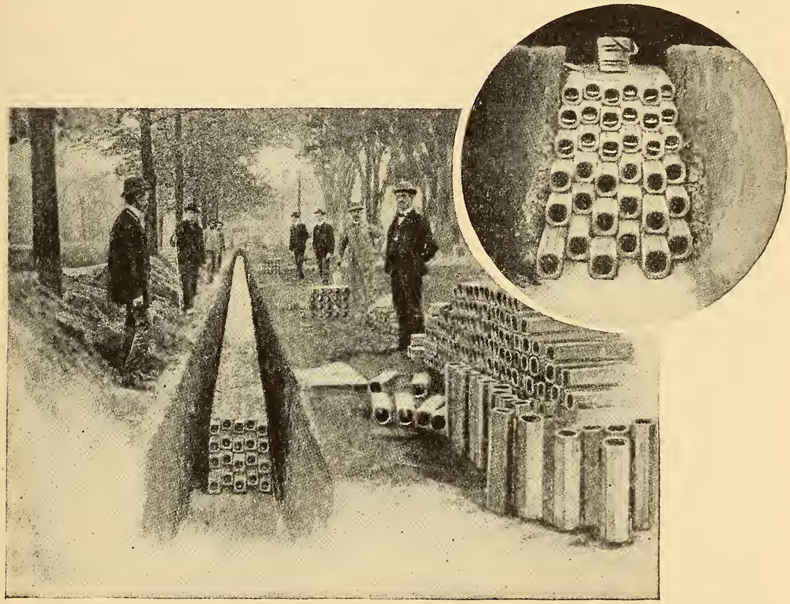

FIG. 618.—TWENTY-DUCT SUBWAY.

hydraulic cement, two parts of clean sharp sand, and five parts of broken stone, screened gravel, or broken brick. The size of the broken stone or brick or gravel should not be larger than one inch in any dimensions. The cement and sand should be thoroughly mixed while dry, and then enough water added to form a soft mortar, after which the broken stone should be thoroughly mixed in.

The mortar should be composed of one part of hydraulic cement and two parts of clean sharp sand, thoroughly mixed together, and then with water as before. It is a matter of greatest importance that the ducts should not be moved while the mortar or concrete is setting.

After the entire subway is laid from one man-hole to the other it is advisable to draw through it a scraper, thus removing all projections on the inside walls. The ducts may then be washed out with a hose, thus removing all grit and leaving a clean, polished tube.

Another style of conduit is cement lined pipe. This, as usually constructed, consists of a wrought-iron pipe of No. 26 B. W. G., with riveted joints, the rivets being set one and one-half inches apart. This pipe is lined with Rosendale cement, the thickness of the lining being five-eighths of an inch, and the interior of the lining being polished. The standard size of this tube is in eight-foot lengths, with a three-inch bore. It is provided with cast-iron ball and socket joints at the ends in order to insure proper alignment and to provide a certain amount of flexibility in making turns.

This conduit is laid in concrete in much the same manner as the clay pipe, it being common practice to separate the different pipes in the layer by about one-half of an inch and the various layers themselves by about one inch. While a great deal of such conduit is in use, not much of it is now being laid.

In laying conduit in city streets numerous obstructions are met, and must be overcome in the manner best suited to the individual case. It frequently becomes necessary to remove the support from heavy pipe lines for a considerable distance, as, for instance, when such a pipe line lies diagonally across the trench. In all cases suitable supports for these pipes or other structures should be provided until such time as the trench is again filled. The usual means adopted is to place a beam of sufficient strength across the top of the trench and support the pipe therefrom by chains or heavy rope. It is frequently necessary in passing an obstruction to fan out the pipes in one layer so that they occupy the same level as those of another layer. Such a construction, and also a rather crooked piece of conduit work, is shown in Fig. 619, where, on account of obstructions in the street, the two layers of two pipes were formed into one layer of four until the obstructions were passed. This particular obstruction was a sub-cellar extending out under the street.

The manholes may be built of various forms and dimensions to meet existing requirements. In the best construction the foundation consists of a layer of concrete six inches deep, the concrete being mixed as specified for the laying of tiles, with the exception that the crushed stone may be considerably coarser. The walls of the manhole are then built of good brick-work of suitable thickness and well plastered on the outside with cement mortar in order to exclude as much dampness as possible. For the ordinary manhole an eight-inch wall is sufficiently thick, but in building very large underground vaults it sometimes becomes necessary to double or treble this thickness. Where these very thick walls are required it

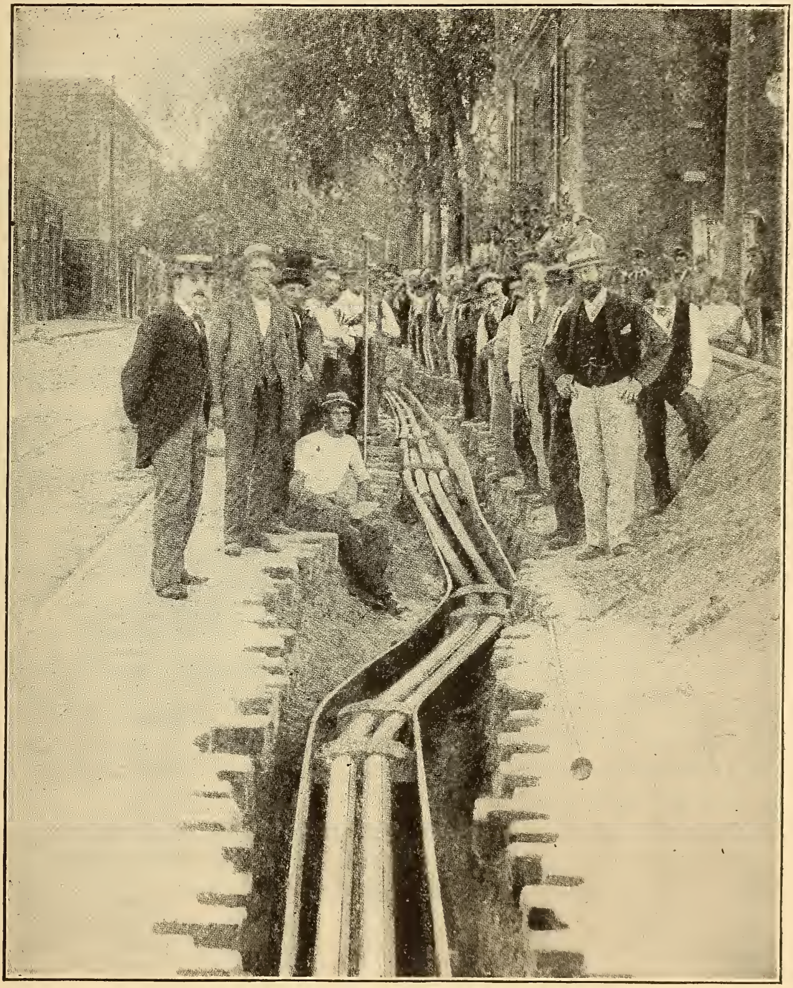

FIG. 619.—AVOIDING OBSTACLES.

is good practice to allow about one inch air space between the outer course of brick and the inner in order to render the interior as dry as possible. A common-sized manhole is five by five by five feet, and smaller sizes down to three by three feet with five feet head room are also common. As a rule a manhole should provide at least enough room for two men to work in conveniently. Of course, where a great number of ducts enter a manhole the size must be increased accordingly.

After the conduits are laid and the manholes finished the next step is the drawing in of the cables. In order to accomplish this a process called rodding is in most cases first necessary, in order that a rope may be stretched through the duct, which is afterwards to be used for drawing in the cable itself. For this purpose a large number of wooden rods about three-fourths of an inch in diameter and four feet long, and equipped with screw or bayonet joints at each end, so that they may readily join together, are necessary. A man stationed in one of the manholes inserts one rod into the duct, and, after joining another rod to it, pushes this also into the duct. Successive rods are joined and pushed through until finally the first rod reaches the next manhole. A rope is then attached to one end of the series of rods, which is then pulled through, unjointing the rods as they are taken out of the duct. Where the ducts are smooth and comparatively straight this process may be simplified by using a continuous steel wire about one-fourth of an inch in diameter in place of the rods. It is a good plan to attach to the forward end of this wire a lead ball, which will facilitate it in riding over obstructions.

The cable reel is then placed near one of the manholes in such manner that the cable will pay out from the top of the reel instead of from the bottom. The end of the cable is then attached to the rope and started into the duct. In the distant manhole the rope is led over one or more sheaves suitably arranged on upright beams placed within the manhole to a capstan or other form of windlass by which the cable may be slowly drawn through the duct. A funnel-shaped shield should be placed at the mouth of the duct into which the cable is being fed for protecting the shield against the sharp corners at the entrance. This shield, however, is not a sufficient protection for the cable, and one or more men should be stationed in the manhole for guiding the cable into the duct. The best way to attach the rope to the end is by means of clamps especially provided by the cable companies for this purpose. However, if these are not used, a secure grip may be had upon the cable end by winding several strands of stout iron wire in opposite directions about the cable sheath for a distance of two feet from its end. An eye may be formed in this wire opposite the cable end to which the rope may be attached. Particular attention should be paid to the sealing of the cable end before it is drawn into the duct, as ducts are always moist, due to sweating of the interior walls, or to leaks.

Where a large amount of cable is to be drawn in the method shown Fig. 620 may be employed. Instead of the hand-operated winch or windlass a three and one-half horsepower horizontal engine and capstan mounted on a low wagon is used. By suitable gearing the engine causes the capstan to revolve slowly. This method was used in the recent extensive underground construction work in St. Louis by the Bell Telephone Company, of Missouri. With this contrivance a speed of twenty-five feet of cable per minute is easily attained without in any way damaging the cable and the remarkably short time in which the enormous amount of cable in-

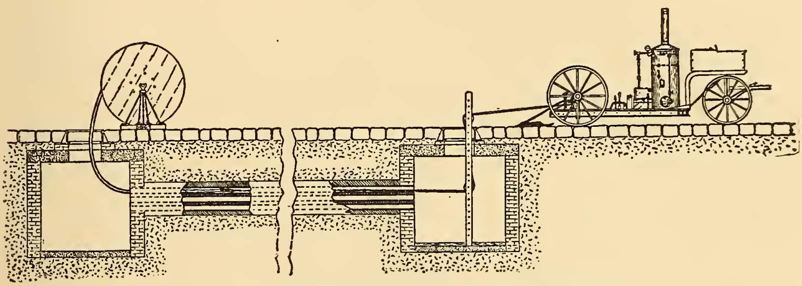

FIG. 620.—DRAWING IN BY STEAM POWER.

stalled by that company was drawn in testifies further to the practical value of this scheme.

Mr. C. L. Zahm has used with success in cable-drawing the form of winch shown in Fig. 621. This is an electric-motor arrangement, the motor being wound to operate on a voltage of 600 or thereabouts, and geared down to the drum. Power is taken from any convenient circuit carrying direct current at 500 to 650 volts, and if it be a trolley wire, the connections are very simply made by means of a portable trolley pole and flexible wire. The wheels on the whole outfit enable it to be taken from place to place with ease. Another convenience used by Mr. Zahm is shown in Fig. 622. This reel-truck has strong spider wheels with ample width of tire, and has an extended shaft enabling a clevis tongue to be attached. A team of horses can then draw the reel and truck. When set for paying off cable the reel turns on the shaft.

Cables, in passing through manholes, should be laid around the side of the manhole and supported on hooks provided for that purpose. Shields formed of sheet lead or of heavy felt should be placed under each cable just at the point where it emerges from the duct, in order to prevent injury of the sheath at that point. Workmen should be cautioned against needlessly bending cables while working in ducts, and the use of the cables in place of ladders for climbing in and out of the manholes should be strictly prohibited. Slack should be left in the manhole, in order to allow room for subsequent splicing when necessary.

Trouble is frequently experienced, due to the presence of gas in

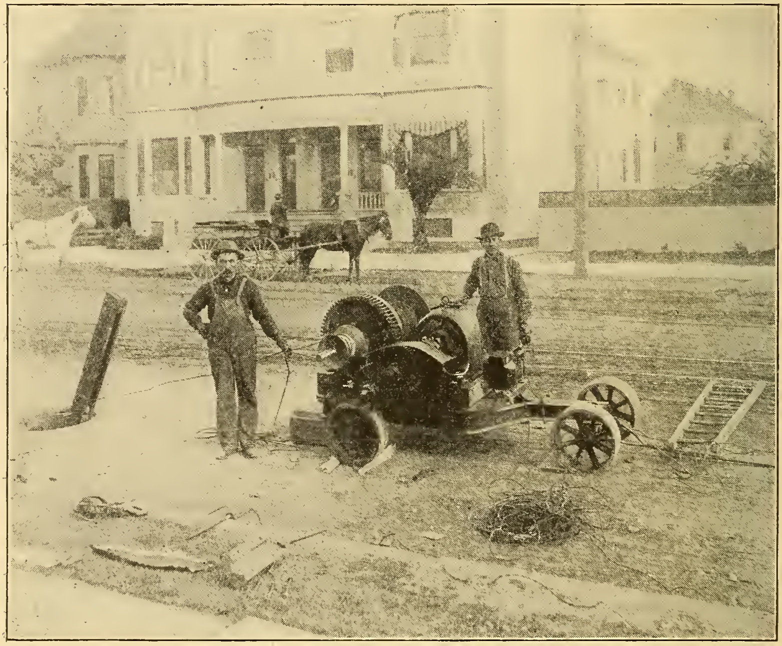

FIG. 621.—ELECTRIC WINCH.

the manhole, due to leakage through the earth from gas mains, and care should always be exercised before striking a match or taking a torch into a manhole, to make sure that all gas has been removed. There are several methods of doing this, one of which is to pump the gas out with an inverted umbrella made specially for the purpose. The umbrella is lowered into the manhole while closed and then suddenly withdrawn, this opening the umbrella and lifting out the gas. Another way of clearing manholes from gas is to place a cloth screen above the manhole and on the side opposite to that from which the wind is blowing. The wind on striking the screen is deflected downward, thus causing an eddy which removes the gas from the manhole. Very serious explosions have been caused by the collection of gas in manholes, which becomes ignited either by an electric spark or by the torch of a workman.

One of the most serious difficulties in connection with underground cable work is that brought about by electrolysis, due to the action of stray earth currents, usually due to the ground return of electric railways. It is found that the electrolysis occurs at points

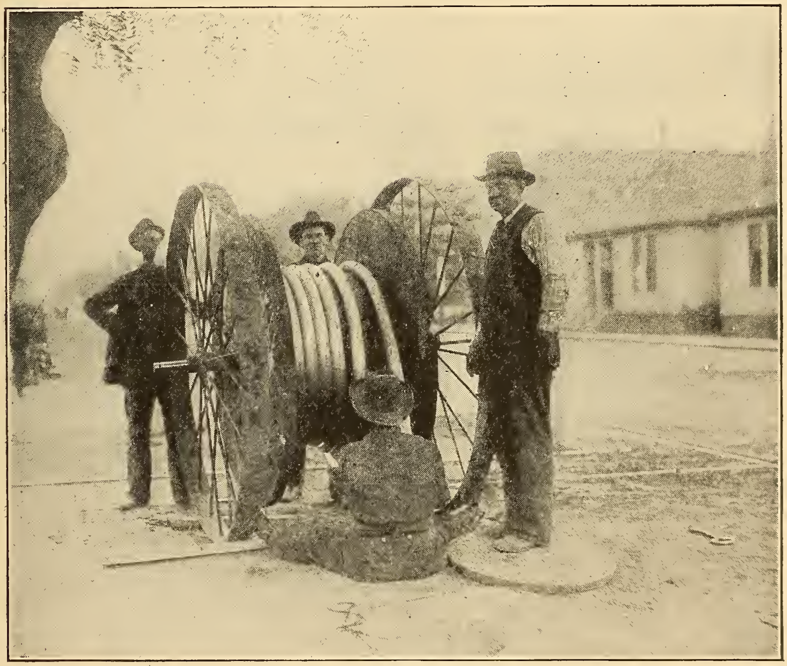

FIG. 622.—REEL TRUCK.

where a current flowing along the cable sheath leaves the sheath and enters the ground. At this point oxygen is liberated, which, with the chemicals in the earth, rapidly corrodes the lead sheath. Of course, the construction of conduits, composed of insulating material, will do something towards the alleviation of this trouble.

Frequent tests should be made, however, on all cable systems to determine the polarity of the cable sheaths with respect to surrounding conductors. The tests for this purpose may be made as follows: Two brass rods about six feet long should be provided, each having a steel contact at one end. Between these two rods should be connected by flexible wires a portable voltmeter—one reading to five volts will usually be found most suitable. The test should be made at the manholes, these being the most available points for reaching the cable. One of the steel contact points should then be placed in firm contact with the cable sheath and the other into contact with any water or gas pipes which run through the manhole, and in each case the voltage should be noted, not only in amount but in direction. Reading should also be taken between the cable sheaths and the rails of adjacent electric railroads, and to whatever underground structures exist in the immediate vicinity. It is evident that where the cable sheaths are negative to the surrounding conductors no danger will exist, as this would indicate that the current tended to flow from the other conductors to the sheath. If, however, the cable is found positive to the surrounding conductors, the matter should be carefully followed up by taking readings in successive manholes. By these means the maximum danger point can be located, it being, as a rule, the point at which the maximum positive difference of potential exists. At this point the cable sheath should be securely bonded by a heavy conductor to the water or gas pipe or to other metallic structures that are in the vicinity. These bonds serve to allow the current to flow from the cable sheath to the other conductors, instead of forcing it to find circuit through the ground or through the walls of the conduit. In some cases the only remedy has been to run separate return circuits from the maximum danger points on a cable directly to the power-house from which the troublesome current emanates.

All of the cable sheaths entering a manhole should be bonded together, the usual method of doing this being to brighten the surface of the lead sheaths and to bend a No. 10 B. & S. copper wire around each sheath, afterwards soldering the connection. This assures the fact that all of the cable sheaths will be at an equal potential and that whatever bonds are run for the protection of one sheath will afford protection for all. The method of bonding to a gas pipe usually adopted is as follows: The surface of the pipe is brightened for a space of about three by eight inches with a coarse file. This surface is then heated by a torch and tinned with ordinary solder. A copper plate about three by seven inches previously tinned is then soldered to the gas pipe, after which the bond wire leading from the cable is wound into a flat coil and soldered to a copper plate. In bonding to a water pipe it is impossible to heat the pipe sufficiently to make it take solder on account of the water flowing within. The method to be followed is to provide a heavy wrought-iron U-shaped band adapted to fit snugly around the pipe. The ends of this band are screw-threaded and pass through a yoke-piece bent to fit the upper portion of the pipe. This yoke-piece is then firmly screwed in place by nuts, the surface of the pipe and the interior of the iron clamp having previously been thoroughly brightened. The bond

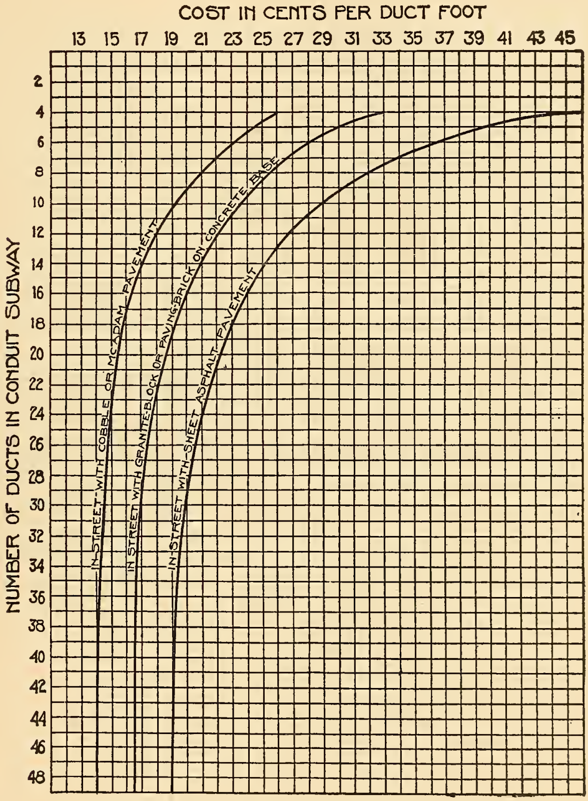

FIG. 623.—CURVE OF CONDUIT COSTS.

wire may then be soldered to this yoke-piece and the whole device smeared with asphalt paint.

A form of duct material other than that made of clay is made of paper or similar fibre, saturated while making, or after making, with some asphaltic or bituminous compound. The form of a complete duct of this kind is round, and of cylindrical bore. The thickness of the walls does not need to be great, and there is next to no danger of breakage. It is claimed that there is an advantage in the fact that this form of material will not absorb moisture, and that there will thereby be very much less danger of electrolytic corrosion. It is certainly true that there is much less weight per foot of duct, and a less loss by breakage. Whether the material is a satisfactory one for a structure that ought to be expected to last fifty years or more is a question which it is not attempted to answer here. It is difficult to see, however, why it is not.

In the matter of estimating the cost of an underground system of distribution of telephone wires, there is no royal road; the costs of the material and labor for the varions parts of even one system will vary so much that there is only one accurate way, and that is to lay out the routes and figure the cost of each, adding the results. For purposes of preliminary estimates, however, it is often necessary to approximate final results, and to do this one may not always need to know all the details of the final plan. Mr. C. J. Field has contributed a valuable compilation of data in giving engineers a graphic table of approximate costs. The curve in Fig. 623 gives such costs based on a duct material price of five cents per foot. To use the curve in compiling an estimate, tabulate the runs of conduit under their various sizes and character of pavement, and look out in the curve the cost per duct foot for each. Multiply the cost thus found by the number of ducts in that trench, and by its length; do the same for all the trenches, and add the result. The sum will be the cost of the system. If the cost of duct material on the ground is less, or more than five cents, the curve must be modified accordingly, but need not be necessarily redrawn.

CHAPTER XLII.

TESTING.

Tests of telephone lines, whether of bare wire on poles or of overhead or underground cables, may be divided into two general classes:

First: Those which are for the determination of the existence of certain conditions, without the necessity of measuring quantitatively the extent to which those conditions exist; in other words, rough tests for the determination of grounds, crosses, or breaks, usually made with instruments such as the magneto bell, telephone receiver and battery, and a few other such simple but often in the hands of an experienced person most effective instruments.

Second: Those for not only determining the existence of certain conditions, but also for their quantitative measurements. These require the use of different and more intricate instruments, and in many cases the operator must be possessed of a fair degree of mathematical training combined with an ingenuity for meeting and mastering unusual problems that arise under different conditions.

The magneto testing set is the most important instrument in making tests under the first class. Such an instrument usually consists of a powerful magneto generator, so wound as to enable it to ring its own bell through a resistance of from 25,000 to 75,000 ohms. A powerful magneto telephone is carried on the outside of the case in suitable clips, and may be switched in circuit alternately with the generator by a small hand switch. This magneto telephone serves as both transmitter and receiver, and enables the lineman or other party to communicate from a pole top or man-hole with any other party on the circuit. Frequently these sets are made to include microphone transmitter and battery; but, inasmuch as the instrument is seldom if ever used to talk over very long circuits, the extra weight of these is considered in most cases undesirable. A small, inexpensive galvanoscope or current detector will also prove very convenient.

In testing for a ground on a wire, whether it be in a cable or bare, and on poles, make sure that the far end of the line is open and then connects one terminal of the magneto bell to the near end of the line and ground the other terminal. The ringing of the bell would seem to indicate that the circuit was complete and the line grounded in this case, but this is not always true, and this test must therefore be relied on only with caution. The static capacity of a long line or of a comparatively short length of cable will often allow enough current to pass to and from the line in charging and discharging to ring the magneto bell.

For testing out local work where there is no room for this capacity effect, the magneto bell is invaluable.

A more reliable means of making tests for grounds or crosses is to connect the current detector in series with several cells of battery and to ground one terminal. Then with the other terminal make contact with the near end of the line. A kick of the needle will take place in any event on closing the circuit, due to the current flowing to charge the line, but a permanent deflection will indicate a ground.

In testing for a cross, as, for instance, with some other wire in the line or cable, one terminal of the magneto bell or the galvanoscope and batteries should be connected to the wire under test and the other to all the other wires in the same lead, for which purpose they are bunched. In case it is not convenient to bunch them, however, the test may be made between the suspected line and each of the others in succession.

Another and perhaps still more simple method for determining a cross or ground is one described in Roebling's pamphlet on Telephone Cables, and illustrated in Fig. 624, as applied to the testing of a cable before it has been unreeled.

N represents the near end, and *F* the far end of the wire being tested. *B* is a battery, of about three cells. *T* is an ordinary telephone receiver. The wire, *N F,* is carefully separated from all the others at each end.

At the near end all the wires are stripped of insulation and, except the one under test, are connected together and also with the sheath. The wire, *C,* connects the sheath to one side of battery, *B*, and the other side of battery is connected to one side of telephone receiver, *T*. The testing man rapidly taps with the wire, *N F,* the unoccupied binding post of the receiver, *T*. The first tap will produce in the receiver a distinct click, and if the cable is long there may possibly occur a second faint click, but if the wire, *N F*, is perfectly insulated no more sound in the telephone will follow the tapping. If, however, the wire, *N F*, is crossed with any wire in the cable, or with the sheath, every tap will be followed by a distinct click, and if there is moisture in the paper, making a partial connection, clicking sounds will occur, which are loud or faint, according to the amount of moisture present.

The philosophy of this method of testing is very simple, and serves to make the operation more readily understood.

When the wire, *N F,* is first connected to the battery it becomes charged. During the process of charging a current flows into the wire and passes through the coil of the receiver and causes the click. If the wire is well insulated, the second tap, immediately following, finds it charged, or nearly so, and there is, therefore, no click, or a very faint one. If, on the contrary, the wire under test is crossed with any of the other wires, or imperfectly insulated from them, or from the sheath, the wire will immediately discharge itself through the cross to the other wires and the sheath, and there will be a flow of

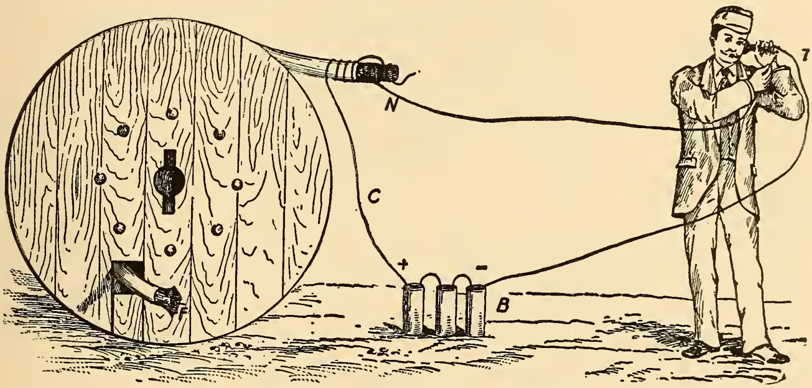

FIG. 624.—RECEIVER TEST FOR CROSSES AND GROUNDS.

current at every tap, and consequently a continuous clicking. If a conductor in a perfectly insulated cable is very long, two or three taps or a long first contact may be necessary to charge it completely.

If the cable is in place or if it is a bare aerial line that is being tested this same method may be used. In case of a new cable it is well to test every wire in this manner, and therefore the wire, *N F*, should be put aside and another slipped out of the bunch and tested in the same way, and so on until all have been gone over.

If any of them are found to be in trouble, it is well to carefully inspect the exposed ends to be sure they are properly cleared from each other and from the sheath. If it is still found to be defective, it should be plainly tagged.

In the manner just described, twenty-five minutes with two men should be ample time for testing one hundred wires, the testing operator listening and his helper attending to the connection of the different wires at *N*.

For this test, as well as many others, it is very convenient to use a regular operator's receiver and head band, as it will save the tester a very tired arm at the end of a long test. As a matter of fact, the receiver is little appreciated as a testing instrument. A very convenient set is formed by a watch-case receiver and head band, and two small-sized cells of dry battery, strapped together so as to be carried in the coat pocket. The receiver and battery are connected in series, the free terminals of the circuit being formed by flexible cords about four feet long. These cords should terminate in

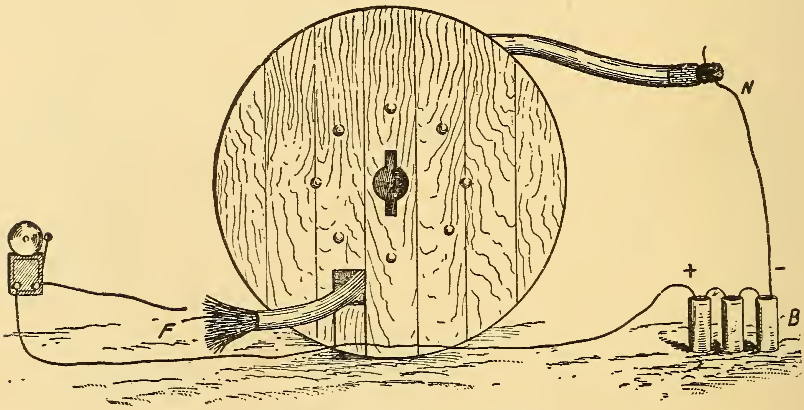

FIG. 625.—CONTINUITY TEST.

convenient clips, or contact points adapted to make contact with the wires to be tested. This arrangement leaves both hands free at all times, and is wonderfully sensitive.

The continuity test, or test for broken wires, may be made with the same simple instruments. The wires to be tested should all be grounded or connected to a return wire at the far end. At the near end, one pole of a magneto bell, or of the battery and galvanoscope, or of the receiver, should be connected to ground or the return wire and the other terminal connected successively to the terminals of the line, which, of course, should all be separated. A ring in the case of the magneto, or a permanent deflection of the needle in the case of the galvanoscope, or a continuous clicking in the receiver, will indicate that the wire is continuous. The same precaution as previously pointed out must, however, be observed with the magneto bell. This same test for continuity is well illustrated in Fig. 625, in which case a vibrating bell instead of the receiver or galvanoscope is used.

In testing a cable all defective wires should be marked "crossed," "grounded," or "broken" at the end at which they are tested. The corresponding ends of the tagged wires at the other end of the cable should then be found and similarly marked. If there are not the requisite number of good wires in a new cable it should be rejected.

It is often desirable to be able to pick out a certain wire at some intermediate point in an open cable, or in a large bunch of insulated wires, in order to establish a branch connection. This is easily done by the foregoing methods if the cable is to be cut, but frequently this is not the case. It may be done without cutting by the following simple method: Ground the wire or wires desired at the distant end,

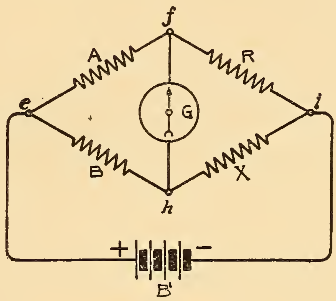

FIG. 626.—DIAGRAM OF WHEATSTONE BRIDGE.

being sure that these wires are free from all the others at both ends. Then having loosened the bunch of wires at the point at which the branch is to be taken off, test each by means of a needle-pointed instrument, connected to ground through a bell or receiver and battery. The needle-point can readily pierce the insulation and make good contact with the conductor within. A knowledge of this very simple test will often save an immense amount of trouble.

In the second class of test—that is, those requiring quantitative measurements—there are three distinct subdivisions, which are as follows: Tests for resistance or conductivity, tests for capacity, and tests for insulation. Tests for the location of faults in lines always depend on the application of one or more of these.

There are three principal methods of making resistance tests: First, by the use of a Wheatstone bridge, which is accurate for all resistances except those very large or those very small. Second, the fall of potential method, which is largely used for making many tests in telephone work. Third, by the use of a sensitive galvanometer in series with a battery. This method is the most accurate for the determination of extremely high resistances and is, therefore, of great use in measurements of insulation resistance.

For general resistance measurements the Wheatstone bridge is the most suitable, being very accurate and exceedingly simple in manipulation. In order to appreciate the possibilities of this instrument its underlying principles should be understood. In Fig. 626, *A, B, R,* and *X* represent resistances. *G* is a galvanometer or instrument for detecting the flow of current. The four resistances are connected together as shown, the galvanometer being connected in the "bridge" between the junctures of *A* and *R,* and *B* and *X.* A battery, *B′*, is connected between the junctures of *A* and *B*, and of *R* and *X*. Each resistance, *A, B, R,* and *X,* forms what is termed an arm of the bridge.

The two fundamental laws upon which the action of the bridge is based may be stated as follows:

1. *No current will flow between points of equal potential;* and

2. *The drop in potential along the various parts of a conductor is proportional respectively to the resistances of those parts.*

Referring again to the diagram, it is evident that a current from the battery flows to the point, *e,* where it divides, part flowing through *A R* and part through *B X,* after which they unite and pass to the negative pole of the battery. But what of the galvanometer? Evidently by Rule 1 the only time at which no current will pass through it will be at the time when the points, *f* and *h,* are at the same potential. By Rule 2 these points will be at the same potential only when *A* bears the same relation to *R* as *B* does to *X*.

That is

$$A : R :: B : X, \text{ or, by alternation,}$$

$$\frac{A}{B} = \frac{R}{X}.$$

A little algebra will render the above evident if not so already.

Call *a* the drop of potential between the points *e* and *i, b* that between *e* and *f*, and *c* that between *e* and *h*.

Then

$$b : a :: A : A + R \text{ by Rule 2.}$$

$$\therefore b = \frac{A}{A+R}\,a.$$

Similarly

$$c = \frac{B}{B + X} a.$$

For a condition of equal potentials at f and h so that no current will flow through the galvanometer, b must $= c$

Then

$$\frac{A}{A + R} a = \frac{B}{B + X} a.$$

whence: $AB + AX = AB + BR,$

and $AX = BR.$

Dividing by BX, we have

$$\frac{A}{B} = \frac{R}{X},$$

which is the equation of the ratios between the resistances of the arms of the bridge, to insure no flow of current through the galvanometer.

The resistance to be measured forms the arm X of the bridge, and in order to determine its value the resistances in the various arms are adjusted till no current flows through the galvanometer. Then the equation just derived holds good and may be solved for X,

$$\text{thus } X = \frac{B}{A} R.$$

The arms A and B are best termed the "ratio arms" of the bridge and arm R the rheostat arm.

In commercial forms of the Wheatstone bridge, A and B are usually so arranged that each may be given the values, 10, 100, and 1000 ohms, and in some cases 1 ohm and 10,000 ohms also. The ratio arms, A and B, may therefore be adjusted to bear any convenient ratio to each other from $\frac{10}{1000}$ to $\frac{1000}{10}$, or, in some instances, from $\frac{1}{10,000}$ to $\frac{10,000}{1}$. The rheostat arm is in reality a rheostat capable of being adjusted to any value from 1 to about 11,000 ohms.

In some bridges a sealed battery is furnished with and forms a part of the instrument. In those having no battery, suitable binding posts are provided, usually marked BB, between which the battery may be connected. Other binding posts, usually marked XX, are furnished for connecting the terminals of the unknown resistance to be measured.

Two keys are usually furnished, one in the battery circuit and the other in the galvanometer circuit. Each keeps its circuit normally open.

The operation of the bridge is very simple. First some ratio between the arms A and B is determined upon. The battery is then connected between the proper binding posts, and likewise the resistance to be measured is connected between its binding posts.

The battery key is first depressed and then the galvanometer key. A deflection of the galvanometer needle will take place which by its direction will after a few trials show whether the resistance in the rheostat arm is too great or too small. The rheostat is adjusted

FIG. 627.—PORTABLE TESTING SET.

accordingly until the galvanometer needle shows no deflection upon the operation of the keys. We then know that our equation

$$\frac{A}{B} = \frac{R}{X} \text{ holds good,}$$

and consequently

$$X = \frac{B}{A} \times R.$$

That is, *the unknown resistance is equal to the ratio between B and A multiplied by the resistance in the adjustable arm.*

Considerable judgment may be exercised in the choosing of the appropriate ratio in the ratio arm to obtain the greatest accuracy. Obviously, if a high resistance is to be measured the ratio should be large, and *vice versa.*

In bridges having resistances of 10, 100, and 1000 ohms in the ratio arms, the following values in arms *A* and *B* will give the best results:

Resistance to be measured.	*A* arm.	*B* arm.
Under 100 ohms, ...	1000	10
100 to 1000 ohms, ...	1000	100
1000 to 10,000 ohms, ...	1000	1000
10,000 to 100,000 ohms, ...	100	1000
100,000 to 1,000,000 ohms, ...	10	1000

As to the accuracy of measurements attainable by the use of the Wheatstone bridge, the following table represents the claim of one reliable manufacturer:

.01	of an ohm	to	an	accuracy of	1	per	cent.
.1	" "	"	"	"	$\frac{1}{2}$	"	"
1	ohm	"	"	"	$\frac{1}{2}$	"	"
10	ohms	"	"	"	$\frac{1}{5}$	"	"
100	"	"	"	"	$\frac{1}{8}$	"	"
1000	"	"	"	"	$\frac{1}{8}$	"	"
10,000	"	"	"	"	$\frac{1}{5}$	"	"
100,000	"	"	"	"	$\frac{1}{4}$	"	"
1,000,000	"	"	"	"	5	"	"

If using the 110 volt lighting circuit as battery power 1 megohm may be measured accurate to $\frac{1}{2}$ per cent.

There is no doubt that with a well-made bridge with a sensitive galvanometer, these results may be equaled if not surpassed. Great care must be taken in using a voltage as high as 110, as there is danger of burning out the coils. Such high voltage should be used only in measuring very high resistances, and the ratio arms should be adjusted to give as high a multiplying ratio as possible.

A particular form of bridge which has come into extensive use in this country and which possesses several unique features is shown complete in Fig. 627 and in plan view in Fig. 628.

The various adjustments of the arms are accomplished by placing plugs in the various holes between the brass blocks arranged in rows as shown in the latter figure. Between each successive pair of blocks are arranged resistance coils having the resistance in ohms designated on the plan. Placing a plug in a hole between two blocks short-circuits the resistance connected between those two blocks. The rheostat arm of this bridge is represented by the top and bottom row of blocks, and if all plugs are removed the resistance in this arm will amount to 11,110 ohms. The ratio arms *A* and *B* are represented by the left and right-hand halves respectively of the center row. A galvanometer and suitable battery, together with battery and galvanometer keys, are all mounted in a carrying case as shown.

The connections of this instrument are indicated in Fig. 628, and are as follows: The top row of blocks is connected to the bottom row by a heavy copper bar joining the right-hand blocks. This connection is made very heavy so as to interpose no extra resistance in the rheostat. On the rheostat formed by the upper and lower rows of blocks any resistance from 1 to 11,110 ohms may be obtained, the resistance being added by *leaving out* plugs. The lower left-hand block of the rheostat is connected to the lower binding post, *D*, forming one terminal of the unknown resistance. The upper post,

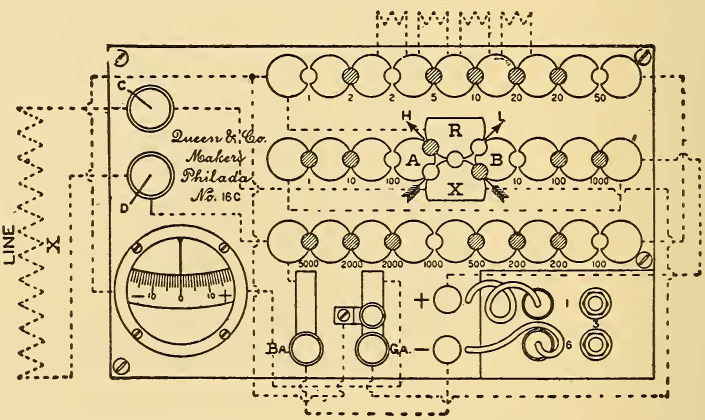

FIG. 628.—PLAN OF PORTABLE TESTING SET.

C, forming the other terminal of the unknown resistance, is connected to block, *X*, which block is also joined to the galvanometer key. The block, *R*, is connected to the upper left-hand block of the rheostat. The end blocks of the middle row are connected together and to the + terminal of the battery. The — terminal of the battery is connected through the battery key to the lower left-hand end of the rheostat. One galvanometer terminal is connected directly to the block, *R*, the left-hand block of the rheostat, and to the back contact of the galvanometer key. The other galvanometer terminal is connected through the key to the block, *X*.

By carefully following out these connections it will be apparent that the parts as connected form three arms of a Wheatstone bridge, the fourth, of course, being the unknown resistance joined to the line posts. This is shown diagrammatically in Fig. 629, where the corresponding parts are similarly lettered.

It will be noticed that this latter figure is practically the same as Fig. 626, with the addition of the center blocks, *A, B, X, R,* forming a sort of commutator. The object of this arrangement is to make it possible to reverse the connections of arms, *A* and *B,* with *R* and *X.* Thus with the plugs in the position shown by the black dots the connection is precisely as shown in Fig. 626, and the equation $\frac{A}{B} = \frac{R}{X}$ holds true. If, however, the plugs are inserted in the holes on the other diagonal, arm, *A,* will be connected to arm, *X,* and arm, *B,* to arm, *R,* and the equation of the bridge will be $\frac{B}{A} = \frac{R}{X}$.

The bridge arms, *A* and *B,* have not the same range of resistances in this bridge, *A,* having only 1, 10, and 100 ohm coils,

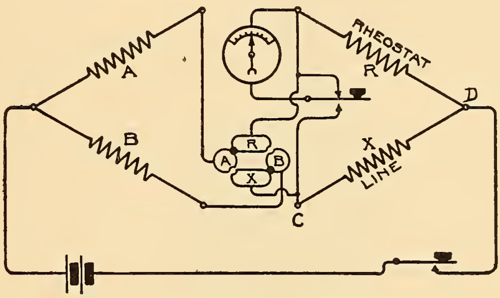

FIG. 629.—CIRCUITS OF PORTABLE TESTING SET.

while the resistances of *B* are 10, 100, and 1000 ohms. Therefore, if a ratio of 1000 to 1 for measuring large resistances is desired, the plugs are inserted in the commutator along the arrow *H* (Fig. 628); while an opposite arrangement of the plugs along the arrow *L* will give a ratio of 1 to 1000 for very small resistances. In this bridge the galvanometer key is so arranged as to short-circuit the galvanometer while the key is up.

The galvanometers usually furnished with the complete bridges consist of a needle so mounted as to swing freely in a horizontal plane. This needle is given a tendency to point in one direction, sometimes by the action of the earth's magnetic field and sometimes by the field of a powerful permanent magnet. By causing the current through the bridge wire to flow through a coil, either stationary and surrounding the needle, or movable and carried on the needle, the needle is caused to swerve from its normal position and to place itself at right-angles to the lines of force due to the permanent field. The deflection of the needle is great or small according to the strength of the current, and to the right or left according to the direction of the current.

In many of the tests to be described later a galvanometer of greater sensitiveness is required, and some form of *reflecting* instrument is used. In these the needle carries a small circular mirror, which reflects a spot of light from a lamp or some other source against a scale. In this arrangement every movement of the needle causes the spot of light to move along the scale, and a little consideration will show that the angle through which the reflected ray of light moves is double that through which the needle travels. Thus this reflected ray of light serves as a needle of any desired length, and has the advantages of magnifying the angular movement of the needle to twice its real amount, and of possessing no mass, and therefore no inertia.

The two galvanometers used to the greatest extent for quantitative measurements in practical work are the Thomson and the D'Arsonval.

The Thomson galvanometer is made in a great variety of forms. The needle consists of several very light bar-magnets arranged side by side and with opposing poles together, so that the directive influence of the earth's field shall be very slight. The needle is directly attached to a small silvered glass mirror, and is suspended within the coil or coils by means of a silk or quartz fibre. The current to be measured is passed through the coils, and the magnetic field set up thereby causes the needle to swerve from its normal position. The Thomson galvanometer is used in the most delicate tests, and is essentially a laboratory instrument. It has the disadvantage of being affected to such an extent by external magnetic fields as to render its use impossible in many cases. A passing street car or variations in the current flowing in a neighboring circuit will cause the needle to swing violently, thus making accurate work out of the question. These disadvantages may be overcome to some extent by inclosing the galvanometer in a heavy iron case—such as an old safe—but they tend to make it a very undesirable instrument for portable work. Where the instrument can be permanently set up and properly guarded, it is unequaled for delicacy and accuracy.

For nearly all practical engineering work, the D'Arsonval galvanometer is sensitive enough, and has the advantage of being much more convenient for general work. In this the needle is a coil instead of a permanent magnet, and is suspended within the field of a powerful permanent magnet instead of in a coil. The needle carries a mirror, as in the Thomson instrument. The current to be measured is passed through the coil, and as this coil lies in the

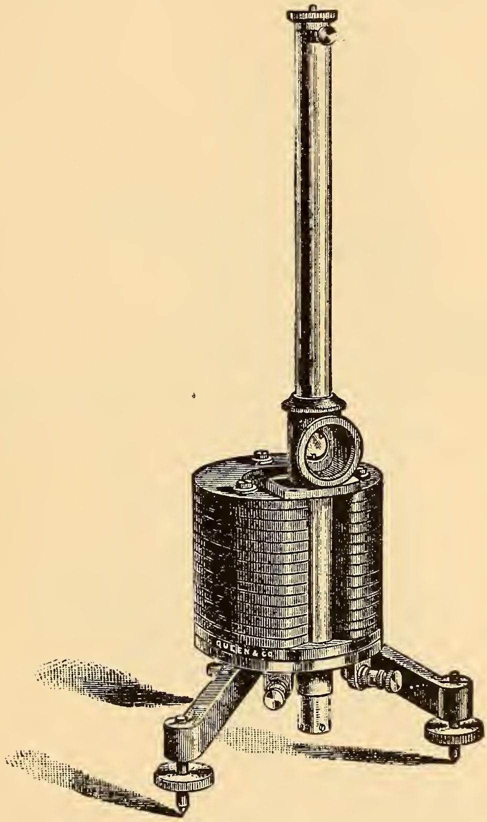

FIG. 630.—D'ARSONVAL GALVANOMETER.

field of the permanent magnet, a rotation of the coil ensues, the action being identical with that which causes the armature of an electric motor to revolve.

In Fig. 630 is shown a much-used form of D'Arsonval galvanometer made by Queen & Co., Philadelphia. The field is built up of a number of horizontal permanent magnets, between the poles of which is suspended the needle. The needle system is shown in detail in Fig. 631. It consists of a coil of wire, *W*, wound on a box-wood frame, *D*, and supported by means of the flat phosphor-bronze filament, *A*, from the torsion pin, *E*. The current is led in by means of the torsion pin, *E*, and suspension wire to the coil; thence to the spiral spring, *B*, and by means of the bottom contact out to the external circuit. A ring, *F*, is joined above the coil frame, and another, *G*, below the coil frame. These are normally a sufficient

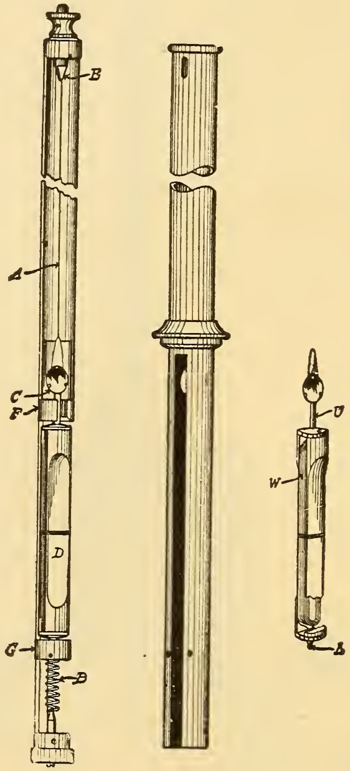

FIG. 631.—SUSPENSION OF D'ARSONVAL GALVANOMETER.

distance apart to enable the system to swing freely, but when packing for transportation the torsion head may be pressed down until the rings above mentioned firmly clamp the coil. In this condition it will withstand shipment satisfactorily. To the right is shown the coil more clearly. The two points, *U* and *L*, have soldered to them the ends of the coil, *W*. The mirror is shown at *C*.

The great advantage of the D'Arsonval galvanometer is that it is unaffected by variations in the external magnetic field. It may even be used close to dynamo machinery without being sensibly affected.

In order to read the deflection produced by a current, in any form of reflecting galvanometers, two methods may be employed. One is to cause the needle to reflect a spot of light from a stationary source, upon a horizontal scale, and by watching the movement of the spot the number of scale divisions deflection may be accurately determined. Another and better way is to focus a telescope on the mirror, in such manner that the horizontal scale will be visible in the telescope. The mirror in its movements will reflect different portions of the scale into the telescope, and the deflection may thus be

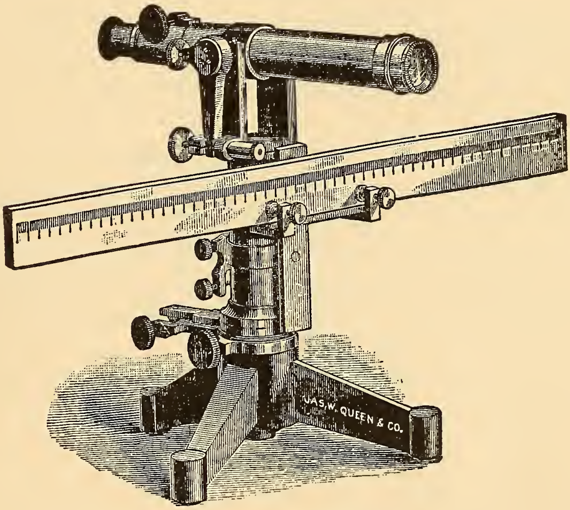

FIG. 632.—SCALE AND TELESCOPE.

observed with great precision. When this method is used the numbers on the scale should be reversed, in order to appear normal in the telescope. Fig. 632 shows a telescope and scale as arranged for this purpose.

Complete testing sets, containing reflecting galvanometers, bridges, batteries, keys and other accessories, are frequently mounted in one case, and so arranged as to fold within small compass when not in use. This arrangement is very convenient, but has one disadvantage—the manipulation of the keys and plugs jar the box to such an extent as to make the readings on the galvanometer unreliable. The separately mounted galvanometer is therefore in general to be preferred. Of course, this applies only to reflecting galvanometers.

It is frequently found that a current that it is desired to measure is so large that it sends the spot of light completely off the scale, thus rendering the measurement of the deflection impossible. In order to increase the range of the galvanometer so as to make it available for measuring both large and small currents, certain resistances called shunts may be placed in parallel with the galvanometer

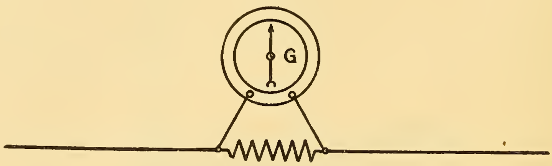

FIG. 633.—GALVANOMETER AND SHUNT.

coil as in Fig. 633. The resistance of the shunt being known, it is easy to calculate the amounts of the currents that pass through the galvanometer coil and the shunt.

Calling R_g the resistance of the galvanometer, R_s that of the shunt, I_g the current through the galvanometer, I_s that through the shunt, and I the total current through both, then

$$I = I_g + I_s.$$

Also when E is the difference of potential between the common terminals of the galvanometer and shunt,

$$I_g = \frac{E}{R_g} \text{ and } I_s = \frac{E}{R_s}.$$

$$E = I_g R_g = I_s R_s. \quad \text{Hence } I_s = \frac{I_g R_g}{R_s}.$$

Substituting this value of I_s, in the first equation we have

$$I = I_g + \frac{I_g R_g}{R_s} = I_g\left(1 + \frac{R_g}{R_s}\right) = I_g \frac{R_s + R_g}{R_s}.$$

The quantity $\frac{R_s + R_g}{R_s}$ is called the multiplying power of the shunt because it represents the number by which the current through the galvanometer must be multiplied, in order to give the value of the current being measured.

Shunt boxes are usually provided for a given galvanometer with a number of coils specially arranged to give such convenient values of the multiplying powers, as 10, 100, and 1000. For this purpose the various coils of the shunt box have resistances of $\frac{1}{9}$, $\frac{1}{99}$, and $\frac{1}{999}$ of the resistance of the galvanometer.

To better show this relation, assume that a multiplying power of 1000 is desired, then

$$1000 = \frac{R_s + R}{R_s}.$$

$$1000 R_s - R_s = R_g.$$

$$R_s = \frac{R_g}{1000 - 1} = \frac{R_g}{999}.$$

A commercial form of shunt box is shown in Fig. 634, the various multiplying values of the shunt being obtained by plugging the block corresponding to the multiplying power desired.

For moderate deflections, the current traversing the coils of a reflecting galvanometer may, without sensible error, be taken as proportional to the deflection of the spot of light on the scale, or

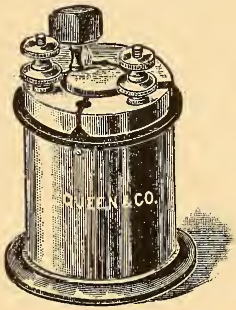

FIG. 634.—SHUNT BOX.

to the deflection read through the telescope. The current is, of course, inversely proportional to the total resistance of the circuit, and from this it follows that the deflections are inversely proportional to the resistance. This fact enables the galvanometer to be used for measuring unknown resistances by comparing the deflection obtained when a given E. M. F. acts through a known resistance with that obtained when the same E. M. F. acts through an unknown resistance.

The general method of measuring resistances by the use of a galvanometer is to note the deflection obtained with a given battery and a known resistance in the circuit, and from this to compute what is called the *working constant.* This working constant may be defined as *the number of scale divisions deflection that would be obtained by causing the current from the given battery to pass* *through the galvanometer and a resistance of one megohm.* Of course such a deflection as this can exist in our imagination only, but it serves, nevertheless, as a convenient standard upon which to base our calculations. Having obtained the working constant, a reading is taken of the deflection produced by passing the battery current through the galvanometer in series with the unknown resistance. As the deflections are inversely proportional to the resistances, the unknown resistance is then readily computed.

If measurements of comparatively low resistance are to be made, then the resistance of the battery and of the galvanometer must be taken into consideration as well as that of the resistance placed in circuit with them, but as the measurements here considered will be those of very high resistances only, the resistance of the battery and of the galvanometer may be neglected. For the purpose of taking

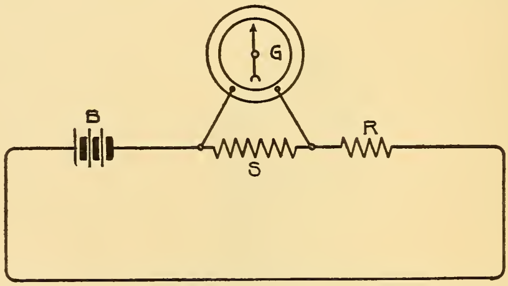

FIG. 635.—CIRCUITS FOR GALVANOMETER CONSTANT.

the constant, connections are made as shown in Fig. 635, where *B* is the battery, *G* the galvanometer, *S* the shunt, and *R* the known resistance. Usually the value of *R* is $\frac{1}{10}$ of a megohm, or 100,000 ohms. With the $\frac{1}{999}$ shunt a certain deflection will be obtained when the circuit is closed. Obviously, if the shunt were not present the deflection would be 1000 times as great, because only $\frac{1}{1000}$ of the current passes through the galvanometer. Therefore the total deflection, if it could be measured, that would be produced through the galvanometer and the 100,000 ohms resistance, would be the deflection noted multiplied by 1000. If, now, the resistance, *R*, had a value of 1 megohm instead of $\frac{1}{10}$ megohm, the deflection would have been only $\frac{1}{10}$ as great as this. Therefore to find the number of scale divisions deflections which the galvanometer alone would give with 1 megohm in circuit, we multiply the deflection noted by 1000 and by $\frac{1}{10}$.

In general we may say: *to find the working constant, multiply* *the deflection obtained by the multiplying power of the shunt, and by the value of the known resistance in megohms.*

As a numerical example let us assume that with the $\frac{1}{999}$ shunt and the $\frac{1}{10}$ megohm resistance, we obtain a deflection of 2000 scale divisions, then the working constant is

$$200 \times 1000 \times \frac{1}{10} = 20{,}000.$$

In other words, 20,000 would be the number of scale divisions obtained were the entire current from the battery allowed to pass through the galvanometer with one megohm in series.

With 50 cells of battery (45 or 50 volts), the constant under ordinary working conditions with a good D'Arsonval galvanometer, will be from 10,000 to 25,000. With a Thomson instrument a much higher constant may be obtained. Mr. George D. Hale of the Western Electric Company's cable-testing department, uses a large four coil Thomson instrument with 600 volts obtained from a motor generator. With this he obtains a constant of 528,000, and by adjusting the suspension for greater delicacy can obtain as high as 2,000,000. Of course this is entirely impracticable for portable instruments, and is, in fact, unnecessary, as good work may be done with a constant of 20,000. In ordinary testing a battery of 50 cells is sufficient. Of course a higher working constant may be obtained with a larger battery, and frequently 100 cells are used.

INSULATION TESTS.

One of the principal uses of the galvanometer in line testing is in the measurement of insulation resistance. The insulation resistance of any line or conductor is the joint resistance of all the *leaks* from the line to the ground or to other conductors. On a pole line every insulator forms a leak to earth, and on a line having 40 poles to the mile there would be 40 such leaks in parallel. The insulation resistance of a line as a whole varies inversely as its length, if the insulation is uniform. Evidently, a line two miles long would have one-half as great an insulation resistance as a similar line one mile long, because on the latter there would be only half as many leaks as on the former. In general it may be stated that a line n miles long will have only $\frac{1}{n}$ as great an insulation resistance as a similar line one mile in length. In order to obtain a standard of insulation resistance independent of the length of the line, it is convenient to express the insulation resistance as so many megohms per mile.

The insulation resistance per mile is found by multiplying the insulation of the line as a whole by the length of the line in miles.

In order to measure the insulation resistance of a line the constant of the galvanometer is first taken and then the known resistance is cut out of circuit and the line insulation resistance substituted for it. Assuming that the insulation resistance to be measured is that of a wire in a cable, the terminals of the circuit which were connected with resistance, *R,* in Fig. 635, will be connected one with the wire and the other with the sheath of the cable as shown in Fig. 636. Care must be taken that the wire being measured is carefully insulated from the sheath at the other end of the cable. The shunt, *S,* is then cut out of circuit in order that the full current may pass through the galvanometer. Before completing the circuit with the cable conductor and sheath, however, the key, *K,* should be closed

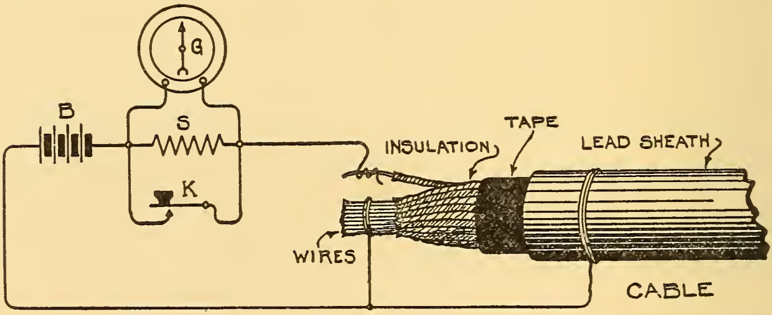

FIG. 636.—INSULATION RESISTANCE OF CABLE.

in parallel with the galvanometer, in order to prevent the rush of current that will take place in charging the cable, from causing the needle to give too violent a kick. After a short time the key is opened and all of the current diverted through the galvanometer. The galvanometer then receives only that current which leaks from the core of the cable to the sheath through the insulation. Under these circumstances a certain deflection will be noted, and by comparing this deflection with the constant already obtained the value of the insulation resistance in megohms is readily determined.

To illustrate, suppose that a deflection of 75 scale divisions is obtained with the apparatus connected as in Fig. 636. If the constant is 20,000, as already determined, we know that the insulation resistance must be 20,000 divided by 75, or 266 megohms, thus indicating that the total insulation resistance of the cable is 266 megohms. That this is true is evident from the fact that the constant, 20,000, represents the number of scale divisions deflection that would be obtained were only one megohm in the circuit. The deflections are inversely proportional to the resistance in the circuit, and therefore the total insulation resistance is equal to the deflection through one megohm divided by the deflection through the insulation resistance, or 20,000 divided by 75. To sum up these operations:

1st. Obtain the galvanometer constant or deflection obtained when the galvanometer in series with one megohm resistance is subjected to the potential of the battery. 2d. Find the deflection obtained when the galvanometer and insulation resistance in series are subjected to the potential of the battery. 3d. Divide the constant by the

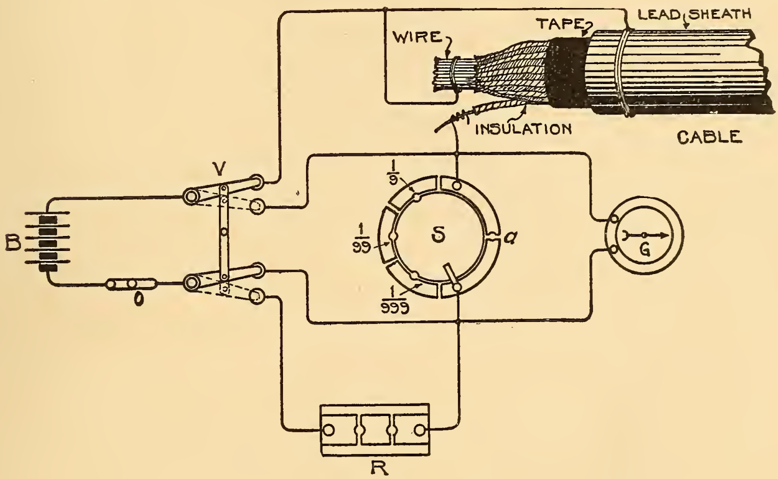

FIG. 637.—CONNECTION FOR INSULATION TEST.

deflection obtained through the insulation resistance, the result being the insulation resistance of the cable expressed in megohms. 4th. To find the insulation resistance per mile, multiply the total insulation resistance by the length of the cable in miles.

If the insulation of the cable is low, a shunt must be used in obtaining the deflection through the insulation resistance. If the insulation resistance is high, the deflection will be small and no shunt will be required. The purpose of the shunt is merely to keep the deflections on the scale so that they may be read.

In Fig. 637 is shown a convenient arrangement of connections for making insulation tests. In this, *B* is the battery of say 50 cells, *R* the $\frac{1}{10}$ megohm box, *S* the shunt box, *G* the galvanometer, and *V* a convenient switch for throwing either the $\frac{1}{10}$ megohm box or the line insulation into circuit with the galvanometer and battery. When the levers of the switch, *V,* are in the position represented by the dotted line, the circuits are those for taking constant of the galvanometer, and when in the position shown by full lines, the circuits are those for obtaining the deflection through the insulation of the cable. Various forms of keys for changing the direction of the battery current through the galvanometer, and for performing other switching operations with the greatest possible convenience, are obtainable, and form an important part of all testing outfits. The scope of this work will not permit of their detailed description.

In making insulation tests the resistance of the lead wires to the cable or line need not be taken into account. It is a matter of the greatest importance, however, that these wires be perfectly insulated from each other. It is a very easy matter in making tests of this nature to measure the wrong quantity.

One very important matter in connection with the insulation tests has not yet been spoken of. When the reading is being taken, with the cable or line insulation in circuit, it will be noticed that a maximum deflection is obtained at first, and that this gradually diminishes, as though the insulation resistance were increasing. This is due to what is called electrification, a phenomenon that is not very thoroughly understood. When the electromotive force of the battery is first applied to the cable or line, there is a sudden rush of current, due to the charging of the conductors. The charges, however, apparently *soak in* to the insulation to a slight extent, thus allowing more current to flow to the conductors. After the first rush due to the first charging of the conductors, there is still a flow of current, due in part to this *soaking in,* and in part to the actual leakage *through* the insulation. It is the current due to the latter that we are concerned with in insulation measurements, and therefore we must wait till the soaking in process ceases, when the flow of current will be practically constant, being that through the insulation. In nearly all telephone-testing work, one minute is allowed for electrification, after which the reading is taken of the deflection. When one is thoroughly familiar with his instruments he may often, where great accuracy is not required, estimate what the deflection at the end of one minute will be, by watching the deflection for 30 or 40 seconds. This method saves time, but must be used with extreme caution.

With a constant of 20,000 a reading taken on a wire in a piece of good new telephone cable, one-quarter mile long, would probably show a deflection of 8 or 10 scale divisions upon the closure of the key. This would decrease to about 6 scale divisions in 2 seconds, and to about 2 scale divisions in 30 seconds, after which it would remain constant. The reading of 2 divisions at the end of the minute would indicate an installation resistance of $\frac{20,000}{2} = 10,000$ megohms, or 2500 megohms per mile.

As examples of deflections on the different wires in various cables the following are given:

Dry cable, $\frac{3}{4}$ mile long, two years old. Galvanometer constant 22,000: Readings, 12—15—15—10—10—15—15—15—13 scale divisions.

Another dry paper cable, 2750 feet long one year old. Galvanometer constant 19,000: Readings, 5—6—5—4—5—5—5—5—6, etc.

A piece of jute and ozite cable five years old, 6000 feet long, gave the following with a constant of 20,000: 7500—2500—1000—1000—600—800—900—800—1000. It was necessary to use the $\frac{1}{19}$ shunt in taking these readings.

Another piece of the same kind of cable, 800 feet long, with a constant of 20,000, gave 175—200—250—270—160—110—120—160—110—125.

CAPACITY TESTS

A very important measurement, especially in telephone cables, is the determination of the capacity of the line conductors with respect to all neighboring conductors. The usual method of making capacity tests is to note the deflection produced when a condenser of known capacity, after having been charged to a known potential, is discharged suddenly through the galvanometer, and to compare this with the deflection obtained when the cable or conductor being measured, after being charged to the same potential, is discharged through the galvanometer. The deflections produced under these circumstances are proportional to the charges, and therefore to the capacities of the standard condenser and the line or cable. The circuits for obtaining the deflection produced by the discharge of the condenser are shown in Fig. 638, where *C* is the standard condenser, *B* the battery, and *G* the galvanometer. When the key is depressed the condenser is charged to the full potential of the battery, *B*. The key is then suddenly released, thus allowing the charge from the condenser to pass through the galvanometer, thus producing a certain throw of the needle. The connections are then made as shown in Fig. 639, the same battery, *B*, being used. When the key is depressed the cable is charged, and when suddenly released this charge flows through the galvanometer and produces another throw of the needle. By comparing the throw produced by the charge of

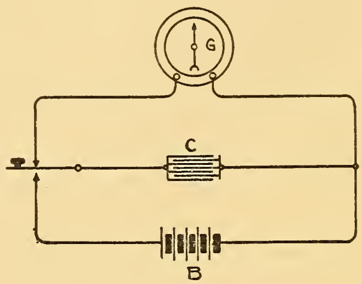

FIG. 638.—CAPACITY TEST.

the condenser with that produced by the charge of the cable, a direct comparison may be made between the capacity of the cable and that of the condenser. Thus, if with the $\frac{1}{999}$ shunt the discharge from the condenser gave a deflection of 100 scale divisions, the capacity of the condenser being $\frac{1}{10}$ microfarad, and if with the same shunt

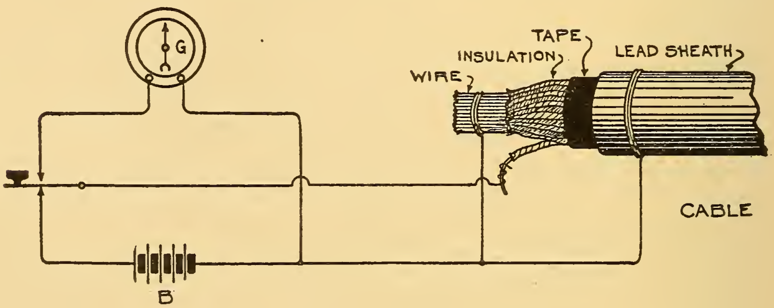

FIG. 639.—CAPACITY TEST FOR CABLE.

the discharge of the cable produced a deflection twice as great, we would know that the capacity of the cable was $2 \times \frac{1}{10} = \frac{1}{5}$ microfarad.

Convenient connections for making capacity tests are shown in Fig. 640, where *G* is the galvanometer, *S* the shunt, *C* the standard condenser *KK* discharge keys, *V* the selecting switch and *B*, a battery of eight or ten cells. With the switch, *V*, at the left and both discharge keys depressed, the current from the battery will flow into the condenser, thus charging it. Upon the sudden release of the discharge keys, the condenser will discharge through the galvanometer and shunt, giving a deflection which should be noted. With the switch, *V*, at the right, the cable may be charged or discharged in the same manner, and the deflection produced by its discharge noted. About seven cells of battery is usually sufficient for making capacity tests on telephone cables. If a non-adjustable condenser only is available, one having a capacity of $\frac{1}{10}$ microfarad is probably most desirable. For accurate work a subdivided condenser, having its

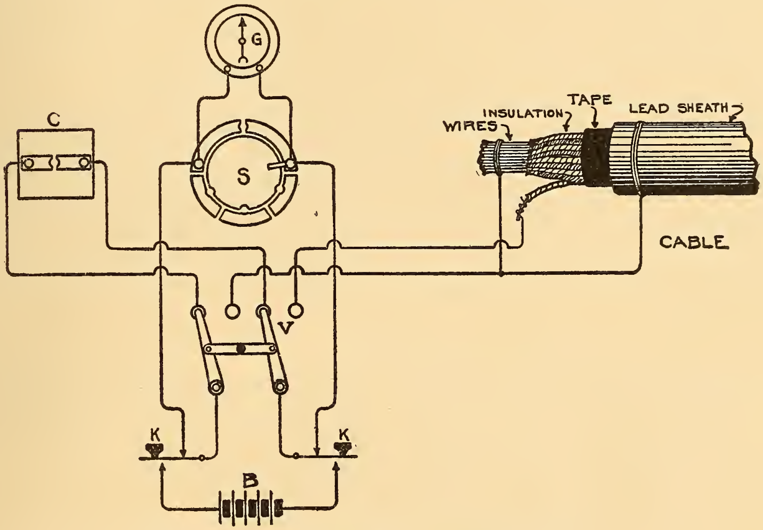

FIG. 640.—CIRCUITS FOR CAPACITY TEST.

divisions so arranged as to be easily connected in multiple or in series, or in combinations of the two, is very desirable. Then the condenser capacity may be varied until the throw from the condenser is nearly equal to that from the cable, thus greatly minimizing the liability to error in the results. In making capacity tests the wire under test should be carefully insulated and all the other wires in the cable should be connected together and to the sheath or ground. Fifteen seconds should always be allowed for the charging of the cable.

If *d* is the throw due to the discharge of the condenser, *d'* that to the discharge of the cable, *K* the capacity of the condenser in microfarads, and X the capacity of the wire being measured, then

$$X : K :: d' : d$$

$$X = \frac{d'}{d} K.$$

If the throws of the galvanometer are too large to be measured, the shunt must be used. In this case d or d' in the formula will be the actual throws observed multiplied by the multiplying power of the shunt.

THE LOCATION OF VAULTS.

When a break occurs in a wire in a line or cable, the ends remaining insulated from other wires and the ground, the only recourse is to capacity tests. The capacity of the two parts of the wire will be proportional to their lengths, the wire being uniform in size and in its relation to other wires, throughout its length.

We may locate a break of this nature in several ways.

Measure the capacity of one end of the broken wire, then go to the other end of the cable and do the same. Calling D the length of the cable in feet, C the capacity of the first portion of the wire, C' that of the other, and X the distance in feet to the break from the first end, then:

$$X : D :: C : C + C'$$

$$\text{and } X = \frac{CD}{C + C'}.$$

When a good wire is available, and this is usually the case, set up the instruments for capacity for testing, and take a throw, d, on the broken wire, another, d', on the good wire, and a third, d'', on the good wire with the broken wire connected to it at the far end.

Evidently the throw on the whole broken wire would be $d'' - d' + d$.

Hence where D and X have the same significance as before

$$X : d :: d : d'' - d' + d$$

$$\text{and } X = \frac{dD}{d'' - d + d}.$$

The location of breaks is much complicated by the presence of poor insulation between ruptured portions, and between other wires. The insulation resistances between these parts should always be taken. If less than one megohm, the results obtained by the capacity tests should not be relied on, and other methods too complex for description here may be resorted to. It seldom pays to open a lead-covered telephone cable for the purpose of joining a few broken wires, the expense of making the splice being usually in excess of the value of the wires.

The location of crosses or grounds is rendered somewhat difficult by the fact that there is nearly always some resistance in the fault itself. If we know the resistance of the defective wire and have no good wire running parallel with it, we may proceed as follows, using a good Wheatstone bridge:

Measure the resistance of one end of the defective wire through the fault to ground. Do the same at the other end. Then calling R the total resistance of the wire (either known or calculated from its size and length), R' the measured resistance from the first end, R'' that from the other end, X the resistance from the first end to the

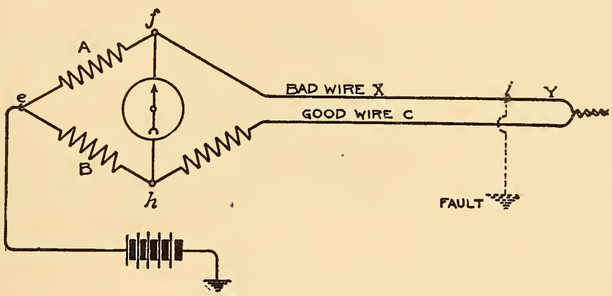

FIG. 641.—VARLEY LOOP TEST.

fault, Y the resistance from the second end to the fault, and Z the resistance of the fault, we have:

$$R = X + Y.$$
$$R' = X + Z.$$
$$R'' = Y + Z.$$

Solving these for X and Y we have

$$X = \frac{R + R' - R''}{2},$$

$$Y = \frac{R - R' + R''}{2},$$

which values are independent of the resistance of the fault. Knowing the resistance to the fault, it is easy to compute the distance to it, from the resistance per foot of the conductor.

When a good wire is available, the Varley loop test should be used, as it is more accurate than the method just described. For this a Wheatstone bridge is used, and connected as in Fig. 641. The good and bad wires are joined at their distant ends, and one terminal of the battery connected to the point, *e*, on the bridge, while the other terminal is grounded. It is not difficult to see that the partial ground or fault now bears the same relation to the bridge as the point, *i*, in the diagram of Fig. 626; the rheostat arm now includes the resistance R, plus the resistance of the bad wire to the fault, while the unknown arm includes the resistance of the good wire, plus the resistance of the bad wire on the other side of the fault.

The equation of the bridge, when balanced, then becomes

$$\frac{A}{B} = \frac{R + X}{C + Y},$$

where R is the unplugged resistance of the rheostat, X the resistance to the fault, Y the resistance beyond the fault, and C that of the good wire.

Now calling L the resistance of the loop consisting of the good and bad wires, we have

$$L = X + Y + C,$$

$$\text{or } C + Y = L - X.$$

Substituting this in the second member of the equation of the bridge, we have

$$\frac{A}{B} = \frac{R + X}{L - X},$$

$$\text{whence } X = \frac{A\,L - B\,R}{A + B},$$

which is independent of the resistance of the fault. When the two ratio arms of the bridge are given equal values we have $A = B$, and the equation for X becomes:

$$X = \frac{L - R}{2}.$$

L may be known from records previously made, may be computed from the size and length of the wires, or, if only one ground is present on the bad wire, it may be measured directly on the bridge.

Sometimes, in ordinary paper cables, a requirement is made that a rubber-covered test wire shall be run through the center of the cable. so that at least one good wire may always be available in testing. Where no good wire is available, a separate wire may be strung to be used as the return in this test.

If the lead wires, from the instruments to the faulty wire, have appreciable resistance, this should be measured, and deducted from the value of X. After this the distance to the fault may be readily obtained from the resistance per foot of the conductor.

A second Varley method, quite as good as this, and very valuable as a check method, is the following: The apparatus is arranged as in Fig. 642, and it will be noted that the conditions are similar to those of the first method, and that only a reversal, at the set, of the good and bad wires is required.

With this arrangement, the bridge equation, when a balance is reached, must be

$$\frac{A}{B} = \frac{X}{R + C + Y}, \text{ or } A\,(R + C + Y) = B\,X.$$

the letters referring to the same things as before.
again calling L the loop resistance of the good and bad wires, we have

$$L = X + Y + C,$$
$$\text{or } C + Y - L - X.$$

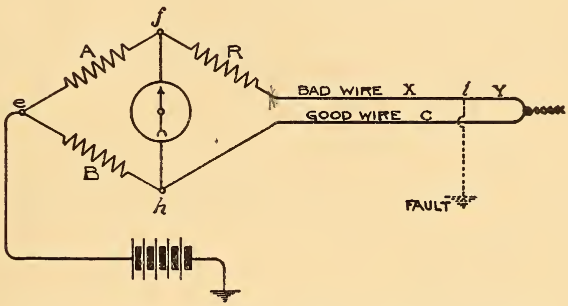

FIG. 642.—VARLEY LOOP TEST—CHECK METHOD.

Substituting this in the second member of the last form of the equation, we have

$$A\,(R + L - X) - BX,$$

$$\text{whence } X = \frac{A\,(R + L)}{A + B}$$

This result also is independent of the resistance of the fault, and it may be said of both Varley methods that the fault resistance may be one which changes its value from moment to moment, without changing the final result. Also the potentials of the two ground connections with reference to the bad wire may change from moment to moment and not harm the result. Indeed, it is possible sometimes to locate a fault with no battery at all, as the difference of potential between the two grounds is frequently great, where grounded trolley systems exist.

These two methods ordinarily will be applied to pairs of wires forming a loop of which the two sides are about alike; this is the case in testing cable conductors for a ground on one or more, when one good cable wire exists; it is also true in testing for a ground on one wire of a metallic circuit open wire line, the other wire being good. In these cases the resistance to the fault always will be less than the whole resistance of either wire. In the second Varley form, therefore, the bridge arms can never be equal, with a ratio of 1, but the arm *A* must always be greater that the arm *B*.

VARLEY TEST BY ARITHMETIC.

The great certainty of the Varley tests in locating grounds and crosses make them of value to all persons having to do with telephone lines; by using the following simple rule, anyone who can add and divide by two can make fault locations by the first method. The connections are shown in Fig. 641 and the conditions are that the good and bad wires shall be alike and the bridge arms equal:

Rule.—Adjust the rheostat till the deflection is the smallest possi-

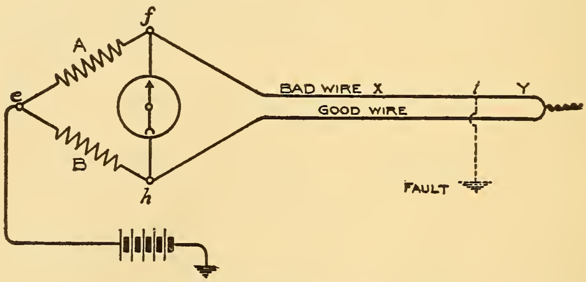

FIG 643.—MURRAY LOOP TEST.

ble; read the resistance in the rheostat and divide it by two; the result is the resistance from the fault to the further end of the wire under test.

It must be observed that the result is not given in ohms from the testing point to the fault, but in ohms from the fault to the other end. This is as serviceable, however, and is sometimes just what is wanted.

There is another loop test not quite so convenient as the Varley for those possessing only an ordinary bridge, but available and reliable where one has a standard resistance box and a galvanometer. This is known as the Murray loop test and connections for it should be made as shown in Fig. 643. The point *e* may be a plug inserted into an intermediate hole in a standard resistance box, the points *f* and *h* being the end terminals of the box. If two separate resistances are available, the two may be connected in series, the point between them being then represented by *e*, in Fig. 642.

The two resistances are manipulated until a balance is obtained, no current being indicated by the galvanometer, when

$$\frac{A}{B} = \frac{X}{C + Y},$$

the significance of the various letters being the same as used in describing the Varley test above. From this is obtained

$$\frac{A}{B} = \frac{L}{L - X},$$

$$\text{whence } X = \frac{A\,L}{A + B},$$

in which L is as before the resistance of the loop. This value of X is independent of the resistance of the fault.

INDEX.

THE END.