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Heywood

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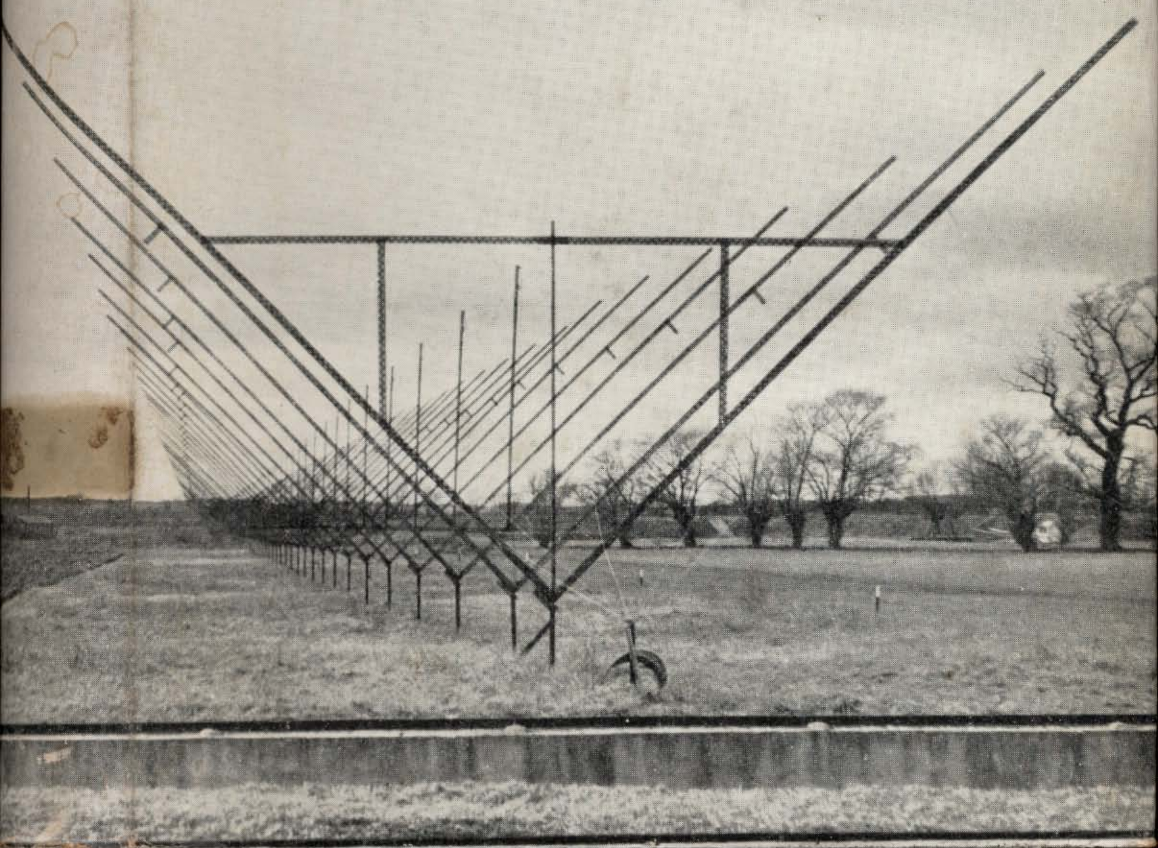
Radio Astronomy Simplified

JOHN HEYWOOD



This is a book for the amateur and describes a simple radio telescope which can be built by anyone with a knowledge of radio-receiver techniques. It does not attempt to enter the field of observational radio astronomy in a detailed way, but it does discuss such observations as can be made on the telescope which the reader builds for himself.

The photograph on the cover illustrates one of the arms of the 7·9 metre Aperture Synthesis Array at the Mullard Radio Astronomy Laboratory, Cambridge. The arms of the corner-V are clearly shown: small corner-V reflectors are easily constructed by the amateur. (Photograph by Ronan Picture Library.)

Illustrated

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John Heywood was a lecturer in the Department of Telecommunications Engineering, Norwood Technical College, and is now at the College of Advanced Technology, Birmingham. He organized the joint British Astronomical Association/Radio Society of Great Britain's measurements on Sputnik II. He is the author of a number of papers and articles on radio astronomy and earth satellites. He was appointed first Director of the Radio Electronics Section of the B.A.A. in 1957.

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Radio Astronomy Simplified

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FOR
PATRICK MOORE

Acknowledgements

I am indebted to the Council of the British Astronomical Association for permission to reproduce many of the illustrations contained in the memoir on Radiotelescopes. To my friend and colleague F. W. Hyde for reading the script. To Dr. F. G. Smith for permission to quote from *Radio Astronomy* (Penguin). Also to all my friends and colleagues in the radio-electronics section of the British Astronomical Association for their help and collaboration. Finally for the many helpful criticisms and suggestions given me by Mr. J. R. Smith.

Mr. J. M. Osborne has given me permission to reproduce the circuits of his simple radiometer. I ought to point out for those who have a communications receiver wanting to modify it for use at a higher frequency that another B.A.A. member, S. F. Denning, has successfully observed the sun at 200 mc/s using a single Yagi array: his basic receiver was an Eddystone. His report has only just reached me and it is not possible to include his ancillary circuits in this book.

Professor M. Ryle, F.R.S. has allowed me to reproduce a photograph of one of the large aerials at the Mullard Radio Astronomy Observatory Cambridge.

It was not unfortunately possible, because of shortage of space to quote from F. G. Smith's article in *The Times Science Review* although I had his permission. If it appears that I have misinterpreted him or anyone else for that matter, I apologize: but as I have explained in the preface, this book is simplified and thus should only be the beginning of your reading.

The diagrams were prepared by Mr. B. R. J. Noble. Other acknowledgements are given with the diagrams.

Contents

Preface

WHEN I began to write this book there were no books about the design of simple radiotelescopes. There were no books to encourage the amateur, apart from one, which devoted a page to telling the prospective enthusiast to write to me!

On the average I receive four or five letters a week asking me how to build a simple radiotelescope. It would seem, however, that most of the enquirers are put off or have become armchair radio astronomers. Some like the two Johns – Osborne and Smith, have persevered and enjoyed themselves. Others, like my friend and colleague Frank Hyde, have persevered and built large arrays which are used for research purposes.

Research has always been the tradition of the amateur astronomer and so the members of the radio-electronics section of the British Astronomical Association have tended to persevere in their own small way along certain lines of research open to the amateur.

The analysis of records has provided ample opportunity for the armchair radio astronomer to do some work without in fact building radiotelescopes.

It is a book intended for the beginner, for the person keen to build a simple back garden radiotelescope. A book to encourage the beginner not to do research, but to have some fun, for fun is education and education is fun.

Two very simple types of radiotelescopes are described – the radiometer and the drift interferometer. They are easy to construct, simple to operate and not too difficult to understand.

There are many good books on observational radio astronomy and it is not my intention to ape the professional writers. Thus the description of current knowledge does not attempt to cover the whole wide field of observation but those which can be made with the simple radiotelescope.

Similarly the treatment of radio theory and the methods of construction is by no means exhaustive although the radio amateur should be able to go ahead on this basis. The absolute beginner will have to read a radio text book and get some help from a local radio amateur. If he writes to the Radio Society of Great Britain he will be able to obtain the names of the local hams or evening classes where he can obtain guidance. Don't be put off by the pen recorder. Amateurs of the B.A.A. section have received considerable help from the Carnegie Trust (United

Kingdom) and now possess a number of these relatively costly instruments. In the text, other more simple ways of recording will be mentioned. No one book will do for the beginner so please turn to the bibliography which contains a list of 'minimum cost' but nevertheless useful references. Several of the more difficult paragraphs have been starred and need not be read.

Sometimes the word 'difficult' is used to emphasize the need of a complicated technique generally beyond the scope of the amateur.

Many are worried by the fact that radio noise is received from outer space. Worried not so much by the possibility that it might be due to other humans but to the fact that it is not. So to dispel these worries the initial chapters are intended to throw some light on the mechanisms of extra-terrestrial radio waves. Some repetition is introduced in the hope that different approaches to the subject will make the problem clearer.

Radio noise from outer space was first observed with very simple radiotelescopes. The aerials had wide beams: amateurs could and can build such instruments. As the science has developed it has become necessary to develop narrow beam aerials. The pictures obtained of the radio sky have changed from relative simplicity to comparative complexity. In the chapters which follow I have tried on the one hand to describe the sky that would be seen by a simple radiotelescope and on the other – to draw attention to some of the current controversies. In this way I hope the amateur will obtain an idea of what his radiotelescope is likely to be able to *see*, whilst knowing its limitations and understanding the need to keep up to date with his reading. For example in Fig. 8:4 I have shown a very simple figure of what the sky might look like to a wide beam radiotelescope. Firstly, there has been a controversy about the nature of the galactic halo – is the radiation simply a spherical? What are the components of background radio emission, etc? Are the radio extra-galactic sources in the positions shown? The answer to the latter is no, for the diagram is only trying to indicate the general picture. These particular sources only contribute a fraction of the emission and in so far as a simple radio telescope is concerned it will probably only be able to locate the sources indicated in Fig. 8:2. In this way, I hope the simplification presents a balanced and relatively undistorted picture.

Finally it is not possible to go into much detail in one small book. It is only possible to present an outline of the two subjects as they are inter-related. Focus is on the basic simplicity in the hope that some readers will be encouraged to enquire further and build a simple radiotelescope.

J.H.

CHAPTER ONE

Radio noise

1 : 1 *Radio Noise from Space*

'EXPERIMENTS are now being planned to detect radio messages aimed at the earth from planets of other solar systems – experiments which few believe will succeed, but which few would not want to see tried. . . .' So begins a technical letter in the May 1961 issue of the Proceedings of the Institute of Radio Engineers from M. J. E. Golay. The remainder of Mr. Golay's discussion does not matter in this text, what does matter is that many people do think that radio astronomers listen to voices from outer space. This quotation makes it quite clear that they do not and that whilst the possibility is envisaged, it is itself very unlikely. In any case the axioms which have been postulated concerning communication with other beings deal with the probability and nature of receiving 'intelligence' from other planets as distinct from voices. After all, the code signals of morse are intelligence, they are certainly not voices. If you cannot receive morse it probably doesn't worry you, for you realize that a telegraphist with specialized knowledge is required. So too with intelligence from outer space – if it can be received, a specialist will be required for its reception, a fact which will probably bring relief to most of my readers!

Nevertheless the popularity of radio astronomy has increased enormously and a person having established that the radio astronomer is not listening to voices often asks – 'What then is this radio noise? How is it made? etc.' The simplest way of answering these questions is to say that it is due to the movement of electrons under certain special conditions. Ordinary thermal heating of a gas is a good example. Most of those who are not initiated in the science would probably accept this as a suitable explanation of the hisses that the radio observer hears. An equally satisfactory explanation would be that the radio noise is caused by similar mechanisms to those which make the sparking plug of a car disturb television programmes when it is unsuppressed.

However, since there are many popular works describing observational radio astronomy and we are concerned with simplifying radio astronomy so that these books may be read with greater ease, it seems appropriate to spend two or three chapters discussing radio waves and other forms of electromagnetic radiation. There are two good reasons for this – the first being that most readers do not want to plough through a text book of radio but nevertheless would like to have some introduction to that science. The second is that it enables the writer to explain some of the terms which have to be used if the design problems of a simple radiotelescope are to be discussed. In this chapter, I propose therefore to discuss some of the particular facets of radio theory promoted by the questions – 'What causes these distant sources to emit radio waves? and, how are the radio waves transmitted?' To do this let us first discuss how radio waves are propagated into space from a simple broadcast transmitter.

1 : 2 *Electric Currents*

The Rutherford model of the hydrogen atom is the model which is most familiar. It is characterized by a planetary electron rotating about a nucleus containing a proton and a neutron. Hydrogen is an element and the elements differ from each other by the number of electrons and protons that they possess: for instance copper has 29 electrons and 29 protons. The number of neutrons may vary and thus alter the atomic weight of the particle. Different atomic weights cause slight differences in the weight of different lumps of the same element and these different lumps are called isotopes of the element.

An atom is in equilibrium or stable when the number of electrons in orbit is equal to the number of protons in the nucleus. The electron is the smallest known electrical charge or, if you like, charge of electricity. If the atom is in equilibrium it is likely that the proton and electron behave relative to each other in an analagous way to that of two magnetic fields of unlike sign, i.e. unlike poles attract (or like poles repel). The charges on the electron and proton are equal and opposite: electric charges have fields in the same way as the magnets attract and repel each other. The electron is of negative sign and the proton positive.

Since matter is made up of atoms which in turn are made up of electrons and protons it is not difficult to think of space being filled with tiny point charges of electricity some positive and some negative, each with its own field. The neutron is electrically neutral.

An electrical engineer utilizes these facts by gathering together the charges of one sign and causing them to move (or flow) in a definite direction. This is easy because the outer electrons can be freed from their parent nucleus with ease under certain

conditions. A conductor is a material in which large numbers of 'free' electrons can be made to flow in a definite direction. An electric current flows in conductors but not insulators and is simply a movement of electrons in a definite direction. When an electron moves, work is done and energy used up. The pressure which causes a current to flow in an electrical circuit is the voltage. The power or the rate of doing work is measured in watts.

Another characteristic of atoms in a gas arises when they collide, for they can lose an electron to another atom or gain an electron. One loses weight the other increases, their velocities also change, the heavier particle slowing down. Such atoms are said to be ionized. An ionized gas like the ionosphere is a gas in which collisions cause the majority of particles to be ions.

Electrons can move in any direction depending on the way the pressure is applied. Consider an electron in the sky. When it is stationary it has the potential to do work, if it is moved in a definite direction, say towards earth. Once it starts to move it is an electric current and does electrical work. The pressure must be equal to the potential difference through which it moves, i.e. an electron 6′ above the ground will do less work than an electron 12′ above the ground in moving towards the earth. The potential difference for the two distances will differ and the pressures required to bring the electron to earth from the two points must also differ. It can be shown that the electrical potential difference and the pressure are the same thing both being measured in volts in the electrical circuit.

Fig. 1:1 shows a simple direct current circuit. It is clear that a

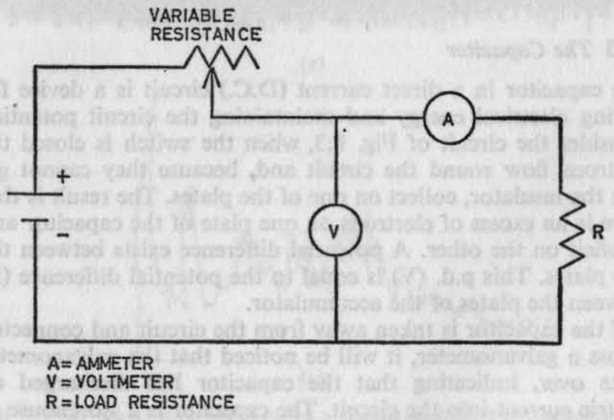


FIG. 1:1. Simple D.C. circuit.

current could flow round the circuit in either direction. *By convention* an electric current flows round the circuit from positive to negative. Another way of defining this, is to say that if an electron flows towards earth it is producing positive current flow whilst if it flows away from earth it is a negative current flow. The pressures would have to reverse the direction of their action

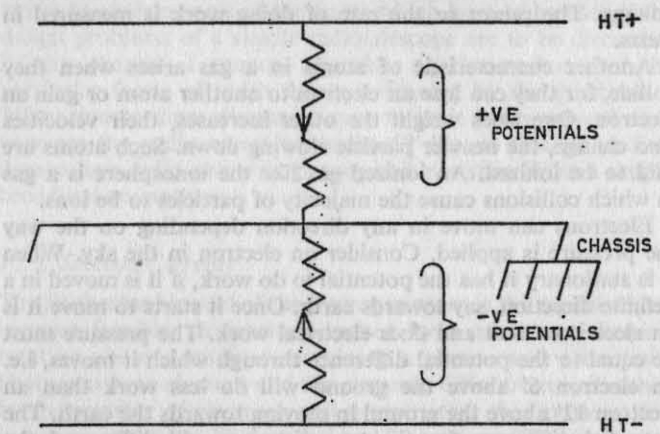


FIG. 1:2

as well – hence positive and negative potentials or voltages. Radio engineers use as their 'earth' the chassis of the receiver. Currents flowing towards the chassis are positive and those away from it negative (e.g. Fig. 1:2).

1 : 3 *The Capacitor*

The capacitor in a direct current (D.C.) circuit is a device for storing electrical energy and maintaining the circuit potential. Consider the circuit of Fig. 1:3, when the switch is closed the electrons flow round the circuit and, because they cannot get past the insulator, collect on one of the plates. The result is that there is an excess of electrons on one plate of the capacitor and a deficit on the other. A potential difference exists between the two plates. This p.d. (V) is equal to the potential difference (E) between the plates of the accumulator.

If the capacitor is taken away from the circuit and connected across a galvanometer, it will be noticed that the galvanometer flicks over, indicating that the capacitor has discharged an electric current into the circuit. The capacitor is a storehouse of electrical energy.

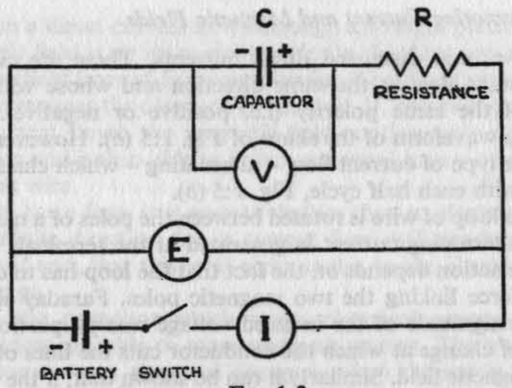


FIG. 1:3

The time taken to charge a capacitor (normally through a resistance R) from a source of supply is known as the time constant of the circuit. The values of C the capacitance or R the resistance can be used to alter the times of charging or discharging. All circuits have a time constant and in radio astronomy the time constant of the output circuit is made long. This is because there are many little fluctuations on the record which result from disturbances other than those originating from the radio source. A long time constant smooths away these variations: illustrations of this effect are shown in the records of Fig. 1:4.

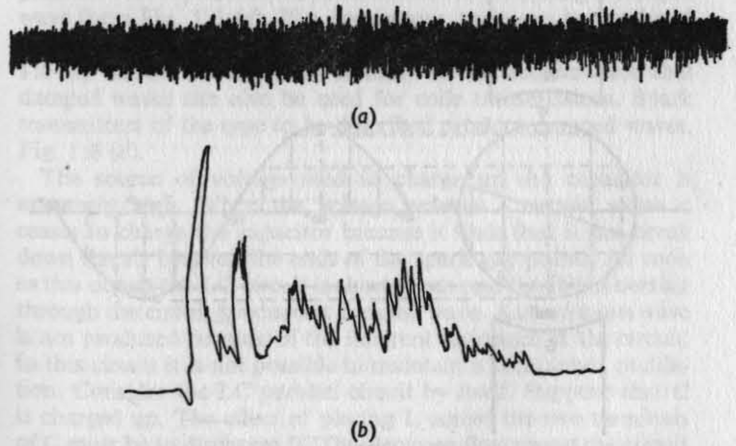


FIG. 1:4 (*a*) Short time constant in a circuit used by Fr. Castelvecchi. (*b*) Long time constant in a circuit used by F. W. Hyde (*B.A.A. Memoir*)

1 : 4 *Alternating Current and Magnetic Fields*

So far, we have discussed direct currents. These are currents which always flow in the same direction and whose voltage is always of the same polarity (i.e. positive or negative). They produce a waveform of the shape of Fig. 1:5 (*a*). However there is another type of current flow – alternating – which changes its polarity with each half cycle, Fig. 1:5 (*b*).

When a loop of wire is rotated between the poles of a magnet's field an alternating current is generated at the terminals of the loop. The action depends on the fact that the loop has to cut the lines of force linking the two magnetic poles. Faraday showed that the magnitude of the induced voltage was proportional to the rate of change at which the conductor cuts the lines of force of the magnetic field. Similarly it can be shown that, if the wire is stationary when a magnetic field of changing flux cuts across it, that a current is induced in the wire.

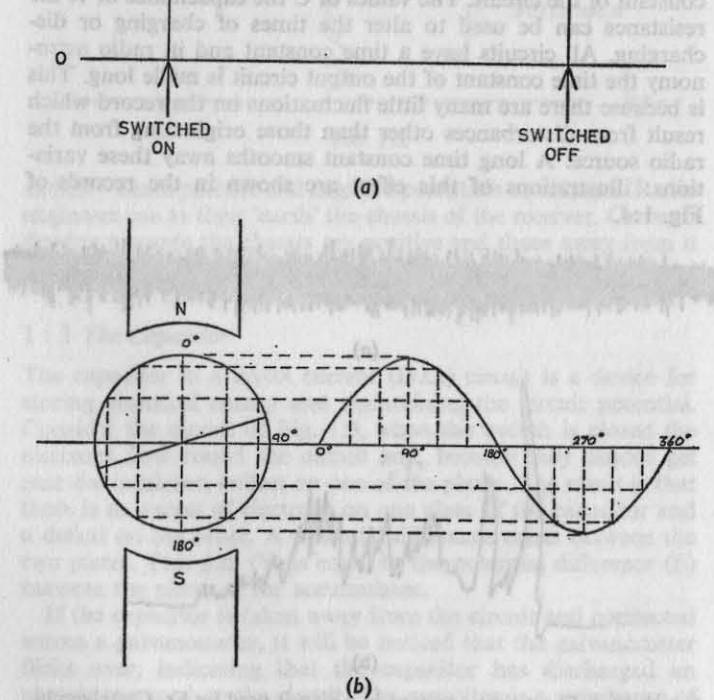


FIG. 1:5

When a direct current flows through a straight piece of wire a magnetic field is set up at right angles to the direction of current flow the field lines of force are circular. The direction of current flow determines the direction of the field. If, however, an alternating current flows, the magnetic field continuously changes its direction and is thus able to induce a current in any other closely adjacent wire.

From these facts it is easy to deduce that an electron flowing in a definite direction (i.e. a current flow) will produce a magnetic field and, that this is at right angles to the electric field of the charge.

Like the capacitor which stores electrical energy, coils or inductances are able to store magnetic energy. The ability of a capacitor to store electrical energy is often defined in terms of its capacitance (*c*). A capacitor is designed to have a specific capacitance. Similarly a coil has specific dimensions which also depend on its behaviour when currents pass through it. The unit to which coils are designed is the unit of inductance (L). A coil having a given inductance will have specific dimensions. Certain materials (e.g. iron dust slugs) alter the value of inductance if they are inserted in the coil. Inductance is a function of the frequency of operation.

1 : 5 *The Production of a Damped Wave*

Fig. 1:6 shows an inductance and a capacitor connected in parallel. This represents the basic circuit for producing a damped wave form Fig. 1:6 (*d*). If a continuous wave can be produced Fig. 1:6 (*b*) then there is the basis for code transmission. Fig. 1:6 (*c*) shows the letter G. It must be stressed however that damped waves can also be used for code transmissions. Spark transmitters of the type to be described produce damped waves, Fig. 1:6 (*d*).

The source of voltage used to charge up the capacitor is extremely high. When the voltage reaches a certain value it ceases to charge the capacitor because it finds that it can break down the air between the ends of the spark gap points. As soon as this occurs the LC circuit is shorted out and the fall in current through the circuit produces a damped wave. A continuous wave is not produced because of the inherent resistance in the circuit. In this circuit it is not possible to maintain a continuous oscillation. Consider the LC parallel circuit by itself. Suppose that C is charged up. The effect of placing L across the two terminals of C must be to discharge C. The electrons flow round the circuit through L to the other plate and then because L is still connected they flow all the way back. The capacitor is continuously

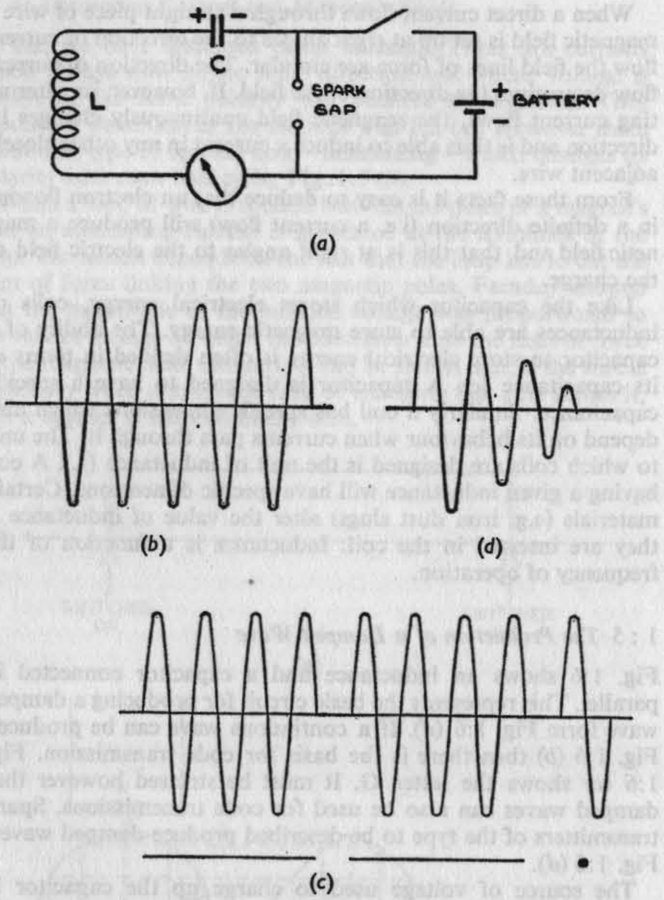


FIG. 1:6

charged in one direction, discharged and then charged in the opposite direction. But each time the current gets smaller. Similarly the radiated magnetic field about the coil also gets smaller so that a damped radiation results. All 'charges' after the first charge are smaller, their actual magnitude depending on the resistance of the circuit.

Continuous waves can be obtained by using a valve in conjunction with the LC circuit. The valve recharges the capacitor to the same peak value each time it has discharged. Valve oscillators

are used in the mixer stage of the radiometer and the beat frequency oscillator of communications receivers.

1 : 6 *The Characteristics of LC Circuits*

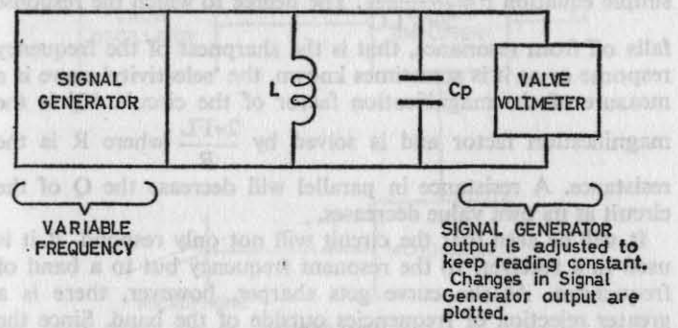


FIG. 1:7

If an LC circuit is connected with a signal generator across its input and a valve voltmeter is connected across the output as in Fig. 1:7 several characteristics of the circuit can be displayed. These are illustrated in Fig. 1:8. Firstly, any LC circuit will give

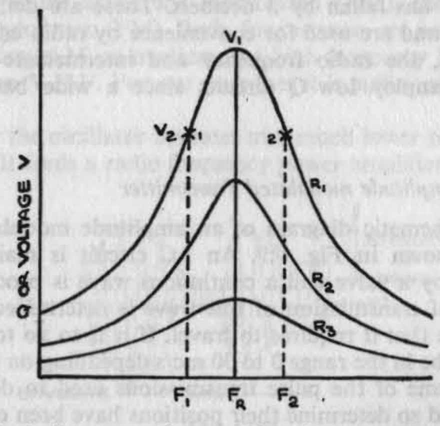


FIG. 1:8. The half power points or 3db points are shown at 1 and 2. These response curves are for a tuned LC circuit. Decibels are a logarithmic ratio of power. In certain circumstances they can also express voltage or current ratios.

$$\text{Power Ratio} = 10 \text{ Log}_{10} \frac{P2}{P1}$$

$$\text{Voltage Ratio} = 20 \text{ Log}_{10} \frac{V_1}{V_2}$$

maximum response to one frequency, the resonant, only. The response will fall off symmetrically on either side of this frequency. This frequency can be determined from a very simple equation $F=\frac{1}{2\pi\sqrt{LC}}$. The degree to which the response falls off from resonance, that is the sharpness of the frequency response or as it is sometimes known, the 'selectivity' curve is a measure of the magnification factor of the circuit. 'Q' is the magnification factor and is solved by $\frac{2\pi FL}{R}$ where R is the resistance. A resistance in parallel will decrease the Q of the circuit as its own value decreases.

It will be seen that the circuit will not only respond, if it is used in a receiver, to the resonant frequency but to a band of frequencies. As the curve gets sharper, however, there is a greater rejection of frequencies outside of the band. Since the sharpness of the curve is determined by Q and Q is in turn determined by the circuit resistance E, the lower the Q the wider the bandwidth. A simple relationship can be established, namely $Q=F/\triangle F$ where $\triangle F$ is the bandwidth. The bandwidth is defined for all tuned circuits as that contained within the curve when the voltage has fallen by 3 decibels. These are defined in the illustration and are used for convenience by radio engineers. In radiometers, the radio frequency and intermediate frequency amplifiers employ low Q circuits since a wide bandwidth is required.

1 : 7 *An Amplitude modulated Transmitter*

A block schematic diagram of an amplitude modulated transmitter is shown in Fig. 1:9. An LC circuit is maintained in oscillation by a valve and a continuous wave is produced. The frequency of transmission of this wave is determined solely by the distance that it requires to travel. If it is to go to Australia then it will be in the range 3 to 30 mc/s depending on the time of the day. Some of the pulse transmissions used to detect earth satellites and so determine their positions have been on 36 mc/s.

In order to utilize the continuous wave it has to be keyed for morse code transmissions. The continuous transmission of constant amplitude is called the carrier.

It is possible to superimpose speech upon this carrier which can be detected by a radio receiver.

Consider a single frequency in the audio range (say 1,000 c.p.s.). If this frequency is allowed to modulate the carrier depending on the method of modulation either (*a*) the amplitude

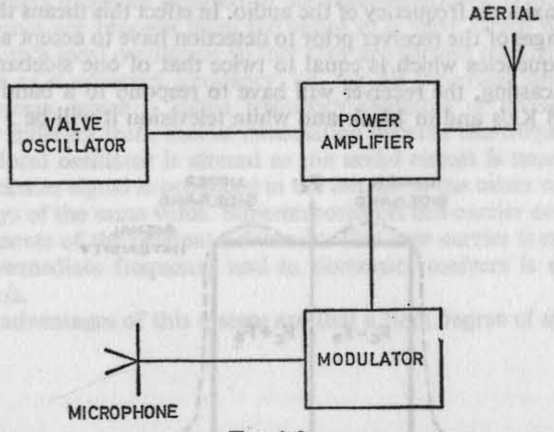


FIG. 1:9

of the carrier (which you will remember is constant) is altered at a rate which corresponds to the audio or (*b*) the amplitude remains constant but the carrier frequency deviates from its true value at a rate which corresponds to that of the audio. The former is called amplitude modulation (AM), the latter, frequency modulation (FM). Both, for instance, are used in British broadcasting, AM on medium and high frequency broadcasting and FM on V.H.F. For our purposes it is sufficient to consider AM.

Usually the oscillator operates at a much lower power than is required. It feeds a radio frequency power amplifier. A separate

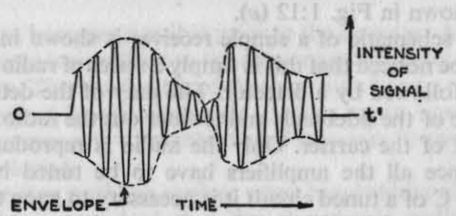


FIG. 1:10

modulator valve is used to superimpose the signal on the carrier. Fig. 1:10 illustrates the resulting wave form. The amplitude of the carrier is continuously varied by the speech.

One result of amplitude modulation is that 'sidebands' are created. In this sense it is a wasteful form of transmission for each sideband contains the same components of the audio frequency, Fig. 1:11. The width of the sideband is determined by the maximum frequency of the audio. In effect this means that all the stages of the receiver prior to detection have to accept a band of frequencies which is equal to twice that of one sideband. In broadcasting, the receiver will have to respond to a band of at least 8 Kc/s and in black and white television it will be 3 mc/s.

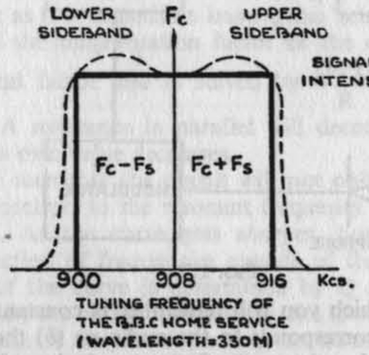


FIG. 1:11

Frequency modulation contains an infinite number of sidebands. However the intelligence can be contained within a band of about 240 Kc/s for broadcasting.

1 : 8 *A Receiver for the Reception of Amplitude Modulated Waves*

The basic schematic diagram of a broadcast receiver for medium waves is shown in Fig. 1:12 (*a*).

A block schematic of a simple receiver is shown in Fig. 1:12 (*b*). It will be noticed that this is simply a series of radio frequency amplifiers followed by a detector. The duty of the detector is to remove one of the sidebands and to filter out the radio frequency component of the carrier. Only the audio is reproduced in the output. Since all the amplifiers have to be tuned by varying either L or C of a tuned circuit it is necessary to gang the chosen component together. When this is done it is found that additional capacitances have to be added to the tuned circuits in order to make each amplifier respond to the frequency to which the first circuit is tuned. This process of 'alignment' is difficult with straight receivers. Another difficulty arises from the radio frequency amplifiers which become unstable when connected in 'cascade', as the frequency is increased. It is unfortunate that a high degree of amplification is necessary in the radio frequency stages.

Designers therefore resorted to the superheterodyne principle. The signals are brought from the aerial to a valve which mixes them with a local oscillation so that they are carried through the receiver at a constant frequency, i.e. for all incoming signals. The process, which is called frequency changing or mixing is slightly different from that of modulation because the frequency of the local oscillator is altered as the aerial circuit is tuned so that a carrier signal is produced in the output of the mixer which is always of the same value. Superimposed on this carrier are the components of the original sidebands. This new carrier is called the intermediate frequency and in domestic receivers is often 470 Kc/s.

The advantages of this system are that a high degree of stable

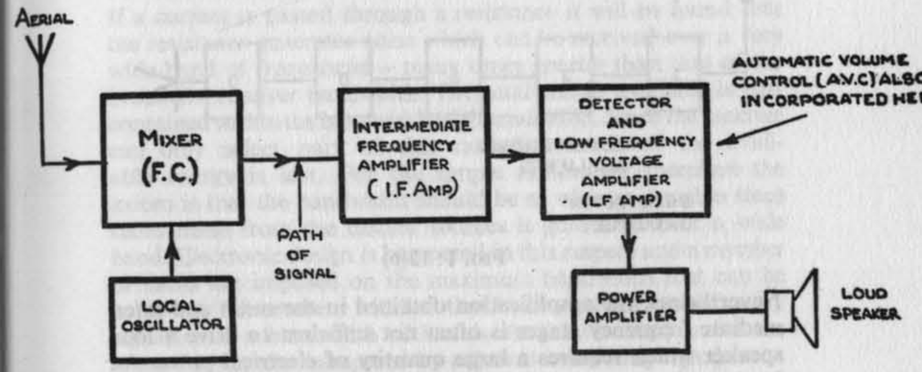


FIG. 1:12 (*a*)

amplification becomes possible prior to the detector. At the same time alignment is simplified to the adjustment of preset capacitors or inductors. The bandwidth of these circuits has to correspond to that required by the sidebands. It does mean however, that standard components – 'Intermediate Frequency Transformers' – can be developed.

An interesting problem evolves when bandwidths of the order of 10 mc/s are required, e.g. for the simple radiotelescope. Clearly the intermediate frequency can no longer be 470 Kc/s or for that matter anywhere in the low frequency part of the spectrum. It is therefore necessary to develop wideband amplifiers which operate in the region of 30 mc/s.

Out of the many facets of design two features immediately characterize the wide band intermediate frequency amplifier. The first is that the bandwidth of the tuned circuit imposes conditions on the valve which reduce the available amplification considerably. Secondly, if it is necessary to obtain the same gain (or more) as that of a domestic receiver it will be necessary to include more stages of amplification. Six amplifying valves at the intermediate frequency is not an uncommon number in this type of work. Suitable I.F. amplifiers are to be found in pulsed radar equipment which generate (and receive) signals of wide bandwidth.

Detection takes place as in the 'straight' receiver. The radio frequency components are removed and the audio components obtained in the output. Diode detectors which are usually used respond to variations between about 500 millivolts and 20 volts.

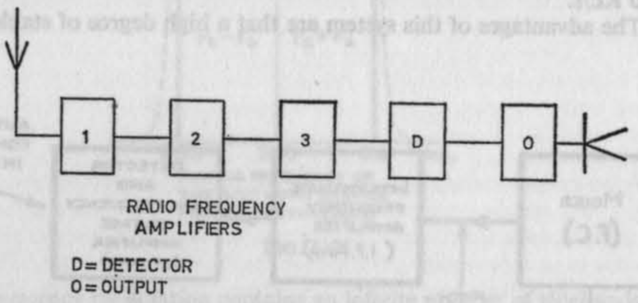


FIG. 1: 12(*b*)

Nevertheless, the amplification obtained in the radio and intermediate frequency stages is often not sufficient to drive a loud speaker which requires a large quantity of electrical power for its operation.

Most receivers therefore incorporate two further stages. The first is a voltage amplifier but operating in the audio range. Its object is to produce sufficient voltage to drive a power amplifier. Power in electricity is the instantaneous product of voltage and current and the power amplifier is operated to maximize these in respect of the audio components of current and voltage.

Although it is often useful, particularly at the lower frequencies, to incorporate a loudspeaker for monitoring it is also necessary in the radiotelescope to incorporate a D.C. amplifier. This responds to the variations in the audio in such a way as to produce changes in the current output. In this way a recording D.C. milliameter can be included and the observations recorded on a chart.

The finer peculiarities of simple radiometer design will be dealt with in chapter four.

It is possible under certain conditions to use specialized communications receivers in the low frequency part of the spectrum.

This type of receiver is designed for reception of long distance signals on H.F. or weak signal reception on V.H.F. The signal strength at the aerial is often too small to operate the mixer satisfactorily and it is necessary to include two or three stages of tuned radio frequency amplification. These receivers are also able to respond to continuous wave morse transmissions having a beat frequency oscillator (B.F.O.) incorporated for this purpose. On the surplus market it is possible to obtain the Marconi CR100 receiver and various Hallicrafter receivers which incorporate these devices. For measurements of Jupiter at 18 mc/s, a Hammerlung Communications receiver has been used.

1 : 9 *The Radio Receiver and the Reception of Noise*

If a current is passed through a resistance it will be found that the resistance generates noise which can be received over a very wide band of frequencies – many times greater than that of the broadcast receiver bandwidth. The total energy available is that contained within the bandwidth of the radiation. Since the receiver can only select part of this radiation much of the available energy is lost. For the simple radiometer therefore the axiom is that the bandwidth should be as wide as possible since radio noise from the distant sources is generated over a wide band. Electronic design is hampered in this respect and a number of limits are imposed on the maximum bandwidth that can be achieved. The amateur will find that he can get quite satisfactory signals with a bandwidth of 3 mc/s. At the low frequencies the bandwidth is also hampered by adjacent interfering signals.

Fortunately for observations of the Sun and Jupiter Communications receivers can be used: observations of the Sun can be made up to 200 mc/s with the aid of converters feeding into Communications receivers tuned to the output frequency of the converter.

CHAPTER TWO

Other aspects of electro-magnetic radiation

2 : 1 *The Colours of the Spectrum*

EVERYONE is familiar with the colours of the rainbow. A careful look at numerous rainbows show that the colours are always arranged in the same order. Of the seven, violet comes first and red last.

It is possible to obtain a rainbow artificially by passing white light through a prism. This simple experiment tells us that the colours are the constituents of the white light. In the same way that a cricket ball requires energy to be propelled, so light requires energy to reach us from a distant source. When the light emanating from the sun is studied, complicated mechanisms containing prisms enable the light to be broken up into the so-called spectral lines. Different colours are seen: they are seen in the same order as the colours of the rainbow. When hydrogen is ignited in the laboratory only some of the colours of the rainbow are visible, and of these, some may appear stronger than others. Those that are present follow the order of the colours in the rainbow.

The same thing applies to any other substance which can be ignited. As it burns, not only does it radiate heat but it radiates light as well. It radiates energy (if you prefer, 'releases energy').

When water is boiled not only is steam given off but heat is radiated. Hot water in a radiator radiates heat into the room. If a kettle is boiled, steam indicates that the water is boiling. However, turn off the gas and after ten minutes or so have elapsed the steam will have gone and the water will have cooled. Energy has been released and dissipated. If the water levels were measured before and after cooling it would be found that the last position would be lower than the original since some of the heat will have caused some of the water to evaporate. Otherwise the water also cools as the heat is radiated away.

Since the sun is a hot mass of turbulent energy, much energy is radiated away. It is received at the earth either in the form of 'wave radiation' (e.g light) or in the form of 'particle radiation' (e.g. cosmic ray particles). More of this 'double nature' later. A

knowledge of the colours emitted by burning materials tells us about the constituents of the sun. Spectroscopists draw up catalogues which show the lines due to the various substances when they are burning and thus radiating light. It is possible from a determination of these lines to determine the energy of the atomic particles which cause them, their temperature and their velocity. Bright lines are due to emission and dark lines to absorption of radiation.

Any substance, therefore, when heated radiates both heat and light. This is a common occurrence which we accept without examining it in detail. Most of us are used to the idea that light is a wave motion – or at least that is the concept which has been accepted for many years.

2 : 2 *The Behaviour of Light – The Light Wave*

Physicists can show that under some circumstances light behaves as if it were a number of particles, whilst in others as if it were a wave motion.

In fact this 'duality' in nature where light is observed to behave in some circumstances as if it were a wave and in others as if it were a particle is further complicated by the fact that physicists are only able to explain certain phenomena by assuming the light to be a wave (e.g. shadows) and other phenomena by assuming that it is made up of a number of particles (e.g. the photo-electric effect).

2 : 3 *The Photo-Electric Effect*

Whilst the particle nature of light is not of great concern in this context it is perhaps worth describing. For the moment it is necessary to say that when certain light rays strike certain metals electrons are emitted. This is the photo-electric effect. Since it is possible to measure both the number of electrons emitted and their average velocity it is also possible to compute their energy. Similarly it must also be possible, from this data, to compute the energy required to dislodge the electron from the metal. This then gives the value of the energy of the light wave.

According to the wave theory of light one would expect an increase in the intensity of the incident light wave to produce an increase in the velocity of the emitted electrons. It is possible to make precise measurements of these effects and their results are rather startling.

Lennard, in 1902, after a series of measurements concluded that the velocity of electrons did not increase in the predicted way. Their velocity was found to be independent of the intensity of the incident radiation. Thus the wave theory of light cannot be used to explain photo-electric emission.

The accepted explanation of this phenomenon came from Einstein in 1905. It began the quantum theory of light which will be referred to again in this chapter.

2 : 4 *The Wave Nature of Light*

The first illustration shows various waveforms in different aspects. Figure 2:1 (*a*) is intended solely for purposes of definition. The shape of the wave (sine wave) is undoubtedly familiar. The distance I is the amplitude; it is related to the intensity. An increase in intensity corresponds to an increase in I the amplitude.

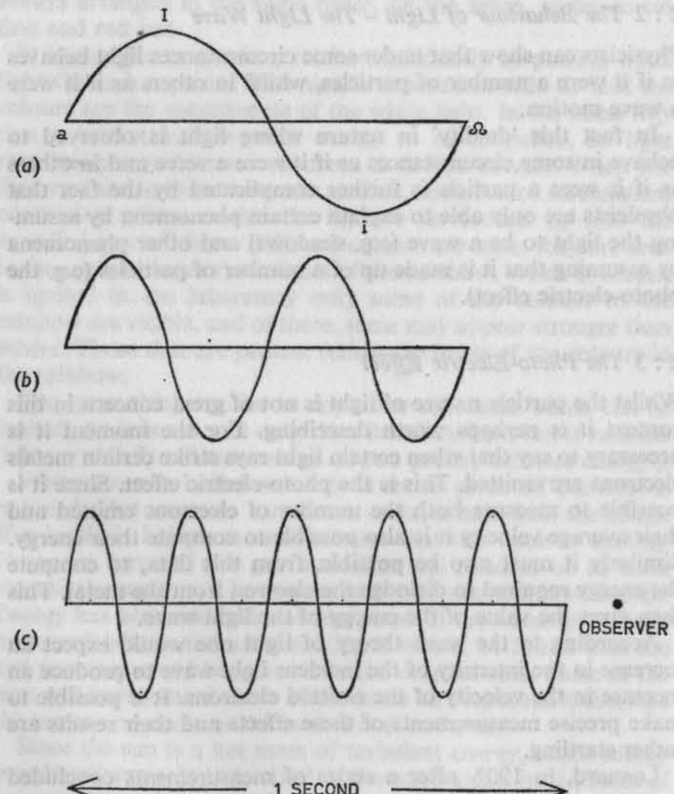


FIG. 2:1

The distance between the beginning and the end of the wave, alpha and omega, along the straight line, is the 'wavelength'. By convention it is measured in metres. Suppose that Fig. 2:1 (*a*) represents a wavelength of 1 metre then Fig. 2:1 (*b*) to the same scale represents a wave of wavelength $\frac{1}{2}$ a metre.

In Fig. 2:1 (*a*) if the wave shape is traced out, i.e. an observer moves along the path α, I, i, Ω, he traces out a 'cycle'. It will be noticed that the $\frac{1}{2}$ metre wave in Fig. 2:1 (*b*) consists of two cycles to every wavelength of the single cycle in Fig. 2:1 (*a*).

A precise relationship between the cycles and the wavelength exists if the number of cycles past a given point per second is measured (Fig. 2:1 (*c*)). In this illustration 5 cycles go past the observer in one second (i.e. 5 c.p.s.). The number of cycles per second is the 'frequency'.

Frequency and wavelength are related. $c = F \times \lambda$ where λ is the velocity of light, F is the frequency and λ is the wavelength. Thus $F = c/\lambda$ or $\lambda = c/F$. In Fig. 2:2 some of the wavelengths used by radio astronomers have been converted into frequency units.

Since the design of radio apparatus has to alter as the frequency of operation changes it is appropriate to draw up a table of frequency bands which correspond to ranges over which the design characteristics are constant. This is given in Fig. 2:2 and these are standard definitions. They are not in fact obtained from design criteria, although they happen to fit such criteria: they are derived from the particular behaviour of radio waves (in these wavelength ranges) as they are propagated through space.

2 : 5 *Radio Waves and Light Waves*

The equations described in the preceding paragraph have indicated that there is a relationship between the velocity of light and the wavelength. This is because radio waves are propagated at the velocity of light. Radio waves and light waves are similar phenomena; they are electro-magnetic waves differing only in respect of their wavelength or frequency. The range of frequencies of electro-magnetic radiation is known as the 'electro-magnetic spectrum'. An illustration of the spectrum is given in Fig. 2:3. It will be noticed that gamma rays (high energy X-rays) occur at the high frequency end of the spectrum, whilst radio waves are in the low frequency region; light waves are sandwiched between the ultra-violet and the infra-red. Heat or thermal radiation is electro-magnetic in characteristic.

Electro-magnetic waves are characterized by two fields, an electric (E) and a magnetic (H) in which their energy is stored. The direction of action of the forces of the two fields are at right

Frequency (megacycles)	18	27	38	60	81·5	100	178	250	408	1420–4	10,000
Wavelength (metres)	16·6	11·1	7·5	5	3·8	3	1·6	1·2	0·73	21·1 cms.	3 cms.
Amateur observations made in U.K.	*	*	*	*			*	*			*
Amateur apparatus	Communications receivers		Radar RX's except mixer	Com-munica-tions receivers				Drift and phase switching interfero-meter			Dicke receiver
Observations made by amateurs	Crab nebula and its occultation by the solar corona										Thermal radiation from Sun
	Solar noise, storms, etc.							The Sun			
	Jupiter							Cygnus			
								Cas-siopeia			
	General Galactic background →						↔				
Other relevant information									Para-metric ampli-fiers now being used	↔ spectral line	Masers in use

FIG. 2:2. A wavelength frequency conversion table with some information about the amateur activities in this country from a paper by the writer in the *B.A.A. Memoir*.

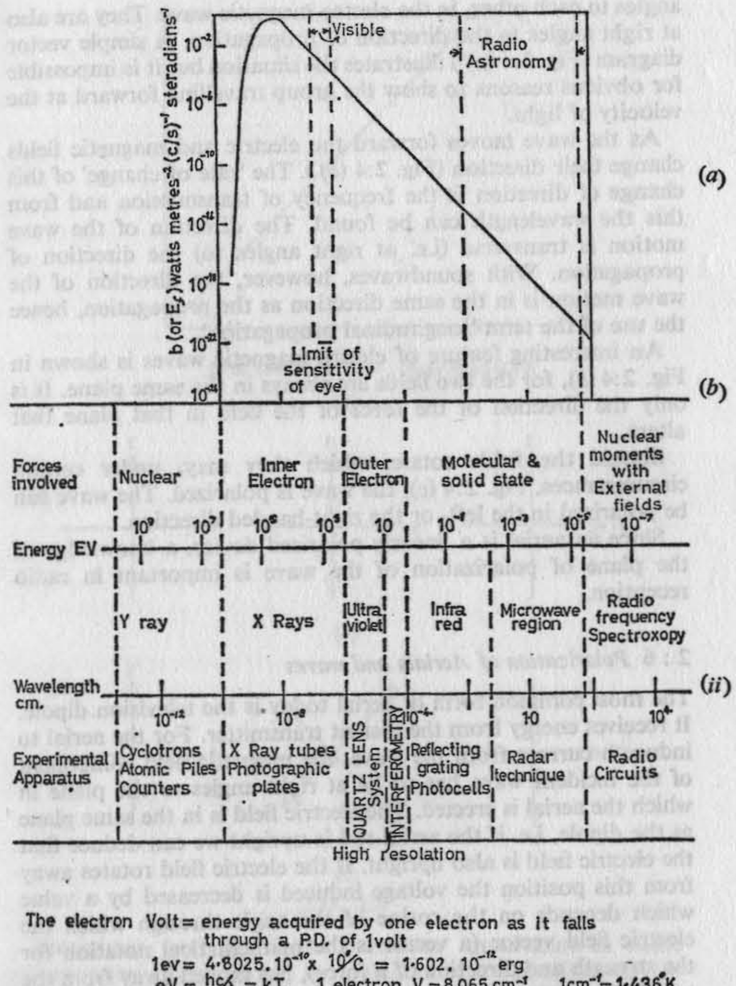


FIG. 2:3 (*a*). The variation of brightness b of a block body with wave-length (Planck's Law) for a range of temperatures from 1 to 10^6 degrees Kelvin. The range in which the Rayleigh-Jeans approximation is better than 1 per cent lies to the right of the dashed line. (*b*) From an idea by D. J. E. Ingram, *Spectroscopy at Radio and Microwave Frequencies*. Butterworth 1955. Shows the Quantum forces involved in producing radiation at a given wavelength (ii) together with the type of apparatus used to observe the behaviour at that wavelength.

angles to each other, in the electro-magnetic wave. They are also at right angles to the direction of propagation. A simple vector diagram (Fig. 2:4 (*a*)) illustrates the situation but it is impossible for obvious reasons to show the group travelling forward at the velocity of light.

As the wave moves forward the electric and magnetic fields change their direction (Fig. 2:4 (*b*)). The 'rate of change' of this change of direction is the frequency of transmission and from this the wavelength can be found. The direction of the wave motion is transverse (i.e. at right angles to) the direction of propagation. With soundwaves, however, the direction of the wave motion is in the same direction as the propagation, hence the use of the term 'longitudinal propagation'.

An interesting feature of electro-magnetic waves is shown in Fig. 2:4 (*b*), for the two fields are always in the same plane. It is only the direction of the force of the field in that plane that alters.

Should the fields rotate, which they may, under certain circumstances, Fig. 2:4 (*c*), the wave is polarized. The wave can be polarized in the left- or the right-handed direction.

Since an aerial is a linearly polarized device, a knowledge of the plane of polarization of the wave is important in radio reception.

2 : 6 *Polarization of Aerials and waves*

The most common form of aerial today is the television dipole. It receives energy from the distant transmitter. For the aerial to induce a current from the wave, the magnetic field component of the incident wave has to be at right angles to the plane in which the aerial is erected. The electric field is in the same plane as the dipole, i.e. if the aerial rod is upright we can deduce that the electric field is also upright. If the electric field rotates away from this position the voltage induced is decreased by a value which depends on the cosine of the angle through which the electric field vector (a vector is the mathematical notation for the strength and direction of a force), has moved away from the aerial. (A vector is represented by a straight line with arrow rotating through an angle.)

In the London area the Crystal Palace transmitter radiates a vertically polarized wave. Since the polarization is defined by the position of the electric field, reception aerials for this signal must be erected in the vertical plane. Similarly in the same area Wrotham transmits a horizontally polarized signal for V.H.F. broadcasting. The corresponding reception aerial is erected in the horizontal plane.

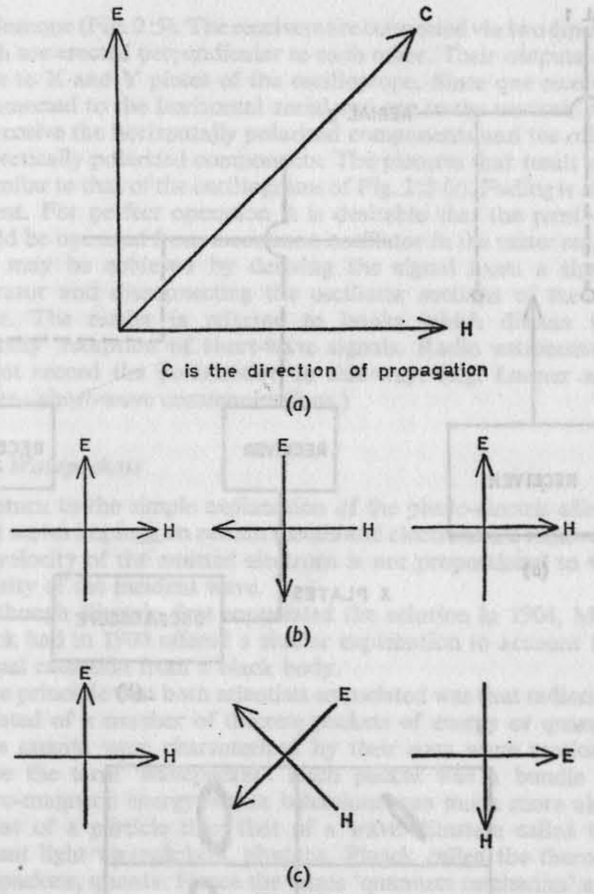


FIG. 2:4

Sometimes, and this is of particular importance in radio astronomical observations, the polarized wave is elliptically or circularly polarized. It continues to rotate, the path that it cuts being in the shape of an ellipse or a circle.

Radio astronomers sometimes require to measure changes in polarization. The instrument used is the polarimeter and the schematic diagram of Fig. 2:5 (a) illustrates its most simple form. It consists of a receiver which is rapidly switched between two aerials. The reader who would like to observe changes in polarization of radio waves is recommended to connect up two communications receivers operating on the H.F. band to an

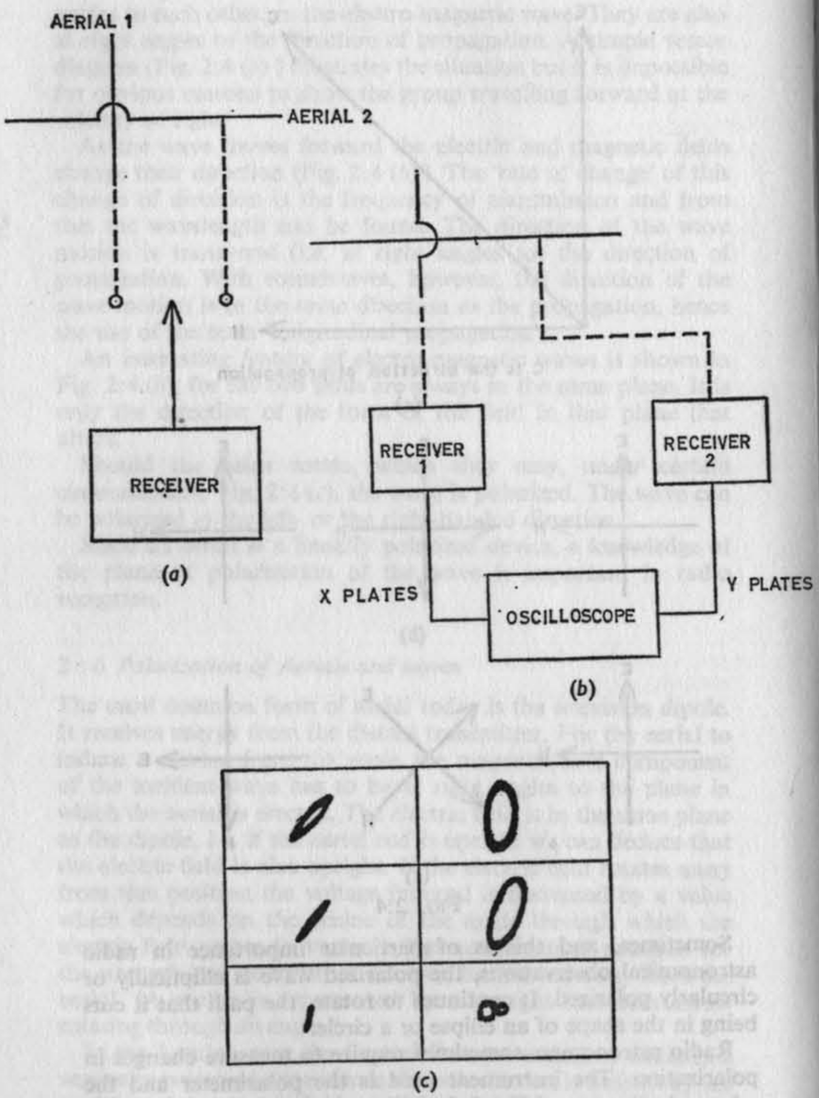


FIG. 2:5. The oscillograms in 2:5(*c*) show the output as recorded on an oscilloscope. These particular drawings are made from photographs taken once every 5 seconds. They were made on an H.F. Communications signal from Australia. Frequency diversity receivers usually employ a common oscillator in the mixer stage. This is not shown.

oscilloscope (Fig. 2:5). The receivers are connected via two dipoles which are erected perpendicular to each other. Their outputs are taken to X and Y plates of the oscilloscope. Since one receiver is connected to the horizontal aerial and one to the vertical, one will receive the horizontally polarized components and the other the vertically polarized components. The pictures that result will be similar to that of the oscillograms of Fig. 2:5 (*c*). Fading is also present. For perfect operation it is desirable that the receivers should be operated from a common oscillator in the mixer stage. This may be achieved by deriving the signal from a signal generator and disconnecting the oscillator sections of the receiver. The reader is referred to books which discuss the 'diversity' reception of short-wave signals. Radio astronomers do not record the polarization in this way. (e.g. Ladner and Stoner—short-wave communications.)

2 : 7 *Wavepackets*

To return to the simple explanation of the photo-electric effect. Light waves impinge on certain metals and electrons are removed. The velocity of the emitted electrons is not proportional to the intensity of the incident wave.

Although Einstein first enunciated the solution in 1904, Max Planck had in 1900 offered a similar explanation to account for thermal radiation from a black body.

The principle that both scientists enunciated was that radiation consisted of a number of discrete packets of energy or quanta. These quanta were characterized by their own wave motions. Hence the term 'wavepacket'. Each packet was a bundle of electro-magnetic energy whose behaviour was much more akin to that of a particle than that of a wave. Einstein called the incident light wavepackets, photons. Planck called the thermal wavepackets, quanta. Hence the terms 'quantum mechanics' and the more generalized subject (arising from later development), 'wave mechanics'.

The solution to the photo-emission problem is now much easier. A billiard ball will move a second billiard ball over a given distance if it strikes the second ball at a given velocity. The mass and velocity of the first ball acquires energy which it imparts to the second. The slower its velocity, the less the available energy to move the second ball. Thus it is that light photons have to acquire a certain quantity of energy before they can release an electron. The reader should have no difficulty in extending his thoughts to the idea that the eye responds to photons and not to light waves!

The energy of the photon is proportional to its frequency: the equation $e = h\nu$ where e is the energy, h is a constant universal in application and generally known as Planck's constant and ν is the frequency, is as important to the explanation of this branch of science as $e = mc^2$ is to relativity! It will be seen from the equation that the shorter light waves possess the larger quanta which is why the photo-electric effect only occurs when the incident light is in the high frequency part of the spectrum.

Before concluding this paragraph it is worth noting the precise formulation in which Planck put forward his theory. He suggested that the atoms of the radiating system held within themselves – oscillators. These oscillators not only radiated energy but absorbed energy. This energy was not, as we have seen, radiated in a continuous wave train, but in very tiny packets which he called quanta. Einstein simply said that the *atoms* radiate light in the same way. The word atoms has been put in italics in the last sentence to emphasize the dependence of electro-magnetic waves on the 'particle' structure of matter. This may, as will be seen later, be due either to elementary atomic or molecular processes. One other important feature of the quantum theory is that the radiation takes place at discrete frequencies and not continuously throughout the spectrum.

2 : 8 *Atoms and the Electro-magnetic Spectrum*

Having emphasized the atomic nature of the emission of quanta it is necessary to examine the structure of atoms more closely. The earliest satisfactory description of atomic structure was due to Rutherford (see Chapter 1).

Planetary electrons should radiate energy continuously as they accelerate and spiral towards the nucleus. This suggests that atoms should be unstable – but, is this the case when they are seen to be in continual collision with their neighbours in a gas? Equilibrium in Rutherford's atom would only be reached when the electron had completed its spiral and become embedded in the nucleus.

If energy is continuously radiated from a source it is characterized by a continuous spectrum. Observations of the hydrogen atom (initially) showed that the spectrum was not continuous but broken up into discrete lines.

Niels Bohr accounted for these spectral observations of the hydrogen atom.

Instead of the electron being allowed to take up any one of an infinite number of orbit tracks (that it could take) as it spirals towards the nucleus, his electron was restricted to a number of orbits which were very stable. These stable orbits are sometimes called stationary states. Each stationary state possesses a definite

amount of energy. This energy is not radiated so the term energy level is also used.

A simplified version of this atom is shown in Fig. 2:6. Two energy levels (or stationary states) E_1 and E_2 are shown. Bohr supposed that if an electron in one stationary state jumped to another that it must either gain or lose energy and that this gain or loss of energy would be in quantum multiples. If the electron is held in an orbit because of the gravitational attraction existing between the negative electron and positive nucleus then a change in the position of the orbit relative to the nucleus will alter the value of the gravitational force required to hold the electron in its new position.

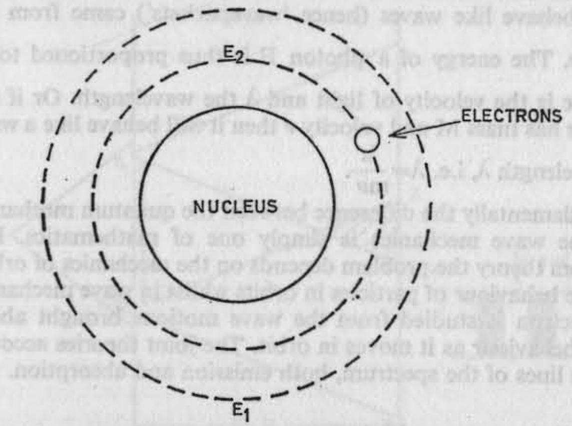


FIG. 2:6. Simple model of the Bohr atom with two energy levels E_1 and E_2. The electron is shown rotating on the inner level.

For instance if the electron takes up an orbit nearer to the nucleus its path will be shorter and it will require less energy to complete one track. If it goes farther away from the nucleus it requires more energy. Bohr supposed that the electron in jumping from one energy level to another would have to gain or lose energy depending on the direction of the jump. It would absorb energy when it jumped farther away from nucleus and radiate energy when it jumped nearer to the central core.

Bohr's basic assumption is expressed in a simple formula, i.e. $h\nu = E_2 - E_1$. From this Bohr was able to show that his theory agreed with the Balmer equation which gave the wavelength values of a series of spectral lines for hydrogen. The visible lines were thus found to be due to the emission of energy from an electron jumping between stable states. In the case of the Balmer series the lines are due to the electrons jumping from the outermost orbits to the second orbit. Different atoms have different energy levels and therefore different 'jump possibilities'. It is these levels which give rise to the spectra of different atoms. Their width and spacing from each other together with their number and wavelength all exist in the identification of atoms and catalogues can be made. The spectra of distant stars can be compared with those in the catalogue to ascertain the constituents of the atmospheres of distant stars.

The hypothesis put forward by Bohr was by no means satisfactory and was resolved by a number of scientists the chief of whom were Heisenberg, De Broglie and Schrodinger. The actual idea was that electrons and all other particles for that matter could behave like waves (hence 'wavepackets') came from De Broglie. The energy of a photon E is thus proportioned to $\frac{hc}{\lambda}$ where c is the velocity of light and λ the wavelength. Or if the particle has mass M and velocity ν then it will behave like a wave of wavelength λ, i.e. $\lambda = \frac{h}{m\nu}$.

Fundamentally the difference between the quantum mechanics and the wave mechanics is simply one of mathematics. For quantum theory the problem depends on the mechanics of orbits and the behaviour of particles in orbits whilst in wave mechanics the electron is studied from the wave motions brought about by its behaviour as it moves in orbit. The joint theories account for the lines of the spectrum, both emission and absorption.

2 : 9 *Wave motion and Interferometry*

Other phenomena can only be explained by wave theories. Interference patterns produced by light rays can only be explained by wave theory. The principle of Young's interferometer is shown in Fig. 2:7. A beam of light is played on to a board in which there are two pin holes. The light diffuses through the pin holes so that two secondary rays are formed which travel towards and fall on a screen. It is the area over which the two secondary beams converge that is of interest for instead of there being light or shadow in this region a pattern of alternate light and dark bands is seen. These bands are called 'fringes'.

A wave theory will account for this effect, since in the region where the rays overlap the components can be considered to be alternately in and out of phase with each other. Fig. 2:8 (*a*) shows two waves which are in-phase and their resultant whilst Fig. 2:8 (*b*) illustrates the resultant of two waves which are in opposite phase, i.e. out of phase by 180° or ½ a wavelength. The

intensity of light is proportional to the amplitude of the wave. When they are out of phase the amplitude is zero and a dark fringe will occur.

If there are changes of phase between the two beams the fringes will start to move. Their movement will be so fast that the fringes will no longer be seen. When the fringes are stationary their positions can be calculated if the dimensions d and D are known.

$$d = \frac{D\lambda}{d}$$

The separation between the fringes can be changed by altering the distance between the pin holes. Interferometers in optical

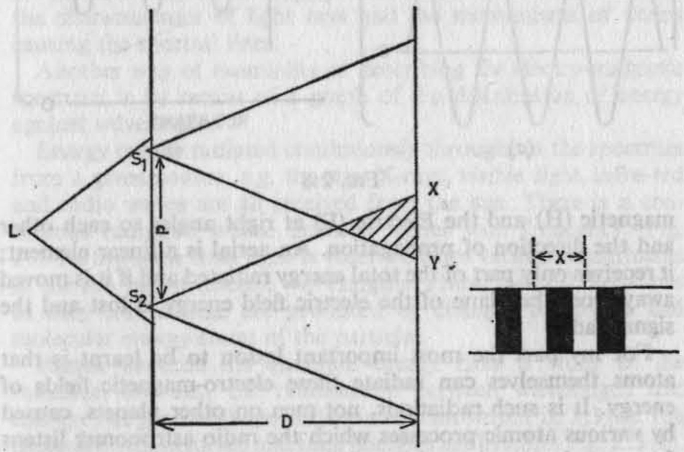


FIG. 2:7

astronomy are used to increase the resolving power of telescopes There is also a radio interferometer and in its simplest form it has two spaced aerials which operate in a way that is analagous to the two pin holes of the optical interferometer. The radio interferometer has the same advantages as its optical counterpart – it increases the resolving power and this is of tremendous importance in radio astronomy since it means that a greater resolution can be obtained without necessarily increasing the size of the aerials.

2 : 10 *Summary*

Radio waves and light waves are electro-magnetic waves. They are propagated at the velocity of light and have two fields, the

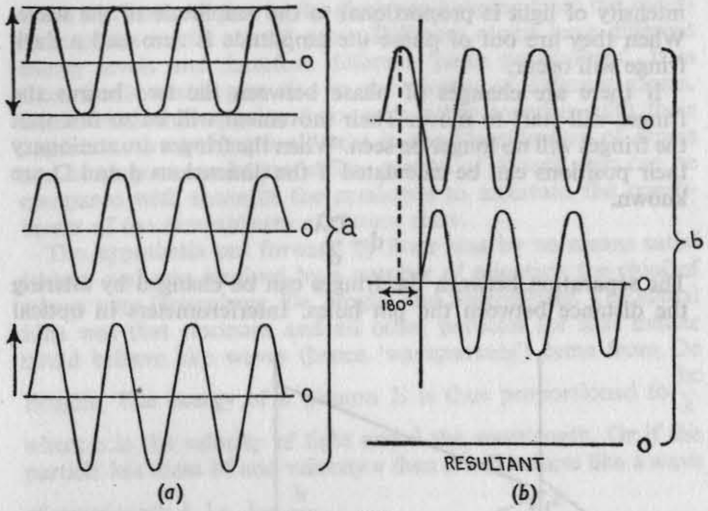


FIG. 2:8

magnetic (H) and the Electric (E) at right angles to each other and the direction of propagation. An aerial is a linear element; it receives only part of the total energy radiated and if it is moved away from the plane of the electric field energy is lost and the signal fades.

For my part the most important lesson to be learnt is that atoms themselves can radiate these electro-magnetic fields of energy. It is such radiations, not men on other planets, caused by various atomic processes which the radio astronomer listens for, records, theorizes about, deducts and concludes!

CHAPTER THREE

Radio noise and its extra-terrestrial causes

3 : 1

IN the last chapter an attempt was made to describe some of the characteristics of light rays and the mechanisms of atoms causing the spectral lines.

Another way of examining or describing the electro-magnetic spectrum is by means of a graph of the distribution of energy against wavelength.

Energy can be radiated continuously throughout the spectrum from a given source, e.g. the sun. X-rays, visible light, infra-red and radio waves are all received from the sun. There is a continuous radiation whose intensity varies with frequency. Fig. 2:3. At the same time light is received from various constituents of the sun but at discrete wavelengths. These spectral radiations as they are termed, are produced by changes in atomic and molecular energy states of the particles.

Planck deduced his quantum theory from a study of the radiation law i.e., the relationship between wavelength and energy. The general shape of the curve is shown in Fig. 2:3 (a). The spectral forces involved and their energies are listed in Fig. 2:3 (b). Also given are the types of experimental apparatus required to determine these lines at the various wavelengths.

Physicists relate all their measurements to a theoretical absolute – 'the black body'. This is a surface which is both (1) a perfect radiator and (2) a perfect absorber. Nightingale in his text book of *Physics* suggests – 'it will help in the appreciation of this if we consider an open window in an illuminated room at night. Viewed from inside the open window looks black, viewed from outside it looks bright, i.e. when absorbing light it looks black, when radiating it looks bright' (published by Bell, London).

Planck's radiation law relates the energy to the temperature of the source and the wavelength. Having determined the spectrum of a black body radiator it is possible to determine the absolute temperature of other sources such as the sun. The photosphere of the latter is 6,000° Kelvin.

A glance at Fig. 2:3 shows that for any black body radiator the available energy in the radio part of the spectrum is small compared with that available in the visible part. One general rule (for which this fact is by no means the only reason) is that radio receivers for radio astronomy have to be highly sensitive because of the low levels of signal strength available at the aerial from the distant radio sources.

Studies of the continuous spectra from the sun, the galaxy and the distant sources are an important part of the radio astronomer's task.

All that is required are a number of measurements of the flux density of the source under observation at different wavelengths.

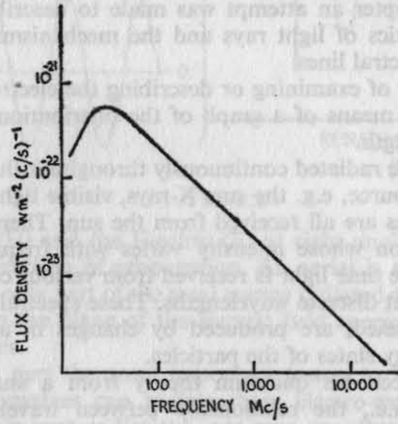


FIG. 3: 1. A typical spectrum of a radio source as derived from large numbers of independent observations.

A graph can then be plotted from which a law relating the frequency to the flux density can be deduced. (Fig. 3:1.) Continuous spectra are observed indicating sources of both thermal and non-thermal origins. Only one discrete spectral line has been observed—the hydrogen.

3 : 2 *Spectral Lines*

In 1945 a Dutch scientist Van de Hulst, suggested that the neutral hydrogen in the interstellar space of the galaxy would emit a line in the radio part of the spectrum. Ewen and Purcell observed this line for the first time in 1951. The first observation was made in America and it was rapidly confirmed by other radio astronomers in Holland and Australia. A glance at Fig. 3:2 shows that the line which is observed at 1,420·403 mc/s or

21·105 cms arises from the orientation of the electron spin caused by a nuclear magnetic moment. Neutral hydrogen possesses one electron only in this state.

Having said that there are many good books on observational radio astronomy let me recommend one by F. G. Smith (Pelican 1960) and at the same time quote his explanation of this phenomenon.

'Spectral lines are emitted by a discrete quantum process, in atoms or molecules. The energy of the emitter can only assume certain levels, and a change from one level to the other, involving a change of energy E, is accompanied by the emission or absorption of energy at a frequency ν, where $E=h\nu$, and h is Planck's constant. For visible lines the change E is of the order of five electron volts, or about 10^{-11} ergs, so that for radio waves where the frequencies are about 10^6 less than light waves, the energy change must be only 10^{-17} ergs. The problem then is to find an atom or molecule which not only has two energy levels only 10^{-17} ergs apart, but which could be expected to exist at these levels when the element was found in the cold spaces between the stars. Van de Hulst was able to show that the unionized hydrogen atom, called by spectroscopists the H I atom, had a pair of energy levels separated by this amount. The "ground state", or lowest energy level, in which a hydrogen atom would normally be found in interstellar space, was in fact split into two levels by a magnetic coupling between the proton nucleus and the single electron. A close analogy is obtained by considering both proton and electron as weak magnets, constrained to lie parallel to one another and magnetized either in the same direction (parallel) or in opposite directions (anti-parallel). The parallel situation has a very small excess of energy over the anti-parallel situation; one can picture the magnets flipping over to the anti-parallel case, using up stored energy in doing so.'

The actual observations made by radio astronomers of the hydrogen line are of clouds of this gas. When the kinetic temperature is measured it is the measurement of the aggregate radiation from many clouds so that the temperature of a cloud will be the average temperature of the aggregate. Both absorption and emission lines are observed.

The records of the hydrogen line are presented in profile form. It will be noticed from the examples given in Fig. 3:2 that the bandwidth and shapes of the profiles change as the radio telescope looks at the Universe. In order to obtain these profiles it is necessary to have a receiver which sweeps out a band of frequencies sufficient to include the widest profile. Such an instrument is called the radio spectrograph. Amateurs of the Radio Society of Great Britain have certainly built apparatus to operate in the centimetric bands but no amateur has, to this writer's knowledge, attempted a radio spectrograph at this frequency.

Observations of the hydrogen line have yielded much outstanding information. The galaxy has been mapped and the position of the sun in relation to the spiral arm of galaxy determined. Attempts have been made to measure the red shift of the distant radio sources but these cannot be said to have been

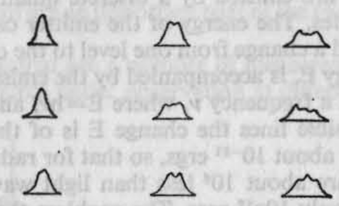


FIG. 3:2. Typical hydrogen line profiles after G. Westerhout, *Paris I.A.U. Symposium*, Cambridge U.P., 1957. Imagine the receiver being swept over a band of frequencies. Each time it goes through the band it records variations in the signal strength at each frequency in the band. One profile is traced. From a number of profiles the motions of the gas can be deduced.

successful. Unfortunately the signals from the distant sources are so weak that considerable improvements in aerial and receiver design will be needed before it is possible to test whether such observations will be successful or not.

Searches for a line due to deuterium have been made in England and Russia without success.

3 : 3 *Thermal Emission*

Heat radiation is a form of electro-magnetic radiation. An easy way to test this proposal arises when there is an eclipse of the sun. As the sun darkens the light fades out and the earth gets cooler.

Clerk Maxwell the great Cambridge physicist of the last century defined radiation as 'energy which travels from one place to another without heating the intervening medium'. Both heat and light are received by radiation from the sun, thus as they are both cut off together it is reasonable to suppose that they travel to the earth at the same speed, i.e. the velocity of light. Not all the radiations from the sun arrive eight minutes afterwards as electro-magnetic radiation. Some particle radiation takes as much as 36 hours.

In the simple form of the theory, heat radiation arises from the self-heat of molecules causing them to vibrate. The vibration

stimulates the medium and the heat is carried away from the medium in a wave motion at the velocity of light.

A maximum of temperature is observed just after the visible spectrum in the infra-red region (Fig. 2:3). This does not mean however, that the molecules only radiate in the infra-red region from their own thermal action. It does mean, however, that they radiate less on either side of the infra-red peak. Since the sun is a hot mass of gaseous matter in perpetual motion yet also in equilibrium there is a considerable amount of thermal radiation in all parts of the spectrum.

Some of the first measurements in radio astronomy were attempts to observe the thermal radiation from the sun. These were performed by Southworth using a radiometer, i.e. an instrument designed for measuring the total power. The best wavelengths to observe the sun's thermal radiations lie in the microwave band. Above that other mechanisms producing noise storms and bursts interfere strongly with the received signals so as to make it difficult to differentiate the thermal component. These will be dealt with in greater detail in the chapter on the sun.

3 : 4 *H II Regions*

In addition to the sun the galaxy is also a thermal radiator. Along the line of the Milky Way there is hot ionized gas. Stars surrounded by hydrogen, heat the hydrogen. Ionization arises from the bombardment of the gas by ultra-violet radiation and being hydrogen it is split up into electrons and protons. It is a gas in which transitions giving rise to electro-magnetic radiation take place quite freely.

Within our galaxy the Orion Nebula and Omega give rise to this type of radio emission.

3 : 5 *The Synchrotron Mechanism*

In the early studies of galactic structure, Hey, Parsons and Philips established that there were peculiar fluctuations in the galactic emissions in the region of Cygnus. This was confirmed by observers both in Sydney and Cambridge. It was a discrete source of emission, probably outside of the galaxy. In 1948 Ryle and Smith also located the intense source in Cassiopeia – a source within the galaxy.

The problem that these discrete sources posed is quite simple for when observations were made at different frequencies and the spectral curve fitted to the results it was shown quite clearly that there was disagreement between the curve computed for a thermal emitter and that actually observed.

Perhaps the most important characteristic of both these sources is the immense intensity of the signal (as observed against density). No thermal mechanism could possibly produce such energy.

Since, under certain conditions it only requires the motion of an electron in a magnetic field to produce radiation in this part of the spectrum the precise activity may well arise from the acceleration of high energy electrons in a magnetic field. These are relativistic electrons. That is to say, they are moving with speeds near to that of light. The magnetic field bends the electron's path as it moves and the amount of energy radiated depends both on this bending and the electron energy. A reciprocal experiment can be made for if the radio spectrum is obtained it is possible to derive the relative numbers of electrons with different energy levels.

As some attempt is being made in these initial chapters to bring home the concepts of electro-magnetic radiation as brought about by the motions of particles I have asked Dr. Smith to allow me to quote yet another paragraph from his book.

'Schwinger (who first described the synchrotron radiation) was interested in the behaviour of electrons inside electrical machines for accelerating nuclear particles to high energies. In one of these machines, a synchrotron, electrons are whirled round a circular track to which they are confined by a very strong magnetic field. At very high energies, the electron beam emits a blue glow of light called synchrotron radiation. Schwinger showed that this radiation was a natural consequence of the acceleration of electrons in a strong magnetic field, and showed that the energy lost in radiation was an important factor in the design of accelerating machines. The acceleration causing the radiation was, of course, there whether or not the electrons were increasing in speed: in fact their speed was so near to that of light that only a very small increase would ever be possible. Any particle constrained to move in a curved path is accelerating, and the acceleration increases in proportion to the curvature imposed upon it.'

The galaxy as well as radiating from a simple thermal process must also contribute radiation due to a non-thermal mechanism because the low frequencies exhibit much greater intensities than would come from ionized hydrogen. At the super-high frequencies, however, the thermal mechanism is the main cause.

There is still much to be understood about the synchrotron process itself and the way in which the electrons obtain these large energies. Even the light generated in these sources may be due to this type of mechanism.

3 : 6 *Nearer Home: Electronic Radio Noise Sources*

Apart from the fact that unsuppressed cars, electric motors of all kinds generate radio noise, valves and resistors also contribute their share.

Use of this principle is made in the construction of the local noise source, the purpose of which is described more fully in the chapter on the radiometer.

There are two main types of simple noise generator. One uses a silicon diode crystal similar to that employed by J. M. Osborne

TABLE 3:1

Simplified classification of extra-terrestrial radio emitters.

A. GALACTIC SOURCES OF RADIO EMISSION:

Source	*Example*	*Mechanism (actually observed)*	
1 The sun		Thermal	Non-thermal
2 Jupiter		Thermal	Non-thermal
3 Saturn		Thermal	
Venus		Thermal	
Mars		Thermal	
4 Normal galactic Nebulosities	Orion Nebula		
5 Remnants of Supernovae Type 1	Crab Nebula	Synchrotron	
6 Galactic Nebulosities of a new type	Cassiopeia A	Synchrotron	
7 Peculiar Nebulosities	Puppis		

B. EXTRA-GALACTIC SOURCES:

1 Normal galaxies	Andromeda	Similar to our own galaxy	
2 Peculiar galaxies (*a*) Colliding galaxies	(*a*) Cygnus A	Synchrotron	
	Perseus Cluster		
(*b*) Possible head-on collision of galaxies	(*b*) Centaurus A	Synchrotron	

and the other uses a saturated diode. Valves constructed for this purpose are easily obtained. Reliable CV172s which were developed during the war and use the same base as the EF50 could be obtained on the surplus market until recently. However, it may be necessary to buy direct from the manufacturers and a typical noise diode suitable for this type of work is the G.E.C. A2087; this has a 4·4 volt 0·64 amp heater.

3 : 7 *Valve Noise Sources*

A diode valve connected in a simple circuit is shown in Fig. 3:3. When the anode is more positive than the cathode a current flows across the valve in the direction of the anode. A meter in the circuit measures the anode current and another the anode voltage. A graph of the effect of anode voltage on anode current is shown in Fig. 3:3 (*b*). It will be noticed that a point is reached

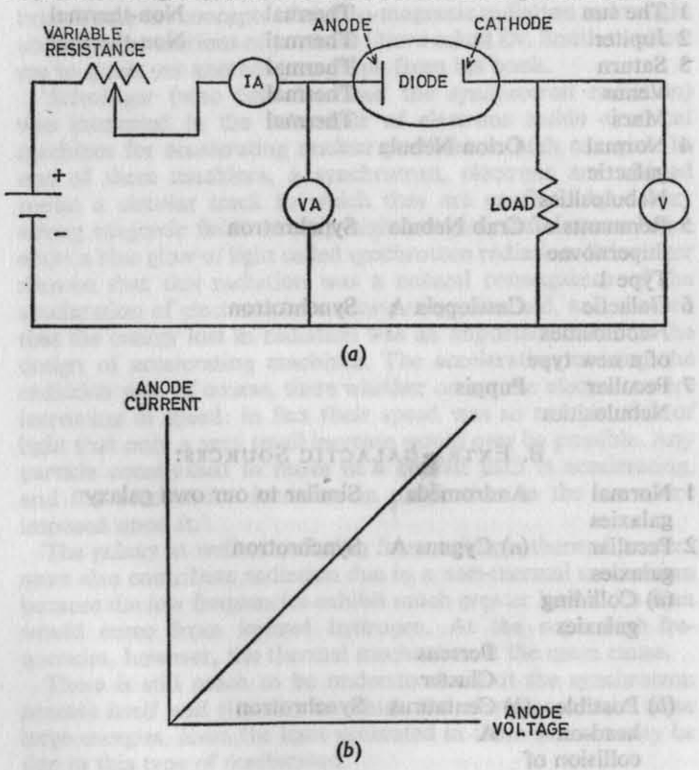


FIG. 3:3

when the anode cannot draw any more current from the filament. This is the saturation point. The figures quoted on the graph will suffice for the CV172. Noise of the level required is produced when the valve is operating just above the point of saturation.

In the radiometer circuit the noise source is frequently connected to the receiver so that its output can be compared with the output of the aerial. The simplest way of establishing the aerial temperature is to adjust the noise source to the same value as that of the aerial and so make a direct comparison.

If this latter method is used the noise source can be calibrated and simple but not very accurate measurements obtained. Radio astronomers in their more sophisticated techniques make the measurement of noise independent of the gain of the receiver.

Since the noise source is connected to the 'front end' of the receiver its output will be a function of receiver gain. As drift is likely to occur at any time false comparisons can be made. The drift may well occur whilst the receiver is connected to the aerial. It is, therefore, a fundamental rule of all measurements of this type to switch between the two sources as often as possible. In the 'Dicke Radiometer' the switching is 30 c.p.s.*

In order to vary the magnitude of the noise it is necessary for the diode to operate over a fairly wide range of current in the saturation region. The supply voltage must therefore be sufficient for the anode to produce the required level of saturation. The usual procedure is to adjust the filament supply leaving the anode voltage fixed. The range of filament voltage for a CV172 is between 5 and 7 volts (A.C.). Radio frequency chokes are inserted in all the circuits to prevent re-radiation and to ensure that the noise is injected into the system. These are very simple to construct but suitable chokes can also be obtained from amateur radio supply specialists. The variable supply consists of two wire-wound potentiometers whose values are chosen such that one acts as coarse control to which the filament is first set and the other as a variable control about this setting. The CV172 will work quite well up to 300 mc/s.

The unit should be enclosed completely in a screened box and the filament controls, switch and meter should be incorporated. However, the power supply should be in a separate unit.

3 : 8 *Feeder Connections*

Aerials are connected by one or other of two methods to a receiver. These are the 'balanced' or the 'unbalanced'. A television receiver is normally fed unbalanced from the aerial with a 'coaxial' cable transmission line.

* Receivers may drift away from the required frequency or in gain.

The LC circuit described in Chapter 1 has a characteristic impedance at its resonant frequency. This is the ratio of voltage to current. At resonance it is the alternating current resistance of the circuit. It always depends on the frequency, L and C. An aerial which is a form of LC circuit has its own characteristic impedance, so too does the transmission line. The situation can be represented by two resistances. One represents the aerial and the other the transmission line. Alternatively some engineers would replace the aerial by a generator having an internal resistance equal to the aerial impedance e.g. Fig. 3:4.

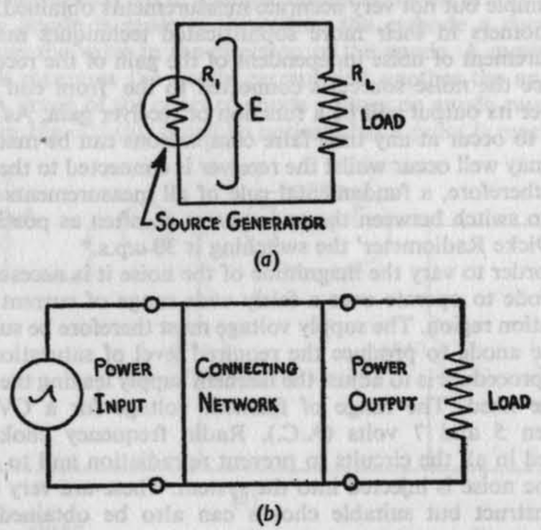


FIG. 3:4

In order to transfer maximum power from the aerial to the transmission line the impedance (Z) of the aerial has to be equal to that of the transmission line. Similarly the receiver has to have the same impedance at its input as the transmission line if maximum power is to be transferred from the line to the receiver. This process whereby maximum power transfer is achieved is called 'matching'. When the line has a different impedance to the load it is necessary to insert a 'matching' device between the load and the line. Suppose, for instance, that the aerial has an impedance of 280 ohms and the line an impedance of 70 ohms. There is a step down ratio of 4 to 1. The simplest way to achieve matching would be to connect a transformer* having a

* A transformer may not only be used to step up or down voltage but may be used for matching impedances.

step-down turns ratio between the aerial and the line (i.e. number of turns on the secondary being smaller than the number on the primary). Some methods of matching will be discussed in the chapter on aerials.

In a radiometer the situation is a little more complex. The noise source has to be connected and correctly matched to the receiver which is alternately connected to it and the aerial. The impedance of coaxial cables varies between 70 and 80 ohms. One side of the coaxial lines is connected to earth at the receiver.

A balanced line which consists of two open wires (and at the receiver to an inductance which has its centre earthed) may have a much higher impedance than the coaxial line, e.g. 300 ohms. Certain electrical circuits must be connected to a balanced line and in order to change to an unbalanced cable a matching or balancing device has to be used. Again the simplest method is by means of a transformer. A centre-fed dipole aerial should be fed by a balanced line.

It is sometimes more convenient to use a balanced transmission line throughout the network from aerial to receiver. This can be an 'open wire' or a simple plastic form. It simply consists of two spaced wires, the spacing being the crucial dimension. An open wire line is spaced by ceramic spacers or suitable insulator for the particular frequency of operation. Although tedious to construct and lay, for it needs to be attached to stakes at regular intervals, it has many advantages over the coaxial cable. It suffers less loss except when wet and is on long runs cheaper to construct.

When balanced transmission lines are used the noise source circuit will have to be changed to provide a balanced output. A typical circuit is given in Fig. 3:5.

Unfortunately another difficulty arises because between the

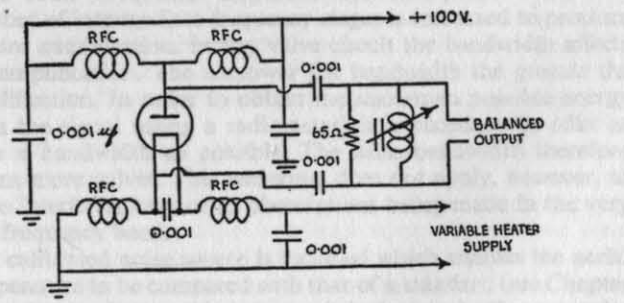


FIG. 3:5. (After Sander, radiolocation convention report. *Journ. I.E.E. 1946*).

anode and the filament of the diode there is a small residual inter-electrode capacity. In the balanced system its effect has to be taken into account (or 'balanced out'). This harmful effect is removed by putting an inductance in parallel with the inter-electrode capacity and tuning out the capacity. It is useful when constructing the balanced circuit to leave a small hole so that the tuning inductance iron-cored slug can be adjusted.

Finally, Osborne had considerable success with a silicon diode crystal and his circuit is given in Fig. 3:6. This circuit should also be enclosed in an earthed aluminium screen. The supplies can be obtained from grid bias batteries but this writer also found it necessary to have coarse and fine adjustments and not the simple rheostat. Much depends on the scale deflection and internal resistance of the meter used when adjusting the values of components for satisfactory operation.

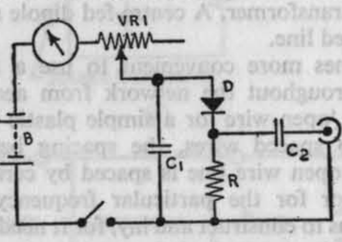


FIG. 3:6. (Reproduced by permission of the Editor of the *Short Wave Magazine*).

CHAPTER FOUR

The radiometer

4 : 1 *Introductory*

IN this book two very simple radiotelescopes will be discussed. They are the radiometer or total power instrument and the spaced-aerial radio interferometer. When the large steerable paraboloid at Jodrell Bank is used by itself it will be operating as a radiometer. The radiometer is a single aerial radiotelescope which feeds a relatively straightforward receiver coupled to some means of recording the output power. In general the latter is a pen recorder but it is also possible to arrange for the observations from any radiotelescope to be put on computer tape or even a tape recorder. Computers have to be used with the 'aperture synthesis' technique employed at Cambridge.

4 : 2 *The Radiometer*

A block schematic diagram of the basic radiometer is shown in Fig. 4:1. The parts contained within the dotted square belong to a normal receiver of the communications type. A broadcast receiver normally employs only one intermediate frequency amplifier since the signal voltage at the aerial is quite high. Similarly its bandwidth is narrow, being of the order of 8 kc/s.

Because signals from the distant sources are weak it is necessary to increase the sensitivity over that of the normal domestic receiver. A similar technique is used in H.F. communications. Thus radio frequency amplifiers are incorporated and the number of intermediate frequency stages is increased to produce greater amplification. In any valve circuit the bandwidth affects the amplification. The narrower the bandwidth the greater the amplification. In order to obtain the maximum possible energy from the signal (using a radiometer) it is necessary to offer as wide a bandwidth as possible. The wide bandwidth therefore means more valves. This reasoning does not apply, however, to radio interferometers or to observations being made in the very low frequency band.

A calibrated noise source is included which enables the aerial temperature to be compared with that of a standard (see Chapter 3). In the simple case this is just switched on and off as a regular check on the record. The practical methods are more sophisticated. Below about 200 mc/s, Machin, Ryle and Vonberg developed an instrument (shown schematically in Fig. 4:2(*a*)) in which the receiver was rapidly switched between the noise source and the aerial. At the same time the signal at the detector was used to control the heater supply to the noise diode and so continuously adjust the noise source to the same power level as the extra-terrestrial noise at the aerial. The recorded signal is in fact the filament voltage of the noise source.

This was not, however, the first radiometer to be described. Dicke's instrument holds that honour and is often referred to in books and papers. Its chief use, when first developed, was at the ultra and super high frequencies and in the original design cannot be considered by the amateur. Part of the difficulty is the

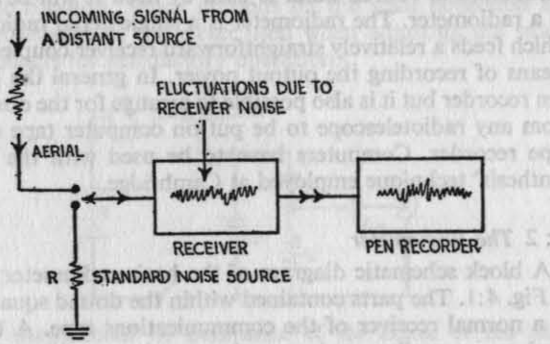


FIG. 4:1

design of an absorption wheel which rotates within a waveguide performing a similar task to the switch. The difference between the aerial and noise source (or load) is measured. The pen recorder is of the centre zero type so that a right-hand deflection corresponds to a positive difference and a left-hand deflection to a negative difference or vice versa. In addition to the usual detector and low frequency amplifier (which incidentally is tuned to the switching frequency of 30 c.p.s.) a synchronous detector is employed. In the Dicke system a D.C. amplifier feeds the output meter. (Fig. 4:2 (*b*).)

One difficulty is the level of receiver noise at the very high frequencies. This is often greater than the available noise power from the aerial at these frequencies. Variations in the receiver gain and thus its noise limit the minimum detectable signal. Since the receiver noise appears to be the same to either side of switch, i.e. to the load and to the aerial when they possess the same impedance, it is possible to ignore changes in receiver gain to a great extent. It is important to realize, firstly, that if the noise power of the load is kept constant, the pen recorder follows

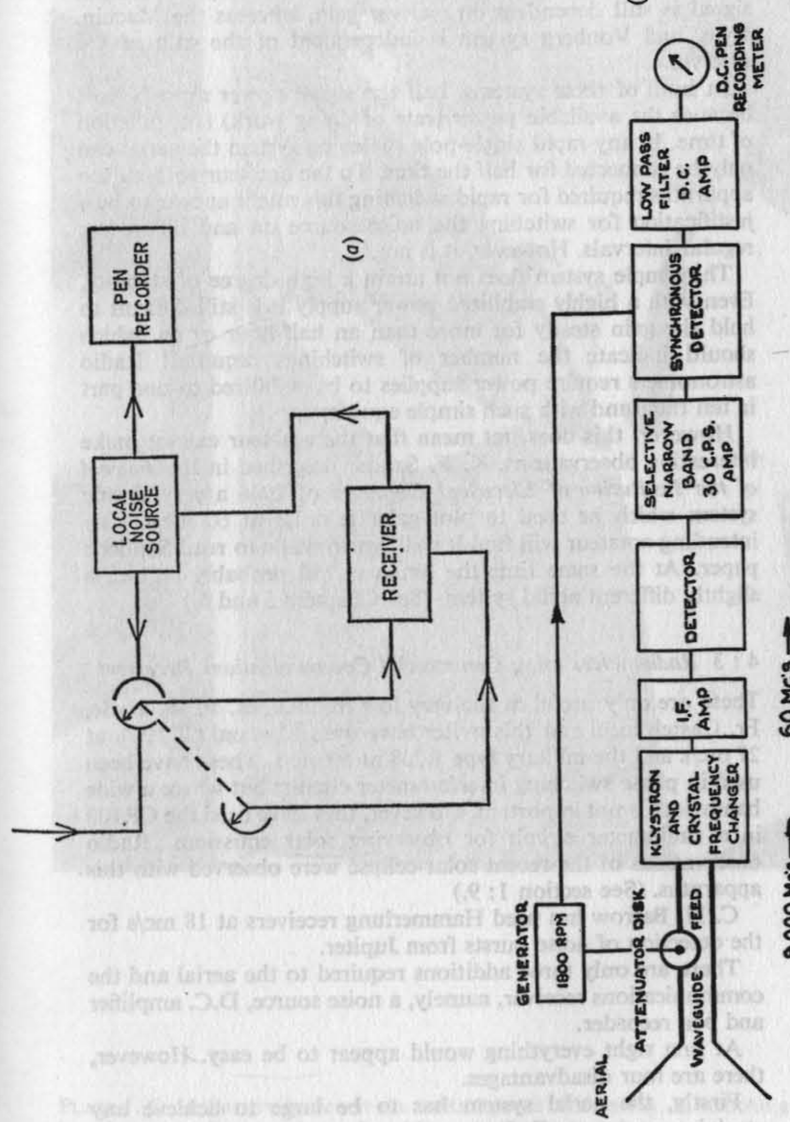


FIG. 4:2

the variations in power delivered by the aerial, enabling signals below the receiver noise to be measured. Secondly, the output signal is still dependent on receiver gain, whereas the Machin, Ryle, and Vonberg system is independent of the gain of the receiver.

In both of these systems, half the signal power must be lost because the available power (rate of doing work) is a function of time. In any rapid single-pole switching system the aerial can only be connected for half the time. To the amateur without the apparatus required for rapid switching this might appear to be a justification for switching the noise source on and off at less regular intervals. However, it is not.

The simple system does not attain a high degree of stability. Even with a highly stabilized power supply it is still difficult to hold the gain steady for more than an half-hour or so, which should indicate the number of switchings required! Radio astronomers require power supplies to be stabilized to one part in ten thousand with such simple equipment.

However, this does not mean that the amateur cannot make interesting observations. K. F. Sander described in the *Journal of the Institution of Electrical Engineers* of 1946 a very simple system which he used to plot galactic noise at 60 mc/s. Any intending amateur will find it well worth while to read Sander's paper. At the same time the amateur will probably require a slightly different aerial system. (See Chapters 5 and 6.)

4 : 3 *Radiometers using Commercial Communications Receivers*

These are only useful at the very low frequencies. F. W. Hyde, Fr. Castelvecchi and this writer have used Marconi CR100's at 27 mc/s and the military type R208 at 50 mc/s. These have been used in phase switching interferometer circuits but where a wide bandwidth is not important. However, they have used the CR100 in a radiometer circuit for observing solar emissions. Radio observations of the recent solar eclipse were observed with this apparatus. (See section 1: 9.)

C. H. Barrow has used Hammerlung receivers at 18 mc/s for the detection of noise bursts from Jupiter.

There are only three additions required to the aerial and the communications receiver, namely, a noise source, D.C. amplifier and pen recorder.

At first sight everything would appear to be easy. However, there are four disadvantages.

Firstly, the aerial system has to be large to achieve any resolving power at all. It may either be an horizontal array of dipoles or a corner V-reflector. In either case it will be large.

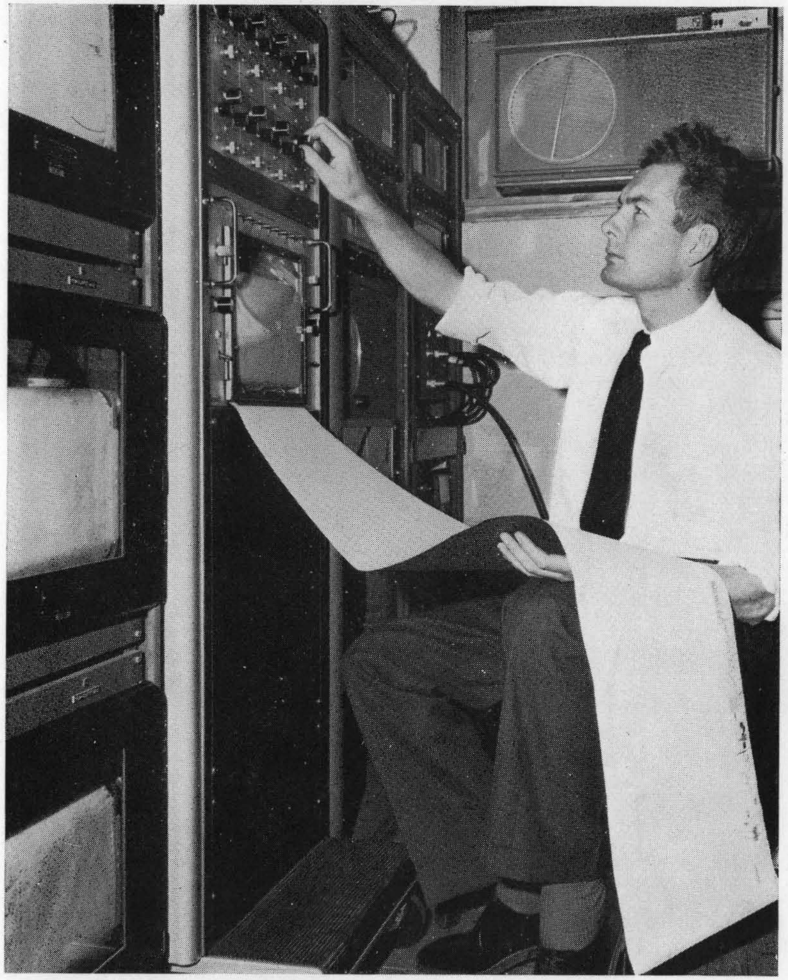


PLATE 1. C. H. Barrow is seen at the control panel of his array. In searching for low frequency Jupiter observations, the observer not only pen recorders but listens to the signals on a loudspeaker.

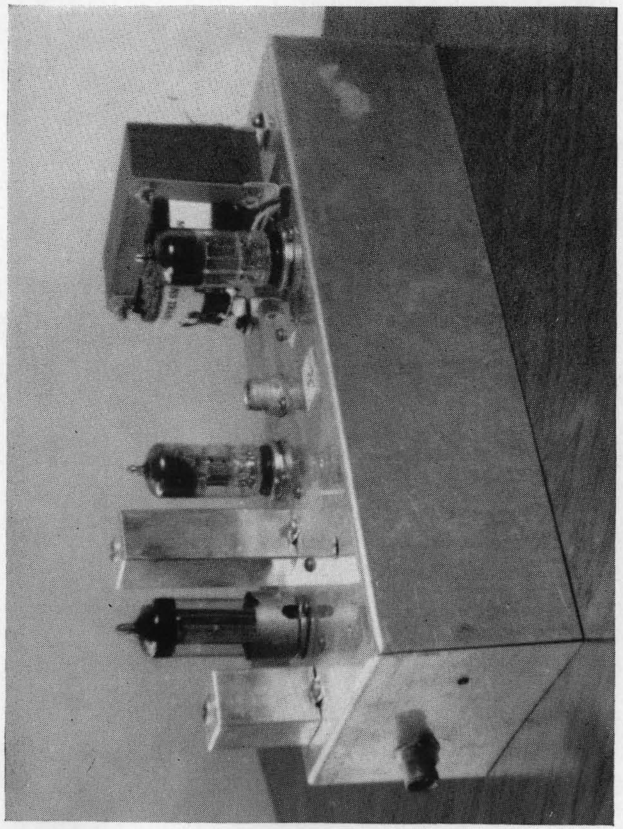


PLATE 2. Shows a preamplifier built as a unit. It was used in a phase switching interferometer operating at 60 mc/s.

Secondly, in addition to local noise which will be received all over the band, there is the difficulty of finding a spot which is clear of communications signals of one sort or another.

Thirdly, there is the problem of choosing a suitable radio star source for in this band the position of the source, the frequency of observation determine the relative effect of the ionosphere to the signal. (See Chapter 10.) Ionospheric changes can cause changes in the record which might be misinterpreted.

Fourthly, the problems already discussed of receiver drift, etc. These can be overcome to a certain extent by adopting a unit system of construction which necessitates constructing ones own stabilized power supply. In addition I.F. amplifiers having a wider bandwidth can be constructed. (Fig. 4:4.)

4 : 4 *Radiometers in Unit Construction*

Fig. 6:8 also illustrates how radio telescopes can be constructed in units. The system described was adopted by the amateurs of the B.A.A. for phase switching interferometers which allow for pre-amplifiers to be installed in the aerial transmission lines. With radiometers of this simple type the recommended procedure is to keep the units together and to bring them as near to the aerial as possible.

Fortunately the television band at 190 mc/s and the V.H.F. broadcasting band at 90 mc/s provide the details of wiring and circuitry techniques. However, this does not mean that it would be wise to convert a television receiver to operate on 240, 200, 178, 81·5, 60 or 38 mc/s (i.e. frequencies which have been used successfully by radio astronomers). However, typical TV converters may be modified for the appropriate frequencies and used, but an I.F. amplifier of wider bandwidth, say 8 mc/s is desirable.

4 : 5 *The Radio Frequency Amplifier*

Illustrations of the circuit and construction of preamplifiers are shown in Plate 2 and Fig. 4:3. The separate power supply shown in the illustration enabled the unit to be used as a preamplifier in the aerial transmission lines of a phase switching interferometer. In the radiometer a more stabilized supply would be required and the radio frequency unit should be near to the I.F. amplifier. The advantage in being separate is utility in that it can be used as a preamplifier in an interferometer. At frequencies in the range 60–100 mc/s this advantage is disappearing since it is possible to use transistors with a battery supply. Surprisingly enough, however, many of the expert amateurs still prefer valve circuits.

In any case all radio frequency amplifiers should be 'low noise' since the noise made in the first stage will be amplified throughout the circuit. The most popular circuit is the 'cascode'. But almost any of the grounded grid circuits used in television receivers are suitable. J. M. Osborne used a modified TV converter and since it worked satisfactorily it is a good starting unit for the amateur. (Fig. 4:3.)

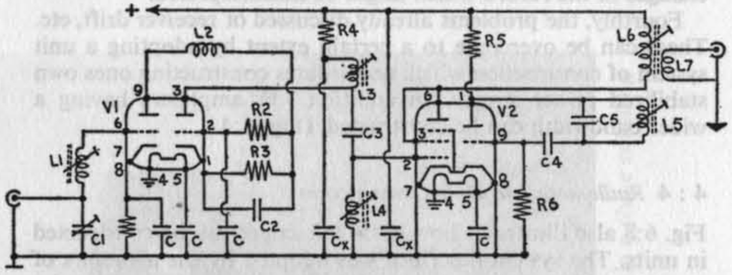


FIG. 4:3. This circuit which includes the mixer is reproduced by courtesy of the editor of the *Short Wave Magazine*. It illustrates the modified 'Rainbow' TV converter used by J. M. Osborne.

It will be noticed that the R.F. unit employs a low noise amplifier followed by a self-oscillating mixer. In this instance the radio frequency amplifier isolates the oscillator signal from the aerial. When, however, the amateur requires to construct a lone pre-amplifier unit which can also be used for amplification in the aerial transmission line of a phase switching interferometer certain other design features must be included. If a coaxial line is used the output from the amplifier has to be matched into the line. One way to do this is to use a cathode follower, a valve circuit which, whilst matching the output to the line, does suffer a loss in gain. Since there is no gain in the low noise circuit it is necessary to include amplification between the two stages which is sufficient to overcome both the losses in the circuitry and the transmission line.

4 : 6 *The Intermediate Frequency Amplifier*

This unit will have to be fitted with a co-axial input and matching to the high impedance of the valve circuit. The Pye strip, the basic circuit of which is given in Fig. 4:4, is an extremely good circuit for this type of work. It has a wide band with considerable amplification. Such units can still be obtained on the surplus market. The greater difficulty is the EF50 valve which is now obsolete. R. Tomkins and this writer developed a similar strip

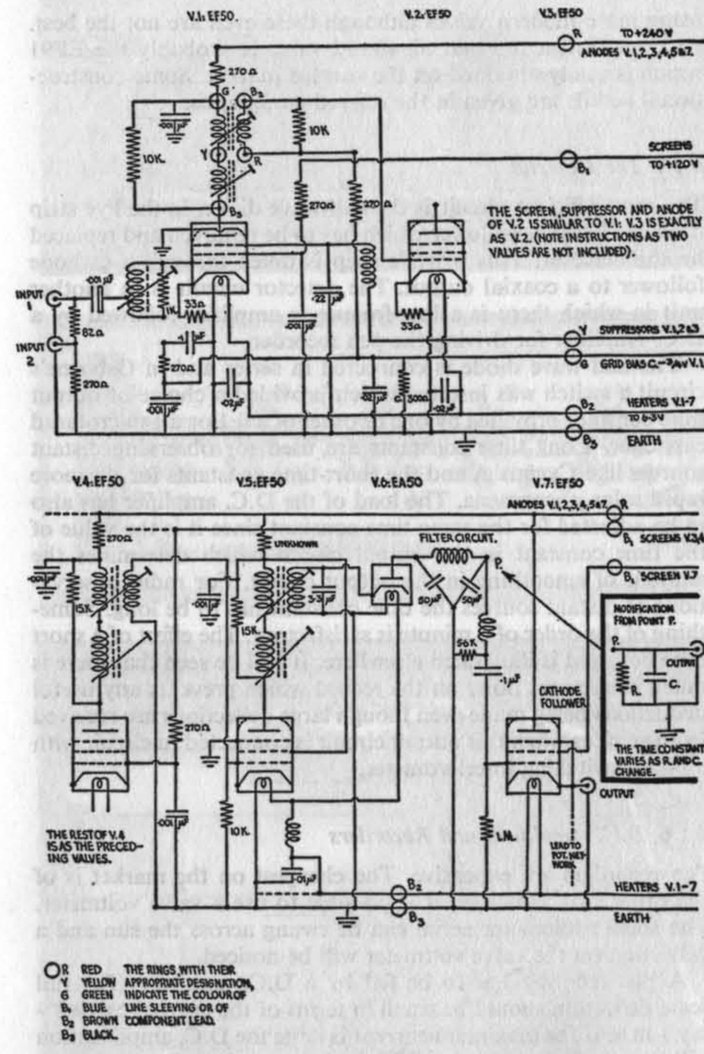


FIG. 4:4. A number of Pye strips have been examined and from this data P. Goodhart constructed this circuit diagram. The colours indicated are typical of the strips studies, but the observer should not take them as necessarily being correct. Since the circuitry of V2 and V3 and V4, except where indicated on the diagram, is similar to V, it has been omitted in this circuit. For details of an alternative modification to the output from the detector, see the paper by J. M. Osborne.

using more modern valves although these even are not the best. At the moment the best all round valve is probably the EF91 which is easily obtained on the surplus market. Some constructional details are given in the starred paragraphs.

4 : 7 *The Detector*

The most efficient circuit is the half-wave diode. In the Pye strip there is a cathode follower which has to be removed and replaced by the detector. This writer's strip is taken through a cathode follower to a coaxial output. The detector circuit is in another unit in which there is a low frequency amplifier followed by a D.C. amplifier for driving the pen recorder.

The half-wave diode is connected in series and in Osborne's circuit a switch was inserted which provided a choice of output time constant provided by one or other of a 0·1 or a 1 microfarad capacitor. Long time constants are used for observing distant sources like Cygnus A and the short-time constants for the more rapid solar phenomena. The load of the D.C. amplifier has also to be adjusted for the same time constant since it is the value of the time constant in the output circuit which determines the amount of smoothing in the output circuit. For radio observations of distant sources the time constant has to be long. Something of the order of $\frac{1}{2}$ minute is satisfactory. The effect of a short time constant is illustrated elsewhere. It will be seen that there is much extraneous noise on the record which prevents any useful deductions being made even though large deflections are received from sources when this output circuit is connected in circuit with a phase switching interferometer.

4 : 6 *D.C. Amplifiers and Recorders*

Pen recorders are expensive. The cheapest on the market is of the order £70. However, it is possible to use a valve voltmeter. The small radiometer aerial can be swung across the sun and a deflection on the valve voltmeter will be noticed.

A pen recorder has to be fed by a D.C. amplifier. The full scale deflection should be small in terms of the current carried – say 1 m.a. If the maximum current is large the D.C. amplification will have to be increased considerably. Sometimes it is necessary to do this if the pen-recording meter has to be used for other purposes (e.g. in a College laboratory) and has a larger full-scale deflection than is required for radio astronomy.

When choosing pen recorders the impedance of the instrument should be noted for it is this which determines the design features of the output circuit in respect of its time constant. Also some

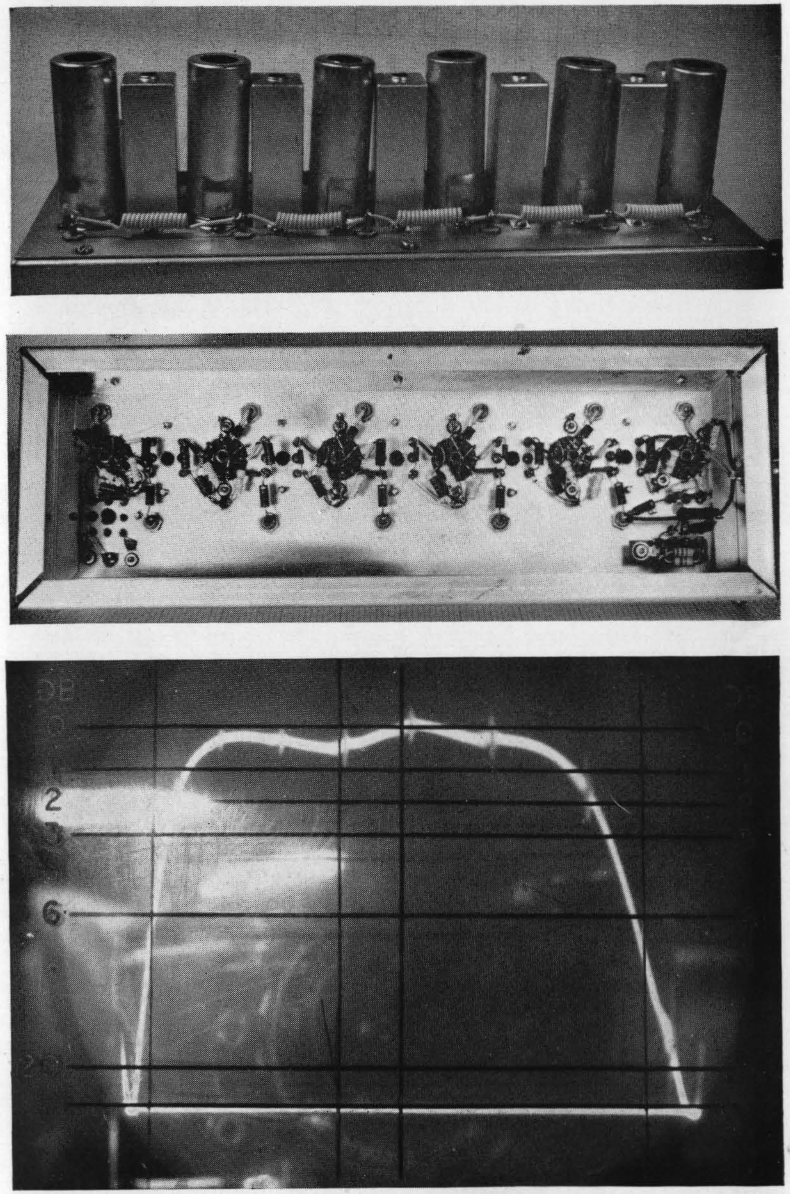


PLATE 3. A 30 mc/s I.F. amplifier built by R. I. Tomkins. The bottom illustration shows the 3 mc/s frequency response of the amplifier. (*Reproduced by courtesy of the B.A.A.*)

PLATE 4. Arrays of Yagis built by F. W. Hyde in the playground of the Salesian College, Battersea.

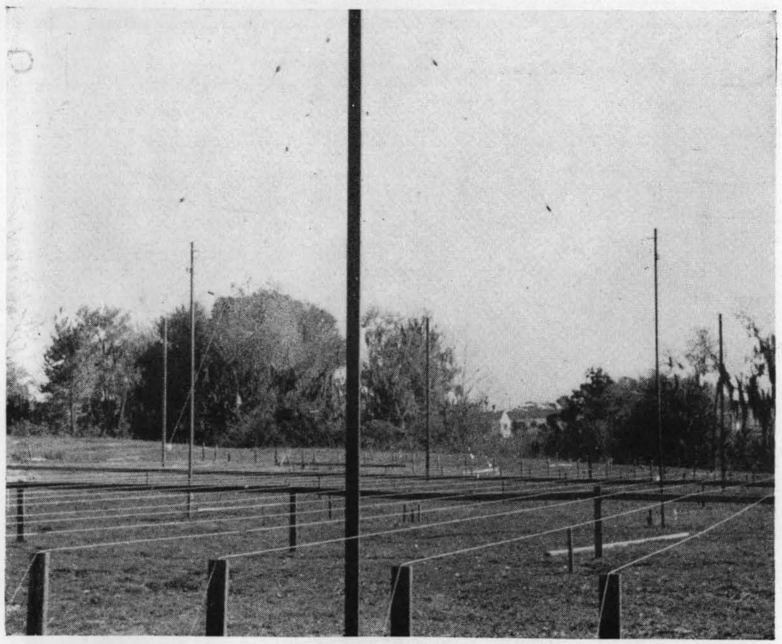


PLATE 5. A horizontal array of dipoles built by C. H. Barrow. The wire reflecting screen is clearly shown.

recording instruments have slow moving pens. The speed of deflection of mechanical pens in radio astronomical work should be of the order 0·2 second for recording some rapid phenomena but this is not necessary for distant sources. Finally, the chart speed is also important. Most recorders usually have two groups of speeds – inches per hour and inches per minute. Clocks are made for inches per second but these are not necessary for radio astronomical observations.

Charts are relatively expensive, say 5/– each, so that they must be used sparingly. During observations 6 inches per hour has been found to be most satisfactory. Three inches per hour cramps the observations and 12 inches per hour wastes too much paper. Three tables have been drawn up by J. R. Smith which are of interest and given in Tables 4:1, 4:2 and 4:3 (by courtesy of the British Astronomical Association).

A typical circuit diagram of a D.C. amplifier is shown in Fig. 4:5, and of great interest is J. R. Smith's attempt to construct a recording instrument, also illustrated, together with a typical recording. (Fig. 4:6.)

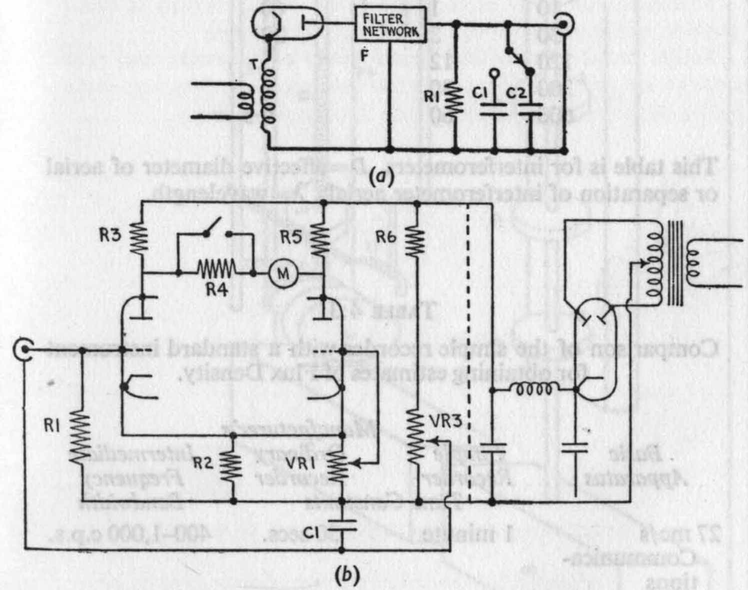


FIG. 4:5(*a*). J. M. Osborne's modification to the output from the Pye strip. (*b*) The D.C. Amplifier. (Reproduced by courtesy of the editor of the *Short Wave Magazine*.)

TABLE 4:1

For Planetary and Solar bursts

Phenomena	*Chart Speed*	*Chart Speed ins. per hr.*	*Time Constant seconds*
Short bursts	Fast	60	0·5
Long bursts	Fast	12	2
Short bursts	Slow	1	5
Long bursts	Slow	1	5

Fast speed for detailed analysis. Slow speed for long-term records.

TABLE 4:2

For Positional and Angular diameter measurements

D / *λ*	*Chart Speed ins. per hour*	*Time Constant seconds*
10	1	60
30	3	20
120	12	5
300	30	2
600	60	0·5

This table is for interferometers. D=effective diameter of aerial or separation of interferometer aerials. λ=wavelength.

TABLE 4:3

Comparison of the simple recorder with a standard instrument for obtaining estimates of Flux Density.

Basic Apparatus	*Simple Recorder*	*Manufacturer's Ordinary Recorder*	*Intermediate Frequency Bandwidth*
	Time Constants		
27 mc/s Communications Receiver	1 minute	30 secs.	400–1,000 c.p.s.
200 mc/s Osborne Design	30 secs.	3–30 secs.	3 mc/s

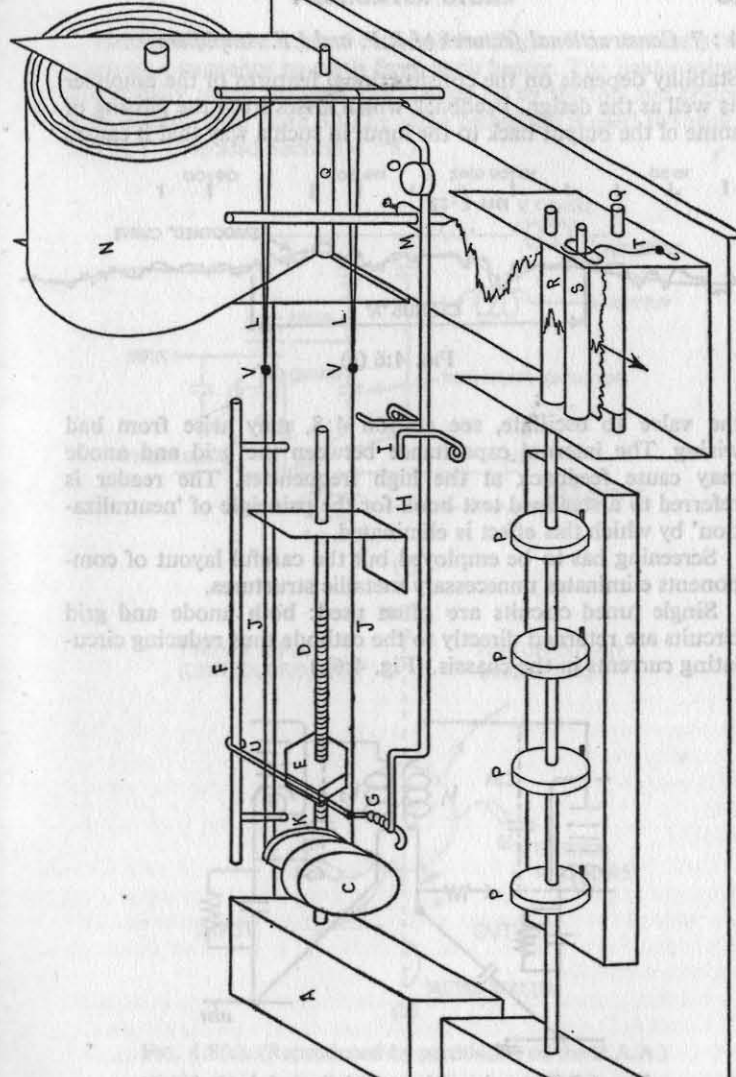


FIG. 4:6 (*a*)

4 : 7 *Constructional features of R.F. and I.F. Amplifiers*

Stability depends on the constructional features of the amplifier as well as the design. Feedback which arises from the passing of some of the output back to the input in such a way that it causes

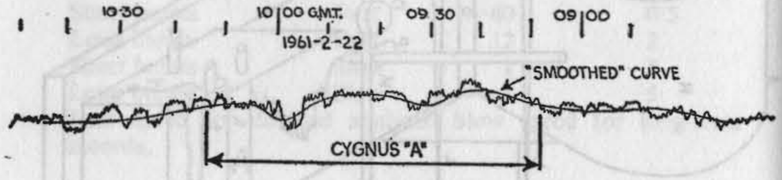


FIG. 4:6 (*b*)

the valve to oscillate, see section 4:8, may arise from bad wiring. The internal capacitance between the grid and anode may cause feedback at the high frequencies. The reader is referred to a standard text book for the principle of 'neutralization' by which this effect is eliminated.

Screening has to be employed but the careful layout of components eliminates unnecessary metallic structures.

Single tuned circuits are often used: both anode and grid circuits are returned directly to the cathode thus reducing circulating currents in the chassis. (Fig. 4:6).)

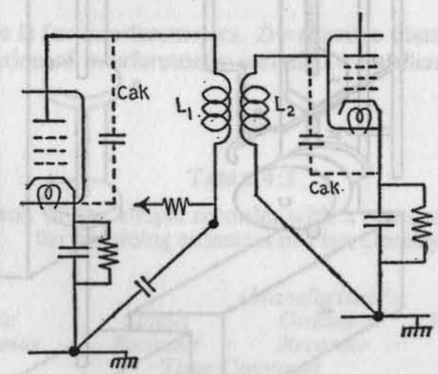
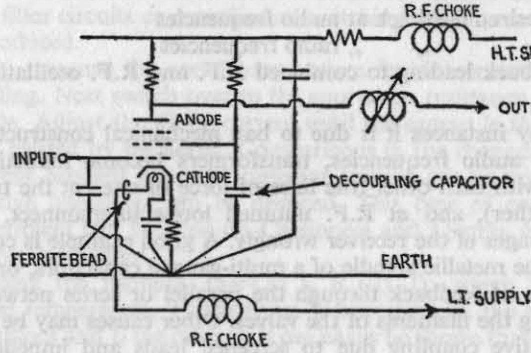


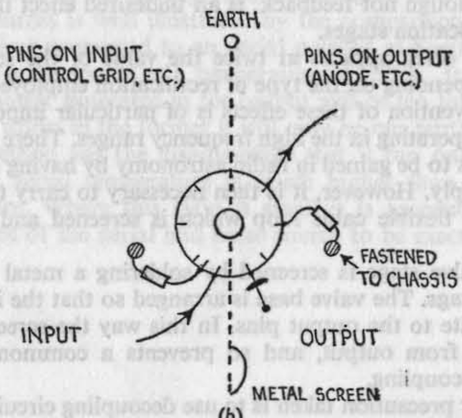
FIG. 4:7 (Reproduced by permission of the B.A.A.)

Leads are returned to one point on the chassis at each valve and this feature is often shown on the circuit diagrams. It is sometimes advisable to return all the by-pass capacitors associated with a valve to one point on the chassis. Two methods of connecting R.F. circuits are shown in Fig. 4:7 and Fig. 4:8.

Heater wires are a great cause of feedback. It is necessary to connect a capacitor to earth from each heater. The heater wires are usually taken through the chassis on to the top and coiled into chokes. (See Plate 3.) The same technique is used to supply the H.T. (See also Section 4 : 8.)



(*a*)



(*b*)

FIG. 4:8(*a*). (Reproduced by permission of the B.A.A.)
(*b*) Simple method of wiring an octal based valve.

★4 : 8 *Undesired Feedback*

Since reception entails the use and generation of several totally different frequencies in addition to the A.C. mains supply, special care has to be taken to prevent them from interacting with each other unless it is desired. If interaction takes place it often causes a spurious oscillation which may tend to modulate or distort the wanted signal. Zepler[1] has given a very thorough treatment of this subject – undesired feedback. It is usually dealt with under three headings –

1 Undesired feedback at audio frequencies
2 ,, ,, ,, radio frequencies
3 Feedback leading to combined A.F. and R.F. oscillations.

In many instances it is due to bad mechanical construction, when, at audio frequencies, transformers become inductively coupled with each other (the lines of force of one cut the turns of the other), and at R.F. untuned loops interconnect, the various stages of the receiver wrongly. A good example is coupling via the metallic spindle of a multi-ganged capacitors, or the possibility of feedback through the parallel or series networks connecting the filaments of the valves. Other causes may be due to capacitive coupling due to screened leads and impedance coupling in common path.

Hum, though not feedback, is an undesired effect in some of the amplification stages.

It quite often appears at twice the value of the supply frequency depending on the type of rectification employed.

The prevention of these effects is of particular importance to receivers operating in the high frequency ranges. There are many advantages to be gained in radio astronomy by having a separate power supply. However, it is then necessary to carry the supply leads in a flexible cable loop which is screened and correctly earthed.

Each valve stage is screened by soldering a metal screen to the earth tags. The valve base is arranged so that the input pins are opposite to the output pins. In this way the screen isolates the input from output, and so prevents a common form of undesired coupling.

Another precaution taken is to use decoupling circuits in both H.T. and L.T. supply leads. In addition to the capacitors already mentioned decoupling of filaments is completed by pushing a ferrite bead (Fig. 4:8 (*a*)) across the insulation of the filament wire and left near the connection of the wire and valve base, this introduces a loss of reactance which together with the capacitor presents a large attenuation to any high frequency present. Similar precautions to these have to be taken to prevent parasitic

[1] E. E. Zepler. *The Technique of Radio Design* (Chapman and Hall).

oscillations which always occur at the very high frequencies and are the cause of distortion.

4 : 9 *Using the Radiometer*

Apart from the starred paragraph enough should have been said to illustrate the ease with which a simple radiometer can be built. No filter circuits or complicated switching techniques have been introduced.

To measure the aerial temperature first observe the output reading. Next switch over to the equivalent resistance and noise diode. Adjust the diode current until the output is the same as that caused by the aerial. Comparisons in the changes of diode current brought about by different sources can be noted. Thus relative intensities can be deduced. This type of comparative experiment can be done on Cassiopeia and Cygnus A with the simple instrument.

★From the formula $Ta=(20\ I_t\ R+1)\ Tr$, where Ta is the aerial temperature, Tr the room temperature, R the equivalent resistance and I_t the current, it can easily be shown that television aerials operating at 40 mc/s have a noise temperature of 6,000°K when pointed at the galaxy. The small signal strength of the distant sources is well illustrated by the comparison of the 40 mc/s receiver connected to an aerial pointed at Sagittarius and then to a noise source at a temperature of 290°K. In the latter case the power generated in the output will be ten times that of the input whilst in the former it will only be one tenth.

This method has the disadvantage that it can only be used when the aerial temperature is much higher than the room temperature. Where this ratio is small it is necessary for the impedances of the aerial and noise source to be exactly equivalent.

CHAPTER FIVE

Aerials for radiotelescopes

5 : 1 *Introduction and Classification*

THERE are many ways of classifying aerials, the simplest is a division into two main types – tuned (resonant) and untuned (non-resonant). Whereas the tuned aerial responds to one fundamental frequency and under certain conditions multiples of this frequency the untuned aerial responds to a wide band of frequencies. Radio astronomers use both types of aerial but for different purposes. The helix and the rhombic are examples of non-resonant aerials which respond to a wide range of frequencies (Fig. 5:1). Amateurs have certainly used the helix but

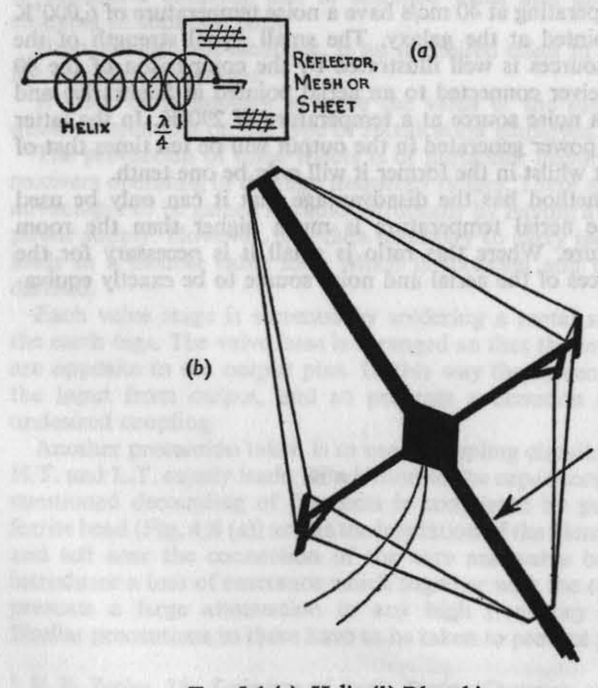


FIG. 5:1 (*a*). Helix (*b*) Rhombic.

most of them use one or other of the various types of tuned aerial.

The simplest form of tuned aerial is the dipole. When reflectors and directors are added to the dipole as with many television aerials in fringe areas it becomes a Yagi. A dipole may also be placed at the focus of a parabola. The Yagi and the parabola are types of beam aerial but the dipole by itself is not. The resolution of a radiotelescope, i.e. a radiometer with a single aerial, arises from the beamwidth of its aerial. A high resolution aerial has a narrow beamwidth.

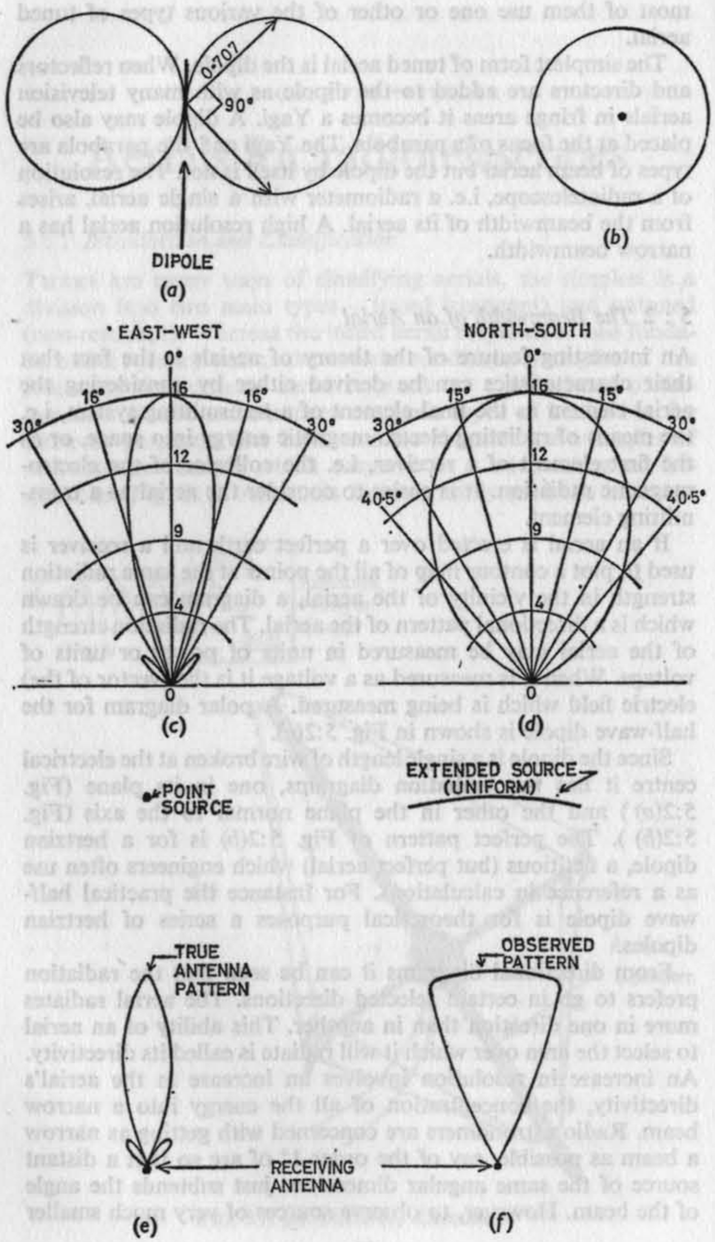
5 : 2 *The Beamwidth of an Aerial*

An interesting feature of the theory of aerials is the fact that their characteristics can be derived either by considering the aerial element as the final element of a transmitting system, i.e. the means of radiating electro-magnetic energy into space, or as the first element of a receiver, i.e. the collector of the electro-magnetic radiation. It is easier to consider the aerial as a transmitting element.

If an aerial is erected over a perfect earth and a receiver is used to plot a contour map of all the points at the same radiation strength in the vicinity of the aerial, a diagram can be drawn which is a directional pattern of the aerial. The radiation strength of the aerial may be measured in units of power or units of voltage. When it is measured as a voltage it is the (vector of the) electric field which is being measured. A polar diagram for the half-wave dipole is shown in Fig. 5:2(*a*).

Since the dipole is a single length of wire broken at the electrical centre it has two radiation diagrams, one in its plane (Fig. 5:2(*a*)) and the other in the plane normal to the axis (Fig. 5:2(*b*)). The perfect pattern of Fig. 5:2(*b*) is for a hertzian dipole, a fictitious (but perfect aerial) which engineers often use as a reference in calculations. For instance the practical half-wave dipole is for theoretical purposes a series of hertzian dipoles.

From directional diagrams it can be seen that the radiation prefers to go in certain selected directions. The aerial radiates more in one direction than in another. This ability of an aerial to select the area over which it will radiate is called its directivity. An increase in resolution involves an increase in the aerial's directivity, the concentration of all the energy into a narrow beam. Radio astronomers are concerned with getting as narrow a beam as possible, say of the order 1° of arc so that a distant source of the same angular dimensions just subtends the angle of the beam. However, to observe sources of very much smaller



angular dimensions very much smaller beamwidths than 1° of arc are required. It is not possible to get these very narrow beamwidths with conventional systems. For this reason the interferometer was designed. Even the sections of an interferometer require to have considerable gain since the reception pattern of an interferometer is that of one of its aerials. For instance the beamwidth of one of the aerials making the Cambridge 2C catalogue was 2½° by 16°. It is fairly clear that the amateur should resort to simple interferometer techniques. A glance at table 5:1 which gives the beamwidths for certain types of Yagi arrays illustrates the problem. Observations of the galaxy are mostly done with single beam systems. It is therefore the first observation that the amateur should make.

The beamwidth of a hertzian dipole is the point at which the power has fallen to half the maximum value. These particular points are sometimes referred to as the half-power points, the measurement being similar to that of obtaining the bandwidth of a resonant circuit.

Aerial designers not only speak of the directivity but the gain of the element. The directivity indicates that the signal strength is increased in a particular direction, i.e. that it has a gain in that direction when compared with the other directions.

One of the uses of a reference aerial is in measuring the gain of a practical aerial which is the ratio of the maximum power radiated by the aerial under test to the maximum power radiated by the reference aerial.

5 : 3 *Resonant Aerials – the Dipole*

A resonant aerial can be considered to be a tuned LC circuit with resistance. The frequency to which the aerial is tuned is determined by the length of the wire or rod. An aerial tuned to a frequency of 300 mc/s will be 1 metre in length.

The most common aerial in use today is the half-wave dipole.

FIG. 5:2. Polar diagrams of a Hertzian dipole in both planes of the dipole. Polar diagrams can be plotted in terms of the amplitude of the electric or magnetic field or the radiated power. The radiated power diagram of (*a*) (which is of the electric field amplitude) is narrower and more elliptical. Its vectors are 0·5 instead of 0·707 of the amplitude giving the same beamwidth. In (*c*) and (*d*) the polar diagrams of a horizontal array of dipoles used by C. H. Barrow are shown.
(*e*) and (*f*) after J. D. Kraus. The passage of a source across an aerial modifies the polar diagram. The larger the source the greater the modification. The source distribution is said to have been 'smoothed'. There is always some smoothing and it is not possible to completely replace all the information. It is a function of the observing technique in terms of the aerial resolution (i.e. beamwidth).

Its length is equal to half the wavelength of the radiated wave in a perfect space known to the physicist as 'free space'. The current in the aerial causes the electric and magnetic fields to be radiated into space. A Marconi aerial is a quarter wavelength long and erected vertically. It utilizes the earth for its action. In order to radiate, the current has to be distributed along the half wavelength aerial (Fig. 5:3); it will be noticed that the terminals of the aerial are in the centre. They are centralized in order to provide the correct distribution of current. The maximum of current is in the centre of the system. It is noticeable that the voltage at the terminals is zero. The ratio of voltage to current in the alternating current circuit is the impedance and in aerial circuits the impedance is of importance.

FIG. 5:3

These considerations have been for a half-wave dipole. If this same dipole is now used at twice that frequency or operates at one wavelength and not a half, the distribution of current and voltage changes. In the first case the aerial is 'current fed', in the second case it is 'voltage fed'. When the frequency is three times the fundamental the element reverts to being 'current fed'. There is thus a change from a low to high impedance on even multiples of the operating frequency.

Since the aerial is a resonant circuit it will respond to a definite bandwidth. It can be shown that a thick dipole has a wider bandwidth than a thin one. But the impedance is different. At resonance a thin dipole has an impedance of about 70 ohms but its length is a little less than the free space wavelength. The thick dipole impedance is lower than 70 ohms at the tuned resonant frequency. The effect of applying a frequency just off resonance to the dipole is to alter the current distribution in the aerial and thus distort the shape of the polar diagram.

In radio astronomy the bandwidth of the aerial may need to be as much as 10 mc/s for the radiometer but in the interferometer it can be less than 1 mc. At the longer wavelengths, say

18 mc/s, wire dipoles of the order 7/22 swg phosphor bronze may be used and aerials of this construction will operate quite satisfactorily up to about 100 mc/s. Above this frequency (which corresponds to a wavelength of 3 metres or nearly 10 feet), the half-wave dipole (5 feet) becomes a reasonable prospect for copper tubing.

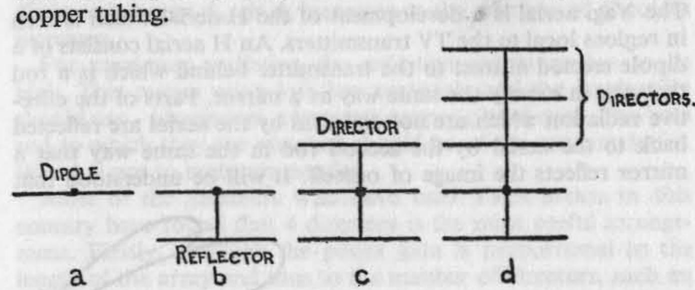


FIG. 5:4

Television aerials are constructed from alloy tubing which gives rigidity to the structure. Set on an equatorial mounting they can be easily steered. Tubing also decreases the losses, with wire dipoles the losses increase as the frequency increases. A novel Yagi aerial which used $\frac{1}{2}$-inch angle aluminium has been used quite successfully by the writer.

5 : 4 *Matching*

An aerial is a device for radiating power. It has its own characteristic impedance. It can therefore, be considered as a load connected to a generator. The means of connecting the load to the generator is a transmission line. In order for the power available at the output terminals to be transferred successfully, the impedances of the load, generator and transmission line all have to have the same value. Whilst coaxial cable can be made to have a value of about 70 ohms, the addition of directors and reflectors to the dipole element may alter the impedance. It is, therefore, necessary to insert a device between the transmission line and the aerial. This device has to make the aerial 'look like' the impedance of the transmission line and the impedance of the transmission line 'look like' that of the aerial in the other direction. There are numerous ways of matching aerials to transmission lines. It must also be remembered that the transmission line has to be matched to the receiver at the other end.

In radio astronomy where the characteristics of the aerial array have to be known and where a high degree of stability is necessary, good and efficient matching is essential. In the simple circuits suggested in the previous chapters there is little difficulty in achieving this aim.

5 : 5 *The Yagi*

The Yagi aerial is a development of the H aerial which is seen in regions local to the TV transmitters. An H aerial consists of a dipole erected nearest to the transmitter behind which is a rod that acts in exactly the same way as a mirror. Parts of the effective radiation which are not collected by the aerial are reflected back to the aerial by the second rod in the same way that a mirror reflects the image of oneself. It will be understood that

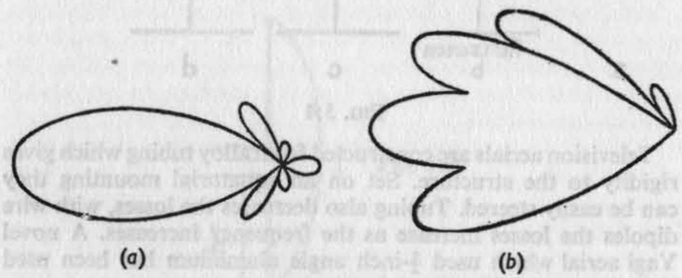


FIG. 5:5

the reflector has to reflect back waves which are in the same phase as those being received at the dipole. If the received and reflected waves are out of phase the signal strength will be reduced. The addition of the reflector alters the impedance of the system if it is not within the range $\frac{1}{8}$ to $\frac{1}{4}$ of a wavelength away from the reflector. It seems that most commercial manufacturers use a distance of 0·25 wavelength although the gain can be increased if it is moved to about 0·15 of a wavelength.

When a rod is placed in front of the dipole it guides the radiation to the aerial element and greatly increases its directivity. A typical pattern is shown in Fig. 5:5 (*a*) for a Yagi. Rods placed in front of the aerial are called directors. Both the directors and the reflectors are 'parasitic' elements.

Introducing parasitic elements into the system causes variations in the terminal impedance of the driven element. Further, it is necessary to make the directors slightly shorter and the reflectors slightly longer than the aerial for effective operation.

The aerial designer has another useful concept, that of the radiation resistance. This is the measure of the useful power and not that lost in the system. At the high frequencies the close spacing of the parasites with the main element causes more

losses and in arrays of four or more elements (e.g. 3 directors, aerial, 1 reflector) it is necessary for the spacing to be reasonably wide. At 38 mc/s useful dimensions for optimum working are shown in Fig. 5:6. Variations in the distance d_2 are a function of the number of directors used but in all the other cases the distance between d_4, or d_5 increases as the number of directors increases.

For maximum radiation the radiation resistance has to be high. This means using low loss materials and the conductors should use – aluminium, copper or copper-plated steel. The base rod to which they are attached should be of the same material. Wood is not to be recommended.

Most of the amateurs who have used Yagis arrays in this country have found that 4 directors is the most useful arrangement. Firstly, although the power gain is proportional to the length of the array and thus to the number of directors, such an array tends to be more temperamental and considerable adjustment of the lengths is required to get the best operation. Secondly, if the aerial is made too long it becomes mechanically unstable particularly when it is used in an array of Yagis. But they are difficult to adjust and it is easy to distort the radiation pattern (Fig. 5:5 (*b*)). The extra lobe easily produces false readings.

The simplest array used for successful observations has been Osborne's. Hyde and Heywood have tended to use more complicated (i.e. in number of yagis) to obtain a greater directivity.

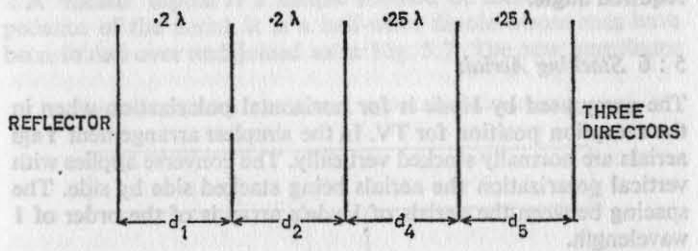


FIG. 5:6

Hyde's first system used close stacked Yagis but these were discarded in 1953 in favour of 1 wavelength of spacing in quadrature. The first experimental system of the British Astronomical Association, Radio-electronics section, used this design. An illustration of this array is shown in Plate 4. It was designed for observing the sun on 200 mc/s. It was also tried by Hyde mounted on a tower. In construction a chicken wire reflector is stretched across the base which has a wooden frame. The frame is mounted by means of U-clamps to a cylindrical boom which is fixed across the top of the tower in the east-west plane. By means of ropes attached to the outer points of the frame it is possible to provide for complete north and south steerage in altitude. It is of interest to note that this particular apparatus was used in a typical suburban district and suffered little interference. The tower was also constructed of wood and stood 15 feet above the ground. A steel tower has advantages if the array can be mounted far enough away from it to prevent the structural pieces of the tower acting as 'loss' elements. In the completely vertical position when the aerials are looking at the zenith this is no problem. Using them for TV, however (i.e. when they are horizontal), does provide problems. Mid-way, at say 54°, the reflector acts as a screen. The steel tower has the advantage that prior to erection it is possible to lie it on the ground with the array attached and assembled so that the whole arrangement can be hauled upright.

It is not necessary to use a tower in 'clear' country localities where there is plenty of space away from electrical sources of interference. With a baseline of 200 wavelengths it is possible to mount the same array on a trestle as in the portable interferometer used for schools. It is not so easy, however, to steer this array.

In neither case is it possible to steer the array to minutes of arc. Large blackboard-type protractors were used with simple plumb lines to bring the system to within a degree or so of the required angle.

5 : 6 *Stacking Aerials*

The array used by Hyde is for horizontal polarization when in the reception position for TV. In the simplest arrangement Yagi aerials are normally stacked vertically. The converse applies with vertical polarization the aerials being stacked side by side. The spacing between the aerials of Hyde's array is of the order of 1 wavelength.

Amateurs in this country have tended to use other types of aerial below about 100 mc/s. The Yagi becomes very large below this frequency and spacings increase. For example, the spacing at 38 mc/s between the individual aerials would have to be of the order 25 feet.

There is a convenient way round this problem which involves the use of matching techniques and this is to stack them with a half-wave space between the aerials in 'paired' and not quadruple stacks.

It is not always undesirable to have small spacing between the aerials because stacking can have the effect of increasing the

number of side lobes. In radio astronomy the side lobes should be kept relatively small so the design criterion is one of small side lobes versus gain. To obtain no side lobes a spacing of $1\frac{1}{2}$ wavelengths is required which gives a beamwidth of 20° increasing to 30° at 1 wavelength. With small side lobes the situation rapidly changes for the single stack (i.e. two aerials) to 30° for a spacing of $1\frac{1}{2}$ wavelengths. Thus at small beamwidths the 'no side lobe' condition may not bring about any increase in the gain hence the choice of 1 wavelength in Hyde's original array.

However, there are other more suitable arrays for the lower frequencies. Single Yagis operating at 20 mc/s and 40 mc/s have been used for observing satellite signals and at 36 mc/s for meteor work.

In order to increase the directivity of the system by stacking, it is necessary that each Yagi should be identical with the other. It is essential that the aerial element should be matched to the line and that all of the aerials in the array should be correctly matched.

5 : 7 *Impedance of the Yagi Aerial*

The effect of introducing parasitic elements into the system is to lower the impedance of the dipole. This means that there has to be a step-up matching device between the aerial element and line.

A 'folded' dipole is a simple method of increasing the impedance of the aerial. It is a half-wave dipole whose ends have been folded over and joined as in Fig. 5:7. The new impedance

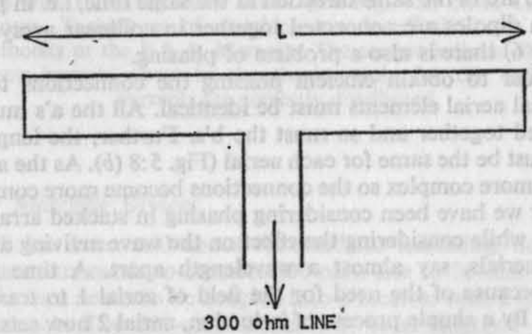


FIG. 5:7. Many TV aerials use folded dipoles. L = 468/Frequency (mc/s). Its impedance is 4 times that of a simple dipole. It also responds to a wider band of frequencies. Addition of reflectors and directors alters the impedance. TV Yagis are connected directly to 75 ohm transmission line.

is four times that of the simple dipole. By itself the folded dipole can be made to have an impedance of the order 300 ohms and is therefore suitable for use with twin-lead transmission line. The effect of the parasitic elements is to reduce the impedance back to its original value. Successful results have been obtained by coupling coaxial cable directly to the aerial terminals.

It is however, possible for a 300-ohm line to be matched in to 300 ohms at the element. This is achieved by making the element of small diameter, say, $\frac{1}{4}$-inch tubing and connecting it to a parallel section of 1-inch tubing, i.e. the two sides of the fold have different diameters. Doubtless most amateurs who are more keen on obtaining observations will be content with the simple fold.

An amateur using Yagis will undoubtedly profit by using the folded dipole which may be connected directly to coaxial cable. As the frequency increases, however, it might be thought advisable to change back to an open-wire transmission line in order to increase the efficiency of the system.

5 : 8 *Phasing*

It will have become clear that most radiotelescope arrays apart from the parabolic reflector, employ a number of aerials. Generally dipoles either in series or as part of the unit of a Yagi stack.

If the currents in the array are not in phase they will not add to each other and the net result at the output terminals will be nil. It is important to ensure that all the currents in the various elements are in the same direction at the same time, i.e. in phase.

When dipoles are connected together in collinear arrays (see Chapter 6) there is also a problem of phasing.

In order to obtain efficient phasing the connections to the individual aerial elements must be identical. All the a's must be connected together and so must the b's. Further, the length of cable must be the same for each aerial (Fig. 5:8 (*b*). As the arrays become more complex so the connections become more complex.

So far we have been considering phasing in stacked arrays. It is worth while considering the effect on the wave arriving at two spaced aerials, say almost a wavelength apart. A time lapse occurs because of the need for the field of aerial 1 to travel to aerial 2. By a simple process of induction, aerial 2 now sets up a field which induces a current at a still later period of time in aerial 1. For the currents in the two aerials to be in-phase they must reach their maxima and minima at the same instant. If there is a time lag there will be a difference in phase between the two aerials. It can be shown that this difference in phase depends

on the distance apart (in wavelengths) of the two aerials. In closely spaced aerials this can cause a 'detuning' of the first aerial. In widely spaced aerials this principle of phasing is the basis of the radio interferometer.

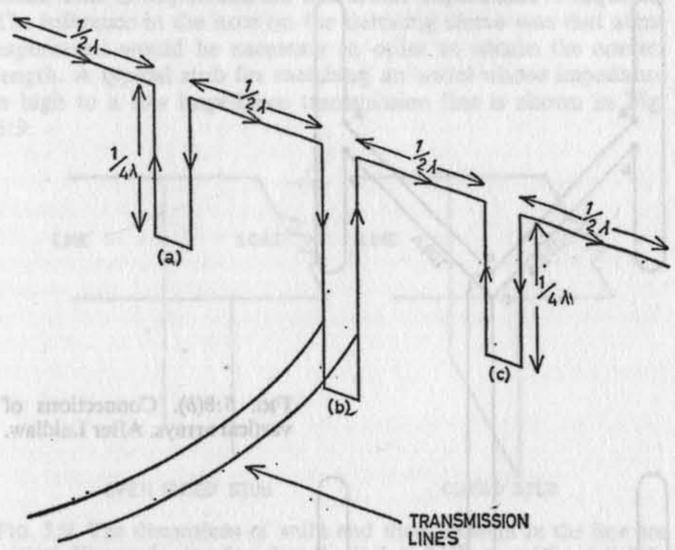


FIG. 5:8(*a*). Arrays of dipoles like this can be used in horizontal arrays with reflecting wires below (see Fig. 6:2) or in Corner V - reflectors, Techniques of matching are described in the A.R.R.L. Handbooks or the B.A.A. Memoirs. The arrows indicate direction of currents brought about by the phasing stubs (*a*), (*b*), and (*c*). The currents are correctly distributed.

5 : 9 *Matching Devices*

Much has been said about the need for matching. Sometimes the amateur needs to connect 300-ohm line to 75-ohm line and this in turn needs to be coupled into a receiver with a high input impedance. The 300-ohm feeder will be a balanced two-wire transmission line whilst the 75-ohm line may well be coaxial and thus unbalanced. A transformer for matching 300 ohms to 75 ohms will require a turns ratio of 4 : 1.

The simplest device for the 'wire' half-wave dipole is to feed it with a twin-wire transmission line of 75 ohms characteristic impedance. The wires of each section of the dipole are connected to a central insulator and the ends of the twin feeder are soldered to the two sections as close as possible to the insulator. Their shape should be as 'Y' to the line, the arms of the 'Y' being made as short as possible. At frequencies above 30 mc/s the coaxial

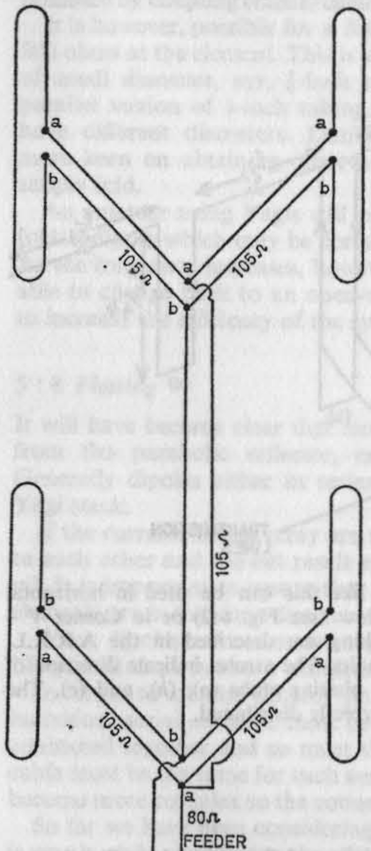


FIG. 5:8(*b*). Connections of vertical arrays. After Laidlaw.

cable should not be connected directly through a 'Y' match to the dipole although it is possible to do this below this frequency. The 'Y' match should only be used at the fundamental frequency of the dipole or odd multiples.

There are many matching arrangements: only a few details are given. Two others are worth mentioning, the matching stub and the 'U' coaxial balun. These have been used extensively in professional and amateur arrays.

The matching stub is simply a length of line inserted in a transmission line which has its ends either open or short-circuited. Although, as with any transmission line, a factor known as the 'standing wave ratio' will have to be measured, once this is known the matching stubs can be fitted to empirically determined directions. This is important, for no further experiment is required. The inference in the note on the detuning sleeve was that some experiment would be necessary in order to obtain the correct length. A typical stub for matching an aerial whose impedance is high to a low impedance transmission line is shown in Fig. 5:9.

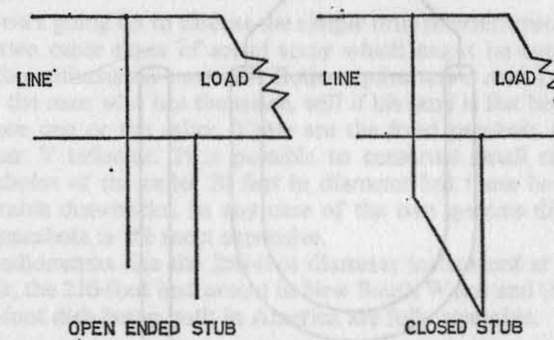


FIG. 5:9. The dimensions of stubs and their location in the line are critical. The reader is referred to the *B.A.A. Memoirs* or the *A.R.R.L. Handbook* for detailed discussions.

A 'U'-type coaxial balun is shown in Fig. 5:10. It has the practical advantage of enabling an insulated line to be connected to the aerial. This prevents any short circuiting that may arise with an open line. Another balun at the end of a short length of coaxial line can be connected to a balanced open wire feeder. In interferometer arrays this system is advantageous since large aerial spacings necessitate long transmission lines. Above 300 mc/s the losses in coaxial cable increase and the standard TV installation line is not satisfactory. Higher quality coaxial cable is correspondingly more expensive. The dimensions show that the 'U' balun is simply a $\frac{1}{2}$ wavelength of coaxial cable folded into a 'U'. Its impedance ratio is 4 : 1. The length of the line connecting the two baluns must be a multiple of half a wavelength.

In phase-switching interferometers pre-amplifiers should be inserted at approximately the same electrical distance from the aerial centre at each array for ease of operation.

Finally, the gain of corner reflectors and horizontal arrays can be increased by using rows of dipoles. These provide an interesting experiment in matching. All of the aerials have to be fed in phase. A block schematic diagram of an array used by Barrow is shown in the next chapter. (Fig. 6:2).

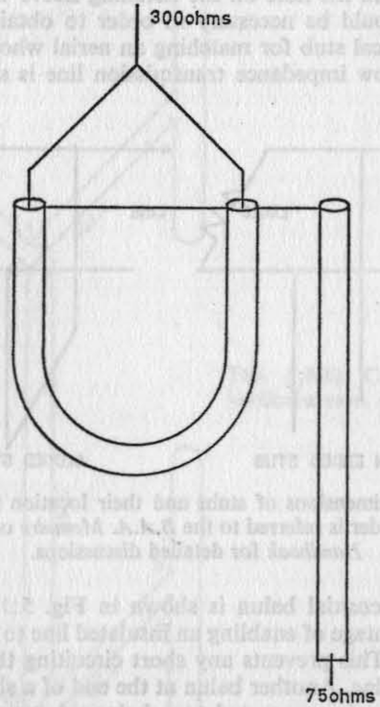


FIG. 5:10. The illustration shows a U-type coaxial Balun for matching balanced to unbalanced lines of different impedance, in this example 300 ohms to 75 ohms. The outer sheaths of the coaxial cables are connected together. The ratio of impedance is about 4:1. The folded cables are 75 ohms. The length of the fold (U) is $\frac{1}{2}\lambda$, (It may be calculated from:

$$L = \frac{0{\cdot}65\lambda}{2})$$

Note that because the phase velocity of coaxial cable for an electro-magnetic wave is different from that of the same wave in free space that one wavelength of cable for a given wavelength is in reality shorter than actual wavelength of operation. Conversion Tables can be found in the *A.R.R.L. Handbook*.

CHAPTER SIX

Other aerial arrays and the drift interferometer

6 : 1 *Introduction*

BEFORE going on to discuss the simple drift interferometer there are two other types of aerial array which might be considered by the enthusiastic amateur. Both require space and I assume that the man who has the space, will if his land is flat be able to choose one or the other. These are the fixed parabola and the corner V reflector. It is possible to construct small steerable parabolas of the order 20 feet in diameter but these have considerable drawbacks. In any case of the two systems discussed the parabola is the most expensive.

Radiometers like the 250-foot diameter instrument at Jodrell Bank, the 210-foot instrument in New South Wales and the giant 600-foot dish being built in America are fully steerable.

6 : 2 *The Parabola*

Parabolic aerials and radiotelescopes go together. This is the fault of the Jodrell Bank giant and the point will receive even greater emphasis when the 600-foot (diameter) colossus is erected in the United States.

Although it has many disadvantages, not least of all its 'sail' properties under severe wind and icing conditions, it also has many advantages. Perhaps its most important advantage is that it is fully steerable.

The Jodrell Bank instrument was, however, preceded by a fixed 218-foot diameter parabola with a long focus. This instrument was one of those used in the pioneer days of radio astronomy and it made many fine observations. This author has long felt that amateurs could build similar parabolas, perhaps not 218 feet in diameter but at least 100 feet in diameter. Even at the half size the amateur would be able to verify for himself some of the historical observations that have been made.

With a parabola the beamwidth is a function of the bowl diameter at the frequency of operation. The lower the frequency the wider the bowl diameter. At the same time it is possible to use the parabola at a number of different frequencies. The limitations of a solid mesh bowl are the profile tolerance at the high frequency end and the diameter at the lower frequencies. An open wire mesh bowl is also limited at the high frequencies by the diameter of the mesh. Successful results can be obtained from a 'chicken wire' mesh although there is also the difficulty of maintaining an accurate profile over the whole surface of the bowl. Apart from the lack of 'steerability' the problem of maintaining the profile shape with a wire mesh was a deciding factor in constructing the steerable instrument at Jodrell Bank.

Weather conditions alter the profile whose distortions should be kept well within the dimension proportional to one-eighth of the wavelength of operation.

The supporting masts can be of wood or steel but it is clear that some fairly accurate surveying will be required to maintain the peripheral shape of each ring of masts.

Fixed parabolic instruments of this type can be made slightly steerable by tilting the mast. A different strip of the sky can then be scanned. However, this technique has considerable limitations one of which is that the polar diagram becomes distorted.

The ambitious beginner should not be thwarted by these limitations but should go ahead for many observations can be made even with a distorted profile. What he has to do, however, is to remember these limitations for they impose severe restrictions on his observations. He must also remember that radio astronomy is a science which has had a very rapid evolution. Thus for satisfaction the amateur will have to compare his results with early observations. Instruments of this type are particularly useful for making (1) continuous measurements of the flux density of discrete sources (see Chapter 9), and (2) observations of the galaxy.

There are three possible positions of focus, long, in the plane of the bowl periphery and short (Fig. 6:1). The bowl depth varies with focal length. The most satisfactory position is that in the

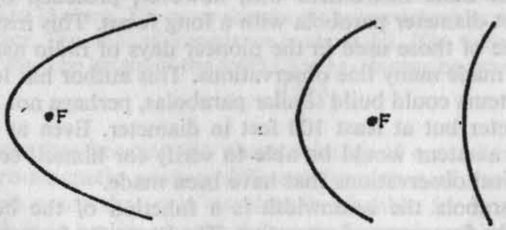


FIG. 6:1

plane of the bowl periphery. However, this will increase the bowl depth. The long focus is therefore the best bet, although much of the radiation will be lost as it overspills.

The long focus instrument also provides mast design problems. If a very thin mast is used large aerials and apparatus cannot be supported at the top. It will also suffer from considerable wind 'whip'. However, V.H.F. taxi radio masts are becoming a familiar sight and providing that the transmission line is not too long can be used to support the aerial alone. A small mast head amplifier will not disturb the equilibrium. Transistors will operate satisfactorily below 100 mc/s.

A steel lattice mast is probably the best bet. It should be able to carry the noise source, frequency changer, intermediate frequency amplifier, detector and line amplifier. This is not necessary and is a matter of preference and easy access. These can feed into a cathode follower matched to a coaxial transmission line. The remaining equipment and pen recorder can then be housed under the bowl.

The best range of frequencies will be 200 to 300 mc/s. Horizontal dipoles with a reflector should be used: one has to get used to the idea that the reflector is nearest to the sky because the aerial element is receiving the reflected radiation from the bowl.

Smaller but not so useful steerable parabolic reflectors can be built by the amateur. K. Stevens of Derby has constructed a steerable parabola (20 ft. diameter) which is erected in his back garden.

However, the smaller the bowl, the shorter the wavelength of operation, the more stringent the profile conditions. Similarly, for satisfactory results very high frequencies will have to be used and not only does the profile become more difficult to achieve but the electronics become difficult.

6 : 3· *Horizontal Arrays of Dipoles*

These are perhaps the most simple of all the arrays to erect. Barrow has had considerable success with these at the lower frequencies between 18 and 30 mc/s. A large array could be obtained at 38 mc/s. They are best described by illustration which show an array of 4 dipoles erected above a curtain of wire reflectors. Dimensions are given on the diagram. Barrow used his arrays for observations of Jupiter. Fig. 6:2.

Sander also used a collinear array of four horizontal dipoles to make his measurements of galactic radiation at 60 mc/s. They were erected an eighth of a wavelength in front of a wire mesh screen. (Chicken wire will do.) The centres of the dipoles were 2·9 metres apart.

In matching the dipoles to the line Sander first made a 'transformation' to his normal line impedance. He then connected the aerials together in a series-parallel arrangement so that the impedance was not altered. Sander himself ran into some difficulties because of the impedance value of his transmission line. The problem of phasing is discussed in the previous chapter.

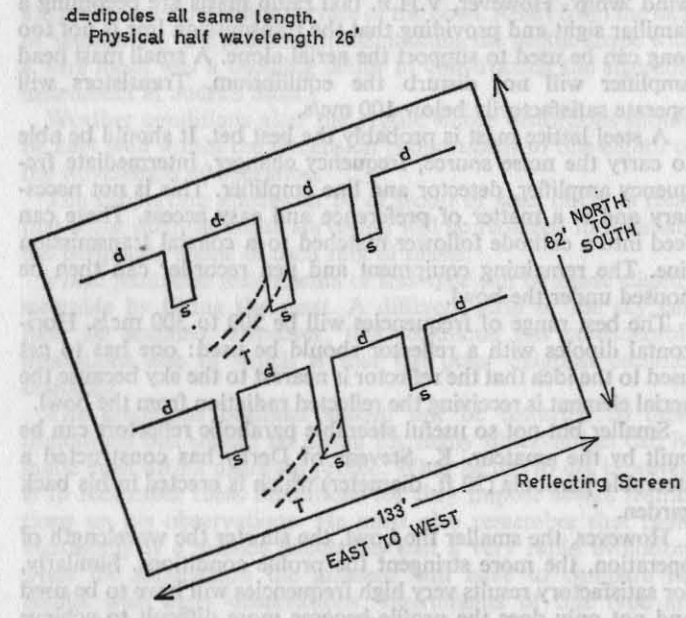


FIG. 6:2

In collinear arrays of dipoles such as these the beam is at right angles to the array.

(Definition – a collinear array is an aerial array in which the elements are all operated in the same phase. It is a 'broadside' aerial if the maximum directivity is at right angles to the line of the elements in the array.)

6 : 4 *The Corner V Reflector*

Below 80 mc/s by far the most popular array used by amateurs has been the corner V reflector. The corner V is an offshoot of the parabola and is not quite so efficient. At Cambridge the aperture synthesis array for 38 mc/s utilizes this principle as well as the 'patent angle iron' method of construction.

F. W. Hyde has used a timber frame making the instrument fully steerable in altitude. The first design of the radio-electronics section used a fixed wooden frame and is illustrated in Fig. 6:3. Wire reflectors (7/22 swg) are stretched across between the supporting masts and booms. In the arrangement erected by Barnes the booms were removed and the ground half of the reflector constructed by connecting the wires to stakes at either end.

In these arrays the corner angle is 90°, hence the term 'square corner', but it is possible to use angles of 60° and 90°. If the angle that the plane through the aerial to the corner junction makes is altered (alpha), an increase will lower the elevation of the beam whilst a decrease will increase the elevation. There is no reason why the reflector should not be of wire netting although this is much more expensive and difficult to stretch tight between the masts but not along the ground via wooden stakes. Since the dimensions of the corner reflector are not very critical wire reflectors spaced at about a tenth of a wavelength will be equally satisfactory. The connections between the dipoles are similar to those of the horizontal array of dipoles and the same matching techniques are used.

Around about 50 mc/s the aerial could be built into two sections standing side by side in a relatively small space. Considerable gain could be achieved with the 8 dipoles and the array would be most suitable for the radiometer. In this country amateurs have used the corner reflector as one section of a two

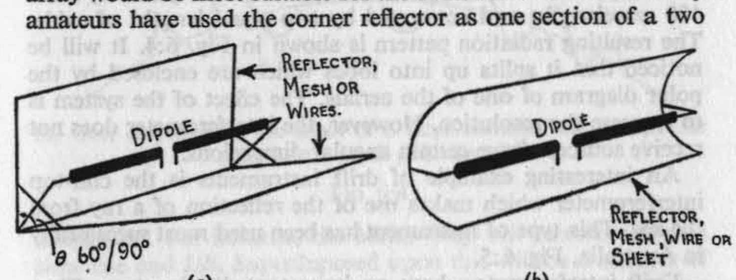


FIG. 6:3. From a paper by F. W. Hyde in the *B.A.A. Memoirs*.

aerial phase switching interferometer. The fixed aerial of the 38 mc/s aperture synthesis array at Cambridge is simply one long corner V with a large number of dipoles.

To summarize these notes: aerials in radio astronomy are usually designed for specific tasks. The rhombic with its wide beam has its place in solar radio astronomy because it presents the same characteristics over a wide range of frequencies and so allows the receiver to scan this range rapidly. Large parabolas would be wasted on such work for they are used more for radar techniques and particular observations on the distant discrete sources. All of the aerials discussed can be used as one section of an interferometer array.

★6 : 5 *Terminology and Introduction to the Interferometer*

It is not necessary for all instruments to be steerable since the aerial can be pointed at the sky and simply steered by means of the earth's rotation. Since the earth both rotates and revolves it will be apparent that the fixed aerial scans a strip of the sky. When aerials are fixed they are prefixed with the word 'drift' since their movement is controlled by the earth's motion. A drift radiometer is a radiotelescope whose beam is fixed in space. Care has to be used in radio astronomy with terms. An example is the Mills Cross array. This is a pencil beam system but of the unfilled aperture type which can also combine the usefulness of phase switching.

Radio interferometers are high resolution systems using two or more aerials. They use the principle of interference between the rays arriving from the same source at two aerials connected to a receiver. Sometimes the output from the two aerials is out of phase and at other times it is in phase depending on the distance between the aerials (i.e. path lengths from the source). The simplest form of interferometer is two aerials spaced by some 100 wavelengths and connected by two equal lengths of cable. The resulting radiation pattern is shown in Fig. 6:4. It will be noticed that it splits up into lobes which are enclosed by the polar diagram of one of the aerials. The effect of the system is to increase the resolution. However, the interferometer does not receive sources above certain angular dimensions.

An interesting example of drift instruments is the cliff-top interferometer which makes use of the reflection of a ray from the sea. This type of instrument has been used most successfully in Australia. Fig. 6:5.

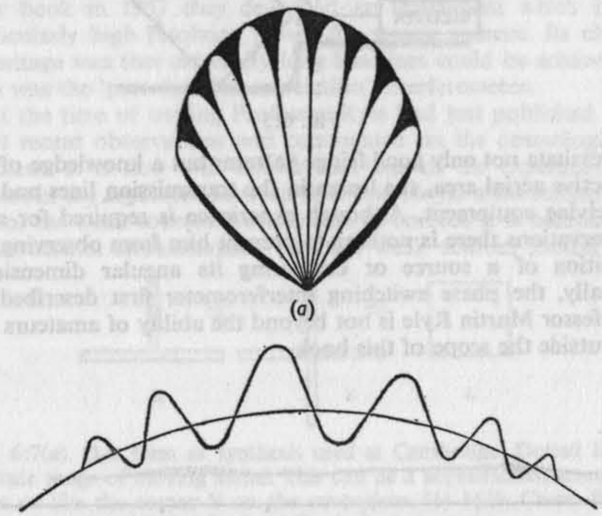
Drift interferometers have an important disadvantage. They receive the background radiation. This background radiation arises from the intense belt along the galactic plane, the surrounding envelope about the galactic disc sometimes known as the halo and numerous extra galactic weak sources.

As the weak distant sources contribute but a fraction of the total received radiation it is clear that in one way or other the background radiation is going to interfere with the observations. It appears as an extended source the small sources being superimposed on the recording.

If we refer again to the diagram Fig. 6:4 and consider the large lobe due to one of the aerials the reader will probably appreciate that in the output of the instrument is a total power component.

The reader will not, however, appreciate or for that matter be expected to appreciate, the reasons why a phase switching interferometer gets rid of this total power component. He will, however, appreciate its significance for it has to be removed if small sources are to be observed.

When a source is large compared with the aerial beamwidth it causes the interferometer to act similarly to a total power



(b) Over emphasizing the effect of a large extended source like the galaxy on a small point source[1]

FIG. 6:4

instrument. For instance, the Milky Way will be recorded as a slow rise and fall. Superimposed upon this will be a number of small patterns (Fig. 6:6) due to the interferometer receiving small sources. A source of the dimensions of the Milky Way radiation is sometimes called an extended source and said to be completely resolved.

An important difficulty arises with very long base lines for the transmission line losses increase. In the drift interferometer it is not possible to use radio frequency amplifiers in the lines because it becomes difficult to adjust the phases of the two lines. Another advantage of the phase switching interferometer is that it enables the use of pre-amplifiers.

[1] This problem is discussed in detail in *The Exploration of Space by Radio*. Sir Bernard Lovell and R. Hanbury Brown.

No amateur should, without considerable knowledge of electronics, attempt to measure the flux density of a source with an interferometer. Whilst it is possible to make simple relative comparisons with sources on the same record, absolute values

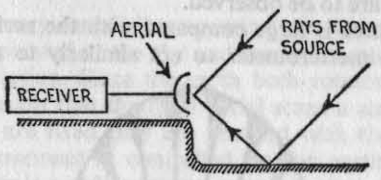


FIG. 6:5

necessitate not only good fringe patterns but a knowledge of the effective aerial area, the losses in the transmission lines and the receiving equipment. Although experience is required for such observations there is nothing to prevent him from observing the position of a source or estimating its angular dimensions. Finally, the phase switching interferometer first described by Professor Martin Ryle is not beyond the ability of amateurs but is outside the scope of this book.

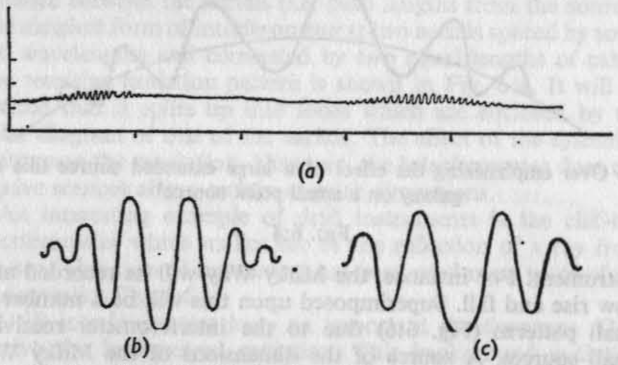


FIG. 6:6. An alternative illustration of the total power effects of the Milky Way as the drift interferometer scans two sources. A phase switching interferometer is not affected by 'extended' sources like the Milky Way and shows up the discrete sources more sharply as in (*b*) and (*c*)

The minimum distance between aerials for reasonably successful results is about 8 wavelengths. A useful distance is about 20 wavelengths. It was mainly for this reason that amateurs first worked at 240 mc/s. Effective spacings can be obtained with relatively small aerial systems.

It is necessary to keep the lengths of the cables exactly equal.

If one line is shortened the lobe moves away from its position at right angles to the base line and begins to rotate. Automatic means are introduced in the rotating lobe interferometer to alter the phase of one of the lines. The total power component of the background is also removed in this instrument. Its other advantage is that the speed of the fringes can be controlled.

When Sir Bernard Lovell and Professor Hanbury Brown wrote their book in 1957 they described an instrument which had particularly high resolving power for strong sources. Its chief advantage was that extremely long baselines could be achieved. This was the 'post-detector correlation' interferometer.

At the time of writing Professor Ryle had just published his most recent observations and commented on the cosmological problem. It is now well known that one of the experimental factors in the argument between Ryle and Hoyle is the minimum size of the weak sources. For Ryle to be correct, it is necessary, under certain circumstances, that his weak sources should be

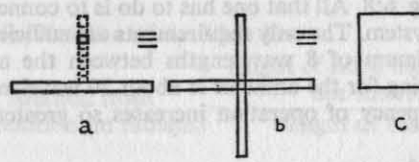


FIG. 6:7(*a*). One form of synthesis used at Cambridge. Dotted lines indicate range of moving aerial. This can be a sophisticated arrangement or like the corner V on the coverpiece. (*b*) Mills Cross. Both aerials are fixed. (*c*) Equivalent aperture.

above a certain minimum angular diameter. To detect sources, therefore, which might be below these minimum dimensions, one requires to have interferometers with extremely wide base lines which may well be improvements on the post-detector correlation technique. Professor Hanbury Brown is at present using an interferometer with a base line of 40 miles in the east-west direction.

An interesting type of interferometer was introduced by Professor Christiansen. The original instrument used 32 aerials, each of them a parabola with dipole feed. Such instruments are particularly useful in establishing the distribution of the thermal component of the sun's radiation. This particular radiotelescope operated at 1,420 mc/s.

No summary of the various types of radiotelescope would be complete without a mention of unfilled aperture instruments (Fig. 6:7). The Mills Cross is one type. Aperture synthesis is, however, the most recent and it is with this technique that Professor Ryle and the Cambridge astronomers have located the more distant galaxies. The Jodrell Bank instrument is a filled aperture. It can be shown that if one side of a square is completed with a long array of dipoles and a single dipole is moved into all the other parts of the square, the same observations being repeated with each move, that the resolution obtained is similar to that of a parabola whose dimensions corresponded to that of the square. In fact it is not even necessary to move the dipole into each square of the chessboard. At Cambridge the high frequency aperture synthesis array employs a movable aerial on railway tracks. The results from the very many observations which have to be made are integrated and passed to a computer for analysis.

6 : 6 *A Simple Radio Interferometer*

Little or no description is required since in its very basic form the apparatus used is that already described in the chapter on the radiometer Fig. 6:8. All that one has to do is to connect another aerial to the system. The only requirements are sufficient spacing to get a minimum of 8 wavelengths between the aerials. An optimum spacing for the amateur is about 20 wavelengths.

As the frequency of operation increases so greater baselines

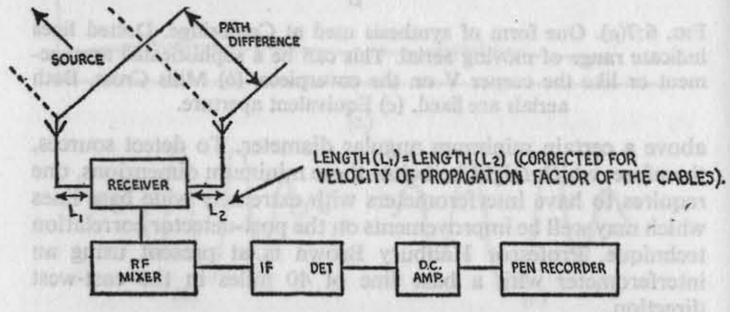


FIG. 6:8

can be achieved. Since it is not possible to use preamplifiers with the drift interferometer a limit on the spacing is imposed by the losses in the cables. Open wire transmission lines are to be preferred to coaxial cable. This may necessitate extra matching lengths. At the same time it is necessary that the lines from the two aerials shall be of equal electrical length. Preamplifiers may be used with a phase switching amplifier, the baseline can then be increased.

In addition to making observations with a fixed baseline

interesting results can be obtained if the length can be varied. The shortening, or lengthening of one of the lines rotates the aerial beam from its normal position at right angles to the baseline.

As the electronic system is no different from that of the radiometer the amateur will be more concerned with the interpretation of the results and the calculation of the lobe width in the central position.

6 : 7 *Width of the Central Lobes*

$$\text{Angular width of the central lobe (in radians)} = \frac{\text{Wavelength of operation}}{\text{Length of baseline}}$$

The widths of the lobes decrease at the edges of the pattern and are only unimportant when strong sources such as Cygnus A are being observed.

6 : 8 *Angular Rotation of the Main Beam*

$$\text{Angle of rotation from normal position (in radians)} = \frac{\text{length of extra transmission line inserted}}{\text{length of baseline}}$$

6 : 9 *Uses of the Drift Interferometer*

Drift interferometers were intended for three functions:

(i) the determination of the position of the source;
(ii) the derivation of information concerning the angular size of the source;
(iii) the derivation of the flux density of the source.

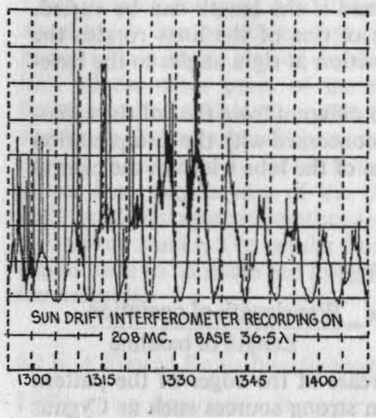
Osborne in several articles has given very satisfactory results for the first with his simple instrument and also discussed the difficulties inherent in obtaining satisfactory measurements of the angular size or the flux density.

His position in declination for Cassiopeia A was 57° 3′ compared with the accepted value of 58° 32′. Fortunately there is a simple equation for deriving the declination which involves the use of trigonometrical tables but not trig!

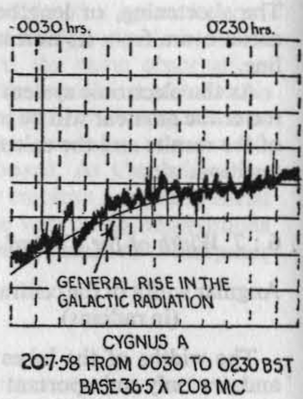
$$\text{Cos d} = \frac{n\lambda}{d \sin H_a}$$

Where n is the number of lobes in the pattern, d is the baseline, H_a the hour angle and λ the wavelength of operation.

The declination is determined by the speed at which it crosses the meridian. A measurement can be made if two instants of



6:9



6:10

FIG. 6:9. Reproduced by permission of the editor of the *Short Wave Magazine*.

FIG. 6:10. Reproduced by permission of the editor of the *Short Wave Magazine*.

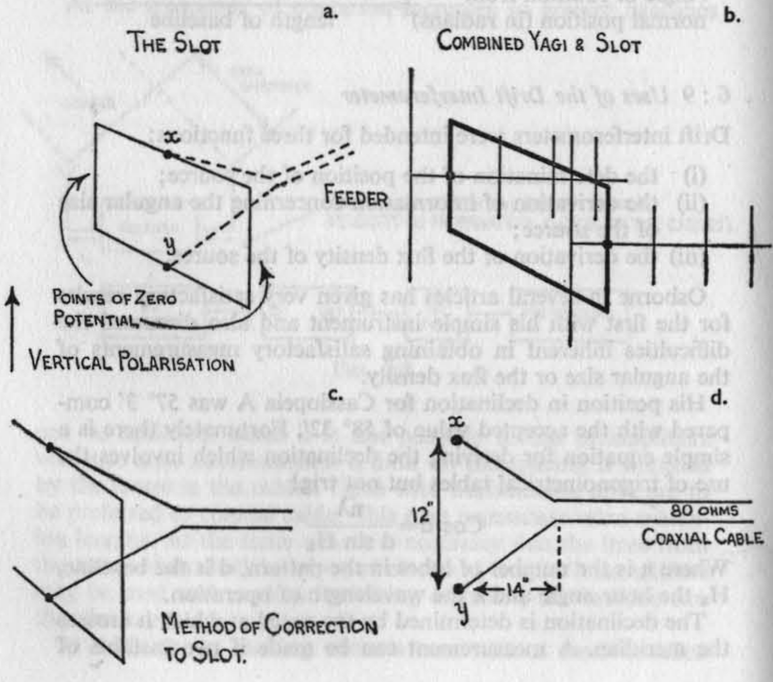


FIG. 6:11

time are measured, t being the first and t_1 the second during the passage of the source across the meridian. So that

$$\text{declination } \delta = \cos^{-1}.\frac{t}{t_1}$$

A detailed analysis of this equation is given by Osborne.

Finally the determination of position requires a knowledge of the right ascension. The right ascension is determined from the time at which the central lobe of the pattern is observed.

Two recordings made by Osborne are shown in Fig. 6:9 and Fig. 6:10. Connections to the 'slot' aerial used in these observations are illustrated in Fig. 6:11.

CHAPTER SEVEN

The radio sun

7 : 1 *Introduction*

THE sun should be the paradise of the amateur radio astronomer. Besides being the nearest star it is an active radio emitter. It is studied by both radio and visual observers in two forms – the quiet and the active. Sunspots, some of which are large enough to be seen by the naked eye, are typical features of solar activity. The area of the solar disc covered by sunspots varies from day to day, month to month and year to year, the average cycle between maxima being of the order 11 years. The chances of there being a great deal of observable activity increase as the area under sunspots increases. Whilst the active features of the sun are irregular in duration and appearance the solar atmosphere like our own is always present and is best studied under 'Quiet' conditions, i.e. when the sun is not active.

Radio emissions from the sun are characterized by a background level of radiation upon which are superimposed bursts. This activity, too, increases with increasing solar activity, i.e. as the solar cycle approaches sunspot maxima. It is of interest to discover whether the background level of radiation varies with the sunspot cycle or not. Since the other radiations due to the active sun mask this basic level, it becomes increasingly difficult to say whether this level changes or not without many difficult and tedious observations.

It is possible to study the radiations from the quiet sun. From them a spectral curve may be derived which can be related to the emission's point of origin in the solar atmosphere. In recent years this has led to the radio study of the outer layers of this atmosphere – the solar corona, by means of experimental techniques other than direct observation.

7 : 2 *The Sun and its Atmosphere*

There are a number of excellent works on the sun and its physical nature in which the information in these short paragraphs is fully developed. The approach here is similar to the one that Professor Ellison has made in his book *The Sun and its Influence*. Fig. 7:1, a sectionalized diagram of the sun, is based on an idea of Professor Ellison.

In the same way that it is only possible to theorize about the structure of the centre of the earth, it is also only possible to theorize about the centre of the sun. Nevertheless, observations of solar activity lend great support to the pioneer work of Sir Arthur Eddington on the internal constitution of the stars.

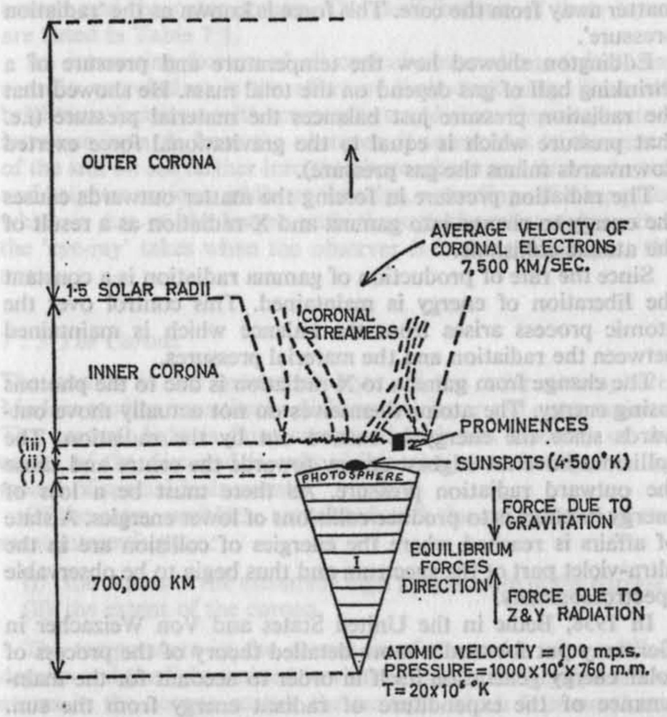


FIG. 7:1. Radio observations out to ten solar diameters and beyond. Region (i) is the photosphere, depth = 200 km. (ii) The reversing layer, depth = 1,000 km. (iii) The chronosphere, depth = 12,000 km. (I) Inner core of sun: energy from the sun is liberated in this zone.

It can, for instance, be shown that the temperature of the core is of the order of 30×10^6 degrees Kelvin. This value of temperature is a measurement of the average motion of the atoms between collisions. The figures noted on diagram 7:1 illustrate that whilst the speeds of particles are great compared with particles in the lower parts of the earth's atmosphere, the pressure is greater than the atmospheric pressure by a factor of a thousand.

The stability of the luminous system arises from the fact that the star is a shrinking ball of gas with a high internal temperature. But the temperature is above that which would arise from the simple transformation of the potential energy in the system to other forms of energy (e.g. to light). So it is necessary to assume that energetic atomic processes take place in the central core of the system. The very high temperature provides energy that drives matter away from the core. This force is known as the 'radiation pressure'.

Eddington showed how the temperature and pressure of a shrinking ball of gas depend on the total mass. He showed that the radiation pressure just balances the material pressure (i.e. that pressure which is equal to the gravitational force exerted downwards minus the gas pressure).

The radiation pressure in forcing the matter outwards causes the energy to change into gamma and X-radiation as a result of the atomic collisions.

Since the rate of production of gamma radiation is a constant the liberation of energy is maintained. This control over the atomic process arises from the balance which is maintained between the radiation and the material pressures.

The change from gamma to X-radiation is due to the photons losing energy. The atoms themselves do not actually move outwards since the energy is carried out by the radiation. The collisions have the highest energy towards the centre and cause the outward radiation pressure. As there must be a loss of energy its effect is to produce collisions of lower energies. A state of affairs is reached where the energies of collision are in the ultra-violet part of the spectrum and thus begin to be observable spectroscopically.

In 1938, Bethe in the United States and Von Weizacher in Germany put forward a more detailed theory of the process of solar energy generation itself in order to account for the maintenance of the expenditure of radiant energy from the sun. Through a carbon-nitrogen cycle helium is synthesized from hydrogen. Such synthesization provides the outward flow of radiation. Since helium has a nucleus of four protons, the problem is to explain how such a nucleus can be built up. To achieve this an abundance of free protons is required together with a stock of carbon or nitrogen. The protons will be available in the form of hydrogen nuclei: in this process the carbon or nitrogen atoms are not destroyed.

The region where the solar gases first become transparent is known as the photosphere. Most of the light and heat received at the earth's surface is from this region and its black body temperature is of the order 6,000° K. Its density is less than a thousandth of that of atmospheric air. The spectroscope sees

continuous emission lines. It is a thin layer in which the pressure decreases rapidly with height so observers see the sun as a bright object with an extremely sharp outline.

Above the photosphere which is also the region where sunspots occur lies the solar atmosphere. The divisions of the solar atmosphere are the reversing layer, the chromosphere, the inner corona and the outer corona. The chief features of these layers are listed in Table 7:1.

An interesting feature of all optical observations (which has a radio correlative) is the effect of limb darkening. Since the brightness increases with temperature and since the temperature increases inwards from the observer, it seems that at the centre of the sun we see farther into the photosphere and thus to hotter and brighter regions, whilst at the edge, a shading-off takes place which is due to the longer path through the photosphere that the 'eye-ray' takes when the observer is looking directly at the sun.

7 : 3 *The Corona*

The corona is the outermost layer of the solar atmosphere. Modern studies necessitate a division into inner and outer regions. The coronal light is faint compared with the intensity of the centre of the disc and is only visible at times of eclipse or by means of special instruments.

Of the many problems associated with the corona two of the most interesting are:

(i) the causes of the extremely high temperature in the corona;
(ii) the extent of the corona.

The temperature in the corona is of the order of a million degrees and the light emitted is white. Further, the highly ionized atoms in the corona scatter the sunlight which falls on them. The electrons are efficient scatterers of radiation and in so doing blur out the fraunhofer lines. Velocities of the order 7,500 km./sec. are required for these electrons to cause scattering; the gas temperature is of the order of a million degrees.

The corona's continuous spectrum is found to possess 29 bright emission lines. These are due to highly ionized atoms of iron, calcium and nickel. Such high degrees of ionization require high energy collisions which are only achieved in gases at temperatures of the order of a million degrees. It is notable that there are no low temperature lines and that the hottest parts of the corona appear to lie over active sunspots. It is also notable that the shape of the corona varies with the sunspot cycle (Fig. 7:2). Some astronomers believe that these rays are the trajectories of charged particles which extend as far as the earth and cause certain types of magnetic storms.

Alfven has suggested that the high temperature in the corona is due to the vertical motion of sunspots. Current flows between points of different potential which will tend to be along the lines

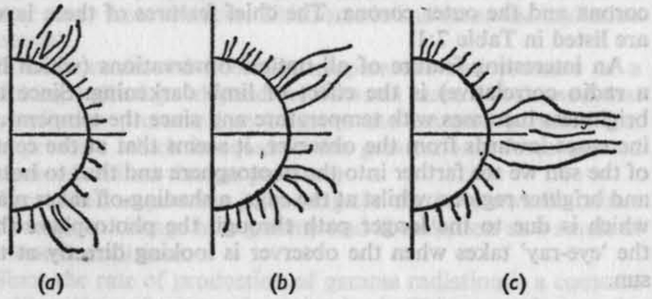


FIG. 7:2. Changes in the Solar Corona with sunspot maximum and minimum.
(*a*) Polar at maximum.
(*b*) Intermediate at middle of solar cycle.
(*c*) Equilateral at minimum. (After H. W. Newton, *The Face of the Sun*, Pelican).

of magnetic force. As some of these lines will extend into the corona these currents heat this region. The prominences may arise from such current flow (see Fig. 7:1).

Another theory due to Bondi, Hoyle and Lyttleton, suggests an external method of heating rather than internal and suggests that the sun's atmosphere catches interstellar dust as it moves through space, the attractive force of the gravitational pull causing the high velocities required to produce the high temperature.

Although it is possible to say that the great extent of the corona arises from the balancing of the gravitational pull and the high atomic velocities there remains the problem of its actual extent.

7 : 4 *Some Aspects of Radio Radiation from the Quiet Sun*

It is helpful to approach this study historically. The first attempt to measure the thermal radiation from the sun was made by Southworth in 1942.

These measurements attempted to plot the apparent disc temperature as a function of wavelength. Curves showing the distribution of radiant energy with temperature in the optical and radio regions are shown in Fig. 7:3. The first curve would occur

if the radiation was of thermal origin and originating in the photosphere. The second curve since it is markedly different indicates that the radio waves from the quiet sun do not have a 'thermal' origin in the accepted sense since the apparent temperature increases with wavelength to about 10^6 °K at 1 metre (300 mc/s). They are either non-thermal or originate in the sun's atmosphere.

Thus Martyn and Ginzburg (1946) independently of each other put forward a theory which suggested that the radio emissions from the quiet sun were due to thermal emission, but originated in the highly ionized gases of the chromosphere and corona.

The problem has two steps. Firstly, the depth at which radio waves of a given frequency originate, and secondly their intensity as a function of a mechanism of thermal emission. From this the graph of the apparent temperature of the quiet sun against

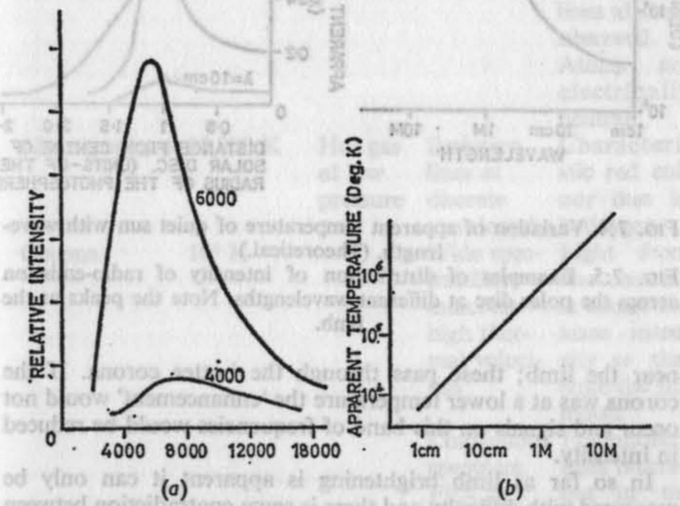


FIG. 7:3(*a*). After H. W. Newton, *The Face of the Sun*, Pelican. (*b*) After Lovell and Hanbury Brown, *The Exploration of Space by Radio* (Chapman & Hall).

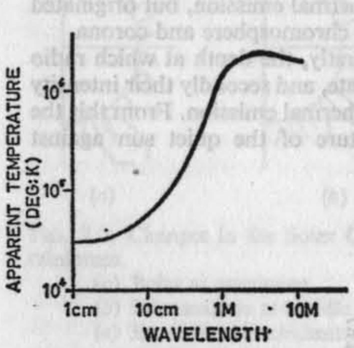
wavelength can be computed and compared with the predicted spectrum from a black body source.

Smerd's calculation illustrated by Fig. 7:5 gives a chromospheric temperature of $3+10^{4}$° K and a coronal temperature of 10^{6}° K.

He predicts a decrease at the low frequency end of the spectrum where in fact actual observations yield an increase. It has, however, been suggested that the 'radio disc' is extra large at these low frequencies.

An interesting feature of Smerd's calculations is shown in Fig. 7:5 where on some frequencies the limb 'brightens' in the region where the visual observer would expect to see limb darkening (i.e. there is an increase in intensity).

This enhancement is due to contribution to the energy of the radio emission in the passage through the longer slanting paths



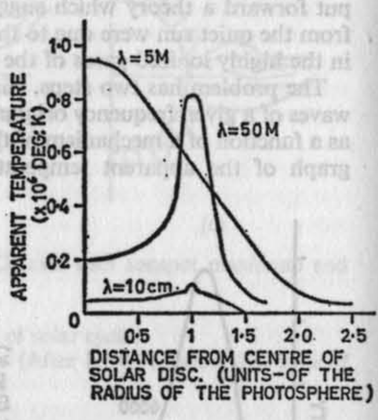


FIG. 7:4. Variation of apparent temperature of quiet sun with wavelength. (Theoretical.)

FIG. 7:5. Examples of distribution of intensity of radio-emission across the polar disc at different wavelengths. Note the peaks at the limb.

near the limb; these pass through the hotter corona. If the corona was at a lower temperature the 'enhancement' would not occur and signals on this band of frequencies would be reduced in intensity.

In so far as limb brightening is apparent it can only be measured with difficulty and there is some contradiction between the results. However, observed distributions of flux over the disc are consistent with theoretical calculations, e.g. Fig. 7:5.

One of the great difficulties in measuring limb brightening arises from the disturbed radio emissions caused by flare and other solar activity.

TABLE 7:1

Some features of the sun classified:

Region	*Black Body T°*	*Density/ Nature of Gas*	*Spectrum*	*Other features*
Photosphere	6,000 K	1/1,000 of air	Continuous	Level at which sunspots occur. Region where the solar gases become transparent.
Reversing layer		Cool gas	Fraunhofer	20,000 absorption lines already observed. Atoms are electrically neutral.
Chromosphere	30,000 K	Hot gas at low pressure	Emission lines at discrete wavelengths	Characteristic red colour due to hydrogen.
Corona	10^5 K		Wide spectral lines indicates high thermal velocities	Light from the corona is about the same intensity as that from the full moon.
			Continuous spectrum FEX to FEXIV	Fraunhofer lines blurred out in the lights scattered by electrons.
				Extent of corona due to high atomic velocities balancing gravitational pull.

7 : 5 *Radio Observations from the Disturbed Sun*

The amateur will have to be content with making observations of noise storms and bursts at certain selected frequencies. Spectrographic observations will be beyond his skill and in many cases a financial impossibility. Nevertheless, if very accurately calibrated records (i.e. in time to the order of a second) can be obtained an amateur with two arrays operating at slightly different frequencies may like to see if it is possible to observe

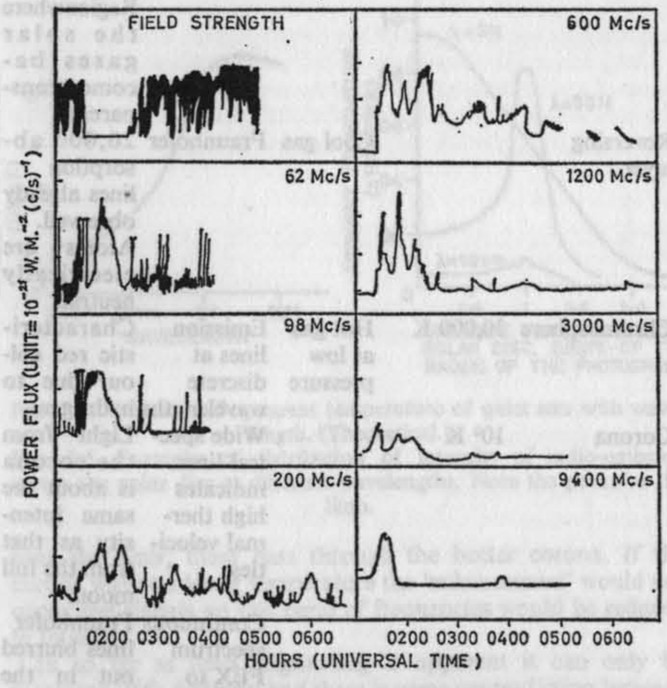


FIG. 7:6. Field strength of the communications signal is shown in top left hand corner (after J. L. Pawsey and R. N. Bracewell).

the frequency drift which is a characteristic of many noise storms. Fig. 7:6 is a sketch of likely records to be obtained on different frequencies during the intense noise storm but these are widely spaced. Where an amateur has a pen recorder and a tape recorder it may be possible to record simultaneously solar radiations and a long distance radio communications signal on the H.F. band. When there are severe noise storms the long distance signal will probably fade. One difficulty is, of course,

the fact that most tape recorders only operate for 45 minutes or so. Since the advent of a noise storm is unpredictable (although some storms are always preceded by others of a different type) this leads to many difficulties.

Although the sun is well observed, I do not think that it is valueless to make continuous records of solar radio emissions and to record in tabular form the chief disturbances, their time, average intensity and duration. They always have co-relative value. They can be compared with the total area under sunspots for which visual observations can also be made and also with the spectrographic records of solar activity. The variations in activity through sunspot minima and sunspot maxima can also be observed.

7 : 5 *Historical*

Since the amateur will be restricted to certain fundamental observations the best approach is from the historical. A good analysis is to be found in the first edition of the book by Pawsey and Bracewell. Further, the spectrographic observations continue to yield new results and it will not be surprising if the more recent classifications have to be revised.

Early studies of the radio sun show three distinct components:

(i) the slowly varying component;
(ii) emissions from the disturbed sun (noise storms);
(iii) the quiet sun (which has been discussed).

The slowly varying component appears between the wavelengths 30 and 60 cms. When Ryle and Vonberg first investigated the day to day variations they found some evidence of a 27-day period. Detailed studies of this component show that the time of this period varies from weeks to months and is related to the total area of the disc under sunspots. The origin of this component has also been discussed by Christiansen and Mathewson. They suggest that it occurs in regions of high electron density in the corona. Their own observations suggest heights from 20,000 to 100,000 kilometres above the regions where plages and magnetic fields are observed. From the observations made at 20 cms. they deduced that the areas of origin were at approximately normal temperatures in the corona and thus due to a thermal mechanical cause. They also made observations for circular polarization and could find no trace. Although the absence of circular polarization rules out the possibility of the 27-day component being caused by the magnetic field above the sunspot the observers were also unable to find any correlation between the magnetic field intensity and the brightness of the radio emission occurring above the spot. The radio sources appear to be very wide and not extended in height to anything like the same extent.

There is also the suggestion that the regions causing this emission are not only in the corona but are associated with the coronal streamers. Long-term observations of solar radio emission at 200 mc/s should illustrate the presence of the slowly varying component to the amateur. He must remember, however, to relate all changes to possible changes in the gain and response of the receiving system. Thus it is ever necessary to observe the rule that the radiometer must be thoroughly checked at regular short intervals to ensure that the observed changes in intensity are in fact real. It appears therefore that the slowly varying component occurs in a region of height between 20,000 km. and 100,000 km. above the plages and magnetic fields of sunspots. (Plages are bright hydrogen and calcium clouds above the group.)

The sudden violent disturbances which occur in the sun's radio emissions are roughly classified in Table 7:2. All of these can be observed below 200 mc/s in the metre range. In this classification the noise storms only last for a few minutes whilst the outbursts might last for hours or days. Nowadays storms are considered to be made of a series of bursts of which there are a number of different types.

TABLE 7:2

Type	*Associated Optical Feature*	*Wavelength(s)*	*Duration*
Noise storms	Large sunspots	Metre	Minutes
Outbursts	Solar flares	Metre, decimetre, centimetre	Hours–days
Isolated bursts	Uncertain	Metre	

Noise storms have reached intensity values ten-thousand times greater than those signals from the quiet sun. Outbursts also rise to equivalent disc temperatures which are many times that of the quiet sun.

Since it has been possible to make extensive studies of the radio sun it is natural that extensive changes should have been made to the simplified classification. The amateur will, however, be on safe ground if he looks for the general characteristics of the noise storms and bursts. The new classification defines Type I to Type IV bursts in addition to which there are 'U' bursts, radio condensations on all wavelengths, microcondensations on the short wavelengths, 'R' centres of non-thermal radiation sunspot radiation which is circularly polarized.

To end this chapter some of the characteristics of the various types of radio emission from the sun are discussed.

Noise storms last for hours and are a succession of bursts. These bursts last for anything from a second or so to a minute. A noise storm can be observed on any number of frequencies below 200 mc/s. The bursts making up the noise storm vary in duration and bandwidth over which they can be received. Sometimes they have a short duration with a wide bandwidth (30 mc/s) whilst others have a narrow band and last for a longer period of time.

Type I bursts are characterized by being of very short duration and of constant wavelength. Another characteristic is their polarization which after being constant for several days of a lengthy storm suddenly changes. de Groot suggests that the duration of the single burst is of the order of a tenth of a second.

Type II and Type III are due to disturbances which rise rapidly from the solar surface into the solar atmosphere.

The Type II burst is of the 'slow' drift variety. It has the characteristic of changing its wavelength (increasing) slowly. Rates of 1 mc/s have been observed. They last for a few minutes and might be associated with the particles that cause magnetic storms. Radio astronomers deduce the velocity of the disturbances causing these emissions, it being suggested that they are of the order 1,000 km/s.

A Type III burst is, however, different, in that its wavelength increases rapidly. As distinct from the 1 mc/s rate of the Type II burst, the Type III burst has been observed to have drift rates of the order of 20 mc/s per second. It appears that there is a good correlation between the occurrence of Type III bursts and solar flares. They may also be associated with cosmic ray particles.

A 'U' burst first decreases frequency and then increases so that the graph of the change in frequency is 'U' shaped. They last for a few seconds.

Noise storms which last for hours, occur after large flares and have a smooth spectrum belong to the Type IV burst category. They are always preceded by Type II bursts and are associated with large flares. A more detailed yet simplified discussion is to be found in F. G. Smith's book on Radio Astronomy.

Enough should have been said to indicate the need for radio spectrographs to observe the true characteristics of the disturbed radio emissions. Nevertheless, it should be clear that the amateur can have a great deal of fun looking for the more general characteristics of storms and bursts described in Table 7:2.

CHAPTER EIGHT

Our galaxy and radio astronomy

8 : 1 *Historical*

ALTHOUGH Sir Oliver Lodge attempted to detect radio radiations from the sun as long ago as 1900, the first positive detection of extra-terrestrial emissions was made by an American engineer, Karl G. Jansky, between 1929 and 1935. He himself was investigating atmospherics and noticed a variation in the received trace that corresponded approximately to the apparent time of rotation of the galaxy. To quote J. L. Pawsey and R. N. Bracewell – Jansky's discovery, 'furnishes a beautiful example of the inter-relation of various branches of pure and applied science, of a fundamental discovery arising in a completely unexpected quarter, and its elucidation by a gifted investigator'.

Karl Jansky through his papers in the *Proceedings of the Institute of Radio Engineers*, inspired Grote Reber to begin work on the construction of an instrument deliberately designed to detect radio waves from the galaxy. Reber says, 'I had been an ardent radio amateur and considerable of a DX addict, holding the call-sign W9GFZ. After contacting over sixty countries and making WAC (worked all continents), there did not appear to be any more worlds to conquer. . . . In my estimation it was obvious that K. G. Jansky had made a fundamental and very important discovery. Furthermore, he had exploited it to the limit of his equipment facilities. If greater progress was to be made, it would be necessary to construct new and different equipment especially designed to measure the cosmis static. . .' So in 1936 began the construction of the first radio telescope.

In 1958 the Editor of the *Proceedings of the Institute of Radio Engineers* describing Reber's contribution said, 'Jansky discovered the existence of radio emissions from outer space as early as 1932, a decade passed before the scientific world began to take an interest in it. During that barren period one man, and one man alone, compelled by a great love of science and research, carried forward Jansky's initial work'.

Two attempts with receivers of increasing sensitivity were made by Reber in 1937 and 1938 to detect emissions from the galaxy, the sun and some of the planets. These were not successful. This is not surprising since, although an amateur, he was

working at a frequency at 910 mc/s, the techniques of which were only just beginning to be explored at that time.

However, by the end of April 1939, Reber was quite sure that he was receiving cosmic static and his preliminary results, which confirmed Jansky's observations, were published in 1940. In 1942 he was able to publish a preliminary survey of the sky. At the same time, however, the receiving equipment was improved immeasurably. This time, however, he was operating in the band 156 to 164 mc/s. It took almost a year to cover the available part of the Milky Way and in the *Astrophysical Journal* of November 1944, where he published these observations, he also gave the details of the aerial polar diagram as taken on the source in Cassiopeia.

In 1943 Reber attacked a new frequency, that of 480 mc/s.

Early in the war, 1942, Southworth in the United States observed the thermal emission from the sun at 9,000 mc/s among other frequencies. Also in 1942, Dr. J. S. Hey, recently awarded the Eddington medal of the Royal Astronomical Society for his pioneering work in radio astronomy, discovered intense but variable radiation associated with sunspots. This type of radiation was particularly noticeable on the lower frequencies (metre range of wavelengths, i.e. 1 to 15 metres).

Hey was also associated with two other discoveries important to the foundations of this young science. With Stewart he showed how meteors could be studied by radar techniques. This discovery revolutionized meteor observations. Phillips and Parsons were with Hey when, making a study of galactic noise, they observed a fluctuation in the intensity of the emission from the galaxy in the region of Cygnus. This brought about the suggestion that there were point or discrete sources of radio emission. In 1948 Bolton and Stanley, two Australian observers, confirmed this suggestion, showing that there was a strong point source of emission in the region – Cygnus A.

8 : 2 *Isophotes*

Radio astronomers do not measure the flux density of the galaxy. Since the whole of the galaxy radiates it appears as an extended source to the aerial and not a point source. The radio astronomer measures the brightness distribution. This is, in the final analysis, converted into temperature. As the aerial looks at different parts of the sky so the received voltage is observed to change. This corresponds to changes in the temperature over the area of emission. Charts of the changes in emission from the different regions of the galaxy, i.e. plots of the galactic radio emission, can be made. They are called 'isophotes'.

An isophote is a contour map. The lines on the chart join points of equal temperatures. A typical isophote of part of the galaxy is shown in Fig. 8:1.

For the amateur who has constructed an interferometer an interesting experiment can be conducted by altering the spacing of the two elements. Obviously this will be easiest at the higher frequency. At 240 mc/s variable spacings between 10 and 100 wavelengths, with observations every 10 wavelengths, will be

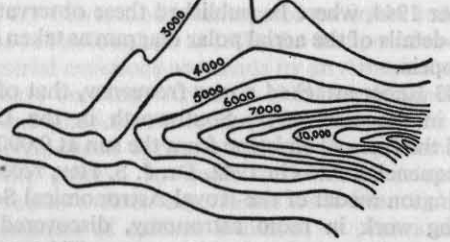


FIG. 8:1. Typical illustration of an isophote. The contour lines represent the temperature. This section is an enlargement of the central regions of the galaxy corresponding to the central part of the sky as plotted by the Cambridge radiotelescope at 81·5 mc/s. For a detailed map see p. 78 of *Radio Astronomy* (Penguin) by F. G. Smith. The survey was made by J. E. Baldwin and is described in *Mon. Nat.* R.A.S. 115, 684, 1955.

required. The maximum intensity will occur at the closest spacing. Different curves will, however, be obtained for different galactic longitudes although the slopes may not differ very much.

Graphs may also be drawn of the variation of the brightness temperature as a function of different galactic latitudes at the various frequencies of observation. These will illustrate the bright emission band lying along the galactic equator quite clearly. The width of this band will be of the order of two degrees so that the changes observed by the amateur will be an indication of the sensitivity of his apparatus.

8 : 3 *Radio Structure of the Galaxy*

The emission from the galaxy is continuous over the spectrum but the intensity decreases as the frequency increases. By making observations at a number of widely spaced frequencies it is possible to deduce a spectral curve for the galactic radio emission. Even over the range 38 to 200 mc/s sufficient observations can be made by the amateur to show the slope of the curve, provided

that at each frequency he knows the gain of his equipment and corrects the output reading accordingly.

When Hey, Parsons and Phillips discovered the change of emission in the Cygnus region they were making a survey of the galaxy. In their paper presented to the Royal Society in 1948 they described their observations at 64 mc/s. Two areas of the sky were missed because of the location of the radiotelescope in England.

Sources readily available to simple amateur radiotelescopes have been plotted for the B.A.A. section by J. R. Smith. Fig. 8:2. This

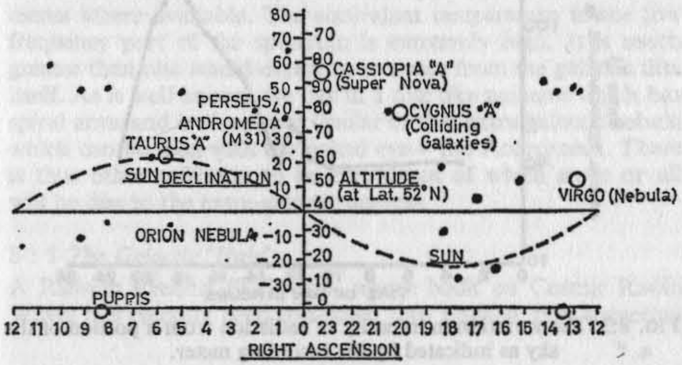


FIG. 8:2

makes it quite clear that the maximum of galactic radiation lies along the Milky Way. At high galactic latitudes the radiation diminishes. Another way of presenting the results is, of course, the first process in producing the isophotes, i.e. to display daily records of the galaxy with the aerial pointing in one direction. See Fig. 8:3.

Knowledge of the spectral distribution and the total radiation coming from the galaxy is important to the cosmological implications of radio astronomy.

8 : 4 *Radio Sources in the Galaxy*

Having ascertained that the fluctuations in the intensity of the Cygnus region were due to a discrete source of radiation, radio astronomers began to increase the sensitivity and resolving power of the radiotelescopes in order to look for more discrete sources. Something like 3,000 possible discrete sources have now been examined. The term radio star is frowned upon in many quarters since only a few of the discrete sources have been found in positions where there is also a known star or galaxy. But the present insistence of the popular press in favour of the term radio star ensures that it is likely to stay.[1]

Further investigations have led to the discovery that some of the radio sources are in the galaxy whilst the majority are extra-galactic.

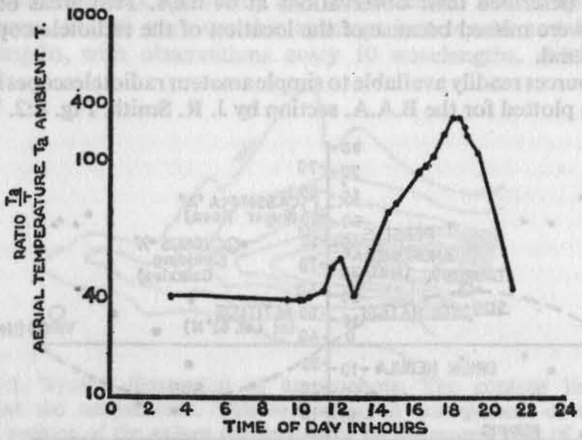


FIG. 8:3. The variation in intensity of radiation from a portion of the sky as indicated by the recording meter.

So far two quite distinct types of radio sources have been found. The first group is of a small number of stars with large angular dimensions having diameters of about one degree or greater whilst the second group to which the majority of radio sources belong are very much smaller angular dimensions but are nevertheless very powerful emitters.

Most of the larger diameter sources are found in the region of the Milky Way and thought to be in our galaxy. The smaller and in the main fainter sources are uniformly (isotropically)[2] located throughout space and thought to be outside of the galaxy. The resulting measurements of the angular diameter and distribution of radio sources provide two of the experiments from which data on the present cosmological controversy is drawn. Contributing, therefore, to the radio noise from the galaxy are the radio stars concentrated in the galactic plane.

For the moment, however, let us digress to a more general picture of the radio universe. Inside our galaxy is the solar system and in addition to solar observations which are a major

[1] Sir Bernard Lovell has recently reported radio observations of flare stars in the galaxy – April, 1963.
[2] Although even this is disputed.

branch of radio astronomy successful observations have been made of the thermal emission from Venus, Jupiter and Saturn. Other types of non-thermal emission are thought to have been received from Jupiter at 18 mc/s. The moon has been used as a radar reflector. Going farther away we arrive at the discrete sources concentrated in the galactic plane. Contributing by far the greatest component of all to the general signal received at the aerial is the radiation from the galaxy.

An important part of the radio astronomer's work is to relate his measurements of temperature to optically derived measurements where available. The equivalent temperature in the low frequency part of the spectrum is extremely high. It is much greater than one would expect to emanate from the galactic disc itself. As is well known, we live in a disc like universe which has spiral arms and is somewhat similar to that extra-galactic nebula which can be seen with the naked eye – the Andromeda. There is thus other radiation to be considered of which some or all will be due to the extra-galactic sources.

8 : 5 *The Galactic 'Halo'*

A Russian scientist Shklovsky, whose book on Cosmic Radio Waves has recently been translated into English, first suggested

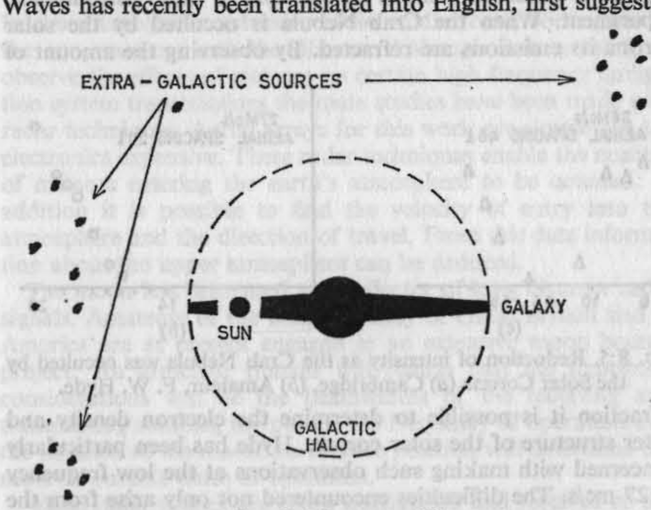


FIG. 8:4 (see page 12)

Simplified picture of the Radio Sky as would be seen by a Broad Beam radiotelescope. The radio sources outside the galaxy contribute 5% of the emission. They are not in the special positions shown – see Fig. 8:2. B. Y. Mills has discussed the detailed structure of the galaxy in Radio Astronomy edited R. N. Bracewell (Stamford).

that the disc was surrounded by a radio Halo. The Cambridge radio astronomer Baldwin subsequently verified this feature of the background radiation. Our sketch (Fig. 8:4) illustrates the general structure of the universe as would be seen by a simple Broad Beam radio telescope.

8 : 6 *The Galactic Radio Sources*

Comparisons of the location of the radio source with stars seen in the optical telescope in the same area of the sky have yielded about 40 identifications only. Of these some are galactic and others extra-galactic. The galactic sources can be grouped into three categories, (i) remnants of supernovae explosions, (ii) extended galactic nebulosities, and (iii) emission nebulae.

8 : 7 *The Occultation of a Radio Star*

Those stars in group (i) are the most interesting to the amateur. The Crab Nebula is a well-known supernova and is easily received by simple drift interferometers. Frank Hyde has made a special study of this source. Part of his work has been devoted to the following-up study first started at Cambridge in which the effect of the solar corona on the radio emissions from the Crab Nebula is observed. This is an example of radio astronomical experiment. When the Crab Nebula is occulted by the solar corona its emissions are refracted. By observing the amount of

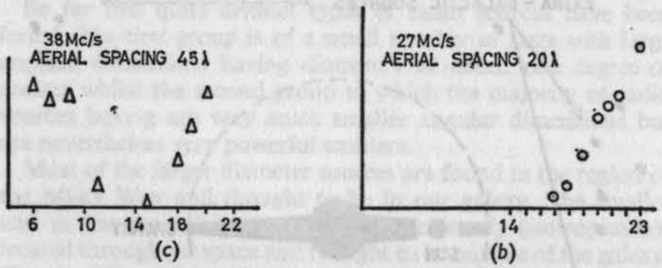


FIG. 8:5. Reduction of intensity as the Crab Nebula was occulted by the Solar Corona (*a*) Cambridge, (*b*) Amateur, F. W. Hyde.

refraction it is possible to determine the electron density and outer structure of the solar corona. Hyde has been particularly concerned with making such observations at the low frequency of 27 mc/s. The difficulties encountered not only arise from the necessity of having very wide baseline but also from the effects of the ionosphere and the sun, particularly when it is disturbed. A typical result is shown in Fig. 8:5.

Apart from this experimental use, the Crab Nebula is of considerable interest because it is the one supernova which has been

thoroughly observed by astronomers. Its radio spectrum is approximately constant at all frequencies whereas Cygnus A and even Cassiopeia. A decrease in intensity as the frequency increases. It was found, firstly, that the light from the Crab Nebula was polarized, and secondly that the radio waves were also polarized at the very high frequency of 10,000 mc/s. This confirms the possible fact that the radio radiation from the Crab Nebula – Taurus A – is due to the synchroton mechanism.

8 : 8 *H II Regions*

H II regions are areas of ionized hydrogen which surround very hot stars. The Orion nebula is a typical example. Trifid, Omega, Lagoon are typical normal galactic nebulosities or emission nebulae.

8 : 9 *Peculiar Nebulosities (Extended)*

Puppis A, Gemini and Auriga belong to this class of source which is characterized by a fairly large diameter inside of which is a filamentary structure.

8 : 10 *The Solar System*

In the solar system extensive radio studies have been made of the sun, meteors and the planets. Although it is possible to observe the effects of meteors on certain high frequency navigation system transmissions the main studies have been made with radar techniques. Aerial arrays for this work are simple but the electronics expensive. These radar techniques enable the number of meteors entering the earth's atmosphere to be counted: in addition it is possible to find the velocity of entry into the atmosphere and the direction of travel. From this data information about the upper atmosphere can be deduced.

The moon has been used as a reflector of long distance radio signals. Amateurs of the Radio Society of Great Britain and in America are at present engaged in an extensive moon bounce project. An armchair thinker will realize that the important considerations will be the beamwidths of the receiving and transmitting stations, the power, the frequency of operation and the position of the moon. Its relative position will determine the most favourable dates of operation.

When radar echoes are being transmitted and received at the same site the relative motions of the earth and moon have to be taken into account. The most important effect is the doppler shift in frequency of the radar echoes which necessitates the receiver being tuned to a slightly different frequency to that of the transmitter.

Relative to the earth the moon appears to have an irregular speed. This causes the echoes to undergo rapid fading. The fading is due to scattering from the lunar surface so that there is a possibility of collecting data about the surface structure of the moon.

Observers at Jodrell Bank have also used the slow fading observed on the returned echoes to derive the electron density of the F region of the ionosphere.

The Jodrell Bank telescope has also been used to transmit signals to Venus. These signals were received back at the station below the noise signal of the receiving equipment. This was indeed a great achievement. The time period of transmission and reception is four minutes.

8 : 11 *Radio Emissions from the Planets*

This is a field of Radio Astronomy in which the amateur ought to be active. Both thermal and non-thermal radiations have been received, thermal on the centimetric band and non-thermal at 18 mc/s. Two of the papers describing the work of Barrow and Carr are in the B.A.A. journal and a third hypothesizing paper by Barrow appears in the same publication. Frank Hyde has disputed the value of some of the low frequency observations, which since, to my knowledge, no observations are being made in this country apart from Hyde's, makes it all the more important for other correlations to be made. The chief problem is the aerial system which, although simple, must of necessity be large.

8 : 12 *Notes on the Radio Apparatus for 18 mc/s*

The beamwidth measured at the half power points is 30° in the east–west direction. The beamwidth in the other plane of Barrow's array was 115°. It is also possible to use corner V reflectors for this work. Although Barrow's arrays are arranged for interferometric work he has made several total power records, one of which is shown in Fig. 8:6.

Since, among other things, the pulses are very intermittent it has been suggested that the mechanism might be similar to that of terrestrial lightning. Such an electrical discharge mechanism would have to be of a much greater magnitude than those of the terrestrial thunderstorms. In fact it is very unlikely that it is due to anything so simple as a thunderstorm. F. G. Smith suggested that if the radio waves at the very low frequencies had very high energies, the cause would probably be related to the differential rotation of the planet.

The rapidity of the bursts indicates the need for a recording instrument possessing a fairly rapid pen movement.

These rapid pulses also indicate that the receiving equipment need not have a wide bandwidth. Barrow and Hyde both use normal type communications receivers whose outputs feed D.C. amplifiers and pen recorders. The loudspeakers are kept in circuit but arranged for switching on and off. Listening is useful since the bursts are distinctive. It is unfortunate that the best

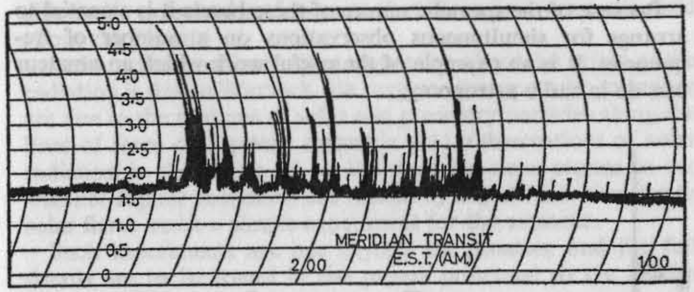


FIG. 8:6. Reproduced by permission of C. H. Barrow and the B.A.A.

observing time is during the early hours of the morning when the ionosphere is transparent to the lower frequencies when the meridian transit of Jupiter occurs at this time. Because of these restrictions Jupiter has only just (again) become visible to radio observers in the United Kingdom, observations not being possible in 1958 and 1959. During the next few years Jupiter rises to the northerly declinations and is thus suitable for study from England.

8 : 13 *Location of the Noise Sources on Jupiter*

A statistical method is used and the results are plotted in the form of a histogram, Fig. 8:7.

The number of occurrences of noise is plotted against the central meridian longitude. This enables the sources to be plotted in longitude but not latitude. Barrow has dealt with the problem of locating the latitude at length in the journal of the British Astronomical Association.

The sources appear to rotate with the planet in a period of 9 hours 55 minutes 28·8 seconds. This value seems to be the same for all the sources that have been observed.

8 : 14 *Radio Spectrum of the Sources*

Both in the United States and in England few signals have been received on 27 mc/s, whereas a large number have been received between 22 mc/s and 18 mc/s. Observations have been made in the region 10–34 mc/s and a suggestion exists that the maxima lies in the region 18–22 mc/s. The non-thermal radiation is thus apparently limited to a narrow band of frequencies. In England communications signals are particularly prevalent in this band and it is only with some patience that a suitable spot can be found. Hence the early morning rise and the use of the loud-speaker. A suitable frequency has been found to be 19.7 mc/s.

Because of the sporadic nature of these bursts it is essential to arrange for simultaneous observations on a number of frequencies. It is an example of the useful work which an amateur can do in radio astronomy.

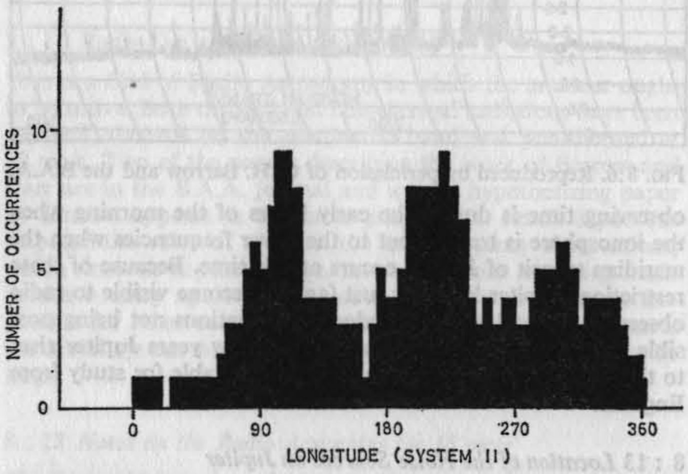


FIG. 8:7. Reproduced by permission of C. H. Barrow and the B.A.A.

In deciding the location of the sources it is important to have an astronomical knowledge of Jupiter. There is only one book which is satisfactory – *Jupiter* by B. M. Peek (Faber and Faber). In its chapters are to be found full details of the atmosphere of the planet, i.e. the visible parts are fully described. In addition to the light and dark bands, observers often see white spots and there is, of course, the phenomenon of the red spot. These details and their description belong to B. M. Peek's book. It is, however, of interest to note that there is no apparent correlation between the longitudes of the two or three regions from which the noise appears to originate and the visually observed features. For example, the rotation period of the noise sources does not relate,

only in so far that it is of the correct order, to the visually observed periods. There has, however, been suggestion that the maximum radiation from the planet should occur at the same time as the red spot is brightest (i.e. has the maximum coloration).

Barrow at the present time is making attempts to observe polarization at 22 mc/s. Amateurs should also be able to make polarization measurements. The bursts seem to be elliptically polarized and suggest that there is a magnetic field about the planet.

Perhaps the most interesting suggestion about the origin of the radiation is due to Warwick. He suggests that sporadic emissions are due to the motions of solar and planetary particles along the lines of force of Jupiter's magnetic field. Observations of solar radiation in the region 38 to 100 mc/s for noise storms to see whether Jupiter radiations are related by any definite time lag to solar flares make a simple experiment for the amateur.

Such experiments are not beyond the amateur and the full details are to be found in the papers presented to the British Astronomical Association.

CHAPTER NINE

Radio stars

9 : 1 *Introduction*

In the last chapter attention has already been focused on the two different populations of radio stars. We must not confuse these with population 1 and population 2 type stars of astronomy.

The two classes of radio star may be defined:

Class 1: a small number of intense sources of large angular diameter situated close to the galactic plane.

Class 2: a considerable number of weak sources of small angular dimensions (particularly at high galactic latitudes) which are uniformly (isotropically) distributed.

A major problem of radio astronomy is the nature of these weak sources; what are they? Three thousand or so of them have been observed but only a few have coincided with the positions of optically identifiable objects. If it is not possible to locate them with an optical telescope is it appropriate to suggest that they must be beyond the most distant galaxy seen by the giant 200-inch telescope. The answer to this question is one of the solutions to the controversy sparked off by Professor Ryle on the cosmological problem.

9 : 2 *Some Possible Types of Radio Star*

The Andromeda nebula is to be seen with the naked eye and emits radio waves. It is a nebula which is very similar to our own galaxy and is spiral in shape. These 'normal galaxies' constitute a class of radio emitters and are the first type of extragalactic radio star.

Apart from normal galaxies there are also 'irregular galaxies' of which the Magellan clouds are a good example. The Coma cluster of galaxies also fall into this category.

By far the most important type of radio star belongs to a class of 'peculiar' galaxy. These do not belong to Hubbles evolutionary sequence which terminates in either section in completed spirals. They are galactic collisions the most famous of which is the source in Cygnus A which has already been referred to and which can be easily observed by amateurs.

Another source similar to Cygnus A is that in Centaurus A. It is not, however, a colliding galaxy.

Not all of the peculiar galaxies are colliding galaxies, indeed only the source in Perseus approaches the idea of the head-on collision of galaxies. The source in Virgo A is an elliptical galaxy with a bright blue jet extending from the centre.

For reasons given in other text books on observational radio astronomy it seems possible to conclude that the majority of the radio stars are similar to Cygnus A. In terms, however, of the total number of stars in the universe they are very rare.

9 : 3 *The Cosmological Problem*

Up to 1947, when Bondi and Gold published their steady-state theory of cosmology, most people ascribed to the theory that the universe evolved and ran down. Mathematically there are an infinite number of variations to the evolutionary theory. For example, the universe could both expand and contract. The evolutionary models arose from the postulates of Einstein's 1917 general theory of relativity together with the observational confirmation of the recessional rates of galaxies by Edwin Hubble in the nineteen-twenties. Observers thought that the relativistic theory had been confirmed since a doppler shift was observed in the spectra of the distant galaxies. A doppler shift is interpreted as a recession or precession from or towards the observer depending on the direction of change of the apparent frequency. All the evidence pointed to recession. The galaxies were running away from each other at tremendous velocities. Thus the universe was expanding.

If the laws of physics are applied on a large scale the conservation of mass/energy law must operate throughout the universe. A recession of galaxies implies a using up of energy when the universe is expanding, i.e. running down at the same time! Thus the ideas about the catastrophic beginning and end of the universe!

For many people this was not very satisfactory. In 1947 Bondi and Gold presented a new theory which, although it accepted the recession of galaxies arising from the doppler shift, modified the model universe so that it was neither running up or running down. It was in the same steady state at all times and places. Whereas an evolutionary universe has a beginning, when, perhaps it explodes hurling the lighter fragments far out into space, the steady-state theory does not cater for a beginning (in this special sense). It says that at any point and at any time, any observer will see the same large-scale 'aspects' of the universe. A cosmologist in talking about 'aspects' means pressure, density and volume. To maintain a steady-state with galactic recession new matter has to be formed if these 'aspects' are to remain the same, for it has to replace that which is lost. Hence the concept of the 'continuous creation of matter' which arises from the steady-state theory.

Fortunately, these theories can be put to observational test. Until Professor Ryle's statement in 1961 at the February meeting of the Royal Astronomical Society many astronomers thought that the evidence was in favour of the steady-state theory. However, Professor Ryle strongly attacked this theory on the basis of his radio star observations.

9 : 4 *Source Counts*

One simple observational approach to the problem is to count the number of stars of a given magnitude whilst at the same time plotting their distribution in space. The astronomer's axiom is that certain stars of given magnitude can be shown to be at a given distance. From such axioms it is possible to compute a distance scale. Distances were first computed by parallax method but F. G. Smith was not able to use this method with radiotelescopes. Suppose that the number of sources at magnitude 20 is the same as those at magnitude 10, then we should reasonably expect to find that the number of sources at intervening magnitudes was the same, i.e. the sources would be uniformly distributed in space. On the other hand, a non-uniform distribution might be one where the density of the objects increases as we go deeper into space (depth density).

Distributions of the spatial density of sources are important to the cosmological problem since the uniform distribution required by a steady-state theory will differ from that of the evolutionary theory. The latter will require an excess of sources of high magnitude.

The simplest way to represent a number/magnitude (or flux density) count is by means of a graph in which one axis measures the observed intensity and the other, the number of stars observed at that intensity, plotted on logarithmic scale. It is convenient to plot the graph for a steady-state model. Since it is a uniform distribution it will be represented by a straight line of slope —1·5 (Fig. 9:1). Any departure from this line will suggest other possibilities. If the departure is at the top of the graph then it is a change of the density in the remoter regions of the universe. If, on the other hand, the departure is at the bottom of the graph then the change is taking place near to us. Source counts, therefore, provide a very simple approach to observational cosmology.

However, the distances which can be reached by the 200-inch optical telescope are not sufficient to provide a solution to the

problem. The radio results become significant for, if Professor Ryle is correct the radiotelescope at Cambridge is seeing into far greater depths than the 200-inch telescope. It is this factor which firmly establishes cosmology on an experimental basis.

9 : 5 *Radio Counts*

The first radio count was made in 1957 by Ryle and his co-workers. They obtained a number/flux density graph whose slope was —2·8, showing an excess of weak sources. This first survey was made with a phase switching interferometer. It came in for some criticism from an Australian survey in which a slope of

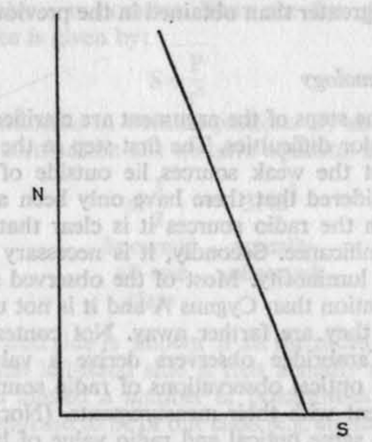


FIG. 9:1

—1·7 was obtained over a similar area of the sky. Later investigations confirmed that the main differences between the two surveys arose from some sources of large angular dimensions, apart from the fact that a different type of instrument was used. These have since been shown by the Cambridge workers to consist of a number of smaller sources. The most recent survey carried out by the new high resolution aperture synthesis technique has given a slope of —1·8 which is found to be consistent with the reliable sources of the earlier catalogue.

One mentions the history because some of the criticisms of Ryle's latest conclusion are simply that he might be wrong again. To quote Professor Bondi at that same meeting of the Royal Astronomical Society. 'With regard to the historical development of Ryle's work we should remember that six years ago he gave the slope of the log N— log S relation as —3 and now it has been reduced to $-1{\cdot}8$. Perhaps there is still a residual error which might account for the relatively small discrepancy between $-1{\cdot}8$ and $-1{\cdot}5$. There is no doubt, however, that Ryle and his team have carried out a most painstaking and careful investigation and I should like to congratulate them upon it.'

In reply Professor Ryle said . . . 'I should also point out that the disagreement with the steady-state theory amounts to a factor of about 10 when expressed in numbers of radio sources. It is difficult to regard this as a small discrepancy.' The significance of the new slope is not so much that it is new to that required by the steady-state theory but that it still possesses an excess of weak sources. Also 90 per cent of the sources studied are at distances greater than obtained in the previous surveys.

9 : 6 *Radio Cosmology*

In this section the steps of the argument are clarified in order to illustrate the major difficulties. The first step in the argument is to establish that the weak sources lie outside of the galaxy. When it is considered that there have only been a few optical co-relations with the radio sources it is clear that this step is not without significance. Secondly, it is necessary to establish a scale of radio luminosity. Most of the observed sources emit much more radiation than Cygnus A and it is not unreasonable to suggest that they are farther away. Not content with this, however, the Cambridge observers derive a value of radio luminosity from optical observations of radio sources and find it to be consistent with their measurements. (Normal galaxies are assigned the same optical and radio value of luminosity in the radio scale). More recently Edge and others have drawn attention to the existence of a number of sources of small angular dimensions in the region of the galaxy where a 'spur' of emission was observed. There are a number of small sources at high latitudes. As Ryle and Clark say 'the presence at high galactic latitudes of radio sources which are presumably in the galaxy and which are apparently unrelated to optical objects must raise the question of whether there are other optically invisible galactic sources'. Since this 'spur' of background emission rises far from the Milky Way, and penetrates parts of the sky from which the cosmological sample is taken, it is important to establish to what extent the presence of a small proportion of galactic sources in the general distribution could be a serious complication in interpreting the results.

As a first step, therefore, Ryle and Clark examine the problem of the radio luminosity function.

★9 : 7 *The Radio Luminosity*

(Following the approach used by F. G. Smith in the Times Science Review.)

In order to set limits to the value of radio luminosity (P) of discrete sources it is necessary to take into account the density of the region. A simple equation expresses the problem:

$$N=\frac{1}{3}\rho r^3 \qquad \text{Equation 1}$$

ρ is the space density of the objects, N the number observed in each unit of solid angle within the distance r.

Now let P be the intrinsic luminosity and S be the flux density as measured by a radiometer. Then the flux density S of the weakest source is given by:

$$S=\frac{P}{r^2} \qquad \text{Equation 2}$$

By simple arithmetic in which equations (1) and (2) are linked and with the elimination of r we have equation 3.

$$\rho P^{\frac{3}{2}} = 3NS^{\frac{3}{2}} \qquad \text{Equation 3}$$

$\rho P^{\frac{3}{2}}$	$3NS^{\frac{3}{2}}$
known if all one class	actually observed

The right-hand side is 'known' if all the radio stars are of one class whilst the left-hand side is that actually observed. If the value of P is altered a number of possibilities arise when the sources are assumed to be of one class (e.g. similar to Cygnus A). The two extremes are:

(i) if P (power) is high and there is a low density in space;
(ii) if P is low with a high density in space.

If the stars were in our own galaxy the second principle would provide the solution. Supernovae such as Cassiopeia A are eliminated as a significant class of radio star because they lie near to the galactic plane. Similarly the sources would have to be isotropically distributed.

It is possible to reproduce a graph relating the possible power P and the space density if all the radio stars belong to one class.

The limiting features of this graph are determined by the points set by the two values of P. On one axis increasing spatial density is plotted whilst on the other the observed-flux density appears (see Fig. 9:2). The line on this graph represents the left-hand side of equation 3. This can be put into simple arithmetic. The upper limit of power and the lower limit to spatial density arise when first we suggest that the weak sources are in the galaxy and secondly the dispersion of the radio luminosities. Dealing with the latter first it is found that there are two major types of extra-galactic source. This conclusion arises from obser-

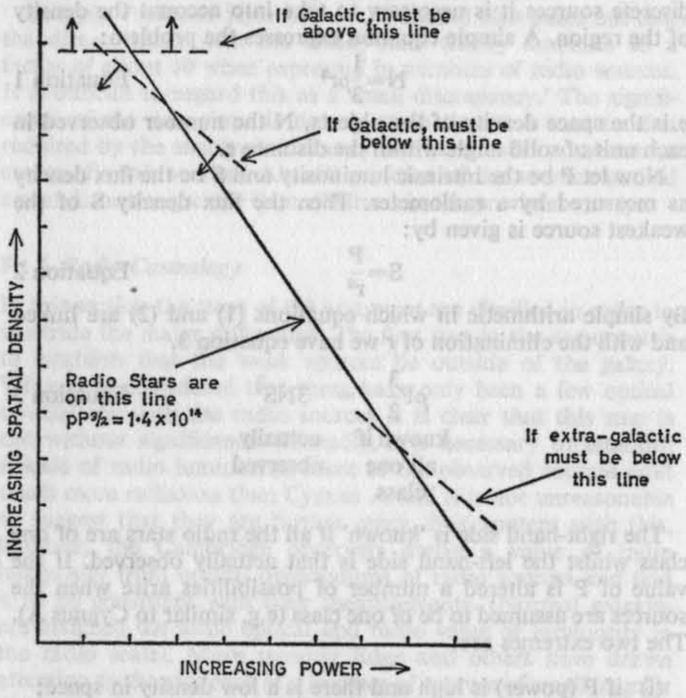


FIG. 9:2

vations of the surface brightness of sources which show that the normal galaxies (which as radio emitters are relatively few) differ considerably from a large number of powerful emitters.

9 : 7 *Are the Stars in the Galaxy?*

The simplest test is to compare the spectral laws of the distant sources and the 'halo' for it can be argued that the sources are in the halo. The results show firstly that the laws differ and secondly that only a small part of the radiation reaching us from the halo and outside is due to the distant sources.

Similarly, it is possible to argue that the radio stars are not isotropic in distribution because we ourselves are not located in

a central position in the galaxy. Observations made of a large extent of the halo at a greater distance than observations made of a smaller region in a much nearer position show no differences in the source distribution. Now let us relate this to the arithmetic.

Suppose now that there is an entirely new type of radio source which is evenly distributed throughout the galaxy. Since we ourselves are in an eccentric position we would see more of these in one direction than in another. Let the latter be at the least distance r_h which we see into the halo. Now the weakest star would, if the sources were in the galaxy, have to be at a smaller distance than r_h so that a star at the distance r_h would have a flux density of

$$S_h = \frac{P}{r_h^2} \qquad \text{Equation 4}$$

This sets an upper limit to P or a lower limit to the density. Thus the line representing the left-hand side of this equation has to be drawn through this point.

Two principal measurements are made to establish the absolute power of the sources.

(i) measurements of the total background radiation;
(ii) measurements of the angular diameter of the sources.

In determining the power-density law, account has to be taken of the possibility that the weak sources are clustered together. Subsidiary investigations have, however, eliminated the possible effects of clustering.

9 : 8 *The Radio Statistics*

To quote Professor Ryle: 'While it is likely to be very difficult to distinguish between evolving forms of cosmology, there is a good chance that there are detectable differences between any evolving model and the steady-state model. In the evolving case we shall expect to find a progressive ageing of the galaxies, and the average distance between the galaxies will steadily increase; on the steady-state model new galaxies are being born to replace those lost by expansion and we shall always find a mixture of old and young galaxies in *any* sample we choose'.

Unfortunately, the amateur can take no part in the number counts for the sources are very weak and can only be distinguished by very large radiotelescopes. Further, the analysis of the records involves a statistical method due firstly to Scheur and more recently to Hewish.

Even with the large radiotelescopes the recordings are 'confused'. The deflections on the record might be due to more than one star. There is a relationship between the distribution of the stars in space and the amplitude of the record. Probability statistics can be used to derive a curve for the steady-state universe. This curve can then be compared with the actual observations. It is found the same difference arises in practice as on the number-flux density counts.

9 : 9 *Conclusions*

Clearly the significance of these results depends on two factors: (i) the assignment of the correct luminosity value and (ii) the exact nature of the radio stars.

All schools of thought will be in agreement with the concept that the radio stars are in fact galaxies probably in collision at distances greater than can be seen with the 200-inch telescope. It would also appear that the radio stars are very strong emitters probably having powers of at least 5 per cent of that of the colliding galaxies in Cygnus A – the most powerful radio emitter.

The cosmological problem rests on the rarity of these radio sources. A steady-state universe requires a uniform distribution of objects in depth. The observations show a non-uniform distribution in depth there being an increase in the number of sources observed as the edge of the universe approaches. Nevertheless, only about 2,000 sources have in fact been observed in a region where this figure could be increased by an extremely large factor (i.e. of the order of millions).

Having established the rarity of the radio nebulae, two possible theories are apparent. Firstly, the radio astronomers are agreed that the majority of radio stars are like Cygnus A or 3c 295 – in fact colliding galaxies. This theory stems from the fact that only such collisions of gaseous matter could produce the tremendous power required to convert the kinetic energy into the observed value of electro-magnetic radiation in the radio part of the spectrum. Radio sources are thus special sources which are distributed isotropically throughout the sky.

If they are a special group then it is equally conceivable that Hoyle and Narlikar's theory that these galaxies are 'old' galaxies of a special type and that it is only the old galaxies that radiate is equally acceptable. Such galaxies should be special since they would be of the order 1 in 10^6 galaxies. Relevant to this argument is the fact that a greater proportion of older type galaxies will occur (in relative proportion) as the edge of the universe comes nearer. According to Hoyle, if the universe evolved from some definite creation it is possible to assign a value of angular dimensions to the radio sources (since their kinetic energy, etc., can be

calculated from the flux densities). The value which he assigns to the smallest radio source is 15 seconds of arc.

Hanbury Brown at Manchester has constructed an interferometer with a 40-mile baseline between Jodrell Bank and Holywell in Wales. With such an instrument it is possible to measure the angular dimensions of such small sources. It is also necessary to use two instruments, one having an east–west baseline and the other a north–south baseline. The present results show that some of the sources give values of less than 15″ arc for the east–west line. However, a glance at a pair of galaxies in collision shows that they could be longitudinal in shape thus necessitating (for all sources) measurement on a north–south baseline, i.e. sausages!

Hoyle postulates that the probability of any one galaxy being a radio emitter varies with the age of the galaxy whilst radio astronomers suggest that the emission of radio waves from galaxies is no more probable at one age than any other.

Whilst Hoyle's work may yet resurrect the steady-state theory in a new form it will clearly not survive in its original. In making comparisons it must also be remembered that the paradox of the age of earth's crust being twice that of the observed recession was resolved by the steady-state theory since there is in this universe no finite age of the universe. The revised time scale reversed the situation. But more recently Hoyle has shown that the age of the globular clusters is much greater than the revised time so that unless the time scale can be revised again there is still a lot to be said for some form of steady-state theory!

Observers are seeing farther into the universe and into the region where the red shift becomes appreciable. These factors have a twofold importance since they emphasize the significance of radio astronomy. Firstly, the red shift has become appreciable so that the flux density per unit bandwidth becomes modified in a way that gives the radio observations prominence. A red shift is a doppler shift in wavelength to the long wavelength end of the electro-magnetic spectrum. Where the shift is appreciable the spectral content of the radiation moves into the radio part of the spectrum. At the same time the energy in the visible part of the spectrum has been greatly reduced because of the shift of spectral energy to the infra-red. Radio observers do not observe such rapid changes in energy as observers of lines in the visible part of the spectrum. Whitfield has produced a spectral radio law which is approximately true for radio sources over the range of frequencies 38–960 mc/s.

Secondly, the type of radiotelescope used, namely the aperture synthesis type of instrument, can be greatly increased in size. It is a relatively cheap instrument to build. The observable limits of the universe can be greatly increased with a large instrument at a relatively small cost. It is likely that the controversy will continue for some time. The immediate effect is likely to be a stepping up of observations at other sites independently of Cambridge. The reader should not at this stage accept any of these statements as the final without perusal of the published papers.

However, the controversy itself gives a clue to other experiments which may be undertaken. An extension in the baseline of an interferometer increases the minimum angular dimension which can be observed. To what extent the baseline can be usefully extended is a matter of considerable interest. Although relatively simple arrays may be used the cost of the link, the determination of phases and its time constant would be high. It is a matter of conjecture whether it will eventually be possible for skilled radio amateurs to arrange a long-distance link, say between Beckford and Clacton. It would be great fun to tax the skill and ingenuity of the B.A.A. and R.S.G.B. observers.

The measurement of the absolute luminosity of the sources is also of importance. Long-term observations are required at 38, 81 and 178 mc/s. By long-term is meant a period of four or five years.

Hogbom and Shakeshaft have recently estimated that the radiation from Cassiopeia A is diminishing at the rate of 1 per cent per annum. As a comparison source they used Cygnus A. Cassiopeia A is a source in the galaxy. Being near, such small changes in its radiation can be detected. Cygnus A, being extragalactic, may or may not be changing its emission characteristic with time. The limits of sensitivity of the apparatus would prevent such measurements from being made. But it might well prove possible to observe the integrated emissions from a number of sources to examine the possibility of detecting secular changes in the observed flux densities from distant sources.

Nevertheless, the observation of stars similar to Cassiopeia A is still of importance for we might argue that since it is only sources in our galaxy that would show a measurable rate of running down that any unidentified source which behaves in this way is galactic. Observations over a period of several years are required of other pairs. This type of experiment is ideally suited to the amateur observer since only relative measurements of intensity are needed.

Edge has suggested to the writer that the unidentified sources with the continuous galactic 'belt' feature present a problem. As has been mentioned, this spur rises far in the Milky Way and some of the cosmological sampling was done in this region, so it is important to know what these sources are. Thus if long-term observations are made of pairs of sources over several years useful data could be obtained by the amateur which could contribute to the problem. Dr. Edge has suggested the following pairs 3C196 with 3C219, 3C298 with 3C317 and 3C409 with 3C433. In these pairs the latter sources are the identified and the former unidentified. Are the unidentified galactic or extragalactic?

The amateur requires simple apparatus the primary feature of which should be a large receiving aerial at 81·5 mc/s or 178 mc/s. A simple phase switching interferometer will do and only relative measurements of the intensity are required. A very large fixed aerial could be used as a radiometer with the sky being strip scanned for variations in the intensity of the sources under observations.

Cross-checking of observations by independent observers is important. In his most recently published work, Sir Bernard Lovell has this to say about the cosmological dilemma, and the work being done at Jodrell Bank:

'An attempt to overcome this dilemma, and to evade the criticism that one could not treat the radio source counts in this statistical manner, has been made at Jodrell Bank. The problem has, in fact, occupied more than a third of the working time of the radio telescope in the first four years of its use, which means that 5,000 or 6,000 hours of work have been spent on this aspect of the problem. In this system the telescope at Jodrell Bank is used in conjunction with smaller aerials that can be moved to different distances from it. The greatest separation so far achieved is 72 miles. The information from these remote stations is transmitted over a radio link and is correlated with the signals picked up simultaneously in the radio telescope at Jodrell Bank. The aim of this experiment is to measure the strength of radio waves and apparent angular diameter of the sources. With this information we would know much more about the distant radio sources and begin to get some scale of distance from these unidentified sources. The experiment is carried out by changing the spacing of the distant aerial until the lobe separation becomes so small that the maximum and minimum in the Interferometer fringe pattern of a particular source begins to disappear. The source is then beginning to be resolved, and it is possible to estimate the actual angular diameter of the emitting region.

'So far, out of 300 of the most intense unidentified radio sources which we believe to be at distances of cosmical significance, only about 10 per cent of them have angular diameters which would indicate that they were at distances greater than 2,000 million light years. Of these, three have proved quite remarkable in that at the greatest spacing of the aerials, the intensity of the fringes has remained unchanged, indicating that the radio sources must have angular diameters less than a second of arc. The interpretation to be placed on this result, based on the known distance and characteristics of the Cygnus source, is that these sources must be situated so far away in the universe that the radio waves have been on their journey for probably 7,000 or 8,000 million years.'

Space forbids a repetition of Sir Bernard's views on whether or not the distant sources are dense clusters of galaxies or Professor Ryle's comment on clustering. I used, in the three equations, F. Graham Smith's approach which appeared in *The Times Science Review*. The reader should read Sir Bernard Lovell on *The Exploration of Outer Space* (Oxford, 1962) and F. Graham Smith on *Radio Astronomy* (Pelican, 1961) for a detailed description and understanding of the problem.

CHAPTER TEN

The ionosphere and earth satellites

10 : 1 *The Ionosphere*

WHETHER we like it or not radio waves from outer space have to pass through the ionosphere. This is a region in the upper atmosphere where the predominating particles are ions. Clouds of these ions form layers and reflect radio waves of certain frequencies (transmitted from the earth), back to the earth. In this way long distance communications are achieved. In the same way the ionosphere reflects radio waves of certain frequencies from outer space. These radio waves never reach the earth. That is one of the reasons for launching earth satellites above the ionosphere so that measurements can be made of these radiations. Much of the ionization in the ionosphere is caused by the sun's ultra-violet radiations, whilst other causes include meteoric activity in the lower layers.

Since it is known that the ionosphere is the cause of radio star scintillations it is conceivable that a study of radio astronomy may lead to further knowledge about the ionosphere. As the ionosphere plays a major part in short-wave radio communications it is clear that any study of this region is of primary importance.

10 : 2 *The Components of a Radio Wave*

Any radio wave consists of three main components; these are illustrated in Fig. 10:1. There is a sky wave which goes up to the ionosphere from the aerial. Sometimes it passes right through the ionosphere and sometimes it is reflected to a distant point depending on its frequency. This is sometimes called the ionospheric wave and predominates in the high frequency range. It is this wave with which we are primarily concerned.

There is also a surface component which predominates at the very low frequencies and when travelling over paths of distance greater than 1,500 km. is affected by the lower layers of the ionosphere. The surface wave as its name implies travels along the surface of the earth and is tilted towards the earth. As it moves forward so its energy is dissipated into the earth. Less energy is wasted when the earth is a good conductor than when the earth is a bad conductor.

The surface wave is part of a total 'ground wave'. There are two other components which go to make up the ground wave. They are the Direct Ray and Ground Reflected Ray. By themselves they also form a wave which is called the Space wave. Communications by the space wave alone are limited to the horizon and by and large, communications at the Very High Frequencies are also limited to communication via these components. However, scattering of the waves at these higher frequencies by turbulences in both the troposphere and the ionosphere gives rise to communication distances of between 300 and

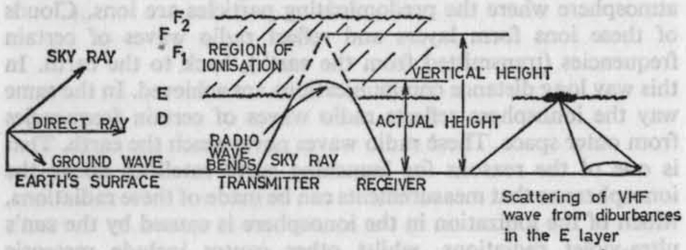


FIG. 10:1

600 km. for the troposphere and up to 2,000 km. by the ionosphere. The chief conditions for scatter communications are that the transmitter and receiver aerial beams overlap at the point in the sky where the scattering is to take place.

10 : 3 *The Regions of the Ionosphere*

There are three main regions in the ionosphere. These are given the letters D, E and F. They are known as layers since they are formed by layers of ionization each quite distinct from the other. The E layer is sometimes called the Heaviside–Kennelly layer after its postulators, and the F layer the Appleton Layer after its discoverer.

When a sky wave enters this region it can either pass right through the region or be reflected. In radio astronomy we are concerned with the conditions which just allow a wave to go through the ionosphere.

In the earth's lower and upper atmospheres there are a large number of molecules. These form the constituent gases of the ionosphere. The ultra-violet radiation from the sun arrives in the

region and removes electrons from the atoms in these molecules leaving positively charged ions. The energy in the ultra-violet radiation is a function of the wavelength of the radiation, different energies being required to ionize different gases. As the ultra-violet wave goes through the ionospheric region it loses energy so that regions at the top of the ionosphere are more densely ionized than those at the bottom. It must be realized, of course, that in the extreme upper atmosphere this type of action does not take place because the gases are very rarefied and very little ionization can take place. At some point the ionization is at a maximum. The whole region over which ionization occurs in the upper atmosphere is the ionosphere. This is only a generalized theory of the formation of the whole region. Furthermore, both meteor and cosmic rays have properties which can cause ionization in these regions. The specific formation of the individual layers is also more complex.

10 : 4 *The Solar Cycle and the Ionosphere*

Since the main agent causing the ionization is the sun it is to be expected that for any place on the earth's surface the region immediately above this point will undergo changes in the ionization density that follow the solar cycle of sunspot activity. There will be changes between the day and night, changes between summer and winter and variations between sunspot minima and sunspot maxima. The variations at different points on the earth's surface during a 24-hour day will also differ, e.g. the poles and the equator.

All these variations contribute to complicating communications since the ionization density determines the frequency which must be used over any specified distance. If the density changes so must the frequency if the same distance is to be achieved.

10 : 5 *The Critical Frequency*

The waves due to H.F. transmissions are not reflected back to the earth's surface directly but refracted. They are bent round. That frequency which will only just be reflected back from the ionosphere when transmitted from the aerial at vertical incidence is called the 'critical Frequency'. Another way of defining the same thing is to discover the angle at which a ray of the same frequency just escapes from the ionosphere. This gives the critical angle. When the critical angle is zero for a given frequency the critical frequency is being measured. The importance of the critical frequency is that it is a measure of the maximum electron density in the ionosphere. Each layer has its own critical frequency and the ionospheric structure can be determined by measurements of the critical frequencies at the different levels.

When measurements of the electron density are being made the height is calculated as if an absolute reflection was taking place. This is called the virtual height. The actual height of refraction can be determined as well. The virtual height varies with frequency. The lower frequencies are reflected by the E layer and the higher frequencies by the F layer. During the daytime the F layer breaks up into F_1 and F_2 layers. The F_2 is higher than the F_1; they merge again at night.

If the transmitter aerial is now beamed in a direction less than the critical angle for a given frequency, higher frequencies (than the critical) will be reflected by the ionospheric layer. However, for any given angle of incidence there is a maximum frequency which can be reflected back to the earth. To frequencies above this value the layer is transparent. This is called the Maximum Usable Frequency (M.U.F.). Calculations of the M.U.F. are important to radio communications. The M.U.F. is the frequency of the ray which will just *not go* through the ionosphere for any given angle of elevation of the beam. It is normally defined in respect of the angle of incidence that the ray makes with the ionosphere.

Some idea of the practical use of M.U.F. can be obtained from the following facts. For example, for distances of 4,000 km. – During sunspot minima the highest value is of the order 20 mc/s at 8 p.m. local time during the summer. In winter time, however, the highest value is about 24 mc/s which is reached at about 12 noon local time. However, the lowest value in winter is 7 mc/s and the M.U.F. curve is below 10 mc/s for 10 hours of the day.

At sunspot maxima during the summer months the M.U.F. is above 20 mc/s except for about 2 hours of the day. In the winter it remains below 10 mc/s for about 5 hours and reaches a maximum at noon when it is of the order 42 mc/s. The ease with which signals from the first Soviet satellite were received in October 1957 during a period of sunspot maxima will be remembered.

The optimum working frequency for radio communications is taken to be about 85 per cent of the M.U.F.

All this has direct application to radio astronomers since at the lower frequencies (e.g. 18 mc/s where radio emissions have been obtained from Jupiter) observations are limited by the refraction properties of the ionosphere. The minimum frequency that can be received from the planet for a given time of the day is different. When the analysis of Jupiter's radio noise was made by Barrow, the observations were made when the planet was low in altitude and were thus restricted not only by the ionosphere but

by the position and movement of the planet to reception during the early hours of the morning.

10 : 6 *Other Aspects of the Behaviour of the Ionosphere*

In addition to waves passing through or being reflected by the ionosphere, a certain amount of the energy is also absorbed. Studies of absorption are made. Two techniques are available from radio astronomy for this study.

The regular behaviour of the ionosphere can be classified into diurnal, seasonal and solar cycle variations. In addition to this there are a number of irregularities and abnormalities which cause departures from the regular variations. These are summarized below:

(i) Sporadic E.
(ii) Scattering of radio waves by ionospheric irregularities.
(iii) Sudden ionospheric disturbance (S.I.D.) – radio fade-out.
(iv) Ionospheric storms.
(v) Abnormalities near auroral zones.
(vi) Winds, tides and other travelling disturbances.

Solar flare effects on the ionosphere arise from a discharge of particles which on reaching the ionosphere cause a fading of communication signals between communications stations on the earth's surface. Secondly, information may be obtained from observations of solar radio noise.

These abnormalities can be recognized by one or another of the following effects:

(*a*) A sudden increase in absorption of downcoming waves.
(*b*) An abnormal increase in the critical frequency,
(*c*) and/or scattering of radio waves.

The mechanisms causing these effects are not well understood. For example, the effects coincident with solar flares previously mentioned. Others may be related to meteoric impacts, or to the bombardment of the ionosphere by solar corpuscles in the same way that aurora are produced. Another probability is that some of the irregularities are produced by electrons which have escaped from thunder clouds.

These irregularities cannot be confined to any definite time period nor can it be ascertained when they are likely to occur. Effects which are apparently due to solar flares may last for several hours, whereas those due to meteor ionization may last for as little as a fraction of a second.

One of the most persistent abnormalities is 'Sporadic E'. The E layer often undergoes very abnormal changes in its critical frequency. These changes are detected by pulse measurements and echoes are obtained from heights in the region 90 to 120 miles. Their characteristics change with differing latitudes. At low and middle latitudes it would appear that meteor ionization is the principal cause. Appleton and Naismith studied this phenomena in 1946 during the Giacobinid meteor shower of October of that year. They have suggested that the occurrence of Sporadic E has a similar seasonal variation to that of the transient meteor trial echoes. Unfortunately, another analysis in the United States has called these results into question since according to the American records true reflections were obtained from Sporadic E regions at the same time as reflections from meteor trials. This means that the two phenomena are not the same thing. The two phenomena are, however, so closely related that it is difficult to distinguish the rightness of either piece of evidence since the experiments are based firstly on the assumption that as the metéor comes into this region of the ionosphere it produces trails of ionization, and secondly, that the meteor ionization produces ion clouds in the E region. The point is that in order to obtain the relevant data, signals are sent up to these clouds which reflect the signals back. From the time taken to go there and back and the amount of absorption which is found from the decreased intensity of the signal it is possible to deduce their position and something about their nature.

At ionospheric research stations throughout the world, Sporadic E is measured by ionospheric sounders which send up pulses in this way. But these same radar methods may also be used to follow meteor trials and it is from a comparison of the two methods that Appleton and Naismith obtained their results.

Certainly the Sporadic E echoes increase during a meteor shower and it is clear that during this particular shower an ion cloud reflecting at 3·7 mc/s was produced.

The American results suggest that the ionospheric recorders also recorded the echoes from the meteor trails. This would also account for the observed increase in Sporadic E activity.

The two factors seem, however, to be too closely related to be ignored and in any case they present a clear-cut cause for radar astronomy which has not been mentioned in this text. But not all of Sporadic E is due to meteor ionization, a fact which is supported by the American records since they show that Sporadic E reflections also existed in other parts of the ionosphere apart from the region where meteor trail echoes were being received.

Wilson has suggested that thunder clouds can cause ionization in regions just below the E layer. When a spark occurs electrons which are already tending to be driven upwards in the cloud by its strong internal electric field are released. They enter into the

E region causing abnormal ionization. Similarly, when a thunder cloud discharges it releases electro-magnetic energy which is received on our radio receivers as atmospherics. It may well be possible that when this field is particularly strong the electric discharge causes an increase in ionization in the E region. The electric field can accelerate electrons. The electron in its acceleration may produce an electrical discharge which could cause the ionization in the cloud which is on the boundary of the E region.

10 : 7 *Scattering*

Finally, in regions of very high latitudes – the poles – it is possible that very fast charged particles coming from the sun may produce ionization.

Any irregularity in the E layer may cause the total energy in radio waves to be scattered over a much wider area than is normal. There are two main types of scattering, namely back scatter and reflective scatter. Reflective scatter is known to be one of the causes of fading.

Back scatter is marked by the fact that signals are heard in the zone of silence or the skip zone. This is one of the reasons that the skip distance is so important in propagation studies. Eckersley found that scattering occurred in regions at a short distance and a long distance away from the transmitter. To these phenomena have been given the names – 'short scatter' and 'long scatter'. Short scatter is due to an ionized irregularity in the E region near to the transmitter, whilst the long scatter is due to a similar irregularity a long distance away from the source. Whereas short scatter occurs as the wave goes out into the ionosphere (outgoing ray) the downcoming ray is the cause of the long scatter. It appears that the scattering is not due to one cloud but due to a number of clouds in the E layer.

10 : 8 *Fading*

When a single downcoming wave is received it is often subject to fading. Some of this fading is due to the uneven bottom of the ionized region. At the bottom the single ray may diffuse into a number of rays which produce a diffraction pattern on the ground of maxima and minima (in a way analagous to that produced by an interferometer). This pattern is subject to continual change and since the receiving aerial can only be at one point on the ground, the received signal fades. The changing diffraction pattern is caused by changing irregularities in the ionosphere. If these irregularities were fixed it would be easy to locate the aerial at a point of maxima. From the fading pattern it is possible to distinguish two types of fading. The velocity of the diffraction over the ground and the size of the irregularities causing the fading can also be determined. Scattering can be the cause of the scintillations in the received intensity of the signals from the radio stars.

As has been mentioned when some solar flares occur, sudden and intense increases in the ionization are observed. The radio signals fade over the sunlit portion of the earth and the duration of the fade may last for some hours. There are also changes in the earth's magnetic field. Fade-outs during which the signals completely disappear are observed on the medium and high frequencies. At the same time, however, low frequencies are subject to an increase in the signal strength. All the levels of the ionosphere are thus affected and it appears that the sun emits strong ultra-violet radiation which penetrates right through to the D layer. The increase in ionization causes heavy absorption. In addition to these effects there is also a lowering of the height of reflection.

10 : 9 *Earth Satellites and the Ionosphere*

When the first earth satellites were launched the amateur was able to make a considerable contribution both to the radio and visual measurements. These have been fully described in the memoir on Earth Satellites published by the British Astronomical Association.

Three types of radio observations were made by members of the British Astronomical Association and the Radio Society of Great Britain. These were observations of (i) the field strength, (ii) the doppler change in frequency and (iii) the telemetry. All of these are passive experiments. Since the satellite will travel through different levels of the ionosphere it provides an ideal means of studying the ionosphere for the electron density can be obtained from the doppler shift (as well as the point of nearest approach) and confirmatory and other studies can be made from the continuous recording of the field strength.

10 : 10 *Field Strength Recordings from Satellites*

Although the apparatus required for recording the field strength is simple it can be costly, for in addition to a communications receiver and output meter a pen recording milliameter will provide sophisticated measurements. A block schematic diagram is shown in Fig. 10:2. In addition to this basic equipment other items may be added to improve the stability and achieve constant gain. For example, a variac transformer can be included in the mains supply.

A typical recording of Sputnik I is shown in Fig. 10:3. These measurements were made by F. W. Hyde and show clearly the possibilities of obtaining the satellite rotation (diagram 3) which in the case of the first satellite was about 7 revs. per minute.

As the signal passes through the ionosphere the earth's magnetic field causes the plane of polarization of the wave to rotate. Since an aerial will only receive one plane of polarization maximum reception occurs only when the wave and the aerial are in the same plane. This – the so-called 'Faraday effect' – gives rise to rapid fading to the type near either end of the record.

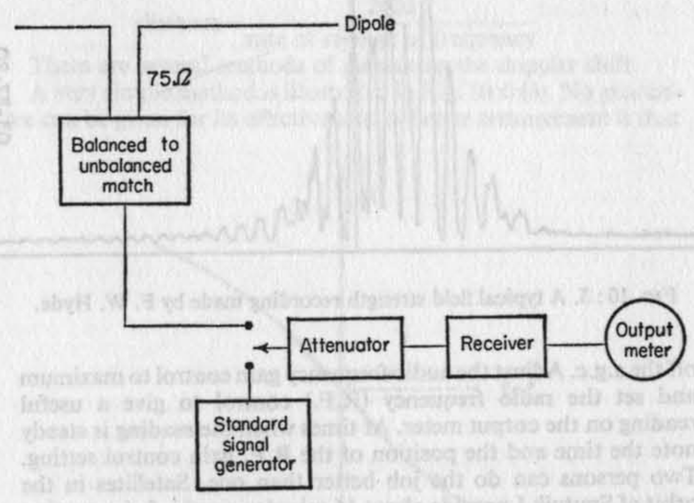


FIG. 10:2. Block schematic diagram of the equipment required for obtaining field strength measurements.

J. A. Ratcliffe has described (in the *Journal of the Institution of Electrical Engineers*) a type of fading which is much faster and less regular than the others, which occurs when the satellite is at high altitudes in the northern part of its track. This type of fading is probably due to irregularities in the distribution of electrons in the ionosphere which are of the order of about 5 kilometres. Deductions about their magnitude are made from a knowledge of the satellite's position and velocity and the speed of the fading.

Field strength observations can also be made with the aid of a simple meter. Although they will not give the satisfaction of permanent recordings comparative studies of the signal strength from transit to transit and of the length of time that the signals can be observed are of interest. In the early days of Sputnik I, J. J. Davies suggested the following method.

Make sure that you can observe for several transits. One transit will be required to tune the receiver into the signal. When this is done leave the apparatus switched on and wait for the next transit. If you are using a communications receiver switch

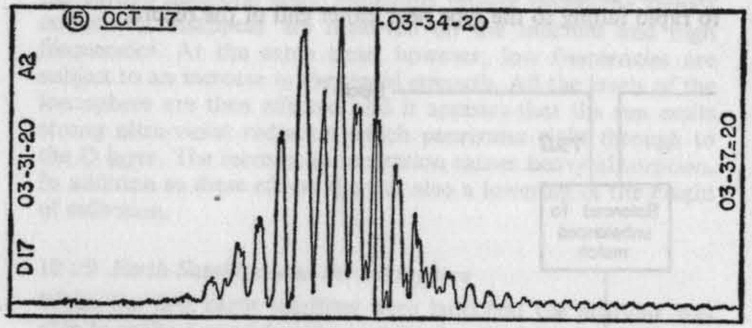


FIG. 10 : 3. A typical field strength recording made by F. W. Hyde.

off the a.g.c. Adjust the audio frequency gain control to maximum and set the radio frequency (R.F.) control to give a useful reading on the output meter. At times when the reading is steady note the time and the position of the R.F. gain control setting. Two persons can do the job better than one. Satellites in the orbit of Sputnik I provide about 16 minutes worth of observation time.

In order to evaluate the results the receiver gain control has to be calibrated, a task which requires a signal generator. The generator applies a signal of the same frequency and of known voltage to the receiver. The R.F. gain control is adjusted to the same 'useful' deflection on the output meter which was obtained when the satellite was first heard and by a series of adjustments of the input voltage a graph of gain control position against input voltage can be plotted. Variations in the signal strength can then be plotted using the graphical conversion table.

This writer used a simple horizontal half-wave dipole for observing Sputnik I. The attenuator marked on the diagram may be the simple R.F. gain control. A useful log or report form can be made up in the form of a Q.S.L. card, a suggestion for a report form is given in Table 10:1.

10 : 11 *Doppler Shift Observations*

As the satellites pass overhead there is an apparent change in frequency. If this change in frequency can be plotted a curve similar to that of Fig. 10:4 results. Amateurs can make doppler measurements and an observation by G. N. Roberts of Sputnik II is shown in Fig. 10:5. Knowledge of the slope of the curve enables the point of nearest approach of the satellite and the electron density to be determined. J. M. Osborne has quoted a simplified equation for approximating the point of nearest approach of a satellite which has a transit time of less than 100 minutes, e.g.

$$\text{distance} = \frac{2400}{\text{rate of change of frequency}}$$

There are several methods of measuring the doppler shift.

A very simple method is illustrated in Fig. 10:6 (*b*). No guarantee can be given for its effectiveness. A better arrangement is that

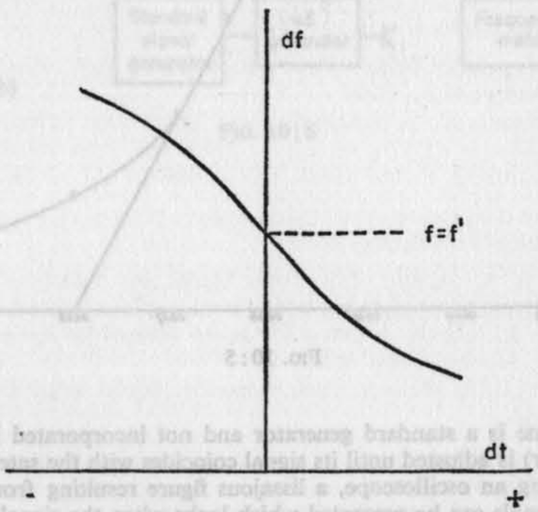


FIG. 10 : 4. Typical Doppler curve of the rate of change of frequency with time. At the mid-point the changing frequency f^1 corresponds to the carrier frequency f.

shown in Fig. 10:6 (*a*) but this involves the use of a frequency meter and oscilloscope. Dr. F. G. Smith suggested a suitable design for this which is illustrated in the British Astronomical Association's memoir on Earth Satellites.

In the first method aural beats are observed with the aid of the Beat Frequency Oscillator of the communications receiver. The signal generator is continuously adjusted as the apparent frequency changes so that the beats are continuously heard. Changes in the frequency are then read off the signal generator.

The latter technique is similar although a separate oscillator tuned to the satellites carrier frequency is used. As the satellite approaches the frequency of Beat Frequency Oscillator (which

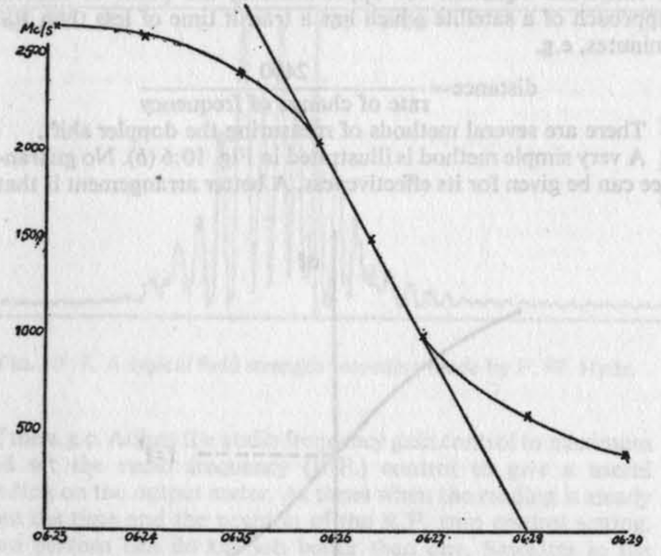


FIG. 10:5

this time is a standard generator and not incorporated in the receiver) is adjusted until its signal coincides with the satellite's. By using an oscilloscope, a lissajous figure resulting from the two signals can be presented which locks when the signals beat together. It is at this instant that the reading on the frequency meter and the time are read.

Satellites in orbit similar to Sputnik I will provide total doppler changes of about 2 minutes. To get a satisfactory curve it is necessary to make an observation every 10 seconds. A great deal of effort in a short time. Full details of how to make Doppler measurement of earth satellites can be found in The B.A.A. memoir on Artificial Earth Satellites (1961).

Nevertheless, doppler observations like simple radio astrono-

mical observations of Cygnus A, the Sun and Cassiopeia are great fun to make, satisfying to achieve and although not for research of great value to the observer in his quest for the whole man in his home the universe!

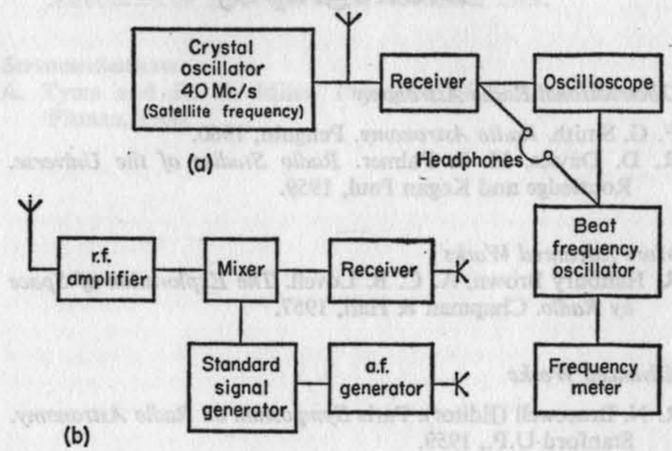


FIG. 10:6

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APPENDIX I

The Amateur in Radio Astronomy

The United Kingdom

Amateur radio astronomy is sponsored by the Radio-Electronics Section of the British Astronomical Association, 303, Bath Road, Hounslow West, Middlesex. This association has members all over the world; advice is given through the directors of the various observing sections.

The radio-electronics section sponsors several observing programmes: these are concerned with Jupiter, the Sun, Occultations of the Crab Nebula by the Solar Corona and observations of the flux density of certain well known sources.

Intending observers seeking the advice of the Association should give the following information in all letters of application:

(i) their own standard of radio and astronomical knowledge;
(ii) the funds available to them;
(iii) the size of the site they intend to use: a map is useful: the E. – W. direction should be shown;
(iv) Average weekly time available.

Advice will then be given about possible observing programmes. The radio section has always encouraged the 'armchair observer'. Several very valuable papers have been written by persons without radiotelescopes.

Applicants will, if possible, be put in touch with other members of the section who might live in the vicinity.

The section also co-operates with members of the Radio Society of Great Britain. In this way the section hopes to give astronomers sound advice about radio problems.

The United States of America

There is (in so far as the writer knows) no society which caters for the amateur in the United States. Research in radio astronomy is carried out at a number of Universities including Stanford, Ohio, Harvard and Florida State.

In charge of the project at Florida State University, Tallahasee, Florida, is Mr. C. H. Barrow. He is a member of the radio-electronics section of the British Astronomical Association and

is willing to advise any intending amateur on observational radio astronomy.

There are, in the United States, large numbers of amateur radio operators who could be contacted for advice on electronic matters. The American Radio Relay League (A.R.R.L.) corresponds to the Radio Society of Great Britain. It publishes a yearly handbook in which receiving and transmitting circuits for operation on the amateur bands are described. Low noise radio frequency amplifiers are described which with suitable modifications to values in the tuned circuits could be used in simple interferometer circuits below about 250 mc/s.

A.R.R.L. also publish a book on the design of Antennas. Simple equations are given in this book which will enable conversion of aerial dimensions to radio astronomical frequencies.

QST is the American amateur radio magazine. Useful constructional details are to be found in this journal. For example in the 1962 issues, the October number has an illustration of home built wooden towers suitable for carrying steerable Yagi's. Amateurs are warned off Yagi's as they have to be stacked to get sufficient gain. Adjustment of the elements is difficult. But some success has been had by J. M. Osborne of the B.A.A. using two yagi's coupled by a slot aerial instead of the usual folded aerial. The October issue of *QST*, Lewis G. McCoy describes the simple Yagi and gives some ideas on their construction.

Designs for Transistor Pre-amplifiers are now available up to 200 mc/s. One using the Philco T1832 (2N1742) V.H.F. transistor is described by James A. Mayhew in the August, 1962 issue. At the present time this transistor costs about $3.00 or just over £1. This amplifier would be quite suitable for interferometers observing the sun. It has a noise figure of 5·5 db. and a power gain of 16 dbs. at 200 mc/s. The circuit described operates at a resonant frequency of 144 mc/s. 156 mc/s has been used for radio astronomical observations.

In the same issue a steerable parabola used for moonbounce communications is shown on page 67. It would be suitable for operation at 9,000 mc/s.

Another low noise transistor amplifier for 50 mc/s. or 144 mc/s is given in the November issue. Also included is the circuit of a low frequency selector for three frequencies below 30 mc/s which might be useful for observations of Jupiter.

V.H.F. helical aerials are discussed by E. A. Scott in the July issue. It is a useful article from the constructional point of view.

A recent development in tubes is the Nuvistor. It is a low noise device. A converter for 220 mc/s is described in the July issue. E. A. Andrade discusses recent trends in Receiver front-end design in the June 1962 journal. A universal matching stub is also described in this issue in which E. C. Kunze describes Space-Age Antenna Ideas.

The American Radio Relay League Inc. is at West Hartford, Conn., U.S.A.

Programmes for the Amateur

These depend on the size of the site, the available finance and the knowledge of the observer.

Circuits given in this text will enable the amateur to construct an interferometer for operation in the range 30 to 250 mc/s. Corner V reflectors can be constructed for any frequency in this range. Osborne used Yagi elements but with a slot aerial (see diagram in the text) element.

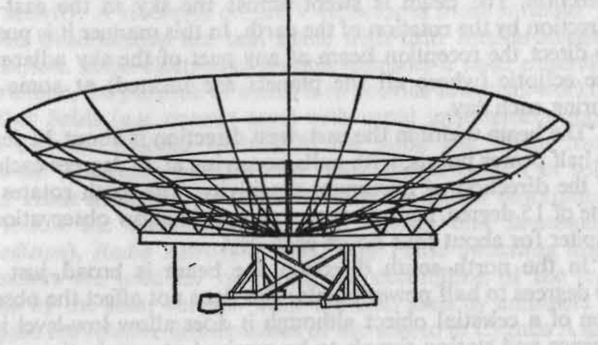
One difficulty arises. The intermediate frequency amplifiers which amateurs have used in the United Kingdom have been from radar receivers – purchased on the surplus market. It is of the utmost importance to ensure that the strip is of recent vintage. Otherwise, it will be necessary to construct the strip. Amateurs in England have successfully used EF80 tubes obtained on the surplus market. American 6BA6 tubes should be suitable. These were built at 30 mc/s. Recent trends have been to build low noise I.F. amplifiers at 10 mc/s.

The most simple experiment is performed with a television receiver: with its audio output connected to a meter (as well as the loudspeaker), its aerial oriented to the zenith out of normal television receiving hours, galactic noise will be received at low frequencies (e.g. 40 mc/s).

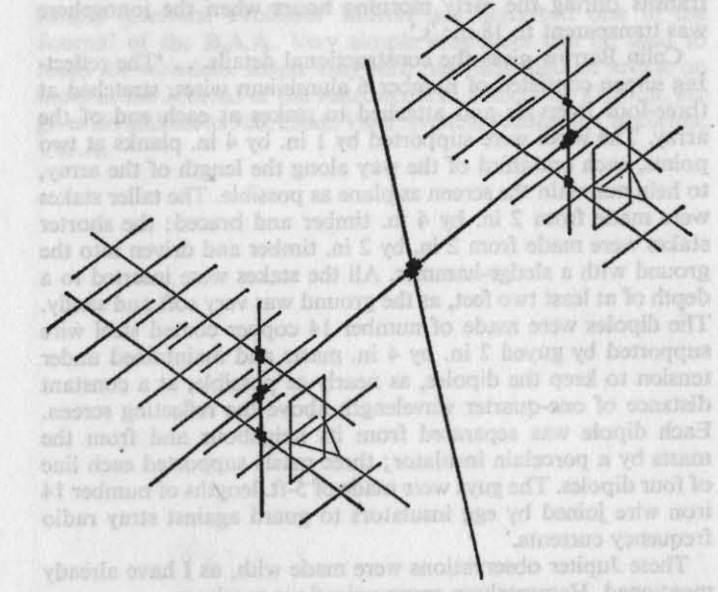
More effective observations of the galaxy can be made with larger aerials and the greater gain of the intermediate frequency amplifiers described in the text. Observations of the galaxy are made with pencil beam aerials. The simplest pencil beam aerial is the parabola. Wire mesh reflectors can be made very effective.

In the range 30 to 250 mc/s arrays of dipoles with reflecting screens can be erected and matched easily. Between 100 and 200 mc/s copper tubing makes the most suitable dipole element. Below 100 mc/s stranded phosphor bronze wire is more useful.

Colin Barrow described a Horizontal Array of Dipoles used for observing Jupiter at the University, Jacksonville, Florida. In his M.Sc. thesis he described the aerials, sketches of which have been included in the text . . . 'Eight half-wave dipoles are arranged in double collinear form a quarter wavelength above a reflecting screen. The dipoles are connected by quarter-wave phasing stubs and the feed from the array to the receiver is movable along the open wire transmission line joining the two lines of dipoles as a



Outline of steerable parabola suitable for construction by amateurs.



The 32 element J-Bean 200 mc. aerial assembly used as the radio telescope at Stowe School, Bucks, for the experiments described by G3HMO, J. M. Osborne. The beam is mounted in such a way that rotation of the pole alone keeps it aimed on any desired target area in the heavens. Some results with the telescope are shown in the trace recordings of noise from the sun, and known radio stars in the text. By separation of the two sections, the system can be used as an interferometer – see text.

means of steering the beam, to some extent, in a north–south direction. The beam is swept across the sky in the east–west direction by the rotation of the earth. In this manner it is possible to direct the reception beam at any part of the sky adjacent to the ecliptic (where all the planets are located) at some time during each day.

'The beam width in the east–west direction is about 32 degrees to half power points, with nulls occurring at 30 degrees each side of the direction of maximum sensitivity. The earth rotates at a rate of 15 degree/hour so the array should allow observations of Jupiter for about four hours each day.

'In the north–south direction the beam is broad, just over 80 degrees to half power points; this does not affect the observation of a celestial object although it does allow low-level interference and station signals to be received at certain times of the day. . . . Jupiter was thus investigated when making meridian transits during the early morning hours when the ionosphere was transparent to 18 mc/s.'

Colin Barrow gives the constructional details. . . 'The reflecting screen consisted of number 6 aluminium wires, stretched at three-foot intervals and attached to stakes at each end of the array. The wires were supported by 1 in. by 4 in. planks at two points, each one-third of the way along the length of the array, to help maintain the screen as plane as possible. The taller stakes were made from 2 in. by 4 in. timber and braced; the shorter stakes were made from 2 in. by 2 in. timber and driven into the ground with a sledge-hammer. All the stakes were inserted to a depth of at least two feet, as the ground was very soft and sandy. The dipoles were made of number 14 copper coated steel wire supported by guyed 2 in. by 4 in. masts and maintained under tension to keep the dipoles, as nearly as possible, at a constant distance of one-quarter wavelength above the reflecting screen. Each dipole was separated from its neighbour and from the masts by a porcelain insulator; three masts supported each line of four dipoles. The guys were made of 5-ft. lengths of number 14 iron wire joined by egg insulators to guard against stray radio frequency currents.'

These Jupiter observations were made with, as I have already mentioned, Hammerlung communications receivers.

Barrow is trying to establish a world-wide network of observing stations at the moment using very simple aerial systems, communications receivers, and the observer as the recording instrument. Jupiter noise is quite distinctive: all Barrow requires is an accurate 'timing' of the events which can be heard and need not be recorded.

At higher frequencies 30–50 mc/s similar wide beam aerial arrays will record solar activity during years of maximum sunspot activity. A steerable corner V reflector is more suitable.

Solar observations are best made with drift interferometers. The B.A.A. radio-electronics section sponsors a solar observing programme, the purpose of which is to provide scientists working in other fields (e.g. cosmic rays) with rapid information about solar activity. Donald Menzel in his book the *Radio Noise Spectrum* (Harvard) describes the main characteristics of solar noise. These amateurs, however, have to use earlier descriptions and follow the classification used in Pawsey and Bracewell's (*1st edition*), *Radio Astronomy* (Oxford). Phase switching interferometers are used for observing the occultation of the crab nebula by the solar corona. They are also used by amateurs to compare the relative flux densities of the source in Cygnus A and Cassiopeia.

Sudden Ionospheric Disturbances can be observed with fairly simple receivers. Professor Ellison has described one in the Journal of the B.A.A. Very simple amplifiers can be used to listen for whistlers. Roger Hayward has published an article on these in the Journal of the Astronomical Society of Victoria. He gives his address as 920, Linda Vista Avenue, Pasadena, California, U.S.A.

APPENDIX II

Constructing a Simple Radio Telescope

The necessary steps toward constructing a simple radio telescope will be found by consulting the following subjects in the chapters and pages listed below, in the order in which they are given.

Aerial system	Ch. 5 and 6
Decision on whether to build a radiometer or radio interferometer	Ch. 4 and 6
This decision depends on the choice of frequency	32
Simplest aerial is a modified TV Yagi ..	75, 76, 77, 78, 79, 82, 96, 153
Larger aerials are:	
(*a*) Corner V reflector	81, 88, 89
(*b*) Horizontal array of dipoles ..	81, 88, 154
(*c*) Parabola	85, 153
It is necessary to know the Polar Diagram of the Array	72, 76
Aerials have to be connected to the receiver via transmission lines	67, 79, 80, 81, 82, 83, 84, 88, 96
Because the frequency of operation is unusual the signal will have to be fed to an amplifier and converter	59, 60, Plate 2
It will then be fed to a communications receiver.	12, 25, 27, 32, 58, 60
Or an intermediate frequency amplifier specially built	60, 61, Plate 3
It is then fed to the detector. The time constant of the output of this circuit is important	17, 62, 63
The output from the detector is fed to a *DC* amplifier	62, 63
And thence to a recorder	64, 65

Name Index

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