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Post Office Engineering Department

TECHNICAL PAMPHLETS
FOR WORKMEN

Subject

Wireless Transmission and
Reception

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WIRELESS TRANSMISSION AND RECEPTION

(C1)

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GENERAL PRINCIPLES.

In all electrical means of communication there are three essential factors : (1) a transmitter, (2) a medium by which the energy is conveyed, and (3) a receiver.

In the ordinary telegraphy systems the key joined to a battery is the transmitter, the wire between the two stations is the medium by which the energy is conveyed, and a sounder or other device is the receiver.

In wireless telegraphy there are the same three essentials —a transmitter, a medium, and a receiver. The transmitter is a generator or producer of electrical alternations of high frequency. Such high-frequency alternations are generally referred to as " electrical oscillations," and more particularly as " high-frequency oscillations." These oscillations are reproduced in the network of wires which is the external characteristic feature of a wireless station, and is generally referred to as the " aerial." From the aerial the energy radiates in the form of electromagnetic waves, and travels through the medium ; in this case the medium is not a tangible medium like a piece of copper wire, but is the same medium which conveys light from the sun to the earth, something which, although intangible, must exist, and to which has been given the name of the " ether." The energy thus transmitted through the ether produces oscillations in the network of wires at the receiving station similar in kind to the original oscillations produced in the transmitter. These oscillations in the receiving aerial produce ultimately an effect in the receiver, which is generally a telephone receiver of ordinary type. There is therefore a method of communication in which the three essential factors are present. The three essentials differ from those of ordinary telegraphy only in the form the energy takes and the manner in which the energy travels through the medium.

The rapidity, or frequency of the oscillations produced by a wireless transmitter is of a very high order; in fact in certain modern transmitters a frequency of approximately sixty million alternations per second is employed, and higher frequencies than this may be utilized in the future. It is this extreme rapidity which accounts for the radiation of energy from the aerial. The energy radiates in the form of electro-

magnetic waves in the ether. A wave disturbance on the surface of water furnishes an illustration of the manner in which the electromagnetic waves are propagated, and will give some idea of what is meant by the " wavelength " of a wireless station.

If a pointed stick is pushed slowly into a pan of water, energy is exerted; but the rate at which energy is expended is slow. The only result is that the height of the water in the pan is raised by a displacement of water equal to the volume of the immersed portion of the stick. If the stick is plunged into the water suddenly and quickly withdrawn, a wave will radiate from the point where the stick strikes the water. If a cork is placed at any point in the pan the wave in passing causes the cork to make one complete oscillation up and down. Energy is expended in oscillating the cork, and this energy is supplied by the act of oscillating the stick into and out of the water. Thus, when a mechanical oscillation is imparted suddenly to a point on the surface of the water, some part of the impressed energy is radiated in the form of a wave, and this wave, in passing a mechanical contrivance, a cork, causes this contrivance to oscillate. It is the suddenness of the oscillation impressed upon the water which is the factor determining wave radiation. In a similar way, in an electrical system, some of the energy expended in impressing an extremely sudden electrical oscillation upon the aerial results in the radiation of an electromagnetic wave in the ether, and this wave, striking an electrical contrivance, the receiving aerial, will set up electrical oscillation in it similar in kind to the originating oscillation at the transmitter. It is important to note that whilst there is no lateral transference of water from the point of impact of the stick by reason of the wave motion, there is lateral transmission of energy. Similarly in electrical wave motion there is no lateral transference of the ether, but there is lateral transmission of energy.

Every medium wherein wave motion takes place exhibits a definite velocity of wave propagation dependent upon the nature of the medium. Sound waves travel in air approximately 1,000 ft. per second; sound waves travel in water approximately 5,000 ft. per second. Electromagnetic waves travel in the ether at the rate of 186,000 miles, or 300,000,000 metres per second—that is, at the speed of light.

The distance from the crest of one wave to the crest of a succeeding wave is called the " wavelength " of the wave. Confining attention at present to waves on the surface of water, if the distance one particular wave travels in one second is noted, there will be a certain number of waves—say f—now intervening between the position the wave first occupied and the

position it occupies after one second. If the wavelength is l, this distance will be $f \times l$, and this will be the distance the wave has travelled in one second, or, in other words, the velocity of propagation (v). The law relating to this velocity may be expressed as follows :—

$$v = f \times l, \text{ or } l = \frac{v}{f}$$

This is the universal law of wave propagation of whatever kind, whether of waves on the surface of water, waves in air (that is, sound waves), or electromagnetic waves in the ether. The wavelength of a wave disturbance in ether will be the space occupied by one complete wave. It cannot readily be measured, but it can be calculated. It will be shown that the number of oscillations per second (f) in an electrical oscillating system is determined mainly by the capacity and inductance of the system, and this number, divided into 300,000,000 (the velocity of propagation (v), in metres per second, of electromagnetic waves in the ether) will give the wavelength of the radiated wave in metres. When it is said that a wireless station transmits on a certain wavelength in metres, it means that the capacitance and inductance are proportioned in the system so as to give to the electrical oscillations a frequency (*i.e.*, the number of oscillations made in a second) which, divided into 300,000,000, is a certain value, which is designated as the wavelength of the station.

In modern practice it is usual when giving particulars of any station to specify both the frequency and wavelength of the station.

In any type of wireless transmitter three main operations have to be accomplished. Firstly, the high-frequency oscillations have to be generated; secondly, these oscillations must be transferred to some arrangement by which, thirdly, they are radiated into the ether. The methods of generating such oscillations are discussed in detail later, when the main types of transmitters are described. The adjustment of these oscillations to a particular frequency and their transference to the aerial circuit will be considered first.

The operation of adjusting a transmitter so that it will transmit on any predetermined wavelength or frequency is known as *tuning*.

Consider any circuit which contains inductance, capacitance and resistance in series. Its impedance Z is given by the expression

$$Z = \sqrt{R^2 + \left(L\omega - \frac{1}{C\omega}\right)^2} \text{ ohms}$$

where R = resistance of the circuit in ohms.

L = inductance of the circuit in henrys.

C = capacitance of the circuit in farads.

ω = 2π × frequency of the electrical oscillations in the circuit.

When the quantity $\left(\omega L - \dfrac{1}{C\omega}\right)$ is equal to zero the impedance of the circuit is a minimum and the circuit is said to be *resonant* or in *resonance*. This condition is attained if

$$\omega L = \frac{1}{C\omega}$$

$$\omega^2 = \frac{1}{LC}$$

$$\text{or } \omega = 2\pi f = \sqrt{\frac{1}{LC}}$$

$$\text{or } f = \frac{1}{2\pi\sqrt{LC}}$$

This frequency is known as the *Resonance Frequency*.

Thus, by choosing suitable values of inductance and capacitance for the circuit associated with the high-frequency oscillation generator, the frequency of the oscillations can be adjusted to any desired value.

Before consideration of the methods by which these high-frequency oscillations are transferred to the aerial circuit, it will be of advantage if the requirements in regard to the aerial are discussed.

Any aerial circuit possesses a certain capacitance and inductance. The aerial may be regarded as forming a condenser, one plate of which is made up of the overhead wires, the other plate being formed by the earth; the layer of air between the two forms the dielectric. The inductance of the aerial is made up of the inductance of the wires in the aerial and the leads connecting the aerial to the transmitter.

Before the aerial is connected to the transmitter it is necessary that the inductance and capacitance of the aerial circuit as a whole shall be so adjusted that it is in resonance with oscillations of the frequency at which the transmitter is to be operated. In other words, the aerial requires *tuning*. As a general rule, in order to tune the aerial a variable inductance is inserted in the aerial circuit, and the value of this inductance is adjusted until the circuit is tuned to the required frequency. This added inductance is known as the *aerial tuning inductance*.

The methods by which oscillations are transferred to the aerial circuit may now be considered.

When two circuits are arranged so that electrical energy flowing in one circuit is transferred to the other circuit, the two circuits are said to be *coupled*, the arrangement being generally termed a *coupled circuit*. There are three methods by which two circuits can be so coupled together. These methods are :—

(*a*) Inductive Coupling.

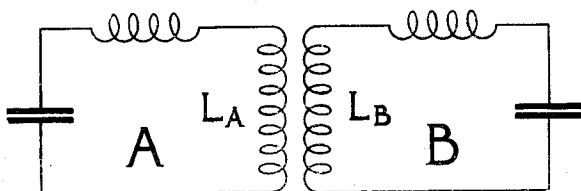A simple illustration of this method of coupling is shown in Fig. 1.

FIG. 1.

A and *B* are two tuned circuits with the inductances so arranged that any high frequency oscillatory current flowing in the coil L_A will induce an e.m.f. in the coil L_B there being magnetic induction between the two coils. The phenomenon is the same as that which takes place in the ordinary iron cored transformer used in alternating current power systems.

When two such circuits are coupled together in the above manner, they react upon one another to a different degree according as the coupling between them is *tight coupling* or *loose coupling*. If a change of current in one circuit has a large effect on the current change in the other circuit the coupling is said to be *tight*; where this effect is small the coupling is said to be *loose*.

It would appear that in order to obtain transference of the maximum amount of energy from one circuit to another the coupling between the circuits should be made as tight as possible. It is, of course, desirable that as much energy as possible should be transferred from one circuit to the other, but this energy must be, as far as possible, at the frequency or wavelength on which it is desired to transmit and as little energy as possible must be transferred on any other frequency. When the coupling between two circuits is *tight* the energy in the second circuit (the aerial circuit, for example) may be radiated on two widely differing frequencies or wavelengths.

A pendulum furnishes a very good mechanical analogy of what happens when energy is transferred from one circuit to another. The number of oscillations which a pendulum makes in a second depends chiefly on its length.
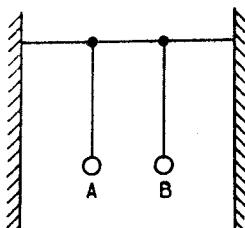

FIG. 2.

In Fig. 2 are shown two pendulums suspended from a string stretched between rigid supports. Being of equal length, and identical in all respects, they would each, independently, make the same number of vibrations per second; that is to say they are in " resonance." If pendulum *A* is made to swing it will gradually come to rest, but in the meantime pendulum *B* will begin to swing. By the time *A* has come to rest *B* will have reached a swing almost as large as the original swing of *A*. *B* will now continue to swing until it comes to rest, and will in turn start *A* swinging, and so on with diminishing duration until both pendulums finally come to rest. There is mechanical coupling between the resonant pendulums provided by the string between them. In the same way in a tuned electrical system, the oscillating and radiating circuits are in resonance. They each have that combination of capacitance and inductance which would make each circuit produce independently the same number of electrical oscillations per second. The relative positions of the two coils of the oscillation transformer determine the electrical coupling between them and the rate of transfer of energy to the radiating circuit. To return to the pendulums : when *A* is made to swing, its effort to make the resonant *B* pendulum swing, and the force expended on *B* to accomplish this, results in the number of swings per second made by *A* being fewer, and the number made by *B* being more, than would be the case were each swinging independently without mechanical coupling between them. The greater the coupling the greater the difference between the two rates of oscillation. There is a similar effect in an electrical system. If there were no electrical coupling between the oscillating and the radiating circuits there would be no

transfer of energy from the oscillating circuit to the radiating circuit; some coupling is, therefore, necessary for the transfer of energy. The amount of electrical coupling is, however, so arranged that, while transfer of energy at the necessary rate is maintained, the two sets of oscillations generated thereby shall not differ widely from each other, but, for practical purposes, shall approximate to one another. There must, therefore, be two conditions obtaining between the oscillating and radiating circuits :—

(1) They must be in resonance.

(2) The coupling between them must not be excessive.

Inductive coupling between two circuits may also be carried out by arranging for all or part of the inductances to be common to both circuits. Such an arrangement is shown in Fig. 3.
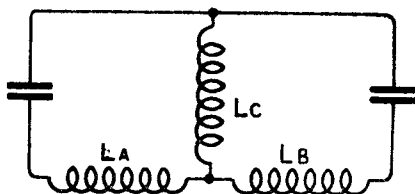

FIG. 3.

In this case the coupling between the two circuits can be adjusted to the required value by variation of the coil L_C which is common to both circuits. The arrangement is termed *direct* or *auto-inductive* coupling, the principle being that of the well-known auto-transformer.

(b) Capacitive Coupling.
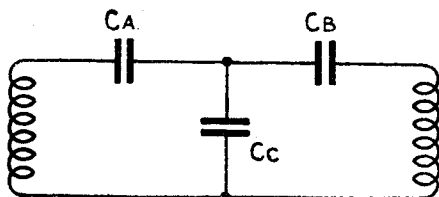
An example of this method is shown in Fig. 4.

FIG. 4.

In this case coupling between the two circuits is provided by means of the condenser C_C which is common to both

circuits. The degree of coupling can be varied by suitable adjustment of the value of the condenser C_C.

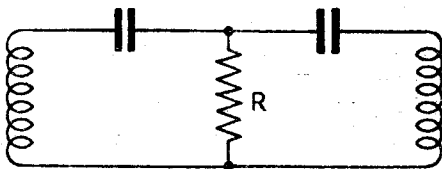(c) Resistive Coupling.

This is illustrated in Fig. 5.

FIG. 5.

The resistance R forms the coupling between the circuits and by variation of the value of R, the degree of coupling between the circuits is adjusted.

The last two methods of coupling have not been discussed in detail, but the theory of coupled circuits applies just as in the case of inductive coupling and the same considerations necessitating employment of loose coupling apply.

Types of Waves.

Before proceeding to a discussion of the various methods of generating high frequency oscillations, it will be convenient if the various types of wave forms are considered. Actually the different types of wireless emissions can be split up into a number of groups, but it will be sufficient for the scope of this book if these groups are divided into two main divisions. These divisions may be termed :—

(a) *Damped waves.*

(b) *Continuous or undamped waves.*

(a) *Damped Waves.*

The commonest example of this type of transmission is the wave emitted by a spark transmitter.

In the spark system energy is radiated from the aerial as a series of short trains of waves which rapidly die away, the whole train lasting only about 1/100,000th of a second. Such a train of waves is set up at each spark, the number of sparks per second varying from 50 to 500 or more according to the type of the transmitter (Fig. 6).
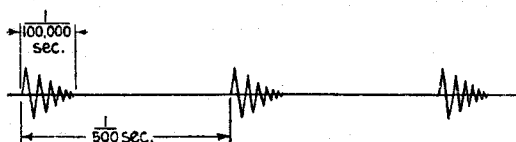
SPARK TRAINS.

FIG. 6.

The more rapidly each train of waves dies away the more heavily damped the system is said to be : the spark system provides the most heavily damped type of wave in use to-day.

Another type of damped wave transmission in which, however, the damping is not nearly so greatly pronounced is the type emitted by transmitters operating on the Interrupted Continuous Wave System (usually termed the I.C.W. system). In this system the wave form of the emitted wave is illustrated in Fig. 7.
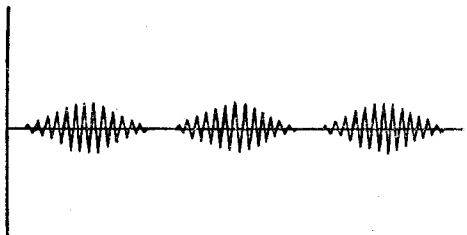

FIG. 7.

In this case there is a very much more gradual diminution of the amplitude of the wave form which is an indication that the damping is less than in the case of a spark train of waves.

It has already been pointed out that it is desirable to radiate the energy from a transmitting station as far as possible on the wavelength of the station. In practice it is not possible to radiate the energy entirely on one frequency or wavelength and this energy is radiated on a small band of frequencies or wavelengths on either side of the scheduled wavelength of the station; the more heavily damped a wave is, the broader the band over which the energy is radiated. This means that a heavily damped wave will interfere with other transmissions to a greater extent than a lightly damped

wave and this is the chief disadvantage of the spark system. For this reason coast stations in this country which originally were operated with spark transmitters have now been converted to the I.C.W. system. The latter being less heavily damped, interferes to a lesser extent. Moreover, the type of transmitter used for the production of interrupted continuous waves, lends itself more readily to exact adjustment to, and maintenance of, the nominal frequency of the transmitter.

(b) Continuous or undamped waves.

The waveform of the continuous wave type of transmission (known as the C.W. system), as the name implies, consists of a continuous wave of unvarying amplitude which is emitted the whole time during which the sending key is depressed. Fig. 8 shows the form of the wave.

FIG. 8.

The C.W. system being undamped interferes to a smaller extent than any other system and it is therefore possible to arrange for stations working on this system to make use of frequencies or wavelengths which can be nearer to each other than with other systems. This is a very real advantage because even now difficulty is being experienced in finding room for any new wireless station that is to work without causing interference to other stations. Another great advantage lies in the fact that *heterodyne* reception (which will be described later) can be used. Heterodyne reception enables an interfering station to be cut out. In general, at present, point to point services operate on the C.W. system and present day tendency is for other services which now employ damped waves to convert to continuous waves. In the case of certain stations operating on short waves however, I.C.W. is preferable in practice to C.W. for two reasons. Firstly, I.C.W. is more likely to be successfully received when what is known as " selective fading " is experienced. Secondly, it is easier to tune in an I.C.W. transmission than a C.W. transmission; this applies particularly to long distance ship-to-shore communication on short waves where the operators frequently require to search among several stations working on different wavelengths for the particular station with which they wish to establish communication. Wireless Telephony requires further considerations and these will be discussed later.

PART II.

SYSTEMS OF GENERATION AND TRANSMISSION.

The systems available for the generation of electro-magnetic waves for wireless communication may be divided into four groups. They are :—

(i) The spark system.
(ii) The Poulsen arc system.
(iii) The alternator system.
(iv) The thermionic valve system.

Of these methods the thermionic valve system is the most modern and the most important and has already largely replaced all other systems; the chief advantages of valve type transmitters over the other types are as follows :—

(a) The emission of a wave that is of steady frequency, pure and free from harmonics can easily be arranged.

(b) The system is equally suitable for low power and high power stations.

(c) It is, for all practical purposes, the only system suitable for radio telephony.

(d) Its first cost is no higher than any of the other systems.

(e) The thermionic valve is the most suitable means by which transmission on the higher frequencies can be effected.

Spark Transmitters.

The spark system is still retained by some ship stations but this system is rapidly becoming obsolete and is giving way to the I.C.W. system ; in fact, by international agreement the use of the spark system, except for powers *not* exceeding 300 watts, will be prohibited after January 1st, 1940.

It is not proposed, therefore, to discuss the principles of spark transmission in detail and as far as this system is concerned, this pamphlet will be confined to a description of a modern spark transmitting equipment.

The power supplied to the oscillating circuit of a spark transmitter is obtained from an alternator or inverted rotary converter at a low voltage and at the predetermined spark train frequency; this voltage is then stepped up to the required value by means of a transformer. The high potential side of the transformer is connected to the oscillating circuit through high frequency chokes which are inserted in order to ensure that the high-frequency energy in the oscillating circuit is confined to this circuit. These chokes offer little

impedance to the low-frequency energy flowing from the transformer to the oscillating circuit but their impedance to any high-frequency oscillations which may tend to get back is much greater. It will therefore be seen that when once the energy is transferred to the closed oscillating circuit, none of it can get back to the charging source. Inasmuch as the potentials set up by the oscillations in the closed oscillating circuit may be very high the chokes are a very necessary precaution in order to prevent these potentials from causing breakdown of insulation in the outside charging circuit.

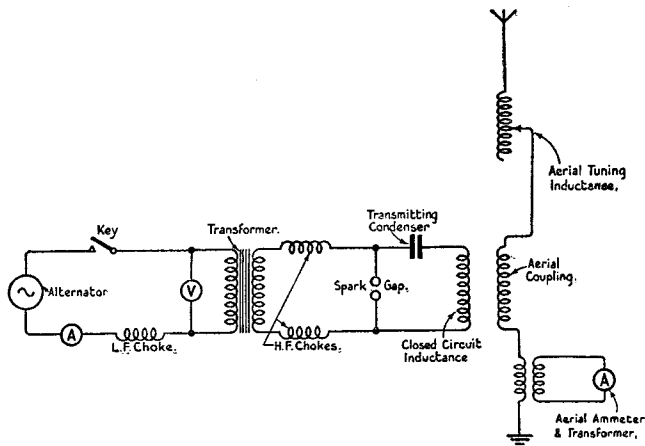Fig 9 is a diagrammatic sketch of a spark transmitter.

FIG. 9.

Keying of the transmitter is carried out by making and breaking the primary circuit of the transformer. For low powers the key may be inserted directly in this circuit, but for higher powers an electro-magnetic type of key is used.

The original type of spark gap consisted of two spherical electrodes placed a small distance apart. This gap was then replaced by the rotary type gap known as a disc discharger. This consists of a disc of copper or aluminium of about 10 inches diameter rigidly fixed to, but insulated from the alternator shaft. Projecting radially from the periphery of the disc are studs and in the casing containing the disc but insulated therefrom are two other studs called electrodes : when the alternator shaft rotates the studs of the revolving disc pass close to these electrodes. By means of this type of gap it is assured that sparking takes place at the correct time.

The most modern type of gap is known as the quenched gap. This consists of a number of small gaps arranged in series. The gap electrodes have faces of silver usually deposited on discs of copper of greater diameter than the actual gap to provide a large surface for rapid cooling; sometimes the electrodes are made entirely of silver. The approximate width of each gap is 0·2 millimetres and their number varies from two or three to 50 gaps for sets of about 40 K.W. input.

The quenched gap has a rapid quenching action as its name implies and it is therefore possible to transfer the energy from the closed circuit to the aerial circuit without retransfer to the closed circuit, and the aerial for the most part radiates the energy on its own tuned frequency. As a rule the use of this type of gap gives the transmitter a higher efficiency and allows it to emit a purer wave.

The Poulsen Arc System.

This system provided for some years during the development of thermionic valves, a successful method of generating continuous waves, particularly for long distance point-to-point communication on the longer wavelengths.

One of the inherent disadvantages of the arc system was that the radiated wave was liable to contain a large proportion of harmonics. Consequently interference from arc stations was very pronounced and sometimes strong enough to interfere seriously with reception on wavelengths far removed from the nominal wavelength of the arc transmitter. This disadvantage was considerably minimized by the introduction of a coupled circuit system between the arc and the aerial and by screening the building housing the arc and associated circuits, but arc transmitters previously used by the P.O. Engineering Department have for some years been replaced by thermionic valve transmitters.

The High-frequency Alternator.

The third method, which is employed only for high power stations, utilizes a high-frequency alternator. An alternator is a machine which generates a voltage which is alternately positive and negative. As the armature is rotated the voltage rises gradually to a maximum value, falls to zero, and repeats the process in the opposite direction, as indicated in Fig. 10, the number of complete changes or cycles per second being known as the frequency. With machines for ordinary power purposes, the frequency is of the order of 50 cycles per second. Machines can, however, by incorporating suitable frequency doubling devices be made to supply frequencies as high as

50,000 cycles per second or more, which frequencies come within the range of wireless oscillations.
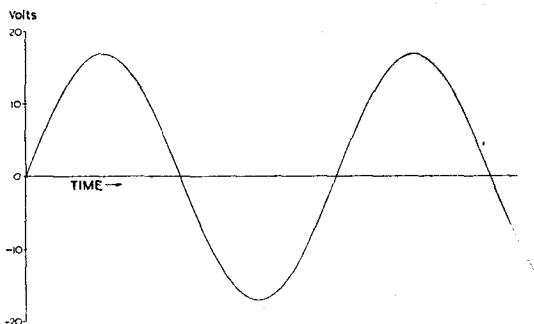

FIG. 10.

If such a machine is connected in series with a circuit containing inductance and capacity as in Fig. 11 and the frequency of the alternator is adjusted to be the same as the
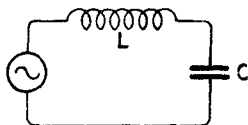

FIG. 11.

natural frequency of the circuit comprising the inductance L and capacity C, the alternator voltage will always be added to the oscillating voltage in the circuit and thus sustain oscillations in that circuit.

The circuit LC must be tuned to the frequency of the alternator. The windings of the alternator itself, however, possess a certain inductance and the effect of this must be added to that of the external inductance coil.

Keying is effected on a high-frequency alternator either by breaking the field circuit of the machine or by short-circuiting the alternator. This throws the circuit out of tune and the oscillations consequently die away. The internal inductance of the alternator prevents the current rising to a dangerous value on short-circuit.

Valve Transmitters.

By the use of the thermionic valve, the art of radio tele-graphy both from the point of view of transmission and recep-

tion, has been revolutionized and radio telephony has been successfully developed. The increased use of radio communication for broadcasting and various commercial purposes has necessitated the change-over of the older types of transmitting stations to the modern system of valve transmission in order to secure immunity from interference from the former. Furthermore, the increased sensitivity of receiving equipment due to the employment of thermionic valves, has correspondingly increased the working range of transmitting stations and it is therefore possible for designers to reduce the power at transmitting stations with the result that possibility of interference is still further diminished.

The original thermionic valve was the two electrode valve invented by Fleming. This valve consisted of a hot body or filament, which was made incandescent by means of an electric current and an anode or plate which was in close proximity to the filament and which was kept at a potential positive with respect to the filament. The whole arrangement was enclosed in a glass bulb and the air exhausted from this bulb so that the operations of the valve itself were carried out in a vacuum. The principle involved is as follows. When the filament is heated, it begins to throw off minute negative charges of electricity or *electrons*; owing to the fact that the anode or plate is at a higher potential than the filament, these electrons are drawn across to the anode and as a result the space between the filament and anode becomes conducting. If, therefore, a circuit is made up as shown in Fig. 12, a current will flow in the filament-anode circuit. (The function of the battery
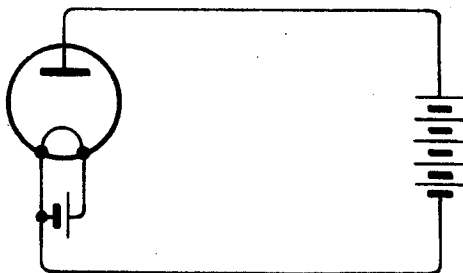

FIG. 12.

which is connected across the filament leads, is to heat the filament only and apart from this it takes no other part in the operation of the valve; it would not matter if the filament were heated by any other method although the use of a battery for this purpose is obviously a convenient solution.) If we

reverse the battery connected to the anode, thereby making the anode potential lower than that of the filament, the flow of current will stop entirely. The fact that a flow of current is only possible in one direction was the reason for applying the term *valve* to the device.

In this valve the current in the anode circuit depends upon the filament temperature and the potential which is applied to the anode. As a rule valve filaments are designed to work at a more or less constant temperature and therefore the only means of varying the current in the anode circuit is by alteration of the potential applied to the anode. The current in the anode circuit will increase as the anode potential is raised until this potential is high enough for the anode to attract all the electrons given off from the filament; any further increase of anode potential cannot, therefore, increase the current in the anode circuit. When the current reaches this value it is said that the *saturation current* of the valve has been reached.

GRID

FILAMENT
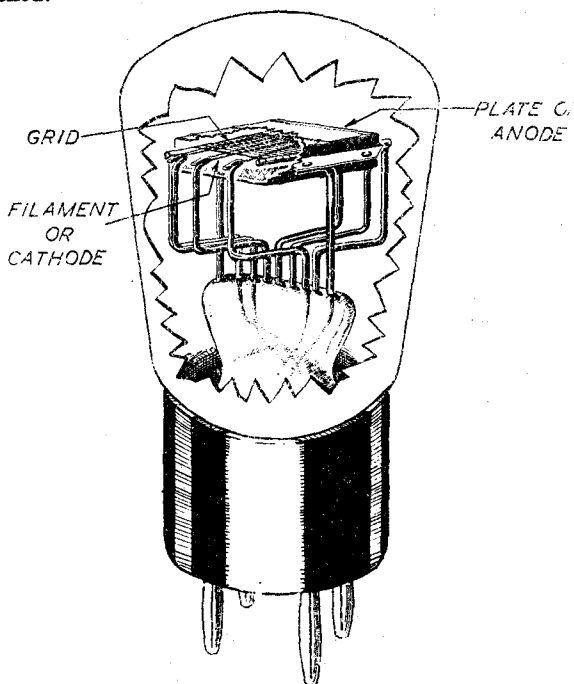OR
CATHODE

PLATE C,
ANODE

FIG. 13.

The Fleming valve or diode, as it is sometimes called, cannot be used for the generation of high frequency oscillations and its use, as far as modern wireless transmitters are concerned, is confined to rectification of high voltage alternating currents for supplying the high direct current potentials required in the anode circuits. This will be dealt with at a later stage.

The introduction of the third electrode or *grid* was a most important step in the development of the thermionic valve and by the addition of this third electrode the use of the valve was extended to include generation and amplification of high frequency oscillations.

The grid usually takes the form of a spiral or mesh of wire surrounding the filament in the space between the anode and filament. Fig. 13 shows the construction of a small form of thermionic valve and Fig. 14 shows diagrammatically a valve associated with its filament and anode batteries.
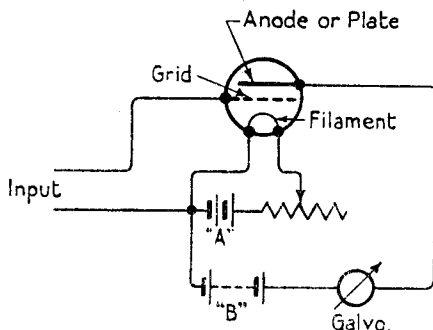

FIG. 14.

In the Fleming valve the anode current for a given filament temperature can be altered only by variation of the anode potential; with the arrangement in the three electrode valve, however, control is effected to a much greater extent by varying the potential of the grid (the potential of the grid is always measured in respect to the filament). This action is best shown by reference to the curve in Fig. 15, which is representative of a small transmitting valve of about 30 watts rating. This curve has been obtained by measuring the anode current for different values of the grid potential. If, therefore, the grid potential is varied by applying an alternating voltage across the grid and filament, the anode current will vary and be of a pulsating form of the same frequency as that which is applied to the grid.

Filament Volts. 7.
Filament Amps. 1·76.

Saturation
Current.

Anode Voltage = 1000

Anode Current in Milliamps

40

30

20

10

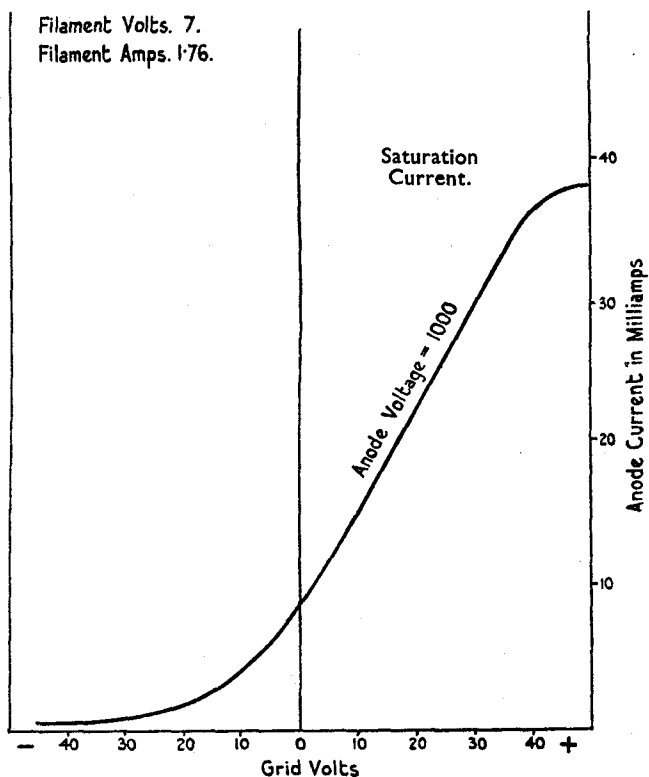— 40   30   20   10   0   10   20   30   40 +
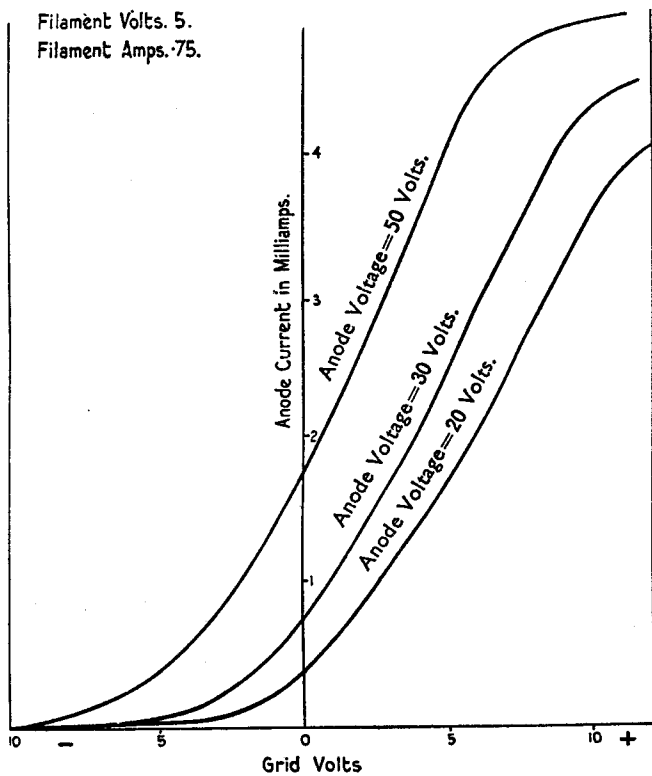
Grid Volts

FIG. 15.

FIG. 16.

It will be seen that the anode voltage and filament current are specified for this particular curve. Any variation in the value of these alters the position of the curve although the general shape remains the same. Fig. 16 shows a series of these curves for different conditions in a valve of a well-known type.

The principle of operation of a simple form of valve transmitter makes use of the regenerative properties of the valve. The action can best be understood by a consideration of a simple valve oscillatory circuit shown in Fig. 17.
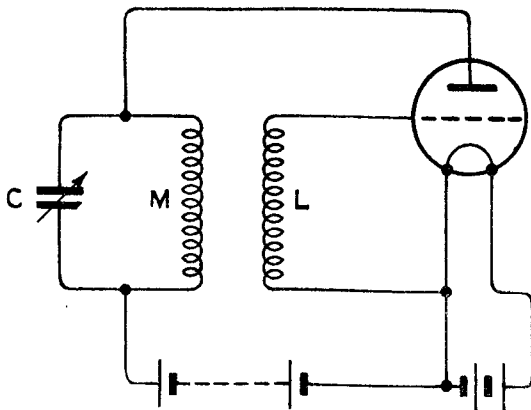

FIG. 17.

In this circuit the anode or plate circuit includes an oscillatory circuit made up of an inductance M and capacitance C and therefore any pulsations in the anode current will cause oscillations in this circuit. The coil M is inductively coupled to the coil L in the grid circuit of the valve and therefore any oscillating voltage in the coil M will set up an oscillating voltage in L. In this way the arrangement is able to produce the variations in grid potential which in turn produce a pulsating current in the anode circuit. It is this property which is peculiar to what are termed regenerative circuits, the whole method being often described as " reaction."

There are three possible conditions which may exist :—

(1) The voltages induced in the coil L may not be sufficient to maintain continuous pulsations of the anode current. In this case the oscillations would die away though not so quickly as they would do if there were no coupling between L and M. The condition

is equivalent to a reduction of the damping of the circuit and is the condition required in a valve receiving circuit employing reaction.

(2) The voltages induced in the coil L may be enough to maintain continuous pulsations in the anode circuit but not strong enough to start such regular pulsations. The sudden starting of such oscillations is known as the " trigger " effect and the effect is made use of in a device known as the trigger relay. A receiver in which too much reaction is used, and is unable to start oscillations, can often be " triggered " into continuous oscillation by an incoming signal. This action has taken place when a receiving set suddenly " bursts " into oscillation.

(3) The last condition is the one which enables a thermionic valve to be used as a generator of high-frequency oscillations. In this case the voltage induced in the coil L is sufficient to *start and maintain* continuous pulsations in the anode current. The pulsations tend to increase in amplitude until the variation lies between zero and the saturation current of the valve. In this case the switching on of the filament current and application of the anode voltage is sufficient to start the oscillations.

This particular method of generating high-frequency oscillations was first employed by Meissner, in 1913, and the actual circuit used by him is shown in Fig. 18.
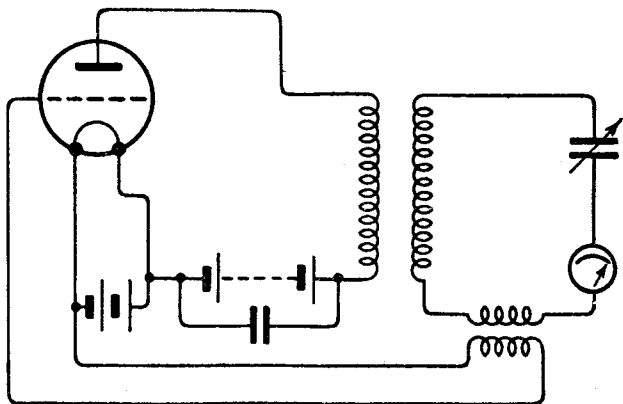
Original Meissner Circuit.
Fig. 18.

It will be seen that a third or intermediate circuit was introduced between the grid and anode circuits; this circuit determines the frequency of the oscillations and improves the control.

Many variations of the Meissner transmitter exist, but the fundamental principle of reaction is the same in each case. It should be noted that the coupling between the grid and anode circuits is not always inductive; capacitive coupling is used a good deal, especially in valve transmitters working on the shorter wavelengths.

Fig. 19 shows a very simple valve transmitting circuit employing the Meissner principle.

FIG. 19.

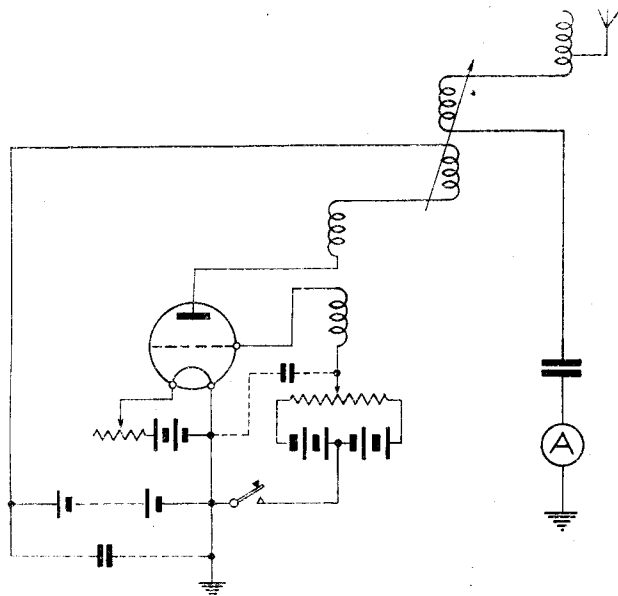In practice owing to the resistance of the grid and anode battery circuits condition (1) or condition (2) referred to on pages 22 and 23 might be obtained. This could be overcome by the use of condensers of comparatively large capacitance connected as shown by the broken lines, to provide low impedance paths for the pulsating currents without affecting the steady potentials applied by the batteries to the grid and anode.

The frequency of the oscillations is determined by the tune of the anode and aerial circuits, and the energy is fed into the aerial by inductive coupling.

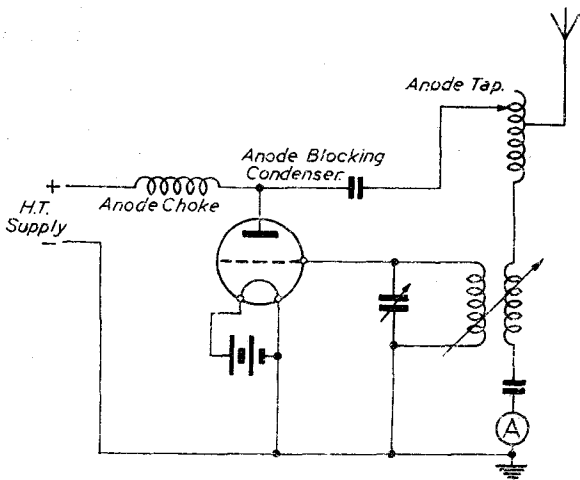A more usual arrangement, however, is shown in Fig. 20.

FIG. 20.

.In this circuit the H.T. supply to the anode is fed through what is known as the *anode choke*; this choke is designed to have a high impedance to high-frequency currents and the current flowing through it will be sensibly direct current only. The function of the anode choke coil is to prevent the oscillatory circuit from being short-circuited by the H.T. supply circuit, or to prevent the high frequency voltage of the anode from being impressed across the supply circuit, as would be the case if the latter presented a high impedance to the high frequency and no choke were provided. The *anode blocking condenser* is inserted to prevent a short circuit of the H.T. supply by the aerial circuit.

The aerial tuning inductance is used in this case as an auto-transformer between the anode and aerial circuits, and the *anode tap* is used to give the necessary adjustment. The best anode tapping point is that at which maximum current is obtained in the aerial circuit without overheating the anode. The advantage of this circuit arrangement is that the dangerous D.C. H.T. voltage is not impressed upon the aerial circuit.

All valves have a certain inter-electrode capacitance, and although this is of small value it is sufficient to provide coupling

between the anode and grid circuits when working on the shorter waves; this capacitance is often made use of for this purpose.

A type of valve transmitter which has been developed by the P.O. Engineering Department employs a valve maintained tuning fork drive; such transmitters are in use at the Rugby, Leafield and Portishead stations.

In this particular type of transmitter a valve maintained tuning fork is used to produce a pulsating current at a frequency of the order of 2,000 cycles per second. By means of the tuning fork associated with this device the frequency of this current is maintained at a constant value; temperature changes may cause very slight variations in this frequency, but under normal conditions these variations are negligible. It is possible, by employing elinvar steel for the fork itself, to make the frequency practically independent of temperature fluctuations.

The frequency at which the fork vibrates is too low to be suitable for direct application to a wireless transmitter, and it is therefore necessary to obtain the required radio frequency from the low but constant frequency output of the valve-fork generator. In order to do this the output from the generator is passed through a device which distorts the wave form so that it contains harmonics or multiples of the fundamental fork frequency. The required harmonic which is at radio frequency is then picked out by means of filters or tuned circuits. This harmonic, being a multiple of the fork frequency, can be varied only by altering the fork frequency itself. In order that a radio frequency of a pre-determined value may be obtained the tuning fork is loaded by means of screws which can be altered to change the fork frequency slightly as required, and thus allow a harmonic frequency of the required value to be available.

Having selected the harmonic at the frequency at which the station is to operate, it is then amplified in successive stages until it reaches the main bank of power valves, which in turn delivers it to the aerial. It should be noted that once the harmonic has been selected, the function of the succeeding valves is confined to their employment as amplifiers, and that they do not act as high-frequency generators.

The advantage of the foregoing type of transmitter is that it is possible by this means to radiate a wave of a frequency which is very constant. In transmitters which do not have such control, variations of anode potential and filament current and sway of the aerial system in a high wind may cause fluctuations of the wavelength or frequency of the transmitting station. This is very undesirable for two reasons.

In the first place the selectivity of a modern receiver has been developed to a very high order, and any transmitting station whose wavelength or frequency wanders cannot be received at all times except by retuning of the receiver; and, secondly, the congestion of wireless services is becoming so great that it is essential that all transmitting stations should keep accurately to their allotted wavelengths.

Another method of ensuring constancy of wavelength or frequency in high powered transmitters is known as the master oscillator system. In this system a small valve generator, which is adjusted to give an output at a constant frequency, is used to drive the main bank of power valves which delivers the energy to the aerial. A further development of the master oscillator principle in which a quartz crystal is employed to control the frequency is briefly described on page 43 in connection with short wave transmitters.

The tuning fork drive and master oscillator system are used in practice chiefly with high powered stations when it is essential that likely interference should be kept as remote as possible. Transmitters of low power usually operate without such controls, and a simplified arrangement has already been given in Fig. 20.

Rectifiers.

In all valve transmitters the power supply to the anode is at a high voltage, and the supply to the anodes of this high voltage power is carried out in practice by two methods. These are :—

    (1) By means of high-tension direct current generators.

    (2) By means of Rectifiers fed from a source of alternating current.

(1) It is not proposed to discuss the first system at any length since the problem of designing a Direct Current Generator capable of supplying power at high voltages, say about 6,000 volts, is not one associated directly with wireless engineering but with the specialist in electrical machine design.

This method is adopted at the Rugby station, where three H.T. generators, each delivering power at a pressure of 6,000 volts D.C., can be connected in series to give up to an 18,000 volt supply to the anodes of the main banks of power valves. The system is also used at certain high powered broadcast stations, and it is claimed that the system is more economical in the long run than the use of rectifiers. In low powered sets of the type used for island communications this system is also used, but in these sets the voltage generated is not much above 1,500 volts, and the current output is small.

(2) The majority of valve transmitters in use to-day employ a rectifying system for the anode supply.

As in spark transmitters the required voltage is obtained from an A.C. generator, or rotary converter, or direct from alternating current mains, and stepped up to the required value by means of a transformer. The output from the transformer is an alternating supply and must be rectified and filtered to give a smooth D.C. supply at the necessary voltage.

The various types of rectifier in use include the Fleming Valve or diode, the Mercury Vapour rectifier, and the copper oxide rectifier. Of these the first is the most common and is suitable for use in low and in high power transmitters. The action of the diode itself has already been discussed; the following description of a simple full wave rectifying system will indicate the principle of a system embodying this kind of rectifier. (Fig. 21.)
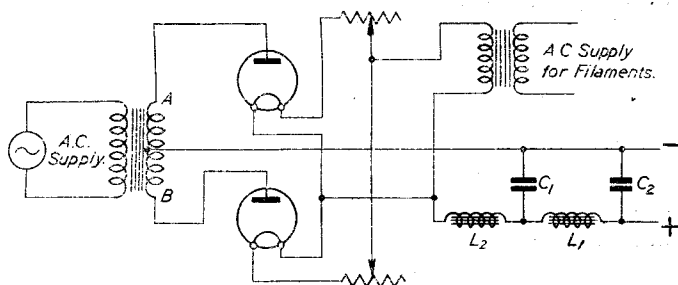

FIG. 21.

An alternating current supply is taken either from mains or generated in the station itself, and this supply is stepped up to the required high potential by means of a transformer. The diode or rectifying valve anodes are joined to the outer terminals of the secondary of this transformer which is centre tapped and from this point is taken the negative D.C. output lead. The positive output lead is joined to the rectifier filaments. The filaments themselves are usually heated by means of the A.C. supply taken through a special transformer; in some cases they are heated direct from a generator while in small equipments a battery is sometimes used.

The action of the rectifier is as follows. As the alternating current supply flows in the secondary of the main transformer the points A and B will alternately become positive and negative with each half cycle; when A is positive, current will flow from the top valve and charge up the condenser C_1; when

B is positive, current will flow from the bottom valve and also charge up the condenser C_2 in the same direction. The condenser stores up these pulses of direct current and delivers it as required. It should be noted that with this particular arrangement one pulse of direct current goes to charge the condenser C_1 for every half cycle of alternating current in the transformer, and the voltage available across this condenser will not be steady, but will rise and fall to some extent with each half cycle. The coil L_1 and the condenser C_2 are used to filter or " smooth " the fluctuating voltage. If L_1 and C_2 are suitably proportioned, the fluctuation of the voltage across C_2 (voltage ripple) will be much smaller than that across C_1 and an approximately steady D.C. output can be obtained. The arrangement of the condensers and choke is known as the smoothing system.

An additional choke L_2 is sometimes connected between the condenser C_1 and the rectifier. Owing to the back E.M.F. of L_2, this has the effect of making the current charging C_1 rise and fall more slowly. Thus for the same output the charging current will not rise to such a high peak value and the filament temperature of the rectifier can be reduced and a longer life obtained.

In large transmitters the preceding arrangement can be adapted for use with a three-phase supply, and under these
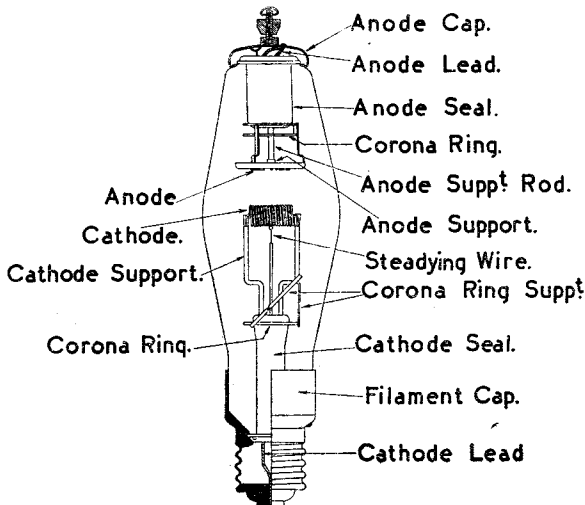

FIG. 22.

conditions it is easier to effect considerable reduction of voltage ripple and to maintain a very steady D.C. high potential output.

Another type of rectifier which has some advantage over the thermionic diode for certain purposes is the mercury vapour rectifier. Fig. 22 indicates the construction of a mercury vapour rectifier which is shown to consist of an anode and a cathode contained in a glass bulb filled with mercury vapour, the cathode being a filament which must be heated by current from a low voltage supply. Larger clearances are employed between anode and cathode and the anode does not surround the cathode as in the evacuated thermionic diode.

The action of a mercury vapour rectifier differs from that of the evacuated thermionic diode in that the current consists of positively charged particles or ions of mercury vapour passing from the region of the anode to the cathode, rather than negative electrons passing from the cathode to the anode. Mercury vapour rectifiers have a much lower internal resistance than thermionic diodes and the voltage drop in the tube is lower and more constant with varying loads.

The rectifier can be connected in circuit in much the same way as the thermionic diode, but special precautions have to be taken to ensure that the high tension anode voltage is not applied unless the filament has reached its proper working temperature and the whole tube is warm.

Another form of rectifier containing mercury vapour and used generally where greater powers are required is known as the mercury arc rectifier. In this type the cathode is a hot-spot on a pool of mercury. The necessary temperature of the hot-spot is maintained by heat caused by the plate current itself, the action of the tube being first started by " striking " an arc between the mercury and an auxiliary electrode which is caused momentarily to touch the surface of the mercury. Fig. 23 shows a typical mercury arc rectifier for a wireless transmitter. The type shown is arranged for six-phase working and is also provided with two additional " exciting " anodes which, operated at a comparatively low voltage, serve to maintain the correct ionised condition of the vapour and the hot-spot in the mercury although the load connected to the main electrodes may vary.

The mercury arc rectifier, like the mercury vapour rectifier, has low internal resistance and therefore has only a small and constant voltage drop and wastes comparatively little power. Further, the mercury arc type, having no filament to wear out, has a much longer useful life than thermionic or mercury vapour rectifiers. A further advantage of the mercury vapour tube is that, by the use of an additional

electrode or grid upon which is impressed a suitable auxiliary voltage, the voltage output of the rectifier can be controlled over a wide range without undue waste of energy.

Where a separate D.C. supply is required for the low power stages of a transmitter, *e.g.* the drive or modulator stages,
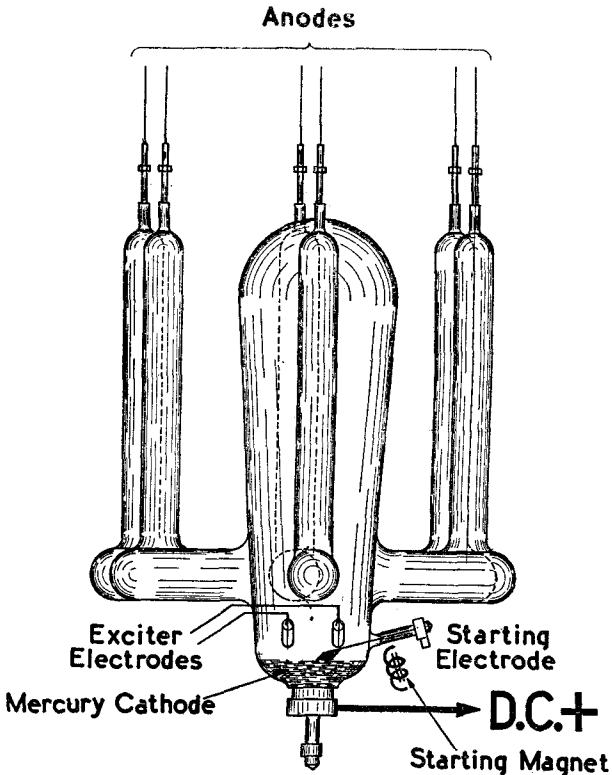
Anodes

FIG. 23.

or for receivers, the copper-oxide or metal rectifier is often used on account of its robust construction and the negligible attention required for its maintenance. This type suffers from the disadvantage of poor " regulation," *i.e.*, the voltage drop in the rectifier is high and increases rapidly with the current taken by the load.

A metal rectifier consists of a metal disc, usually of copper, one face of which is oxidised by special heat treatment. Such an arrangement when connected in an electric circuit will pass more current in the direction from oxide to metal than in the reverse direction, from metal to oxide. Thus, if an alternating

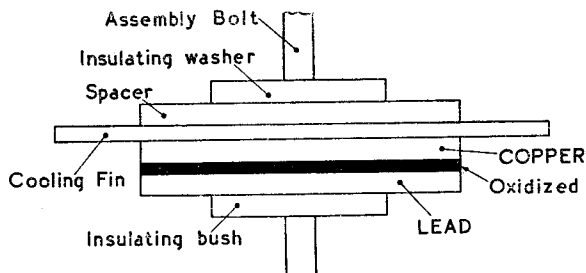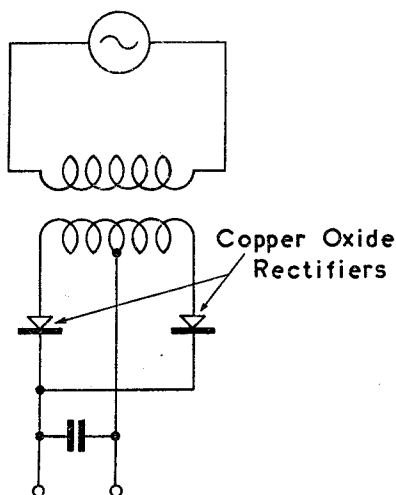FIG. 24 (a).

FIG. 24 (b).

voltage is applied to the circuit the resulting current will consist mainly of undirectional impulses which can be smoothed by means of condensers and chokes to give a nearly steady direct current. Thus the metal rectifier behaves in much the same way as a diode, the metal corresponding to the anode and the

oxide to the cathode or filament. The current passing through the rectifier develops heat in the disc, and as the temperature increases the difference between the conductivities in opposite directions diminishes, *i.e.*, the efficiency of the rectifier is decreased; further, overheating may cause chemical changes which permanently impair the action. The current, of course, depends on the applied voltage; hence there is an upper limit to the voltage which may be applied across any one disc. For higher voltages two or more discs are connected in series, and for heavier currents at a given voltage larger discs are used, or a suitable number of rectifiers are connected in parallel. Ordinary rectifiers therefore consist of groups of discs suitably connected in series and in parallel; adjacent discs are separated by lead washers and by conducting discs provided with large fins which serve to dissipate the heat developed. The arrangement of a single rectifier is shown in Fig. 24a, and Fig. 24b shows two rectifier units connected to the secondary of a centre-tapped transformer supplied with alternating current to give full wave rectification. This circuit corresponds to the full wave valve rectifier circuit of Fig. 21.

Interrupted Continuous Wave Transmitters.

It has already been stated that with continuous wave transmitters it is usual to employ a heterodyne receiver. If, however, the receiving station has not such a receiver, it is necessary to arrange that the transmitting station shall emit a wave whose amplitude varies at some *audible* frequency. In spark equipments this is arranged for because a train of waves is sent out and the number of trains per second is at the required audible frequency. In this way a musical note is received, since each wave train is rectified into a single pulse and the number of pulses per second is equal to the number of wave trains per second. The operation of a wireless receiver is discussed in detail at a later stage.

Coast station and ship transmitters are at present changing over from spark transmitters to interrupted continuous wave valve transmitters; this change is due to the fact that spark transmitters are a source of serious interference to stations which operate on adjacent wavelengths. The wave emitted from an I.C.W. station varies at audible frequency and can therefore be received without a heterodyne oscillator, but it is not so heavily damped as the wave from a spark station and therefore does not cause such serious interference.

Of the various methods by which I.C.W. transmission is produced the following are the most usual :—

(1) It has already been seen that with a valve rectifying system the high voltage alternating current from the main

transformer is rectified into uni-directional current pulses, and that these pulses are smoothed out into a steady supply by means of a smoothing system which as a rule consists of a condenser and choke coils. If the smoothing arrangements are cut out then the voltage from the rectifier unit will not be steady, but will rise and fall as each pulse of current passes through the rectifying valves. When this varying voltage is applied to the anode of the valve generator, the effect on the high frequency oscillations will be that their amplitude will rise and fall periodically in step with the voltage variations on the anode. The effect is illustrated in Fig. 25. When the amplitude of the high frequency oscillations is made to vary sinusoidally a form of I.C.W. transmission is produced which is known as " tonic train " transmission.

Voltage from Rectifier
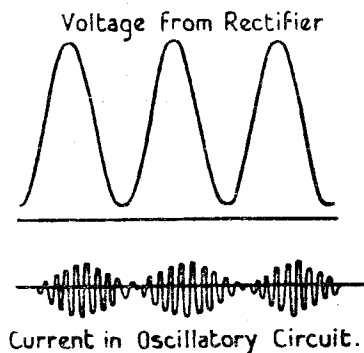
Current in Oscillatory Circuit.

FIG. 25.

This particular method of generating I.C.W. transmission is adopted when the same transmitter is required to transmit also on C.W.; a switch is fitted in the rectifier smoothing circuit by which the smoothing system can be cut in or out when C.W. or I.C.W. transmissions take place.

(2) It follows from the preceding method that I.C.W. transmission can be effected by applying an alternating voltage direct to the anode of the valve generator. If only one valve is used the arrangement is sometimes known as a single pulse I.C.W. circuit because only one half of the alternating voltage cycle will cause the transmitter to oscillate; during the other half cycles, when the anode is made negative with respect to the filament, the valve does not generate and the oscillations in the aerial die away.

It is possible to make use of both halves of the cycle by adopting an arrangement similar to that in the rectifying system which has been previously described. A circuit diagram of this type of transmitter is illustrated in Fig. 26, the filament and H.T. supply being from an alternator.
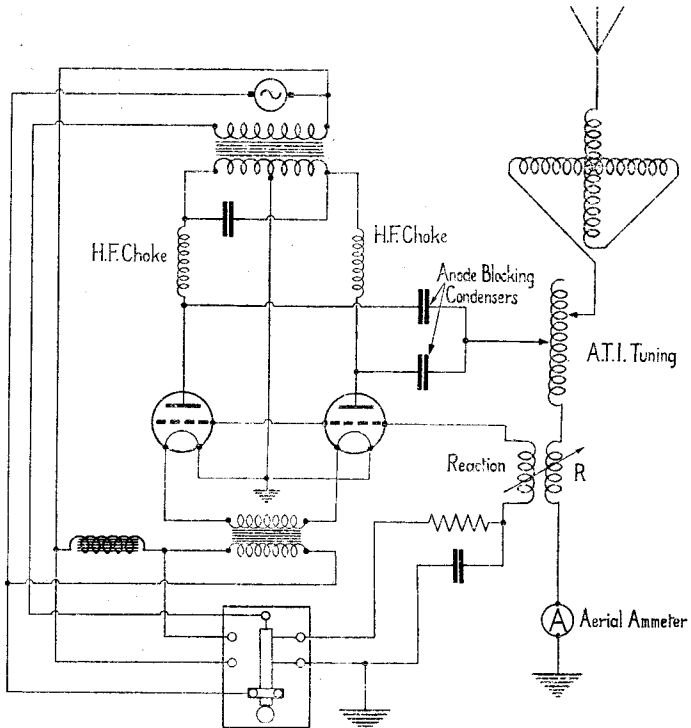
FIG. 26.

This type of transmitter is used for ship installations and in radio beacon stations. It should be noted that if one valve fails it is still possible to transmit, but only one half of the wave of the H.T. supply is used and thus the note frequency is halved.

It should be pointed out, however, that transmitters of this type, especially when used on short waves, often radiate over a very wide band of frequencies. This happens because

the frequency radiated depends not only on the tuned circuit but on the valve impedance, which in turn depends on the voltages applied to the anode and filament of the valve.

(3) A third method of producing I.C.W. is to interrupt the oscillations at an audible frequency by making and breaking the grid circuit of the oscillating valve. This is done either by inserting a buzzer or some form of mechanical interrupter in the grid circuit; in this way a train of waves is emitted, the frequency of the train being controlled by the speed at which the interruptions are made. Sometimes this system is known as " chopped C.W."

This system is used for the low power transmitters employed at P.O. Coast Stations in cases of emergency due to breakdown of the main transmitter or the public power supply from which the main transmitter takes its power.

(4) A fourth method, which has definite advantages over the preceding methods, in that it is capable of giving a very pure note and that the note can be easily made to have any desired frequency, is to modulate the high frequency oscillations by one of the methods described later for the modulation of telephony transmitters, the modulation being due to low frequency oscillations at the required note produced by a small valve oscillator instead of the complex oscillations generated by the action of sound waves upon the microphone.

Keying of Valve Transmitters.

In order to convey intelligence by means of a radio transmitting and receiving system, it is necessary for the energy radiated by the transmitter to be suppressed or modified at intervals in such a way that the received signal is in the form of impulses corresponding to a recognized code, or in the case of telephony, as described later, to speech impulses impressed upon a microphone. The most common telegraph code is the Morse code, but other systems which are designed to allow of higher speed working, direct printing of the received message, and more accurate reception through atmospheric interference are also in use. The processes of suppressing or modifying the radiated energy at intervals in telegraph transmitters is generally referred to as " Keying."

There are many methods by which a valve transmitter may be keyed; in the case of a simple low-power system a hand key may be inserted directly in the primary circuit of the high-tension transformer or in the grid lead of the oscillator and in the case of a high-power transmitter, different parts of the circuit may be keyed simultaneously by means of relays.

In transmitters of moderate power, from $1\frac{1}{2}$ K.W. to 3 K.W., it is usual to key in two or three places. The key may be inserted in the low-tension side of the main A.C. transformer while two pairs of back contacts come into operation at the same time. One set of these contacts is in the grid circuit while the other set is in the filament circuit. The filament circuit is not actually broken by this second set of contacts but when the key is depressed a " compensating choke " in the filament circuit is short-circuited in order that there shall be no diminution of filament brilliancy when the load comes on to the supply alternator. When the key is up this " compensating choke " is brought into the filament circuit so that the rise of alternator voltage does not vary the temperature of the filaments. The key indicated in Fig. 26 functions in this way.

Radio Telephony Transmitters.

In ordinary continuous wave telegraphy the transmitter radiates continuous oscillations so long as the key is depressed and heterodyne reception is utilized in order to make the signals audible in a telephone receiver. If, however, the oscillations at the transmitting end were caused to vary in amplitude periodically then the waves would reach the receiver already *modulated*. If these variations in amplitude are carried out at an audible frequency then corresponding
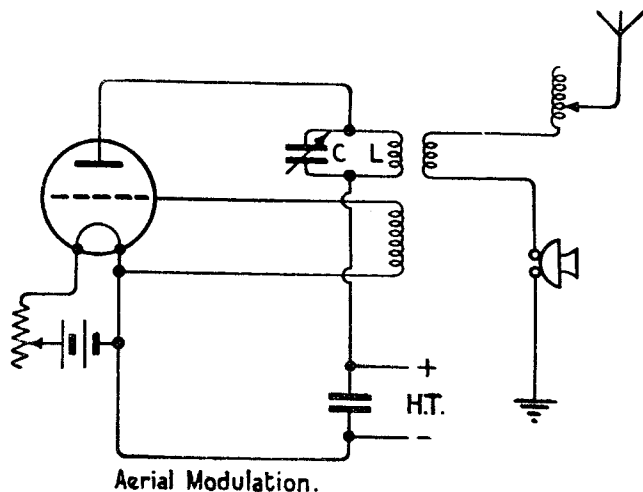

Aerial Modulation.

FIG. 27.

variations of current would occur in a receiver and a note would be reproduced. It follows that if the amplitude of the transmitted wave were made to follow the speech variations set up in a microphone, then speech would be reproduced in the receiver.

The process of varying the amplitude of the high-frequency oscillations of a radio telephony transmitter in accordance with speech or music vibrations is known as *modulation* and the high-frequency oscillation is known as the *carrier wave*.

There are various methods of modulating the carrier wave but they may be grouped into three main divisions.

(*a*) The first method, which is the simplest, is quite effective for low-powered transmitters. The necessary modulation in this case is obtained by varying the aerial resistance. Fig. 27 illustrates a simple arrangement of this kind.

The oscillatory circuit *LC* energizes the aerial and by speaking into the microphone *M*, which is inserted in series with the aerial, the resistance of the latter is varied and so the amplitude of the carrier wave is modulated in accordance with the low-frequency pulsations impressed upon the microphone by the voice.

This particular method obviously can be applied only to low-powered transmitters.

(*b*) The second method is known as grid modulation, since the speech variations are impressed on the grid of the valve which is producing the carrier wave. Fig. 28 represents a grid modulation circuit.
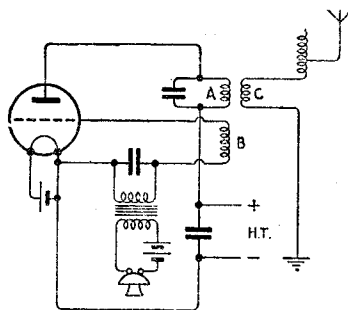

FIG. 28.

In this case the microphone is placed in the grid circuit and during speech the grid potential is varied above and below its normal potential when the microphone is idle. This voltage variation reacts upon the anode current, and therefore

upon the aerial current, by means of the valve and the coils *A* and *C*. This has the effect of changing the amplitude of the carrier wave in accordance with the vibrations impressed upon the microphone diaphragm.

When higher powers are required for transmission, the speech currents may be passed through some form of valve amplifying circuit before reaching the grid of the oscillating valve.

(*c*) The last method, which is probably the most satisfactory and the most usual, is to modulate the anode voltage. The method is sometimes known as choke control and in this system a modulating valve or valves are employed. Fig. 29 gives a circuit illustrating a simple choke control telephony transmitter.

FIG. 29.

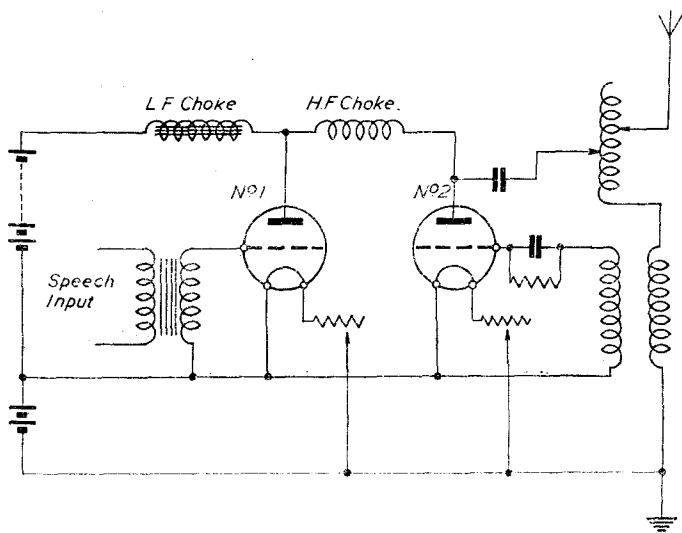As in the second system the speech input is applied to the grid of the first or modulator valve. This varies the potential of the grid of valve No. 1, and therefore the resistance between anode and filament, and so the anode current to valve No. 1 will be varied at speech frequency. A small fraction of the fluctuating current flows through the low-frequency choke and owing to its very high impedance at

speech frequencies, large fluctuations of voltage at the speech frequencies are set up across it. When the grid of valve No. 1 is above its normal potential the voltage applied to its anode is reduced; owing to its relatively high grid potential the increased current to valve No. 1 is maintained, but that taken by valve No. 2 is decreased by an amount nearly equal to the increase in current to valve No. 1. Thus, as the current to valve No. 1 fluctuates at speech frequencies, the voltage and current to valve No. 2 and hence the amplitude of the radio-frequency current generated by the latter valve fluctuates accordingly. The purpose of the high-frequency choke is to prevent high-frequency currents from flowing in the modulator valve circuit and the H.T. supply circuit.

Good reproduction of speech depends not only on the type of microphone used but also upon the modulating system. In cases where a high standard of modulation is required, such as in broadcast transmitters, microphones of a special character are employed and the modulating systems must be carefully designed.

The nature of the modulated output from a telephony transmitter is such that a band of frequencies are transmitted. Suppose that it is necessary to modulate the carrier wave by any of the speech frequencies from 300 to 3,000 and that the carrier wave frequency is 1,000,000 cycles per second, it will then be necessary to transmit—

(1) The carrier wave frequency, *i.e.*, 1,000,000.

(2) The band (1,000,000 + 300) to (1,000,000 + 3,000), *i.e.*, 1,000,300 to 1,003,000 which is known as the upper side band.

(3) The band (1,000,000 − 300) to (1,000,000 − 3,000), *i.e.*, 999,700 to 997,000, which is known as the lower side band.

It is possible by the use of suitable circuits to transmit the speech on one of the side bands only and to eliminate the carrier and the other side band. This system is in use at Rugby for the long wave Transatlantic telephony service. The chief advantage gained by using this system is that it is necessary to reserve a smaller band of frequencies for any particular telephony service, and by confining the distant reception to this smaller band, less interference from atmospheric disturbances is experienced. In addition, saving in power is effected since about $\frac{2}{3}$ of the total energy radiated from an ordinary telephony transmitter is in the carrier, which can be supplied at the receiving end much more economically.

Short Wave Propagation.

From a transmitting aerial of simple design consisting of a system of elevated wires connected by a vertical lead to the transmitter, energy is radiated radially outwards in a horizontal direction and to some extent, at all angles to the horizontal plane. The subsequent paths of the waves depend very much upon the wavelength. Very long waves are bent so as to follow the curvature of the earth, while very short waves appear to travel in a path limited in the same way as light waves by a tangent to the earth's surface; such waves below 10 metres in length are employed by the P.O. for radio links between telephone trunk lines. Shorter waves diminish in intensity more rapidly than longer waves; nevertheless, using short waves of from 10 to 50 metres length it is possible to communicate over great distances with comparatively low-powered transmitters. This is due to the fact that such waves, following a path inclined to the horizontal, are reflected from the upper layers o ṭhe atmosphere to the earth at some distance from the transmitter where they may again be reflected from the surface of the earth, to be reflected again from the upper atmosphere and received at a still greater distance from the transmitter. Waves following such paths diminish less rapidly than those following a path along the earth's surface. The propagation of short waves is associated with certain phenomena which are due mainly to the reflection referred to above and are much less noticeable in the case of longer waves. The following are some of the more important :—

(1) *Fading.* This is the name given to the occurrence of fluctuations in the intensity of the received signal at a given point. The fluctuations may take place at audio frequency or may have longer periods of from one to four seconds.

(2) Great differences between the intensity of signal received during day and night are experienced.

(3) Certain wavelengths may be suitable for certain transmissions while slightly shorter or longer wavelengths are unfavourable and it is necessary to vary the wavelengths used for a particular channel according to the time of day or night and the season of the year.

(4) *Skip distance.* It is found that in the neighbourhood of a short wave transmitter there is a zone where the signal strength is considerable; around this zone and further away from the transmitter another zone may exist where the signal strength is very small and around this second zone and still further away from the transmitter a third zone may exist where the signal

strength is again considerable. The width of the second zone where the signal strength is small is generally known as the " skip distance." For example, a short wave transmitter operating in the British Isles may be inaudible in this country except within 20 miles of the transmitter itself and yet may be received in, say, America, at considerable signal intensity. Skip distances vary according to the wavelength, and according to certain authorities, do not generally occur with wavelengths above 50 metres; at about 40 metres the distances may be from 60 to 120 miles and with lower wavelengths may be very much in excess of 1,000 miles.

The generally accepted explanation of skip distance phenomena is that the energy which is received close to the transmitter is due to the direct wave which travels along the surface of the earth, and that this wave is very quickly diminished due to absorption; on the other hand, the energy received in the zone beyond the skip distance is due to energy which returns again to the earth by reflection from the upper layers of the atmosphere.

The design of transmitters for short wave propagation demands special considerations which need not be taken into account for long waves. Slight variations in the high tension supply voltage and the filament voltage are sufficient to cause the main oscillator frequency to alter over too wide a range for commercial operation; in addition especial care has to be taken to keep the electrical constants of the transmitting circuit as constant as possible and to eliminate the effect of all stray capacitance. The valves used for short wave transmitters have to be designed so that their inter-electrode capacitance is at a minimum.

The difficulties which attend the production of a stable frequency output in short wave transmitters which use a simple valve oscillatory system only, have led to the development of other systems which can be depended upon to have an output at constant frequency.

These latter systems adopt the same principle as that of the tuning fork drive transmitter which has been described previously. A low-powered master oscillator system, which on account of the small power employed, can be arranged to give an output at constant frequency, is used as the source of the electrical oscillations which are then amplified by several stages until they are radiated from the aerial. The capacitance between the anode and grid circuits of the valves used, though small, will at high frequencies provide appreciable coupling, tending to cause the amplifying stages to generate oscillations. The frequency of these oscillations may differ from the fre-

quency of the oscillations generated in the drive stage and will depend upon the voltages applied to the filaments, grids and anodes of the valves and upon the electrical constants of the aerial, which may vary appreciably with atmospheric conditions or as the aerial moves in the wind. Consequently, special precautions have to be taken in the construction of the amplifiers to eliminate the effects of all such capacitance and so to ensure that the drive stage frequency determines the frequency of the oscillations radiated from the aerial.

A type of frequency control which designers are adopting to ensure stability of frequency in a short wave transmitter is known as a piezo-electric crystal drive. Certain quartz crystals which have been cut in the correct manner can be set into mechanical oscillation by applying an alternating E.M.F. across them. The frequency of the applied E.M.F. must coincide with the mechanical frequency of vibration of the crystal to produce the above effect and, when this condition is obtained, quite small voltages are sufficient to set the crystal into oscillation. The frequency of vibration of the crystal depends upon the linear dimensions of the crystal.

For short wave transmitters the crystal is usually associated with the grid circuit of a small valve generator and the output from this generator is remarkably constant in frequency; the frequency is predetermined by grinding the quartz crystal to the required dimensions. For most types of crystal in common use the frequency of the oscillations generated by the crystal drive stage is affected by changes of temperature and a higher degree of constancy is secured by enclosing the crystal or the complete drive circuit in an electrically heated box or oven constructed of heat insulating material, the temperature inside the oven being controlled by an electrically operated thermostat.

For wavelengths below 80 metres it is usual to employ a crystal cut to give a frequency lower than that required to be radiated and to select a harmonic of the crystal frequency (usually by means of one or more low power stages in which the output frequency is arranged to be double the input frequency), oscillations of the higher frequency required being then amplified and passed on the aerial circuit by the power stages.

PART III.

RECEPTION OF WIRELESS SIGNALS.

When any electromagnetic waves travelling through the ether strike a conductor, they induce in this conductor an alternating E.M.F. of their own frequency. The value of the E.M.F. set up in such a conductor will depend upon the

field strength of the wave in the neighbourhood of the conductor and this field strength depends in general upon the power of the transmitter and the distance between the latter and the conductor. In any receiving station such a conductor or aerial is employed to collect the E.M.F. induced by the high frequency wave emitted from the transmitting station, and associated with the aerial is the receiving apparatus which converts the received energy into suitable form for reception by aural or other means. Besides receiving the signal intended for it, the receiving station equipment must be so arranged that there is no interference from other signals which are being transmitted to other stations.

In its simplest form the receiver consists of :—

(1) A circuit coupled to the aerial, which is tuned to the frequency of the incoming signal and which will therefore respond to that particular frequency most readily.

(2) A detector which converts the energy so received into a suitable form for reception by

(3) A device by means of which the signals can be heard or printed.

In the more complex types of receivers the circuits associated with the aerial may be arranged in a series of stages which are all tuned to the same frequency and are coupled together in this way to give great selectivity; before passing to the detector the high frequency signal may be amplified by various stages of a high frequency valve amplifier before being delivered to the telephones or printing device. In order to increase the degree of selectivity still further the high frequency and low frequency amplifiers may be arranged in the form of filter circuits. A receiver of the above type is usually employed for long distance high speed reception and in many cases is associated with a directional aerial system.

A simple form of receiving circuit for the reception of damped waves is illustrated in Fig. 30.
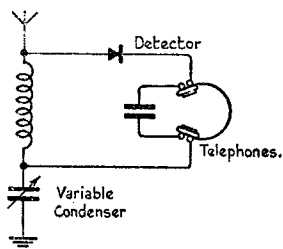

FIG. 30.

The aerial circuit is tuned to the required frequency and the energy collected by this system is rectified by the detector and produces a note in the telephones. The aerial circuit in this case is tuned by means of a variable condenser but in some cases a variable inductance such as a variometer is used. A greater degree of selectivity can be obtained by having the detector in a second tuned circuit which is loosely coupled to the aerial circuit.

Detectors.

The frequency of the energy emitted from a radio transmitter is so high that the inductance of a telephone receiver will not allow passage of current at this frequency; in addition, the diaphragm could not vibrate at a radio frequency, and even if it could the human ear would not respond to such a frequency as it is not able to perceive sound waves above anything of the order of 20,000 oscillations per second. Detectors are used therefore to convert the high frequency energy into energy at a frequency which will operate the telephones and so that the sound produced thereby can be perceived by the human ear.

Before any detector such as those employed in a wireless receiver can be used for the above purpose it is necessary to modulate the wireless wave in some way. In spark transmitters this is done by making the spark train frequency, which, as has been seen, depends upon the alternator frequency, lie in the audible range and this is usually somewhere between 300 and 1,000 trains per second. In I.C.W. transmitters the amplitude of the high frequency output is made to vary at some audible frequency usually between the limits 600 and 1,200 periods per second and in a telephony transmitter this modulation is of course carried out in accordance with the frequencies of speech and music. In continuous wave transmitters the output is not modulated and the necessary modulation must therefore be carried out in the receiver; this is known as heterodyne reception and will be described later.

The action of a detector is to rectify the modulated pulses and so turn each group of high frequency pulses into a low frequency pulse which will pass through the telephone windings.

Many types of detectors have been used but those in common use at present are the crystal detector, the valve detector, and the copper oxide or metal detector. For commercial purposes the valve detector has almost totally replaced the crystal detector, but a small type of copper oxide rectifier of recent introduction having low shunt capacitance

is employed in some cases as an economical and efficient substitute for a thermionic diode, since it requires no filament and high tension supply.

The Crystal Detector.

If an alternating voltage is supplied to certain combinations of two crystalline substances, or a crystalline substance and a metal in contact, it is found that current passes more readily in one direction than in the opposite direction, *i.e.*, the combination acts as a rectifier. Hence when an electrical oscillation, such as the incoming signal, is impressed upon a circuit containing such a crystal detector, a series of unidirectional currents will pass. For each train of waves this series of currents will act for telephonic purposes as one unidirectional current giving for each train a movement of the telephone diaphragm. In this way the note produced by the telephone diaphragm will vary in accordance with the number of trains of waves per second emitted by the transmitting station or in the case of a telephony transmitter in accordance with the speech variations that modulate the emitted wave of the transmitter.

The Valve Detector.

It was mentioned on page 17 that the Fleming diode would conduct current in one direction only, from anode to filament or cathode. The original use of this valve was for the purpose of substituting crystal and other early forms of detection in wireless telegraph receivers. Diodes are still used as detectors in receivers for special purposes, but are often combined with a three electrode valve, or another diode, or both in one glass envelope and share a common cathode with these other elements. The most common arrangement for detection purposes in radio receivers utilizes a three electrode valve.
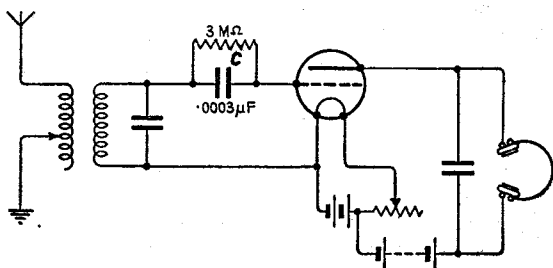

FIG. 31.

Rectification by means of a three electrode valve can be obtained in two ways as follows :—

(1) Grid rectification.

For this method the high frequency voltages induced in the aerial circuit are applied across the grid and filament of the valve through a small condenser. The arrangement is illustrated in Fig. 31.

The action is as follows. When the grid is made positive, electrons pass to it from the filament; this electron flow ceases, however, when the grid is made negative. Through the interposition of the condenser C the electrons cannot flow back to the filament but charge the condenser. Each positive charge on the grid, therefore, attracts a small negative charge to the condenser C which thus gradually becomes more and more negatively charged as long as the signal impulse lasts, since the electrons are small negatively charged particles of electricity. The result will be that the grid is made negative with respect to the filament and therefore the current flowing in the anode circuit of the valve is reduced. For each train of waves or each variation in amplitude of the incoming signal, there will be a momentary mean variation of anode current in the opposite sense which will cause a movement of the telephone diaphragm and the latter will give out a note corresponding to the train frequency or modulation of the incoming wave.

Since the grid condenser C continues to become more and more charged as the signal impulse persists, it will be seen that the method is cumulative and therefore very sensitive. After each impulse it is necessary to restore the grid to its original condition with respect to the filament and so, as it were, reset the device. For this purpose a high resistance leak (of the order of 3 megohms) is placed across the condenser to enable the charge on the condenser to leak away after the impulse ceases, so leaving the device responsive to the next train of waves. The value of this leak is important since if it is of too high a value a big negative charge on the condenser will not be able to drain away fast enough to reset the device. If the leak is of too low a value the condenser would not become charged. In either case the valve would be inoperative as a rectifier.

2. Anode bend rectification.

If a curve is drawn by plotting the different values of anode current for varying grid potentials we shall obtain a curve
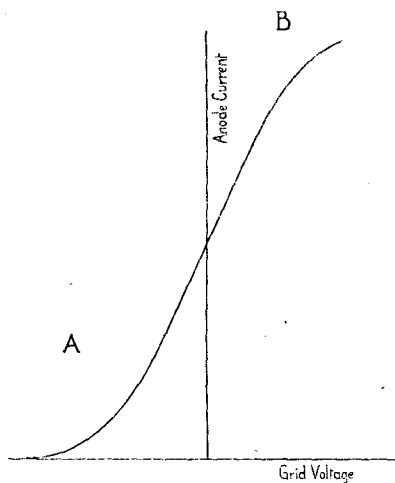
FIG. 32 (a).

similar to that shown in Fig. 32 (a). In Fig. 32 (b), the lower
bend of the curve is shown to a large scale.

(This curve is known as the characteristic curve, and has
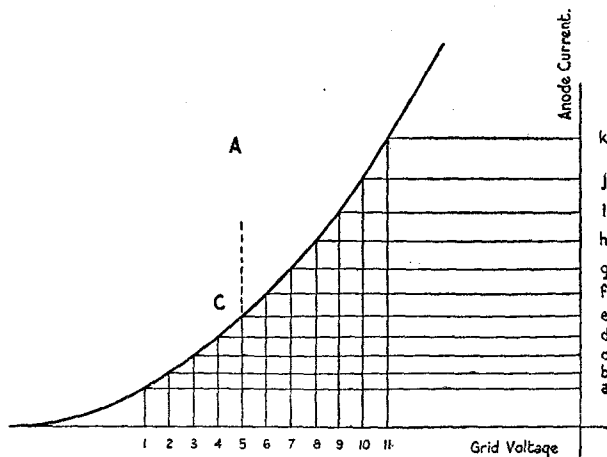already been discussed, *see* Figs. 15 and 16.)

FIG. 32 (b).

Anode bend rectification involves the use of either of the portions marked *A* and *B* on the curve; if the valve is operated under the conditions which exist at the part *A*, it is known as bottom bend detection, and when working at *B* upper bend detection. The action is similar in both cases, and it will suffice if one, bottom bend detection, is described.

It is obvious that to carry out detection by this method it is essential that some means should exist by which the valve can be operated at the required part of the characteristic curve. This is done by associating a potentiometer in the grid filament circuit, and the valve in its non-operative condition can then be set to work on any portion of the curve by adjusting the potential of the grid to the required value.

Consider the points 1, 2, 3, 4, 5 —— 11, on Fig. 32 (*b*). They are equally spaced, and 1–2, 2–3, 3–4 ——10–11, there-fore, represent to scale *equal changes* of grid voltage taking place at different points around the bend of the curve at *A*. It is obvious that the corresponding *changes* in anode current are represented to scale by a–b, b–c, c–d —— j–k respectively, and it will be seen that these are progressively increasing in magnitude from the minimum change " a–b " to the maximum change " j–k."

If, then, the potentiometer is adjusted so that the valve's non-operative position is at *C*, say, and a signal impulse is impressed between the grid and filament, the negative half of the wave will make the grid more negative and cause a reduction in the anode current by an amount of the order e–d, e–c, e–b, or e–a, whilst the positive half of the wave will make the grid more positive and cause an increase in anode current by an amount of the order e–f, e–g, e–h, etc.

As shown previously, the magnitudes e–f, e–g, etc., are greater than e–d, e–c, etc., and therefore the *average* value of the anode current will increase while signals are being received, and the necessary rectifying effect will be obtained. The sharper the bend of the characteristic, the more efficient will be this rectifying or detecting effect, and the stronger the signal the better the detection.

The same thing takes place when using the upper bend of the curve, except that in this case the average value of the anode current will be reduced during periods when reception is taking place.

It is more usual to operate on the lower bend of the curve since the anode current and therefore the power consumption is lower than when using the upper bend.

Indirectly heated Valves.

In the valve shown in Fig. 13 the filament is also referred to as the " Cathode." In many cases, particularly in certain receivers where it is desired to use alternating current to heat the filament, this is made independent of the cathode which is then made in the form of a tube of radio active material (*i.e.* a material capable of emitting electrons in suitable quantities when heated by the filament). The filament and cathode are insulated from each other. Such valves are termed " Indirectly heated Valves." The active material is usually a coating round a metal tube, this tube fitting closely over a cylinder of insulating material in which the filament is embedded.

A sketch of the arrangement is shown in Fig. 33 (*a*) and the symbol used in diagrams for this type of valve in Fig. 33 (*b*). The cathode so constructed is more rigid than a simple filament consequently the grid may be brought very close to it, thus allowing improved operating characteristics to be obtained. On account of the comparatively large amount of material which the filament current must heat at the same time as the active material, about 30 seconds elapses after switching on the filament before the cathode has reached the temperature required for normal emission.
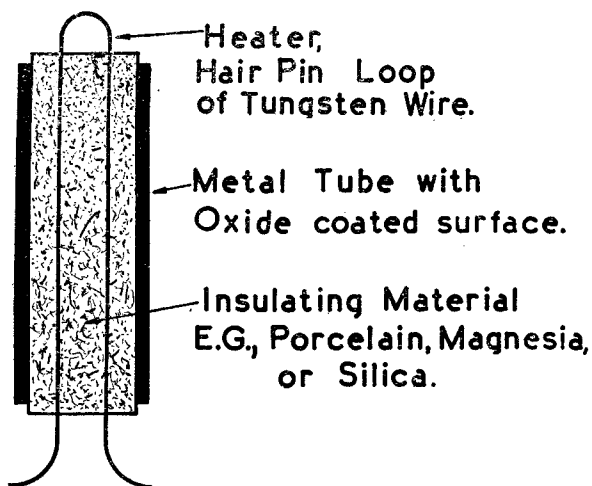
Heater,
Hair Pin Loop
of Tungsten Wire.

Metal Tube with
Oxide coated surface.

Insulating Material
E.G., Porcelain, Magnesia,
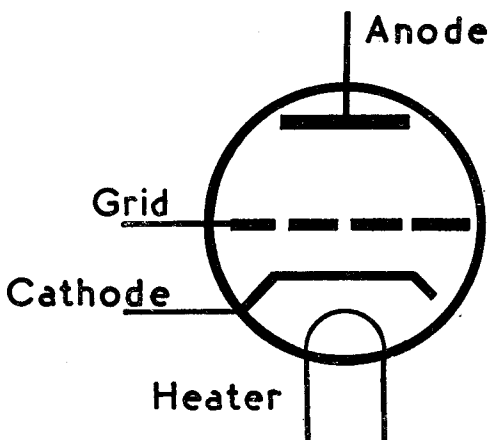or Silica.

Fig. 33 (*a*).

FIG. 33 (b).

In naming the types of valves referred to below, viz., three electrode or " triode," four electrode or " tetrode," five electrode or " pentode," the heater in indirectly heated types is not counted as an electrode since it serves merely to maintain the cathode at the necessary temperature.

Multi-electrode Valves.

Three electrode valves may be employed as already described, as rectifiers or amplifiers or as generators of high frequency oscillations.

In an ordinary 3 electrode valve, the grid in close proximity to the anode constitutes a condenser of capacitance of the order of 2 to 8 micro-micro-farads for receiving valves, and of somewhat higher values up to about 50 $\mu\mu$ F for the larger valves used in transmitters. If such a valve is used as an amplifier at high frequencies, this comparatively high inter-electrode capacitance provides a coupling between the anode and grid circuits and results in a proportion of the amplified signals in the anode circuit being fed back to the grid circuit, whence it is reamplified by the valve. This effect is obviously cumulative and generally results in instability, the valve tending to act as a generator of high frequency oscillations and to provide an undesirable capacitive coupling between the grid and anode circuits. Early methods of overcoming these effects involved the introduction into the grid circuit of resistance to damp the oscillations, but this reduced the efficiency

of the circuit. Considerable improvement can be effected by the "neutralized" circuit, in which the voltage fed back through the valve is opposed and cancelled by an equal and opposite voltage intentionally fed back from the anode to the grid circuit through the "neutralizing" circuit. This system suffers from the disadvantage that generally the circuit is completely neutralized for one frequency only and that additional adjustment of the neutralizing circuit is necessary if the frequency is changed.

In the "screened grid," "tetrode," or four electrode valve the effective capacitance between grid and anode is reduced to an extremely small value and the feed back thereby rendered negligible, by interposing a screening grid between the normal (or control) grid and the anode of the valve; the screening grid is maintained at a potential about two-thirds that of the anode. In order to take full advantage of the "screened grid" valve it is usual to separate all parts of the circuit connected to the control grid from that connected to the anode by means of an earthed metal screen. In some cases the valve is so mounted that it projects through a hole in the screen so that the screening grid practically closes the hole, the cathode and grid with its associated circuits then being on one side of the screen with the anode and its associated circuit on the other. In other cases the outside of the glass
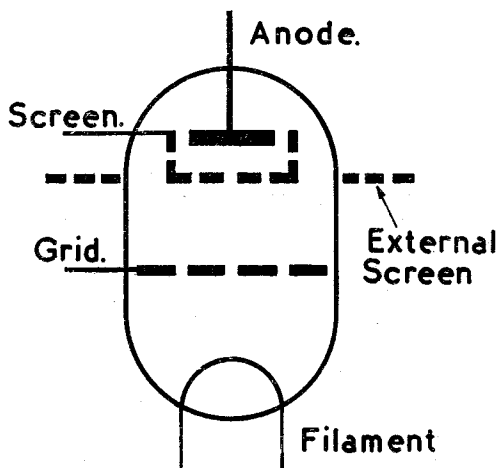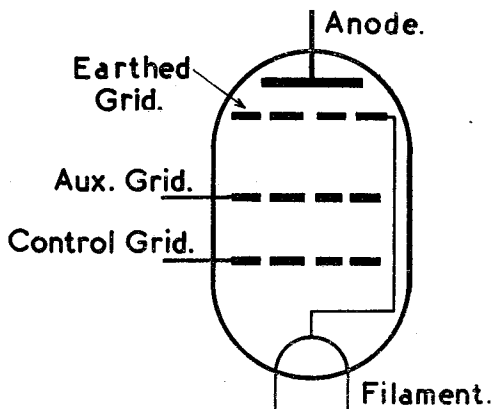

FIG. 34 (a).

FIG. 34 (b).

envelope of the valve is sprayed with a metal coating which can be earthed. Such arrangements provide very efficient amplifiers free from instability. The symbol used in diagrams for a tetrode is shown in Fig. 34 (a).

The " Pentode " Valve.

When electrons strike an obstacle such as the anode of a " screened grid " valve, the disturbance causes other electrons to be thrown out from the surface of the anode termed secondary electrons, which may leave the surface with sufficient velocity to come within the influence of the screening grid which, since it is at high potential, will collect and conduct them away to the high tension supply. This stream of secondary electrons or " secondary emission " constitutes a current from the anode in the reverse direction to the normal anode current, and in a tetrode will cause the total anode current to fall rapidly as the anode voltage is reduced below a certain critical value approaching the value of the screening grid voltage. Now the variation of current in the anode circuit, due to a signal impressed upon the control grid, will be accompanied by variations of the voltage at the anode of the valve, hence the strength of the signal which may be applied to the grid must be limited so that the resulting anode voltage does not fall below the critical value referred to above. Thus although a tetrode provides a satisfactory means of securing high amplification for weak signals, for signals above a certain strength amplification is limited and distortion occurs due to the effects of secondary emission.

Secondary emission is effective only if there exists near the anode an electrode at high potential which can collect the secondary electrons moving towards it. If, therefore, an additional electrode in the form of an earthed grid is interposed between the screening grid and the anode, any secondary electrons emitted from the anode will return and will therefore have no effect upon the characteristics of the valve. Such a valve is termed a " Pentode " and the " earthed " grid is actually connected to the cathode inside the valve. Moreover the earthed grid is also between the anode and control grid and the screening grid is no longer required to function as an electrostatic screen but it is used to give the electrons the necessary acceleration to carry them through the earthed grid to within the influence of the anode, and in the pentode is usually referred to as the " auxiliary," or " priming," grid. The fixed potential applied to this grid is not critical and values equal to, and as low as one half of the anode potential, are employed according to the design of the valve and the requirements of the associated circuits.

The characteristics of the pentode are such that at high frequencies high amplification with stability can be obtained for weak signals, but the strength of the applied signal is not limited to the same extent as with the " screened grid " valve; *i.e.*, the pentode is capable of dealing with a comparatively strong signal applied to the grid. The pentode valve, suitably designed for use in the low frequency output stages of a receiver, is also capable of delivering a large output of audio frequency power for a comparatively small voltage applied to the grid. Fig. 34 (*b*) shows the symbol used in diagrams for a pentode.

" Variable-Mu " Valves.

The relative sensitivity of two valves may be judged by comparing their " mutual conductances," the mutual conductance of a valve being a figure which indicates the number of milliamperes change in anode current caused by 1 volt change in grid voltage. Referring to the curve of Fig. 15 it will be seen that when the grid voltage is changed by 10 volts from zero to + 10 volts the anode current change is from 9 m.a. to 15 m.a., *i.e.*, a change of 6 m.a. Hence the mutual conductance is given by $\frac{6}{20} = 0\cdot6$ m.a. per volt approximately.

Similarly, if the grid voltage is changed from 20 to 30 volts, the anode current changes again by 6 m.a. from 23 m.a. to 29 m.a., again giving a mutual conductance of approximately $0\cdot6$ m.a. per volt. It is seen that the mutual conductance is approximately constant where the grid voltage anode current curve is a straight line, *i.e.* in Fig. 15 from about

—2 volts to +40 volts, but is progressively less where the graph curves towards the part where it is nearly horizontal. Thus a weak signal superimposed on a steady grid bias of 20 volts negative would cause a smaller fluctuation of anode current than would an equal signal with a steady grid bias of say 5 volts negative. Certain screened grid and pentode valves are so designed that the curved portion of their grid voltage—anode current characteristic is exaggerated and much longer than in normal valves; such valves are termed " Multi-mu " or " Variable-mu " valves. By varying the grid bias applied to these valves the amplification of a receiver can be controlled. The bias may be varied by hand, or automatically in sympathy with the fluctuations in the strength of a received signal, in order to minimize the effects of fading.

Several other arrangements of electrodes are employed in receiving and transmitting circuits for special purposes, but these can generally be considered as combinations of two or more of the types described (diode, triode, tetrode, or pentode), arranged in one envelope and employing a common cathode.

Heterodyne Reception.

With Spark, I.C.W. and telephony systems the wave emitted by the transmitter is already modulated at some audible frequency, and it is necessary only to provide a detector for complete reception of any signal. With a continuous wave system, however, the high-frequency signal will be of constant amplitude and unbroken. Consequently, with a detector alone the only sound heard in the telephones would be a faint click at the beginning and end of the signal. It is therefore necessary to modulate the incoming wave at some audible frequency in the receiving system itself, and the method universally employed is to use what is known as a *heterodyne oscillator*.

Before going into the details of such an oscillator it is necessary to consider what happens when two oscillations, whose frequencies differ slightly, are impressed upon any circuit. Suppose the circuit is so arranged that in addition to the incoming signal, we impress upon the grid-filament circuit of the detector valve a second high-frequency oscillation, the frequency of which differs slightly from that of the incoming wave. The term given to this second frequency is *heterodyne*. The action that takes place when these two oscillations combine is illustrated in Fig. 35.

Owing to the difference in frequency between the two oscillations, they will at one time be in step and then gradually fall out of step until they oppose each other; this process will be repeated at regular intervals, resulting in a combined

modulated oscillation of the type shown in *C* of Fig. 35. The two oscillations are said to *beat* with one another, and the frequency of the beat will be equal to the difference in frequency between the two sets of oscillations. For example, if the incoming signal frequency is, say, 50,000 cycles per second, and we adjust the heterodyne to 49,000 cycles per second or 51,000 cycles per second, the beat frequency will be 1,000 cycles per second; and when the combined wave is rectified
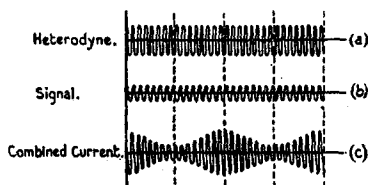

FIG. 35.

after passing through the detector stage, the note heard in the telephones will be at a frequency of 1,000 cycles per second. When the heterodyne and incoming signal frequencies are very close together the beat may be so low as to be inaudible, and this condition is known as the " dead space " or " silent point."

The advantages of heterodyne reception are as follows :—

(1) The heterodyne frequency, and therefore the beat note, is under the control of the operator, and therefore can be adjusted to any pitch that suits his hearing.

(2) It makes reception more selective, as it is easy to get rid of an interfering station by either setting the heterodyne so that the interfering station comes in the dead space or by setting the heterodyne so that the difference in notes between the station it is desired to receive and the interfering station is clearly marked, thus making it easy to read either of them through the other.

(3) A certain degree of amplification is obtained by use of a heterodyne since the maximum value of the beat oscillations is equal to the sum of the incoming signal and the local oscillation, which is, of course, greater than the signal itself.

There are two usual arrangements by which this kind of reception is carried out. The first and more usual is to employ a separate heterodyne oscillator, which is in effect a small transmitter. The output from this oscillator is coupled to the

grid circuit of the detector, and so beats with the incoming signal. The arrangement is shown in Fig. 36.

FIG. 36.

The frequency of the heterodyne is controlled by the variable condenser C.

The second method is to arrange that the detector valve shall fulfil the double function of a rectifier and a heterodyne oscillator.

Such an arrangement is known as a self heterodyne or autodyne circuit and is illustrated in Fig. 37.

FIG. 37.

In this case the reaction coil L_3 is adjusted so that the coupling to the coil L_2 is sufficient to make the valve oscillate, which it will do at a frequency determined by the tune of the circuit L_2C_2. This circuit is adjusted normally to be slightly

out of tune with the aerial circuit to which it is coupled so that there will be the necessary difference between the frequencies of the incoming signal and the oscillations generated by the valve to produce the required beat, which, after rectification by the valve, produces an audible note in the telephones. With the simple arrangements of Figs. 36 and especially Fig. 37 the heterodyne oscillation will be radiated from the aerial and may cause interference with neighbouring receivers tuned to the same or to slightly different frequencies. This difficulty can be eliminated by interposing one or more high frequency amplifying valves, preferably of the screened grid type, between the aerial and detector circuits.

Valve Amplifiers.

These may be divided into two classes :—

      (1) High-frequency amplifiers.

      (2) Low-frequency amplifiers or Note Magnifiers.

High frequency amplifiers are used for magnification of a weak signal before it reaches the detector valve and may comprise several stages which are coupled together in various ways and may be either tuned or aperiodic. With this type of amplifier there are two difficulties in design which have to be met. Owing to the high frequency of the signal which is being amplified the capacitive coupling between each stage formed by the inter-electrode capacitance of the valve is often sufficient to make the arrangement oscillate. It is therefore necessary to neutralise the effect of this capacitance which may be done by means of a small condenser coupled between the anode and the grid ; this method is now superseded by the use of tetrode or pentode valves. Capacitive coupling between one stage and another may also be provided by the capacitance between the various leads and coils in the amplifier ; careful spacing or alternatively screening of the leads is necessary and in many cases each stage, or each component part, is completely screened in a metal box.

Low-frequency amplifiers which amplify the signal after detection are not quite so prone to instability, such as described above, but even in these types the number of stages cannot be increased indefinitely without self oscillation. When transformer coupling between each stage is adopted, the transformers must be arranged so that there is no possibility of the fields being too close, and in modern transformers the additional precaution is taken to screen the windings and to earth the screen. Low frequency amplifiers for telegraphy reception may be tuned and this increases the selectivity of the set to a large degree ; with telephony receivers, however, this is the reverse of what is required and the amplifier is

designed to amplify all audio frequencies to the same degree. When, however, an amplifier of this type is used, say, only for commercial reception of speech, the arrangement can be made so that a certain necessary band of speech frequencies only is amplified and some degree of selectivity is obtained.

The Super-heterodyne Receiver.

A type of receiver, which has the advantage of combining a high degree of selectivity and sensitivity with ease of tuning, is known as a superheterodyne or double detection receiver. In such receivers a " heterodyne " or " beating oscillator " is applied to the incoming signal which produces a beat at a frequency intermediate between the signal frequency and the audio frequency. This beat frequency is passed by the first detector to the intermediate frequency amplifier and allows of considerable amplification at the intermediate frequency, and of the application of a filter passing frequencies within a limited band, thus giving a high degree of selectivity without the necessity for retuning the selective circuits for incoming signals of different frequencies. The intermediate frequency signals are then applied to a second detector and are further amplified at low frequency, a second heterodyne being applied before the second detector if the signals are not already modulated.

In the case of short wave reception the incoming signal may vary in frequency to such an extent that the resulting variation in the beat produced by a second heterodyne makes aural reception very uncomfortable; arrangements are therefore made for the signal to be modulated by a steady tone at an earlier stage of the receiver, or for the final rectified signal to " key " the output of an audio frequency oscillator.

The frequency of the oscillations produced by the first heterodyne beating with the desired signal is, after rectification by the first detector, the difference between their respective frequencies, and is made to coincide with the tune of the intermediate frequency amplifier circuits by adjustment of the heterodyne frequency to a value greater or less than that of the desired signal by the value of the frequency to which the intermediate amplifier is tuned. It will be clear that there will always be two signal frequencies which, for a given setting of the beating oscillator, will produce a beat note of the intermediate frequency. Thus if one of these is the desired signal, a signal at the other frequency will cause interference with reception. The interfering signal is referred to as the image signal, and to avoid such interference it is necessary to provide a selective circuit before the first detector, this circuit usually taking the form of an amplifier tuned to the signal frequency.

In some cases two intermediate frequencies are used necessitating three detectors; the first " intermediate frequency " may be higher than the highest signal frequency to be received, the first beating oscillator having a still higher frequency. This increases the frequency separation between the image signal and the required signal to such a high value that elimination of image signal interference can be secured without the use of a specially selective tuned signal frequency input circuit. Moreover, it is possible with this arrangement, to receive signals over a wide range of frequencies without changing the coils of the first heterodyne, and for this reason the names " Quick-search " or " Single-Span " are applied to this type of receiver. Such a receiver gives a high performance with great ease of control and is especially advantageous where, as in reception from ships operating on short wavelengths, the receiver has to be tuned rapidly from one frequency to another.

The Super-regenerative Receiver.

The circuit of Fig. 37 may be used for the reception of modulated signals provided the coupling between L_3 and L_2 is insufficient to maintain self oscillation. Moreover as the coupling between the anode or " reactive " coil is increased the effective amplification of the circuit increases since amplified signals in the anode circuit are fed back to the grid circuit and re-amplified.

In an ordinary receiver the amount of energy which may be so fed back to the grid circuit is limited to that amount which is just insufficient to start oscillation, but in a super-regenerative receiver a high degree of reaction is used but by means of an additional oscillator working on a much lower frequency (usually just above the limit of audibility), the oscillations which would otherwise be built up are periodically suppressed. By this means a very high degree of amplification is obtained without instability. The super-regenerative receiver is only useful when the ratio between the frequency of the incoming signals and the quenching frequency is very large; this type of receiver is therefore particularly useful for reception of signals of very short wavelengths *e.g.* below 10 metres.

Fig. 38 (*a*) shows a circuit diagram of a simple super-regenerative receiver in which the oscillations built up in the reactive circuit are automatically and periodically suppressed by the action of a grid leak resistance R and grid condenser C. As the oscillations increase in amplitude the grid condenser becomes charged negatively and the oscillations are suppressed. No grid current then flows, and as the grid condenser dis-

charges through the resistance, the grid potential becomes less negative and allows oscillations to build up again.
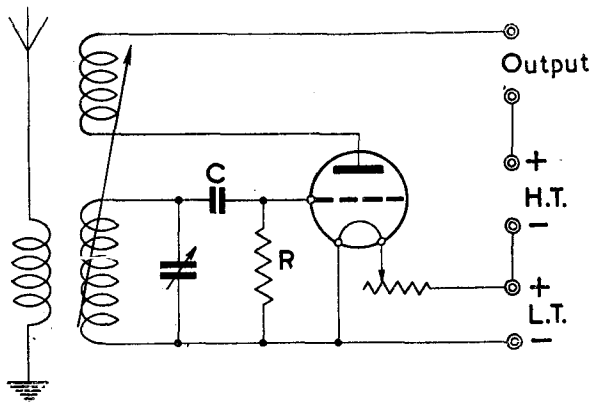

FIG. 38(a).

In Fig. 38 (b) the receiver shown is of the balanced or " push pull " type, with the tuned input circuit LC connected across the anode circuits of two triodes and to the grid circuits through the reaction condensers C_R. A separate triode supplies the suppression or " quenching " oscillation the frequency of which is determined by the adjustment of the tuned circuit C_1, L_1, and a proportion of which is impressed on the high frequency circuit through the condenser C_F and
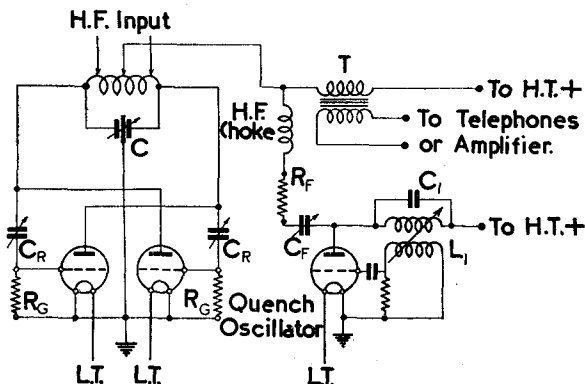
FIG. 38(b).

resistance R_F. A high frequency choke isolates the quenching oscillator from the high frequency circuit. The audio-frequency iron cored transformer T presents a high impedance to the quenching oscillations so that the voltage applied to the anode circuit LC is varied at the quenching frequency.

Automatic gain Controls and Limiters.

When it is desired to pass the received signal to a sub-scriber, or operator at some distance from the receiver, the output from the low frequency amplifier may be connected to the line through a suitable transformer in the case of modulated telegraph signals or telephony, or if D.C. telegraph signals are required at a distant office, the rectified low frequency signal is caused to operate a mechanical or valve relay, which then sends to line a steady pulse of current in one direction as long as a mark is received and a steady current in the opposite direction during spacing periods.

Except for exceptionally weak signals, or exceptionally strong signals, the amplification of a simple valve receiver will not vary greatly for signals of varying strength. An exceptionally weak signal, for instance, may cause a detector to operate inefficiently or an exceptionally strong signal may cause a valve to reach its saturation current so that further increase in signal strength can cause no further change in the current, thus " limiting " the amplification, and in the case of tone or telephony modulated signals causing the output to be distorted. For the reception of signals on short wavelengths over considerable distances the fading experienced often results in fluctuations of signal strength much greater than the range over which a simple receiver can operate without distortion in some form occurring in the later stages of the receiver. Moreover, if a relay is to be operated satisfactorily, the current change in the coils of the relay should be the same for the weakest signal as for the strongest, or, if the modulated signals are to be passed on to line, it is important that they should be applied to the line at a predetermined strength or " level," and that this level should not vary greatly during reception. Where the signals are required to be heard only by an operator who can control the receiver throughout the whole period of reception a hand operated control of the amplification or " gain " of the earlier stages of the receiver should suffice to deal with slow fading. Such an arangement however would not serve to compensate for the more rapid types of fading and an automatic form of gain control must be used; in the case of telegraph signals a limiter may be used. Automatic gain control circuits usually involve the use of variable-mu valves in the early stages of the

receiver the gain of which is caused to be reduced as the received signal strength increases, by means of an increased grid bias voltage developed across a resistance in the anode circuit of a detector valve connected with its grid in parallel with the normal detector valve. Fig. 39 shows a simplified diagram of a double detection receiver with a simple autogain circuit.
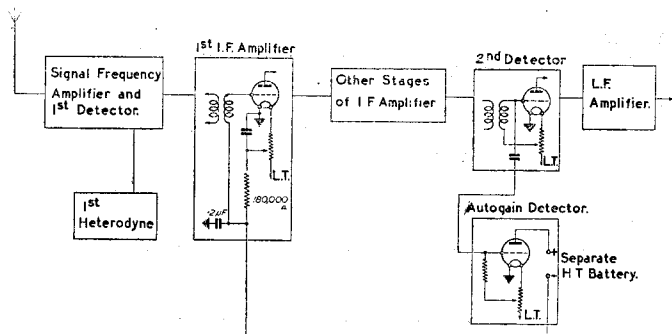

FIG. 39.

Limiting devices for telegraph signals may take several forms; the increased signal strength on mark may be arranged to increase the voltage on the grid of a triode valve so that for signals above a certain strength the grid is made positive with respect to the cathode, and current flows from grid to cathode; this current flowing in a resistance connected in the grid circuit then causes a fall in grid potential, this tending to limit the grid potential to that at which grid current commences to flow. The change in anode current between mark and space which is passed on to the remaining valves is correspondingly limited. A more effective device is to arrange for the working signal to reduce the grid voltage of a triode so that, when the signal is weak, the anode current is reduced to zero; any stronger marking signal can do no more than this since the anode current cannot reverse, and the signals passed on to the rest of the receiver are at constant strength. In addition to the required signal, there are always unwanted signals passing through the receiver due to external interference and to minute variations of voltage which always exist in the coils and valves of a receiver without any external cause. The sum of these unwanted signals constitute what is known as " noise " and the greater the ratio of the required signal strength to the strength of the noise in the receiver output, the clearer will be the reception. If the signal/noise

ratio is reduced below a certain limit, then communication becomes difficult or even impossible. A limiting device reduces a strong signal without reducing the noise while an automatic gain control reduces the amplification of both signal and noise and so maintains a higher signal/noise ratio than a limiting device.

Wavemeters.

Wavemeters are used for the purpose of adjusting transmitters or other apparatus involving tuned circuits, to the desired frequency. A wavemeter in its simplest form consists essentially of a circuit containing inductance and capacitance and a device for indicating when the current induced therein is a maximum. The resonance frequency of the part of the circuit containing the inductance and capacitance is made variable, usually by the employment of a variable condenser, and this circuit is calibrated against a known frequency standard to show the frequency or wavelength to which the circuit will resonate for any setting of the condenser.

The indicating device may consist of a valve detector with a galvanometer in its anode circuit, a neon lamp, or if the apparatus to be tuned can be energized by a modulated generator such as a modulated valve oscillator or by means of a buzzer and battery (which constitutes a small spark transmitter), a detector and headphones may be used. The circuit is illustrated in Fig. 40.
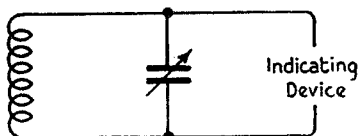

FIG. 40.

In tuning any circuit by means of such a wavemeter the principle involved is that of resonance between two circuits. We know that when one circuit is transferring energy to another, maximum energy will be transferred when the two circuits are in tune, *i.e.*, when the LC values of each circuit are equal. In order to use the wavemeter therefore it is brought near to the circuit of the transmitter which has to be tuned and the condenser of the wavemeter is adjusted until maximum current is flowing in the wavemeter; this will be indicated by the galvanometer, lamp or crystal and headphones. It is usual and more satisfactory to bring the wavemeter near enough only to show a small reading of the indicating device. The setting of the wavemeter will then be sharper and a more accurate reading is obtained.

It is possible by using a small buzzer and dry cell or a valve oscillator to energize a wavemeter circuit and thus use it as a very low powered transmitter. In this way a receiver can be tuned to any desired wavelength.

The use of a piezo-electric crystal for controlling the frequency of a short wave transmitter has already been mentioned. It is possible to use such a crystal as a standard of frequency and to construct a wavemeter embodying a crystal which will serve as an accurate check of frequencies which are the fundamental or harmonics of the natural period of the crystal.

Fig. 41 (a) shows a crystal wavemeter consisting of a tuned circuit with a current indicator in series with the inductance and capacitance, and a crystal in parallel with the tuned circuit, which is tuned approximately to the crystal frequency. If a source of oscillations of variable frequency is applied to the tuned circuit and the frequency is varied, the variations of the current indicator will be as shown in Fig. 41 (b), a sharply defined " crevasse " being obtained at the crystal frequency.
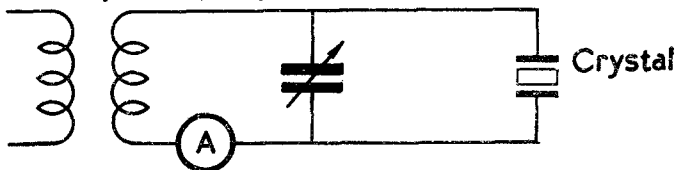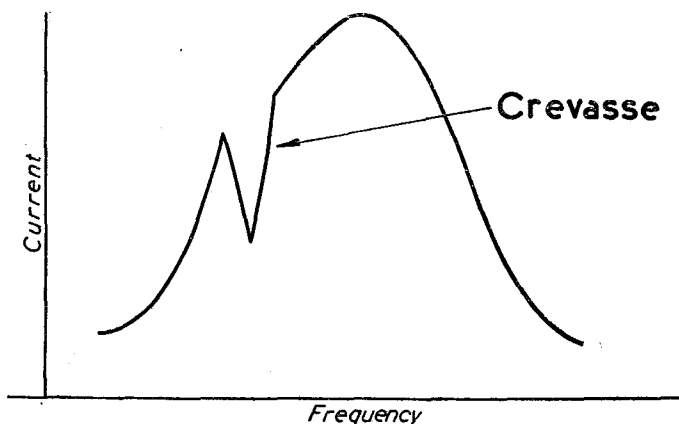

FIG. 41 (a).

FIG. 41(b).

PART IV.

DIRECTION FINDING AND DIRECTIVE RECEPTION.

The use of wireless direction-finding receivers whose primary object is to obtain the direction of the station whose signals they are receiving, is mainly confined at the moment to ship and shore and aircraft wireless services. For the ship and shore service there are two methods of procedure. Most of the Post Office coast stations are equipped with D.F. apparatus which is calibrated for obtaining bearings from ships and
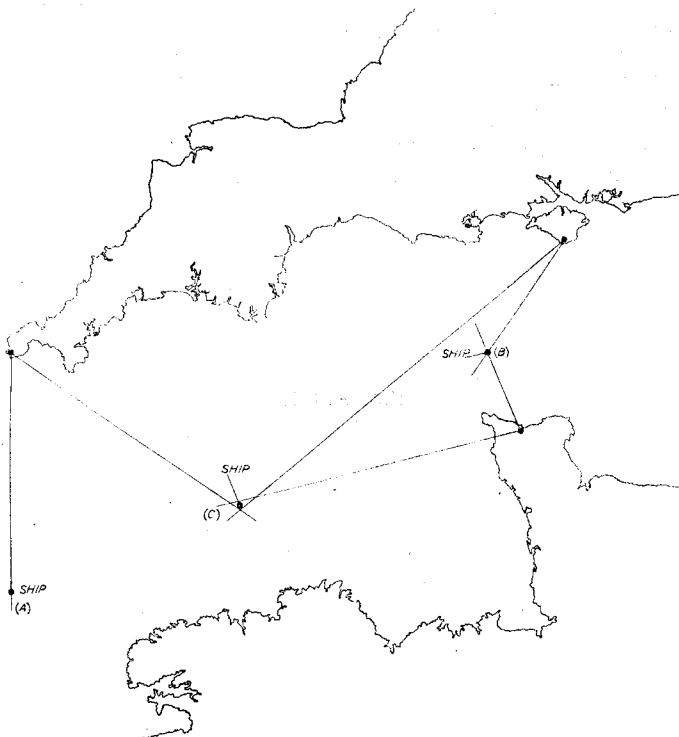

FIG. 42.

supplying such bearings to ships which require them. Thus a ship can obtain a single bearing as a check on its position as assumed from the navigator's normal reckoning; two bearings from adjacent Coast Stations plotted on a chart will give the

position independently of the navigator's reckoning; if a bearing from a third station can be obtained each serves as a check on the other two and the probable accuracy of the result can be gauged. Fig. 42 (a), (b) and (c) illustrates the use of 1, 2 and 3 bearings respectively in the determination of a ship's position.

Many ships have D.F. receivers fitted as part of their radio installation and such ships can take their own bearings on land stations whose positions are known and thus obtain the necessary information to enable them to chart their positions. Several wireless beacon stations are erected at various points round the British Isles for the purpose of providing known land stations on which ships can take bearings; these stations are usually erected at or near well-known lighthouses and transmit at regular intervals on a wave of about 1,000 metres.

Another system in use for ships and aircraft, which obviates the necessity of a direction finder on the craft or a directional receiver at the land station, employs a transmitter at a fixed point on land with a loop aerial having directional transmitting characteristics similar to the directional reception characteristics of a loop aerial as shown in Fig. 44. In addition to the signals sent out to identify the beacon, characteristic signals are transmitted when the loop is pointing in certain directions.

The ship or aircraft operator's procedure is to note by means of a stop watch the interval of time between one of the characteristic signals and minimum received signal strength and from the time interval his bearing from the beacon can readily be found. This system is also operated on a wave of about 1,000 metres.

Apart from the above, however, nearly all modern receivers for long distance reception employ directive reception and for short wavelengths directive aerials are employed for both transmitting and receiving. On very long wavelengths, directional reception is almost essential from the point of view of elimination of atmospheric interference, and increases the ratio of received signal strength to unwanted noise (due to combined external interference and noises generated in the receiver circuits) for a given power expended at the transmitting station.

D.F. Systems.

The only aerial system which has no directional effect is a vertical wire; all other systems have directional properties in some degree and are more responsive to signals coming from certain directions than from others. The type of aerial which has a special application in direction finding is the loop aerial; this aerial consists of a loop of wires (consisting either of one or

several turns) which is supported with the plane of the loop vertical. It is capable of rotation and the loop itself may be of any shape provided it is absolutely symmetrical about the axis of rotation; the usual shapes employed are round, square and triangular.

Consider, for example, a square loop aerial as shown in Fig. 43 and assume that it is connected to a valve receiver.
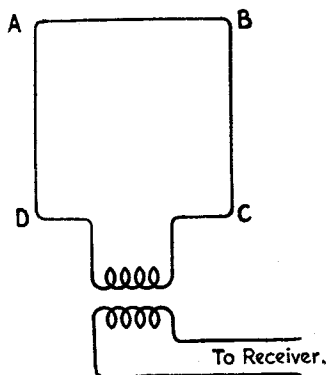

FIG. 43.

Such a loop will receive a maximum strength of signal from those transmitting stations situated in a direction along the plane of the loop; from directions perpendicular to the plane of the loop, however, no signals will have any effect upon it and between these directions the strength of received signal will vary. The intensity of received signal from any particular direction can be illustrated by drawing what is known as a polar diagram. If we lay off from a centre, *i.e.*, the receiver position, the angles through 360° and make the lengths of the radii from this point represent the intensity of signal strength received from that direction we shall obtain a curve as shown in Fig. 44.

It will be seen that the curve consists of two circles touching at O to form a figure of eight. In the directions OA and OB which are in the plane of the loop we shall receive the maximum signal strength represented in magnitude by the lengths OA and OB. In the directions OC and OD at right angles to the plane of the loop we shall have a zero strength signal while in directions OE and OF we shall receive a signal whose strength is proportional to the lengths OE and OF. Thus, if we are receiving signals from a given transmitting station and turn the frame round we shall obtain two positions of the

frame, differing by 180°, at which no signal will be received. In each of these positions the plane of the frame will be at right angles to the direction of the transmitter. In the same way, there will be two positions at right angles to these where the received signals will be maxima. It is preferable to adjust the frame to positions of minimum received signal when taking bearings however, since the ear will detect more accurately the positions of minimum rather than maximum sound as the frame is rotated.
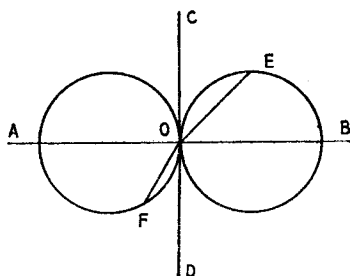

FIG. 44.

It will be seen that, while it is possible by means of the above rotating frame to obtain two bearings differing by 180°, some additional device must be added to obtain "sense," i.e., it is necessary to know which of the above bearings indicates the actual direction of the station. This is done by coupling to the receiver, in addition to the frame aerial, a small vertical aerial, the polar diagram of which is a circle and which is so arranged that the strength of signal received is equal in intensity to the maximum received by the loop. The dotted curves in Fig. 45 will show the polar diagrams of the two aerials, loop and vertical.
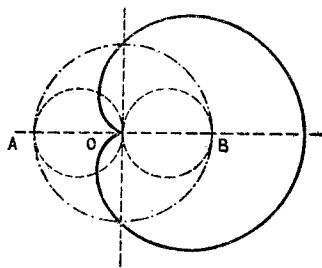

FIG. 45.

These two diagrams when combined will give a combination of total reception represented by the full line curve, since in the direction OA the vertical and loop currents will cancel out and add in the direction OB. By using the above combination, we are able to obtain one minimum only on the transmitting station, and by this arrangement we are able to determine the true direction or " sense " of the transmitting station. The minimum obtained in this way is not, for various reasons, a particularly sharp and well-defined one, and it is, therefore, usual to obtain the numerical values of the bearing by using the loop alone and to differentiate between these two by using the combination arrangement shown above.

It is necessary in order to obtain sharp bearings, *i.e.*, bearings in which the minima are well defined, to employ particular care in the design of the receiver. Since the rotating frame is small, it is necessary to employ several stages of high frequency amplification. It is essential that signals should be received only by the loop itself and the receiver must be carefully screened to avoid direct " pick up " in the set.

There are other systems of direction finding in addition to the single frame type already described, but the fundamental principles apply in all cases. One such system is the Bellini-Tosi system developed by the Marconi Company; this is the system which is employed at nearly all the Post Office coast stations.

This system consists of two large loops which are similar in size and shape and are erected at right angles to each other. These two loops are fixed and are led into an instrument known as a radiogoniometer. This instrument consists of two exactly similar coils which are fixed at right angles to each other and which may be looked upon as the duplicate of the large coils and will produce fields proportional to the energy induced by the incoming wave in the large loops.

Inside the two fixed coils in the radiogoniometer is a third coil which rotates; this third coil is tightly coupled in all positions to the fixed coil system and is known as the " search coil " and corresponds to the rotating frame of the system previously described. Bearings are obtained by rotating the search coil which has a pointer swinging over a circular scale marked out in degrees from 0° to 360°. According to the direction from which signals are being received a difference in signal strength will be obtained on the outside loops which will be reproduced in the goniometer fixed coils; as the search coil is swung round two positions will be found differing by 180° where the minima are and it is from these that the bearings are obtained. It is then necessary to use the sense diagram to discriminate between the bearings.

The advantages of the Bellini-Tosi system are mainly two :

(1) The radiogoniometer is a small instrument and is more convenient for taking bearings from the operating point of view. Bearings can be taken more rapidly and there are no mechanical difficulties in erection as is the case with rotating frames.

(2) Large outside loops can be used and less amplification is therefore necessary. This also makes for sharper bearings.

On the other hand, the design of a D.F. receiver using the single frame presents fewer difficulties from the electrical point of view and generally the minima so obtained are sharper than those found with the Bellini-Tosi type. As a rule, it is not possible to obtain an absolutely sharp minimum in Bellini-Tosi equipments, and it is usual to take swings on either side of each minimum position and to take the mean of these swings as the bearing. With practice this can be done very quickly and with a close degree of accuracy.

It is obvious that bearings taken with a receiver or receivers using frame aerials from two or more positions will, if plotted on a map, intersect at the position of the transmitter. Thus, with a portable frame aerial receiver, a compass and map, the position of a transmitting station may be located from bearings obtained with the portable receiver set up at two or more points around the transmitting station. With such an arrangement a sense finder is not required

An efficient directional aerial system, such as is required for long distance communication, consists of several units fed from one transmitter, or feeding one receiver, and placed
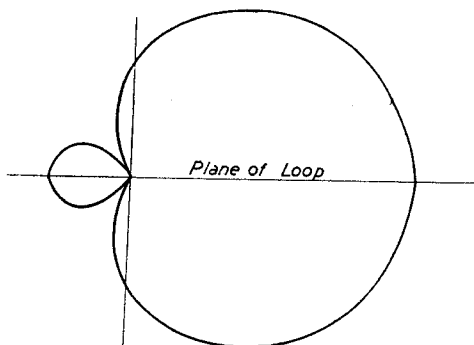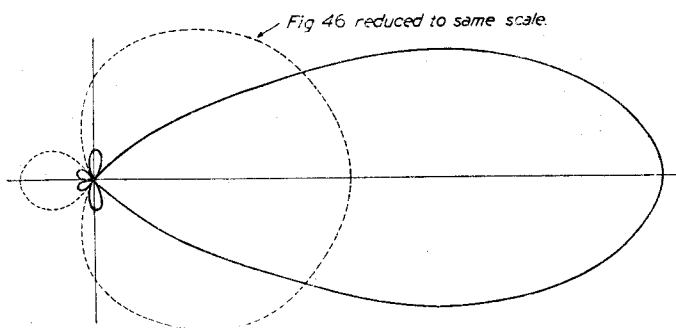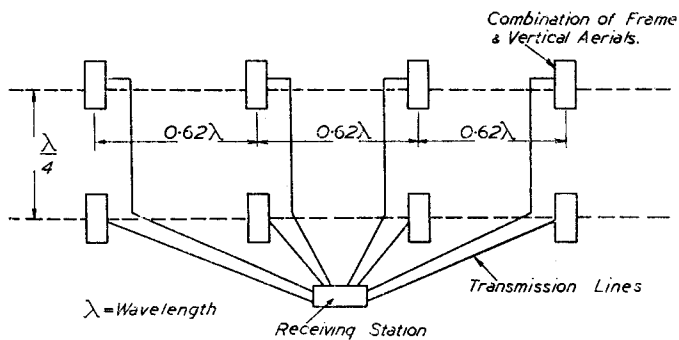

FIG. 46.

Fig 46 reduced to same scale.

FIG. 47.

Combination of Frame & Vertical Aerials.

$\frac{\lambda}{4}$

0.62λ   0.62λ   0.62λ

Transmission Lines

λ = Wavelength

Receiving Station

FIG. 48.

Heaviside Layer.

Earth's Surface.
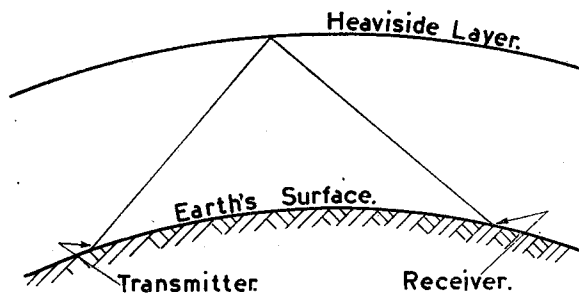
Transmitter.   Receiver.

FIG. 49.

apart at distances which are determined by the wavelength used. For very long wavelengths the area covered by the directional aerial must be correspondingly great, and practical considerations preclude the use of such directional transmitting aerials for stations operating on very long wavelengths. For reception on long wavelengths of the order of 5,000 metres the Post Office employs a system of several fixed frame aerials directed towards the transmitting station, each frame being combined with a vertical aerial to give the approximately heart shaped polar diagram of reception shown in Fig. 46.

Referring to Fig. 45 it will be seen that such a polar diagram can be obtained by making the strength of the signal received on the vertical aerial greater than the maximum received by the frame.

Fig. 47 shows the polar diagram of reception obtained by suitably combining at the receiver the energy received in eight such units arranged in two parallel rows at right angles to the direction of reception and spaced as shown in Fig. 48. For a wavelength of 5,000 metres such a system embraces an area of nearly six square miles.

For short wavelengths effective aerial systems suitable for transmission or reception can be arranged in a much smaller space. The units employed are vertical or horizontal straight wires of length approximately equal to one half or one quarter of a wavelength and arranged in one or more flat " curtains " parallel to each other and at right angles to the path of the transmitted or received wave. There are many methods of arranging the units in the " curtains," resulting in various forms of polar diagram of reception or transmission.

In connexion with short wave working, it will be appreciated from the notes on short wave propagation that, for a particular service, it may be advantageous to radiate or receive the maximum energy in a direction in the vertical plane at a particular angle to the earth's surface rather than along a tangent to the surface. The proportion and arrangement of the units are in many cases adjusted to secure this advantage. This point is illustrated in Fig. 49 which indicates a typical transmission path between two stations separated by a considerable distance.

The various combinations of aerial units referred to above are usually termed " Arrays."

Fig. 50 shows the arrangement generally known as a " Pine Tree " or " Koomans " array, consisting of a number of horizontal half wavelength active units (heavy lines) in one curtain facing the path of reception or transmission, with a second curtain of isolated half wavelength units, one quarter wavelength behind the first, which serve as reflectors. The
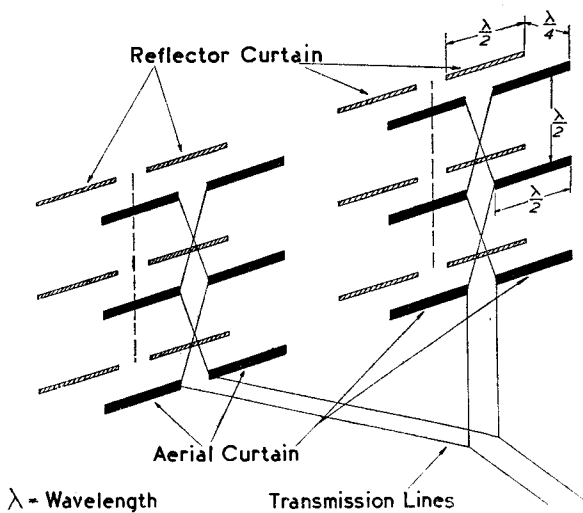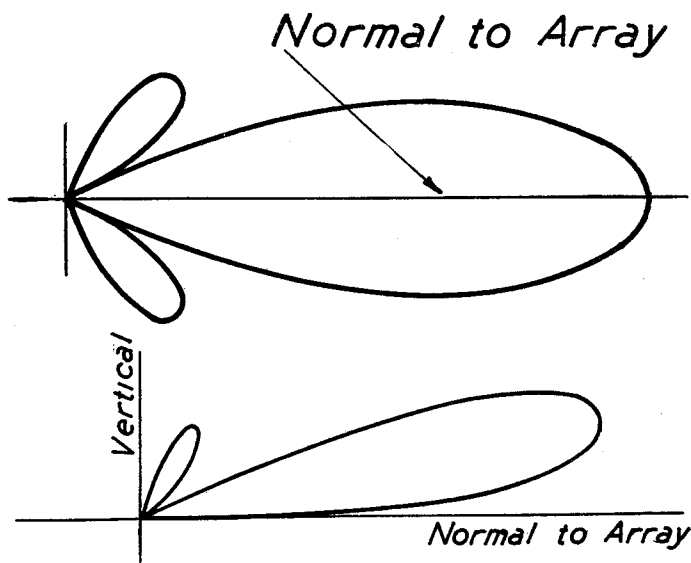
FIG. 50.

FIGS. 51 AND 52.

other lines indicate the method of interconnecting the active units to the transmission line so that the energy fed to or received by these units shall be additive for the path for which the array is designed.

Figs. 51 and 52 show respectively the horizontal and vertical polar diagrams of transmission or reception obtained with such an array.

═══ LIST OF ═══
Technical Pamphlets for Workmen
(*continued*)

18 Distribution Cases, M.D.F. and I.D.F.
19 Cord Repairs
20 Superposed Circuits. Transformers. Bridging Coils and Retardation Coils
21 Call Offices
22 Units, Amplifying (*Not on sale*)

GROUP E
1 Automatic Telephony. Step by Step Systems
2 Automatic Telephony. Coded Call Indicator (C.C.I.) Working
3 Automatic Telephony. Keysending " B " positions

GROUP F
1 Subscribers' Apparatus. Common Battery System
2 Subscribers' Apparatus, C.B.S., Part I—C.B.S. No. 1 System
3 Subscribers' Apparatus. Magneto
4 Private Branch Exchanges—Common Battery System
5 Private Branch Exchange—C.B. Multiple, No. 9
6 Private Branch Exchanges—Magneto
7 House Telephone Systems
8 Wiring of Subscribers' Premises

GROUP G
1 Maintenance of Secondary Cells
2 Power Plant for Telegraph and Telephone Purposes
3 Maintenance of Power Plant for Telegraph and Telephone Purposes
4 Telegraph Battery Power Distribution Boards

GROUP H
1 Open Line Construction, Part I
2 Open Line Construction, Part II
3 Open Line Maintenance
4 Underground Construction, Part I—Conduits
5 Underground Construction, Part II—Cables
6 Underground Maintenance
7 Cable Balancing
8 Power Circuit Guarding
9 Electrolytic Action on Cable Sheaths, etc.
10 Constants of Conductors used for Telegraph and Telephone Purposes

GROUP I
1 Submarine Cables

GROUP K
1 Electric Lighting
2 Lifts
3 Heating Systems
4 Pneumatic Tube Systems
5 Gas and Petrol Engines