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The Amateur Mechanic and Work

Wireless Telegraphy and Telephony
And How to Make the Apparatus

BY
E. REDPATH

NEW EDITION

WITH 87 ILLUSTRATIONS

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EDITOR'S PREFACE

This Handbook (which supersedes a former and now out-of-date volume in the same series, entitled "Wireless Telegraphy and How to Make the Apparatus") is from the pen of Mr. E. Redpath, who, besides possessing a sound theoretical grasp of his subject, enjoys the advantage of having had many years of practical experience in wireless telegraphy and telephony, upon which he has drawn to the advantage of his readers. He makes clear the general principles involved in the understanding of his somewhat difficult subject; explains the chief technical terms used; and gives full instructions, based on his own experience, on the making of various pieces of apparatus, these including a valve panel and a five-valve amplifier. In a late chapter he shows how much of the information in the early chapters of this book applies also to wireless telephony.

Every piece of apparatus which Mr. Redpath describes is good and practicable, but should unexpected difficulties be met with, readers should address their queries to The Editor, "The Amateur Mechanic and Work," La Belle Sauvage, E.C.4, in whose columns, but not by post, information will readily be given.

B. E. J.
CONTENTS

CHAPTER                  PAGE
1. General Principles of Wireless Telegraphy  1
2. Some Informative Experiments  9
3. Tuning and Resonance Explained  16
4. Transmission and Reception  21
5. Various Detectors Explained and Described  31
6. Thermionic Valves as Detectors, Amplifiers and Generators  40
7. Making a Single-circuit Receiving Set  56
8. Making a Complete Short-wave Receiving Set  68
9. Making a Valve Panel for a Receiving Set  96
10. Making a Five-valve Amplifier  109
11. Wireless Telephony  137
12. Arrangement and Erection of Aerials  142
Index  151
WIRELESS TELEGRAPHY
AND TELEPHONY
AND HOW TO MAKE THE APPARATUS

CHAPTER I

General Principles of Wireless Telegraphy

In general, the purpose of wireless telegraphy is to afford a method of communication between two or more points (stations) by electrical means and without employing any tangible medium connecting the points, such as, for instance, a telegraph wire. There is, however, a medium called the "ether," intangible and all-pervading, and use is made of this, as will be fully explained later.

A simple analogy may be made with sound. Suppose there are two stations about a mile apart, and a steam whistle be blown at one of them. The consequent disturbance in the air travels outwards from the point of disturbance (the whistle) in the form of sound-waves, and the passing of some portion of the waves over the distant station could be detected by the sense of hearing of a person at that point. It will be obvious that the strength of the received sound, neglecting losses in transit, would depend principally on the strength (or amplitude) of the disturbance caused by
the transmitter (the whistle), and the pitch of the note heard at the receiving station would depend on the number of waves per second striking the ear-drum of the person at that point, which is equal to the number of waves (or disturbances) at the transmitter (the whistle). This number of waves or disturbances per second is known as the frequency.

It will be seen at once that on the frequency (the number of waves per second) and velocity (rate of travel) depend the distance between any two successive waves. This distance, measured between two points of corresponding amplitude in any two successive waves, is known as the wave-length, and is denoted by the symbol (lambda) \( \lambda \). The diagram presented by Fig. 1 will, it is hoped, make clear exactly what is meant by amplitude \( a \) and wave-length \( \lambda \). It is also to be noted that frequency \( F \) and wave-length \( \lambda \) vary inversely, that is to say, if \( F \) be doubled \( \lambda \) will be halved. The velocity \( V \) depends on the medium through which the waves are propagated, and the case of sound-waves through air is approximately 1,100 ft. per second. The relationship between these values is expressed as follows, and is sufficiently important to be carefully noted by the beginner: 

\[
F = \frac{V}{\lambda}, \quad \text{or} \quad \lambda = \frac{V}{F}
\]

Suppose, for instance, that in the foregoing analogy the pitch of the note emitted by the whistle corresponds to the middle C of a piano, the frequency of which is approximately 260 per second, then from the above expression,

\[
\lambda \, (\text{in feet}) = \frac{1,100 \, \text{ft. per second}}{260} = 4.23 \, \text{ft.}
\]
The reader will profit from this simple analogy, in which the action can readily be visualised, as it were, by substituting the following: Two stations, say 100 miles apart, each provided with an electrical conductor in the form of a wire or series of wires known as the "antenna" or "aerial," suitably held aloft and carefully insulated. At the transmitting station apparatus is provided by means of which electrical currents at a predetermined and definite frequency are made to surge to and fro in the aerial, the lower end of which is connected via the apparatus to earth.

The surging to and fro, or "oscillating" of the current in the aerial wire, sets up in the surrounding ether electro-static strains which give rise to electric pressure-waves radiating from the aerial in all directions with the speed of light, namely, 186,000 miles (or 300,000,000 metres) per second. Oscillatory currents in the aerial wire thus give rise to the radiation of electric waves through the ether, and, conversely, electric waves impinging on an aerial wire set up
oscillatory currents in that wire. At the receiving station the aerial wire is connected to suitable instruments (and thence to earth), and the surging or oscillating currents set up in this aerial wire by the incoming waves are made to indicate their presence—usually by means of sounds produced in a suitable telephone receiver.

The statement or formula as quoted in the case of the sound-waves remains true, but the velocity (V) will now have a different value, namely, 300,000,000 metres per second, so that in the practical case of a vessel or shore station fitted with a wireless installation and adjusted (or tuned, as it is called), to radiate waves 300 metres in length, the frequency of such waves (and of the oscillations causing them) will be

$$F = \frac{V}{\lambda} = \frac{300,000,000}{300} = 1,000,000 \text{ p. sec.}$$

It is hoped that the foregoing simple analogy will make clear the meaning and relationship of amplitude, frequency, velocity and wave-length; but it is to be remembered that in considering analogies of this description an exact comparison cannot be made between the mechanically produced sound-waves and the electrically produced "wireless" waves.

It is now proposed to show how the waves used in wireless telegraphy may be produced, and how, after travelling through the ether, they may be detected. Fig. 2 shows a series of experiments carried out by Hertz. By these he demonstrated that electric waves of a definite period could be generated in the medium,
and also that by the employment of resonators they could be detected.

At A (Fig. 2) is shown a pair of conducting surfaces separated by a sheet of insulating material provided with two bent rods with balls at their extremities so arranged that there is a small gap G. The pair of conducting surfaces form a condenser, and it has been found that when a condenser is discharged through a circuit of negligible resistance, that the discharge is oscillatory and has a definite period which depends on

![Fig. 2. Diagrams showing the Principles of the Hertz Oscillator](image)

the capacity of the condenser and the inductance of the circuit.

The radiation of energy from such an arrangement as shown at A is insignificant, because it does not give the necessary combination of electrostatic and electromagnetic effects; the former is almost entirely confined to the thin layer of dielectric which separates the plates, and the latter therefore returns its energy into the circuit at every half swing by a process similar to that by which a moving mass gives up its energy to a spring to which it is attached.

B represents the same oscillator with the insulating
plate removed, the rods straightened, and the front conducting plate swung outwards. Such an arrangement is still an oscillator, but we have replaced the solid dielectric by a wide air space. As air has considerably smaller dielectric capacity than glass, ebonite, etc., and as the space across which the electric stress must act is greatly increased, the capacity is enormously reduced, and the frequency is consequently raised to a high value.

The energy which a given voltage is capable of storing is, in this case, comparatively insignificant, but, what is far more important, the electrostatic lines are freer, and can reach out into the space surrounding the plates sufficiently to enable them to detach themselves in combination with the magnetic whirls round the rods and travel out as radiated energy; such energy never returns to the circuit and must continue onward indefinitely until it meets with some body that reflects or absorbs it.

At c is shown a further stage in the opening out of the plates, the final arrangement of which is shown at d, where both plates and rods lie in the same plane. The capacity is now still smaller and the frequency still higher, but the electrostatic field reaches out widely into the surrounding space and distributes itself along lines which leave one plate, curve outwards to some distance, and return to corresponding points on the other plate. The arrangement as shown at d radiates so rapidly that only a few swings are completed before the energy has all left the circuit, and the oscillations have died away.
The detector used by Hertz was a circle of wire or metal rod with a micrometer spark-gap introduced at some point in its circumference. Such a ring, used as shown in Fig. 3, acts as a receiver of the waves, which induce in it oscillations surging backwards and forwards diametrically in a direction parallel to the axis of the rods $RR$. These surgings manifest themselves as minute sparks at the gap, provided that the ring is of such dimensions that its natural period of oscillation is the same as that of the vibrator.

A pair of simple brass rods in line with each other and separated by spark balls forms a good oscillator; waves that may be detected even at a distance of several yards occur when a minute discharge takes place between an electrophorous plate and a polished brass door knob. The contact spark of an ordinary electric bell is accompanied by oscillatory disturbances which can be detected at a distance of several yards, a fact that is made use of in testing the adjustment of receiving apparatus in wireless telegraphy.

It is now established that all ether wave-motions are electromagnetic in nature, the only difference being in wave-length, and therefore in frequency. The oscillations which produce heat and light waves are
WIRELESS TELEGRAPHY & TELEPHONY

molecular in their dimensions, whereas in wireless telegraphy we are concerned with waves which may be several hundred yards in length. The degree of transparency of substances is largely dependent on the frequency of the waves in question. For instance, heat radiation passes easily through ebonite, which is opaque to light. Good conductors always absorb Hertzian radiations, the metals being very highly opaque. Insulators are comparatively transparent to Hertzian waves unless they are damp, but wood, cloth, earth, bricks, etc., when wet, are highly opaque, and these with semi-opaque substances are capable of acting as partial reflectors.
CHAPTER II

Some Informative Experiments

Such experiments as those described in the foregoing chapter demonstrate the principles of wireless telegraphy, but in actual practice much more sensitive apparatus must be used, and for detection purposes, in place of the visual evidence of the existence of an electro-magnetic wave, audible evidence is provided by means of a detector and sensitive telephone receivers.

It has been made clear that the essential operations are: (1) Charging and discharging the aerial at the transmitting station, that is, the setting up of oscillatory currents in that aerial with consequent radiation of electric waves. (2) Detection of the arrival of such waves (or a portion of same) on the aerial at the receiving station.

These can be demonstrated in an interesting and practical manner by means of a simple experimental transmitting and receiving apparatus which may be constructed as follows:

Simple Transmitting Apparatus.—The materials or components required for a simple transmitting apparatus are as follows: One wooden baseboard, 10 in. by 3 in. (or nearest) with two supports about 18 in. long, as shown in Fig. 4. One small spark-coil, to give, say, ½ in. spark. A small ignition coil will prove
very suitable, or failing any type of coil, a "buzzer," or simply an electric bell with the gong removed may also be used. One push-button or simple "tapping-key" consisting of a strip of springy brass (say 2 in. long by ½ in. wide), screwed to the baseboard and fitted with a button or knob at the free end, and making contact upon the head of a brass screw driven into the baseboard beneath the knob. One or two dry cells, to operate coil or buzzer. Two brass terminals, holed type. Twelve feet (exactly) of No. 16 or No. 18 s.w.g. bare copper wire to form "aerials." This apparatus is to be arranged upon and secured to the baseboard as shown in the two views in Fig. 4, the aerial wires being formed into spirals by winding them on a wooden rod which should be approximately 1 in. in diameter.

Simple Receiving Apparatus.—The materials required for a simple receiving apparatus are as follows: One wooden baseboard with supports, exactly as for transmitter. One crystal detector, which may be purchased (in which case it can subsequently be used in a more complete receiving set) or made to consist of a piece of "fused silicon" mounted in a small brass cup (by filling the latter with molten solder and pressing the crystal well into the solder and holding there until set), with a pointed piece of springy brass mounted above it and capable of being pressed lightly on the surface of the crystal by means of a screw passing through a hole in the brass, and driven into the baseboard as shown in Fig. 5. Four terminals, same type as for the transmitter. Twelve feet of wire, as for the transmitter.
SOME INFORMATIVE EXPERIMENTS

One telephone receiver. A cheap "watch-pattern" receiver will answer the purpose, though, if desired, a good "wireless" telephone complete with headgear may be purchased, and will prove a useful acquisition later.

![Plan and Elevation of Simple Experimental Transmitting Set, showing Arrangement of Aerial Wires and Apparatus on Baseboard]

This apparatus is to be arranged on its own baseboard, observing that all dimensions of the aerial systems in both sets exactly correspond. Both sets are to have their components connected up as shown in Figs. 6 and 7.

![Two Elevations showing Construction of Crystal Detector]

Method of Operation.—To commence with, the transmitter and receiver should be set up at opposite ends of a table, and friendly assistance requisitioned to "press the key" and so operate the transmitter, which, however, must first be adjusted as follows:
WIRELESS TELEGRAPHY & TELEPHONY

Adjust the distance separating the two ends of the aerial wires (between the two terminals) until a steady spark occurs between them each time the transmitting key or push-button is depressed. Adjust the interrupter of the spark coil to as high a speed as possible consistent with obtaining a good steady spark at the gap between the aerial wires, that is, the "spark-gap."

In the case of a "buzzer transmitter," the spark used is that which occurs at the interrupter itself each time the circuit is broken, and the two aerial wires in this case are to be connected to opposite sides of the interrupter, one to the fixed contact and the other to the pillar carrying the vibrating armature, no separate spark-gap being employed in this method.

When these adjustments are completed, place the telephone receiver of the "distant station" to the ear,
and whilst someone else operates the transmitter, carefully vary the pressure of the brass point on the silicon crystal. If the detector is the very simple one described above, turn the adjusting screw by means of a screwdriver having a wooden handle. When the correct adjustment is found, the spark-note of the transmitter will be clearly heard in the telephone receiver. It may sometimes be found necessary to vary the point of contact between the brass point and the crystal by slightly altering the position of the crystal holder on the baseboard, or by bending the brass point to one side. This adjustment of the detector is somewhat critical, and in general a light contact will be found to give best results.

When everything is working satisfactorily, try the effect of increasing the distance between the "stations." The transmitter may be carried about whilst signals are being sent, and may be taken into adjoining rooms without interfering with the reception of the signals, provided the intervening distance is not made too great.

These simple sets illustrate clearly the transmission and reception of signals by means of electric waves, and the action is as follows: At the transmitting station, each time the key is depressed, current from the battery flows in the primary winding of the coil, and being interrupted by the "make-and break" device, induces current at a high voltage in the secondary winding. To the ends of this secondary winding are connected the aerial wires and the spark-gap, so that a difference in electrical pressure or
potential is caused between opposite sides of the system, and when this potential difference is sufficiently increased, the insulation resistance of the air-space in the spark-gap breaks down and a spark discharge takes place, with surging to and fro of current from one aerial wire into the other. That is to say, oscillatory currents are flowing in the aerial wires with consequent radiation of electric waves from the system, through the medium of the ether.

Each spark at the "gap" sets up oscillatory currents which, however, very rapidly die away (or decrease in amplitude) owing to losses which occur, firstly due to the resistance of the wires forming the aerials, and secondly due to the "radiation" of energy from the aerials. This effect is known as "damping," and circuits in which the oscillations last only a very brief time are said to be "heavily damped."

The amplitude of the radiated waves decreases accordingly, and such waves are called "damped" waves. So it will be seen that each spark at the transmitter results in the radiation of one group of damped waves, and the aerial system is then idle until again charged up to high potential and discharged across the spark-gap, the total radiation therefore consisting of groups (or trains) of damped waves with separating blank intervals.

At the receiving station, a portion of the radiated waves (for it is to be remembered that they are radiated in all directions), striking the aerial wires, causes oscillatory currents to be set up in them. Now the frequency of these currents (unlike that of the
SOME INFORMATIVE EXPERIMENTS

sound waves in the case of the "steam whistle" analogy) is very high, in this particular instance certainly in the neighbourhood of ten million per second, so that the telephone diaphragm could not possibly respond to them, and, moreover, if it could the human ear could not detect the vibrations emitted. But the crystal detector possesses the property of permitting current to flow in one direction only across the point of contact, a property known as uni-lateral or uni-directional conductivity, and this is made use of to "rectify" or convert the oscillatory currents into uni-directional impulses which are passed through the windings of the telephone receiver.

These impulses, however, are too rapid to impart separate movements to the telephone diaphragm. Instead they have a cumulative effect, and all the rapidly succeeding impulses of each group of oscillations cause only one deflection of the diaphragm, and as the group frequency depends only on the rate of sparking at the transmitter, the note heard in the telephone equals in frequency (or pitch) the spark note of the transmitter.
CHAPTER III

Tuning and Resonance Explained

The efficient operation of wireless apparatus in practical working, especially as regards "selectivity," or prevention of interference, depends very largely on use being made of the principles of "tuning" and "resonance."

By "tuning" is meant the determination of the frequency (and consequently of the length) of the waves to be radiated from a transmitting station or receiver at a receiving station.

By "resonance" is meant the adjustment of one circuit to have the same frequency as another circuit, the two circuits being either the aerial circuits of transmitter and receiver, or two circuits in the one set of apparatus at either station.

A frequently observed illustration of resonance occurs when some ornament or trinket in a room gives forth a jarring sound when a certain note on the piano is struck. Only the one particular note on the piano produces this effect on the ornament in question, which is due to the natural frequency of vibration of the ornament corresponding to the frequency of the note sounded. In other words, the two are in consonance.

Oscillatory Circuits.—In connection with wireless telegraphy, tuning and resonance apply particularly to
circuits known as "oscillatory circuits." Any circuit possessing inductance and capacity, and having only a low resistance, is an oscillatory circuit. A charge of electricity imparted to such a circuit sets up oscillatory currents which swing to and fro until the energy is dissipated (or damped out, as it is called) by the resistance of the circuit, and by radiation in the form of ether waves. Inductance may conveniently be considered as the electrical equivalent of inertia in mechanics, that is, opposition to change of motion; whilst capacity means ability to hold or store an electrostatic charge.

There are two varieties of oscillatory circuits, the closed oscillatory circuit, in which the inductance and
capacity are concentrated as it were in a coil of wire and a condenser, shown respectively at \( L \) and \( C \) in Fig. 8, and the open oscillatory circuit, in which the inductance and capacity are more or less spread over the system as illustrated in Fig. 9, which represents an aerial wire \( \mathcal{E} \) having inductance in itself and distributed capacity to earth \( \mathfrak{e} \) as indicated by the dotted lines, with a further inductance value in coil \( L \). The natural oscillation frequency of such a circuit depends on the values of the capacity and inductance in the circuit, and currents will swing to and fro more slowly in a circuit having large capacity and inductance values than in a circuit having smaller values. The wavelengths of the circuits will, of course, vary inversely.

The closed oscillatory circuit is a good and persistent oscillator, but a poor radiator, therefore the damping or dissipation of energy is slight, whilst exactly the opposite is true of the open oscillatory circuit.

An open and a closed, or two closed oscillatory circuits may be arranged so that their respective inductance (in the form of coils of wire) are close together, when energy in one circuit will be transferred to the other by electro-magnetic induction. Circuits so placed are termed "coupled" circuits, \( a \) (Fig. 10) illustrating a "tight coupling" and \( b \) and \( c \) two forms of "loose coupling." If the two coupled circuits are in resonance, energy can be transferred from one to the other with a loose coupling; but if resonance is not attained the coupling may have to be fairly tight to force the oscillations from one circuit into the other.

Experiments by means of which the foregoing
theory and action can readily be appreciated may be performed by means of the simple apparatus shown in Fig. 11, consisting of a long board with two uprights about 9 in. high, having a thin string about 18 in. long stretched between them and secured as shown, together with two shorter pieces of strong thread, each having a weight, such as a small nut, attached. The thread marked T is to be tied to the horizontal string; but that marked R is to be fitted with a miniature "tent-rope block," made of thin celluloid or even cardboard, so that its length is readily adjustable. Before the weight R is placed in position, hold the weight T a little to one side, out of the perpendicular, and release it. The swinging to and fro, through gradually decreasing distances, illustrates the oscillations taking place in a closed oscillatory circuit, with gradually decreasing amplitude as the energy is lost owing to the
resistance of the circuit. Now attach the weight \( R \) about 12 in. from \( T \), making the length of its thread exactly equal to that of \( T \), and again set the latter swinging. Observe the following points: (a) Energy from \( T \) is transferred to \( R \). (b) \( T \) comes to rest much sooner than before. (c) When \( T \) is at rest \( R \) is swinging with maximum amplitude. (d) \( R \) now begins to transfer energy back to \( T \), and these alternate actions are repeated some considerable time.

Now (a) illustrates the effect of resonance; the result of dis-tuning \( R \) by varying the length of the thread (and consequently the natural frequency of vibration) should be noted. Item (b) illustrates the "damping" of the oscillations due to both resistance and radiation losses. Item (c) shows the "lagging" effect between two coupled oscillatory circuits, and (a), (b) and (c) together show the slow building up of small impulses into large oscillations. Lastly, (d) illustrates the "reaction" effect which occurs in coupled circuits, especially noticeable if the coupling is tight, as by placing the weights \( T \) and \( R \) closer together.
CHAPTER IV

Transmission and Reception

Practical Transmission Apparatus.—The essential circuit arrangements of a complete wireless transmitter are shown in Fig. 12. It is not intended to deal with the actual construction of transmitting apparatus,

![Diagram showing Circuit Arrangements of Complete Transmitter](image)

Fig. 12.—Diagram showing Circuit Arrangements of Complete Transmitter

owing to the fact that it is desirable to occupy the pages of this book with matter of an essentially useful nature, there being no point in describing the construction of apparatus that the majority of readers
would not be permitted to operate. However, a good understanding of the processes involved at the distant station is really necessary, and adds greatly to the interest of operating an experimental receiving station.

Referring to Fig. 12, A represents an alternator from which alternating current is led to the primary winding of a step-up, iron-core transformer T via the transmitting key K, so that each time the key is depressed current flows in that winding and a high-voltage electro-motive force (or E.M.F.) is set up in the secondary winding, the ends of which are connected to the opposite sides of the spark gap s.g. Thus the condenser C (which with the primary inductance P forms a closed oscillatory circuit broken only by the spark-gap) is charged to high potential.

When this potential is sufficiently high, the insulation resistance of the gap breaks down, a spark occurs, and the energy stored in the condenser oscillates to and fro in the circuit through the primary inductance P. This inductance, however, is electro-magnetically coupled to the open oscillatory or aerial circuit, consisting of the aerial itself \( \mathcal{A} \), the aerial tuning inductance \( \mathcal{T} \) and \( \mathcal{I} \), the secondary inductance S and earth E. Therefore, provided that the open and closed oscillatory circuits are in resonance, oscillations will be set up in the aerial circuit with consequent radiation of waves from the aerial in groups of "trains"; one group per spark, as previously described.

The alternator and transformer shown in Fig. 12 simply take the place of the batteries and spark coil.
of the small demonstration set described in the earlier article, that is to say, they form a "charging circuit."

As the aerial circuit has to be tuned to resonance with the closed circuit, the frequency (and, of course, wave-length) of the radiated waves depends on the frequency of the latter circuit, which in practice has always to be adjusted or tuned first.

It has been stated that the "oscillation frequency" and wave-length of any oscillatory circuit depends on the values of inductance and capacity in such circuits. In this particular case, therefore (Fig. 12), the values of the inductance $P$ and the condenser $C$ determine the wave-length of the set.

The inductance $P$ usually consists of from one to three turns of separately insulated, stranded wires wound in a square or circular former, and its "inductive value" may be expressed in various terms according to the system of units employed. It may be stated in micro-henries or in centimetres, 1 micro-henry (generally written "mic.") being equal to 1,000 centimetres. Formulæ for the calculation of inductance are numerous and somewhat complicated to introduce here.

The condenser $C$ usually consists of two sets of metallic plates carefully separated by glass plates about \(\frac{1}{8}\) in. thick (the latter forming what is termed the "dielectric"), the whole being immersed in oil in a suitable container. All the plates of each set are connected together and the "capacity" of the whole condenser depends on the total area of opposing surfaces of metal, the distance separating them and the quality of the glass (or other material) between them.
WIRELESS TELEGRAPHY & TELEPHONY

The value may be expressed in centimetres, jars, or micro-farads, the relationship being as follows: 1,000 centimetres = 1 jar; 900 jars = 1 micro-farad.

For flat plate condensers as above described the capacity can readily be calculated from the formula:

$$C_{\text{cms.}} = \frac{A_{\text{cms.}}}{4\pi d_{\text{cms.}}} \times k$$

where $A$ = total area of opposing surfaces (or area of dielectric under strain) measured in centimetres, $d$ = thickness of dielectric (that is, the distance separating the plates), also in centimetres; $\pi = 3.14159$, $k$ = a constant depending on the nature of the material forming the dielectric; air with a value of one has been taken as standard, and $C$ = resultant capacity expressed in centimetres.

Expressing the capacity in micro-farads and the inductance in centimetres, the wave-length (in metres) of any oscillatory circuit may be calculated from the formula:

$$\lambda_{\text{(metres)}} = \frac{59.6}{\sqrt{C_{\text{mfas.}} \times L_{\text{cms.}}}}$$

Practical Receiving Apparatus.—Fig. 13 illustrates the essential circuit arrangements of a complete receiving set. $\Xi$ represents the aerial, $\Lambda T I$ the aerial tuning inductance (variable, as indicated by the arrow), and $\Pi$ the earth connection, these comprising the aerial oscillatory circuit. The inductance coil $L$ and condenser $S$, both variable, form the secondary or closed oscillatory circuit, whilst the remaining circuit (the detector circuit) includes the crystal $D$, potentiometer $P$ with battery $B$, and telephone receivers $T E L$. The purpose of the potentiometer is to apply to the crystal detector, via the secondary inductance, a suitable initial potential in order to render it more sensitive. Some
TRANSMISSION AND RECEPTION

crystals, however, work well without this applied potential, in which case the potentiometer may be omitted altogether.

The action of the receiving set illustrated is as follows: The aerial circuit is tuned, by varying the value of the inductance, so as to have the same wavelength as the distant transmitting station from which it is desired to receive, in order that the received waves may set up oscillations in that circuit of maximum am-

![Diagram showing the Circuit Arrangements of Complete Receiver](image)

plitude. Coupled to the ATI is a secondary inductance coil $L$, and if the inductive value of $L$ and the capacity of the condenser $S$ are adjusted so that the closed circuit is in resonance with the aerial circuit, oscillations will be set up in this closed circuit, and opposite plates of the condenser $S$ will be charged alternately positively and negatively.

Due to the rectifying action of the crystal detector one-half only of each complete oscillation will be allowed to pass, and, flowing through the winding of the telephone receiver, will, in conjunction with the
remaining rectified oscillations of each group or "wave-train," cause one movement of the telephone diaphragm.

The rapidity with which the sparks follow one another at the transmitting station determines the number of groups radiated per second, which in turn governs the rate of vibration of the telephone diaphragm, and consequently the pitch of the note emitted. In this connection care must be taken to distinguish clearly between (a) radio-frequency = wave-frequency = for 600-metre wave 500,000 per second, and (b) spark-frequency = group-frequency = (say) 300 to 1,000 per second.

Continuous-wave Methods.—Up to the present only those methods of exciting an aerial circuit which give rise to the radiation of damped waves have been considered, and it has been shown that the waves are sent out from the transmitting aerial in groups with comparatively long intervals between. Methods employed to generate continuous oscillations in an aerial circuit, and the radiation of undamped waves will now be discussed.

It will be remembered that the rapidity with which the aerial could be "impulsed," in the case of the transmitter discussed previously, depended upon the number of times the main condenser discharged, which in turn depended upon the frequency of the alternator.

Referring to Fig. 14, which represents a train of damped waves, suppose the frequency of impulses given to the aerial circuit could be increased so as to impart fresh energy at the instants represented at \( x, x_1, x_2 \),
TRANSMISSION AND RECEPTION

$x_i$, etc., then the waves would not die away, but would attain constant amplitude as indicated by the dotted lines, provided the fresh energy impulses were in the correct direction and accurately timed. There would then be radiated one long wave-train of constant amplitude as long as the transmitting key remained depressed.

Due to the absence of the long intervals between groups which previously occurred, during which the aerial was idle, the large impulses then required are not now necessary. Each impulse need only be small, and, if desired, can be given direct to the aerial circuit.

Continuous waves permit of the fullest advantage being taken of the principles of resonance as between the transmitting and the receiving stations, and result in a considerable increase of range for a given power. There have been many attempts made to bring about this very desirable state of affairs but it will be sufficient here to briefly consider the four important methods.

The first of the four methods is the "arc method." The arc is formed between copper and carbon electrodes enclosed in a suitable gas-tight vessel containing either coal-gas or hydrogen, and its ability to maintain...
oscillatory currents in an inductance-capacity circuit shunted across it is due to the fact that a decrease of current through the arc causes an increase in voltage across it, and vice versa. Signalling is carried on by arranging that the transmitting key short-circuits a certain number of turns of the aerial inductance, thus effecting a change in the length of the radiated waves, the oscillations in the aerial circuit being maintained by the arc without interruption.

A second method is that employing a specially designed high-frequency alternator, with which is sometimes incorporated some form of "frequency changer." It may be mentioned that in order to obtain an initial frequency of 10,000 per second, a 400-pole machine with a speed of about 3,000 revolutions per minute is necessary.

Another method of generating continuous oscillations consists in having a number of separate closed-oscillatory circuits, each with synchronised rotary spark-gap, arranged to discharge consecutively, the oscillations thus set up in the common aerial circuit overlapping in correct phase relationship so as to prevent the decay of energy and thus obtain, as the resultant of these discharges, continuous oscillations. The complete arrangement forms a transmitter capable of dealing with considerable power.

The fourth method of generating continuous oscillations makes use of the special properties of thermionic valves having three electrodes, which will be described later in detail.

Continuous-wave Reception.—With regard to the
TRANSMISSION AND RECEPTION

reception of continuous waves, it is clear that, as there are now no groups with separating intervals, the ordinary method of rectification as already described will no longer serve. Incoming waves which produce in the circuits of the receiving apparatus continuous oscillations at radio-frequency are now being considered, so that the most that can result when employing the ordinary detector is one "click" in the telephone receivers when the transmitting key at the distant station is depressed, and another when the key is released, which is obviously inadequate for Morse signalling.

There are two practicable methods by which the incoming waves may be made to produce audible signals. The first is to introduce in the aerial or associated circuits some device for breaking up the oscillations into groups at audio-frequency. A buzzer arrangement, consisting of a vibrating armature carrying platinum contacts and operating in a manner similar to the ordinary electric bell may be used; also a device employing a vibrating wire called a "tikker," or a rotary interrupter capable of careful regulation of speed, known as Goldschmidt's tone wheel.

These methods have been used commercially and proved quite practicable, but they have the great disadvantage that a considerable portion of the received energy in the aerial circuit is not utilised in the production of signals. Up to the present, the most successful method of detection of continuous waves is that known as "heterodyne," of interference-beat reception, which depends upon and makes use of the physical law concerning superimposed waves.
If any two waves—of air, water, or electricity—of almost equal frequencies and not greatly differing in amplitude are superimposed, the resulting wave produced exhibits the peculiar property of waxing and waning in amplitude or intensity at a frequency equal to the difference between the frequencies of the two original waves. Thus, if an incoming wave sets up oscillations in the aerial of a receiving station at a frequency of, say, 500,000 per second, and by some means additional oscillations at a frequency of either 500,500 or 499,500 can be set up in the same circuit, the resulting oscillations will vary in amplitude at a frequency of 500 per second, and can, therefore, after rectification by a crystal or other detector, produce a pure musical note in the telephone receivers at this last-named frequency. Further, as this note depends only upon the difference between the two frequencies, if one of these is variable the note emitted by the telephone diaphragms can also be varied within the limits of audibility.

In the radio-telegraphic application of this principle, the incoming signal forms one set of waves, the second being generated locally at the receiving station, and, being under the control of the operator there, enables him to adjust the resulting note in the telephones to the most suitable pitch. It will be seen later that there are two practicable means of generating the superimposed oscillations at the receiving station; firstly, by means of a separate generating device (known as the "independent heterodyne" method), and secondly, by employing a self-heterodyning receiving apparatus.
CHAPTER V

Various Detectors Explained and Described

It has been shown in earlier chapters that a means must be provided for converting the energy in the electro-magnetic waves into currents in metallic conductors, and (from the discussion on syntony) that a "receiving" aerial system, tuned to the correct wavelength, effects this. As, however, the oscillatory currents thus obtained are at frequencies much above the audible limit, and are, moreover, of very small values, there must be provided at the receiving station, in addition to syntonising devices, a means of detecting and making visible or audible the presence of the feeble electric currents. Such devices are called "detectors," and are of such importance that it will be useful to consider the various types.

The current and potential in a syntonised earth-connected aerial, responding to incoming waves, are distributed exactly as in the case of the transmitting aerial, the potential rising to a maximum at the top and the current being greatest at the bottom.

Now suppose that there are two detectors, one depending for its action on the strength of the current passed through it, and the other on the value of the potential difference set up between its terminals. If the first detector were of fairly low initial resistance
it would clearly work best when inserted between the base of the aerial and the earth, where the current is greatest. This, however, is an unsuitable method of connecting a detector which depends on potential difference for its action.

The difficulty is not surmounted by placing the detector at the top of the aerial where the potential is high, for it is only high with regard to the earth, and to get the required potential difference a wire cannot be brought down to the earth from the second terminal of the detector; such a wire would act as a receiving aerial, and its potential would rise to a maximum at the summit, the distribution being the same as in the original aerial. Thus the detector would be connected between two points of equal potential, an obviously absurd arrangement.

The two methods that have been devised for overcoming this difficulty are shown in Fig. 15. In diagram (a) the aerial A is shown connected through the primary P of a step-up oscillation transformer, the secondary S being connected to the detector D. Such an arrangement can be made to give a potential difference between the terminals of the detector which is even greater than that existing between the top of the aerial and the earth.

The second method, as shown at (b) in the same figure, employs the "auto-transformer" principle. The first method is known as "inductive," and the second as "direct" coupling.

Up to the present only one type of detector has been mentioned, namely, the crystal detector, but there
are many others, and although in some cases their use has been discontinued, a brief review of them will be useful.

Branly Coherer.—Probably the earliest practical form of detector was the improved form of Branly coherer, which consisted of an evacuated glass tube containing two silver plugs, separated by a small gap, in which was placed a mixture of nickel and silver filings (Fig. 16). Connections to the plugs were made by means of wires sealed in the glass, and the complete coherer was placed in circuit with a cell and some form of relay or a recording instrument. The potential applied to the coherer by means of the cell was adjusted until just insufficient to cause the metallic filings to cohere without the additional potential of an incoming wave.

An arrangement was provided for tapping the coherer after each signal so as to restore it to normal condition ready for the next one, which necessitated a rather slow rate of signalling.

The action of this detector was greatly interfered
WIRELESS TELEGRAPHY & TELEPHONY

with by atmospheric disturbances, and no means were then available for eliminating or distinguishing such from regular signals. The operation of a near by transmitter was very liable to put the coherer out of action.

Wheel Coherer.—The next practical development was probably the self-restoring coherer used in the Lodge-Muirhead receiving apparatus. In this a small steel disc with a fine knife edge was arranged so as to rotate at a slow speed over an ebonite tube filled with mercury, the edge of the disc just touching the surface of the mercury, which was covered with a thin film of oil. As with the Branly coherer, an E.M.F., which

Fig. 16.—Improved form of Branly Fillings Coherer

in this case must be just sufficient to break down the film of oil, was applied by means of a local battery. The self-restoring property of the coherer is obtained by the rotation of the disc.

Magnetic Detector.—Use was made by Marconi of the apparatus shown in Fig. 17, where two magnets M M are represented with like poles placed together so as to magnetise the endless band of stranded iron wire c; this continually moves through the coil g, being carried round by the pulleys P P, one of which rotates by clockwork. The hysteresis lag causes the field to be carried on by the wire a little beyond the central point, and when oscillatory currents flow through g the residual lagging flux is annulled, and the magnetism may be said to jump back to the central position.
This slight though rapid shifting of flux induces a current in the coil w, so that a click is heard for each spark transmitted. Thus a dot is rendered by a short crackle, and a dash by a long buzz. The sounds are not very loud, but the action is regular. This is a current-operated device, and can be inserted directly between the aerial and earth.

**Electrolytic Detector.**—Fig. 18 shows a simple electrolytic detector which consists of a very fine platinum point with a screw adjustment and a small vessel containing an electrolyte into which the platinum point dips, a metal plate or wire of much larger dimensions being immersed in the liquid to serve as the second electrode. The action of the electric waves is to produce an alteration of resistance which appears to depend on the formation of a protective film of gas on the surface of the platinum tip, the film...
being either broken down or increased by the wave-induced oscillatory E.M.F.s.

**Hot-wire Detector.**—The essential part of this detector (Fig. 19) is an excessively fine platinum wire. A short loop of this wire \( f \) is securely fastened to two wires \( w \) \( w \), which are suitably held in a glass support \( g \). To facilitate radiation it is enclosed in a silver shell \( s \), which is attached to the glass support \( g \). The shell is then enclosed in a glass bulb, the wires are sealed in and the bulb exhausted. When the oscillatory currents from the aerial pass through the loop it is heated, and its resistance increases, producing a change in the value of the current supplied by a battery placed in opposition to a potential divider; the minute changes in the current operate a telephone.

**Crystal Detectors.**—The crystal type of detector has already been referred to. They constitute a very important class, particularly for amateur use. Their action depends upon the fact that, in general, conductors, or contact between two conductors, through which the current does not vary proportionately to the applied E.M.F., are capable of rectifying oscillatory currents. The contact is, in some cases, between a metal and a crystal, and in others between two different kinds of crystals.

Of the former type the carborundum-steel detector is an example, and this combination makes a very good and reliable detector if used in conjunction with a local battery and potentiometer. The purpose of the battery
VARIOUS DETECTORS EXPLAINED

is to supply an initial potential, and the potentiometer is required to so adjust this to bring it just to a critical or balanced condition, when the oscillatory current produced by the incoming signal causes a large increase of current in one direction, but only a small decrease in the reverse direction. This is equivalent to cutting off one-half of each oscillation, thereby converting the original oscillatory current into unidirectional impulses.

Another example of the crystal type is the tellurium-zincite detector, which may be used without any locally applied potential. Of the second class, there are numerous combinations, of which the following will serve as examples: Zincite-bornite, zincite-galena, silicon-zincite.

Thermionic Detectors.—If the carbon filament of an ordinary glow lamp is surrounded by a metal cylinder, a current can be passed between the filament and the cylinder if the following conditions are satisfied: The negative pole of the source of current must be connected to the end of the filament which goes to the negative pole of the battery supplying the lamp, while the positive pole of the source of current must be connected to the cylinder. If the source of current is reversed there is no flow. Accordingly, the apparatus acts as a rectifier, and if inserted in the receiving circuit of an aerial it will cut off half of the wave and will enable the pulsating portion of the wave which is not cut off to actuate an ordinary sensitive galvanometer.

The action of this detector, or thermionic valve, as it is now called, depends upon the following facts:
The hot filament emits from its surface minute negative charges of electricity called electrons, which are subject to the usual laws of electrostatic repulsion and attraction. The metal cylinder or anode, being maintained at a potential positive to that of the filament, attracts the electrons. The flow of electrons, however, does not vary according to Ohm’s law. There is a critical point upon the voltage-current curve where a slight increase in anode potential causes a large increase in the flow of electrons, the necessary slight increase being provided by the incoming signal.

As the flow of electrons through the valve can take place in one direction only, the oscillatory currents in the coils of the receiving apparatus are converted by the valve detector into unidirectional impulses which are subsequently caused to actuate the diaphragms of the telephone receivers.

Subsequent development of this type of detector, or valve, led to the introduction of a third electrode in the form of a small sheet of perforated metal or of wire gauze, having more or less open mesh, placed between the filament and anode, and known as the “grid.”

Owing to the extremely important position which thermionic valves hold in modern radio-telegraphy and telephony the subject is specially dealt with in the next chapter.

**Telephone Receivers.**—With the introduction of improved detectors came the substitution of telephone receivers in place of the various forms of recording apparatus in use, the received energy being thus made to give audible signals. The telephone receivers em-
ployed are identical in principle with those in everyday use, but their construction and sensitiveness is of a much higher order, and they are provided with "headbands" so that they may be worn by the operator, thus leaving both hands free. The introduction of the telephone made for higher signalling speeds and increased range of communication.
CHAPTER VI

Thermionic Valves as Detectors, Amplifiers and Generators

General Considerations. — These devices in their modern form consist essentially of an exhausted glass vessel containing three electrodes, namely: A cathode consisting of a filament of tantalum, platinum or tungsten capable of being heated to incandescence by passing through it current from a local secondary battery. An anode in the form of a metal plate; and a third electrode, which consists of a perforated plate, a sheet of wire gauze, or sometimes merely an open spiral of thin wire, placed between the filament and the anode.

To understand the mode of action of a valve necessitates some acquaintance with the modern electron theory and the laws governing the passage of electricity through a gas. Owing to limitations of space, these matters can be but briefly discussed; to go fully into the subject would require a fair-sized textbook, but it is hoped that the explanation which follows will make clear the action of a valve, though not attempting to deal with the abstruse fundamental theories.

It is generally accepted that a molecule or smallest known portion of matter consists merely of positive and
negative charges of electricity, different arrangement of such charges determining the nature of the material of which the molecule is a part. In a normal molecule, the positive charge exactly equals the negative charge, and such a molecule is therefore unaffected by electric forces, and is called a "neutral molecule." It is possible, however, by a process known as "ionisation," to so disturb the charges within a previously neutral molecule as to cause it to have an excess of either positive or negative electricity. There also exists separate free charges of negative electricity called electrons, the movement of which consists what is known as an electric current.

The removal of one or more electrons from a previously neutral molecule, leaves the latter with excess positive charge, in which case it behaves in an electric field as a positively charged body and is called a positive ion. The addition of one or more electrons to a previously neutral molecule causes it to have an excess negative charge and to behave as a negatively charged body, being then known as a negative ion.

When an electric current flows in a metallic conductor, the electrons pass readily from molecule to molecule, and as long as it is remembered that, as the electrons are negative charges, the flow is really from negative to positive, the idea is fairly easy to grasp.

But in dealing with the passage of electricity through a more or less rarefied gas, the matter is somewhat complicated by the participation, under certain conditions, of the positive and negative ions in the conduction. It has been found also, that although
electrons will pass easily from a gas to a metallic conductor, they cannot be made to enter a gas from a metal unless the latter is heated usually to incandescence.

The simplest form of valve, consisting of a closed, exhausted glass vessel is shown in Fig. 20 in which \( F \) is a filament capable of being heated by current from the battery \( B \), through the regulating resistance \( R \), the electrons emitted from \( F \) being attracted to and absorbed by the plate or anode \( A \), which is connected by means of a wire sealed in the glass to the positive terminal of the battery \( B_{1} \), the negative terminal of which is connected to one side of the filament. This is known as the 2-electrode valve. A micro-ammeter \( M/A \), or a sensitive galvanometer, indicates the flow of current in the anode circuit, which is exactly equivalent to the stream of electrons from the filament to the anode through the valve.

The conditions under which ionisation may or may not occur depend on: (1) The gas pressure within the valve, i.e. the degree of vacuum obtained in exhaustion. (2) The strength of the electric field, i.e. the potential difference between the anode and filament due to the anode battery. If, during the course of their movements, an electron and a molecule collide, either one of two distinct changes may occur, depending upon the relative speed of the charges at the instant of collision. If their relative speed is fairly low (less than about 1\( \frac{1}{4} \) million feet per second), the electron adheres to the molecule by the usual laws of electrostatic attraction, and a negative ion results.

If, on the other hand, the relative speed is higher
than the above-mentioned value, the impact so disturbs the charges in the molecule as to detach one or more electrons, which, together with the original electron, move along towards the anode. The result in this latter case, therefore, is the production of one positive ion and several electrons, and the action is known as ionisation by collision. Now, if the gas pressure in the valve is fairly high (i.e. poor vacuum), the number of molecules will be considerable, and an electron will not travel far before a collision occurs, so that "ionising velocity" may not be attained.

As the density of the gas is reduced, the distance travelled by the electron before collision will increase, and as the acceleration is very rapid, ionising velocity may be reached. If the density of the gas is reduced to extreme limits, the number of molecules remaining in the valve will be so small that the electrons, though attaining high velocities, may reach the anode without a collision at all. Such a condition produces what is called a pure electron discharge, and is employed in practically all modern valves, being rendered possible

Fig. 20.—Diagram illustrating principle of Two-electrode Thermionic Valve

D 43
by greatly improved methods of exhausting the valve, by which very high vacuum is obtained.

The function of the third electrode or "grid" is to control the flow of electrons from filament to anode, which is effected by varying its potential with respect to the filament. If the grid is strongly negative to the filament, it tends to drive the emitted electrons back into the filament, despite the attraction of the positively charged anode. As the negative grid potential is decreased, electrons begin to flow through the spaces in the grid to the anode, but the flow does not follow Ohm's law, for at a certain critical value a small change of grid potential results in a large change in the anode current, that is, in the number of electrons reaching the anode.

This property is made use of when employing 3-electrode valves as amplifiers, but the actual grid potential varies according to the closeness of the mesh of the grid, the anode potential employed, and the general design of the valve and the degree of vacuum in it.

The unidirectional conductivity of the valve is made use of when employing it as a rectifier of alternating or oscillating currents, and upon a suitable combination of these two basic properties depends the action of a valve in setting up and maintaining continuous oscillations in a transmitting aerial with consequent radiation of undamped waves, and, further, enables a receiving apparatus to be self-heterodyning for the beat-reception of such undamped waves.

Valves are classified according to the degree of
THERMIONIC VALVES AS DETECTORS

vacuum in the bulb and the closeness of the grid mesh, being called "soft" or "hard" as the vacuum varies from low to high values, and "open grid" or "close grid" as the spaces in the grid vary from those in an open spiral of fine wire to those in a sheet of fine wire gauze.

Applications of the Valves.—The applications of thermionic valves in modern radio-telegraphy may be classified as follows:

1. Detection of damped-wave signals.
2. Amplification, high- and low-frequency.
4. Heterodyne reception of undamped-wave signals.

Each application of these developments will be briefly dealt with separately, so that a general idea of the functioning of the valve in practical use will be obtained.
Detection of "Damped-wave" Signals.—In this application, unidirectional conductivity of the valve is made use of, as mentioned in the chapter relating to detectors. There, however, the simple 2-electrode valve was considered, whereas now it is necessary to consider the application of the modern 3-electrode valve. Fig. 21 shows diagrammatically a typical arrangement employing the 3-electrode "ultra-audion."

This type of valve contains an appreciable amount of gas (air), and is therefore classified as "soft," and is liable to ionisation. The grid is of a very open type, and consists of two "gridirons" of well-spaced wire placed between the filament and the double anode, the latter consisting of small square plates of nickel arranged one on either side of the filament. Owing to the large spaces between the wires of the grid, an appreciable number of electrons flow to the anode even when the grid is at zero potential. Due to the grid condenser \( G \), the normal potential of the grid will always have a value zero, or very near zero; thus there is normally a steady flow of current from the anode battery through the windings of the telephone receivers.

The cumulative effect of the incoming wave-train is to cause the grid to collect electrons from the filament, and so, together with one side of the condenser \( G \), to become negatively charged with respect to the filament. This immediately causes a reduction in the number of electrons reaching the anode, and hence in the current through the telephone windings.

As this reduction takes place once for each complete wave-train, obviously the note in the telephones will
correspond in frequency with the spark of the distant transmitter. During the comparatively long interval between wave-trains, the negative charge upon the grid is neutralised, partly by leakage through the grid condenser, due to insulation leakage, and partly by the grid itself collecting positive ions from the gas.

In the case of a very "hard" valve giving a pure electron discharge, there would, of course, be no positive ions to effect this neutralisation, so an additional leakage path is provided by shunting the grid condenser with a resistant having a value of from 1½ to 2 megohms, and known as the "grid leak." The condenser R, connected across the anode battery and telephones T, permits of rapid changes in the value of the anode current, which would otherwise be impeded by the resistance of the battery and the inductance of the telephone windings. This condenser is usually known as the "reservoir" condenser.

There are numerous other arrangements of circuits and apparatus possible, but that shown in Fig. 21 is quite typical. The grid may, however, be connected directly to the aerial circuit, and the closed secondary circuit L S be dispensed with altogether, a quite efficient arrangement, though not as selective as that shown in Fig. 21.

Amplification.—The fundamental fact upon which amplification in a valve depends may be briefly stated as follows: When a valve is in proper adjustment, a small change of grid potential causes a large change in anode current. From this it will be seen that if we connect up a valve, as shown in Fig. 22, the oscillatory
changes of potential which occur in the aerial circuit, due to an incoming wave-train being impressed upon the grid, give rise to similar oscillations in the circuit Ls connected to the anode and a source of D.C. supply at from 50 to 100 volts, but of much greater amplitude. As the currents in the circuit Ls are oscillatory, it is necessary to provide for their subsequent rectification before they can actuate the telephones T, which is done by inserting a detector at D, that shown in our figure being of the crystal type.

As the amplification takes place at radio-frequency, this particular application is known as high- or radio-frequency amplification. Low- or audio-frequency amplification is obtained by connecting the valve in circuit at a point where the currents have already undergone rectification by the crystal or other detector, and where the total change of grid potential occurs at a frequency equal to the group frequency of the incoming signals. The circuit in this case is as shown in Fig. 23.

In each of the foregoing cases the detector may be a suitably arranged valve, so that it is possible to dispense with the ordinary detector altogether, and arrange a number of valves in series, the anode circuit of one actuating the grid circuit of the next.

For instance, five valves could be used, the first two being made to perform high-frequency amplification, the third to act as a rectifier or detector, and the last two to perform low-frequency amplification. By this means very great magnification of feeble incoming signals may be obtained. The anode circuit of one
THERMIONIC VALVES AS DETECTORS

valve is usually connected inductively to the grid circuit of the next by means of suitable transformers, those used in H. F. circuits being constructed, as a rule, without iron cores.

Generation of Continuous Oscillations.—It has been shown that if energy impulses can be given to an oscillatory circuit (for instance, an aerial-earth system) with sufficient rapidity, the radiated waves maintain a constant amplitude, provided the impulses are correctly timed to coincide with the oscillation frequency of the circuit. (See Fig. 14, continuous-wave methods.) The thermionic valve, being an instrument which depends for its action upon change of electrical potential only—that is, in which there are no moving parts save the electrons themselves—and which is capable of operating at frequencies of millions per second, is peculiarly adapted for controlling impulses to an aerial circuit at radio-frequencies.

Fig. 22.—Diagram showing Circuit Arrangements of Three electrode Valve as High-frequency Amplifier

49
The method of application is perhaps best explained with the help of a diagram. (See Fig. 24.) The aerial circuit, comprising the aerial, aerial tuning inductance \( A T I \), condenser \( BC \), and "earth," is the only oscillatory circuit in the apparatus, so that if impulses can be applied at the exact frequency to which this circuit is tuned, the resulting waves will have a single frequency. The anode circuit comprises the anode \( A \), part of the \( A T I \), a source of high-tension D.C. supply at (say) 1,000 volts, shunted by a reservoir condenser \( R \), of large capacity, and lastly, the valve filament \( F \). The valve itself must be "hard," i.e. of a high degree of vacuum, in order to stand the application of a high anode potential without ionisation by collision occurring.

Impulses, in the nature of "puffs," of direct current, are given to the aerial circuit by the pulses of current flowing from the source of supply to the anode through part of the \( A T I \). The means adopted for controlling and timing these impulses is extremely ingenious. In the grid circuit is placed an inductance \( M \), called the "reactance coil," inductively coupled to the \( A T I \), and a grid condenser \( GC \), which becomes shunted by a high-resistance leak \( L \) when the operating key \( K \) is depressed. With the key up, the grid should be completely insulated from the filament, which necessitates the use of insulation materials of best quality in the grid condenser and base of operating key.

The action of the complete apparatus is as follows: Suppose the filament to be glowing and the H.T. battery connected. Negative electrons flowing towards the anode are intercepted in part by the grid, which,
being insulated, accumulates a considerable negative potential, becoming possibly as much as 400 volts

Fig. 23.—Diagram showing Circuit Arrangements of Three-electrode Valve in Low-frequency Amplification

negative to the filament, and completely cuts off the flow of electrons to the anode. When the transmitting key $k$ is depressed, the leak $L$ is shunted across the grid condenser and the negative potential of the grid $g$ is greatly reduced, permitting the electrons to flow to the
anode and causing a pulse of current from the H.T. battery to charge the "earth" positively and commence to grow in the inductance A T I. As this pulse of current grows in the A T I, it induces in the reactance coil an E.M.F. in such a direction, as determined by the "sense" of the respective windings, as to make the grid negative again. This again cuts off the flow of electrons, and so the current in the oscillatory circuit, having attained a maximum value, swings in the reverse direction and induces an E.M.F. in the reactance coil in the opposite sense to the first one, thus restoring the grid to a potential which permits the flow of electrons, and, as it were, turning on the anode current again.

As long as the correct average grid potential is maintained by the operating key and grid leak, this action continues, and as the variations of grid potential are effected by induction from the oscillations themselves, the "puffs" of anode current given to the aerial are correctly timed to the frequency of the aerial circuit.

The coupling between the aerial and reactance coils is variable, and the adjustment of same for best results is usually somewhat critical. In the case of a close-grid valve, an initial positive potential is applied to the grid when the operating key is depressed, because the "average grid potential" for such valves has a positive value, usually in the neighbourhood of 8 volts; whereas the value for an open-grid valve, as employed in the arrangement just discussed, is generally from 100 to 200 volts negative.
THERMIONIC VALVES AS DETECTORS

With these continuous-wave valve transmitters great distances have been successfully covered; for instance, a small set using two valves and weighing but a few pounds can effect successful transmission over a distance of about 500 miles, the total power employed being less than 100 watts.

Heterodyne Reception.—There are two distinct methods by which heterodyne reception can be carried out, as previously stated. The first of these, the "independent heterodyne" method, employs a miniature continuous-wave transmitter to produce undamped oscillations in a tuned circuit at a frequency differing slightly from that of the received waves, and by suitably coupling this circuit to the aerial circuit, the two sets of oscillations are superimposed, thus giving rise to "beat" currents at any desired audible frequency. These "beat" currents, after rectification, actuate the telephone diaphragms. By this means continuous-wave signals can be received using apparatus originally intended for "spark" reception only, without in any way altering the apparatus.

With the second method, the interfering oscillations are generated in the valve-receiving apparatus itself, the action depending upon the reactance principle explained on page 30, but with the connections of anode and grid circuits reversed. Fig. 25 shows a typical arrangement, and if this is now compared with the transmitter diagram (Fig. 24), it will be seen that the aerial circuit, which in the transmitter was impulsed direct, is now impulsed inductively by the varying currents in the reactance coil R (Fig. 25).
In the transmitter the grid potential was varied by means of the operating key and grid leak, and an impulse was given to the aerial circuit. In the receiver the grid potential, adjusted to the best average value, is varied by the incoming signal, and an impulse is given to the telephone windings, but in traversing the reactance coil some of the energy of each impulse is transferred by induction to the aerial circuit. If the correct degree of coupling is maintained between the reactance and aerial coils, continuous oscillations are maintained in the aerial circuit, the frequency of which can be varied by means of the variable contact of the aerial tuning inductance. Suppose an incoming wave at a frequency of 200,000 is being received, and the receiving set to be oscillating, i.e. generating continuous oscillations in the aerial circuit; if the aerial is tuned exactly to a frequency of 200,000 there will be no sound in the telephone receivers.
THERMIONIC VALVES AS DETECTORS

On slightly mistuning, either by increasing or reducing the frequency of the locally generated oscillations by (say) 600 per second, a clear musical note of that frequency will be heard in the telephones. Obviously this "beat" note may be varied by the receiving operator to any convenient pitch, this being, in fact, a recognised indication that continuous waves are being received. Reception of spark signals may be carried out with this same arrangement and great magnification obtained, but the characteristic spark-note of the transmitting station is lost, the sounds in the telephones being more in the nature of a loud rustling noise.
CHAPTER VII

Making a Single-circuit Receiving Set

In this chapter the construction of a simple, yet practical, wireless receiving set will be fully described. The range of wave-lengths is 600 to 3,500 metres. In its design it has been borne in mind that even the simplest of apparatus should not be made and "scrapped" later, so this present set is designed with a view not to only satisfying immediate requirements as a complete receiving set, but subsequently, after certain minor alterations, forming an important component in a more elaborate receiving station.

Fig. 26 is a front view of the complete set, the overall dimensions being, length 10 in., height 6½ in., and width 7 in. The set comprises an inductance or "tuning" coil (fitted inside the box or casing and shown dotted in Fig. 26) wound on an insulating tube or former 9½ in. long by 5 in. in diameter, tappings from which are taken to the tuning switches A and B, a crystal detector D, telephone terminals T and T1, and "aerial" and "earth" terminals E and E.

All "live" metallic parts (that is, switches, detector, and terminals) are mounted on an insulating panel of ebonite secured to the front of the box containing the tuning coil. The construction of the various items will now be considered in detail.

Panel.—Fig. 27 shows the ebonite panel (7 in. by
A SINGLE-CIRCUIT RECEIVING SET

4½ in. by ¾ in. thick) drilled to receive the brass fittings. The contacts are formed of No. 4 B.A. cheese-headed screws ¾ in. long, screwed into holes tapped in the ebonite as shown, the heads being then filed down until the slot disappears, care being taken to leave all the heads the same height above the ebonite. The four stops are similar screws with the heads sawn off. The four holes for the terminals may be drilled to suit the particular size of terminals available, whilst the holes for counter-sunk-head screws securing the detector may be left until the detector is completed and marked off direct from same. The same thing applies to the corner holes for the screws securing the panel to the wood box front.

Fig. 26.—Front Elevation of Single-circuit Receiving Set

Fig. 28 shows to scale the details of the crystal detector, A being a front view, and B a side view showing more clearly the arrangement of the brass spring to which the upper crystal-holder is attached. Fig. 29 shows the shapes of the two brass brackets, and Fig. 30 the shape of the brass spring before bending.

57
The crystal combinations recommended for use in this set are zincite-bornite or tellurium-zincite, the zincite in the first-named combination being the upper crystal and in the second the lower. Any small caps or sockets will serve for crystal-holders, a hole being drilled through the end, and a small screw inserted.
A SINGLE-CIRCUIT RECEIVING SET

with head inside the holder, which is then filled with molten solder in which the crystal is set.

Fig. 31 shows the construction of the two tuning switches, which are in every way alike, and as all necessary dimensions are given further explanation is considered unnecessary. If screws of exact length are available, the screw-head will replace the lower nut shown.

All these component parts being completed, the panel may be marked for the four detector screws, and the holes drilled and tapped.

The twenty contact screws are next to be smeared on the thread with thick shellac varnish (that is, shellac dissolved in methylated spirit) and screwed in place, the heads being filed down after the shellac has properly set.
The remaining parts may then be fitted in the following order: (1) Tuning switches, which should be forthwith adjusted so as to make proper contact on all the studs over which they pass, and to work smoothly and easily. (2) The four small stops at the ends of each range of studs. (3) The four terminals— aerial, earth and two telephones. (4) The detector (without crystal-holders), the securing screws of which should pass right through the panel, as one is required at the top and another at the bottom for connecting purposes. At this stage the completed panel may be laid aside until required for final assembly.

Inductance Coil.—The next item requiring attention is the inductance coil, which consists of 300 turns of No. 28 s.w.g. d.c.c. copper wire, the approximate weight being \( \frac{1}{2} \) lb. The best material for the former or tube on which the coil is to be wound is ebonite, pertinax, of some such insulating material, say, \( \frac{3}{8} \) in. thick. But as this may not always be obtainable of the required dimensions, a stout cardboard tube well coated with shellac will make an effective substitute. Failing this, proceed as follows: Obtain two wooden discs 5 in. in diameter by \( \frac{3}{4} \) in. thick, and a sheet of either thin fibre, presspahn, or even flexible cardboard 9\( \frac{1}{2} \) in. by 16\( \frac{1}{2} \) in. by (say) \( \frac{3}{4} \) in. thick. Carefully roll the sheet round the two discs, and secure it thereto with small brass tacks, one disc at each end of the tube thus formed. Glue down the lap-edge, and when set give the whole at least two good coats of shellac. If a ready-made tube of any description is to be used, the two wooden discs are still required; but their diameter
A SINGLE-CIRCUIT RECEIVING SET

will be determined by the inside diameter of the tube. The discs are to be inside the tube and flush at each end.

A simple and very convenient device to facilitate the winding of the wire on the former is shown by Fig. 32, and consists of a length of stout tubing about \( \frac{3}{8} \) in. outside diameter, which passes through a hole in

one disc, and has one end secured to the bench or table, the other being plugged to hold a screw passing clear through the second disc. Thus secured, the former can easily be rotated with one hand by means of a small handle (for instance, a thread bobbin) temporarily attached to the outer disc, while with the other hand the wire is guided into place on the tube. The
winding can, of course, be performed without this device, but it is a slow and somewhat tedious operation.

Commence the winding at about 3 in. from the end of the tube nearest to the bench, and take care to keep the turns smooth and free from "kinks" with adjacent turns close together. The end turn is secured by passing the loose end of the wire (which should be left about 12 in. long to serve as a connecting lead) several times under and over it and carefully drawing up tight. The most difficult portion of the winding is the first thirty turns, as "tappings" have to be taken every third turn as shown in Fig. 33.

There are several different methods of taking off tappings, but that here described is probably the easiest, and will be found quite satisfactory. At each "tapping-point" the wire is bent back on itself (say for 3 in.), and the small loop thus formed is taken between the finger and thumb and twisted round two or three times, the winding being then continued, leaving the loop standing as shown in Fig. 33. Subsequently each loop is cut at the outer end, the two ends of wire are carefully cleaned and twisted together along with the cleaned end of a length of insulated connecting wire, and the whole is soldered.

The arrangement of the necessary tappings will be seen on referring to Fig. 33. The last turn is to be secured in a similar manner to the first, and again the loose end of wire should be left about 12 in. long. Before anything is done to disturb the winding the coil must be given two coats of shellac. Indeed, it is a good plan to apply this as a fixative at frequent
A SINGLE-CIRCUIT RECEIVING SET

Intervals as the winding proceeds, as in this way the trouble and annoyance of having the turns slip and become loose may be averted. When the shellac is quite set the tappings may be treated as above described, the connecting wires employed being 12-in. lengths of wire left over from the coil. The advantage of these long connecting wires will be apparent when they are being soldered to the contact screws.

Case.—The tuning coil, complete with connecting wires, may now be laid aside while attention is given to the construction of the box into which it is to be fitted.

The constructional details of this box may be varied according to the reader's inclination and skill in joinery, and as long as the dimensions given are adhered to, the result may be either a simple nailed or screwed box of, say, pine or teak, or a nicely dovetailed and polished mahogany "cabinet." The inside dimensions must be as follows: Length, 9½ in. (to correspond with the tuning coil); height, 5½ in.; width, 6½ in. (to allow clearance for connections, etc., on the back of the ebonite panel). Material ⁸⁄₃ in. thick is recommended, which just makes up the overall size previously mentioned. The front must have an opening cut to afford clearance for connections to the back of the panel.

Assembling.—The final assembly, including the making of all connections, is now to be undertaken (see Fig. 34). The connections on the back of the panel (apart from coil connections) may be made first, namely, (1) from the E terminal to the upper detector bracket D,
(2) from the Ξ terminal to the right-hand telephone terminal, (3) from the lower detector bracket to the remaining telephone terminal. The wire employed for these three connections may also be that left over from the coil; but for the two other panel connections—namely, from the Ξ and Ξ terminals to the adjacent tuning switches—light insulated flexible cable must be used to allow for the movement of the switch spindles.

The coil may now be secured in place in the box by two brass screws through each end. There remains the operation of soldering each of the coil-connecting wires to its correct contact stud, which, if the box containing the coil is set square before the constructor with the panel lying face downwards on the bench and close up to the box, is not a difficult matter, though great care must be exercised in selecting the wires before cutting to exact length and soldering. Reference to Fig. 34, which is a complete diagram of connections, will make clear the required arrangement. Throughout all soldering operations have the soldering-bit clean and hot; but avoid excessive heat or lengthy application of the hot bit to screws in the ebonite.

When all connections are satisfactorily made, the whole of the wires and fittings at the back of the panel, except the tuning switch spindles and nuts, should receive a coat of shellac, and when this is dry the panel may be lifted into place (the connecting wires being carefully stowed away in the space provided), and secured by means of four brass screws through the corner holes. The crystal-holders, having been fitted
A SINGLE-CIRCUIT RECEIVING SET

with suitable crystals, may be attached to the detector, and the set is complete.

Telephones.—With regard to the telephones, double receivers having a total resistance of 4,000 ohms (that is, 2,000 each ear-piece) are recommended; but provided the total resistance is not less than about 1,000 ohms, it is the workmanship and general design of the telephones which count for most.

Operation.—Telephones being available, some means of testing and adjusting the detector is necessary, and for this purpose a small buzzer, as used for Morse practice, is employed to emit feeble signals, which, being received on the windings of the tuning coil, actuate the detector and give rise to sounds in the telephone receivers. Carefully adjust the contact between the detector crystals until loudest signals are
heard when the "testing buzzer" is operated. The buzzer should not be too close to the receiving set, or, by induction, signals may be heard when the crystals are not touching at all. A good plan when the aerial and "earth" are connected to the receiving apparatus, is to place the buzzer several feet away from the set, but quite near to the earth lead.

The maximum wave-length to which this receiving set will tune depends on the dimensions of the particular aerial with which it is used; but in general, signals should be received on wave-lengths varying from 600 metres to about 3,500 metres.

The following brief explanation of the action of a single-circuit receiver, though in some respects a repetition of what has been said in earlier chapters, will, it is hoped, form a fitting conclusion.

Electro-magnetic waves from a distant transmitting station striking the aerial of the receiving station tuned to the same frequency, set up in the aerial-earth circuit oscillating currents, that is to say, the aerial end of the tuning coil shown in Fig. 34 is at one instant positive and the next instant negative compared to the earth end of the coil. By reason of the peculiar property, already discussed, possessed by the detector of passing more current in one direction than in another (known as uni-directional conductivity), these oscillatory changes of potential give rise to uni-directional impulses through the detector and the telephone windings.

These impulses, however, being much too rapid for the diaphragms of the telephones to respond to, produce a kind of cumulative effect, that is, the
diaphragms are deflected when the impulses commence, remain deflected during their passage, and are released when the impulses cease. But the incoming waves from a spark transmitter arrive in groups (wave-trains) with intervals between, one group for each spark at the transmitter, so the deflections of the telephone diaphragms occur at a rate equal to the spark frequency of the transmitting station. Hence the receiving operator hears in the telephones the same note as that of the distant spark.

Modification for C.W. — The set just described may be modified as in Fig. 34a for use with the valve panel described in Chapter IX to enable C.W. signals to be received. The additions required are: A variable condenser (maximum capacity, .001 mfd.); a series-parallel switch; and a reactance coil consisting of a former approximately 4 in. in diameter by 5 in. long closely wound to within, say, \( \frac{1}{2} \) in. of each end with No. 28 s.w.g. d.c.c copper wire and provided with four equal tappings connected to a suitable 4-point switch. The terminals to which "Grid," "Fil" and "Reactance" are to be connected are clearly shown in Fig. 53, p. 97.
CHAPTER VIII

Making a Complete Short-wave Receiving Set

The almost continuous signalling which goes on between the coast stations along our shores and on the Continent, and the shipping in adjacent waters is an almost unfailing source of "radios" with which much interesting experimental work can be done, and which, previous to the limited aerial now permitted, was to a large extent neglected in the search for long-distance stations.

There is also a constantly increasing field of interest in wireless telephony, much of which is of short-wave length. It is to be remembered that there are no different principles involved in the reception of radiotelephony from those governing the reception of ordinary "spark" radio-telegraphy.

Readers may be assured that keeping in touch with passing vessels and catching the brief signals transmitted, demands considerable skill in manipulation of the apparatus, rapid adjustment of inductance and condenser values, coupling, etc., and possesses an interest quite its own. Incidentally it affords splendid practice in Morse reading and in commercial procedure. A fair knowledge of the latter, in addition to general proficiency in reading Morse, should be possessed by all amateur wireless experimenters, more especially by
those who have, or who hope to have, transmitting stations.

The construction and operation of a fairly simple but efficient short-wave receiving set, capable of receiving signals on wave-lengths varying from about 150 to about 700 metres when used in conjunction with a regulation amateur aerial, will be dealt with in this chapter.

This range of wave-lengths provides for the "normal" ship wave, sometimes known as the "long commercial" wave, of 600 metres, also the short ship wave or "short commercial" wave of 300 metres. In addition, the "amateur wave," that is, 180 metres, can be received satisfactorily, so that, if desired, the set to be described can form part of a complete amateur receiving station.

The constructional details will be gone into very carefully, and if the instructions are followed exactly, possibilities of failure with the completed set will be unlikely.

To commence with, the general arrangement and the functions of the component parts will be dealt with.
Fig. 35 shows the completed set. The over-all dimensions of the box are as follows: Length, 9 in.; width, 5 in.; and height, 5\(\frac{1}{2}\) in.; and it contains the primary and secondary windings of the oscillation transformer, the coupling between which is variable by sliding the secondary coil on a wood spindle fitted between the ends of the box. It also contains the telephone condenser, shunted across the two telephone terminals T and two small dry batteries (flashlight size), to operate the buzzer for testing the detector and potentiometer.

Usually it is better to have this testing buzzer at some distance from the receiving set (in the adjoining room is a convenient place); but it is considered advisable to include one in the set on this occasion, so that separate loose gear need not be carried if the set is to be taken about at all. A and E (Fig. 35) are the aerial and earth terminals respectively, and T the terminals for attaching the telephone receivers.

Switches 1 and 2 are the aerial tuning switches, No. 1 being for rough and No. 2 for fine tuning. Switch 3 is the secondary tuning switch, and 4 a lever with index pointer moving over a scale, for sliding the secondary into and out of the primary, and so varying the coupling between the two circuits. All switches, contact-studs and terminals are mounted on a panel of ebonite; 5 is the secondary condenser, of a tubular-rotary pattern, forming with the secondary inductance a closed oscillatory circuit, and possessing sufficient capacity to effect tuning over the desired range of wavelengths; 6 is the detector, of the crystal variety, of which there are available several excellent combina-
tions, and as to which the reader with previous experience may suit his own individual taste.

The following combinations are recommended: (a) Tellurium and zincite, (b) zincite and bornite, and (c) steel and carborundum. Good crystals used in conjunction with an applied potential, carefully adjusted by means of the potentiometer 7, will give good results. For use without an applied potential, silicon-brass, galena-copper wire, and "permanite"-copper wire are excellent; but combinations a and b above may also be used, and work fairly well without.

Mounted just to the right of the detector, on the top of the box, is a small push-button 8, which actuates the testing-buzzer 9.

With the addition of the necessary telephone receivers, which should be of "high resistance," and as good as can be obtained, the whole forms a very compact receiving station, and one which can be constructed without a very extensive outfit of tools or great amount of skill in using same, and at a very modest cost. Some notes relating to the operation of the set are given later.

The construction of the component parts will be dealt with in the following order: Ebonite front panel and fittings; aerial or primary inductance; closed-circuit or secondary inductance; wooden containing box; secondary condenser; telephone condenser; detector; potentiometer; buzzer, push-button, and battery.

**Ebonite Front Panel and Fittings.**—Panel: One piece of ebonite 9 in. by 3\(\frac{3}{4}\) in. by \(\frac{1}{4}\) in. thick; weight 71
6 oz. **Terminals**: Four of any convenient size. **Contact studs**: Twenty brass cheese-head screws, No. 4 B.A., \( \frac{1}{4} \) in. long. **Stops**: Six brass cheese-head screws, No. 4 B.A., \( \frac{1}{2} \) in. long. **Switch spindles**: Three brass cheese-head screws, No. 2 B.A., 1\( \frac{1}{4} \) in. long, each with one nut, three plain and one spring washer. **Switch arms**: Spring brass or phosphor bronze, total 4\( \frac{1}{2} \) in. of \( \frac{1}{4} \) in. wide and 18 gauge or nearest. **Switch handles**: One piece of ebonite rod, 3 in. long by 1\( \frac{1}{4} \) in. diameter; weight 4 oz. Shellac varnish, made by dissolving best shellac in methylated spirit.

Fig. 36 shows exactly how the ebonite panel is to be marked off in readiness for drilling. First square off the ebonite to the dimensions given, and file out the portion cut away at the top right-hand corner. Then with scriber, straightedge and compasses, mark off exactly as shown. Next commence drilling, employing a sharp (but not acute) twist drill of the required diameter, and taking care to ease the pressure on the drill a little while before the point emerges, otherwise pieces of the ebonite round the hole will break away. It is convenient to drill first the three holes for the tuning-switch spindles, then the panel can be secured to the edge of the work-bench by means of two round-head screws through each outer hole with a washer under the heads in such a manner that all the holes for contact studs project over the edge of the bench, and can be drilled and subsequently tapped, very conveniently. The six holes for the "stops" should be omitted for the present.

In the absence of taps of the required size, it will
be found that if one of the No. 4 B.A. screws has four flats filed on the point, with a slight taper, it will cut quite a presentable thread in the ebonite, but must be used with care, as ¼-in. ebonite is not very strong. When all the holes are drilled and tapped as required,

remove the panel from the bench and polish with soft rag, rouge and sweet oil.

When the polishing is completed and the contact studs are to be fitted, screw the panel to the bench as
before, dip the point of each screw into good thick shellac varnish, insert in place and screw home tight. Take care, however, not to strip the thread in the ebonite. When the shellac has had time to set, the heads of the screws are to be filed down until the slots are no longer visible. Before filling remove the screws securing the panel to the bench, and cover the polished ebonite except the screw heads with a strip of cardboard to prevent accidental damage from the file. Finish off the surface of the contact studs with fine emery and remove any "rag" from the edges.

The six holes for the "stops" should now be drilled and tapped, on the line of centres of the studs, and close to the outer studs of each of the three sections. Shellac and insert the six screws; then cut off the heads and file level, leaving about \( \frac{1}{8} \) in. projecting above the level of the studs. At this stage the engraving of numbers for studs and distinguishing letters for terminals may be done if desired.

Now take the brass strip and cut to shape as shown in Fig. 37, two being required to shape A and one to shape B, and drill the hole in each to admit the spindle. Fit each spindle in its respective hole in the ebonite, with washers arranged as shown at C (Fig. 37), and screw down the nut until the spring washer is compressed so that the spindle can just comfortably be rotated with the finger and thumb. By means of pliers, bend the outer ends of the switch arms to make contact with the studs, and try in place, adjusting as may be found necessary.

Remove the three nuts, and having carefully
cleaned the underside of each switch arm and the flat side of each nut, solder one nut to each switch arm so that the holes coincide. The proper way of doing this is first to tin each article with a thin coating of solder, and then to hold the two articles in correct position in the pliers, and apply the hot soldering-bit, subsequently running a little solder round three edges of the nut in contact with the brass strip to strengthen the joint. When cool, polish the top sides and edges of the switch arms, using fine emery followed by metal paste, and fit in places on the spindles. With a light application of the hot iron run a little solder round each spindle, just where it emerges from the switch arm; but avoid filling more than two or three threads with solder.

Inspect carefully to make sure that each switch makes proper contact on all the studs in its particular segment, and that good and strong attachment has been made to the spindles. There is no necessity to have excessive pressure upon the contact studs, and the switches should turn easily and smoothly.
The three switch handles are now to be turned from the 1\(\frac{1}{2}\)-in. diameter ebonite rod, as shown at D (Fig. 37), and the bosses drilled and tapped with No. 2 B.A. thread. If it is desired to engrave the distinguishing letters—P, primary; F, fine tuning; and S, secondary—this may be done now. Before screwing down to touch the brass strip smear the threads of the spindles with thick shellac varnish. These handles are not likely to work loose and there is no necessity to fit a locking pin.

The terminals should now be fitted in place, and this completes the front panel, which should now appear as in the photograph (Fig. 38).

**Aerial Tuning (or Primary) Inductance.**—*Former:* Tube, 3\(\frac{1}{4}\) in. outside diameter by 4 in. long. This should be of ebonite, paxolin, micanite, or similar good insulating material, \(\frac{7}{8}\) in. thick; but in lieu thereof, may consist of stout cardboard tube, well dried and shellac varnished. *End plug:* A round wooden disc, \(\frac{1}{2}\) in. thick, to fit inside one end of the above-mentioned tube. *Wire:* 100 ft. of No. 24 s.w.g. d.c.c. copper wire, the approximate weight of which is 3 oz. *Screws:* Brass screws for wood—three each \(\frac{1}{2}\) in. long, and two each \(\frac{3}{4}\) in. long, and all any convenient thickness.

The primary of the oscillation transformer is to consist of 92 turns of wire as specified, wound with adjacent turns touching (but, of course, insulated from each other by the cotton covering of the wire), and divided into twelve sections by means of thirteen tappings. The sections are to be arranged as follows,
counting from that end of the former-tube inside which is fitted to the wooden disc:

6 sections of 12 turns each = 72 turns
1 section ,, 10 ,, ,, = 10 ,,  
5 sections ,, 2 ,, ,, = 10 ,, 

Total ... ... ... 92 turns

This arrangement will be readily understood on reference to Fig. 39, and constructional operations are as follows: First, take the former-tube, which, if of cardboard, is to be prepared as mentioned in the specification, and the wooden disc. Drill a \( \frac{3}{8} \)-in. hole through the centre of the latter, and fit it neatly inside one end of the tube just flush with the end, securing by means of three \( \frac{1}{2} \)-in. screws passing through the tube \( \frac{1}{4} \) in. from the edge.

Commence the winding from the same end, quite close to the three screws. To secure the first turn, a small piece of silk tape should be placed round the wire, and the ends of the tape covered and thus secured, by succeeding turns of wire, as shown in Fig. 39. As the coil is but small and easily held, it is not really
necessary to arrange a winding device, though this may be done if desired on the same lines as described on page 61. Count the turns as they are wound on, and at the twelfth full turn make the first "tapping."

At the tapping-point make a 3-in. loop in the wire, and twist the projecting wires together two or three times close to the tube. Continue winding, performing a similar operation at each tapping-point. When the completed inductance has received two good coats of shellac varnish, and this has been allowed to set quite hard, the twists of the wire are to be gently undone, the insulation removed for, say, ½ in. from each wire, the copper scraped clean and bright, the wires twisted together again and soldered. Then one wire is to be cut just above the soldered connection. This, when straightened out, forms a connecting lead 6 in. long.

Alternatively, the insulation may be removed from the wires as each tapping-point is reached; then when once twisted together they need not again be disturbed. Any tendency to slip which the turns of wire may exhibit during winding operations is best checked by an application of shellac varnish up to the point reached at the moment. A pause of a few minutes will give time for it to set quite sufficiently to hold the wires in place.

The 12-turn tappings may be arranged along the coil in a straight line; but the 2-turn tappings should be "staggered" a little to avoid crowding and so facilitate handling, soldering, etc. The finishing end of the coil may be secured either by means of a piece
of tape (as already mentioned), or by passing the end of the wire itself through two small holes near the end of the former-tube. When completed, the whole of the winding and each connecting lead should be given at least two good coats of shellac varnish and placed in a warm dry place to set.

Secondary Inductance.—Former: Tube of ebonite, micanite, or stout cardboard shellac varnished, 2½ in. outside diameter by 3½ in. long. End plugs: Two wooden discs to fit inside the above-mentioned tube, each ¾ in. thick with a ¾ in. hole through the exact centre. The disc at the outer end of the secondary tube should have an additional ¾ in. hole drilled above the centre hole to allow the tappings to be brought from inside the coil to the respective studs. Wire: 150 ft. of No. 36 s.w.g. d.c.c. copper wire; approximate weight, 1½ oz. Flexible leads: About 4 ft. or 5 ft. of very light, flexible insulated wire. Spindle: Wood, 8½ in. long by ¾ in. in diameter. (Material known as "dowelling" is very suitable.) Screws for wood: Six of brass, each ¾ in. long.

The secondary of the oscillation transformer is to consist of 175 turns of wire as specified, wound on the "former-tube" with adjacent turns touching, and divided into six sections by means of seven tappings. The sections are to be arranged as follows, counting from that end of the secondary which, when completed and mounted on the spindle, is nearer to the primary coil. One section of 50 turns and five sections of 25 turns; total, 175 turns. The process of winding is exactly similar to that employed in the case of the
primary coil, but the method of making the tappings and fixing the connecting leads differs.

As the secondary itself is to be movable, while the contact studs under the secondary tuning switch are fixed, the connections to the studs from the tapping points must be made by means of flexible conductors as specified above. Commence winding, securing the first turn as already described. Wind the first section of 50 turns, and apply a coat of shellac to retain the turns in place. At the point where the tapping is to occur, make a small hole through the cardboard tube to permit the bared end of a 6-in. length of flexible lead to emerge. Actually, of course, it will be more convenient to put the wire through this hole from the outside, and draw it down to the proper position with, say, $\frac{1}{4}$ in. projecting. Carefully bare the 36-gauge wire for, say, $\frac{1}{4}$ in. of its length, and wind it round the end of the flexible lead, bend the strands of the flex over the thin wire, and solder all together. Stow the lead out of the way and continue winding, repeating this tapping operation every 25 turns until the winding is completed.

See that the 36-gauge wire is not broken at any tapping-point, and that any slight pull on the flexible leads is taken by the lead itself and not applied to the turn to which it is connected. Apply shellac liberally about the holes through which the connecting leads pass. Give the completed coil two good coats of shellac varnish, and place in a dry situation to set.

**Wooden Containing Box.**—The choice of material is left to the individual taste of the reader. Mahogany
SHORT-WAVE RECEIVING SET

is recommended, but yellow pine suitably stained and polished leaves little to be desired. The dimensions of the pieces are as follows: *Ends*: Two pieces, each \(4\frac{3}{4}\) in. by \(4\frac{1}{2}\) in. by \(\frac{1}{2}\) in. thick. *Top and bottom*: Two pieces each 9 in. long by \(4\frac{1}{2}\) in. by \(\frac{3}{8}\) in. *Back*: One piece 9 in. long by \(5\frac{1}{2}\) in. by \(\frac{3}{8}\) in.; or if desired \(\frac{7}{8}\)-in. plywood may be used here. *Front strips*: Two pieces 9 in. long by 1 in. wide by \(\frac{1}{4}\) in. thick; or again, \(\frac{7}{8}\)-in. plywood may be employed. *Screws*: Thirty-six brass screws \(\frac{3}{4}\) in. long; twenty-two \(\frac{1}{2}\) in. long are required instead of \(\frac{3}{4}\)-in. screws if plywood is used. Three brass screws are required for securing the primary coil to the end of the box.

A front elevation *a*, a plan *b*, and an end elevation *c* (Fig. 40), will, it is hoped, make clear the method of construction of the box without further explanation.

Note the recess in the centre of one end (\(\frac{3}{4}\) in. in diameter and \(\frac{1}{8}\) in. deep) to take the end of the wooden spindle which carries the secondary coil.
Tubular Condenser.—Base: Wood, 4 in. by 2 in. by ¾ in. thick. Ends: Plywood, ⅛ in. thick, 2½ in. by 2 in., cut to shape. Disc supporting outer plates, of wood, 1½ in. in diameter by ¾ in. thick. Screws: Six small brass screws, say, ¼ in. long. Plates and cover: One square foot of thin brass (or tinplate) will be ample for these. Roller carrying inner plates: Wood, 1½ in. in diameter by 3½ in. long. Handle: Ebonite rod, 1 in. in diameter and 1 in. long. Leads: Short length (say 6 in.) of light insulated flex for connecting inner and outer plates. Dielectric: One piece of mica 5½ in. by 3½ in. by (say) 1 mm.

The design of this condenser will, it is thought, be new to many readers, so a word or two as to its action will not be out of place.

Referring to Fig. 41, which is an end view of the plates only of the condenser, it will be seen that as the inner plates c and d are each connected to the outer plate beneath which they lie, there is practically no capacity between the points x and y. If, however, the inner plates are rotated in the direction indicated by the arrows, c will gradually pass beneath b, and d beneath a, thus giving a variable capacity between the points x and y (that is, between the plates a and b, to which connecting leads are attached), which is at maximum value when c is entirely underneath b, and d under a. In the case of the actual condenser now to be described, the maximum capacity will only be small, but will be sufficient for the present purpose where a small capacity only is required.

With regard to the construction, proceed as follows:
First prepare the wooden stand as shown in Fig. 42, and temporarily remove one end. Two small holes are to be drilled through the base near the end to which the fixed plates are attached, to permit the two connecting leads from the condenser to pass through. Next cut two pieces of the thin brass (or tinplate) each $3\frac{1}{4}$ in. by $\frac{3}{4}$ in., bend round a 1$\frac{1}{2}$-in. diameter roller, and fit to the circular disc, securing thereto by means of the six small brass screws, so as to form a split tube $3\frac{1}{4}$ in. long by $1\frac{3}{8}$ in. in diameter having adjacent parallel edges about $\frac{3}{8}$ in. or $\frac{3}{16}$ in. apart, as shown in Fig. 42, but for greater convenience have the slots vertically one above the other.

Place the 1$\frac{1}{2}$-in. diameter roller inside the outer plates, and see that it is a very loose fit, having
clearance of, say, \( \frac{1}{16} \) in. all round. Also try it for length, by placing the other end of the stand (that is, the shaped plywood) against the end of the base as finally intended. The roller should clear this end by about \( \frac{3}{16} \) in.

The two inner plates have now to be cut, each \( 2\frac{3}{4} \) in. by \( 2\frac{3}{16} \) in., with a small tab left on one corner, to which the flexible lead can be soldered. If these plates are bent round a 1-in. diameter roller they can then be sprung on to the \( 1\frac{3}{4} \)-in. roller and will remain in place. The space between adjacent parallel edges of these plates should be the same as in the case of the outer plates. After trying in place and adjusting as necessary, remove and apply to the roller a coat of thick shellac varnish, springing the plates into position again when the varnish has become "tacky."

Prepare a very thin sheet of mica, by splitting up the sheet specified, of such dimensions as will enable it to be wrapped once round the roller and inner plates with an overlap of, say, \( \frac{1}{2} \) in., and of a length to ensure the plates being well covered at the ends. Coat the outer surface of the plates (and the roller between) with thick shellac, and when "tacky" carefully wrap the sheet of mica round same, fastening down the overlap with shellac. If trouble is experienced in making a satisfactory and smooth joint, the whole may be covered with one layer of thin tough paper.

When the shellac has thoroughly set, one end of the roller is to be fitted with a "bearing-pin," consisting of a brass screw \( \frac{3}{4} \) in. long with the head cut off, which turns in a central hole in the \( 1\frac{3}{4} \)-in. wood disc.
The other end of the roller requires drilling to suit the screw attached to the ebonite handle.

Fig. 42 shows the completed condenser minus the cover, a being a side elevation and b an elevation of the front end showing the ebonite handle and scale. Small stops, not shown, should be fitted to prevent the handle and roller being turned through more than 180°. A small mark on the ebonite handle indicates when moving over the scale the amount of rotation, and therefore the comparative amount of capacity in circuit.

The whole should now be carefully assembled, pairs of plates (one inner and one outer) connected together by means of flexible conductor long enough to permit the necessary rotation, soldered to the small tab of each inner plate and in the middle of the semicircular outer edge of the corresponding outer plate. To ensure easy rotation, the roller may be lightly smeared with vaseline before being inserted. A length of insulated wire should be soldered to one of the securing screws at the back end of each outer plate, and led through the hole prepared in the base.

A cover for the complete condenser should be made from the sheet brass or tinplate, bent to shape and secured by means of small screws along each side of the base-board. Subsequently this cover and the ends of the stand may be enamelled black.

**Telephone Condenser.**—Seven pieces of mica, approximately 1/500 of an inch thick, each 1½ in. by 1 in.; two pieces of mica, the same size but thicker (say 1/100 of an inch); seven pieces of tin-foil (or copper foil) each 1½ in. by 3 in.; two small pieces of soft brass,
WIRELESS TELEGRAPHY & TELEPHONY

each 1 in. by ½ in. by 1/32 in. or nearest, and some silk or linen tape will be required for the telephone condenser. To each of the seven pieces of thin mica, attach one of the pieces of foil by means of shellac varnish, allowing the foil to project ½ in. over one end. There will thus be ½ in. clear round three edges of each foil. When the varnish securing the foil to the mica is properly set, apply a coat of varnish over the foil itself.

While the shellac is still "tacky" build up the plates of mica and foil as shown in Fig. 43. Place between two pieces of blotting-paper, cover with a warm (but not hot) flat iron, and leave to set. Make two small clips of soft brass as shown in Fig. 43, which also shows how the projecting ends of the foil are to be bent over and held by the clips. Connections are made by means of wires soldered to each clip before the latter is placed in position over the foil.

The complete condenser may now be bound round with silk or linen tape and varnished.

Detector.— Base: Ebonite, 3 in. by 1½ in. by ⅜ in. thick. Pillar: Brass rod, ½ in. in diameter by 1⅛ in. long, bored to clear No. 2 B.A. screw, and sawn into three pieces as shown in Fig. 44. Securing screw: One No. 2 B.A. screw, brass, cheese-head, 2 in. long, with nut and washer. Adjusting screw: One No. 2 B.A. screw (as above), but 1¼ in. long, fitted with ebonite knob. Crystal holders: Small brass cartridge cases make effective cups, the crystals being set in them by means of molten solder, or better still, "Woods Metal" alloy. Springs: Two pieces of
SHORT-WAVE RECEIVING SETS

spring brass, each $1\frac{1}{4}$ in. by $\frac{3}{8}$ in. by $\frac{1}{6}$ in. thick. Crystal-holder bases and bracket for adjusting screw: Three pieces of $\frac{3}{16}$-in. brass, as per diagram.

Fig. 43.—Details showing Construction of Telephone Condenser

Fig. 44.—Side Elevation of Detector

Fig. 45.—Switch end of Potentiometer

Fig. 46.—Elevations of Potentiometer Sliders

Fig. 47.—Push-button for Testing Buzzer
Fig. 44 shows the completed detector, and, taken in conjunction with the foregoing specification, should render further particulars unnecessary.

**Potentiometer.**—*Base*: Wood, 4 in. by 2 in. by \(\frac{1}{2}\) in. thick. *Ends*: Wood, 2\(\frac{1}{2}\) in. by 2 in. by \(\frac{3}{8}\) in. thick, cut to same shape as the ends of the variable condenser. *Former*: Wooden rod, 1 in. in diameter by 4 in. long. *Slider rod*: Brass rod, 4\(\frac{3}{4}\) in. long by \(\frac{1}{2}\) in. square or nearest. *Slider*: Piece of ebonite rod (say) \(\frac{1}{2}\) in. in diameter or to suit the slider rod, and one fitting out of an electric lamp-holder. *Wire*: 20 yd. of No. 36 s.w.g. d.s.c. “Eureka” resistance wire, or nearest gauge. *Switch*: One piece of \(\frac{1}{16}\)-in. brass, 1\(\frac{1}{2}\) in. long by \(\frac{1}{4}\) in. wide. Three No. 4 B.A. cheese-head screws, \(\frac{3}{4}\) in. long with nuts and two washers. Small ebonite knob.

First make the stand complete, similar in every way to that of the variable condenser, but having a square slot in each end to admit the slider rod. On the front end fit up the switch as shown in Fig. 45. Next wind the 1-in. diameter rod with approximately 200 turns of the resistance wire, and give two coats of shellac varnish. Commence and complete the winding about \(\frac{1}{2}\) in. from each end respectively, in each case securing the end of the wire under the head of a small brass screw.

Construct the slider and fit to the square brass rod, as shown in Fig. 46, with the spring of the fitting making contact on rod. The rod may then be fitted in place, and the potentiometer coil tried in place below it and marked off for correct position, with the spring
plunger of the slider pressing on the winding. Remove
the slider and rod, and fix the coil in position.

Solder an insulated wire to each of the brass screws,
securing the ends of the coil. That at the back is to
pass through a hole drilled in the base, whilst that at
the front end, which must be a flexible conductor, is
to be soldered to the back of the switch spindle.

Replace the slider and move over the coil,
scraping off the insulation along the line where the
slider has touched. A wire must be soldered to the
back of one of the switch contacts and one to the slide-
rod screw at the front end, and both are to pass through
holes in the base.

In connection with this item there is required a
small battery, such as is used in conjunction with
pocket flashlamps.

**Buzzer, Push-button and Battery.—** All of these
may be purchased for a small amount, though the
push-button is very simply made and fitted.

The most convenient type of buzzer for present
purpose is the small circular type with removable cover.
The battery may be similar to that employed for the
potentiometer.

A push-button can be made consisting of two small
pieces of spring brass or phosphor-bronze and one
No. 4 B.A. cheese-headed screw \( \frac{3}{4} \) in. long fitted with
a small ebonite knob or button. If desired, silver
or platinum contacts—say from an old electric
bell—may be soldered to the metal strips, as shown
in Fig. 47, which should make the arrangement
quite clear.
Assembling.—Before proceeding to fit any of the components in the containing box, make all connections from both primary and secondary inductance coils to the contact studs of respective switches, as in Fig. 48, in which the panel is shown lying face-downwards for soldering the leads to the contact studs.

Make and fit to the secondary coil the coupling handle or lever, of \( \frac{3}{8} \)-in. brass with small ebonite knob fitted on to a brass screw and the latter soldered to the strip brass, as shown in Fig. 49.

The two coils, together with the spindle (\( \frac{3}{8} \) in. in diameter by \( \frac{3}{4} \) in. long), are now to be fitted in place as follows: First, attach the primary coil to that end of the box which has no recess in the centre, by means of two brass screws. The containing box at this stage should consist merely of the bottom, recessed end and back. Now place the \( \frac{3}{8} \)-in. spindle in position with the secondary coil on it, insert one end into the recess in the box end, and screw the end carrying the primary to
SHORT-WAVE RECEIVING SET

coil to the bottom and back of the box. Mark off the box top, and drill all holes for connecting wires from the variable condenser, potentiometer, buzzer, and detector. Having attached connecting wires to each of above-named components, screw them on the box top, screw the latter to the ends of the box, and remove the backboard.

At this stage the box, consisting only of two ends,

Fig. 50.—Complete Diagram of Connections for Short-wave Receiving Set

The complete connections from the studs to the tuning coils are to be as shown in Fig. 48. top and bottom, contains the two inductances, and has the ebonite panel with all connections made to tappings on the coils, lying face downwards on the bench, whilst on the top of the box are all necessary components, with insulated leads of ample length passing down through holes drilled in the box top.

Fig. 50 is a complete diagram of connections, and if this is carefully studied there should be no great difficulty in making the remaining connections.
Note that the tuning switches do not operate all in the same way, that is, Nos. 2 and 3 increase inductance when moved to the right; but No. 1 increases by a movement to the left.

The telephone condenser and dry batteries are to be stowed in the space beneath the coils, and held in place by means of small pieces of spring brass bent twice at right angles and screwed to the bottom of the box inside.

**Testing.**—When the assembling is completed and all connections made and checked by the diagram (Fig. 50), the apparatus should be tested before trying the set on the aerial. The "testing apparatus" may consist of either a battery and flashlamp or battery and buzzer, connected in series and having leads, say, a foot long attached. In Fig. 50, \( \mathfrak{w} \) is the aerial terminal, \( \mathfrak{z} \) the earth, \( \mathfrak{p} \) the primary inductance, \( \mathfrak{s} \) the secondary inductance, \( \mathfrak{c} \) the secondary condenser, \( \mathfrak{d} \) the detector, \( \mathfrak{n} \) the potentiometer, \( \mathfrak{z} \) the buzzer, \( \mathfrak{b} \) the push-button, \( \mathfrak{k} \) the telephone condenser, and \( \mathfrak{x} \) and \( \mathfrak{y} \) the batteries.

1. Test for continuity of primary winding and connections by attaching the testing leads to the aerial and earth terminals respectively, and moving the tuning switches over all studs. The test lamp should light with the switches in any position.

2. Insulation between the primary and secondary circuits may be tested by touching one test-lead on to the secondary tuning switch, the other test-lead remaining attached to either the aerial or the earth terminal. The lamp should not light.
3. Test for continuity of secondary circuit by connecting the telephone receivers to the proper terminals on the panel and listening, with the detector short-circuited temporarily, while the potentiometer-battery switch is moved "on" and "off," the position of the tuning switch being varied over all contact studs. Clicks in the 'phones indicate that the circuit is in order.

4. Test for accidental short-circuit in the secondary condenser by lifting the secondary tuning switch off the studs on to a piece of mica, and making and breaking the potentiometer-battery switch as before. Clicks should still be heard, but much fainter than before.

**Operation.**—If these four tests give satisfactory results, the set may be connected up to the aerial and earth, and the detector carefully adjusted to give a signal in the telephones when the testing buzzer of the set is operated. Adjust the mechanical pressure between the crystals first (that is, with the potentiometer-battery switched off) until good signals are heard, then switch on the battery and adjust the electrical pressure by means of the potentiometer slider, to improve signals.
To assist the reader in obtaining signals without a long period of fruitless "searching," the above table of adjustments is given and is to be read in conjunction with Fig. 51, which shows the numbering of the primary and secondary contact studs. The marking of the variable condenser in "degrees" from 0 to 180 indicates the amount of rotation, and the marking of the "coupling scale" reckoned as a percentage from 10 per cent. (loose) to 100 per cent. (maximum tight). As actual adjustments will vary with different aerials, the fine tuning switch is given in all cases as from 1 to 6.

When searching, set the secondary condenser to the lowest value, and coupling to the highest value shown in the above table, and move switch F to and fro over the six studs. When faint signals (or indications of same) are heard, adopt the following sequence of operations: (1) Set switches p and f to give best results. (2) Set switch s to give best result. (3) With the left hand vary the coupling, and with the right hand adjust the secondary condenser. (4) Re-set switch F. (This is only necessary if the coupling has been altered appreciably.)
SHORT-WAVE RECEIVING SET

When receiving signals which appear likely to continue for some little time (for instance, the repetition of a lengthy message), carefully readjust the detector in the manner already described. It will often be found that the "buzzer adjustment" can be much improved on.

With regard to telephone receivers, these should be the best obtainable, and should have a resistance of 2,000 to 4,000 ohms. Double receivers are strongly recommended, 2,000 ohms each ear-piece; these will be found to give splendid results.

There should be no difficulty in receiving signals from practically all the English commercial coast stations (usual wave-length 600 metres), and in most cases the signals from the vessel with which the coast station is in communication will also be heard.

Fig. 52 is a photograph of the complete original set, on which good readable signals from many stations have been received, including Marseilles.

Fig. 52.—Photograph of Complete Short-wave Receiving Set
CHAPTER IX

Making a Valve Panel for a Receiving Set

The instrument, of which the construction is described in this chapter, may be effectively employed with practically any existing receiving set, from the simplest single- or two-slide tuning-coil outfit to the most elaborate inductively-coupled tuner. Thus the construction of this one piece of apparatus and the purchase of the necessary three-electrode valves, 4-volt or 6-volt accumulator and high-tension (or anode) battery, opens up a wide and extremely interesting field for experimentalists. There are advantages in commencing C.W. and "valve" experimental work with a comparatively simple piece of apparatus, and the constructional work is well within the capabilities of the average wireless amateur. The type of valve with which this valve panel is intended to be used is the "hard, open-grid" valve.

The theory and action of valves has been dealt with in an earlier chapter, and such further information as may be necessary for the operation of this panel will be given later.

Referring to the photographs (Figs. 53 and 54), these show a front and back view respectively of the panel, and as all the component parts are clearly labelled, they can readily be identified in the following specification:
Fig. 53.—Photograph of Front of Panel without Valve

Fig. 54.—Photograph of Back of Panel
Specification of Materials.—**Panel:** Ebonite sheet 7 in. by 5 in. by $\frac{3}{8}$ in. thick. **Knob for rheostat:** This may be purchased ready-made or turned from ebonite rod $1\frac{1}{2}$ in. in diameter by 2 in. long, which includes for holding in lathe chuck. **Rheostat:** One disc of fibre, 2$\frac{1}{2}$ in. in diameter by $\frac{1}{2}$ in. thick; 3 yd. of No. 21 s.w.g. "Chronic" resistance wire; one brass cheese-head Whitworth screw, $\frac{1}{4}$ in. in diameter by 1$\frac{1}{4}$ in. long; one piece of hard brass for contact arm, 2 in. long by $\frac{1}{2}$ in. wide by (say) $\frac{3}{8}$ in. thick; two No. 4 B.A. screws $\frac{3}{4}$ in. long and two No. 4 B.A. screws $\frac{1}{2}$ in. long for securing resistance wire and to act as "stops" for switch; two No. 2 B.A. screws $\frac{3}{4}$ in. long, for securing rheostat to back of ebonite panel. **Valve holder:** Four brass cheese-head Whitworth screws $\frac{1}{4}$ in. in diameter by $\frac{3}{4}$ in. or 1 in. long. **Grid condenser:** Three pieces of mica, each 1$\frac{3}{4}$ in. by 1$\frac{1}{2}$ in. by .005 in. thick; two pieces each 1$\frac{3}{4}$ in. by 1$\frac{1}{2}$ in., but thicker, say .05 in.; three pieces of tinfoil or copper-foil, each 1$\frac{3}{4}$ in. by 1 in. and any convenient thickness, say .01 in.; two pieces of soft brass (or copper), each 1$\frac{1}{2}$ in. by $\frac{5}{8}$ in. and (say) $\frac{3}{8}$ in. thick. **Grid leak:** The high-resistance "leak" employed in this particular instrument is of the "pencil-line" type. **Reservoir condenser:** As shown in the photograph, this is of the "Mansbridge" type, in Helsby case, as extensively used in connection with commercial telephone sets. A satisfactory condenser of smaller capacity may be constructed, the materials required being 20 sheets of tinfoil or copper-foil, each 2$\frac{1}{2}$ in. by 1$\frac{1}{2}$ in.; 21 sheets of mica, each 2 in. by 1$\frac{1}{2}$ in. by .005 in. thick; and 2 pieces of soft brass, each 1$\frac{1}{2}$ in.
VALVE PANEL FOR A RECEIVING SET

by 1 in. by (say) \( \frac{3}{4} \) in. thick, to form end clips and connections. **H.T. battery switch**: A ready-made switch may be employed, or a simple "knife" switch may be made from two terminals and a small piece of strip brass. **Terminals**: Ten terminals are required in all, and these may be of any convenient size and
pattern. *Containing box:* The material of which this is to be made is left to the individual taste and convenience of the reader. The box may conveniently be made 2 in. deep, and the overall size, of course, will be the same as the ebonite panels, 7 in. by 5 in.

*Connecting wires:* Well-insulated bell wire will prove very suitable for connections. The pieces of mica shown (intended to prevent surface leakage over the ebonite) may be omitted provided the ebonite is tested with dry-cell and telephone receiver to ensure that surface leakage will not occur.

**Panel.—** The ebonite panel may conveniently be dealt with first, and is to be squared up on the edges by means of a file and fine glasspaper. It is then to be marked off and drilled in accordance with A and B (Fig. 55). If desired, the holes for the valve-pin sockets may be tapped right through the ebonite from the front and the sockets made to a somewhat different pattern (*see detail B, Fig. 56*), and screwed home from the front. These sockets are next to be made as at A or B (Fig. 56), and carefully screwed into place, having first had a little thick shellac varnish applied to the threads.

All necessary terminals may next be fitted in place and screwed up tight. Here again the application of shellac varnish may obviate future trouble due to the terminals working loose.

The H.T. battery switch (constructed in accordance with C, Fig. 56) may also be fitted. At this stage the panel should be placed on one side whilst attention is given to the condensers and filament rheostat.
Grid Condenser.—To one side of each piece of mica a piece of foil is to be attached by means of shellac varnish, leaving $\frac{1}{4}$ in. of foil projecting at the end, as shown at A (Fig. 57). The three pieces of mica are then to be placed together, observing that the foils are separated by mica and that the two outer foils project at one end and the inner foil at the other. The two thicker pieces of mica are to be shellac-varnished on one side and placed one above and the other below the condenser, and whilst the shellac is still "tacky" the whole is to be laid on a flat surface and covered with a warm (but not hot) flat iron. The two pieces of soft brass should be cut and bent as shown at B (Fig. 57), to form clips with connecting and securing lugs.

When the shellac in the condenser is properly set, take a soft graphite pencil and draw a heavy line (say $\frac{1}{16}$ in. broad) from end to end of one of the outer pieces of mica. Fold over the projecting foils at respective ends, so that they make contact on opposite ends of the pencil line, and place the brass clips in position and squeeze up in a small vice or with flat-nosed pliers.
The completed condenser is shown at c (Fig. 57). The best value of resistance (that is, thickness of pencil line) is subsequently to be determined by actual trial under working conditions, and when correctly adjusted a light coat of shellac varnish will render it permanent. In view of this it is necessary to mount this condenser on the panel with the "leak" outwards and readily accessible.

Filament Rheostat.—First take the resistance wire and wind closely round a wooden former about 1/8 in. in diameter (for instance, a blacklead pencil). When released, the wire will spring back somewhat, and the coil increase in diameter, probably to about 1/4 in. The fibre disc should be grooved around the circumference as shown in Fig. 58, to afford a seating for the coil of wire. The centre hole for the spindle and two holes for securing screws should also be drilled. Two No. 4 B.A. screws 1/4 in. long are to be screwed into tapped holes in the edge of the disc (in the groove) about 1 in. apart, and one end of the wire having been secured under the head of one screw, the coil is to be carefully stretched round the disc, and the remaining end secured by the second screw. Observe that adjacent turns of the resistance wire do not touch one another.

The disc, with resistance wire attached, may now be fitted and screwed in place on the back of the panel, and the centre hole (for spindle) drilled right through the panel.

Next make the rotating switch-arm. Drill it and solder to under side of the head of the spindle (1/4-in. Whitworth screw), and mount up as shown in Fig. 58,
adjusting the contact arm until it presses firmly but not too heavily on the wire.

Rotate the switch clockwise until the contact arm presses on the end turn of the wire, mark the position, and fix a No. 4 B.A. screw in the face of the fibre disc to act as a stop. This is the "full-on" position. Rotate the switch arm in an anti-clockwise direction until just clear of the resistance wire, which, if found necessary, should be bent down a little to allow of easy movement of the arm. Here place a second stop-screw. This is the "off" position.

![Diagram of Valve Panel](image)

**Fig. 58.—Sectional Elevation of Valve-filament Rheostat**

The \(\frac{1}{4}\)-in. brass nut may be soldered to the spindle if desired; but this should not be necessary, as the ebonite knob, if screwed well up against the nut, will act as a lock-nut. Apply a little shellac to the threads at the end of the spindle before finally screwing up the ebonite knob.

**Reservoir Condenser.**—This condenser is so called because it acts as a kind of "reservoir" to the anode or H.T. battery, in a manner somewhat analogous to the usual india-rubber gas-bag placed between a gas-engine and the gas-pipe, in order to maintain a smooth
and steady supply. There is no exact capacity required; the condenser should simply be as large as can conveniently be arranged up to, say, one-quarter microfarad.

A condenser built up of tinfoil and waxed paper, as used across the interrupter of an induction or spark coil, will be quite suitable, provided the insulation and dielectric strength of the waxed paper will withstand the voltage of the H.T. battery.

The necessary materials as specified being available,

![Diagram of Connections at Back of Valve Panel](image)

Fig. 59.—Diagram of Connections at Back of Valve Panel

the construction of the condenser may be proceeded with on precisely similar lines as in the case of the grid condenser.

Similar brass contact-clips will be required, but these will be of larger dimensions.

Both condensers may now be secured in place on the back of the panel by means of No. 4 B.A. screws, and the whole carefully wired up as shown in the diagram of connections (Fig. 59). Care should be taken to leave a clear space along all four sides of the panel, corresponding to the thickness of the sides of the containing box.
Containing Box.—This box is simply to form a base for the completed panel, and afford protection for the components and connections on the back of it. It should consist of four sides and bottom only, as the ebonite panel itself forms the top, and should measure overall 7 in. by 5 in. by 2 in. deep.

If it is required to fix the completed panel in a vertical position (for instance, against a wall or board), this may easily be done by removing the ebonite panel and passing suitable screws through the bottom of the box. Small brass mirror-plates may be employed instead, if desired.

This completes the construction of the valve panel.
and Fig. 60 is a photograph of same, minus containing box, showing the valve in place and all ready for putting to work. Note the small diagram of connections mounted on the front of the ebonite panel beneath a piece of transparent celluloid.

**Notes regarding Operation.**—The application of the valve as a kind of magnifying detector is shown in circuits Figs. 61 and 62, and the reader should have no difficulty in arranging his apparatus accordingly. Neither arrangement, however, is capable of detecting C.W. signals. For this purpose an additional inductance is required, as shown at \( \mathcal{R} \) in Fig. 63 and known as the "reactance" coil.

As an example, a suitable reactance coil for use with a tuning coil 6 in. in diameter, say 10 in. long and wound with No. 28 s.w.g. wire, might consist of 100 to 150 turns of No. 38 s.w.g. d.s.c. copper wire wound in one length without tappings on a 4\( \frac{1}{2} \)-in. or 5-in. diameter former about 2\( \frac{1}{2} \) in. or 3 in. long, and arranged to slide inside the tuning coil.

The purpose of this reaction coil is to pass some of the magnified energy in the anode circuit back into the grid circuit in correct phase, so as to increase the energy in the latter circuit, which is again applied to the grid itself and undergoes further magnification in the valve. This provides a means of greatly increasing the sensitivity of the valve as a detector, and consequently increasing the strength of spark signals, and for the best effect the reactive coupling will be somewhat critical. If the coupling is increased beyond this point, the transfer of energy from the anode to the
VALVE PANEL FOR A RECEIVING SET

grid circuit is such that continuous oscillations are maintained in the circuit, and the valve is said to be "oscillating."

By short-circuiting the grid condenser and leak, the panel just described may readily be adapted for use as an amplifying panel or unit. For diagram illustrating
the method of using it as a low-frequency amplifying panel in conjunction with the short-wave receiving set, see Fig. 63a. Many readers have written since the inauguration of the B.B.C. service to tell of their excellent results with the apparatus described in Chapter VIII. Considerable increase in the strength of the received telephony may be obtained by using the short-wave set in conjunction with the valve panel as described in the present chapter. The set itself need not be interfered with. The valve panel, being originally designed for rectification purposes, contains a grid condenser and leak which, when the panel is to be used for low-frequency amplification (as now suggested), should be short-circuited. The addition of an iron-core intervalve transformer (preferably having a step-up ratio of 1 to 5) completes the necessary apparatus. (See Fig. 63a.)

Fig. 63a.—Circuit Diagram of Short-wave Set with Valve as Low-frequency Amplifier.

108
CHAPTER X

Making a Five-valve Amplifier

The apparatus described in this chapter does not include tuning coils, but forms a complete and separate amplifier unit capable of the reception of spark or C.W. signals, and also, of course, of radiotelephony. It may be used in conjunction with any type of single-circuit or inductively-coupled receiving tuner, and readily permits the use of any number of valves from one to five. The usual 4-volt
or 6-volt filament lighting battery and 60-volt anode dry-cell battery are also extraneous to the amplifier, and are to be connected thereto by means of terminals provided.

The external appearance of the completed amplifier is shown by the photograph (Fig. 64). The five circular ebonite knobs shown operate the filament rheostats, a separate rheostat being provided for each valve. The small bright circles (six in a horizontal row near the bottom of the set, two being occupied by plugs) are the projecting ends of telephone jacks, which afford a convenient method of changing over connections when it is desired to vary the number of valves actually in use.

The single jack above the centre of the row of six, and shown as occupied by a plug, is for the reactance-coil connection which may be cut out of circuit, when self-oscillation of the receiver is not required, by simply withdrawing the plug. Fig. 64 shows the tops of the five valves, also the three plugs with leads attached for connecting the tuner, reactance and telephone receivers. The plug with the white-lead, occupying the third jack from the left, connects the aerial and earth of whatever tuner is employed to the grid and filament of the rectifying valve. Moving this plug to the left connects the tuner to the amplifier, so that either one or two high-frequency amplifying valves are included before the rectifying (or detecting) valve.

The reactance coil employed is to be connected to the leads attached to the plug shown inserted in the
MAKING A FIVE-VALVE AMPLIFIER

single upper jack, which is included in the anode circuit of the rectifying valve. This jack is provided with short-circuiting contacts, so that the anode circuit is not broken when the plug is withdrawn.

Telephone receivers, the leads of which are provided with a telephone plug, are shown connected (via a low-frequency, iron-core transformer inside the set) to the anode circuit of the rectifying valve, this valve only being in use. Moving the telephone plug to the right adds either one or two low-frequency or note-magnifying valves after the rectifying valve and between it and the telephone receivers.

From the foregoing and by reference to Fig. 64 it will be apparent that the amplifier may be used with any type of tuner, and that any number or combination of valves from one to five may be employed simply by varying the positions of the plugs, whilst by means of the separate filament rheostats only those valves actually in use have their filaments glowing.

There is another advantage about the design which will appeal particularly to those who are obliged to pause and consider the financial aspect, and that is, the work may be undertaken in portions and each portion put into service as completed. For instance, having the complete containing box with valve sockets, filament rheostats, jacks and battery terminals, one valve only may be purchased and fitted up as the rectifying valve, other valves with attendant transformers being obtained later (singly if desired) and added as opportunity offers. A complete set consisting of three valves only—that is, one H.F., one rectifier
and one L.F. valve—may readily be arranged in lieu of the present design by slightly modifying the dimensions and arrangements, though in general it is advised that the complete set be constructed as to be described, even though three valves only are to be used, as it will then be possible to try various combinations of valves merely by transferring the valves from one socket to another.

The total magnification obtainable when using the five valves is tremendous, and with most of the commercial stations usually received by amateurs, signals are quite deafening, so that the telephones have to be removed from the ears and laid on the bench.

The photograph shown by Fig. 65 gives a back view of the set, the backboard with lid attached being readily removable to facilitate the fitting and wiring up of the various components. Referring to Fig. 65, the sockets for the five valves are fitted into an ebonite strip which in turn is screwed to the wooden shelf of the containing box. The valves employed are of the French R type, that is, open grid, hard valves requiring four or six volts for filament lighting together with a 60-volt anode potential.

The three upper filament rheostats will be observed behind the valves, the two lower rheostats, which are arranged in the spaces between the upper ones, being obscured by the transformers fitted to the under side of the shelf. In the right-hand bottom corner may be seen the projecting screws of the L.T. battery terminals, whilst immediately beneath the shelf the common negative filament lead may be seen, looped
back to make connection with the negative filament socket of each valve holder.

Attached to the under side of the shelf are the transformers, the two H.F. transformers (ebonite cylinders with slots and vertical row of connecting pins) being to the right, and the two L.F. inter-valve transformers, each with a small fixed condenser connected across the primary winding, to the left.

The telephone transformer (in this instance of the hedgehog type) occupies the left-hand bottom corner with the fixed condenser (across primary winding) directly above, and behind these and not visible in the photograph is placed a fixed condenser of large capacity connected across the H.T. battery terminals and known as the reservoir condenser.
Upon the ebonite strip between the third and fourth valves, and therefore readily accessible for adjustment, is placed the grid condenser and leak, the latter consisting of a short piece of slate pencil with pointed ends held between two brass springs. The inner portions of the tuner, telephone and reactance jacks are also visible, together with some of the connecting wires.

With all five valves in operation the action is as follows. Oscillatory E.M.F.'s from the tuner are applied directly to the grid and filament of the first valve, so varying the potential of the grid with respect to the filament and giving rise to amplified current fluctuations in the anode circuit of the valve. By means of the first air-core H.F. transformer, these amplified E.M.F.'s are applied to the grid and filament of the second valve, and there undergo further amplification before being applied (via the second air-core H.F. transformer and the grid condenser) to the grid of the rectifying valve.

From this it will be seen that the incoming signals, having already undergone two successive stages of high-frequency amplification, will strongly affect the grid potential of the rectifying valve and so permit of very effective rectification.

The magnified uni-directional pulses of current in the anode circuit of the third valve are then applied, via the first low-frequency iron-core transformer, to the grid and filament of the fourth valve, and similarly (after magnification in the valve) from the fourth to the fifth valve.
MAKING A FIVE-VALVE AMPLIFIER

To the anode or output circuit of this last valve are connected the high-resistance telephone receivers, by means of an iron-core step-up transformer.

Assuming, for example, an average amplification factor of 5 for each valve and an incoming signal strength of unity (1), then the relative strength of the signals would be as follows:

<table>
<thead>
<tr>
<th>Incoming signal</th>
<th>...</th>
<th>...</th>
<th>...</th>
<th>...</th>
<th>strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal, after first valve</td>
<td>(1 × 5)</td>
<td>...</td>
<td>,,</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>,, ,, second valve</td>
<td>(5 × 5)</td>
<td>...</td>
<td>,,</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>,, ,, third valve</td>
<td>(25 × 5)</td>
<td>...</td>
<td>,,</td>
<td>125</td>
<td></td>
</tr>
<tr>
<td>,, ,, fourth valve</td>
<td>(125 × 5)</td>
<td>...</td>
<td>,,</td>
<td>625</td>
<td></td>
</tr>
<tr>
<td>,, ,, fifth valve</td>
<td>(625 × 5)</td>
<td>...</td>
<td>,,</td>
<td>3,125</td>
<td></td>
</tr>
</tbody>
</table>

That is to say, the resultant energy in the telephone receivers, neglecting transformers and other losses in the set itself, is approximately 3,000 times greater than that of the incoming signal.

The construction of the amplifier is described in easy stages so that expenditure may be made by degrees and each portion put to work and experimented with as completed.

The first portion or rectification stage of necessity includes the containing box or case and preferably all valve sockets, filament rheostats and telephone jacks.

The second and third portions deal fully with one H.F. and one L.F. amplification stage respectively, and the fourth and fifth portions similarly. It is advised that the construction be proceeded with in this order.
Specification of Components (Rectification).—(1) Wooden containing box, the inside dimensions being 14 in. long by 10 in. high (including lid) by 4 in. wide. Lid 1 1/2 in. deep inside. Shelf 2 3/4 in. wide. All of 3/8-in. mahogany or other suitable wood, except the screw-on back, which may conveniently be made of 1/2-in. three-ply wood. (2) Five exactly similar filament rheostats. (3) Seven telephone jacks and three telephone plugs. (4) Four good terminals for battery connections. (5) Valve sockets. Ebonite strip 13 in. long by 2 1/4 in. wide by 3/8 in. thick and twenty brass Whitworth-thread cheese-headed screws, 1/4 in. in diameter by 1 in. long. (6) Grid condenser and leak. Tinfoil and mica, soft strip brass, say 1/2 in. thick, for condenser, and slate pencil and springy brass strip for leak. (7) One L.F. iron-core inter-valve transformer. This is to act as telephone transformer when using only one valve, but may be omitted at present if desired and the telephone receivers connected directly in the anode circuit. (This, however, will necessitate alterations to the wiring when adding the L.F. amplifying valve or valves later.) (8) Stabilising condenser. Tinfoil and mica, also soft brass strip. This condenser is required across the primary of the inter-valve transformer if fitted at this stage. (9) Reservoir condenser, 3 microfarad capacity. To be connected directly across the H.T. battery terminals. (10) One R-type valve and batteries. A 4-volt or 6-volt accumulator battery required for lighting valve filaments; 30 to 40 actual ampere-hours' capacity. Sixty-volt dry-cell battery required as H.T. or anode battery.
Fig. 66 is a diagram of connections of the complete amplifier, and as all the components are numbered in accordance with the foregoing specification, it will be an easy matter to identify each and the places occupied by them in the circuit. Items numbered from eleven
to twenty inclusive, covering the components required for stages two to five, are included in the above-mentioned diagram.

Careful examination of the diagram will show that the short-circuiting contacts of the second and third jacks are made use of in a special manner, whilst in the first, fourth, fifth and sixth jacks these contacts are not made use of at all, and are therefore omitted from the diagram. In the reactance jack the circuit is completed when the plug is withdrawn.

The small fixed condensers across the primary windings of the L.F. iron-core transformers are for the purpose of reducing the impedance of the windings, that is to say, they form a kind of by-pass for the rapidly pulsating currents in the several anode circuits and add to the efficiency and stability of the set. The reservoir condenser across the H.T. supply, as its name implies, acts as a kind of storage tank, being kept fully charged by the battery and supplying the rapid impulses of current to the anode circuits instantly on demand.

The construction of the various components will now be dealt with.

Box.—Figs. 67 and 68 show the constructional details of the containing box. The choice of wood is entirely a matter of individual taste; mahogany, teak or walnut are very suitable. The back is to be screwed on, and to this is hinged the lid of the box so that during the assembly of the apparatus the back and lid are removed together out of the way. Each pair of battery terminals should be screwed through
MAKING A FIVE-VALVE AMPLIFIER

a piece of \( \frac{1}{4} \)-in. ebonite (say 2 in. by 1 in.), and after drilling clear holes (say \( \frac{3}{4} \) in.) for the terminal screws to project inside the box, it should be screwed to the box front as shown. A small brass catch as a means of securing the lid when closed will be found a convenience. Seven holes for jacks are to be drilled through the box front as shown. For standard jacks \( \frac{3}{4} \) in. holes will be required, but in any case it will be better to measure the actual jacks to be fitted and drill holes accordingly.

Filament Rheostats.—For each filament rheostat, of which there are five, will be required one circular fibre disc, \( 2\frac{1}{2} \) in. in diameter by \( \frac{1}{2} \) in. thick, with a groove radius \( \frac{3}{8} \) in. and depth \( \frac{1}{6} \) in. turned round the periphery. Three yards of No. 21 S.W.G. "Chronic" or nickel-chrome resistance wire—total resistance
about 5 ohms. One brass Whitworth screw, cheese-head, \( \frac{1}{4} \) in. in diameter by 1\( \frac{3}{4} \) in. long (to form the spindle), and three washers to fit it. One piece of springy brass, say 2 in. long by \( \frac{1}{4} \) in. wide by \( \frac{1}{2} \) in. thick, for the contact arm. Two No. 4 B.A. cheese-headed brass screws \( \frac{1}{4} \) in. long for securing resistance wire in place in the groove. One ditto, but \( \frac{1}{2} \) in. long, to act as a stop for the contact arm. Two countersunk-head wood screws \( \frac{1}{2} \) in. long for securing the completed rheostat to the inner side of the box front. One turned or moulded ebonite knob, tapped \( \frac{1}{4} \) in. Whitworth thread.

When the rheostat is completed and fitted in place, the knob should be screwed home and pinned through the spindle to prevent it working loose.

It is advisable to make all five rheostats at once, therefore five times each of the above-mentioned quantities will be required. The method of assembly is as follows. First wind the resistance wire closely round a former such as a blacklead pencil (say \( \frac{5}{6} \) in. in diameter). When released the coil will spring a little and the diameter increase. In each fibre disc drill the centre hole for the spindle, also two holes for wood screws, and two in the groove about \( \frac{3}{4} \) in. apart to be tapped for No. 4 B.A. screws. Reference to Figs. 69 and 70 will make the construction quite clear.

Secure one end of the coil of resistance wire to one of these last-named screws, carefully stretch the wire round the disc (in the groove), and secure the opposite end to the second small screw, observing that adjacent turns of the resistance wire do not touch.
MAKING A FIVE-VALVE AMPLIFIER

The disc with resistance wire in place may now be secured in place on the inner side of the containing box, and the centre hole for the spindle drilled right through the box front.

Next make the rotating switch-arm, drill it and solder to the under side of the head of brass spindle and try in place, adding washers on the spindle and adjusting the shape of the contact arm until it presses evenly on the resistance wire. Rotate the spindle clockwise until the arm makes good contact on the end turn of wire, mark the position and drill for the ½ in. No. 4 B.A. screw to form a stop. This is the full-on position, and when the spindle is rotated in an anti-clockwise direction until the stop is again reached, the arm must be just clear of the wire at the opposite end, that is, in the off position.

When these adjustments have been satisfactorily completed the ebonite knobs may be screwed on, and unless a very tight fit, preferably pinned by drilling a small hole, say ⅛ in. in diameter, right through the
boss of the knob and spindle and gently driving in a short piece of $\frac{1}{16}$ in. diameter brass wire.

The positions to be occupied by the rheostats are shown in Fig. 67.

Jacks and Battery Terminals.—Drill, fit and secure in place the seven jacks and four battery terminals all as indicated in Fig. 67.

Valve Sockets.—Take the strip of $\frac{3}{8}$-in. ebonite and remove all polish with finest glasspaper. Mark off as shown in Fig. 71 and drill all the holes as shown in detail in Fig. 72. Lay the drilled strip on the wooden shelf in the containing box, in the position it will eventually occupy, and mark on the shelf the positions of all holes, including the holes for securing screws, and which should be well marked to ensure the ebonite fitting again into exactly the same place.
MAKING A FIVE-VALVE AMPLIFIER

In the shelf are to be drilled five large holes (say 1\(\frac{1}{4}\) in. in diameter) through which the valve sockets will project without touching the wood. These holes are each to accommodate the four sockets of any one valve, and are indicated by dotted lines in Fig. 71.

The twenty brass Whitworth screws are next to have the heads turned down, and to have a \(\frac{3}{8}\)-in. hole drilled right through the centre of each as shown in Fig. 73, and the corresponding holes in the ebonite strip having been carefully tapped through (\(\frac{3}{4}\) in. Whitworth thread), the brass sockets are to be screwed home in the ebonite. The application of a little thick shellac varnish to the threads before screwing in will prevent any tendency on the part of the sockets to work loose. The ebonite strip, complete with five valve-holders, may now be secured in place on the shelf, and the necessary battery terminals being already in place, the wiring-up of the complete set of filament circuits may be proceeded with as shown by the thick black lines in Fig. 66.

Before proceeding farther test these filament circuits by placing a valve in each holder in turn. Any adjustments which may be found necessary can then be made before further components are fitted into the box.

**Grid Condenser and Leak.**—For this component will be required four pieces of mica of good quality, each 1 in. square by \(0.005\) in. thick (or nearest); two pieces of mica, also 1 in. square but thicker, say \(0.01\) to \(0.02\) in. thick; four pieces of tinfoil, each 1 in. long by \(\frac{3}{8}\) in. wide; two pieces of soft brass or copper strip,
each 1 in. by $\frac{1}{2}$ in. by, say $\frac{1}{2}$ in. thick (or nearest); two pieces of thin springy brass or phosphor bronze, each 1 in. long by $\frac{1}{16}$ in. wide.

The condenser is first to be assembled as follows: To one side of each of the four thin pieces of mica a piece of tinfoil is to be attached by means of shellac varnish, leaving $\frac{1}{4}$ in. of foil projecting at one end as shown in Fig. 74. These are next to be assembled, observing that adjacent foils are separated by mica, and that foils 1 and 3 project at one end and foils 2 and 4 at the other. The two thicker pieces of mica are to be varnished on one side and placed one above and one below the condenser to strengthen it mechanically, and whilst the shellac varnish is still "tacky" the whole is to be laid on a flat surface and covered with a warm (but not hot) flat iron or similar metal weight.

The two pieces of soft brass should be cut and bent as shown by Fig. 75 to form clips with projecting lugs for screwing the condenser in place and for making connections to it. When the varnish in the condenser is properly set, fold over the projecting foils at opposite ends, place the brass clips in position over them and squeeze flat in a small vice or with a pair of pliers. The completed condenser is shown in Fig. 76.

The grid leak is to consist of a piece of ordinary slate or composition pencil, 1$\frac{1}{2}$ in. long by, say, $\frac{1}{16}$ in. in diameter, to which graphite pencil-lines may be added subsequently if found necessary on trial. Each piece of springy brass is to be bent and have holes
drilled, one to correspond with the securing hole in the lug of the condenser and one smaller (say \( \frac{1}{8} \) in.) to take the pointed end of the pencil leak. The complete condenser with leak-clips is to be mounted on the ebonite strip between the second and third valve sockets from the left, and the pencil with pointed ends sprung into place as shown in Fig. 77. Fitted in this position in the set, the leak is readily accessible should adjustment be required.

**L.F. Intervalve Transformers.**—Three intervalve transformers are required, and a simple type may be made, dispensing with specially-shaped iron core-pieces in accordance with the following particulars.

Core: \( \frac{3}{8} \) in. in diameter by 4½ in. long of soft
Swedish iron wires, say No. 30 or No. 32 S.W.G., carefully bundled together and tightly bound for 1 1/2 in. in the centre with silk tape and dipped in molten paraffin wax, subsequently being drained and hung up to set.

Foundation-tube: 1 1/2 in. long by 3/8 in. bore made by wrapping stout drawing-paper of correct width three or four times round the taped portion of the iron core, securing with shellac varnish applied during the wrapping process, and when set removing from the core.

Winder or coil former: This should consist of two brass discs, each 3/8 in. or 7/16 in. thick and 1 1/2 in. in diameter with separating bush of brass, 3/8 in. outside diameter by 1 1/2 in. long, the whole being secured on a 3/8-in. spindle by means of 7/32-in. brass nuts. The spindle is to be mounted in simple bearings, and is to have one end cranked to form a handle by means of which the complete former may be rotated. When assembling the former ready for the winding, two discs of drawing-paper, each 1 1/2 in. in diameter, are to be placed in position, one against the inner face of each brass disc, with the paper foundation-tube on the brass bush between them. This arrangement will be understood on referring to Fig. 78, and is very similar to that adopted when winding the secondary sections of a spark coil. It is possible in this connection to arrange to drive the winder from the flywheel of a sewing-machine, in which case the spool-winding attachment may be utilised to space the turns of wire as they go on the foundation-tube, but this is a matter for the ingenuity of individual readers.
MAKING A FIVE-VALVE AMPLIFIER

Primary winding: About twelve layers, approximately 2,500 turns, and occupying a depth of about \( \frac{1}{2} \) in. of No. 38 S.W.G. d.s.c. copper wire. Approximate weight of wire, 1\( \frac{1}{4} \) oz. insulation between windings, two layers of thin silk tape 1\( \frac{1}{2} \) in. wide, previously dipped in molten paraffin wax and pressed between blotting-paper.

Secondary winding: About 10,000 turns of No. 42 S.W.G. d.s.c. copper wire, to fill remaining space on former up to \( \frac{1}{2} \) in. of the edge of the brass discs. Approximate weight of wire 2 ozs. Outer insulation: Four layers of silk tape (waxed as before) or two layers of Empire cloth, the lap-joint being secured with a little Chatterton's Compound. A further alternative is to wrap carefully with ordinary sticky tape as used by electricians.

Avoid the use of shellac varnish in the body of the windings, but use it on the foundation-tube and first layer of the primary, on the first layer of the secondary, and fairly liberally throughout on the inner faces of the two paper discs and adjacent turns of wire, so that the papers will adhere to the windings when the latter are complete. Observe that the shellac does not get on the brass discs to any extent, or it may be found difficult to remove the completed windings. Probably a little vaseline smeared over the brass winder beforehand will prevent this happening.

When the winding and insulation are complete, the brass winder is to be carefully taken apart, and the windings removed and placed in position on the iron core. Then, having protected the leading-out
wires by means of insulating sleeving—preferably of different colours—and secured it in convenient positions by means of narrow tape, the two ends of the iron core are to be carefully spread out and bent back over the windings from opposite ends to meet in the centre, and the whole transformer neatly bound with common linen tape and preferably fitted into a small wooden box with ebonite lid and four terminals, to which the ends of the two windings should be suitably connected by soldering.

This latter arrangement will not only give adequate protection to the transformer, but will prove very convenient for mounting in place in the amplifier, whilst the small fixed condenser may either be fitted in the box or attached to the primary terminals outside, as preferred.

Stabilising Condenser.—To standardise as much as possible, this condenser may be similar to the grid condenser as regards the dimensions of foils and mica and method of construction; but in this instance the number of plates is to be increased to six, three each side. When completed this condenser is to be connected directly across the primary windings of the L.F. transformer.

Reservoir Condenser.—Very satisfactory condensers of large capacity—up to ½ microfarad and of conveniently small dimensions—are now on the market and obtainable for two or three shillings. One of these, say of 3 mfd. capacity, is recommended.

A servicable condenser, though of much smaller capacity, may be readily made in a similar manner to
MAKING A FIVE-VALVE AMPLIFIER

the grid condenser and stabilising condenser already described, except that the foils or plates of this condenser should be 2 in. long by $1\frac{1}{2}$ in. wide, and there should be at least twenty of them, ten each side. The mica sheets will, of course, have to be of increased dimensions to correspond, allowing a margin of, say, $\frac{3}{8}$ in. clear round the three sides of each foil. The best quality of mica should be used and should be approximately '005 in. thick.

The completed condenser should for convenience be mounted on a piece of ebonite, say $\frac{1}{2}$ in. or $\frac{3}{8}$ in. thick, by means of, say, No. 4 B.A. brass screws $\frac{1}{4}$ in. long which will also serve as terminals. Allow space, and drill holes for small brass wood screws by means of which the condenser may be secured in place in the amplifier. As previously mentioned, this condenser is to be connected directly across the H.T. battery, hence the necessity for good insulation throughout.

Valve and Batteries.—The purchase of one R-type valve, 4-volt or 6-volt accumulator and 60-volt H.T. or anode dry-cell battery, completes the first portion of the work, and the constructor is now in a position to assemble the various components, secure them in place in the containing box, and proceed with the wiring in accordance with the diagram (Fig. 66).

When this is completed the batteries should be connected to the proper terminals, the valve inserted in the middle socket, and having connected the several flexible leads (with plugs attached) to the tuner aerial and earth and reactance which it is proposed to use,
the three plugs are to be placed in the jacks exactly as shown in Fig. 64, and with the valve filament glowing at the correct brilliancy by proper adjustment of the rheostat, signals can be received on the one valve.

At this stage it will be a good plan to test carefully with regard to the best value of the grid leak, adding graphite to the slate pencil until the best results are obtained, and the "howling" of the valve prevented except with a very tight coupling of the reactance coil to A.T.I., and in general making sure that the best possible results are obtained with this one valve before proceeding to add further valves.

Having carefully tested the efficiency of the rectifying valve, it remains to add the two H.F. and two L.F. amplifying valves in order to complete the set. It is advised that the additions be made in the order in which they will now be described, and as each stage is completed, careful trial will show whether the work up to such point has been properly carried out.

As already mentioned, if the amplifier itself is completed, the purchase of only three valves will permit of several different arrangements being tried, such as a comparison of the respective merits of H.F. and L.F. amplification when used for strong or weak signals.

**Specification (continued). Amplification—Stage 2.**

—(11) One H.F. air-core intervalve transformer.  (12) One "R" type valve.

**Stage 3.**—(13) One L.F. iron-core intervalve transformer after the first L.F. valve.  (14) Stabilising
condenser. Tinfoil and mica, also soft brass strip, exactly as for (8). (15) One "R" type valve.

Stage 4.—(16) One H.F. air-core intervalve transformer. (17) One "R" type valve.

Stage 5.—(18) One L.F. iron-core telephone transformer. (19) Stabilising condenser. (Exactly as for 8 and 14.) (20) One "R" type valve.

**High-frequency Air-core Intervalve Transformer.**—For this the following materials will be required:

*Bobbin*: One piece of ebonite 1\(\frac{3}{4}\) in. in diameter by 2\(\frac{3}{8}\) in. long. *Connecting pins*: 16 No. 9 B.A. brass screws each \(\frac{3}{8}\) in. long. *Windings*: Approximately 2 oz. of No. 40 S.W.G. d.s.c. copper wire or, alternatively, 2\(\frac{1}{2}\) oz. of No. 38 S.W.G. d.s.c. wire may be used; but in this case the ebonite bobbin should be 2 in. in diameter. *Securing Brackets*: Two pieces of soft brass strip each 1\(\frac{1}{4}\) in. long by \(\frac{3}{8}\) in. wide and \(\frac{1}{16}\) in. thick and four No. 4 B.A. brass screws.

The ebonite bobbin is first to have a \(\frac{1}{2}\)-in. hole bored through the centre, and eight parallel grooves cut in it, each groove being \(\frac{3}{32}\) in. wide by \(\frac{1}{2}\) in. deep (\(\frac{5}{32}\) in. deep in the case of the 2-in. bobbin). The thickness of ebonite between adjacent grooves is to be \(\frac{5}{32}\) in. and about \(\frac{5}{8}\) in. at each end. Small holes are to be
carefully drilled and tapped, and the sixteen small brass screws (with heads cut off) are to be screwed in place as shown in Fig. 79, having first had their points dipped in shellac varnish to prevent any tendency of the screws to work loose later.

Bend and drill the soft brass strips to make the two securing brackets. The necessary holes for these should also be drilled in the ends of the bobbin and tapped for No. 4 B.A. screws; but the brackets themselves should not be fixed in place until after the winding is completed.

Before commencing to wind the transformer, carefully "tin" the projecting portion of each connecting-pin. The use of separate pairs of pins enables the winding in each groove to be tested for continuity, thus facilitating the locating and repairing of any fault which may occur.

For the actual winding operation, the ebonite bobbin requires to be mounted on a suitable spindle in simple bearings of some description, which may, for instance, be similar to those used for winding the L.F. iron-core transformer, although on account of the large number of turns to be wound it might be found a great advantage if some mechanical means can be found to rotate the bobbin at an increased-speed ratio, making use of a revolution-counter to indicate when the correct number of turns have been put on.

In each of the eight grooves are to be wound 400 turns of wire, the commencing and finishing ends of each section being temporarily wound round the respective connecting-pins as the winding proceeds.
MAKING A FIVE-VALVE AMPLIFIER

All sections are to be wound in the same direction, and particular care must be exercised when connecting sections in series to preserve this correct direction.

Sections 1, 3, 5 and 7 are to be connected in series to form the primary winding, and sections 2, 4, 6 and 8 similarly to form the secondary. The ends of each section are to be carefully freed of insulation and soldered to respective connecting-pins, and each section tested for continuity by means of a single dry-cell and telephone receiver, after which the sections may be connected together by short pieces of bare copper wire (say No. 26 S.W.G.) as shown in Fig. 79.

When these connections are all made the continuity of each complete winding and the insulation between windings should be tested with cell and telephone, as before, and if found correct the completed transformer may be fitted in the containing box.

Although the transformer as described will be found to give good results over a wide range of wave-lengths, it is well known that the best possible results on any one particular wave-length are obtained when a transformer is used which has been specially wound to suit such wave-length. Should any reader desire to make use of this fact to some extent, either switches or plugs and sockets may be provided, and leads taken from appropriate connecting-pins of the transformer so that the first two sections only are used as primary and secondary respectively for the shortest wave-lengths, while further sections are added in couples as the wave-length to which the receiving set is tuned is increased. This modification will doubtless yield
improved signals on the shorter wave-lengths, and as this presents no especial difficulty, the details are left to the ingenuity of individual readers who decide to adopt it.

If desired, the original scheme may be adhered to at first, and the suggested modification tried later, in which case the value of it would be known by comparison of strength of signals before and after the alteration.

It remains only to connect up the transformer in accordance with Fig. 66, to obtain a second "R" type valve, place in the correct valve-holder and move the tuner plug one jack to the left, which completes Stage 2.

Stage 3.—(13) One L.F. iron-core intervalve transformer. (14) One stabilising condenser. These are to be connected in every way similar to those described on page 128, and are to be fitted in place in the containing-box and connected up as per diagram of connections (Fig. 66). The addition of these items, together with a third "R"-type valve, enables one low-frequency stage of amplification to be put into use, the telephone plug being moved one jack to the right.

Stage 4.—This comprises (16) and (17), which are to be in every way similar to (11) and (12) respectively, and when duly connected up and required to be used, the tuner plug is to be moved into the jack on the extreme left.

Stage 5.—This comprises (18), (19) and (20), which are to be similar to (13), (14) and (15) respectively.
MAKING A FIVE-VALVE AMPLIFIER

When connected up and in use, the telephone plug is to occupy the jack on the extreme right.

With regard to the wiring-up of the various components as per Fig. 66, care should be taken to arrange all connecting wires systematically, to have them as short as possible and always well clear of adjacent wires. For this purpose No. 20 or No. 22 S.W.G. copper wire, tinned and covered with insulating sleev­ing as fitted in place, is strongly recommended.

It should be remembered that with three or more valves in operation, the set is extremely sensitive and quite small causes give rise to more or less powerful effects in the telephone receivers.

Badly fitting or dirty valve pins, faulty connections, loose or dirty terminals or stud contacts on tuner, loose telephone-lead connection to telephone receivers or defects in the telephone leads themselves, faulty H.T. batteries or connections thereto, are amongst the principal causes of loud crackling and clicking noises in the receivers, though similar sounds may be due to atmospherics.

If a loud howl is set up when H.F. valve or valves are added after receiving on one valve only, the reactive coupling should be promptly loosened. Should the howl not cease, even when the reactance plug is withdrawn, possibly a disconnection has occurred in the aerial-grid circuit of the tuner, or the resistance of the grid-leak is excessive and the addition of graphite pencil lines to the slate pencil already fitted is probably required. The effect of reducing the filament brilliancy of the valves should also be tried.
The addition of H.F. valves during the reception of any signal will probably be found to cause an appreciable alteration in the tuning, and a readjustment of A.T.I. or variable condenser will be necessary.

Fig. 80 illustrates the method of using the amplifier with a typical short-wave tuning arrangement,

![Diagram of amplifier setup](image)

Fig. 80.—Method of Using Amplifier with Typical Short-wave Tuner for Spark or C.W. Signals

and will, it is thought, be readily understood without further explanation.

If the foregoing instructions have been carefully followed and proper care taken with each portion of the work, the completed amplifier will be found to work well, giving very loud signals indeed with incoming signals of less than average strength, and affording a means of receiving from considerably increased distances.
CHAPTER XI

Wireless Telephony

Theoretically, any set of receiving apparatus as used for wireless telegraphic reception, and employing a crystal or valve detector, is equally suitable for the reception of wireless telephony, but until the inauguration of the British Broadcasting Service, which employs several radio-telephone transmitting stations, each with a fairly considerable power (namely, 1½-kilowatts), a

Fig. 81.—Typical Valve-set in Operation

137
receiving set fitted only with a crystal detector was of little practical use. Nowadays, however, there are scores of thousands of simple crystal receiving sets in use within a radius of, say, fifty to sixty miles of each of the various broadcasting stations.

With a view to giving the reader a general understanding of the essential principles involved, we will consider, briefly, the sequence of operations necessary to enable speech, music, etc., to be transmitted from one point to another without the aid of connecting wires as follows:

1. Sound waves in air produced by the speech, etc.
2. Electric current varied by the sound waves.
3. Electro-magnetic (or "wireless") waves controlled by the sound waves and radiated by a special form of wireless transmitter.
4. A wireless receiving apparatus, tuned to the same wave-length as the distant transmitter.
5. Detecting device and telephone receivers.
6. Movements of telephone diaphragms, caused by the received variations of current, resulting in the reproduction of the speech, etc.

In common with the commercial line telephone systems in everyday use, the microphone plays an important part in radio-telephony, but whereas in the former case the varying electric currents caused by the changing electrical resistance of the carbon granules under the action of impinging sound-waves are conducted by wires to the distant telephone receiver, in the latter case the microphone currents
WIRELESS TELEPHONY

must be applied to, and in some way control oscillatory high-frequency currents which cause the radiation of energy in the form of electro-magnetic waves from the aerial system of a wireless transmitting station, so that not the waves themselves but the microphonic variations only are detected and become apparent in the telephone receivers of the receiving station.

Present methods of attaining the desired object require that a wireless transmitter capable of radiating electro-magnetic waves of constant wave-length and amplitude be employed at the sending station, and that either the wave-length or amplitude (or both) of the emitted waves be varied at audible frequency by the current changes through a suitably-connected microphone.

The principal difficulties at the transmitting station consist in: (1) Satisfactorily maintaining the radiation of appreciable energy in waves of unchanging length and amplitude. (2) Efficiently varying or modulating this radiation at speech-frequencies.

Any type of continuous-wave transmitter may be adapted to fulfil the required conditions, but for small or moderate power, "C.W. valve sets" are being used in increasing numbers.

The microphone may be connected to the wireless set in a variety of ways, such as: (1) Directly in the earth lead. (2) In the grid-filament circuit of the oscillating valve, usually via a step-up iron-core transformer. (3) To a special control valve which in turn is connected either to the grid or main supply circuit of the oscillating or power valve.

J 139
A further practical difficulty lies in the present necessity for switching over from transmitting to receiving, and this point offers considerable scope for experimental work.

At the receiving station, in addition to the usual tuning inductances, etc., some form of quantitative detector is required. An ordinary crystal detector is of this type, but, as stated earlier, in order to obtain greater sensitiveness a three-electrode valve (with reactive coupling) is preferable.

If a valve is employed and provided with reactive coupling between anode and grid circuits, this coupling, if too tight, will cause the receiving set to oscillate, in which case the steady emission (or carrier-wave) from the distant transmitter will give rise to beats and a corresponding note in the telephone receivers. Under these conditions reception of speech is impossible except in the exact resonance or silent point, and even then there is much undesirable distortion of the received speech, etc. Further, the reception of the speech, etc., by adjacent receiving stations is interfered with as the radiated waves from the oscillating receiver form beats with the carrier-wave to which such adjacent stations will, of course, be tuned, and since the introduction of broadcasting, the use of self-oscillating receiving sets has been prohibited by the Post Office. Such circuits may be used, of course, but not on any account within the range of wave lengths on which the broadcasting takes place (300 to 500 metres).

A reactive coupling may be used, however, and
with good effect, but such coupling must not be made to the aerial circuit. Once the carrier-wave is heard and the note tuned down to silence point, the coupling should immediately be loosened until the receiving set is just short of oscillating. As this alteration of reactive coupling will incidentally cause some variation in tuning, a slight readjustment will be necessary.

For satisfactory reception of radio-telephony from low-powered stations at considerable distances, the addition of amplifying valves (either high- or low-frequency, or both) is advisable and usually necessary.

The inductance coils and variable condensers forming the tuned receiving circuits should be capable of very fine adjustment and should preferably have long insulated control handles to obviate the close approach of the operator's hand which, on account of added capacity, causes a variation in the tuning.

Another item (the skill and experience of the receiving operator) cannot be overestimated in importance, and involves a clear understanding of the principles underlying the action of the apparatus, a familiarity with the particular set of apparatus in question, with knowledge of tuning and other adjustments, and last but by no means least, a carefully cultivated habit of listening intently. It is sometimes surprising to find that signals are "there" and have probably been coming in for some little time, but only when absolute quietness is obtained and full attention given to listening are the signals heard. Then, once signals (speech, etc.) are actually heard, improvement is fairly easy as a rule.
CHAPTER XII

Arrangement and Erection of Aerials

Permission to experiment with wireless is granted subject to certain restrictions, and it is necessary to consider the subject of aerials from a practical point of view, having particular regard to the conditions laid down by the Postmaster-General.

The present Regulations regarding the dimensions of aerials for experimental wireless stations are as follows:

The combined length and height of the aerial must not exceed one hundred feet, irrespective of the number of wires employed. By length is meant the length of the horizontal or main span, and the height is to be reckoned as the vertical height of the highest part of the aerial measured from the leading-in point.

From this it will be seen that it is of little use to discuss ideal aerials of, say, two wires, each 150 ft. in length, for the simple reason that they are not permitted. Broadly speaking, permissible aerials fall into four classes, which will include the aerials (or proposed aerials) of the majority of readers.

The four classes of ordinary aerials are as follows: (1) A single-wire aerial having a short lead-in; (2) a single-wire aerial having a long lead-in; (3) a double-wire aerial having a long lead-in; and (4) a double-wire aerial having a short lead-in. All these are taken as...
ERECTION OF AERIALS

being either T or inverted L aerials. The umbrella-type aerial is but little used nowadays, scarcely ever by amateurs. In addition there are the indoor types of aerials which will be noticed later.

Now the "electrical length" of an aerial, which determines its fundamental or "natural" wave-length, is the distance from earth direct to the end of the aerial wire (see Fig. 82). It is clear that, for a given length of wire, the L aerial has the greater electrical length, and therefore the longer natural wave-length, so that at the outset the T aerial can be dismissed from the discussion, except in so much as to mention that it will certainly give some results should considerations of situation, space, etc., be such that only a T aerial can be erected satisfactorily.

In almost all cases it will be desired to receive wave-lengths in excess of the natural wave-length of the aerial. It would appear, therefore, that the longer the natural wave-length of the aerial to commence with, the less inductance will have to be added to tune in any particular wave. This must be qualified somewhat, as will be shown when discussing the effect of aerial capacity.

The calculations involved in finding the natural wave-lengths of an aerial are complicated, and the results obtained are often wrong. A sufficiently accurate result, for all practical purposes, can be arrived at by multiplying the electrical length of the aerial by a constant which normally varies between 3.5 and 4.5. For present purposes it will be satisfactory to take a value of 3.5 for a single-wire aerial, and 4 for a double-
wire aerial, if in the latter case the two wires are well spaced. So the natural wave-lengths of the two aerials A and B in Fig. 82 are respectively 340 ft. and 240 ft., or, in metres, 102 and 72. The general cases will now be taken in order.

Case 1. (Single-wire aerial with short lead-in.) This does not necessarily mean that the aerial itself is low. The horizontal component of the aerial may be 50 ft. high, but if the instruments are in an upper room, say 30 ft. above ground level, the lead-in will be comparatively short, namely, 20 ft.

Considering this case, and keeping in mind the maximum length of wire allowed, it will be supposed that the horizontal wire is 80 ft. long and the down-lead to instruments 20 ft. The natural wave-length of such an L aerial would be—(80 ft. + 20 ft. + length of earth lead, say 30 ft.) \times \text{constant } 3.5 = 455 \text{ ft.}, or 136.5 metres. This would certainly prove quite a serviceable aerial, provided a good "earth" is obtained and the resistance of the earth lead kept as low as possible. The disadvantage is the length of the earth lead. The arrangement is shown in Fig. 83.

Case 2. (Single-wire aerial with long lead-in.) The total length of wire being limited, as the lead-in is much longer, the horizontal component must be correspondingly reduced.

An average case might be as follows, in which it is supposed that the instrument room is on the ground floor: Height, 50 ft.; horizontal wire, 50 ft.; lead-in, 50 ft. In this case the length of the earth lead can be neglected. The natural wave-length of this aerial
ERECION OF AERIALS

would be 3.5 times \((50 + 50) = 350\) ft., or 105 metres. This is 31.5 metres less than that of the aerial in Case 1, but, on the other hand, this aerial has the advantage

that the whole of the electrical length is properly situated for absorbing the energy of incoming waves. Fig. 84 illustrates this arrangement.
Transferring the instruments to a room 15 ft. above ground level would allow of a further 15 ft. being added to the length of the horizontal wire. The natural wave-length would then be 3.5 \( (65 + 35 + 15) = 402.5 \text{ ft.} \), or 120.6 metres. Other variations of length and height will occur to the reader, and the natural wave-length can easily be estimated for each case.

Case 3. (Double-wire aerial with long lead-in.) Supposing a height of 40 ft. and a length of 50 ft. can be obtained, the arrangement as shown in Fig. 85 will give an aerial having a natural wave-length of 340 ft., or 102 metres.

Case 4. (Double-wire aerial with short lead-in.) This case is really only a variation of Case 3, unless the effect of transferring the instruments to an upper room is considered. The result of doing this can be ascertained by the reader if desired.

The next matter to be considered is the effect of varied aerial capacity. As is well known, the wave-length of any oscillatory circuit is dependent on the product of the inductance and capacity of that circuit. Therefore, in order to tune a circuit of small capacity up to a given wave-length, more inductance will have to be added than in the case of a circuit possessing a greater capacity. The capacity of an aerial depends on the number of wires and upon the height above the ground.

As a reasonable height is necessary in order that the aerial may be raised above surrounding earth-connected bodies (that is, buildings, etc.), which by absorption would deprive the aerial of energy, the practical
ERECTION OF AERIALS

means of increasing aerial capacity is by increasing the number of wires.

Now, adding wires in parallel, whilst increasing the capacity, has the effect of reducing the inductance of the aerial as a whole, so that, unless the wires are a considerable distance apart, the natural wave-length of the aerial will be only slightly increased. Increasing the value of the multiplying factor to 4 allows for this.

The principal advantage of an increased capacity is found when tuning to long wave-lengths, as less inductance has to be added than would otherwise be the case. At the same time, there is no advantage in having an aerial of very large capacity for reception. Firstly, the detector, being a "potential operated" device, requires the highest voltage obtainable from the incoming wave, the total energy in which is quite definite and very limited. Now the aerial acts as a condenser, and, with any given amount of electrical energy, a small condenser will be charged to a higher potential than a large one. Secondly, with large-capacity aerials, "static" effects are most pronounced and may be very troublesome. Lastly, the weight of a multiple-wire aerial demands very strong "fixings," and, due to the inevitable sagging of the wires, the effective height is somewhat reduced.

In general, it will be found that an aerial consisting of two wires, spaced from 4 ft. to 6 ft. apart, will prove the most serviceable for all-round experimental reception work. The down-lead from such an aerial should really consist of two wires spaced on a spreader,
and connected together just where they enter the instrument room, but a single wire may be used and will prove quite satisfactory.

The diagrams (Figs. 86 and 87) show typical arrangements of single-wire and double-wire aerials. In Fig. 86 the single-wire aerial has a natural wavelength of 120 metres (approx.), aerial capacity of 200 cms. (approx.), aerial inductance of 20 mics. (approx.), and inductance to be added to tune to 600 metres of 480 mics. (approx.). In Fig. 87 the two-wire aerial has a natural wave-length of 114 metres (approx.), aerial capacity of 290 cms. (approx.), aerial inductance of 12 mics. (approx.), and inductance to be added to tune to 600 metres of 330 mics. (approx.). The values of inductance and capacity given are only approximate, but quite near enough to enable a comparison to be made between the two arrangements.

It is impossible to lay down any hard-and-fast rules
ERECTION OF AERIALS

as the conditions under which aerials have to be erected for amateur stations vary so much, but a few simple experiments carried out along the lines herein indicated will quickly show which arrangement gives the best results in any particular case.

Care should be taken over the insulation of a small aerial as the total energy picked up does not leave much margin for leakage. There is no need, however, to employ massive insulators; quite small insulators of the "reel" pattern, coupled up in series of three or four, will be quite satisfactory.

The down-lead from the aerial should be kept as far as possible from the walls of buildings, etc. Insulated wire is not necessary. It may be an advantage in the case of a station on the sea coast where bare copper wire quickly corrodes.

Stranded or "braided" copper wire is the best for aerials, but single, hard-drawn copper or phosphor-bronze wire of, say, No. 16 s.w.g. will be found good enough for all purposes. Old telephone wires make a very satisfactory aerial and may often be obtained cheaply.

Indoor Aerials.—A carefully arranged indoor aerial, used in conjunction with sensitive receiving apparatus, will often give quite good results. Such results, however, do not as a rule compare with those obtained on the regulation outside aerial.

A roll of wire netting supported under the rafters makes a very suitable indoor aerial, or alternatively the usual two wires may be used. In either case the down-lead should be kept well away from the walls.
Frame Aerials.—Reception on frame aerials is quite out of the question when a crystal detector alone is used, as the received energy is insufficient to actuate such a detector efficiently.

The most efficient method of employing the frame aerial is to let the turns of wire wound upon the "frame" form the total inductance in the oscillatory circuit (exclusive of leads, of course), which circuit is completed by connecting a suitable variable condenser in parallel with the frame coil. The range of wavelengths obtainable under these conditions is in general somewhat restricted, and depends upon the capacity of the condenser (or condensers) available.

A usual arrangement consists of a variable condenser (maximum value, say, .001 mfd.) and a number of additional fixed condensers in multiples of this value which may be switched in parallel with the original variable condenser.

A convenient size for a "frame" aerial is 4 ft. square, and the woodwork may be in the form of a letter X with cross-pieces at the extremities of the arms to carry the wires, or in the form of a square.

Earths.—The simplest way of making the earth connection is to lead a wire to the nearest main water-pipe, and attach it thereto by soldering.
INDEX

AERIALS, capacity of, 146
—, down-leads for, 119
—, frame, 150
—, indoor, 149
—, length of, 142
—, outdoor, 142
—, wave length of, 143
—, wire for, 149
Alternator, 22
Amplification, 47
Amplifier, 109
—, connections of, 117
Amplitude defined, 2
Detectors, electrolytic, 35
—, Hertz, 7
—, hot-wire, 36
—, magnetic, 34
—, thermionic, 37
Direct coupling, 32
Down-leads for aerials, 119
Earth, 150
Electric waves, 3
Electrolytic detectors, 35
Filament rheostats, 102, 119
Frame aerials, 150
Frequency defined, 2
Generation of continuous oscillations, 49
Grid condenser, 101, 123
HERTZ detector, 7
—, oscillator, 5
Heterodyne, independent, 30, 53
—, reception, 29, 53, 108
—, self, 30, 53
High-frequency intervalve transformers, 131
Hot-wire detectors, 36
Independent heterodyne, 30, 53
Indoor aerials, 149
Inductance, 17
Inductance coil, 60, 75, 79
—, winding, 60
Inductive coupling, 32
Insulation testing, 92
Interference-beat reception, 29, 53, 108
Intervalve transformers, high-frequency, 131
—, low-frequency, 125
Jacks, 122
Leak, 123
Loose coupling, 18
Low-frequency intervalve transformers, 125
Magnetic detector, 34

Batteries, 129
Branly coherer, 33
Buzzer, 10, 89

Capacity of aerials, 146
Circuits, closed-oscillatory, 17
—, coupled, 18
—, open-oscillatory, 18
Coherer, Branly, 33
—, wheel, 34
Condenser, 23
—, formula, 24
—, grid, 101, 123
—, reservoir, 103, 128
—, stabilising, 128
—, telephone, 86
—, tubular, 82
Connections of amplifier, 117
—, short-wave receiving set, 91
—, valve, 107
Continuous oscillations, generation of, 49
—, waves, 26, 108
—, production of, 27
—, reception of, 28, 108
Coupled circuits, 18
Coupling, direct, 32
—, inductive, 32
—, loose, 18
—, tight, 18
Crystal detector, 36, 57, 86

Damped-wave signals, 46
Damping, 77
Detectors, 7, 31, 34, 35, 36, 37, 57
86
—, crystal, 36, 67, 86
INDEX

Operation, method of, 65, 93, 106, 135
Oscillator, Hertz, 5
Oscillatory circuits, 16, 17, 18
— — closed circuits, 17
— — open circuits, 18

Panel switch, 56, 71
— — valve, 96, 106
Potentiometer, 88
Primary testing, 92
Push button, 59

Reactive coupling, 140
Receivers, action of, 25
— — telephone, 38, 65
Receiving apparatus, practical, 24
— — simple, 10
— — set, short-wave, 68
— — single-circuit, 56
Reception, continuous-wave, 28
— — heterodyne, 29, 53, 108
— — interference beat, 29, 53, 108
Reservoir condenser, 103, 128
Resonance, 16
Rheostat, filament, 102, 119

Secondary testing, 93
Self-heterodyne, 30, 53
Short-circuits, testing for, 93
Short-wave receiving set, 68
— — — — connections, 91
Single-circuit receiving set, 68
Stabilising condenser, 128
Switch panel, 56, 71
Switches, tuning, 59, 76

Telephone condenser, 86
— — receivers, 65
Telephony, wireless, 137
— — reception, wireless, 141
— — sequence of operations for wireless, 138
— — wireless, transmissions, 139
Testing, 92
— — insulation, 92
— — primary, 92
— — secondary, 93
— — for short-circuits, 93
Thermionic detectors, 37
— — valves, (Sea Valves)
Tight coupling, 18
Transformers, 22, 125, 131
— — high-frequency, 131
— — low-frequency, 125
Transmitting apparatus, practical, 21
— — simple, 9
Tuning, 16
— — switches, 59, 76

Valves, 37, 40, 42, 44, 129
— — action of, 37, 40
— — applications of, 45
— — classification of, 44
— — connections for, 107
— — simple, 42
— — sockets for, 122
— — three-electrode, 44
— — two-electrode, 42

Wave length defined, 2
— — of aerials, 143
Waves, electric, 3
— — production of, 4
Wheel coherer, 34
Wire for aerials, 149

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