RADIO
ENGINEERING

A COMPLETE GUIDE FOR ALL
CONCERNED WITH RADIO MAINTENANCE
PRODUCTION AND DEVELOPMENT

EDITED BY

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" ELECTRICAL TRADING AND RADIO MARKETING "

FOREWORD

THIS is a book written for all those who wish to learn about Radio. Dealing with receiver repairing and manufacture, radio in aircraft and ships, sound amplification, battery charging, electronics, television, interference suppression—as well as those fundamental principles without a knowledge of which skilled work is impossible—the book covers a wider scope than any other single volume. The treatment is practical and visual, and the text has been written by a panel of authors who combine expert knowledge of their special subjects with the ability to provide simple yet accurate explanations.

The illustrations and diagrams, numbering more than 600 in all, interpret the text in a detailed way, and form in themselves an illustrated guide to the study of Radio.

To those who are not actually engaged in Radio work, but who are none the less keenly interested, this book will also have a wide appeal. In it the listener will find explanations of how his receiver works and how it is made; how he can do simple repairs; what short-waves are and why they are so useful; what television will be like; and through it he will gain a fascinating insight into some of the less-known uses of Radio technique.

The vital part played by Radio in modern life has opened up many opportunities in the way of a career and employment. In addition to the scientific side offering fascinating and remunerative work, very large scope for employment is available in the repair and manufacture of domestic receivers and in the installation, maintenance and operation of apparatus used in aircraft, ships and a hundred-and-one commercial and industrial applications.

Advances in relays, television, ultra-short waves and electronics, may before long revolutionise Radio's service to the public and to industry, and increase very greatly the potentialities of Radio Engineering as a progressive and important career.

Those who are in the Services, in which Radio now plays such an important part, will find that this book presents much valuable information bearing on their particular problems.

With such a technical subject the reader may occasionally come across terms not sufficiently explained in the immediate context. In this event full use should be made of the Index, which will disclose further guidance in other chapters.

Finally we would thank our collaborators and all those who have so readily assisted by the provision of information and valuable help in connection with the illustrations.

R. C. N.

CONTENTS

AN IMPORTANT STAGE IN RADIO-RECEIVER PRODUCTION

Skilled engineers are here seen applying tests and making various adjustments to completed receivers. Exhaustive tests are carried out at every stage of production prior to the assembly of the sets. Note the protective chassis-cradles and the overhead conveyer. (See Chapter 16: "Production Methods.")

WHAT IS RADIO?

LIGHT- AND HEAT-WAVES. MAGNETIC FIELDS. ELECTRONS. PROTONS. ETHER
WAVES. FREQUENCY SPECTRUM. INFRA-RED RAYS. ELECTRIC CURRENTS.
OSCILLATORY CIRCUIT. CONDENSERS. INDUCTANCE. AERIALS. WAVELENGTHS.
ATMOSPHERICS. DETECTORS. AUDIBLE FREQUENCIES. MODULATION.

RADIO communication is auto-matically associated with the name of Marconi, the Italian inventor who first harnessed the mechanism of ether waves and demonstrated how such waves could be generated and used for communication at a distance without the use of any connecting wires.

This possibility was foretold many years earlier by a British mathematician, Clerk Maxwell, as a result of his analysis of light- and heat-waves. These he showed to be what he called an electro-magnetic wave, and he pointed out that there must theoretically be a whole range of such waves, of which light- and heat-waves were only one very small portion.

Wave Disturbance

Before proceeding farther it will be as well to consider what a wave is. If we drop a stone into a pond, the water will be disturbed at the point where the stone enters. This disturbance, however, is not confined to this one point. A series of waves will be produced, travelling outwards in concentric circles (Fig. 1) until the edge of the pond is reached. A water-spider residing at the edge of the pond would be affected by the wave reaching it, though it was far from the origin of the disturbance and might, indeed, be quite unaware of the cause of the upheaval.

Oscillatory Action

If we examine this wave more closely, we find that it arises because the water at the point where the stone entered the pond is forced upwards to make way for the stone. This portion of water which has been forced above its normal height tries to regain its original level by pushing out the water immediately surrounding it, so that an ever-widening circle of disturbance is produced as the various particles of water displace their neighbours in an endeavour to regain their equilibrium.

Usually the first upward displacement of the water by the stone is followed by downward displacements as the water closes over the stone, so that a sort of oscillatory action is produced, which usually lasts for several complete cycles of alternate rise and fall. Each one of these generates its own wave, so that we have a regular series of waves following one another at intervals.

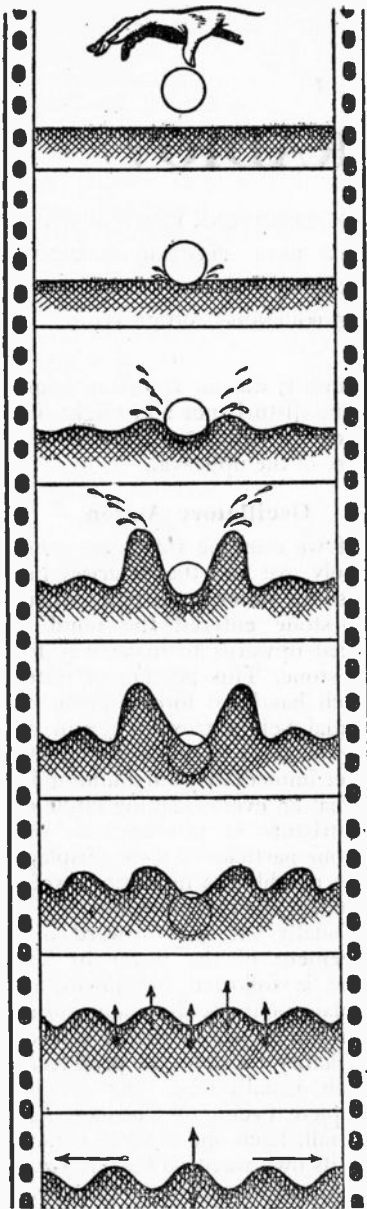If we consider the motion of a small particle of wood resting on

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Fig. 1. When a stone is dropped into a pond the wave travels outwards but the water only moves up and down.

the face of the pond, it will be clear that this particle will be forced up when the first wave arrives and it will then fall in the trough which follows, so that it will be maintained in a state of oscillation upwards and downwards as long as the waves continue to pass by. In this analogy we have a complete picture of what happens in the course of radio transmission.

Pressure Variations

In talking of radio and sound waves we do not refer to anything actually resembling waves such as occur on the pond, but to the wave-like sequence of pressure variations. Fig. 2 illustrates this by showing that if we record the pressure variations caused by waves in a tank during a certain interval of time, we get a wave diagram. The diagram, however, is a record of *pressures*, and not a portrait of the actual waves.

Sound waves are wave-like variations of pressure in the medium of air (Fig. 3). They are energy in transit, and the air itself does not move. Ether waves of light, heat and radio do not require any physical medium, but travel through even a vacuum (Fig. 4).

Although both light and radio are waves in space (or "ether", which is the same thing) our senses react to the former (Fig. 5) but not the latter. As we shall see later, it depends on the frequency with which the waves are produced. We have to devise our own methods for the generation and reception of radio waves.

In radio, then, what corresponds to the dropping of the stone into the water? In other words, what generates the wave in the first place?
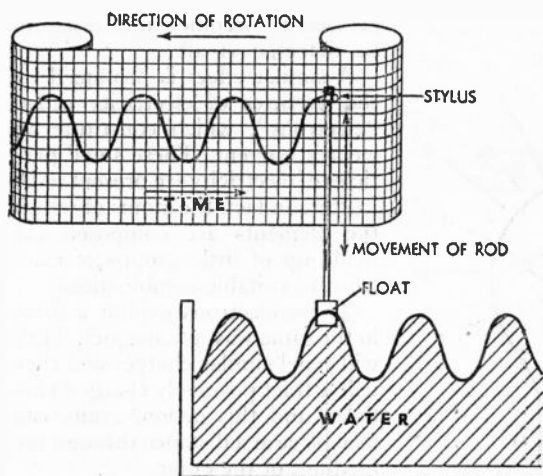
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Fig. 2. A wave in a diagram represents how a pressure, voltage or current varies during time. This diagram illustrates the principle (it is not a practical arrangement) and shows how an up-and-down movement gives a wave graph, the horizontal direction representing time.

It is, however, possible to detect the magnetism at much greater distances, one simple experiment being to use a magnetic compass, which is a small magnetised steel needle pivoted in the centre so that it is free to turn. If we bring a bar magnet within a few feet of this needle, as shown in Fig. 6, the needle will swing round on its pivot because of the invisible magnetic force exerted by the magnet.

It is said, indeed, that there are "lines of force" radiating from the magnet, and that all these lines of force surrounding the magnet produce what is called a magnetic field (Fig. 7).

One of the properties of this ether is that it can transmit electric and magnetic forces at a distance. One of the most common examples of this is the ordinary magnet, which will attract pieces of iron some distance away. If the magnet is powerful and the distance is only small, the attraction will be so strong that the iron will jump through the intervening space and attach itself to the magnet.

Close to the magnet there are many lines of force in a given space, so that we say that the field is strong, which means that the attraction produced is powerful, whereas as we get farther away the field gets weaker and weaker, until
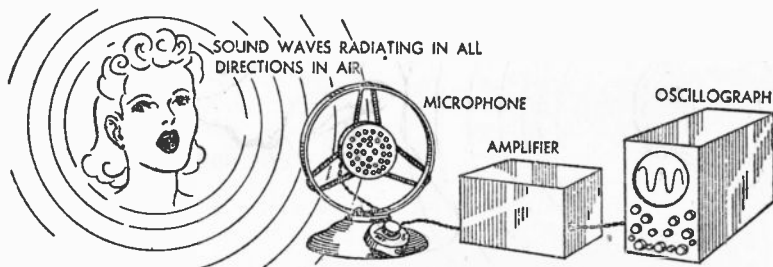

Fig. 3. Sound waves are energy travelling through the medium of air. When they strike a microphone they set up electric currents, which can be shown, by the kind of apparatus illustrated, to vary their strength in wave fashion.
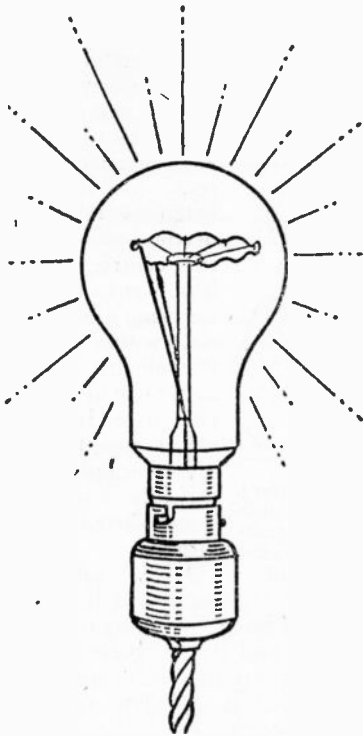
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Fig. 4. Radio and light waves travel through the ether, or space, and do not require the medium of air, as is proved by the ordinary electric lamp.

at last it becomes too small to be detected at all.

A similar effect is produced by the particles of electricity called "electrons", which constitute an electric current. These small particles of electricity are present in all matter. In fact, the atoms of which the elements are composed are made up of little groups of electrons in suitable combinations.

These electrons exhibit a force in the same way as a magnet. They will repel similar charges and they will attract positively charged particles, and this action, again, can take place at a distance through the medium of the ether.

Here also we assume that the electron is surrounded by lines of force which radiate from it in all directions, as shown in Fig. 8, and, as in the case of a magnet, the strength of the action falls away quite rapidly until it is negligible.

Normally the various electrons in the atoms are grouped around positively charged particles called "protons" in such a way as to maintain equilibrium, but under certain conditions we can disturb this balance and arrange for an
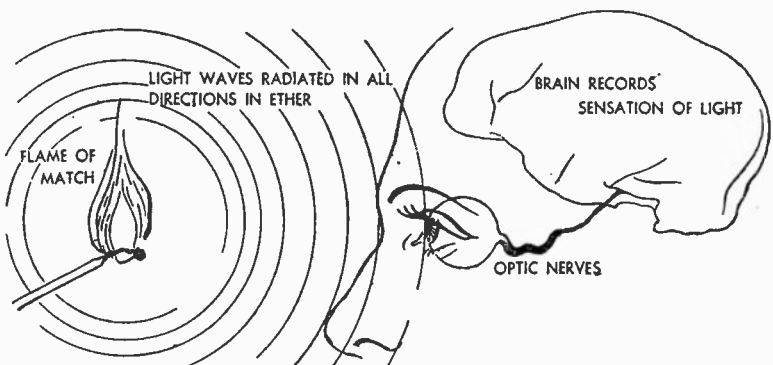

Fig. 5. The simple act of striking a match sets up ether waves which are similar to radio waves except for their frequency. We have no natural sense, however, corresponding to sight, for the "reception" of radio waves.

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ORIGINAL POSITION
OF COMPASS NEEDLE

NEEDLE DEFLECTED BY
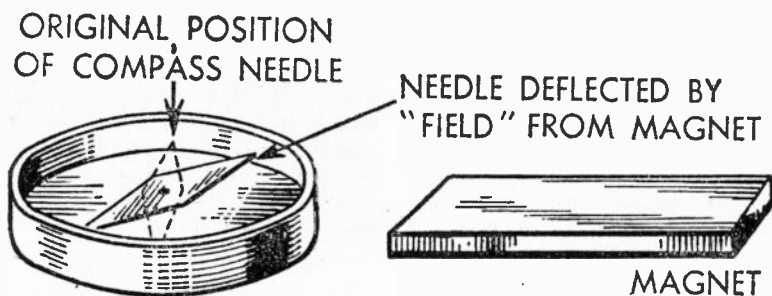"FIELD" FROM MAGNET

MAGNET

Fig. 6. A compass needle is moved when a magnet is brought near it. The force necessary to move the compass needle acts through space, and the region in which this force is effective is known as a "magnetic field".

accumulation of negative electrons in certain portions of a material, in which case it is said to be charged with electricity.

Some materials, known as "insulators", will only permit this partial displacement of the electrons, but other materials, principally metals such as copper, aluminium, and the like, are so constructed that the electrons can leave their original atoms and travel through the material. Electrons in motion in this manner constitute an electric current, and the more electrons we set in motion the larger is the current.

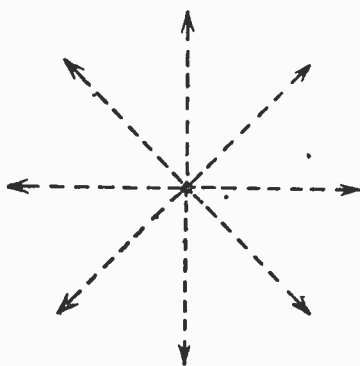Now, with this brief outline in mind, we can obtain a picture of the generation of an ether wave or

Fig. 8. The electron, the smallest possible charge of negative electricity, possesses an electric field (not to be confused with magnetic) and has electric lines of force radiating into space.

electro-magnetic wave. Each of the electrons in a wire carrying a current will produce an electric field, and it can in fact be regarded as carrying with it a radiating system of lines of force as shown in Fig. 8.

Suppose we consider just one of these lines. As long as the electron moves fairly slowly the line of force can move with it without difficulty, but if the electron begins to move at all rapidly, the lines of force are unable to keep up with it.
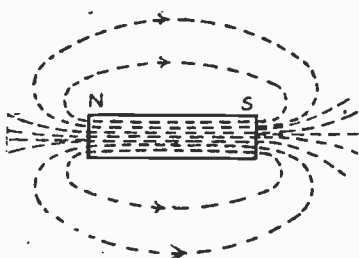
A very simple analogy will serve

Fig. 7. The field round a magnet is said to consist of "lines of force". These lines indicate the direction of the "pull" of the field and its strength.

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to illustrate this point. Suppose we take a rope and fix the far end to a suitable post, as shown in Fig. 9. We now take the free end in the hand and move the hand slowly up and down. The whole rope will follow the movement, although the actual movement will become less and less, until at the far end it is

down the rope with almost undiminished intensity. When the hand is moved slowly there is practically no movement at the far end of the rope. When it is moved quickly, however, the ripple travels down the rope, and at the far end there is then quite a large amount of movement.

Radio Transmission

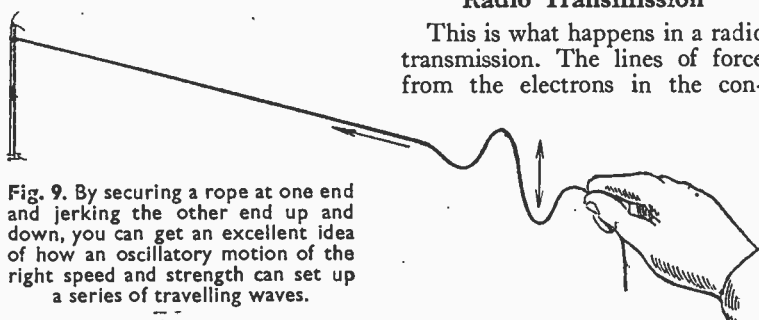This is what happens in a radio transmission. The lines of force from the electrons in the con-

Fig. 9. By securing a rope at one end and jerking the other end up and down, you can get an excellent idea of how an oscillatory motion of the right speed and strength can set up a series of travelling waves.

negligible. This corresponds to the case of a slowly moving electron.

Now rapidly move the hand up and down. The weight or inertia of the rope will prevent it from moving as a whole, and what will happen will be that only the portion of rope nearest to the hand will move.

Transmitting Movement

This movement, however, will be transmitted to the next bit of rope, and in turn to the next bit, thus producing a ripple or wave which will travel down the whole rope.

The reader would be well advised to try this experiment for himself, because it is illuminating. The wave or ripple is only produced when the hand is moved quickly, and the intensity of the wave is again dependent upon the speed with which the hand moves. The more rapid the jerk the stronger is the ripple produced.

Perhaps the most interesting feature is that the wave travels

ductor carrying the current spread out into the surrounding space, but their effect is negligible quite a short distance away.

If the electrons are set in motion, however, and caused to oscillate backwards and forwards with sufficient rapidity, then we obtain this ripple or kink in the lines of force, which travels outwards in all directions just like the waves produced by the stone which is dropped into the pond.

Producing Light Waves

Having obtained a simple idea of what an electro-magnetic wave is, our next consideration is how we can produce such waves. One of the simplest methods, as we have seen in Fig. 5, is to strike a match. The heat generated will be sufficiently intense to produce light waves which travel from the match to our eye, and we shall say that the match is alight.

This is such a common pheno-

menon that we entirely forget that the intelligence is communicated from the match to our eye over an appreciable distance; and actually all our sight and vision are accomplished by means of light waves which are electro-magnetic waves of extremely high frequency.

Wave Frequency

The frequency of a wave is the measure of its rapidity of oscillation. If the electrons carrying the lines of force move up and down a million times per second, we say that the frequency of the oscillation is a million cycles per second, the term cycle being used to denote one complete oscillation backwards and forwards.

In the case of light waves the oscillations of the electrons are extremely rapid and extremely small. The electrons, indeed, do not leave their atoms, but are simply set in a state of agitation (produced in the case of a match by the chemical interaction resulting from the striking of the match on the side of the box and subsequently by the burning of the match-head). The frequency of light waves varies according to the colour of the light, and white light is a mixture of a large number of oscillations covering the whole frequency spectrum.

The general order of frequency involved is 400–800 billion vibrations per second (using the English billion, here, meaning one million million). It is a little difficult to appreciate this enormous rate of vibration, though it by no means represents the limit, for we have evidence of electro-magnetic waves generated by oscillations of a frequency at least one million times faster than light waves.

However, our present concern is with the form of electro-mag-

netic wave used for radio communication, and it is obvious that a light wave is not suitable for this purpose, mainly because it is very quickly dissipated or absorbed by the atmosphere and it is stopped almost completely by any obstacles in its path.

Actually, if we reduce the frequency of the oscillation, we find that the penetrating power begins to increase. The light becomes more and more red in character, until finally it ceases to be visible as light at all, and we are only aware of the presence of the wave due to the sensation of heat.

Heat waves lie in what is called the infra-red region, and the reader will be aware that heat waves will penetrate apparently solid obstacles where light will not. There is also the case of infra-red photographs taken by special cameras with special plates sensitive to these invisible infra-red rays, which are capable of penetrating misty and even foggy atmosphere, in which ordinary light waves are quite cut off.

Clerk Maxwell's Theories

The calculations of Clerk Maxwell and others seemed to indicate that if only waves could be produced having very considerably lower frequency, they ought to possess quite remarkable penetrating powers, enabling them to be sent over distances far greater than would be possible with light or infra-red waves. It was necessary not to reduce the frequency too much, for, as we have seen, the effect of an electro-magnetic wave is only created when a reasonably rapid oscillation is produced (compare the effect of a slow movement of the end of the rope in the earlier analogy, as against

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the effect of a rapid jerk); but it seemed that somewhere within these two extremes there should be a series of waves awaiting the results of discovery.

Since those days we have explored and found uses for a tremendously wide spectrum of ether-waves as shown in Fig. 10.

For radio, since the waves are set up in the first place by the movement of electrical particles or electrons, it is clear that we must find a method of causing electrons to move backwards and forwards with the required degree of vibrational rapidity.

In the case of the match the electrons within the atoms themselves vibrate sufficiently to produce the waves, but as we reduce the frequency we find that in order to obtain the necessary radiation the movement of the electrons has to increase, and calculation again shows that if we are to find this mysterious hidden range of waves we shall have to cause electrons to move backwards and forwards over distances of many yards.

Electric Currents

Now, when we have electrons in motion and travelling from one point to another in this fashion, we say that an electric current is flowing, and our problem therefore resolves itself into finding a means of producing a very rapidly oscillating current in a length of wire suitable for the purpose.

It was not long before scientists found the way of producing such a current by using what is, in effect, an electrical pendulum. The reader will be familiar with the ordinary pendulum, which is, in essence, a weight or "bob" suspended from the end of a cord or other suitable support. If we draw the bob to one side and then let it go, it will swing to and fro, and the reason for the swinging is worth analysis.

When we release the weight it falls towards the ground under the influence of gravity. It cannot fall far because of the cord to which it is attached, but it will move towards the lowest position possible, which is at B (Fig. 11). When it has reached this point, however, it has acquired a certain amount of momentum, which carries it past the bottom of the swing and causes it to overshoot to the point C.

All the time it is travelling from B to C the bob is actually being lifted, because it is still attached to the end of the cord, and it will continue to swing upwards until the momentum which it has acquired in its downward swing has been entirely used up.

Having reached the point C, it will come to rest, and will then begin to swing back in the other direction, and the whole process will be repeated. One can, indeed, imagine the bob in a condition of complete bewilderment, for it tries to reach the bottom of its swing, and, having triumphantly succeeded, it finds that it cannot stop, and is forced to carry on against its will. And so it goes on swinging backwards and forwards, and were it not for the fact that air friction uses up a small amount of energy at each swing, the pendulum would continue to swing indefinitely. In practice, the loss of energy due to friction causes each swing to be slightly less than the preceding one, so that ultimately the bob comes to rest completely.

Now, the frequency at which the pendulum will swing depends upon the length of the cord, as the reader may verify for himself. With a short cord the rate of swing

FREQUENCY (M = 1,000,000)
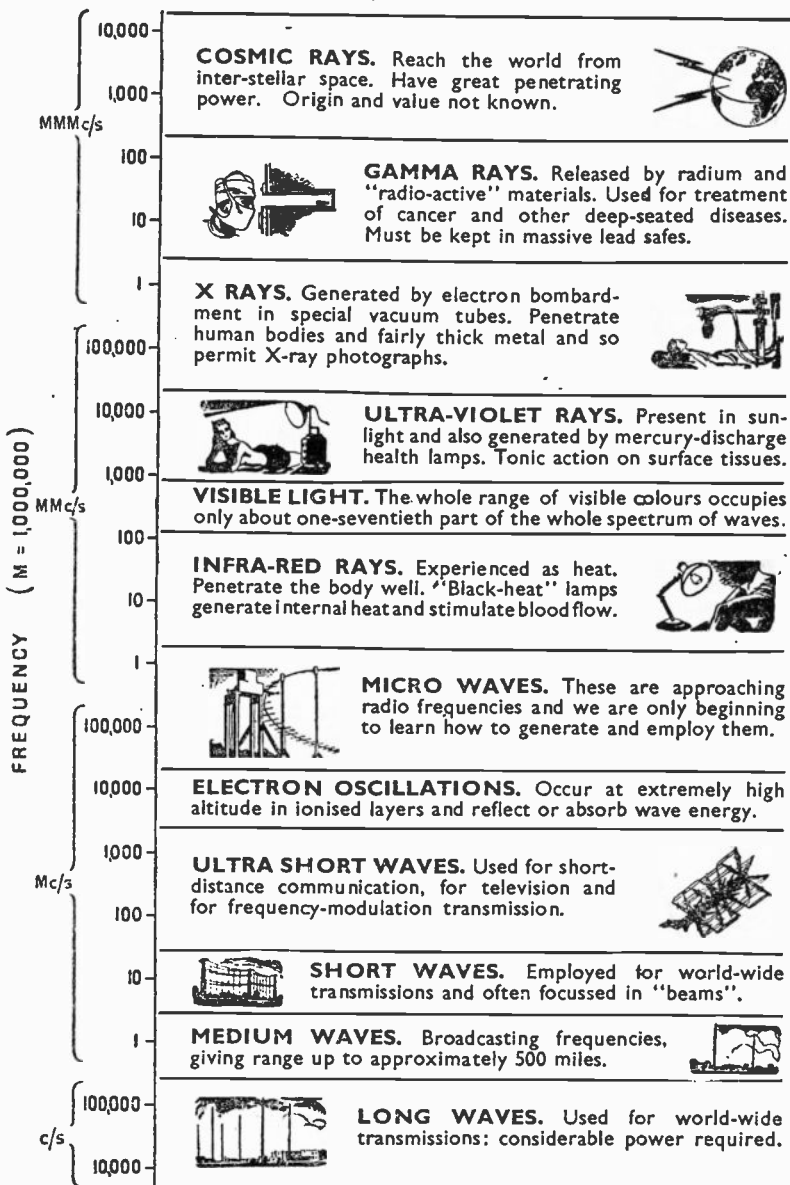
COSMIC RAYS. Reach the world from inter-stellar space. Have great penetrating power. Origin and value not known.

GAMMA RAYS. Released by radium and "radio-active" materials. Used for treatment of cancer and other deep-seated diseases. Must be kept in massive lead safes.

X RAYS. Generated by electron bombardment in special vacuum tubes. Penetrate human bodies and fairly thick metal and so permit X-ray photographs.

ULTRA-VIOLET RAYS. Present in sunlight and also generated by mercury-discharge health lamps. Tonic action on surface tissues.

VISIBLE LIGHT. The whole range of visible colours occupies only about one-seventieth part of the whole spectrum of waves.

INFRA-RED RAYS. Experienced as heat. Penetrate the body well. "Black-heat" lamps generate internal heat and stimulate blood flow.

MICRO WAVES. These are approaching radio frequencies and we are only beginning to learn how to generate and employ them.

ELECTRON OSCILLATIONS. Occur at extremely high altitude in ionised layers and reflect or absorb wave energy.

ULTRA SHORT WAVES. Used for short-distance communication, for television and for frequency-modulation transmission.

SHORT WAVES. Employed for world-wide transmissions and often focussed in "beams".

MEDIUM WAVES. Broadcasting frequencies, giving range up to approximately 500 miles.

LONG WAVES. Used for world-wide transmissions: considerable power required.

Fig. 10. Electro-magnetic waves have many uses, depending on their frequencies, which are shown approximately in this scale. The term "rays", applied to the radiations between cosmic and infra-red, is synonymous with "waves".

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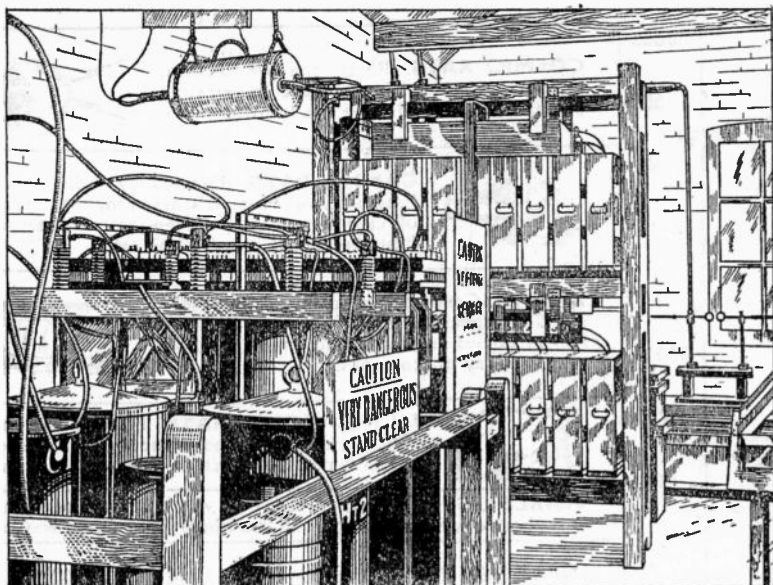
This historic picture shows some of the apparatus at Marconi's Poldhu transmitter from which the first signal to span the Atlantic was radiated on December 12, 1901. On the left are transformers, in the centre are banks of condensers, and on the right the spark-gap can be seen.

is more rapid than with a long one, and there is a simple relationship between the length of the cord and the time of swing. The pendulum, in fact, is a mechanical oscillator of which the frequency is controlled by altering the length of the cord (Fig. 12).

What we require is an electrical circuit which will behave in a
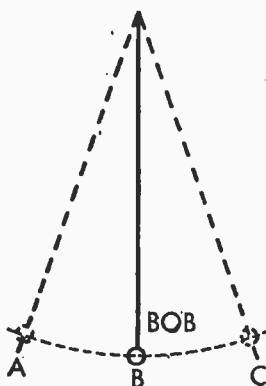
Fig. II. A simple pendulum is a mechanical oscillating system. For explanation see page 12.
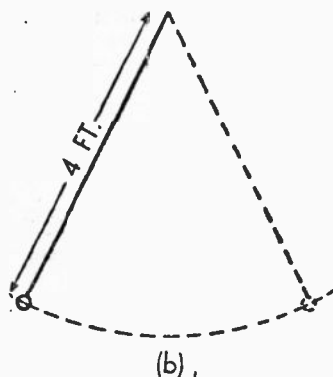
Fig. 12. With a pendulum the speed of oscillation is determined by the length of the cord. Pendulum (a) will swing twice as fast as (b).
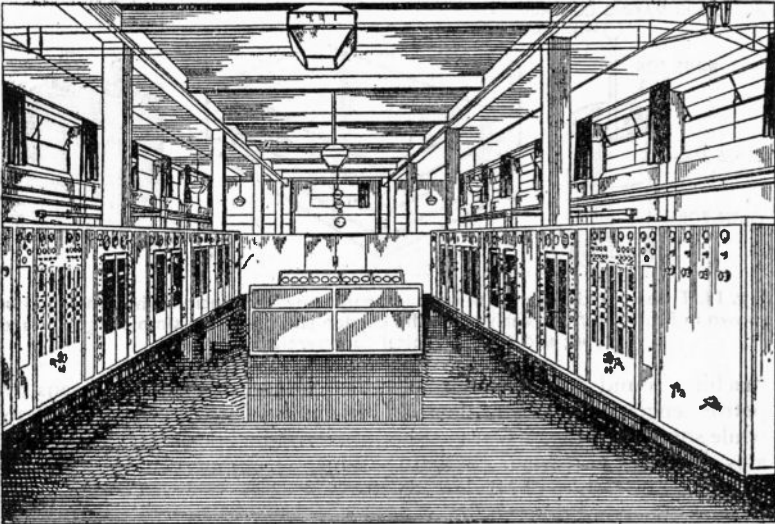
And this is one of the latest Marconi transmitters—radiating high-quality speech on two wavelengths, with a power of 100 kilowatts for each. The equipment has automatic protection and includes meters which show any slight variation.

similar manner to the mechanical arrangement just described, and this can be contrived by using a coil of wire (called an inductance) in conjunction with a device for storing electrical energy, known as a condenser. In order to understand this electrical circuit, we must first consider these two component parts in considerably greater detail.

In its simplest form, the condenser consists of two parallel metal plates separated by some insulator such as air, oil, mica, glass or other suitable material (Figs. 13 and 14). If we connect a battery across these two plates, the electromotive force (or voltage) of the battery at once begins an endeav-

our to set the electrons in the circuit in motion.

Throughout electrical engineering we are continually encountering these electro-motive forces (or EMFs, for short). They are forces which try to cause the electrons in a circuit to move and may be generated by various means.

In the case of a battery it is the chemical action, which produces the force. With a dynamo the EMF is generated by driving the
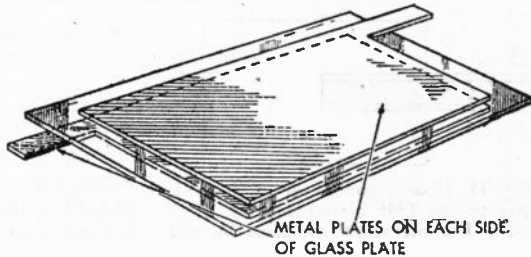
Fig. 13. In its simplest form an electrical condenser consists of two metal plates (conductors) separated by a non-conductor (dielectric) such as a sheet of glass.
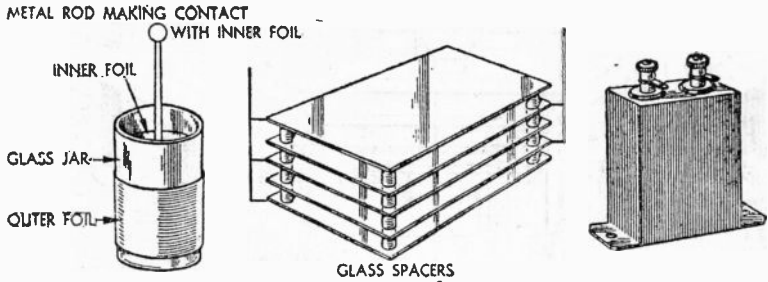
Fig. 14. Three practical forms of condenser utilising, in principle, the construction shown in Fig. 13. *Left,* an early type, the Leyden jar; *centre,* a simple high-voltage type; and *right,* a typical commercial condenser.

machine round with a steam or petrol engine or other device, while sometimes the circuit generates its own EMF. Such cases are always the result of trying to change the conditions when the circuit seeks to oppose the change, as we shall see shortly.

Now, with our condenser we have seen that the two plates are insulated from one another so that there cannot be any continuous flow of electrons, but under the influence of the battery there will be a movement or displacement of the electrons which will result in a momentary current, caused by electrons being moved out of one plate through the battery on to the other plate, where they will remain as long as the battery is there to maintain the force (Fig. 15).

Suppose now that we remove
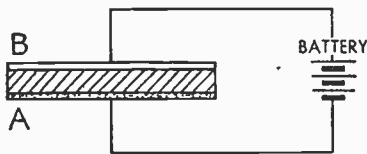
Fig. 15. How a condenser is charged. Due to the EMF of the battery, electrons are attracted to plate *A* and expelled from plate *B*. A charging current flows until the "back EMF" of the charge in the condenser becomes equal to the battery EMF.

the battery. There is no means by which the electrons can get back to their original position, so that they remain accumulated on one plate,
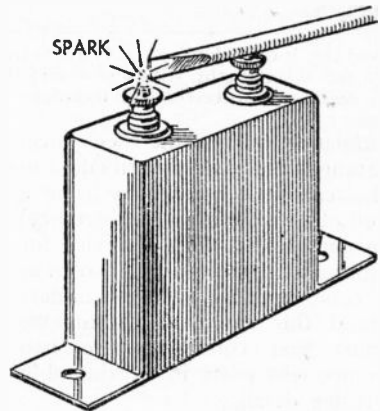

Fig. 16. The way a condenser holds electricity can be shown by first charging it from an HT battery, waiting a minute or so and then shorting the terminals by means of a screw-driver. A spark will be produced by the discharge.

and we say that the condenser is charged. If the insulation between the plates is perfect, the condenser will remain charged in this way, and it is quite interesting to obtain a condenser of say 2 mfd. and connect an HT battery of about 100 v. across it.

On removing the battery the

charge in the condenser can be demonstrated by short-circuiting its connections with a screw-driver, when there will be a visible spark (Fig. 16). The interesting thing is that if the condenser is a good one it can be charged with a battery and then put on one side for some minutes. The application of a discharge circuit such as a screw-driver across its terminals will then still produce the same spark, illustrating the fact that a good condenser can store an electrical charge for a long time.

Inductance

Actually this capacitance for storing charge is a point which has to be remembered in practice, for sometimes the charge which can be stored is dangerous, and it may remain on the condenser after the apparatus has been apparently switched off; so that sometimes one has to go to considerable trouble to make sure that any such condensers are suitably discharged, to avoid danger to life.

Now, it is in the manner of dis-
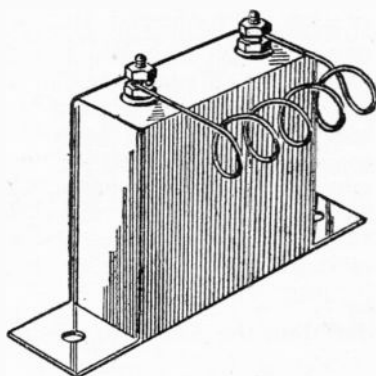
Fig. 17. An electrical oscillatory circuit is obtained by discharging a condenser through an inductance, i.e., a coil of wire. The current which flows through the coil produces a magnetic field.

charging the condenser that we encounter the question of inductance. If the circuit which we connect across the condenser in order to discharge it is made in the form of a coil, as illustrated in Fig. 17, the current which flows through the coil will produce a magnetic field.

The effect of passing a current through a coil may quite easily be verified by the reader using the

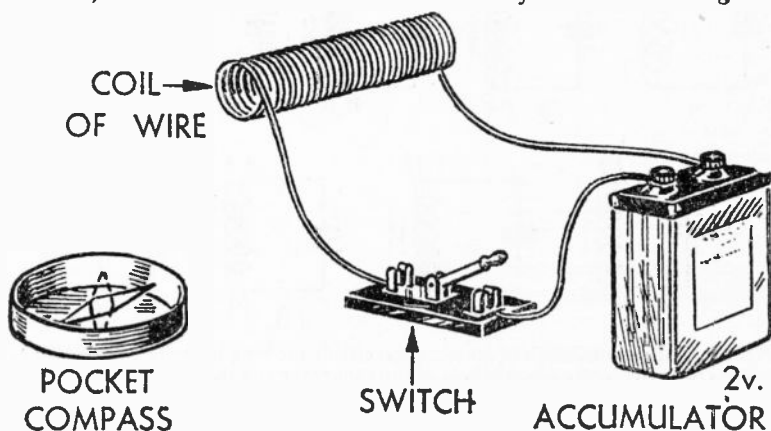COIL → OF WIRE

POCKET COMPASS

SWITCH

2v. ACCUMULATOR

Fig. 18. This experiment shows how a coil carrying a current produces a magnetic field and corresponds to a bar magnet. The coil should have about 200 turns on an inch diameter cardboard tube. This experiment is fully described on page 18.

arrangements shown in Fig. 18. Obtain a small pocket compass and place this on a table. Make up a coil of wire and place this near the compass in the position shown. On connecting up the battery the current which flows will produce a magnetic field, which will either attract or repel the compass needle, causing it to swing, just as with the bar magnet in Fig. 6.

Building the Magnetic Field

Any coil of wire carrying a current will generate a magnetic field, even if it is only comparatively small. But in the production of this field we come up against a very interesting natural law, known by various names, according to the branch of physics in which it is encountered. In brief, we may call it the law of laziness. Nature is, in fact, lazy, and strongly resents any attempt to change the conditions existing at any time.

This effect comes into play when we pass a current through a coil of wire. The magnetic field cannot suddenly appear from nowhere. It has to build up slowly, and during the process it generates forces which try to stop the current from flowing. The voltage applied to the circuit is able to overcome these "back EMFs" but is slowed down in the process and the current does not immediately rise to its full value.

Similarly, when we connect a coil across a condenser the discharge is not instantaneous, but the current gradually builds up until the condenser has completely emptied itself of charge. When this point is reached there is no voltage left to maintain the current, and it begins to die away. But once again the magnetic field objects and does its best to maintain the current, which therefore continues to flow for a short period, getting less and less all the while.
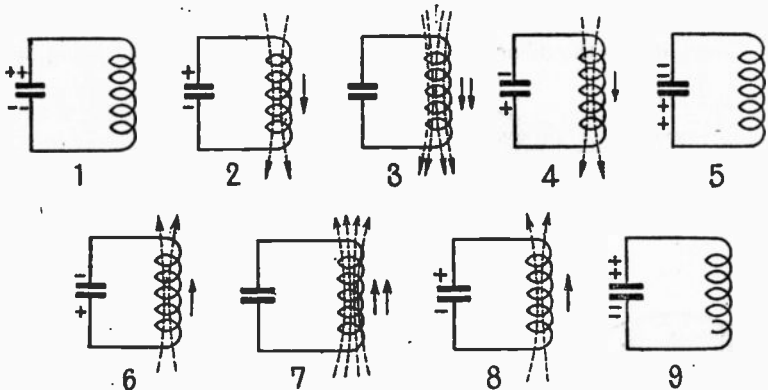
It can, however, only continue

Fig. 19. A single oscillation of an electrical circuit showing how the energy swings to and fro between the electric field of the condenser and the magnetic field of the coil. The stages are: 1. Condenser charged; 2. Condenser partly discharged; 3. Condenser fully discharged. Maximum current; 4. Condenser partly recharged; 5. Condenser fully recharged, opposite direction. No current; 6. Condenser partly discharged; 7. Condenser fully discharged. Maximum current reverse direction; 8. Condenser partly recharged; 9. Condenser fully recharged in original direction (same as 1). If we record the current as in Fig. 19a, shown on page 19, in which the horizontal line represents zero, we get our wave shape.
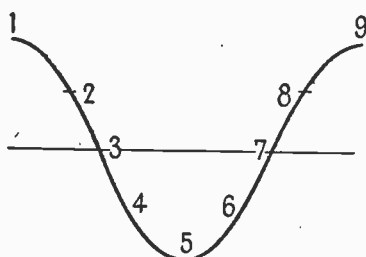
Fig. 19a. This diagram shows the wave shape of voltage as described in Fig. 19.

to flow into the condenser, and it will therefore proceed to charge it up *in the opposite direction* (Figs. 19 and 19a. This process will continue until the current has died away to nothing, leaving the condenser charged practically to the same value as before, but in the reverse direction.

When this state of affairs is reached the conditions will reverse and the condenser will once more begin to discharge. Once again the current will overshoot, and the condenser will become recharged in its original direction. Thus we have a complete electrical equivalent to the pendulum, since the current swings backwards and forwards in a series of oscillations which would continue indefinitely if it were not for the losses due to

the resistance of the circuit (for there is electrical friction between the atoms of the material, so that the movement of the electrons causes some loss of energy, which is said to be due to the electrical "resistance" of the material). With some materials the resistance is much less than in others, so that for circuits which are required to give the least loss we use copper or silver or aluminium.

Now, with this electrical oscilatory circuit we find that we can alter the frequency of the oscillation by changing the value of the condenser or the inductance. If we only use a small number of turns of wire so that the inductance is small, obviously the restricting action will be small, and the current will consequently rise to its full value very quickly.

Producing Oscillation

Similarly if we only have a small condenser it does not take very long for it to empty itself of charge, and in consequence, by making both the inductance and capacity small, we can produce an oscillation of a very short duration.

A coil of wire consisting of about 100 turns on a 3-inch diameter former and a condenser
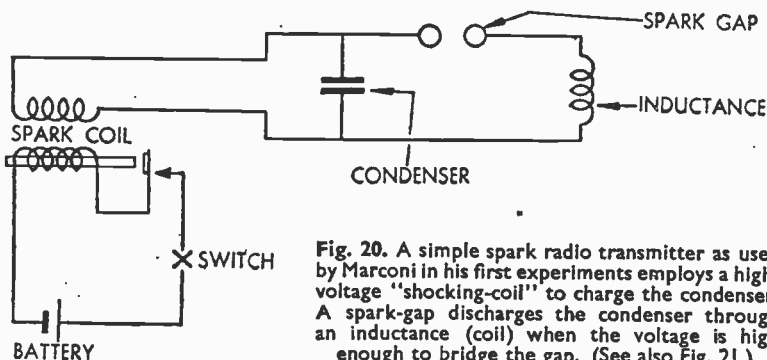

Fig. 20. A simple spark radio transmitter as used by Marconi in his first experiments employs a high-voltage "shocking-coil" to charge the condenser. A spark-gap discharges the condenser through an inductance (coil) when the voltage is high enough to bridge the gap. (See also Fig. 21.)
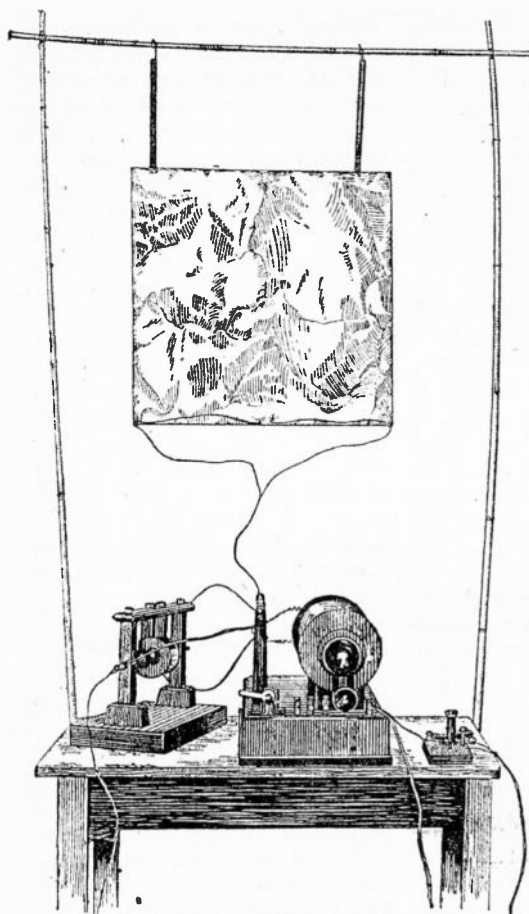
It is obvious that we require the current to be as large as possible, and one way of doing this is to charge the condenser up to a large voltage. To achieve this, use was made in the early experiments of the spark-gap in an arrangement as shown in Figs. 20 and 21.

By using a so-called spark-coil, which was an arrangement which produced a high voltage between the two electrodes, it was possible to charge the condenser to several thousand volts. Across the condenser was connected an inductance in series with a spark-gap. This consisted of two balls of metal separated by a small fraction of an inch.

When the voltage on the condenser was made high enough, the insulation between the two balls would break down and the condenser would discharge with a visible spark, the actual current being of an oscillating nature due to the presence of the inductance as just described. Actually this simple form of circuit has many disadvantages, but it will suffice at the moment for the development of our story.

Another requirement is that the travel of the electrons shall be as large as possible. Referring again to our rope analogy, it is clear that the more the hand is jerked up and

Fig. 21. Drawing from a photograph of some of the original spark-coil apparatus used by Marconi in his early radio experiments. Note particularly the sheet of tin foil employed as an aerial.

consisting of a pair of plates 1 ft. square and $\frac{1}{16}$ inch apart will constitute a system which will oscillate approximately a million times a second, and this is within the range which calculation shows to be suitable for radio communication. These, then, are the sort of values which Marconi used in his early experiments.

down the larger will be the ripple which will travel down the rope, and therefore it is necessary to devise some means of increasing the initial movement of the electrons.

To do this the simple circuit just described is expanded mechanically, so that it occupies a larger space. The condenser, which in its simple form consists of two parallel plates, is made on a larger scale, the plates being farther apart and of larger area to compensate for the greater distance between them.

The next step is to replace one of the plates by the surface of the earth itself. Then, instead of having a solid sheet of metal for the upper plate, we find that we can use a network of wires, and this arrangement is called an aerial or antenna.

Actually even the connecting wire between the aerial and the earth has some capacitance to ground, so that it is pos-

sible to omit the horizontal top portion altogether, and Figs. 22 and 23 illustrate the successive stages in the development of the aerial. The exact form which is used depends on the requirements, and we shall refer to this again further on in this chapter.

Now, if by some means, such as a spark transmitter (or a valve transmitter, as we shall consider later), we cause currents to oscillate up and down this aerial, the electrons will rush up and down the wire, and will generate the electro-magnetic waves which we
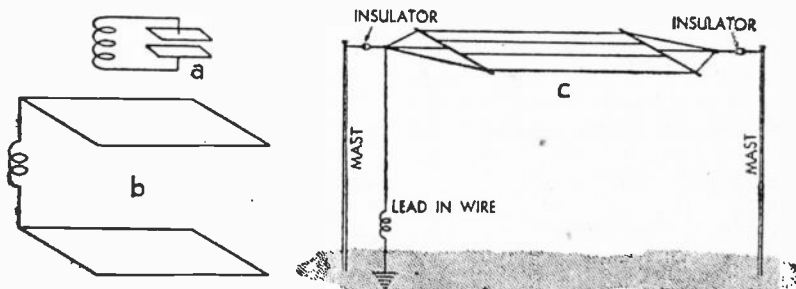
Fig. 22. An aerial is an oscillatory circuit "opened out". Stages *a*, *b*, and c show how aerial lead-down and earth correspond to the plates of a condenser and possess the inductance of a coil, thus illustrating the development of the aerial.
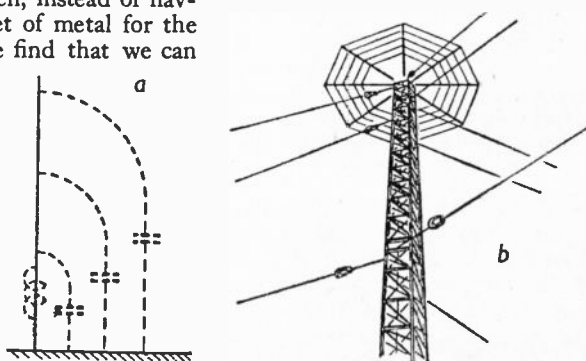

Fig. 23. Even a simple vertical wire possesses capacitance and inductance and, therefore, forms an oscillatory circuit (*a*). Many modern transmitter aerials (*b*) consist solely of an insulated mast with its connections.

require. The strength of the wave produced will be proportional to the height of the aerial and to the actual current, both of which factors are linked up in practice with the frequency of the wave.

If we make the aerial system large, so that it has a large capacity, it is possible to obtain a large current, but the frequency of the oscillation is low. A typical example of this type of construction is in the Rugby Station of the British Post Office, which uses masts 820 ft. high. The frequency of the oscillation generated is 20,000 cps., and the current is many hundreds of amperes.

Wavelength

These oscillations generate an electro-magnetic wave of long wavelength. By wavelength is meant the distance in space between the successive ripples. The point is illustrated in Fig. 24, where a wave is indicated diagrammatically in the form of a ripple in a line of force travelling outwards. The disturbances generated by the movement of the electrons in the aerial will travel out into space. Let us assume that at a point A the electric field at a given instant is downwards. By the time a complete cycle has been obtained and the field is again downwards the first downward field will have

reached a certain point some distance away, at B.

This distance between similar points on consecutive waves is known as the wavelength of the wave. It is found that the speed with which the disturbance travels outwards is always the same for any electro-magnetic disturbance. The speed is actually 300,000,000 metres per second—the velocity of light which, as we have seen, is a similar electro-magnetic wave.

It also follows that if the velocity with which the waves travel is constant, then the more rapid the oscillation the closer together must the waves be. This leads to the simple relationship:

Frequency × wavelength = velocity.

From this relationship it follows that the wavelength of the waves radiated by the Rugby station just considered is 15,000 metres—*i.e.*, about $9\frac{1}{2}$ miles—and it is obvious that a wave of this type will have very considerable penetrative properties. An object will only act as an obstacle if its dimensions are large compared with those of the wavelength.

Obstacles to Reception

As an example of this one can consider a barrel floating on a pond. Little wavelets would be stopped and turned back by this
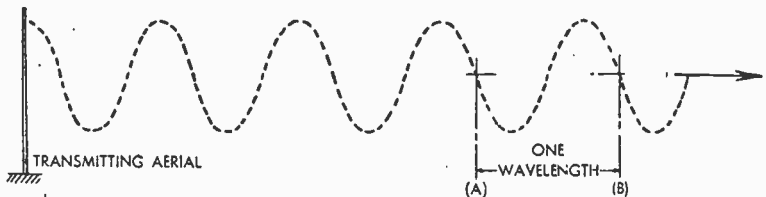

Fig. 24. The frequency of the radiated wave determines the distance between points of similar strength, *i.e.*, the wavelength. The higher the frequency, the greater the number of waves in a given distance and the shorter the wavelength.

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barrel, whereas large waves would merely flow around it comparatively unaffected. This was the reason for the choice of wavelengths of about 300 metres in the original development of wireless communication, for such wavelengths are quite large in comparison with the ordinary obstacles, such as trees, houses, and so on.

These waves are, however, still subject to absorption by hills, and they are also subject to other disturbances, which are considered in later chapters, so that the development was always in the direction of longer and still longer wavelengths, until one reaches wavelengths of many miles.

This increasing wavelength, of course, means that the frequency is being reduced all the time, and, as we have seen, the strength of the wave is dependent on the rapidity of the vibration, so that what is being gained in greater penetrating properties is being paid for in the poorer radiation efficiency of the system, to compensate for which the power input has to be increased. Whereas two kilowatts of power may suffice at a few hundred metres, several hundred kilowatts would be required for wavelengths from 10,000 to 15,000 metres.

Atmospherics

Another factor which operates adversely at these long wavelengths is the atmospheric disturbance generated by Nature herself. All over the surface of the earth there are minor electrical disturbances taking place—cloud discharges, thunderstorms, magnetic storms, and so on—and these generate electro-magnetic waves of the same type as we have been considering, although they are of a very brief duration.

These disturbances, which can be very intense, are known as atmospherics or X's. They are of varying frequency, but those of comparatively low frequency generate long-wave disturbances which travel for long distances, whereas the higher-frequency disturbances are more local in character. Consequently, as we increase the wavelength we find that, mixed up with the signal which we require, there is also a fairly large proportion of atmospheric signals, and if these become too large it is impossible to hear the wanted signal through the background noise.

Reception

For the reception of the waves generated by the transmitter we erect a similar aerial, and in this the electric fields moving past the aerial will induce EMFs which try to set the electrons in the aerial in motion. At a considerable distance from the transmitter, of course, these induced voltages are very minute—a few millionths of a volt only—and consequently the currents set up are negligible to all intents and purposes.

Fortunately, however, we can overcome this difficulty by the process of tuning, which means adjusting the receiving aerial to a similar condition to the transmitter, so that if any oscillations are started in the receiving aerial, they will not immediately die out, but will continue to oscillate.

Obviously if the aerial is in a suitable condition such as this, then the successive impulses received from the electro-magnetic wave travelling past the aerial will always be exactly timed to strengthen the currents which are existing in the aerial. Thus the current will build up to quite a

large value relative to what would be the case without tuning.

It is possible· to construct a simple experiment to demonstrate this. Connect a piece of cotton across the two opposite corners of a room, as shown in Fig. 25. It should not be stretched too tight, but the cotton should sag about six inches in the middle.

About 2 ft. from one end connect a pendulum consisting of a small weight on the end of a length of 4 ft. of cotton. At a similar distance from the other end connect another pendulum, making it this
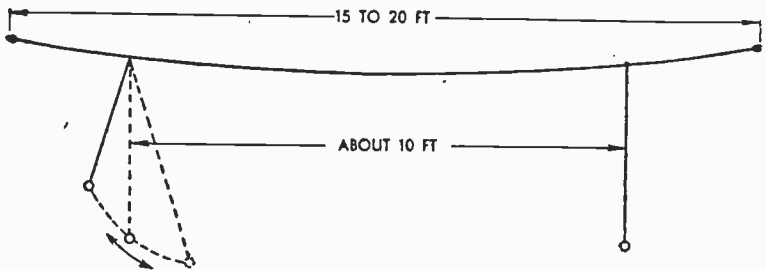
Fig. 25. A simple experiment which demonstrates tuning. The oscillation of the pendulum on the left will cause sympathetic oscillation of the one on the right—but only when both the pendulums are of exactly the same length.

time only 3 ft. long, so that we have two pendulums separated by anything from 6 to 10 ft.

Draw the smaller pendulum to one side and let it go. It will commence to swing, and the impulses produced by this pendulum will be transmitted through the stretched cotton to the second pendulum; but apart from the fact that it will bob about slightly in an indeterminate manner, nothing particular will happen.

Now adjust the length of the second pendulum to be exactly equal to the first, so that the times of swing are the same. If the experiment is now repeated it will be found that the second pendulum will almost at once begin to build up into an oscillation of its own until
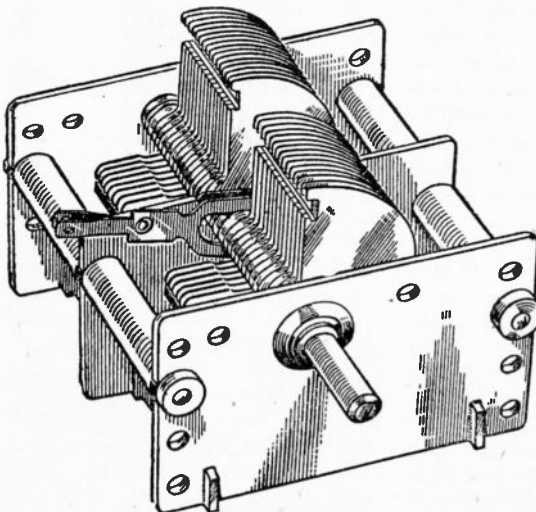

Fig. 26. Receivers are usually tuned to the transmission it is desired to receive by varying the capacity of the tuned circuits by a variable condenser such as this.

both pendulums are swinging together.

This is the principle used in tuning a receiving aerial; and to do this we make arrangements to vary the effective inductance or, more usually, the capacity of the aerial, by a device consisting of a series of plates which move in between a series of other fixed plates. The more the plates overlap the more is the capacity, and the device therefore is called a variable condenser (Fig. 26). The inductance used is varied in stages by switches to cover different wavebands. A typical tuning inductance (coil) is seen in Fig. 27.

A further advantage of the tuning is that it enables us to select the particular signal we need from among all the signals which are passing the receiving aerial at the time. Indeed, with the amplification which is available to-day the increase in the strength of the current due to tuning is really of less importance than this "selectivity" which results from the process; and in order to obtain the degree of discrimination demanded by modern conditions it is necessary to pass the current through a whole succession of tuned circuits, each of which selects the signal required and rejects unwanted signals.

Detectors

The first radio transmissions were made using a spark transmitter and a receiver known as a "coherer", for Marconi found that if high-frequency oscillating currents were passed through a series of metal filings in a glass tube the filings tended to cohere and become more conducting, whereas without the influence of the radio-frequency currents the filings passed very little current. Later

this arrangement gave place to a device called a crystal detector (Fig. 28).

If converted by some means into air waves, radio frequencies would not be audible, for the limit of hearing is in the neighbourhood of 20,000 cycles per second, whereas ether waves often oscillate at several million cycles per second. Consequently it is necessary to provide some device which will detect the presence of high-frequency currents and turn them into some form in
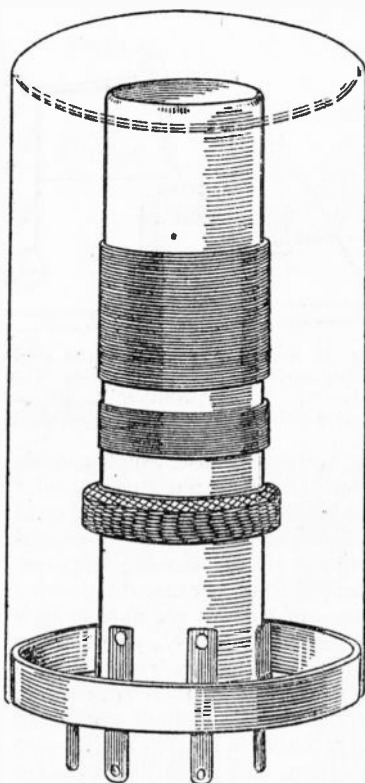

Fig. 27. The tuning inductance is generally a coil and the amount of inductance required for a given waveband is selected by external switching.

which we can be fully aware of their existence.

Every radio receiver, therefore, must contain a detector. A crystal detector is a contact between two crystals such as zincite and bornite, or between a crystal such as carborundum and a metal such as steel. Suitable combinations such as this have the property of passing current more readily in one direction than in the other.

Now, ordinarily the average value of the oscillation is zero, because each little pulse of current is immediately followed by an equal
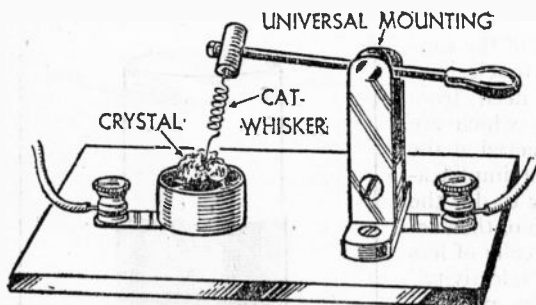

Fig. 28. A crystal detector of the kind used by listeners in the early days of broadcasting. The device operated only when the "cat-whisker" made contact with a sensitive point on the crystal, often difficult to obtain.

and opposite pulse. which cancels it out; and if we put a pair of telephones in the circuit we should hear nothing. Including a crystal detector in the circuit, however, alters matters, because the positive pulses of current are able to flow comparatively easily, whereas the negative pulses are reduced to a small fraction of their true value, so that there is a small amount of current always flowing in the same direction, and this will produce a pull on the telephone diaphragm.

If the waves are sent out from the transmitter in a series of short groups separated by regular inter-vals, we shall obtain a pull on the telephone diaphragm at the receiver for every one of these groups, and if the groups or trains of waves are sent out at a musical frequency, then we shall hear a musical note in the receiver.

This leads up to the question of modulation. As long as the waves are continuous they can communicate no intelligence. It is always necessary that they should be modulated or broken up in some way so that the strength changes.

In a telegraph transmitter we break up the waves by interrupting them at regular intervals, and of course in the old spark transmitters this interruption was automatic, because there was one train of waves generated every time a spark occurred; and as the sparks used to follow one another at a few hundred cycles·per second only, the result was that the receiver emitted a similar note.

The range of human hearing is from about 50 to 20,000 vibrations .per second. Very low frequencies have a very low pitch, and as we increase the frequency the pitch of the note rises, until it becomes so shrill that it cannot be heard.

Young people can usually hear at frequencies approaching 20,000 cps., and the squeak of a bat is of this order of frequency. As one grows older the ear becomes less sensitive, and it is impossible to hear frequencies higher than 10,000 or even 8,000 cps. Fortunately the ordinary range of speech
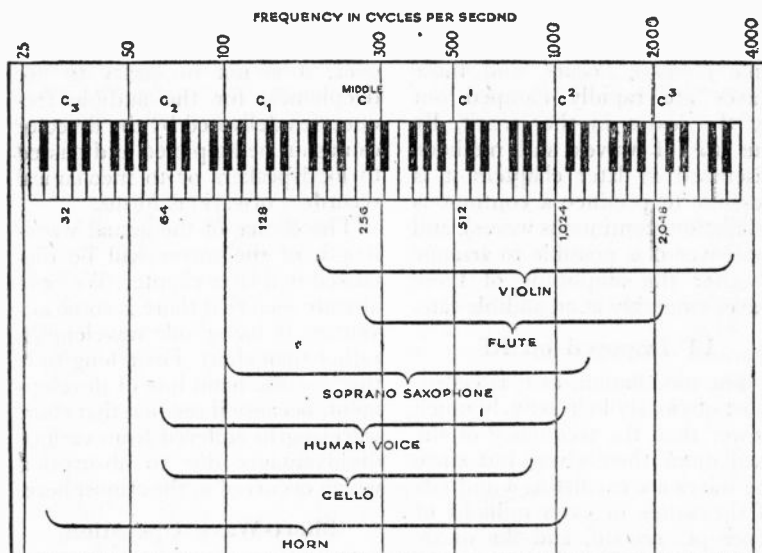
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Fig. 29. The frequency of sound waves gives them pitch, and middle C, for example, has a frequency of 256 cps. An instrument sounding middle C also produces harmonics (multiples) of the fundamental frequency. The timbre or quality of different instruments is produced by differences in the strength of the harmonics. The above diagram shows fundamental frequencies, the harmonics extending to about 15,000 cps. or more.

is covered within a more restricted scale than this, ranging from about 200 to 5,000 cps.

Music covers a wider range, from 50, and sometimes even less, up to 15,000 cps. The diagram in Fig. 29 shows the fundamental frequencies covered by different instruments.

Harmonics Give Timbre

It is the lower frequencies ranging up to a few thousand cycles per second which constitute the main body or fundamental of the note, while its distinctive quality is imparted to it by what are known as "harmonics", which are smaller oscillations having frequencies two or three times the fundamental frequencies. The same note played on the flute and on the violin sounds quite different, because the flute gives a very pure oscillation, whereas the violin note contains a large number of harmonics.

When dealing with amplifiers and radio transmitters and receivers generally, it is necessary to allow for all this. Sometimes compromise is necessary, and where one is dealing solely with speech it is only important to handle modulation frequencies within the limits of 200 to 5,000, while with high-quality reception for music a much wider range is necessary.

Reverting to our radio transmitters, it is clear that if we interrupt the transmissions at a rate of a few hundred times per second we shall hear a fairly low musical note in the receiver, and this is what is done for telegraphy transmission. With the simple spark transmit-

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ters already described we only generate a train of waves every time a spark occurs, and these waves are rapidly damped out by the losses in the circuit. By the use of valves and methods discussed in later chapters it is possible to produce a continuous oscillation (continuous waves), and moreover it is possible to arrange to alter the amplitude of these waves smoothly at an audible rate.

LF Imposed on RF

The modulation, as it is called, must obviously be relatively much slower than the frequency of the oscillations themselves, but since the waves are oscillating hundreds of thousands or even millions of times per second, and the maximum modulation frequency we want is something under 20,000 per second, this condition is satisfactorily complied with.

The actual mechanism of modulation is discussed in detail in another chapter, but it is clear that if we can alter the amplitude of the wave in this manner, then when we pass these waves through a detector at the receiver we shall get a varying current through the telephones which will vary at the same rate.

Varying the Amplitude

Obviously this procedure is not restricted to simple regular variations producing a musical note. It is possible to vary the amplitude in a complex manner to reproduce the frequencies contained in audible speech or music, and this is the basis of radio telephony. ·

At the receiver it is also possible to use valves instead of just a simple crystal detector, and this enables signals of very much smaller amplitude to be picked up

and satisfactorily amplified until they will operate a detector. Moreover, it is not necessary to use telephones, for the audible frequencies delivered by the detector can again be amplified and passed to loudspeakers or to mechanical recorders of various forms.

The choice of the actual wavelength of the waves will be discussed in a later chapter. We have already seen that there is some advantage in using long wavelengths rather than short. For a long time this was the main line of development, because it seemed that short wavelengths suffered from various disadvantages due to absorption which occurred in the atmosphere.

Short-Wave Operation

Later, however, the reason for these absorptions became more clearly understood, and it was found that considerable improvement could be obtained by a marked reduction in the wavelength, which resulted in a whole new field of technique known as short-wave operation. This whole subject, however, together with consideration of the manner in which wireless waves can travel round the curved surface of the earth, is discussed elsewhere.

We close this chapter having obtained a general view of radio—a large outline map on which detail can be drawn by the following chapters, some of which have just been mentioned. We have seen what radio waves are and, broadly, how they are used as carriers of "intelligence", as the expression is.

The following chapters explain the practical methods by which signals are produced, radiated and received—whether they be for the amusement of the listener or for the guidance of airplane or ship.

HOW RECEIVERS WORK

PRINCIPLES OF RECEPTION. AERIALS. TUNING. SELECTIVITY. FIDELITY.
GANGED TUNING. RF AMPLIFIER VALVES. RF AMPLIFICATION. DEMODULA-
TION. AF AMPLIFICATION. POWER AMPLIFICATION. VALVES IN PARALLEL
AND PUSH-PULL. LOUDSPEAKERS. IMPEDANCE MATCHING. SUPERHETERO-
DYNE CIRCUITS. FREQUENCY CHANGING. GANGING. MIXING. FREQUENCY
CHANGER VALVES. IF AMPLIFICATION. SUPERHET DEMODULATION. AUTO-
MATIC GRID BIAS AND VOLUME CONTROL. HEPTODE VALVES. POWER
SUPPLY. TUNING INDICATORS. TONE CONTROL. VARIABLE SELECTIVITY.
AUTOMATIC TUNING AND FREQUENCY CONTROL. BATTERY RECEIVERS.
HT ECONOMISER CIRCUITS. BATTERY AND MAINS SETS.

IN this chapter we take a radio receiver, which to the un-initiated may seem like a box of tricks, and see how it is that by turning two or three knobs we can pick up a radio signal, which cannot be detected by any of the human senses, and produce, if necessary, a volume of sound adequate to fill the largest room or a big open space.

Reception Principles

To understand the principles on which radio reception is based we do not need to be advanced mathematicians or physicists—there is a very big difference between the designing of a set which will function correctly (which we will leave to the research engineers) and operating the set when it is finished, or even repairing it when it becomes faulty. A motor mechanic may not comprehend the various chemical and physical changes which occur in an internal-combustion engine when it is working, but he knows how to make it go again when it stops.

In this chapter we shall, there-fore, be approaching the subject in an essentially practical way, introducing only the barest minimum of theory where it is essential to the understanding of a particular process, or to prevent wrong impressions being gained. For the theoretical side of radio, readers are referred to a later chapter of this book.

The information in these pages is applicable mainly to domestic receivers, but the same principles are employed in the sets used by the Services and also, to a large extent, in television receivers.
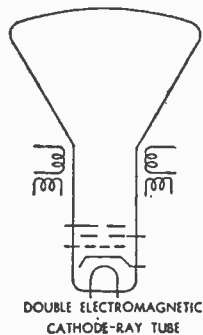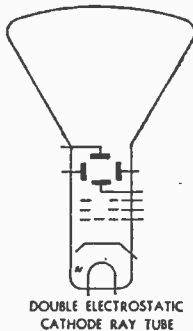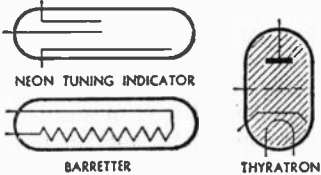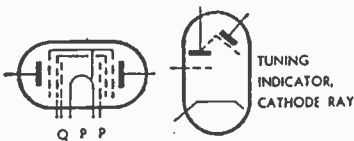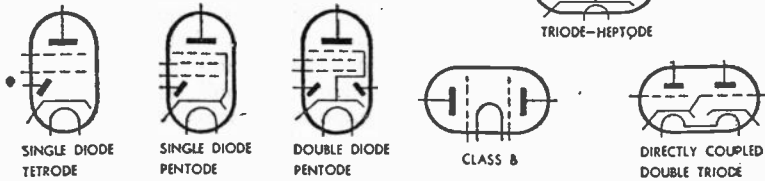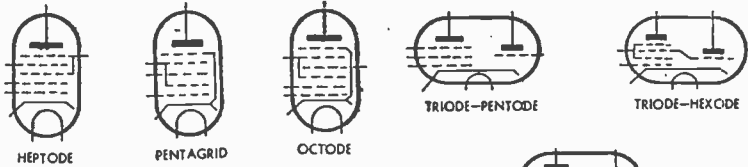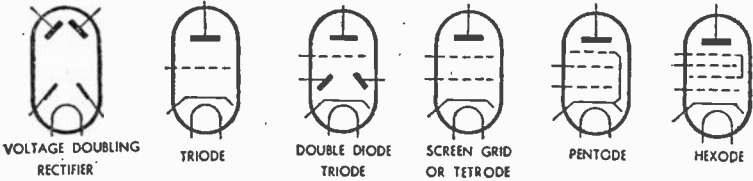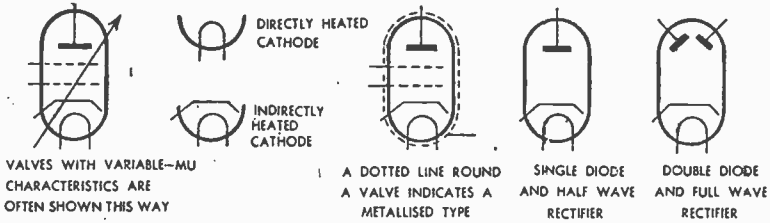
High-Frequency Carrier

The signal which is sent out from the transmitting station is an electro-magnetic wave, and before it can be made audible to the listener in the form of sound waves it must undergo a number of changes in the receiver. The design of the receiver depends on the form of the wave, and fortunately the majority of transmissions from stations all over the world take the same form and are receivable on the same set, providing they are

AC MAINS   AERIAL   AERIAL FRAME OR LOOP   AERIAL, DIPOLE   AMMETER

POSITIVE

NEGATIVE

BATTERY, SINGLE CELL   BATTERY HT   BATTERY LT OR GB   CHASSIS, OR EARTH   CHOKE, HF OR TUNING COIL

VARIABLE PERMEABILITY

CHOKE, HF (IRON DUST CORED)   CHOKE, LF (IRON CORED)   CONDENSER, FIXED   CONDENSER, ELECTROLYTIC

GANGED

CONDENSER, VARIABLE TUNING   CONDENSER, TRIMMER   DIAL LAMP

EARTH, OR CHASSIS   FILAMENTS OR HEATERS   FUSE

JACK   LOUD SPEAKER   MAINS PLUG   MICROPHONE   MILLIAMMETER

NEON TUBE   PHONES   PICK-UP   PLUG & SOCKET   POTENTIOMETER

RECTIFIER, METAL OR CRYSTAL   RESISTOR, FIXED   RESISTOR, TAPPED

RESISTOR, VARIABLE   SCREEN OR SCREENING CAN   SCREENED LEAD

SWITCHES   TRANSFORMER, HF   TRANSFORMER, LF OR MAINS (IRON CORED)

VOLTMETER   JOINS   CROSSOVERS

COMPONENT AND VALVE SYMBOLS

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VALVES WITH VARIABLE—MU
CHARACTERISTICS ARE
OFTEN SHOWN THIS WAY

DIRECTLY HEATED
CATHODE

INDIRECTLY
HEATED
CATHODE

A DOTTED LINE ROUND
A VALVE INDICATES A
METALLISED TYPE

SINGLE DIODE
AND HALF WAVE
RECTIFIER

DOUBLE DIODE
AND FULL WAVE
RECTIFIER

VOLTAGE DOUBLING
RECTIFIER

TRIODE

DOUBLE DIODE
TRIODE

SCREEN GRID
OR TETRODE

PENTODE

HEXODE

HEPTODE

PENTAGRID

OCTODE

TRIODE—PENTODE

TRIODE—HEXODE

TRIODE—HEPTODE

SINGLE DIODE
TETRODE

SINGLE DIODE
PENTODE

DOUBLE DIODE
PENTODE

CLASS B

DIRECTLY COUPLED
DOUBLE TRIODE

Q P P

TUNING
INDICATOR,
CATHODE RAY

NEON TUNING INDICATOR

BARRETTER

THYRATRON

DOUBLE ELECTROSTATIC
CATHODE RAY TUBE

DOUBLE ELECTROMAGNETIC
CATHODE-RAY TUBE

USED IN CIRCUIT DIAGRAMS.

sufficiently powerful to be picked up by the receiving aerial.

Certain stations in America are now operating with a slightly different type of signal (frequency modulated), which is not receivable on an ordinary set without certain modifications, but these stations, so far, are decidedly in the minority.

The standard transmitted wave consists basically of a high-frequency "carrier", which in itself contributes nothing in the way of sound to the final result, but merely acts as a means of getting the speech or music which it is desired to transmit disseminated as far and wide as possible. That is why it is called a "carrier".

Audio-Frequency Currents

The sound-waves in the studio cannot be transmitted as they are, even with the help of the carrier. They are first of all converted into audio-frequency "low-frequency") currents, and in this form they are impressed on the carrier wave. This process is known as "modulation", and it is the modulated carrier wave which is picked up by the aerial of the receiver.

Modulation can be carried out in a number of ways, but the most usual form of it is that which is known as "amplitude modulation", in which the amplitude of the carrier wave is varied at audio frequency by the modulation impressed on it.

Picking up the Signal

The problem at the receiving end of the broadcasting chain is first of all to pick up the signal. This is done with an aerial, which may take various forms, according to requirements. The radio wave, on striking the aerial, produces minute modulated radio-frequency voltages in the aerial system.

The power of the signals picked up is so small as to be useless without amplification. At the transmitter the energy put into the aerial may be anything up to 100 kilowatts or more; at the receiving aerial the energy picked up may be a small fraction of a microwatt, which is almost negligible. However, by amplification it can be made fully adequate for all our requirements.

This, then, is the second necessary function of the receiver—namely, to amplify the incoming signal to the required degree. This amplification takes place at radio frequency, and at the end of it our signal is unchanged in form, but much more powerful. However powerful it is, it is nevertheless still not suitable for operating a loudspeaker, for which an audio frequency is required.

Demodulation

The next step, therefore, is to remove the RF carrier wave, leaving the audio frequency modulation, which is what we want. This process is now usually termed "demodulation", since it is the opposite process to that which took place at the transmitter when the carrier wave was modulated. The process of demodulation was previously known as "detection", and is still known by that term in some quarters.

Having demodulated the amplified signal, we are left with an audio- or low-frequency (LF) signal which will operate a loudspeaker or headphones, though possibly at very low power. Consequently, it is usual to amplify the LF signal until it is of sufficient power to operate the speaker at the volume required.

The function of the speaker is to convert the LF signal into the

final form in which it can be appreciated—namely, sound waves. It is important to understand that from the time when sound waves operate the microphone at the transmitting studio to the time when they leave the loudspeaker of the receiver, radio transmission is purely electrical, and sound does not enter into the process at all.

The processes at the receiving end which have been briefly outlined are those which occur in a receiver of the so-called "straight" type, to which the term "tuned radio frequency" or TRF is sometimes applied. The block diagram in Fig. 1 shows the various sections of this type of receiver, which have already been described.

The Superhet

In recent years a rather different type of receiver has become increasingly popular on account of its many advantages. This is the superheterodyne (usually abbreviated to "superhet"), and a diagram showing its various sections is given in Fig. 2a. Again we have an aerial to pick up the signal, followed, in many cases, by an RF amplifier. As, however, this

may not always be present, it is shown dotted.

Next comes a stage which is not found in the "straight" type of receiver—the frequency changer. The function of this is to convert the incoming RF signal to one of lower frequency, known as the intermediate frequency, or IF. The benefits of this process will be fully explained later, when we come to consider superhet circuits in detail, but briefly it has the advantage that amplification of a signal at the lower frequency is easier than at the original transmitted frequency.

The next stage is the IF amplifier in which the converted signal is amplified to the required degree before being passed to the next stage, the demodulator. This has the same function as the same stage in the "straight" type of receiver—that is, to separate the modulation from the carrier wave (which, although converted to a lower frequency, is still in the same form as when it entered the receiver).
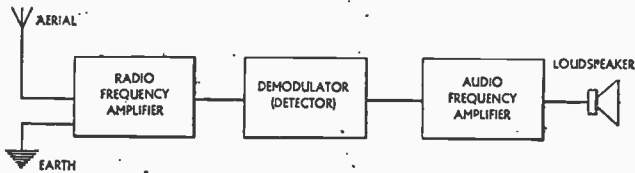
Fig. 1. The various links in the chain, or stages as they are called, which go to make up a complete receiver of the tuned radio frequency (TRF) or "straight" type.
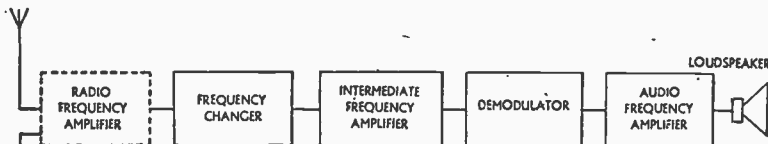
Fig. 2a. The superheterodyne type of receiver ("superhet") also divides into stages, but there are extra stages for frequency-changing and intermediate-frequency amplification.

Following the demodulator, the superhet receiver is the same as the straight type, and the audio frequency modulation is amplified in the LF amplifier and then fed to the loudspeaker.

On examining Figs. 1 and 2a it will be noticed that each type of receiver divides up into a number of definite sections, all linked together. In fact, the analogy of the links in a chain can be strictly applied. It is proposed here to examine each type of receiver link by link. There is no need for the reader to know in great detail what goes on in each link, provided that he knows what the link should do, and the relation which it bears to the other links.

As Fig. 2b shows, even the most complex receiver becomes intelligible when divided into its stages.

Figs. 3 and 4 show the layout of the components on the decks of typical TRF and superhet chassis respectively. The main parts are indicated, and it will be observed that the difference in external appearance is not great, except that the superhet (in Fig. 4) is of a

somewhat more elaborate nature owing to its extra stages.

The aerial and earth system is an important part of a receiver installation, for on this depends the strength of the signal which will be picked up and, therefore, how sensitive the receiver must be to enable good results to be obtained from a certain station.

Aerial and Earth Systems

Strictly speaking, the aerial and earth system should be regarded as an integral part of the receiver. In a portable, which uses a frame aerial, this is the case, the frame winding forming the first tuned circuit of the receiver.

In other types of receiver, to which the term "open aerial receivers" is applied, the aerial and earth are, of course, external to the instrument, and for this reason but scant attention is usually paid to them. This is a pity, because although it is true that a modern receiver will work with a poor aerial, and sometimes no aerial at all, it will work much better with a good aerial. A poor aerial means
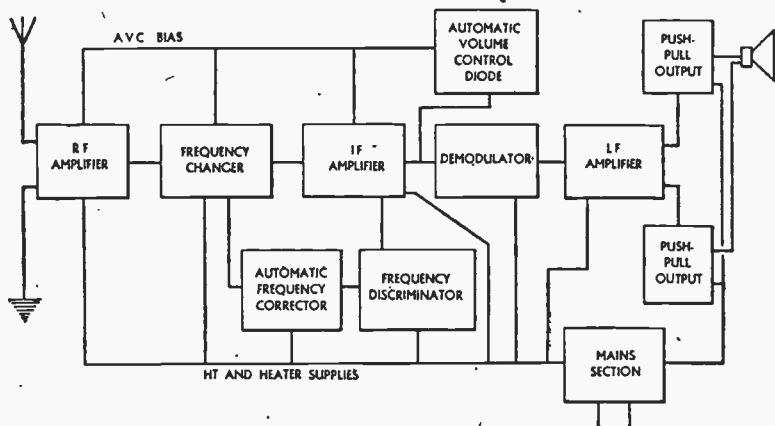
Fig. 2b. Even the most complicated de luxe receiver can be sectionalised as indicated here, and then becomes much less formidable to understand.

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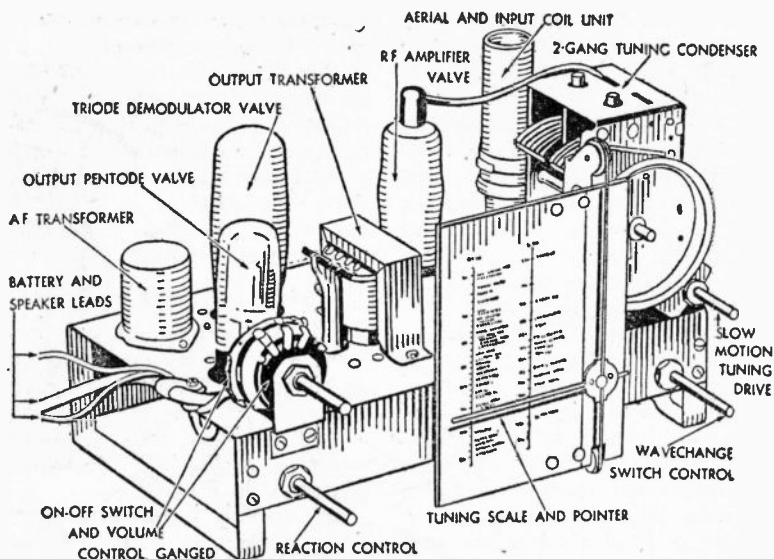
Fig. 3. Chassis of a simple three-valve TRF or "straight" receiver for operation from batteries. Small resistances and condensers, the wiring and certain coils and switches are out of sight below the chassis.

that a small signal is passed to the first valve, and consequently extra amplification is necessary in the receiver. This tends to introduce background noise, which would be entirely avoided if a really good aerial were in use.

Use of Beam Aerial

It has been seen that a radio signal is sent out from the transmitting aerial in the form of a complex wave. Usually it radiates in all directions from the transmitting aerial, although in certain circumstances the energy from the transmitter is concentrated in one direction only by means of a special "beam" aerial.

If the receiving aerial is placed in the path of the transmitted wave, it abstracts energy from the wave, this energy producing tiny voltages and currents in the aerial–earth system which correspond

with the large voltages and currents in the transmitting aerial.

Up to a point, the larger our aerial, the bigger the energy we shall absorb; the higher our aerial, the bigger the energy; and the nearer we are to the transmitter, the bigger the energy. Usually we cannot control the latter, but we can certainly see that our aerial conforms to the requirements of size and height.

Height of Aerial

A low aerial not only fails to pick up a good signal by virtue of its lack of height, but, being low, it is also probably screened by buildings and metal structures, and is also close to sources of electrical interference (see Chapter 9), and is therefore more susceptible to them. This indicates that height is very important.

The size of an aerial depends to

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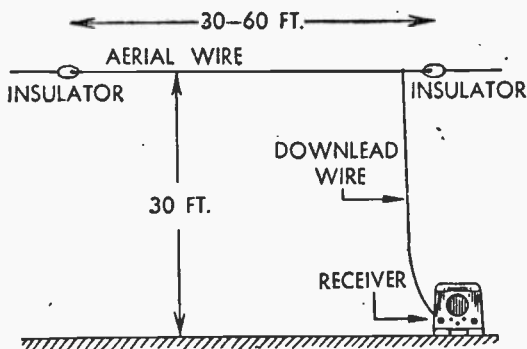
Fig. 5. A simple and effective type of aerial known as the "inverted L".

theless, earthing is always desirable, and in many cases essential. A good direct connection to a main water-pipe, to an earth-tube or spike driven into damp soil, or to a buried metal plate or net, is usually recommended. Gas-pipes, electric conduit, hot-water systems, and so on should not be used for earthing a radio set. Examples of typical earths are shown in Fig. 8.

chosen as to cause it to resonate somewhere in the middle of the waveband in which we are most interested, we shall obtain optimum results in this waveband. That is why dimensions of the order of those given in Fig. 5 are generally adhered to in an ordinary broadcast aerial.

Sometimes an actual earth connection is dispensed with, and a so-called counterpoise system is used instead. A diagram of this is in Fig. 9. This system uses an ordinary aerial, while suspended below it is a similar span of wire (or several wires), which is also insulated from earth, and has a lead-in to the receiver. The aerial wire and counterpoise form the two plates of a condenser, across which the incoming signal voltages are developed. Counterpoise systems are mainly used at transmit-

Insulating the Aerial

The insulation of the aerial is important, for any leakages of the small currents picked up will seriously affect its efficiency. The insulators used should have a large leakage path, and should preferably be so designed that dirt is not readily picked up and retained on the surface. Examples of typical insulators are shown in Fig. 7a and b. Highly glazed porcelain, glass, or pyrex are popular materials for insulator construction.

The earth connection is also important, though most receivers will operate without an external earth. Never-

Fig. 6. The "T" aerial has good features from a theoretical point of view, but is usually not as well suited to ordinary gardens as the "inverted L".
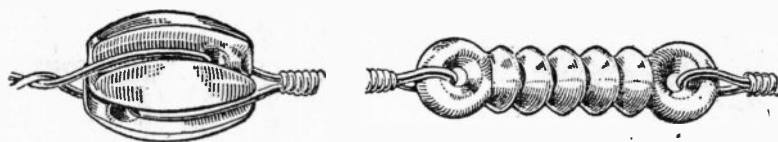
Fig. 7a. Three types of aerial insulator. The surfaces are highly glazed to minimise pick-up of dirt and moisture, and the shapes are devised so that any current leakage which may occur from aerial wire to stay must travel by the longest possible path.

ting stations, but they have advantages in cases where a proper earth for the receiver cannot be obtained, and also for use in connection with certain specialised types of receiver.

So far we have been mainly concerned with aerials for use with ordinary domestic receivers. In the case of special short-wave receivers there is usually an advantage in employing a specialised short-wave aerial system. In most cases these systems are of the resonant or tuned type, and enable better reception to be obtained on a certain waveband than would normally be the case with the ordinary open type of aerial. Since the dimensions of resonant aerials depend on the wavelength at which resonance is desired, true resonant aerials can only be erected for use on the shorter waves in the average garden.

Dipole Aerials

It is not intended here to go into full details regarding short-wave aerials, because this is covered in Chapter 7. The most common type is the dipole or doublet aerial, which consists of two wires stretched horizontally in line, having a total length approximately equal to half the wavelength at which optimum recep-

tion is desired, but separated from each other at the centre.

Connection from the aerial to the receiver is not made by an ordinary lead-in wire, but by a twin feeder, each wire of which is attached to one "pole" of the aerial at the centre. This is shown in Fig. 10. The impedance of any centre-fed dipole aerial is of the order of 75 ohms, and for correct operation the feeder cable must be of a type having the same impedance. The feeder must also be properly matched to the receiver at its other end.

One type of feeder consists of two parallel wires suitably spaced in insulating material to give the correct impedance, while another, known as the concentric type, consists of a cylindrical outer screen forming one connection, with an axial wire running down it and forming the other connection (Fig. 11).

Television aerials usually consist of vertical dipoles, either alone, or with a reflecting element at a quarter or an eighth of a wavelength behind them. The elements are in the form of rods or tubes, and the special type of feeder
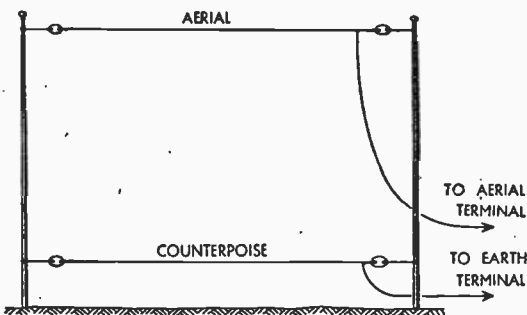
Fig. 9. Seldom used but valuable in exceptional cases is the counterpoise aerial-earth system. The earth of the set is connected to an insulated wire a short distance above the ground and below the aerial.

want, and reject all those we do not want, we make use of the principle of tuning. In the following explanation we shall be referring to frequencies, rather than wavelengths, as this will be more convenient, but it should be remembered that frequencies are related to wavelengths in an inverse ratio (*see* page 22.)

that the aerial picks up a minute signal from the station we wish to receive, but it should be realised that in most cases it also picks up signals of various intensities from every other station which happens to be transmitting at the time. Some of these stations, of course, will produce only a negligible signal in our aerial, but others may be of an intensity equal to or greater than that of the signal we desire.

In order to select the signal we

Tuning is carried out by a combination of inductance (the attribute of a coil) and capacitance
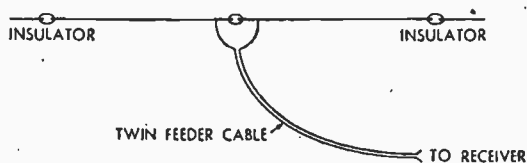
Fig. 10. For reception of short-waves efficiency is increased if the aerial itself resonates with the signal. This is the idea behind the dipole or doublet aerial.

(the attribute of a condenser). The reactance of a coil, or the barrier it offers to an alternating current, increases with the fre-
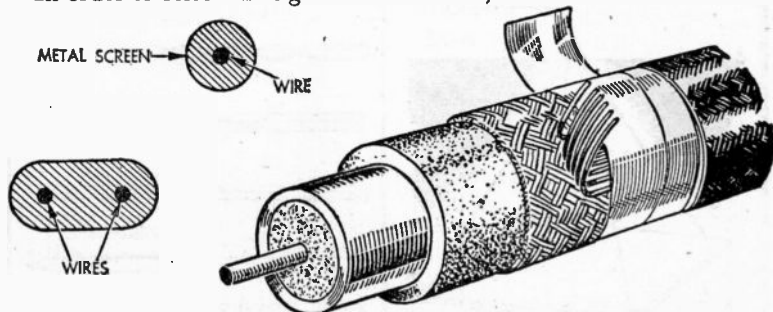
Fig. 11. Dipole aerials are connected to the receiver by special twin "transmission" cable. Another type of lead-down has a single conductor for the signals and an outer flexible metal sheathing to screen off local interference.
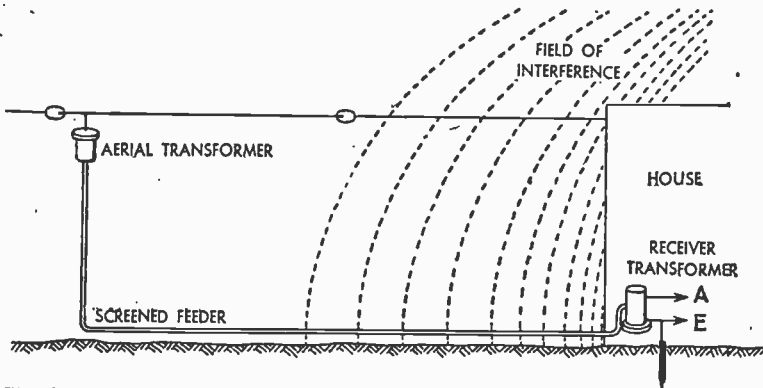
Fig. 12a. Interfering "noise" is usually strongest in the region of the house. By arranging the collector part of the aerial at the bottom of the garden and conducting the signal to the receiver through a screened wire much "cleaner" signals are obtained. Further reference to anti-static aerials is made in Chapter 9.

quency of the current (*see* Chapter 17). The reactance of a condenser, on the other hand, decreases with the frequency, and if we arrange matters so that the coil and the condenser have equal reactances at a certain frequency, an interesting state of affairs results, to which the term "resonance" is applied.

Fig. 12b. In another form of anti-interference aerial, a rod collector raised above the "noise" field is employed.

In Fig. 14, diagram *a* represents the signal of frequency *f* applied to the coil of inductance L_1 and the condenser of capacitance C_1 connected in series. When the reactance of L_1 equals the reactance of C_1, the alternating voltage across L_1 is equal in value to that across C_1, but, in the usual manner of inductances and condensers, the two voltages are 180 deg. out of phase—that is, they oppose each other.

Since the voltages are equal in value, the net result is that there is

Fig. 13a. A tuned frame aerial as used in portable sets, showing directions of maximum and minimum signal pick-up.

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age at resonance. This means that in addition to the station of frequency f_1 which we want, a number of stations on either side of f_1, depending on the width of the resonance curve, will be received, though they will get weaker and weaker as their frequency gets farther from f_1.

Resonance Curve

The reason for having a resonance curve of appreciable width is that our tuned circuit can never be perfect, and in addition to inductance and capacitance, it will always contain resistance. The lower the resistance the higher the magnification of the circuit, as we have seen, but, in addition, the narrower will be the resonance curve, and the greater the "selectivity" of the circuit, as it is called.

Thus in Fig. 16 the dotted curve might represent our resonance curve when the resistance of the tuned circuit was reduced, and it will be observed that it is taller and narrower. Our "wanted" station will now develop a voltage of V_3, and the unwanted station of frequency f_2 develops a voltage of V_4. Obviously, the ratio of voltage of the wanted to the unwanted signal (V_3/V_4) is now considerably greater than it was before (V_1/V_2).

Use of Tuned Circuits

Besides improving selectivity in the way mentioned, the same effect can also be achieved by using two or more tuned circuits. The more tuned circuits, the greater the selectivity, and anything from two to six or more circuits may be used in a modern receiver, according to the type to be provided for.

One would be inclined to think that the greater the selectivity the better would be the receiver. In practice, however, for the reception of speech and music, one has to make a compromise, for reasons which will now be detailed.

We have seen that the signal is sent out as audio-frequency modulation impressed on a carrier wave. So far, in considering selectivity we have been assuming that the signal is of a single frequency, that of the carrier. It can be shown mathematically, however, that a carrier wave of frequency F modulated by a frequency f can be replaced by three separate waves, of frequency F, $F - f$ and $F + f$.

If the carrier is modulated by numerous audio frequencies, as it will be in the case of music, the signal then consists of the carrier with a whole band of frequencies on either side of it. These are known as sidebands. If f now represents the highest audio frequency transmitted, the wave sent out will extend in frequency from $F + f$ to $F - f$, and its width will thus be $2f$.

High Selectivity

Obviously, if we make the selectivity too high, we shall accept such a narrow band of frequencies that the whole of the transmitted signal will not be able to enter the set, and we shall get a cutting off of sidebands. Since the highest audio frequencies are on the outside of each sideband, the effect of too high a selectivity will be a reduction in the upper register of the music received.

The compromise between selectivity and fidelity is one of the problems of the designer of a receiver, and in some cases he introduces a feature whereby the selectivity can be made variable according to requirements.

Having briefly given the simple theory of tuning and selectivity, we can pass to more practical details. The signal picked up by the aerial is fed first of all to a tuned circuit which precedes the first valve of the receiver. Typical methods of coupling the aerial are shown in Fig. 17.

At *a* the aerial is coupled via a small fixed condenser, C_1. The reason it is not directly coupled is that the aerial has a fairly high capacity, and would have a big effect on the tuning of the circuit L_1, C_2. This would not matter if there were only the one tuned circuit, but, as we have seen, there may be a number of such circuits in a receiver, and in order to simplify tuning they must all be tuned by the operation of a single knob. The circuits are then said to be "ganged" together, and they must all have similar characteristics.

If we connected the aerial direct to L_1, C_2, this circuit could not be easily ganged with the others. Hence we make the aerial coupling as small as possible and, although this reduces the input somewhat, it assists in making one-knob tuning possible. It also makes the receiver more or less independent of the type of aerial employed, as far as tuning is concerned.

Another method of coupling is shown at *b* in Fig. 17, where the coil L_2 in the aerial circuit is in-

ductively coupled to the tuned circuit L_3, C_3. This has similar advantages to those of the other circuits. L_2 and L_3 really form a radio-frequency transformer with a tuned secondary winding.

Ganged Tuning

So far we have not considered how we can make the tuning variable, to enable us to select any one
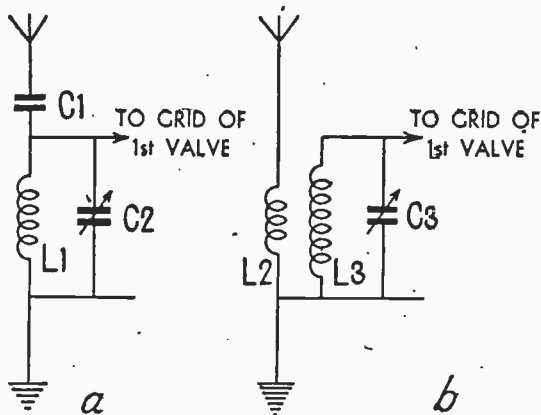
Fig. 17. Two methods of coupling the aerial to the first tuned circuit of a set, (a) by a small series capacity, C_1, and (b) by a winding, L_2, inductively coupled to the tuned coil, L_3. Both methods are described on this page.

of a wide band of frequencies. Since a tuned circuit consists of a coil and a condenser, we can tune by altering either the inductance of the coil or the capacitance of the condenser. Both methods are, in fact, employed, but in the ordinary radio-frequency circuits it is usual to employ a fixed coil and a variable condenser.

The modern type of variable condenser consists of a stator, into which a bank of similarly spaced vanes (the rotor) can be caused to mesh by turning a knob. When the rotor and stator are completely out of the mesh, the condenser is at its lowest capacity (usually
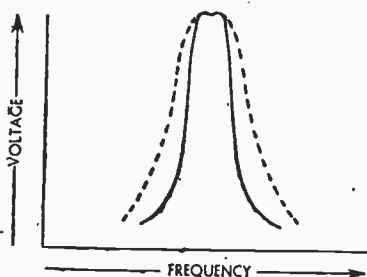
Fig. 20. A band-pass curve (full line) compared with that of a single tuned circuit (dotted). Note the steeper sides but flatter top giving better selectivity and at the same time wider audio-frequency response.

full-line curve shows "band-pass" characteristics—that is, it will pass a signal of a certain band-width

such as when the two tuning coils at *a* are inductively coupled to each other.

Having selected our station at the tuned input stage of the set, where it produces a voltage across the tuned circuit, we are now in a position to amplify it with the aid of a suitable valve. Valves are dealt with in Chapter 16, so we shall not go deeply into their theory here.

The simplest type of valve which can be used for amplifying is the triode, consisting of a filament (or heater-cathode assembly in the case of an indirectly heated mains valve), a grid and an anode. This is shown at *a* in Fig. 22. Unfortunately, the triode is
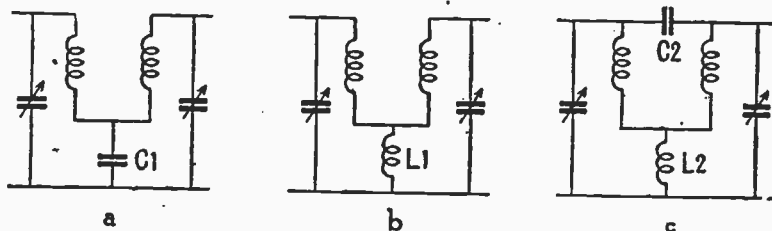
Fig. 21. Three typical forms of band-pass circuit as used for a single waveband and showing different types of coupling.

without attenuation, but outside this frequency band, on either side, the cut-off is abrupt.

Typical two-stage band-pass circuits are shown in Fig. 21. At *a*, the two tuned circuits are coupled by virtue of the fact that condenser C_1 is common to each of them. At *b*, the coupling is by the common reactance of the coil L_1, while at *c*, coupling is by the reactance of L_2 and also by C_2. *a* represents capacitive coupling, *b* represents inductive coupling and *c* is a combination of both, known as "mixed coupling". Mixed coupling can also take other forms,

not very suitable for RF amplification, owing to the fact that there is a small but definite capacity between its grid and anode which causes feed-back at radio frequencies and also causes instability of the circuit.

Consequently a special form of valve, with a screen between the
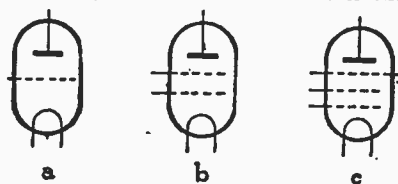
Fig. 22. Symbols representing triode, tetrode (screened-grid) and pentode valves.

grid and anode which reduces the anode–grid capacity, was developed for RF amplification. This is shown at *b* in Fig. 22, and is known as a screened-grid valve, or a screened tetrode. The electrode nearest the filament is the control grid, as in a triode, while the electrode between this and the anode is the screen.

The screen is usually fed with a positive voltage less than that of the anode, and is connected via a large condenser to earth. Otherwise it does not enter into the circuit at all.

Screened Pentode

The screened tetrode is quite satisfactory for RF amplification, and has been used in many receivers. It is now often replaced, however, by a screened RF pentode. This contains one more electrode, as shown at *c* in Fig. 22. The new electrode is called a suppressor, and is situated between the screen-grid and the anode. It is usually connected to earth, and its function is to get rid of the effects of what is known as "secondary emission" from the anode, whereby in an ordinary screened tetrode the shape of the anode current curve is so altered that distortion may occur with large signals in the anode circuit.

In normal RF practice this state of affairs does not occur, but nevertheless the screened pentode (which also has the advantage that its amplification can be made higher than that of a tetrode) is now in general use.

So far we have mentioned what may be termed normal RF tetrodes and pentodes. The amplification obtainable from these can be varied by altering the positive voltage applied to the screen; variation in the anode voltage within limits has little or no effect. This suggests a method of controlling the amplification of the RF amplifier stage, as shown in Fig. 23.

R is a potentiometer across the HT supply, from which varying voltages can be obtained for the screen. *C* is the screen by-pass condenser.

This arrangement works satisfactorily as far as controlling
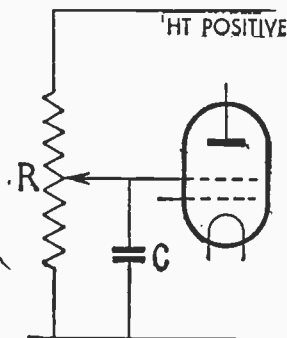
Fig. 23.—Controlling the amplification of a screened tetrode by altering its screen voltage.

amplification is concerned, and therefore operates as a pre-detector volume control.

Distorted Signals

This arrangement has certain disadvantages, however. The chief one is that as the screen voltage is reduced, which also reduces the amplification of the valve, the signal which can be handled without distortion is also reduced. As we shall usually need to reduce the amplification mainly for a powerful signal, this signal will not be handled by the valve without distortion, which is unsatisfactory.

What is needed is a valve with controllable amplification which, as the amplification is reduced, will also handle a larger signal.

For this purpose a special "variable-mu" valve is generally used, "mu" being the Greek μ, representing amplification factor. This valve is constructed so that the negative bias on the grid controls the amplification factor.

Bias Control

With a large negative bias the amplification factor is lowered; with a small or zero bias, full amplification is obtained. At the same time, the large bias used for minimum amplification also permits the valve to handle a large input signal on its grid without overload
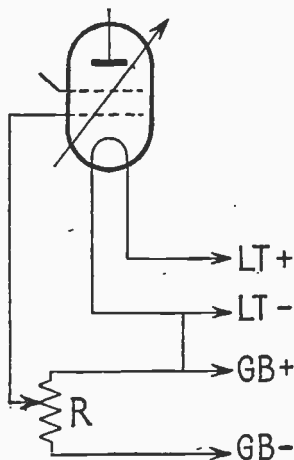

Fig. 24. A variable-mu tetrode or pentode has its amplification ·controlled by varying the negative bias which is applied to the grid.

or distortion. Variable-mu tetrodes and pentodes are available, the latter being most popular to-day.

Fig. 24 shows one method of varying the bias on a variable-mu screened pentode. Occasionally, variable-mu properties are indicated by an arrow drawn through the valve diagram. Between GB+ and

GB— is a grid-bias battery, and R is a potentiometer connected across this. The moving contact of the potentiometer goes to the grid of the valve, which can thus be given a bias, relative to LT negative, of anything from zero up to full negative voltage of the bias battery.

Having seen the types of valve used for radio-frequency amplification, we must now consider the complete stage. The principle of amplification in any valve is that the signal is applied to the control grid, and the variations in the voltage on this grid produce corresponding variations in the anode current through the valve. This anode current, of course, flows through the external circuit, which is connected to the anode.

The RF Stage

If now we place in the external anode circuit a resistance or an impedance, usually termed the "load", the variations in the anode current through the load will produce a corresponding variable voltage across the load. So, by applying a variable voltage, which may be our signal, across the grid circuit of the valve, we produce a signal across the anode load which will be identical in form with that on the grid (providing that the valve is free from distortion), but, owing to the amplification factor of the valve, will be many times as great. In other words, the signal has been amplified.

While a resistance or an untuned inductance could be used as a load in an RF amplifier (a condenser would not do, since it would prevent the HT voltage reaching the anode), it is more usual to employ a tuned circuit or a tuned transformer to couple the anode circuit to the next valve (which may be
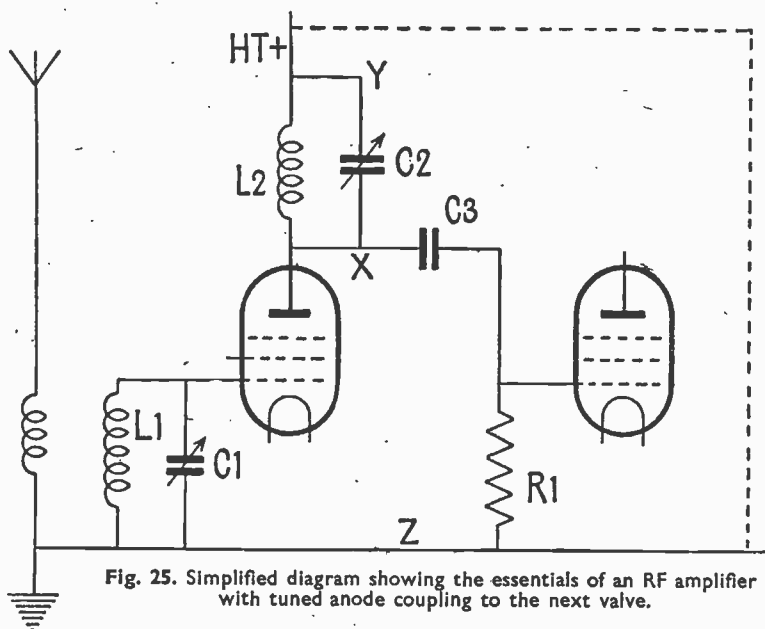
Fig. 25. Simplified diagram showing the essentials of an RF amplifier with tuned anode coupling to the next valve.

another RF amplifier or the detector of the set).

Fig. 25 shows a skeleton RF stage employing a single tuned input circuit L_1, C_1, and a tuned anode circuit L_2, C_2 coupling the RF valve to the next stage. The RF voltage across the parallel circuit L_2, C_2 is also present between the anode of the valve and earth, since, as far as RF is concerned, the HT supply circuits are effectively at earth potential. This is indicated by the dotted line.

The RF voltage between X and Y is, to all intents and purposes, also between X and Z, whence it can be applied across the grid circuit of the next valve. It is essential, however, that the DC anode voltage of the first valve does not reach the grid of the next valve, and we therefore insert condenser C_3 in the position shown to isolate the grid of the second valve from

DC from the first stage. C_3, of course, is high enough in value to present no barrier to the RF voltages. R_1 is necessary, in lieu of any other connection between grid of the second valve and earth, to permit bias to be applied to this valve, which otherwise would not work.

Transformer Coupling

Fig. 26 shows another popular form of RF amplifier circuit using a transformer coupling between the two valves. L_1, C_1 is the tuned circuit, as before, while L_2, L_3, C_2 form the coupling. L_2, which may be regarded as the untuned primary winding of the transformer L_2, L_3, is in series with the anode circuit of the first valve, and acts as the load.

The amplified RF voltage across L_2 is transferred to the tuned secondary circuit L_3, C_2 by reason of the inductive effect between L_2

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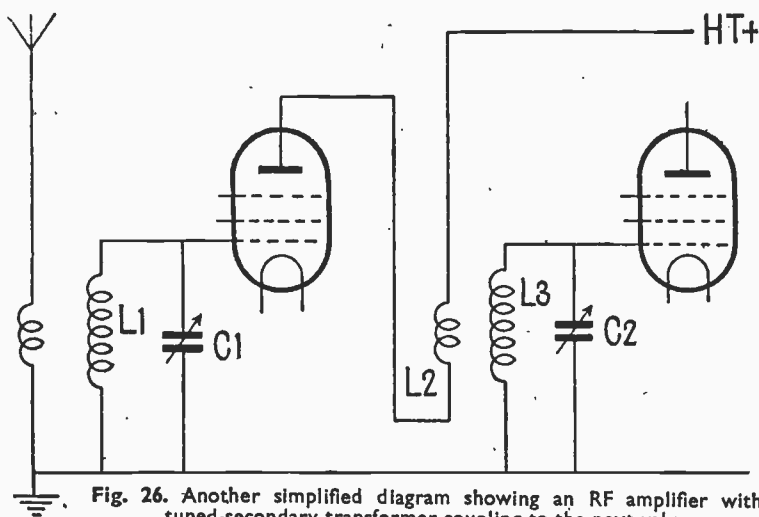
Fig. 26. Another simplified diagram showing an RF amplifier with tuned-secondary transformer coupling to the next valve.

and L_3, which are coupled together. Note that the intervalve coupling here is very similar in form to the aerial coupling coil and the tuned input circuit.

Ganged Circuits

The pairs of tuned circuits shown in Figs. 25 and 26 are always ganged together in modern sets, and, of course, coil switching for different wavebands in the intervalve couplings is as necessary as it is in the case of the tuned input circuits (see Fig. 19a).

Despite the comparative freedom from instability in modern RF amplifier circuits using screened tetrodes or pentodes, it is usual to limit the stages of RF amplification to two, and very often there is only one stage. If two stages are used this will involve another coupling between the second and third valves, and hence another tuned stage, making three in all, or four if the input circuit is of the band-pass type. Four sections is about the limit for a ganged variable condenser, and modern sets rarely employ one having more than three sections.

After the incoming signal has been amplified by one or two RF stages it is still in the same form as it was when picked up by the aerial (assuming no distortion or side-band cutting in the RF amplifier), but of considerably greater voltage. The next step is to take our amplified signal and remove the AF (audio, or low, frequency) modulation from the carrier. We have no further use for the latter, so it is discarded, but the AF modulation is retained for additional amplification. The removal of the modulation is known as "detection" or "demodulation", the latter being the more accurate description.

Crystal Detectors

Although in the early days of broadcasting it was customary to use the rectifying effect of certain types of crystal for demodulation, the crystal detector, as it was

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called, lost its popularity when valves began to be developed for use in receivers. Nevertheless, crystal detectors operated by virtue of the same characteristics as that possessed by the valve type of demodulator—namely, the ability to conduct a current passing through them more easily in one direction than the other.

Handling Large Signals

The simplest form of valve demodulator is the diode, a two-electrode valve with a filament (or heater-cathode assembly) and an anode. This is not largely used in TRF receivers, since it is not so sensitive as other types, and does not operate well with small inputs. It has the advantage of being able to handle large signals without overload and distortion, and is therefore used almost exclusively in superheterodyne receivers, as we shall see later.

Diode Demodulation

It is necessary here to present a simple picture of what takes place in the demodulator section of the receiver. Fig. 27 represents the simplest diode demodulator circuit. The diode does not conduct until its anode is made positive relative to the filament or cathode, since only then can electrons from the filament reach the anode. Since the diode is virtually in parallel with the tuned circuit L_1, C_1 preceding it, the signal voltage is applied between anode and filament of the diode, via the resistance R, across which is a small RF by-pass condenser C_2. The incoming signal is of the form shown in Fig. 28, and consists of an RF carrier modulated at audio frequency.

Since the diode only conducts when its anode voltage is positive,
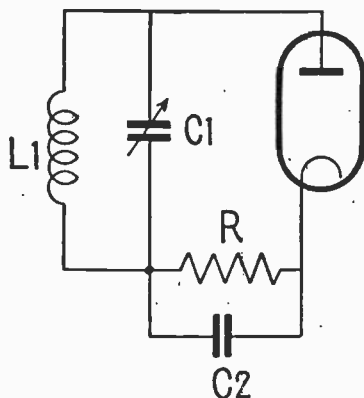
Fig. 27. The simplest diode demodulator circuit. A steady voltage due to the rectified carrier and a low-frequency signal voltage appear across R–C_2.

the current through the diode will correspond to the variations of input voltage which occur *above* the horizontal base line in Fig. 28. In other words, the current through the diode will be in a series of pulses, as in Fig. 29. Since the individual pulses are occurring at radio frequency (actually, at carrier frequency), their mean value may be represented by the dotted line through Fig. 29. This is shown again in Fig. 30, where it will be seen to represent a DC voltage V, with the audio frequencies corre-
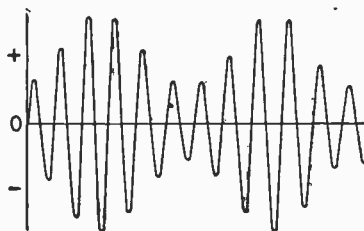
Fig. 28. Diagrammatic representation of a modulated RF signal as applied to the diode demodulator. Actually a far greater number of RF oscillations occurs during each low-frequency wave.

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Now, with the grid thus biased, if we apply our signal to the grid as well, the grid voltage will vary between C and D, the length of CD depending on the signal strength. The effect of negative peaks in the signal will be to increase the instantaneous negative bias of the valve by the amount AC; the effect of the positive peaks will be to *decrease* the negative bias by the same amount, AD.

Anode Current Changes

Owing to the shape of the curve, however, equal changes in bias on either side of A do not result in equal changes in anode current. The negative peaks reduce the anode current from OB to OE; the positive peaks increase it from OB to OF. Consequently, the net result is that when a signal is applied, the mean anode current increases by the amount $FB - BE$, and the negative excursions of the incoming signal are practically suppressed in the resultant anode current variations.

These are shown in Fig. 33, the horizontal line XX representing the anode current under no-signal conditions. The dotted line represents the mean anode current when the signal is applied, and its variations will be seen to follow the modulation of the original signal. The anode current flows through

Fig. 34. Application of negative grid bias is the main characteristic of the anode bend demodulator.
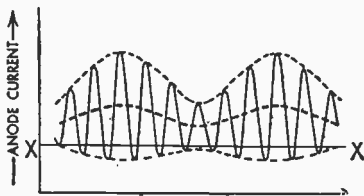
Fig. 33. Current in the anode circuit of an anode bend demodulator. The heavy dotted line shows the track of the audio-frequency variations.
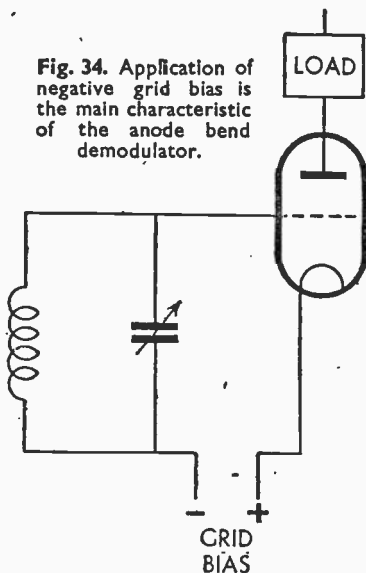
the external load in the anode circuit of the valve, producing voltage variations across it, and it is these variations at audio frequencies which are utilised in later stages in the receiver.

Owing to the amplification of the valve, the anode bend detector also amplifies the signal, but not to such a great extent as the cumulative grid detector. It will, however, handle a larger signal, and in fact is more efficient with a large input signal. Furthermore, it does not place a load on the preceding tuned circuit, as does the grid detector, in which grid current flows.

The circuit of the anode bend detector is shown in Fig. 34. Comparing this with the grid detection circuits of Fig. 31, it will be seen that anode bend detection needs no grid condenser or leak, but it *does* need the application of negative bias to the grid to enable the valve to operate around the correct

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point on its characteristic curve (X in Fig. 32).

One can always discover whether grid or anode bend demodulation is being used in a set by inserting a milliammeter in series with the anode circuit. First note the anode current when no signal is being received, then tune in a signal. If the indicated anode current falls, grid detection is in use; if it rises, the indication is that anode bend rectification is being employed.

Reaction

The demodulator stage is the point at which one can introduce an arrangement for increasing the sensitivity (and the selectivity) of the receiver, known as reaction, retro-action or positive feedback. This was almost universally employed in simple receivers a few years back, and is still used in certain modern TRF receivers.

Reaction can be used with a triode demodulator, on account of the amplification which takes place within the triode; it cannot be used with a diode, which does not amplify. At the anode of the triode there is an RF component as well as the amplified AF modulation, and if by some means a controllable portion of the RF component is fed back to the grid circuit in the same phase as the incoming signal, it enhances the signal, which in turn results in an in-

creased signal at the anode, and so on.

Carefully used, reaction can greatly improve the sensitivity of the receiver, and it also has the effect of counteracting resistance losses in the tuned circuit, and so increasing selectivity. If the feedback is increased too far, the effect will be to cause the receiver to go into self-oscillation. This phenomenon is used in certain circuits, but in a TRF receiver it must be prevented.

Fig. 35 shows a simple form of grid detection with reaction. L_1, C_1 is the tuned input circuit. L_2 is the reaction coil, inductively coupled to L_1, and wound in such a direction that the feedback is positive—that is, it increases the signal across the tuned circuit. C_2 is a variable condenser, which, by varying the reactance of the series circuit, controls the voltage fed back from the anode. In older receivers the feedback was controlled by varying the physical relation of L_1 and L_2, but the variable condenser control is now more common.
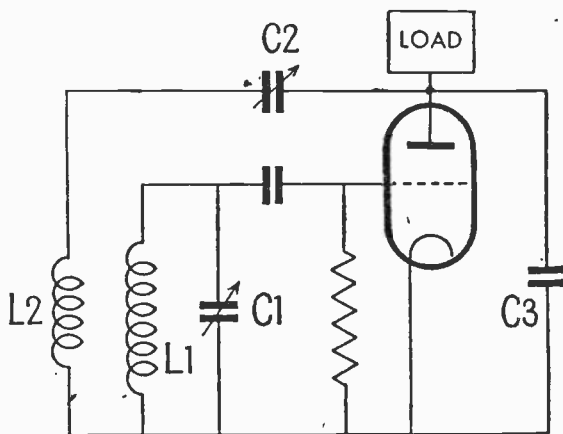
Fig. 35. Circuit of a cumulative grid demodulator (often called a leaky-grid detector) complete with capacity-controlled reaction.

developed across P is transformed to S by virtue of the inductive coupling between P and S.

Since the two windings are not in electrical contact, the HT supply is isolated from the grid of V_2, and no grid resistor is necessary, since the DC bias can be applied via the winding S. By introducing a step-up ratio between the number of turns in P and S, a useful increase in voltage between P and S is obtained; but for various reasons the ratio between P and S is rarely made greater than 1 to 5, and 1 to 3 is more common.

Class A Amplification

Now let us see what happens in the amplifier valve itself. Assuming that we are using a triode, the grid voltage–anode current characteristic for a certain anode voltage may be represented by the full-line curve of Fig. 38. It will be observed that this is straight for a
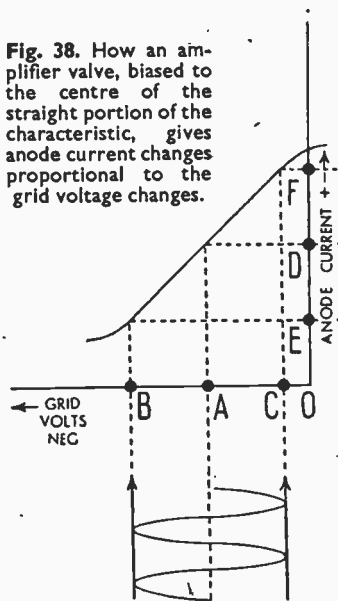
Fig. 38. How an amplifier valve, biased to the centre of the straight portion of the characteristic, gives anode current changes proportional to the grid voltage changes.

considerable portion of its length, and for distortionless amplification we must work exclusively on this straight portion, at any rate for what is known as Class A amplification, with which we are at present dealing.

Initially, the grid of the valve is negatively biased by the amount OA, which brings us to the centre of the straight portion of the characteristic, the corresponding anode current being represented by OD.

If now our AF voltage is applied to the grid of the valve (as shown at the bottom of Fig. 38), the voltage of the grid will be swung between the limits B and C, with A as the centre point, at the frequency of the incoming AF signal. The result is that the instantaneous anode current will vary from E to F, at the same frequency. Providing we operate entirely on the straight portion of the valve's characteristic, the anode current variation will be a true copy of the incoming signal variation, but the *average* anode current D will not change.

The variations in the anode current will, of course, be present in the external anode circuit, and if we insert a load in series with this circuit as shown in Figs. 36 and 37 a corresponding AF voltage will be developed across this load. Owing to the amplification factor of the valve, this output voltage will be a number of times greater than the input voltage, and so the input signal has been amplified.

An important point to note is that the grid of the valve in Class A amplification must never be allowed to become appreciably

positive, otherwise distortion will occur. The total peak grid-swing caused by the input signal must never be greater than twice the negative bias of the valve.

Various Forms of Coupling

Variations of the basic forms of AF coupling shown in Figs. 36 and 37 are common. One of these is shown in Fig. 39. This is really a combination of resistance and transformer coupling, which retains the advantage of voltage step-up in the transformer T. R is the demodulator anode load resistance, C is the coupling condenser to the primary P of the transformer, and S is the transformer secondary.

This method of coupling per-

This method of coupling is generally known as resistance-fed or parallel-fed transformer coupling.

Another form of coupling is shown in Fig. 40, and is known as auto-transformer coupling. This is similar to Fig. 39, except that the transformer T is replaced by the tapped choke L, which acts as an auto-transformer and provides a step-up in voltage across the grid circuit of the AF valve.

It is possible in all the circuits shown to replace the load resistance R, by an iron-cored choke, which acts as an inductive load, but although this may be encountered in old receivers, it is not very common to-day.
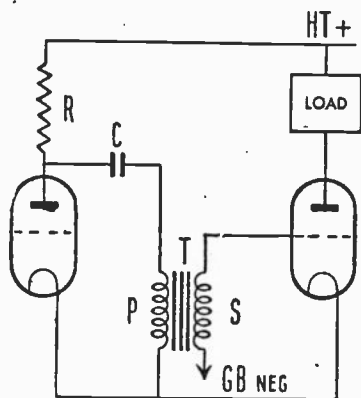
Fig. 39. Resistance–capacity fed transformer coupling. This arrangement is also called parallel-fed or parafeed coupling.
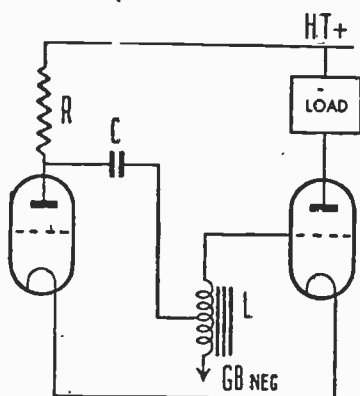
Fig. 40. Auto-transformer or tapped choke coupling.

mits the transformer to be used with no DC flowing through its primary winding (cf. Fig. 37), and this means that a relatively inexpensive transformer can be used, since there is much less chance of its core becoming "saturated" and so having its efficiency reduced, which may give rise to distortion.

As has already been seen, the result of amplifying the signal from the demodulator stage is to produce a larger signal, in the form of a voltage developed across the AF valve anode load, its magnitude depending on the type of valve used and the constants of the stage. Although this voltage may be high, the signal still contains

which opposite ends are connected to the valve anodes, while the centre-tap goes to the HT positive supply.

In this way the signals in the anode circuits which are out of phase recombine in the primary winding in the same phase, and induce the signal into the secondary of T_2, which feeds the loudspeaker.

Push-pull amplification has several advantages. The two valves will deal with at least twice the input signal which could be
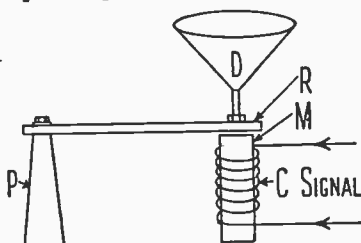
Fig. 45. In the moving-iron speaker, the reed and attached cone vibrate under the magnetic influence of the signal current which flows in the winding C round the magnet M.

handled by one of them, and, furthermore, distortion due to slight curvature of the valves' characteristics is largely cancelled out. Also, since the DC supply to each anode passes through the primary in opposite directions, it cancels out as far as saturation of the iron core of the output transformer is concerned.

Special forms of push-pull are also used in battery receivers, as will be seen later, to provide a comparatively large power output for the expenditure of the minimum HT power.

With the output stage we reach the end of the chain of receiver circuits, and our signal, in the form of AF currents, is present in

the anode circuit of the output valve. The problem is how to render these signals audible, by converting AF power into sound-waves. This was first done by the use of headphones, but as their principles were the same as those of early types of loudspeakers, we shall not consider headphones in detail.

The Loudspeaker

The earliest loudspeakers were of the moving-iron type, and Fig. 45 illustrates the basic principle. M is a permanent magnet, around which is wound a coil of wire, through which the signal currents can be passed. R is a reed of soft iron, the free end of which is over the end of the magnet M, the other end being firmly supported on the pillar P.

Matters are adjusted so that R is close to, but not touching, M. Mounted on the reed R is a diaphragm D, the movement of which produces the required sound-waves.

When no signal is passing through C, the magnet M exerts a pull on the end of the reed, which takes up a definite position. Now, when a signal is passed through C, the signal currents produce a varying magnetic field, which alternately strengthens and weakens the magnetism in M, which thus exerts a greater or lesser pull on the reed R. As a result, R moves slightly towards and away from M, at the frequency of the signal, and consequently the diaphragm D is caused to vibrate in the same way and produces sound-waves.

Fig. 46 shows a moving-iron type of loudspeaker, and it should be pointed out that various different magnet and reed systems have
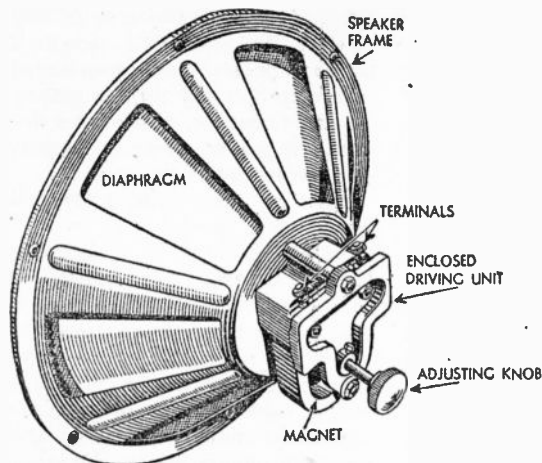
Fig. 46. A moving-iron loudspeaker showing the cone in its chassis mounting and the speaker unit itself in a bakelite housing. Compare with moving-coil type in **Fig. 47.**

other models employ permanent magnets, and so are termed PM types.

In Fig. 47, which is a section through the loudspeaker, M is the magnet, containing a field coil F, which is wound round the central pole-piece P, and is supplied with direct current, usually the HT anode current in mains sets.

The pole-piece P is actually cylindrical, and projects into a circular hole in the front face of the magnet, leaving a narrow annular gap between it and the magnet,

been used in commercial loudspeakers.

Moving-Coil Type

It was soon found that this type of loudspeaker did not reproduce low notes very well, the reason being that in order to produce a low note of reasonable power a fairly large movement of the diaphragm was necessary. The form of construction shown in Fig. 46 does not permit large movements of the reed. Although this difficulty was obviated in certain forms of construction, there was still the rigidity of the reed to be contended with.

Consequently another distinct type of reproducing instrument came into being. This is the moving-coil loudspeaker, which to-day is in almost universal use, even in the least ambitious type of receiver. Fig. 47 shows the basic principles of a moving-coil speaker of the "energised" type. The term "energised" implies that the unit incorporates an electromagnet, but

Fig. 47. Sectional diagram of an energised moving-coil speaker. The electromagnet, M, is magnetised by current through the field coil F. Signal current flows through C, a coil working in a circular gap.

across which, when the magnet is energised, there is a very strong magnetic field.

D is the conical diaphragm of
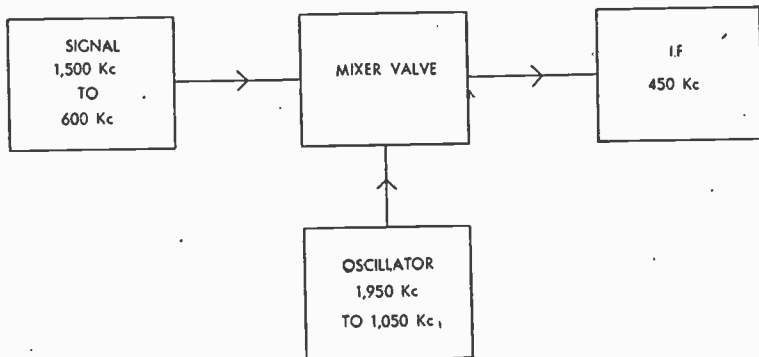
Fig. 49. Block diagram illustrating how the combination of signal and oscillator frequencies in the mixer valve produces an intermediate frequency.

cured with stability; furthermore, the selectivity of the IF stages, once adjusted, remains constant for all incoming signals.

It is obvious that some principle not yet mentioned must be used to convert variable-frequency RF signals into a fixed IF signal. This principle is known as frequency changing, and the stage in which it occurs is the frequency-changing stage.

Frequency Changing

The value of the intermediate frequency in a modern receiver is usually of the order of 450 kilocycles per second, which is equivalent to 667 metres. Suppose our incoming signal has a wavelength of 250 metres (1,200 kc.). In the frequency changer stage we have to convert the 1,200-kc. signal to one of 450 kc., and we do this by a "mixing" process.

For instance, if we mix our 1,200-kc. signal with one of 1,650 kc. we produce as a result additional frequencies of values equal to the sum and difference of these two—namely, 2,850 and 450 kc. The latter is just what we want and will be amplified in the IF stages

and the 2,850-kc. signal we can let run to waste.

The 1,650-kc. signal for mixing is produced in the receiver itself by means of an oscillator valve. This is indicated diagrammatically in Fig. 49.

If we consider one waveband of the receiver, say the medium band of 200–500 m. (1,500 to 600 kc.), it is obvious that to produce the *fixed* intermediate frequency the oscillator must be variably tuned so that it is always 450 kc. higher (or lower) than the signal circuits. For various reasons the higher value of oscillator frequency is nearly always used. The result is that in the case quoted the oscillator circuit must be tuneable from 1,950 to 1,050 kc., and furthermore, the signal and oscillator tuning must be ganged and adjusted in such a way that the 450-kc. difference is always maintained.

There are several ways in which this can be done. One is to use a special "superhet" ganged condenser in which the oscillator section has a different maximum capacity and vanes of different shape from those in the other section(s) (Fig. 49a). Another

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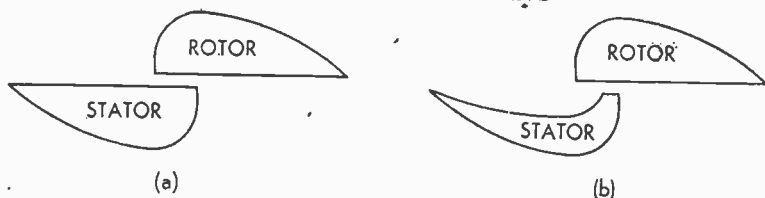
Fig. 49a. Comparison of the vanes of an ordinary tuning condenser (a) with those sometimes used for tuning the oscillator (b).

method is to use a normal ganged condenser, but to provide special "trimming" and "padding" condensers in the oscillator circuit to keep it out of step with the signal frequency circuit(s) by the desired constant amount. This

In the frequency-changer stage we can either use two separate valves for producing the "local" oscillation and mixing the two frequencies, or a special frequency-changer valve.

The oscillator valve (or the sec-
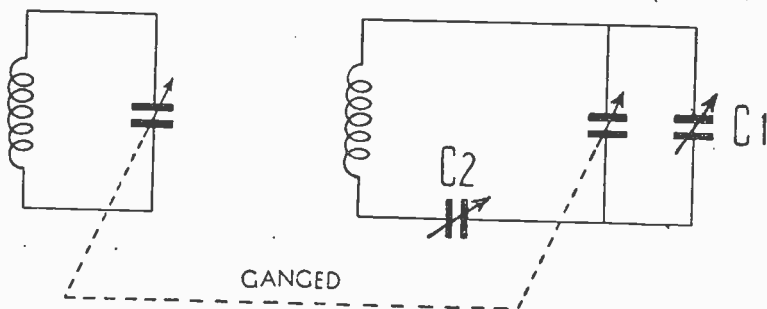
Fig. 50. In most modern sets correct "tracking" between signal and oscillator circuits is obtained by introducing trimming, $C1$, and padding, $C2$, condensers.

is shown in Fig. 50. The signal circuit is tuned as usual by one section of the tuning condenser, which is ganged with the section tuning the oscillator circuit.

$C1$ is a parallel condenser of low capacity which is adjusted initially to give the required frequency difference between the two circuits at the high-frequency end of the scale. $C2$ is a series "padder" of fairly high value, adjusted to give the correct frequency difference at the low-frequency end of the scale. The two coils will also differ in inductance. By this means fairly accurate "out-of-step" ganging can very readily be secured.

tion of the FC valve used as oscillator) is usually a triode, and Fig. 51 shows a typical circuit. $C1$ and
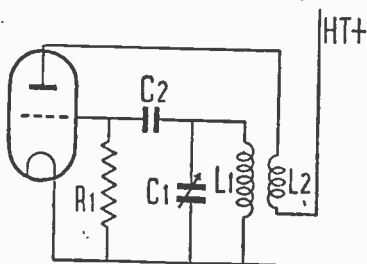
Fig. 51. Simplest form of oscillator circuit. Energy fed back from the anode to the grid by inductive coupling between $L2$ and $L1$ makes the valve oscillate at the resonant frequency of $C1-L1$.

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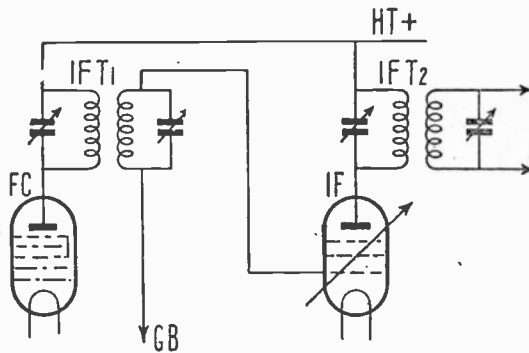
Fig. 55. "Skeleton" circuit arrangement of a complete IF amplifier stage.

which this signal is taken off for amplification in the AF amplifier. From this point onwards the superhet receiver is identical with the TRF type, so there is no need to consider the later stages again.

In actual practice the demodulator diode usually forms part of a multiple valve, either a double diode, a double diode triode, or a double diode pentode. The second diode, as will be seen shortly, is used for a special purpose, while the triode or pentode section, if present, is used for AF amplification. One example of a double diode triode circuit is shown in Fig. 57.

$R1$ is the load resistance, which actually takes the form of a potentiometer, the sliding contact of which is connected via the usual AF coupling condenser $C1$ to the grid of the triode section of the valve. $R2$ is the grid leak.

mainly in superheterodyne receivers, on account of the fact that it operates well with the comparatively large signals obtained from the IF amplifier. Since the action of the diode demodulator has already been described, it is only necessary now to see how it is connected into the superhet circuit. This is shown in Fig. 56, which should be compared with Fig. 27.

$R1$ is the load resistance (with by-pass condenser $C1$) across which the AF signal is developed. The arrow shows the point from
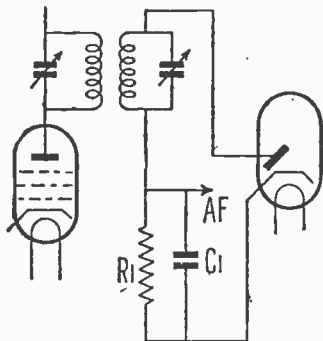
Fig. 56. Fundamental arrangement of a diode demodulator showing where AF is obtained.

Fig. 57. Diode demodulation followed by a stage of AF (audio or "low" frequency) amplification using a double diode triode valve.

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When the slider of $R1$ is at the upper end, the whole voltage across $R1$ is passed to the amplifier grid; when it is at the bottom end, no voltage is passed on. Consequently $R1$ becomes a volume control as well as a load resistance.

Battery Receivers

Now let us consider the power supply to receivers. In the case of battery receivers we have to supply the valves with low-tension current for the filaments, high-tension current for the anodes and screens, and bias voltages for the grids.

It is usual to employ valves having 2-volt filaments in battery receivers, and to connect all the filaments in parallel so that they can be operated from a 2-volt accumulator. Recently, however, 1·4-volt filament valves have been introduced which can be operated from a single dry cell of reasonable capacity, which thus enables an "all-dry" battery receiver to be designed.

HT supply is usually from a dry battery of the requisite total voltage. In the past it was the practice, in cases where certain electrodes needed lower voltages than the maximum of the battery, to provide a number of positive leads to suitable tappings on the battery. This has now been largely superseded by applying the maximum voltage to the positive " bus-bar" of the receiver circuit, obtaining the lower voltages by means of resistors such as $R1$ in Fig. 58.

By virtue of the current flowing through them, these resistors cause a voltage drop of value $V = IR$, where R is the value of the resistance in ohms and I the current flowing through it in amperes. Condenser $C1$ by-passes any undesired RF, IF or AF currents to earth, preventing them from entering the HT circuit, where they might produce undesired coup-
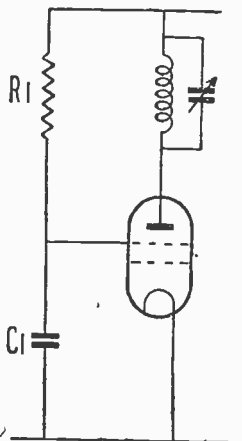
Fig. 58. Method of securing an HT voltage lower than that of the main HT line. Together with $C1$, $R1$ also prevents HF entering the HT line.
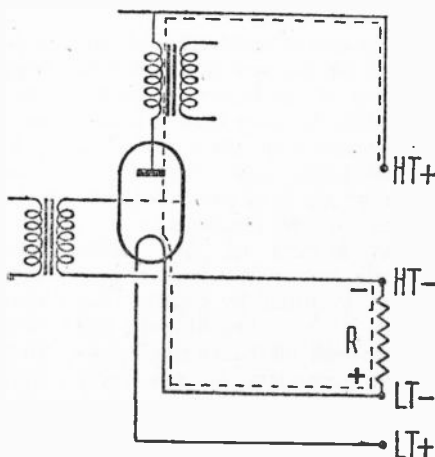
Fig. 59. In a battery receiver automatic bias can be obtained by including a resistance in the negative HT line. The voltage drop across R is introduced between grid and filament of the valve. The dotted line shows the HT current path.

illustrated in Fig. 63. R_1 is the cathode bias resistor, and C_1 is a by-pass condenser across it. Through R_1 flows the total cathode current of the valve, which is made up of the currents taken by all the valve electrodes—anode, screens, etc.

Effect of Current

The effect of the current flowing through R_1 is to cause a voltage drop across it, so that the cathode is positive to the chassis. Since the grid circuit is returned to chassis, the cathode is thus made positive relative to the grid, which is the same as the grid being negative to the cathode. Thus the grid is negatively biased by the amount of the voltage drop across R_1. By choosing different values of R_1 any desired bias can, therefore, be readily applied to the grid.

them across the mains, via a "ballast" resistance which reduces the mains voltage to the correct value.

Under these conditions one can use valves having different heater voltages, if desired, but all the heater currents must be the same. The circuit is shown in Fig. 64, where R_1 is the ballast resistance (Fig. 64a.) The valve heaters are usually connected in some definite order to reduce the tendency for hum to be introduced. One side of the mains is connected to the chassis of the receiver, and the latter is earthed via the buffer condenser C_1.

The circuit for HT supply uses a half-wave rectifier of which the heater is included in series with those of the other valves. The anode of the rectifier goes directly to one side of the mains, while from
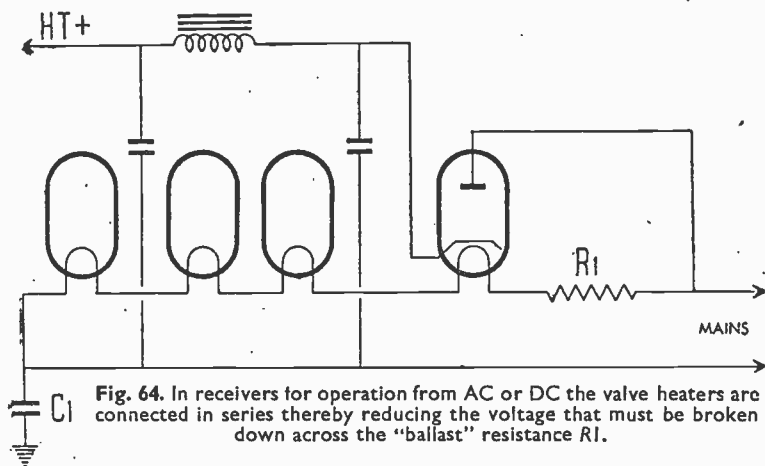
Fig. 64. In receivers for operation from AC or DC the valve heaters are connected in series thereby reducing the voltage that must be broken down across the "ballast" resistance R_1.

Many receivers operate from either AC or DC mains, and their power-supply arrangements are different from those for AC only. The heater supply is obtained by connecting all the heaters in series, and connecting

the cathode is taken the rectified current (when the set is used on AC), which is subsequently smoothed as in the case of purely AC receivers.

When the receiver is used on DC mains, of course, no rectifier

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It will be remembered that in dealing with RF amplifier stages (page 52) it was pointed out that the gain or amplification of these could be conveniently controlled by varying the bias of the amplifier valve, providing that this was of the "variable-mu" type, and that such variation in the gain could be used as a form of volume control.

Bias Regulation

Automatic volume control operates by controlling the gain of one or more stages of the receiver; in fact, it is more correctly described as "automatic gain control". It·is applied almost exclusively to the superheterodyne type of receiver, although TRF receivers could be provided with the same feature if they were sensitive enough to make it necessary.

Since the gain of a variable-mu valve is controlled by the bias, being greatest when the negative bias is reduced, and vice versa, the problem is to provide a negative bias which rises and falls with the strength of the incoming signal. Then, if the signal increases in strength, an increased negative bias is applied to the controlled stages, thus reducing their gain, so that the output from the receiver does not change. Conversely, if the signal fades, the control bias falls, the amplification of the set increases, and the output still remains steady.

The control voltage must be DC for bias purposes, and to obtain it we rectify the carrier wave of the signal at a point in the set where it has been amplified sufficiently. This is usually at the output of the IF amplifier, where, in fact, the signal is also demodulated for AF purposes.

Fig. 64a. A wire-wound ballast resistance on a tube of ceramic material with metal bands forming tappings for the different heater voltages.

is really necessary, only smoothing being required. Nevertheless, the rectifier valve remains in circuit, and when the set is plugged into the DC mains in such a way that the rectifier anode is connected to the positive of the mains, the valve conducts, and, in fact, merely behaves as a resistance of low value.

Automatic Volume Control

One important feature of modern receivers is known as automatic volume control, or AVC. Originally introduced to counteract the fading effects of distant stations, it also has the advantage that overloading of the receiver by powerful signals is obviated.

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Sometimes the same diode valve which demodulates the signal is also used to provide the AVC bias, as shown in Fig. 65. R_1 is the usual diode load resistance, with its IF by-pass C_1. The AF signal is led off via the coupling condenser C_3 to the AF amplifier.

However, the voltage across R_1 actually consists of the AF signal

we take their grid return leads to the AVC bias line, the grids will be negatively biased to an extent depending on the strength of the signal.

The connection of the bias line to the grid return circuit is also shown in Fig. 65. R_3 is a cathode resistance which applies a small fixed bias to the valve. This is
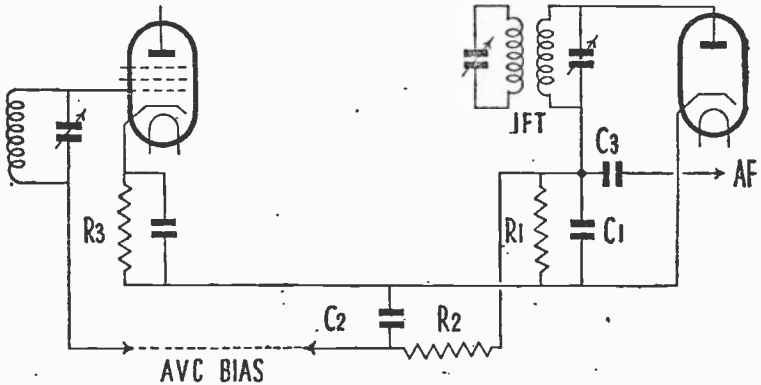
Fig. 65. Simplest form of AVC circuit showing how the control bias is applied to a preceding RF or IF amplifier. Connection of bias line to grid circuit is also shown.

superimposed on DC due to the rectification of the amplified carrier of the incoming signal. This DC voltage is naturally blocked by C_3 from entering the AF amplifier, but can be taken off, via resistance R_2, to provide the required AVC bias. R_2 and C_2 filter off any residual IF and RF voltages, and prevent them from being fed back to the early stages, where they might cause the receiver to become unstable. In addition, they tend to smooth the DC which is obtained from the top of R_1.

This DC is negative relative to the cathode of the diode, which is at chassis potential, so that if the cathodes of the controlled valves are also at chassis potential, and

necessary, because with very weak or zero signals the AVC bias will be negligible, and without the minimum bias provided by R_3 the valve might become unstable.

AVC Bias Control

AVC bias can be used to control one or more of the stages of the receiver prior to the demodulator, providing that the valves used are of the variable-mu type. In a simple superheterodyne receiver the mixer section of the frequency-changer and the IF valve are usually controlled—that is, their grid returns are taken to the AVC bias line. Sometimes one valve receives the full bias voltage, while the other receives only a fractional portion of it.

The method of obtaining AVC bias just described is the simplest one, and it is more usual to employ a separate diode rectifier for this purpose. Double-diode and double-diode-triode valves are commonly employed, one of the diodes being used for demodulation as already described, and the other for AVC purposes.
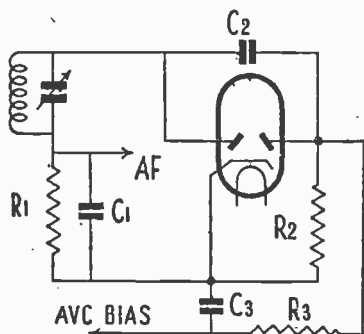
Fig. 66. A double diode valve providing both signal demodulation and simple AVC rectifier.

Fig. 66 shows a simple double-diode circuit, the left-hand diode anode being used for demodulation, with R_1 and C_1 as usual. The right-hand diode, fed from the final IF transformer via condenser C_2, is the AVC rectifier, with R_2 as its load resistance. The DC voltage at the top of R_2, which is negative relative to chassis, is passed to the controlled valves via resistance R_3. R_3 and C_3 correspond to R_2 and C_2 in Fig. 65.

Both arrangements described provide what is known as simple AVC. This suffers from the disadvantage that even very weak signals will produce a control voltage and will, therefore, be further attenuated by the reduction in gain which this control voltage produces. To avoid this difficulty, matters are generally arranged so that for signals below a certain value the AVC action is prevented from operating. Such a system is known as "delayed" AVC, and a simple form of it is shown in Fig. 67.

Comparing this with Fig. 66, it will be seen that a double diode triode is used in place of a double diode, and is provided with a bias resistance R_2 for the triode section. The AVC load resistance is returned to chassis, as before, but the signal diode load resistance is returned to the cathode of the valve, and not to chassis. The signal diode does not receive any bias from R_2, and operates as in Fig. 66. The AVC diode anode, however, being returned to chassis, is negatively biased, relative to cathode, by the voltage which exists across R_2.

When a small signal arrives at the signal diode, it is demodulated as usual; the same signal, applied to the AVC diode anode, is not rectified if its positive peaks are too
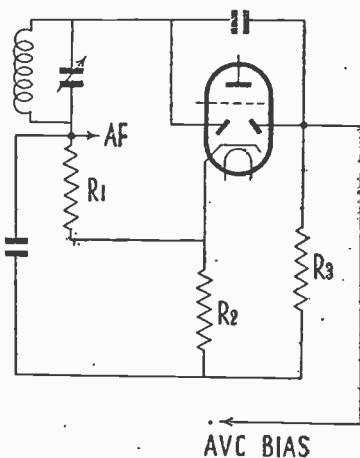
Fig. 67. Simple form of delayed AVC, using a double-diode triode.

small to overcome the negative bias of the anode. Thus all signals with positive peaks below the voltage existing across R_2 produce zero control voltage, and the AVC is inoperative. Signals greater than the delay voltage overcome the delay, and produce an AVC bias proportional to the amount by which they exceed the delay.

Securing Delay Voltage

In cases where a double-diode valve is used, the necessary delay voltage is secured by returning the cathode of the valve to the cathode of another valve which has a suitable bias resistance. The valve following is generally employed for this, and sometimes the connection is made to a tapping on its bias resistance to provide the requisite amount of delay voltage.

Elaborate receivers sometimes employ special AVC systems, of. which one amplifies the AVC voltage before using it for control purposes. Such systems usually need an extra valve, and are not commonly found in modern British receivers, though the AVC so provided can be made to approach nearly to the ideal.

Visual Tuning Indicators

In early types of receivers the selectivity was generally so poor that tuning-in a station presented no problem—the difficulty, indeed, being how to exclude it in order to receive one on a nearby wavelength. With the increased selectivity of modern sets the accurate tuning necessary is found to present a problem to the non-technical user. The tuning of receivers having good band-pass characteristics is also difficult, because the best possible quality of reproduction is only secured when the set is tuned accurately to the centre of the transmission, and any mis-tuning results in shrill and possibly distorted quality.

Manufacturers, therefore, set about providing some sort of electrical tuning indicator to supplement the calibrated dial and pointer, which, in mass production, cannot be relied upon for a high degree of accuracy. The first type of indicator used (often in amateur receivers) was a milliammeter connected in the anode circuit of the demodulator valve.

It was seen, when dealing with this part of the circuit, that the arrival of a signal resulted in a change in value of the average anode current. With the grid leak type of circuit the anode current falls, and with the anode bend type it rises. The maximum rise (or fall) obviously occurs when the station is accurately tuned, and the milliammeter thus becomes a tuning indicator.

Accurate Tuning

In the case of a superhet receiver employing AVC, another convenient gauge of accurate tuning is available, and that is the anode current of one of the AVC controlled valves. With no signal coming in, the negative bias on the valve is low, and the anode current is high. When a strong signal arrives, the bias on the controlled valve increases, and the anode current falls. A meter of some sort in the anode circuit of the valve therefore is employed to act as a tuning indicator.

Indicators of this type have been used in commercial receivers, but, in general, the meters employed are not particularly helpful in the case of weak signals. Meters in combination with some optical

arrangement for throwing an arrow, a beam of light, or a shadow on a small screen have also been used from time to time.

Neon bulb or tube indicators have also been popular in commercial receivers and operate by the change of anode voltage of one of the AVC valves. Fig. 68 shows one arrangement which has been used. R_1 and C_1 are the anode decoupling resistance and condenser of the IF valve of the receiver. R_2 is another resistor feeding the anode of the miniature neon indicator N, the cathode of which is connected to chassis.

Neon Voltage

Matters are so arranged that under no-signal conditions the neon receives a voltage just below that necessary to make it glow. When a signal is tuned in, the AVC bias increases, so that the

Fig. 68. Indication of correct tuning may be obtained by a miniature neon lamp, N, connected as shown. As the signal increases, AVC increases the bias, thereby reducing HT current and increasing the voltage across N.

anode current falls. The voltage drop across R_1 is in consequence reduced, so that the voltage at the bottom of R_1 is increased. Thus the voltage across the neon indicator is increased, and the indicator glows, the brightness of the glow increasing with increase of signal strength.

Cathode-ray Indicator

Another type of neon indicator is of tubular shape with a cathode in the form of a metal rod. The arrival of a signal in this case causes a glow to extend up the rod, the length of the column of light depending on the strength of the signal.

In recent years a much more sensitive and accurate type of indicator has been developed and is now very largely used, to the exclusion of the other types. This is the cathode-ray or "magic-eye" tuning indicator. It really consists of a miniature cathode-ray tube, combined with a triode amplifier valve in a single glass bulb, the screen of the cathode-ray section being viewed through the end of the valve.

Internally, the cathode supplies electrons which are accelerated by a positive voltage applied to an electrode known as the "target" anode. This is coated with fluorescent material, and glows when the tube is operating.

Control Electrode

Between the cathode and the target there is a special control electrode. This electrode causes a shadow to be produced on the target screen, the shadow having sharp edges, and varying in shape according to the positive voltage on the control electrode. The triode section of the indicator is

Fig. 72a. Variable tone control is often introduced by a condenser and variable resistance in parallel with the valve.

ing to its setting. When the resistance is at its minimum position, so that its value is very low, the condenser has its maximum effect on the circuit. As the resistance is increased the effect of the condenser is gradually decreased, until, with the resistance at maximum, the effect of the combination on the tone of the receiver is negligible.

Instead of a fixed condenser and variable resistance, a variable condenser may also be employed for tone control. Furthermore, the tone control can be applied in different parts of the circuit—for
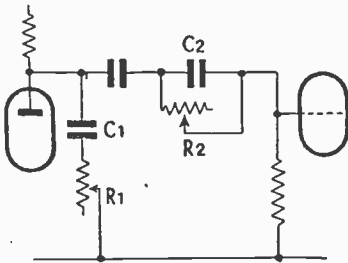
Fig. 72b. Simple additions to a resistance-coupled amplifier which provide variable control of the response in the treble ($C1$, $R1$) and the bass ($C2$, $R2$).

instance, between the grid of one of the AF valves and the chassis.

Some receivers have elaborate tone-control circuits employing special filters which modify the upper or the lower register, or both, at will.

It will be remembered that when considering the selectivity of a receiver it was pointed out that a compromise usually has to be made between selectivity and quality. If the selectivity is high, the modulation sidebands are cut, and the upper register suffers; on the other hand, if the selectivity is reduced, all the sidebands are received and the upper register is normal. This immediately suggests a method of tone control, which is used in certain modern receivers. The method adopted is to vary the coupling, mechanically or electrically, in one or more of the intermediate frequency transformers.

Mechanical Variation

The mechanical method is illustrated in Fig. 73. $L1$ is the primary, and $L2$ the secondary of an IF transformer. By sliding or rotating $L2$ relative to $L1$, the coupling between the two can be varied. With "tight" coupling the response curve is broadened, the selectivity is reduced, and the upper register response is increased. With loose coupling, high selectivity is secured and the upper register is reduced.

Various electrical methods can be employed for altering the effective coupling in the IF transformer. One is shown in Fig. 74, in which the extra coupling coil L can be switched in or out of circuit, giving two degrees of coupling between the primary and secondary of the transformer. This
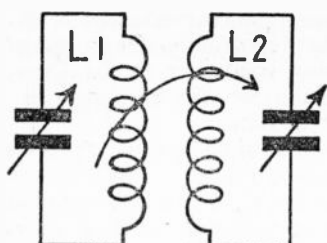
Fig. 73. Circuit representation of mechanical control by varying IF coupling.

Fig. 74 (*right*). Electrical method of selectivity control obtained by switching in extra coupling turns, *L*.
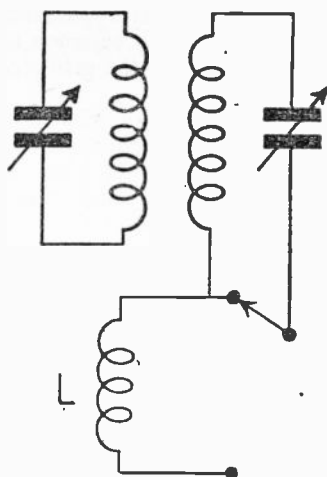
form of control is not continuous, and gives merely the two alternative effects.

"Negative feedback" is a form of tone compensation sometimes employed to improve the quality of reproduction in a receiver. A portion of the voltage available in the output circuit is fed back to the input of a preceding valve in opposite phase to the incoming signal, so that it reduces its value.

If certain notes are over-emphasised in the AF amplifier, they feed back a larger signal than the remainder of the AF output, with the result that the frequency which is over-emphasised is reduced in value relative to the rest of the incoming signal, and this compensates for the excessive amplification at this frequency. The overall response thus tends to be levelled. The use of negative feedback also has the advantage of improving the stability of an amplifier.

A simple method of introducing negative feedback is shown in Fig. 75. Here the voltage across the secondary of the output transformer is fed back across the low-resistance R_1 in the cathode

circuit of the first AF valve. R_2 is the usual bias resistance.

It is also possible to feed back to the grid circuit of a preceding stage, providing that the signal fed back is in opposite phase to the signal on the grid.

Finally, it may be pointed out that the omission of a by-pass condenser across the bias resistance of an amplifier valve intro-
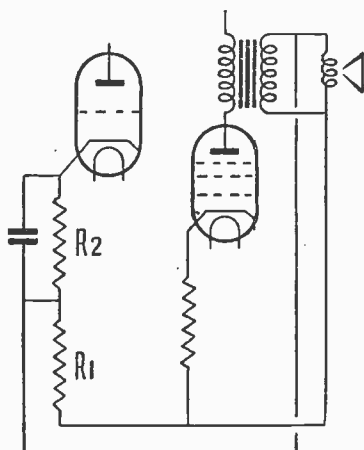
Fig. 75. One method of employing negative feedback for tone compensation.

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the spindle causes one spiral electrode of the condenser to mesh into another. The press-button then operates a simple plunger system which presses the gang condenser spindle forward to cause the electrodes to mesh to the correct degree for a given station (Fig. 76b).

Finally, before leaving mechanical systems, mention must be made of another group which, in place of press-buttons, uses dials to pull round the tuning condenser to pre-set stops—something on the lines of those used in an automatic telephone dial.

Pre-tuned Circuits

The second form of automatic tuning receiver is that which makes use of pre-tuned circuits for different stations, any one of which can be selected, as required, by press-button switches. This system is usually applied to receivers which employ only two or three variably tuned circuits, such as a simple superheterodyne with merely a tuned aerial input circuit and a tuned oscillator circuit.

It is obvious that with a single tuning coil and a number of condensers, each of which can be placed in parallel with the coil at will, one can, by suitably choosing the value of each condenser, select a number of stations. For station selection purposes the condensers are usually made semi-variable, and are of the pre-set type, which are adjusted once when a station is selected, and then do not need to be touched until it is desired to set up this particular circuit for some other station.

In order to keep the tuning of a particular circuit dead accurate over a long period of time, it is clear that the capacity of the pre-set condenser must not change. This is particularly important in the case of the oscillator circuit tuning; it is less essential in the aerial circuit, where tuning is not so critical.

It is customary in the oscillator circuit to employ pre-set condensers of a special form of construction which do not alter in capacity with change in temperature or humidity.

A typical pre-set automatic tuning arrangement is shown in Fig. 77. L_1 is the aerial tuning coil and C_1 the usual manual tuning condenser, brought into circuit by the closing the switch S_1. L_2, C_5 and S_5 are the corresponding components in the oscillator circuit. C_1 and C_5 are, of course, the two sections of the gang condenser.
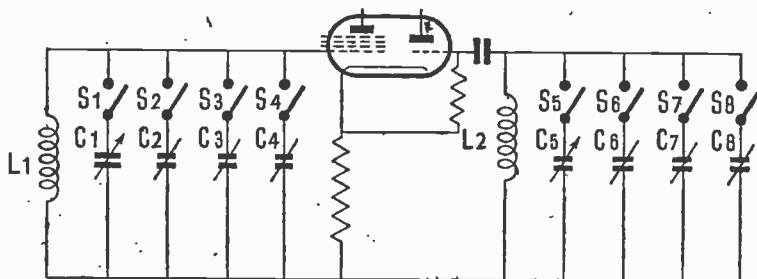
Fig. 77.—Basic arrangement of a pre-set automatic tuning system. Each pair of condensers C2, C6, etc., tune the coils L1, L2 to a station.

$S1$ and $S5$ are also ganged together and operated by one of the press-buttons, usually labelled "Manual". When this is pressed, manual tuning can be carried out in the usual way.

$C2$, $C3$, $C4$ and $C6$, $C7$, $C8$ are the aerial and oscillator pre-set condensers enabling three stations to be automatically selected. Obviously, any number of pairs of condensers could be used. Each

connecting tags. By suitable choice and positioning of the moving and fixed contacts, many switching operations can be catered for.

Fig. 78 shows a typical push-button switch unit. A feature of all these units is that when a button is pressed, any button which has previously been operated is automatically released, so that it is impossible to have two buttons in the "in" position at the same time.
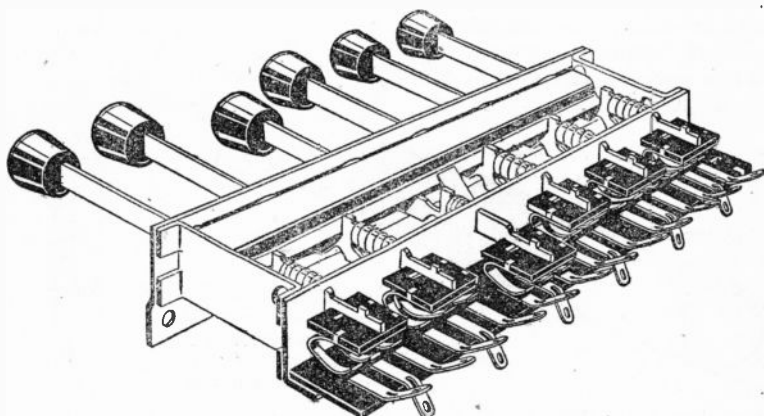
Fig. 78. A push-button switch unit showing the sliding and fixed contacts. Note the return springs on the button shafts, which are automatically released.

condenser is brought into circuit, across $L1$ or $L2$, by switches $S2$, $S6$, $S3$, $S7$ and $S4$, $S8$. These pairs of switches are ganged, and each pair is controlled by one press-button, labelled with the name of the station it tunes in.

The press-button switch unit is of a special type, the button being at the end of a plunger which terminates with a contact shoe, forming the moving element of the switch. This may carry a number of spring contacts, which slide over suitable metal strips forming the fixed contacts. The latter are mounted on strips of insulating material, and are provided with

Owing to the need for extreme accuracy of tuning of the oscillator stage, and therefore the importance of absolutely unvarying electrical constants in this stage, the fixed inductance $L2$ (Fig. 77) and the pre-set condensers $C6$, $C7$, $C8$ are now usually replaced by variable inductances for each pre-selected station, in combination with a fixed condenser.

The inductances used for this purpose consist of a coil on a hollow former, into which is fitted a core made of special iron dust mixed with a suitable binding material and moulded to the required shape. Arrangements are

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mains transformer and M the motor, with windings 1, 2 and 3, which drives the spindle of the ganged condenser C through a reduction gear. The spindle is extended at the other side of the condenser and carries a selector disc, made up of two metal semi-circular sectors $D1$ and $D2$, which are entirely insulated from each other.

A semi-circular rail R carries a number of spring contacts X, Y, Z which can be moved to any required position for the reception of a particular station. These contacts press on one of the sectors $D1$ or $D2$, according to their position, and make electrical contact with it. The contacts are insulated from each other and from the rail

R. $S1$, $S2$ and $S3$ are the three press-button switches, each associated with one of the contacts.

In the position shown, $S2$ has been closed, and its contact Y is pressing on the insulation between $D1$ and $D2$, so that the circuit is broken. Now suppose the button controlling $S1$ is pressed, closing $S1$ and opening $S2$. The circuit from one side of the secondary of transformer T is via $S1$ and contact X to sector $D2$, which is connected (via a flexible lead) to winding 3 of the motor, then via winding 1 to the other side of the secondary of T. Consequently the motor circuit is completed, and the motor runs, driving the tuning condenser (and the selector disc) clockwise until the insulating bar between $D1$ and $D2$ comes under contact X. This breaks the circuit and stops the motor, so that the station controlled by this button is tuned in.

If now the button controlling $S3$
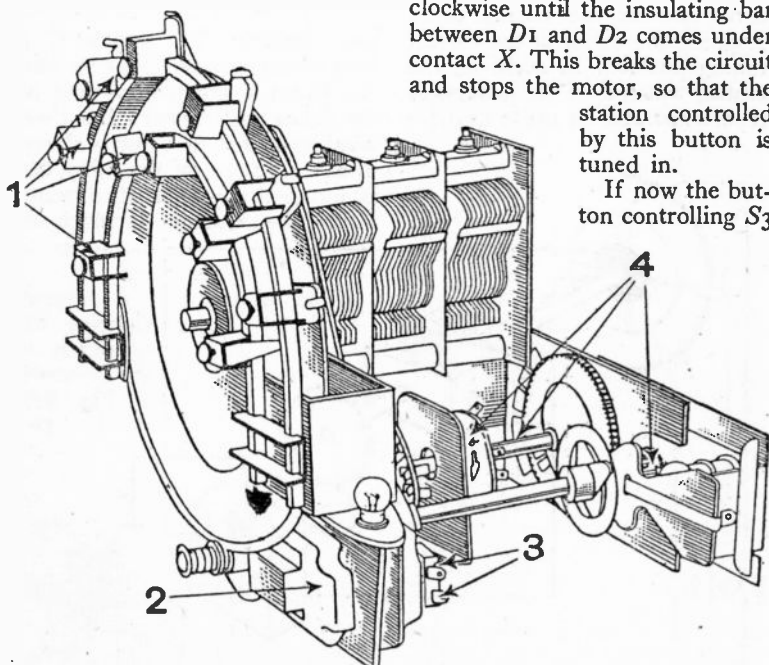
Fig. 81c. Mechanical layout of a motor-driven automatic tuning system (as used by Ekco) which performs both station and waveband selection. I, station selector contacts. 2, motor. 3, muting switch contact. 4, wavechange switches and selector mechanism controlled by pressing one button.
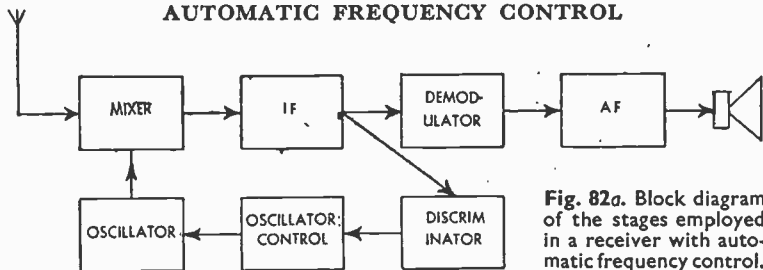
Fig. 82a. Block diagram of the stages employed in a receiver with automatic frequency control.

is pressed, S_3 closes and S_1 opens. The circuit is now via S_3, contact Z, sector D_1, motor windings 2 and 1 and the other transformer secondary. This time the motor runs in a direction to turn the condenser anti-clockwise (since motor winding 2 instead of 3 is in use). In due course the insulating bar between D_1 and D_2 comes under contact Z, breaks the circuit and stops the motor, when the station controlled by this particular button is tuned in.

By placing the contacts at various points on the rail R, any stations can be selected, and will always be tuned in when the button controlling the switch associated with a particular contact is pressed.

This, without going into details of refinements, is the principle of the motor-driven system, but it may be mentioned that automatic combined waveband switching and station selection can be achieved in a similar way merely by pressing one button (Fig. 81c).

One refinement which is often used in motor-driven receivers is known as automatic frequency control (AFC) or automatic tuning correction. The difficulty with the motor-driven system is that it is very difficult to cause the motor to stop the tuning condenser *exactly* at the right position, with the result that the station may be slightly off tune.

When this is so, the AFC circuit comes automatically into operation, and corrects the tuning of the oscillator circuit of the receiver by an electrical method which does not involve altering the setting of the tuning condenser.

A simple description of how this circuit operates is as follows. Suppose when the tuning condenser reaches its final position the oscillator circuit is 5 kc. off tune. The IF signal produced will also be off tune by the same amount, which, of course, will result in very bad distortion. When AFC comes into action it increases or decreases the oscillator frequency by 5 kc. and so causes it to produce the correct IF signal.

The adjustment of the oscillator circuit can be achieved in several ways using an oscillator control stage, which usually employs one valve. While the oscillator control stage alters the tuning of the oscillator circuit suitably, it is clear that this stage must be fed with some sort of signal which indicates to it whether the oscillator frequency is correct, and if not, the extent of error, and whether it is above or below the correct oscillator frequency. Another stage is used for this purpose, known as the discriminator, and this also employs an extra valve. Fig. 82a shows the schematic diagram of a receiver fitted with AFC.

The discriminator, it will be

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noticed, is fed from the IF stage. It includes a transformer tuned to the IF of the receiver, with a secondary connected to the two anodes of a special double diode valve, having two separate cathodes. From cathode to cathode is a centre-tapped load resistance.

When an IF signal which is too high or too low reaches the discriminator transformer, a control voltage is produced across the diode's load resistance which is positive or negative according to whether the IF signal is above or below the correct frequency. In those cases where the frequency happens to be correct, no control voltage is produced.

Oscillator Control

The control voltage obtained in the discriminator is now passed to the oscillator control stage. Here a number of different arrangements may be used. The input capacity of the control valve, shunted across the oscillator tuning circuit, may be caused to change, and so alter the tuning; the inductance of a coil coupled to the oscillator tuning circuit may be varied, with the same result, or the impedance of

Fig. 82b. Response curve of a discriminator circuit. *O* represents the intermediate frequency. The automatic control will pull-in signals lying between the frequencies *A* and *B*.

the control valve, shunted across the tuned circuit, may be varied. The variation in tuning, however produced, is always in the direction necessary to correct the IF signal produced in the set.

Need for Correct Tuning

Naturally, if the receiver is so far off-tune that the station required is not received, no amount of AFC will bring it in. The system merely corrects the tuning, and the latter must therefore be reasonably accurate (say within 8 kc. one way or another) before AFC will operate (Fig. 82b).

AFC can be, and sometimes is, applied to systems of automatic tuning not of the motor-driven type, and in this case it takes care of slight errors in tuning due to wear in the mechanical systems, or changes in the constants of components in pre-tuned systems.

It will be appreciated that motor-driven automatic tuning is a big step forward towards the remote control of radio receivers.

Problems of Battery Sets

One of the big problems in the design of battery receivers, and particularly portable types, is to obtain a relatively high power output with the minimum HT consumption. The economical output obtainable from an HT battery is closely related to the size of the cells used in it, and obviously a receiver consuming 15 ma. of HT current will need a larger battery (though not necessarily one of higher *voltage*) than will a set with more modest requirements of, say 7 ma.

In general, the main part of the HT supply of a receiver goes to feed the output stage, so that if we can reduce the requirements of

Fig. 83. Class B push-pull output stage with "driver" valve, V1. V2 consists of two identical triodes contained in one "bottle".

this stage, for a given power output, we shall effect a very appreciable saving.

In the simplest type of battery receiver the output valve may be a specially efficient pentode which needs only a small HT current. The output obtainable, while sufficient, is not high, and for a bigger output special push-pull arrangements are often used.

The first of these is known as Class B push-pull, and it is usual to employ a special Class B output valve, incorporating two identical triodes in the same bulb. A diagram of the stage is given in Fig. 83.

V_1 is a triode which precedes the double output valve V_2, and is followed by a "driver" transformer, with a centre-tapped secondary, which feeds the double output valve. T_2 is the output transformer with centre-tapped primary.

So far, the stage resembles closely an ordinary push-pull

stage as shown earlier in Fig. 44. The actual operating conditions are, however, different. The triode valves used have a high impedance and operate with a very small bias. The anode current, when no signal is being applied (that is, when the valve is "quiescent"), is low.

Positive Grids

When a large signal is applied to the grids of the valve, at any instant one is made more negative, and the other more positive (or less negative), owing to the push-pull action of the input transformer. The valve whose grid is made more negative is paralysed, and does not amplify. The other valve, however, becoming more positive, amplifies, and at the same time its anode current rises in proportion to the strength of the signal.

When the signal reverses, the grid of the first valve is made more positive, so that this valve amplifies and the other does not. Consequently, the two valves amplify

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alternately, and their outputs are combined in phase by the centre-tapped output transformer in the usual way.

The total anode current of the output valve varies with the strength of the signal. When no signal is arriving, the standing or "quiescent" current is negligible, but as the signal increases in strength the current rises, and on loud signals it may rise momentarily to 20 ma. or so. On the average, however, the mean anode current over a period of time is always much lower than if a normal push-pull stage were in use.

Signals of even moderate intensity overcome the small "standing" bias, and the grids regularly become positively biased. This is a state of affairs not to be tolerated in ordinary AF amplifiers, since it causes current to flow in the grid circuit which results in distortion and other troubles. In a class B circuit, however, provision is made for grid current by means of the preceding "driver" stage

which supplies the necessary power. V_1, preceding the output valve, is a small power valve, and T_1 is a special transformer having a low ratio and capable of transferring power from primary to secondary.

The second special push-pull arrangement used in battery receivers is known as quiescent push-pull, or QPP. The circuit is shown in Fig. 84, and once again it is similar to an ordinary push-pull arrangement, except that this time the output valve is a special double pentode, consisting of two battery operated pentodes in the same bulb. These pentodes have common filament connections, and a single connection for the two screens. The suppressor grids are connected internally to the filament.

The quiescent current of a QPP stage is reduced by providing a high value of negative grid bias. When a signal arrives, one section of the valve has its grid driven more negative, while the other valve re-

Fig. 84. Quiescent push-pull output using a special double-pentode valve.

HT POSITIVE (1)

HT POSITIVE (2)

V2

V1   T1   T2

↓ GB−

portion of the output voltage, rectifying it, and feeding the rectified voltage back to the bias circuit of the output valve, thus causing the bias to vary according to the power the output stage is called upon to handle at any moment.
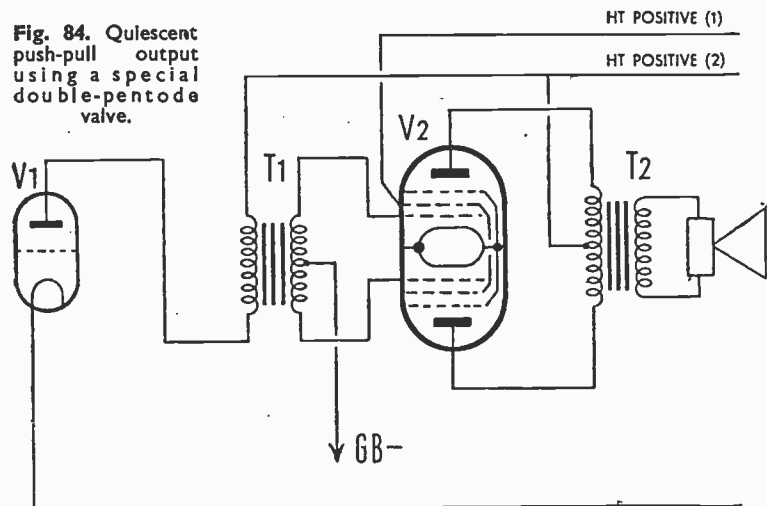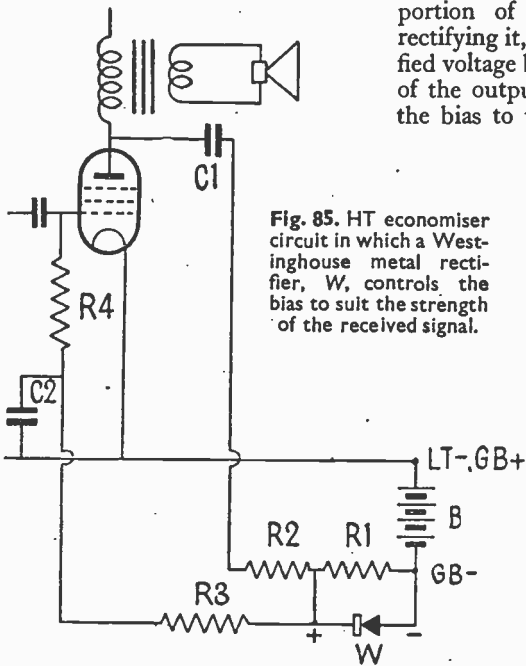
Fig. 85. HT economiser circuit in which a Westinghouse metal rectifier, W, controls the bias to suit the strength of the received signal.

The circuit of this arrangement is shown in Fig. 85. This represents a pentode output stage provided with a high value of grid bias by means of a battery, B. Between the anode of the valve and the GB negative connection are connected $C1$, $R2$ and $R1$ in series.

$C1$ is merely a high-value "blocking" condenser to prevent the HT voltage from reaching the grid circuit. $R2$ and $R1$ form a potentiometer across which the AF voltage at the anode of the valve is developed. $R2$ and $R1$ may be in the proportion of about five to one, so that only a fraction of the total voltage is developed across $R1$. Across $R1$ is connected a metal rectifier W of a special type suitable for AF rectification.

The effect of this is to rectify the AF across $R1$ at any instant, producing a unidirectional voltage which is positive relative to the GB negative end of $R1$. Consequently it opposes the battery GB voltage and, when a signal is received, the bias becomes less negative by an amount proportional to the signal strength. The resultant bias is picked up at the junction of $R1$ and $R2$ and fed via

ceives a more positive bias—that is, its bias is less negative. This section of the valve now amplifies, but the "more negative" section is paralysed by the bias, and does not amplify.

In the next half cycle the position is reversed, as in the case of Class B operation. Again, the HT current of the section which is operating at any instant rises in proportion to the incoming signal, but the average current of the complete stage is less than would be the case with ordinary push-pull.

Apart from special push-pull output stages for reducing the average HT consumption of battery receivers, "economiser" circuits have been employed from time to time in conjunction with ordinary output valves. The most popular form of battery economiser operates by taking a small

R_3 (and the grid leak R_4 in this particular case) to the grid of the valve. R_3 and the condenser C_2 form a filter which serves to smooth out irregularities in the rectified portion of the GB voltage.

This circuit permits a saving in HT consumption similar to that obtained with the special push-pull output stages.

Portable Receivers

Battery portable receivers introduce problems of their own, quite apart from the necessity of reducing the HT current, owing to limitations in the size and weight of the receiver. Naturally, an internal frame aerial, of relatively small dimensions, has to be employed, which means that the receiver should preferably include a stage of RF amplification preceding the frequency-changer if a superheterodyne circuit is used.

Microphonic Troubles

Owing to the proximity of the loudspeaker to the valves in the average portable receiver, one often encounters "microphonic" troubles. The sound waves from the speaker, impinging on the valves, set the electrodes in vibration, and this "modulates" the electron stream and produces a musical note which builds up into a loud hum, or a shrill whistling noise, depending on the physical characteristics of the electrode system.

Once this noise starts, it usually continues until the set is switched off. Often a note of some particular frequency emanating from the loudspeaker will start up microphonic troubles, and it is usually the demodulator valve in a "straight" receiver which is most prone to microphony. Very often,

if this valve is replaced by another of the same type, the trouble is cured; the microphonic valve can then often be used in another receiver without causing any trouble.

Microphonic trouble may sometimes be cured by shielding the affected valve from the loudspeaker by packing cotton wool round it or fitting rubber tubing tightly over the bulb.

In short-wave receivers a similar effect is sometimes produced by sound-waves setting the vanes of the tuning condenser into a state of vibration.

Economy Valves

The need for economy in power supply, both HT and LT, in battery portables has resulted in the production of "economy" types of valve. Whereas a few years ago a filament rating of 2 v., 0·1 or 0·15 amp. was common in battery valves, it is now possible to obtain similar results from valves rated at 2 v., 0·05 amp. This means that it is possible to use a much smaller accumulator, while the HT requirements are also smaller.

To avoid the use of an accumulator for LT supply, special valves have recently been produced which operate from a single dry cell. Their filaments are rated at 1·4 v., 0·05 or 0·1 amp. These valves have made it possible to produce "all-dry" battery portables, and usually a combined 1·5 v. LT and 90 v. HT battery is employed, with a 4-pin plug and socket connector. Grid bias in these receivers is usually automatic, so that battery replacement is extremely simple.

The introduction of the 1·4 v. type of valve has made possible the design of a very interesting type of portable receiver which will

operate from dry batteries, AC mains or DC mains at will. The principle employed in this type of set is to connect the filaments in parallel for battery operation and in series for mains operation; in the latter case they are energised from the smoothed HT supply.

Owing to the fact that in some types the filament of the output valve needs a current of 0·1 amp., whereas the other filaments need only 0·05 amp, a series-parallel arrangement may have to be made to ensure all valves getting their correct current. In other cases the output valve filament may be rated at 2·8 v., 0·05 amp., so that a simple series arrangement for mains operation is possible; for battery operation the filament, which has a centre-tapping, is connected with its two halves in parallel, so that it operates at 1·4 v., but consumes 0·1 amp.

Naturally, the rearrangement of the filament and the change in HT supply for battery or mains operation necessitate fairly complicated switching. In some sets this is performed manually but in others it is quite automatic, being performed by a relay. The latter arrangement gives the set some further interesting features.

Suppose the set, with batteries connected, is plugged into the mains, but that the mains are not switched on. Now if the *set* is switched on, it will operate immediately from its battery supply. When the *mains* are switched on, the relay operates, disconnects the battery supply, re-arranges the circuit and the set continues to operate from the mains. Should
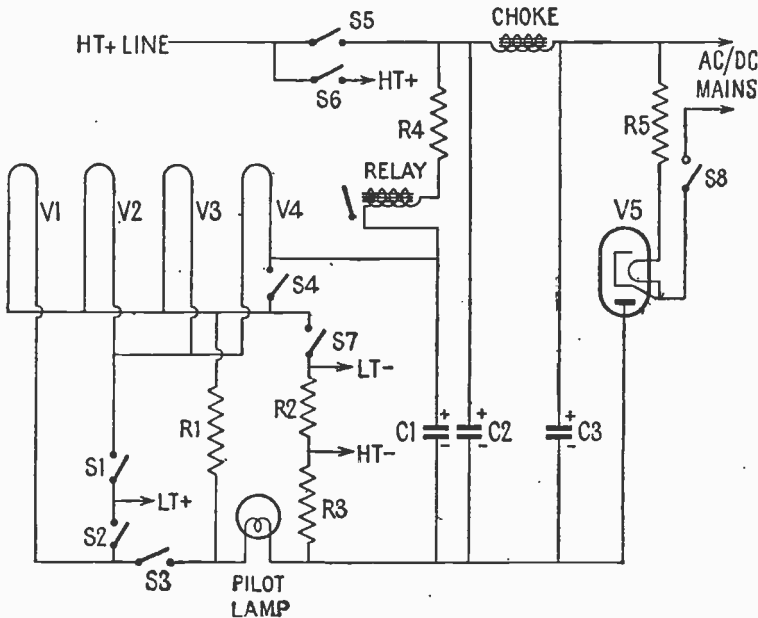
Fig. 86. Power supply circuits of a receiver which operates from AC or DC mains or all-dry batteries. If the mains supply is interrupted the batteries are immediately connected by the relay and the set continues to operate.

the set be unplugged from the mains, or the mains fail, the set immediately reverts to battery operation.

A simplified circuit of the power supply arrangements is given in Fig. 86. V_1–V_4 are the valve filaments, V_4 requiring 0·1 amp. and the others 0·05 amp. each. R_1 is the shunt resistance for V_1 filament, used on mains, so that the total current through V_1 and R_1 in parallel is 0·1 amp. R_2 and R_3 are automatic grid-bias resistors.

Ballast Resistance

R_4 is the ballast resistance for the valve filaments when the set is operating from mains, and R_5 is the ballast resistance for the heater of the rectifying valve V_5. C_1–C_3 are smoothing condensers. S_1–S_6 are the switches operated automatically by the relay. S_7 and S_8 are the LT battery and mains switches, ganged together, and forming the master on-off control of the set.

With the set switched on by closing S_7, but no mains supply provided, the switches S_1, S_2, S_4 and S_6 are closed, S_3 and S_5 being open. The filament circuit is from LT battery negative, via S_7 (closed), to one side of V_1 filament, the other side going via S_2 to LT positive. Filament current from LT negative also goes to one side of V_2 and V_3 and via S_1 to LT positive; and also to one side of V_4 filament via S_4, then via S_1 to LT positive. Thus all the filaments are in parallel across LT negative and LT positive (1·5v.).

The HT circuit is from HT negative of the battery, via bias resistance R_2 to LT negative; and from HT positive of the battery, via S_6, to the HT positive line of the set.

Now suppose the set is plugged into the mains and switched on (if this has not already been done). First of all, the receiver operates from its batteries. But as emission from V_5 cathode commences, a current starts to flow from the anode of V_5 through R_3, R_2, S_7 and S_4 (which is still closed), through the relay winding, R_4, the smoothing choke, and R_5, back to cathode of the valve.

When this current has built up to a certain pre-determined value the relay operates opening S_1, S_2, S_4 and S_6, and closing S_3 and S_5. The latter connects the HT positive supply from the rectifier valve to the HT positive line of the set. HT negative is connected via R_3, R_2 and S_7 (which remains closed) to chassis.

The filament circuit forms three paths: (1) from V_5 anode, via the mains pilot lamp, V_1 filament and R_1 in parallel (S_3 being closed); (2) through V_2 and V_3 filaments in parallel; and (3) through V_4 filament (which needs 0·1 amp.), the relay winding, and R_4, to the HT positive line.

Where no relay is fitted, switches S_1–S_6 are operated manually by a knob on the control panel. Receivers of this type truly justify the description "universal".

Quality Receivers

A modern standard receiver of a reputable make can be relied upon to provide a very acceptable quality of reproduction, but it naturally cannot compete in this respect with certain special "quality receivers". Such receivers aim at securing the best possible reproduction of local-station signals and do not usually attempt to provide a high degree either of sensitivity or of selectivity.

. In the early days of the super-heterodyne, the badly designed frequency-changing arrangements and highly selective intermediate frequency couplings resulted in this type of receiver getting a bad name for reproduction, and "quality" receivers were usually confined to the tuned radio-frequency type.

Later certain receivers were introduced to combine the best points of both circuits, and by switching arrangements could be instantly converted from TRF to superhet operation, or vice versa. This can be achieved as shown in the block diagram in Fig. 87.

With both switches down, the

that diode demodulator valves are used with a large signal input, distortion at this stage can be minimised.

It goes without saying that the AF stages of such receivers must also be designed to give the best possible response. A stage of resistance-capacity coupling, followed by a push-pull stage feeding at least two output valves, is a common arrangement. The output valves are usually large power triodes, although pentodes with negative feedback can be made to give excellent results.

For a real "quality" receiver, the undistorted power output must be high, say 10–15 watts, in
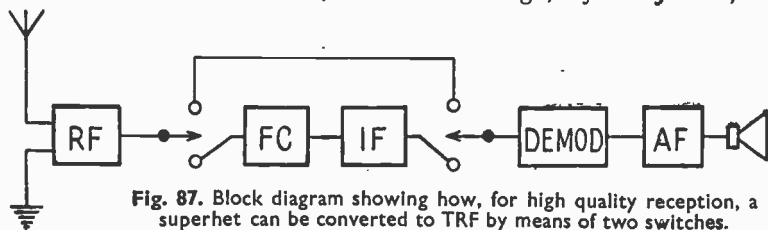
Fig. 87. Block diagram showing how, for high quality reception, a superhet can be converted to TRF by means of two switches.

receiver is a superhet with an RF stage. With both switches up, the output from the RF stage is taken direct to the demodulator, cutting out the frequency changer and IF stages, and converting the set to TRF operation. Where no RF stage is fitted it is sometimes arranged to make use of the mixer section of the frequency-changer valve as an RF amplifier for TRF operation.

Minimising Distortion

By the use of carefully designed IF stages, preferably with "variable selectivity" couplings (previously described), the modern type of superheterodyne circuit can be made to give high-quality reproduction. Owing to the fact

place of the 2–5 watts of an ordinary receiver. This does not imply that the set is necessarily intended to operate always at high volume levels, but the high power is there to take care of sudden fortissimo passages in music which momentarily require a considerably larger power output than the general level of the music.

The loudspeaker arrangements of a quality receiver vary considerably. To a large extent the response of a loudspeaker depends on the size of its diaphragm, and it has been common practice to employ two or more loudspeakers of different sizes in order to secure a level overall response. Thus, a large diaphragm loudspeaker, which favours the low and middle

registers, can be paired with a small diaphragm unit, which will look after the upper register.

Moving-coil Speaker

The moving-coil type of speaker is almost universally employed, but for high audio-frequency work the "tweeter" type of speaker is sometimes used. This is a small diaphragm unit, in which the diaphragm is driven, not by a coil, but by the movement of a crystal of Rochelle salt which occurs when a varying potential is applied across two of its faces. This is known as the piezo-electric effect, and is used in

Fig. 88. Method of connecting a piezo-electric "tweeter" speaker in connection with the normal moving-coil type.

specialised loudspeakers, microphones and also in gramophone pick-ups.

The method of connecting up a speaker of this type in conjunction with a moving-coil unit is shown in Fig. 88. It is fed from the ends of the primary winding of the main speaker transformer, via two fixed blocking condensers of about 1 mfd. each. There is, of course, no DC path through the loudspeaker, which is actually equivalent electrically to a condenser. In order to control the high note output, it is usual to employ another fixed condenser in series with a potentiometer across the piezo speaker unit in the manner shown in Fig. 88.

High-quality receivers some-

times use dual speakers, both units being ordinary moving-coil types. Usually there is a single input transformer and the two speech coils are connected to the secondary.

The diaphragms are generally of different sizes so that the larger provides the better bass response and the smaller extends the upper limit of the frequency range.

It is not correct to refer to these speakers as bass and tweeter units, however, because both cover practically the whole range. The real value of the system is electrical in that when speakers are operated together in this way any resonant peak voltages are much reduced in strength.

The speaker or speakers in a quality receiver must be mounted either on a large flat baffle-board or in a specially shaped and lined cabinet, in order to preserve the bass response, and to prevent cabinet resonance, which would mar the quality, particularly at high volume levels.

In this chapter we have "taken to pieces" all the familiar types of receiver and obtained some appreciation of the functions of the different parts. We have been as practical as possible; readers wishing to know more of the whys and wherefores behind various arrangements should go over this chapter again, studying it in conjunction with Chapter 17, which explains the theoretic principles underlying radio practice. The chapter that follows is planned to increase the reader's ability to "read" complete receiver circuits.

CIRCUITS EXPLAINED

CIRCUITS AND WIRING DIAGRAMS. SYMBOLS. SUB-CIRCUITS. EFFECT OF PRACTICE ON THEORETIC DESIGN. READING DIAGRAMS. THREE-VALVE BATTERY SETS. BAND-PASS INPUT. ALL-DRY PORTABLE. TRF AND SUPERHET MAINS RECEIVERS. FREQUENCY-CHANGER. AUTOMATIC VOLUME CONTROL. OSCILLATION STOPPER RESISTORS. NEGATIVE-FIELD BIAS SYSTEM. HUMDINGER. UNIVERSAL AC–DC RECEIVER.

THE word "circuit", although it has quite a precise technical meaning (see Chapter 17), is also applied to diagrams which form either a part of a circuit or a number of related circuits. For example, we commonly talk of the "circuit of a coil" when actually the coil is only a small part of a circuit; similarly, we refer to the "circuit of a transmitter" when really the apparatus consists of numerous circuits.

To make these differences clear, we might be tempted to talk instead of "wiring diagrams"—but this would not do. Generally, wiring diagram is taken to refer to a scale drawing showing the actual layout of the equipment and the disposition of the connecting wires.

Circuit Symbols

A circuit diagram represents the various component parts in the simplest possible way—in fact, by symbols based on the fundamental electro-mechanical construction of the parts (see pages 30 and 31)—and shows as clearly as possible how these components are inter-connected. In the interests of clarity, the arrangement of the parts in the circuit is largely standardised and has little, if any, regard to the actual physical layout of the set.

Occasionally, a constructional feature is indicated—such as dot lines to show that condensers or switches are "ganged" (operated by the same knob)—but, as a whole, a circuit does not give the slightest clue to the appearance of a receiver.

Identifying Components

In the days of simple home-constructor receivers it was the practice to issue wiring diagrams, but with modern sets such drawings would be too complex for rapid study. Instead, therefore, the professional service man is usually provided with a circuit diagram—the resistances and capacities of components being indicated—plus a drawing of the chassis identifying the most important components and any detail drawings necessary to identify the various terminals of complex parts, such as coils and transformers.

It will be evident that it is necessary for the repair engineer to be able to "read" circuit diagrams with fair ease. Needless to say, it is a job requiring some training and practice.

The first thing is to learn the "alphabet"—*i.e.*, the standard symbols. The second step is to get to recognise the sub-circuits in which these are arranged—for instance, the tuning circuit, the

L_{10} is an HF choke which opposes these currents and encourages them to flow to LT— via either the reaction circuit or C_3.

L_{11} and L_{12} are an iron-cored LF transformer which passes the signal on to V_3 grid while isolating the grid from the positive potential of V_2 anode circuit.

V_3 is provided with bias, via L_{12}, by means of a separate bias battery. It is a pentode valve operating the moving coil (L_{15}) of a loudspeaker indirectly by means of a step-down transformer L_{13}–L_{14}.

C_4 is a condenser in shunt with V_3, and it by-passes high audio-frequencies which, owing to over-emphasis by the pentode, would cause shrillness. C_5 decouples the main HT and C_6 decouples the lower HT voltage applied to V_1 screen.

Note that when the on-off switch S_4 is closed, HT—, LT— and GB+ are all connected to earth and chassis.

Typical values of components are: C_1, 0·0001; C_2, 0·0003; C_3, 0·0002; C_4, 0·005; C_5, C_6, 0·1 mfd.; R_1, 1 megohm; L_{11}–L_{12}, step-up ratio 1–3·5.

Variable Bias Control

In Fig. 2 is a more advanced "battery three" circuit. The aerial connection includes an optional rejector wavetrap L_1–C_1. The two tuning condensers are ganged on one shaft and the small parallel trimmers T_1, T_2 are provided to compensate for any initial capacity difference between the two tuned circuits.

The amplified signal is developed in the anode circuit of V_1 by a high frequency choke, L_5,
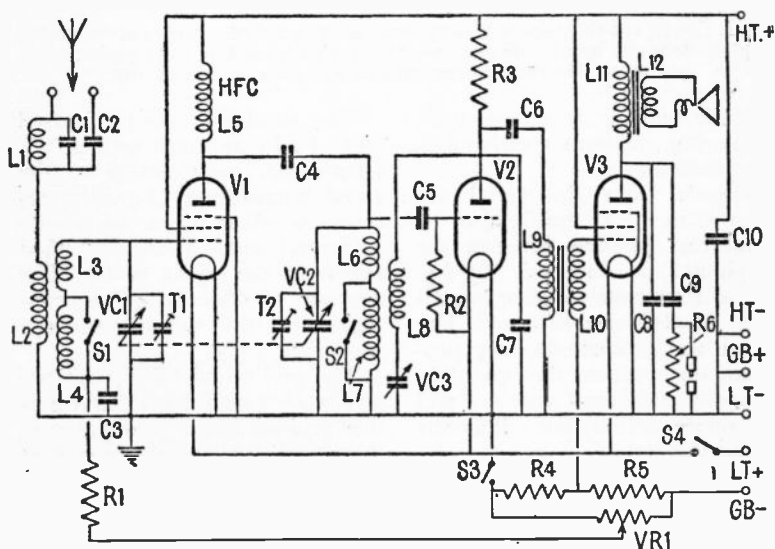
Fig. 2. Another three-valve battery set. Note the aerial wavetrap, L1–C1, the choke-fed RF coupling between V1 and V2 and the parallel-fed transformer coupling between V2 and V3. Volume is controlled by VR1 which regulates the bias of V1, a variable-mu RF pentode amplifier valve.
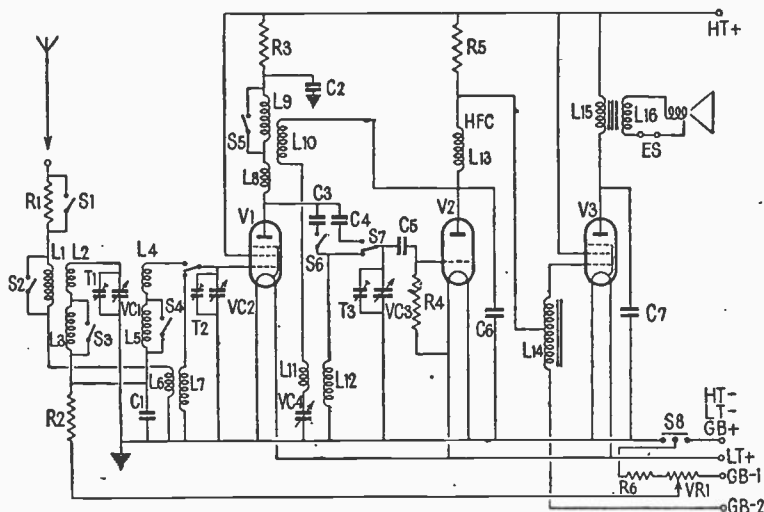
Fig. 3. A three-valve battery set with band-pass aerial input on medium and long waves and transformer input (L6–L7) on short waves. The RF coupling is a tuned anode on M and LW but on SW L8–L9 act as a choke, parallel-feeding L12.

and passed on to the tuned grid circuit of V_2 via C_4.

In this set the anode of V_2 contains simply a resistance R_3. Having practically no inductance or capacity, this presents equal opposition to both HF and LF currents. The former pass to earth through the reaction circuit, L_8–VC_3, and through C_7. The LF signal goes to earth through C_6 and L_9, the primary of the LF transformer.

The advantage of this parallel-fed transformer arrangement is that no inductance is lost due to the passage of a steady anode current through the primary.

Across V_3 is an adjustable tone control C_9–R_6. When the plug is inserted, R_6 is shorted and an increased proportion of high-note response is by-passed through C_9.

The bias battery is connected across R_4 and R_5, the steady leakage through these ensuring that the bias voltage will fall at

about the same rate as the HT voltage. This preserves the correct ratio between anode and bias voltages.

V_3 does not receive the full bias voltage, but that part of it produced across R_4. VR_1 in parallel with R_4–R_5 is a variable potentiometer, and any required negative voltage up to maximum bias can be applied to the grid of V_1. V_1 is a variable-mu pentode, its amplification (and, therefore, the output volume) being controlled by the amount of negative bias.

Voltage Fluctuations

R_1 and C_3 decouple V_1 grid, preventing any voltage fluctuations from the LF side being introduced to the HF side. Note that the bias circuit must be switched (S_3) apart from the LT switching (S_4). C_{10} decouples the HT battery.

Band-pass input tuning on medium and long waves and
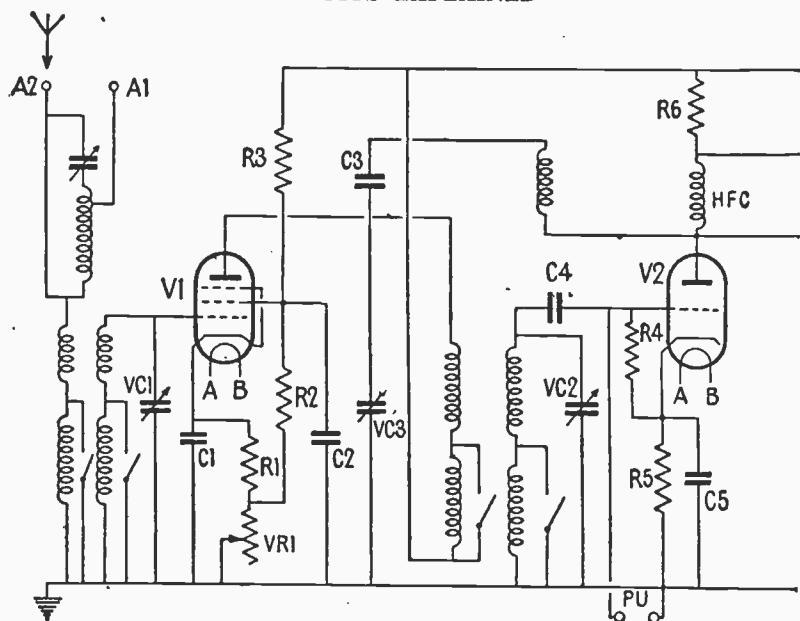
Fig. 5. A three-valve plus rectifier TRF receiver for AC mains operation. VI is a variable-mu RF amplifier and amplification is controlled by VRI. LI–CI0–CII smooth the HT current provided by the full-wave rectifier V4.

the band. T_4 and T_5 are long wave trimmers and T_6 the long wave padder.

R_1–C_2 are the oscillator grid leak and condenser. R_2 and R_3 give a smoother feedback of energy over the different frequencies.

Intermediate Frequency

The oscillator frequency introduced by grids 1 and 2 and the signal frequency introduced by grid 4 beat together to form the intermediate frequency. This is transmitted to V_2, and thence to V_3 through transformers tuned to the intermediate frequency by pre-set trimmers T_7–T_{10}. V_2 is an IF amplifier.

V_3 contains a single diode which produces demodulated (low-frequency) signals across a "load"

resistance VR_1, which is also the LF volume control. R_7 with C_5 and C_6 filter out the IF and pass it to earth.

A steady voltage due to the rectified carrier wave appears across R_5 and R_6, and a proportion of it is taken to the grids of V_2 and V_1 for automatic volume control. As the strength of the carrier wave increases, the negative bias developed across R_6 and applied to V_2 and V_1 also increases, thereby reducing the amplification and tending to keep the output of the set at a uniform level. C_3 is an AVC decoupling condenser which smoothes out any rapid fluctuations occurring in the carrier voltage.

Low frequency is tapped off from VR_1 and taken via a DC

isolating condenser, $C7$, to the grid circuit of $V3$. As the signal to be handled is not great, this valve is left to develop its own bias across the grid leak $R9$.

$R10$ develops the amplified LF, which is passed on to the $V4$ grid circuit by $C9$. $V4$ is biased by returning the leak $R11$ to HT negative. The total HT current, returning from the valve filaments, has to flow through $R12$ to reach HT—, and the voltage drop across $R12$, it will be seen, is introduced between $V4$ filament and grid.

$C8$ is an HF by-pass and $C10$ a high-note by-pass. $C11$ across the HT battery, provides a current reservoir which ensures a smooth supply, thus preventing the varying current demand of $V4$ having any effect on the operation of the other stages.

Typical values are: $R1$, 250,000 ohms; $R2$ 10,000; $R3$, 15,000; $R5$, 1 megohm; $R6$, 4 megohms; $R7$, 100,000 ohms; $VR1$, 500,000; $R10$, 1 meg; $R12$, 750; $C2$, 0·001 mfd.; $C3$, 0·05; $C4$, 0·01; $C5$, $C6$, 0·00005; $C7$, 0·01; $C8$, 0·0001; $C9$, 0·005; $C10$, 0·002; $C11$, 8.

"Straight" Three Mains Set

Coming to the first mains set circuit, Fig. 5, we have a very simple "straight" three for working from AC. Apart from the features due to the nature of the current supply, the design is like the circuits already described.

Each of the three receiving valves is an indirectly heated type biased by resistances between cathode and HT negative. These resistances, $R1$–$VR1$, $R5$, $R9$, convey the anode current to chassis, and the voltage drop across them makes the cathodes positive. As the grids are returned to chassis they are negatively biased.

$VR1$ controls the volume by regulating the bias and, therefore, the amplification of $V1$, a variable-mu HF pentode. The bottom end
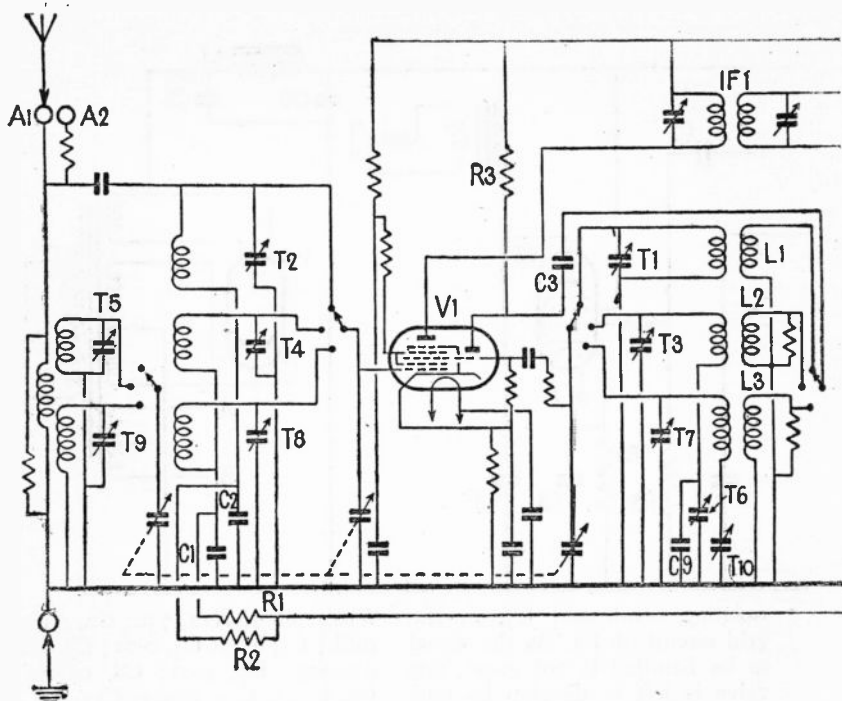
of R_3–R_2 is taken to the cathode circuit, so that the screen voltage changes "in step" with the bias. R_1 is included so that even when VR_1 is at minimum, V_1 will have sufficient bias to prevent overloading and instability.

Note that V_2, as a detector, is run without bias because the grid leak R_4 is returned to the top of R_5. The valve is biased when a pick-up is connected.

HT current is obtained from a full-wave rectifier, V_4. The filament is HT positive (see Chapter 17), and the centre-point of the HT secondary winding is negative. Ripples are smoothed out of the HT by a choke L_1 (probably the loudspeaker field energising coil) and two electrolytic condensers, C_{10}, C_{11}.

The filaments of the valves serve only to heat the cathodes, and are run from low-voltage AC, the circuit being connected to earth at its centre-point to minimise the introduction of hum via the cathode-heater capacities.

Typical values are: R_1, 200 ohms; VR_1 5,000; R_2, 40,000; R_3, 10,000; R_5, 1,000; R_9, 150; C_1, C_2, C_5, 0·1 mfd; C_8, 25; C_{10}, 12; C_{11}, 8.

"Short" AC Mains Superhet

In Fig. 6 is a good example of a "short" (without RF stage) AC mains superhet. On medium and long waves the input circuit is of band-pass type, while a single tuned circuit is provided for short waves. A special refinement is the use of different AVC decoupling components on M–LW (R_1·C_1) and SW (R_2–C_2).
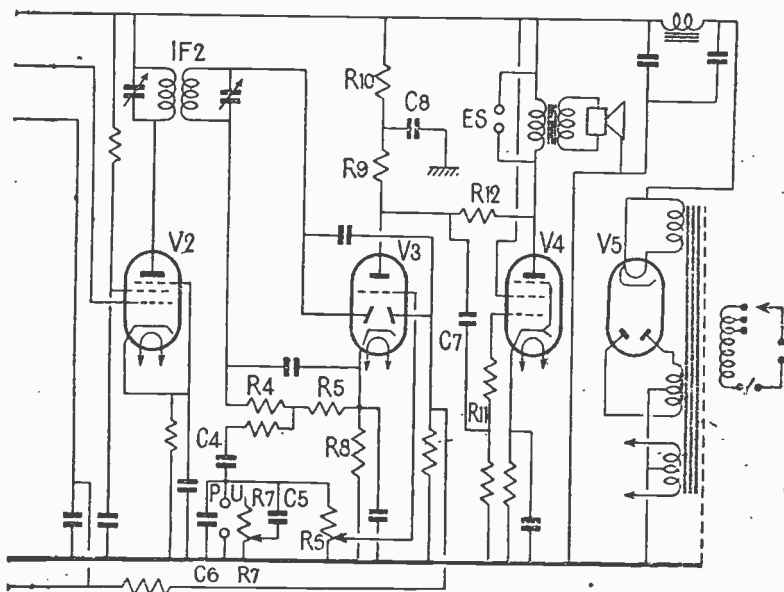
Fig. 6. An AC mains superhet covering three wavebands and with band-pass input on M and LW only. $V1$ is the frequency-changer, $V2$ the IF amplifier, $V3$ the double-diode triode, $V4$ the output pentode and $V5$ the full-wave rectifier.

The oscillator section of $V1$, the frequency-changer, is perfectly straightforward, there being a separate reaction winding for each band ($L1$, $L2$, $L3$). These coils are parallel-fed through $C3$, the actual oscillator anode load being $R3$.

All the oscillator and aerial coils have separate trimmers to compensate for stray capacities, and $T6$ and $T10$ are the padders. There is no padder on SW as specially shaped vanes of the oscillator section of the gang condenser provide correct tracking.

$R4$–$R5$ form a split signal-diode load, the LF being taken via $C4$ to the volume control $R6$. $C5$–$R7$ form a tone control, and $C6$ is an IF by-pass condenser.

$R8$ provides bias for PU working and also gives the AVC diode a negative delay bias, so that it does not operate until the signal has reached a certain strength.

$R9$ is the $V3$ anode load furnishing a signal to $V4$ via $C7$. $R10$–$C8$ decouple the $V3$ anode circuit. $R11$ prevents spurious HF oscillations in $V4$, and $R12$ provides negative feedback between anode and grid circuits for better tone.

Connections for an extension-speaker are provided on the primary or high-impedance side of the output transformer, and an additional speaker would, therefore, need its own matching transformer.

Fig. 7 shows the circuit of a superhet with an RF amplifier, $V1$, in front of the frequency-changer, $V2$. It uses a triode output valve, $V6$, for high-quality reproduction and incorporates a
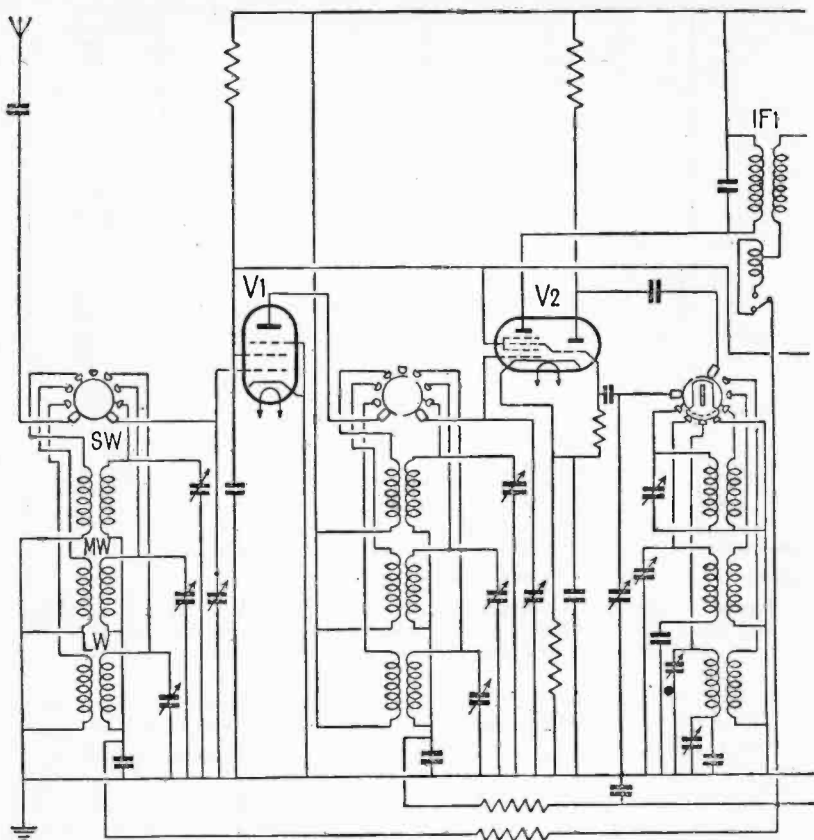
cathode-ray-type tuning indicator, V_4.

All the tuned circuits use straightforward transformers with trimmers across the secondaries. The first IF transformer includes extra turns which can be switched on the secondary to broaden selectivity when required.

At IF_2 both AVC and signal connections are taken from tappings, an arrangement which contributes to the normal high selectivity of the receiver. R_{12} is the AVC diode load.

In the signal diode circuit R_1–C_1–C_2 are an IF filter, and R_2, the volume control, forms the diode load. The DC of the rectified carrier is taken via R_3 to operate the tuning indicator, and the LF is taken via C_3 to the triode grid. R_4 is the grid leak and R_5 represents a "stopper" of spurious oscillation.

In this set the tone control C_4–R_6 is across the first LF valve. Resistance-capacity coupling leads to V_6, which, as indicated by the "breaks" in the diagram, is on a separate chassis with the mains section. R_7 is another "stopper".
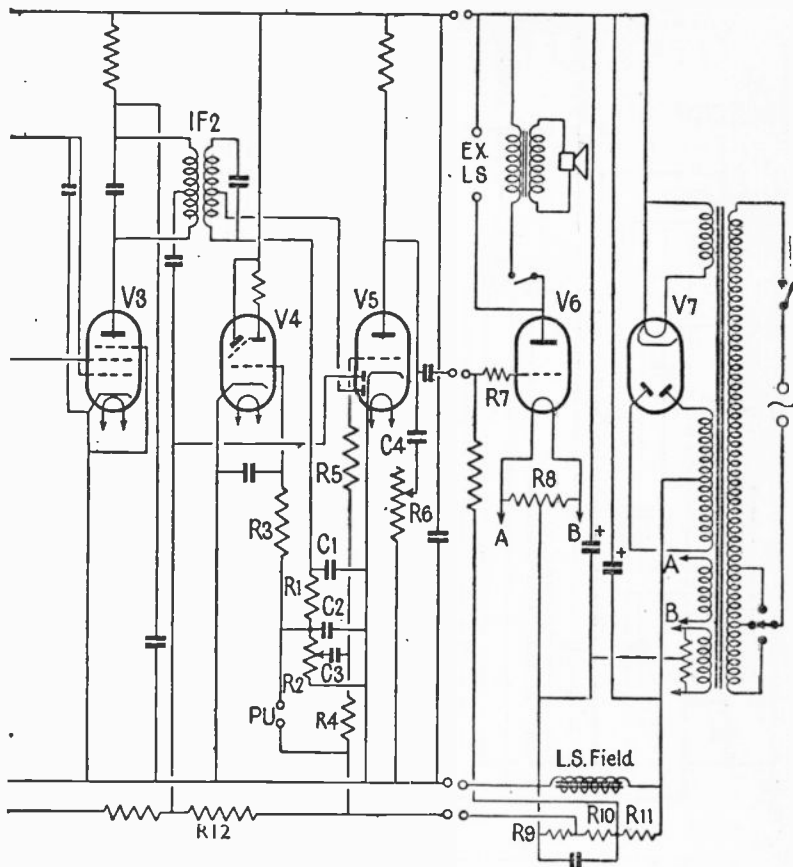
Fig. 7. A large superhet with an RF amplifier, V1, preceding the frequency-changer, V2. V4 is a cathode-ray type tuning indicator. The speaker field, used for smoothing, is in the negative HT line and the voltage across it is tapped off by the potentiometer R9–10–11 for the purpose of biasing V6 and V5.

$V6$ is directly heated and, to minimise hum, an electrical centre-point for the negative HT path is obtained by $R8$, sometimes called a "humdinger".

An outstanding feature is that the smoothing choke (the speaker field winding) is included in the negative HT path. The voltage drop across it is tapped off by the potentiometer $R9$–$R10$–$R11$ for biasing $V6$ and $V5$. The arrange-ment saves HT voltage as, if the choke was in the positive lead, the voltage drop across it would be additional to the drop across the bias system.

It will be realised that this "negative field" method makes the chassis positive with respect to HT—(the secondary winding centre-tap). The junction $R10$–$R11$ is more negative with respect to chassis than the junction $R9$–$R10$.

TRANSMITTERS AND LEARNING MORSE.

ACTION OF TRANSMITTER. SELF-OSCILLATORS. SERIES AND PARALLEL FEED CIRCUITS. SIMPLE TRANSMITTERS. GRID BIAS. KEYING TRANSMITTERS. WAVEMETERS. FREQUENCY CONTROL. CRYSTAL CONTROL. NEUTRALISING. TRANSMITTING AERIALS. LONG- AND MEDIUM-WAVE AERIALS. THE MORSE CODE. READING, SENDING AND LEARNING MORSE. MORSE PRACTICE.

THE basis of radio is the oscillatory circuit, which can be defined as a circuit having inductance and capacity and with a sufficiently low resistance (see Chapter 17). Fig. 1 represents an oscillatory circuit in which the inductance L is formed by a coil of wire or copper tubing and the capacity C by a condenser. Such a circuit has a natural frequency of oscillation given by

$$= \frac{1}{2\pi\sqrt{LC}}$$

where $f =$ frequency in cycles per second, $L =$ inductance in henries and $C =$ capacity in farads.

It follows that if L or C is adjustable, the natural frequency can be varied at will between the limits imposed by the range of adjustment. This is the original meaning of the term "tuning", though this word is now applied to any controls on transmitters or receivers.

Closed Oscillatory Circuit

The circuit of Fig. 1 is called a closed oscillatory circuit, its features being that the inductance is concentrated mainly in the coil and the capacity mainly in the condenser. Not much of the

energy supplied to a closed oscillatory circuit is radiated in the form of ether waves, because the condenser plates are close together, and only a small volume of ether is subjected to both magnetic and electric strain.

To transmit radio waves over useful distances, an open oscillatory circuit must be used. An open oscillatory circuit is usually called an aerial or antenna, and may take many different forms. In all cases, however, the inductance and capacity are no longer separated, but distributed more or less uniformly throughout the circuit.
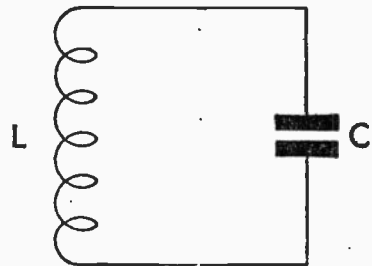
Fig. 1. A coil and condenser in parallel form a closed oscillatory circuit.

Fig. 2 represents a well-known form of aerial, called an "inverted-L". The purpose of the small coil in series is to form a convenient
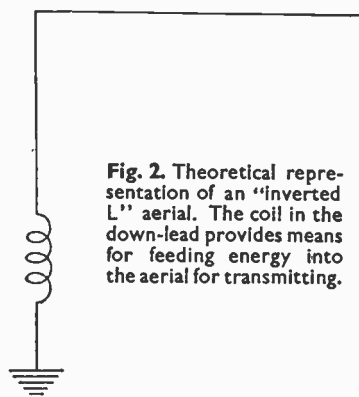
Fig. 2. Theoretical representation of an "inverted L" aerial. The coil in the down-lead provides means for feeding energy into the aerial for transmitting.

point for supplying energy to the aerial in the case of a transmitter or for taking energy from it in the case of a receiver. More will be said about aerials shortly.

Action of Transmitter

If the capacity of a circuit such as Fig. 1 is charged up and then allowed to discharge, the discharge will be oscillatory in character. Fig. 3 illustrates this discharge, and the graph can be taken to represent the current in the circuit.

The time taken by the discharge would be only a very small fraction of a second. For example, if the frequency was 500 kc. and the circuit went through 1000 complete cycles of oscillation before the energy finally disappeared, this would take only 1/500th of a second. In order to make practical use of the waves radiated from an open oscillating circuit, the oscillation must be maintained for as long as desired—*i.e.*, as long as the key is pressed in telegraphy, or for as long as the microphone is in use in the case of broadcasting or radiotelephony.

There are various methods of securing continuous oscillation in an oscillatory circuit, but the thermionic valve is now practically universal.

Fig. 4 shows the basic principle of using a triode valve in this way. The coil L in the aerial circuit also forms part of the valve anode circuit. If a radio-frequency EMF is applied between grid and cathode of the valve, there will be a radio-frequency variation of anode current. As this necessarily takes place in the coil L, there will be a radio-frequency EMF across L and hence in the aerial circuit.

The aerial is thus "driven" at the frequency of the EMF applied to the grid, and if the aerial is tuned to resonance by means of

Fig. 3. When a condenser is discharged through a coil the current oscillates backwards and forwards. The energy is expended with great rapidity.
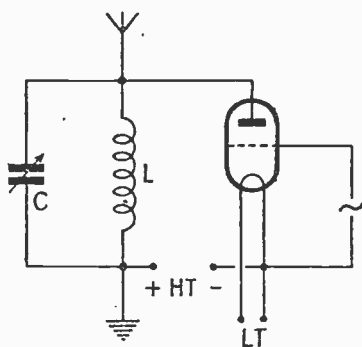
Fig. 4. Basic method of using a triode valve to maintain continuous oscillatory current in a tuned circuit.

the condenser C, for example, maximum current will flow in the aerial, and the radiation of electric wave energy will also be at a maximum.

The radio-frequency EMF applied to the grid (sometimes called the grid exciting voltage) may be obtained from the oscillating circuit itself. This arrangement is shown in Fig. 5. The coil $L2$ in the
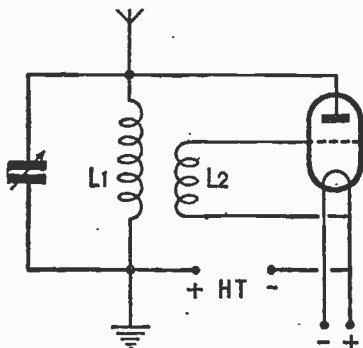
Fig. 5. By means of a coil, $L2$, inductively coupled to the coil, $L1$, the oscillation of the valve can be maintained by the tuned circuit itself.

grid circuit is magnetically coupled to the aerial coil $L1$.

Aerial oscillation is now maintained for as long as the valve is switched on.

The sequence of events, which is "kicked" off by the heating up of the valve cathode and then repeated continuously, is as follows:

Aerial oscillation causes
Radio-frequency current in $L1$ which causes
Radio-frequency EMF in $L2$ which causes
Radio-frequency EMF on grid which causes
Radio-frequency variation of anode current which causes
Radio-frequency EMF across $L1$, which maintains aerial oscillation.

This is called a self-oscillator, and is the usual method of generating a radio-frequency current. The source of the energy supplied to the aerial is of course the HT supply, the valve acting as a linking mechanism, which releases the energy in a series of pulses automatically timed by the aerial circuit itself. The best mechanical analogy to a self-oscillator is a watch, and the following comparisons should be carefully studied.

Self-Oscillator.	*Watch.*
HT supply	Mainspring
Oscillatory circuit:—	Vibrating Mechanism:—
Inductance	Balance wheel
Capacity	Hair-spring
Valve and grid circuit	Escapement.

The frequency at which the watch "ticks" is determined by the size and weight of the balance wheel and by the tension of the hair-spring. The frequency at which the electrical circuit oscillates is determined by the inductance and capacity in it.

Series and Parallel Feeds

The simple circuit of Fig. 5 is of the type known as series-feed, in which the coil of the oscillating circuit is in series between HT and the anode and carries the DC anode current.

Fig. 6 shows the circuit for a parallel-feed oscillator. The DC anode path does not include any part of the oscillatory circuit, but the radio-frequency choke $L3$ deflects the radio-frequency variations of anode current through the coil $L1$ via the "blocking" condenser $C2$. $C2$ is necessary because otherwise the coil $L1$ would constitute a short-circuit of the HT supply.
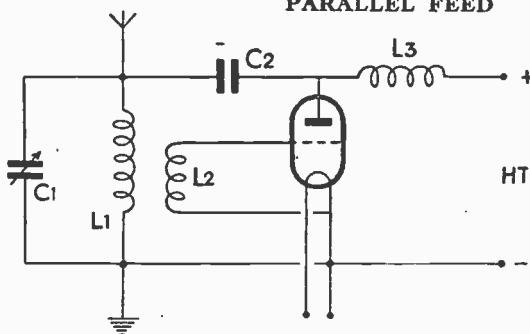
Fig. 6. In the parallel-feed arrangement the tuned circuit C1–L1 is in parallel with the HT supply, which passes through a radio-frequency choke, L3. The oscillatory current passes through C2.

aerial in conjunction with L_1 and C_1. L_2 is the grid coil magnetically coupled to the aerial coil for self-oscillation. C_2 is the blocking condenser and L_3 the radio-frequency choke. C_4 is a large-capacity condenser which serves as a smoothing device for HT and as a radio-frequency by-pass for any RF current passing the choke L_3.

A is an ammeter in series with the aerial circuit, and indicates the oscillatory current in the aerial. A milliammeter in the negative HT lead is for indicating DC anode current.

This circuit illustrates a very important principle which is constantly applied to valve circuits. It is the splitting of the anode circuit into two parallel paths, one for the DC component of anode current and one for the radio-frequency AC component.

By inserting the choke L_3 in the DC anode circuit, this path is made to offer a high impedance to any radio-frequency variation of anode current. The anode-cathode path comprising C_2 and L_1 cannot carry DC, but offers a comparatively low impedance to the radio-frequency component of anode current.

An identical principle is seen in reaction circuits and decoupling devices.

Certain additional components must be added to the circuits of Figs. 5 and 6 to make a workable transmitter. Fig. 7 shows a simple one-valve parallel-feed continuous-wave transmitter with all essential parts.

The oscillatory circuit is formed by the.

Oscillation is started and stopped by the Morse key, which makes and breaks the negative HT circuit. A condenser C_3 is in parallel with the key to absorb inductive impulses and prevent sparking at the key contacts.

Grid Bias

The energy taken from the HT supply is spent in two main ways: (1) Energy supplied to the aerial
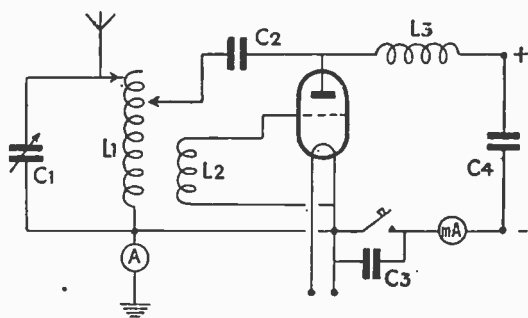
Fig. 7. A parallel-feed one-valve continuous-wave transmitter with all essential parts.

and (2) energy dissipated as heat at the anode of the valve (a little is also lost in the conductors).

Heat at the anode is obviously wasted as far as communication is concerned, and must be reduced as far as possible. This is done by applying a negative EMF to the grid of the valve, so that anode current is normally suppressed.
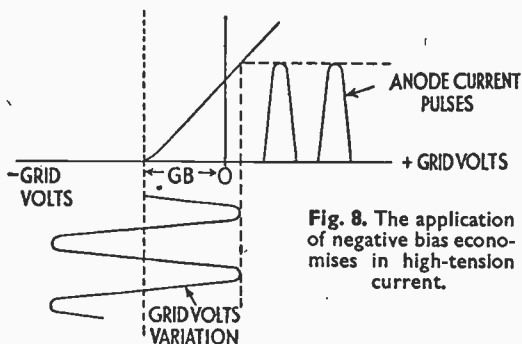
Instead of rising and falling about some average value, the anode current now flows in a series of pulses.

The action is illustrated in Fig. 8. It will be seen that the valve has a "rest" on each negative half-cycle, because anode current is then zero. The heating effect at the anode is, therefore, greatly reduced.

Pulse Excitation

This "pulse" excitation of the aerial corresponds to a person pushing a swing, each push being given as the swing starts moving away from him. Without grid bias the action of the valve would be similar to a person running backwards and forwards alongside the swing, pushing continuously in the appropriate direction, obviously a very fatiguing and uneconomic method.

The correct grid bias voltage de-

pends on the characteristics of the valve, and is obtained by means of a voltage drop across a resistance or from a battery or a DC generator.

Fig. 9 shows a simple method of obtaining grid bias by means of a high resistance called the "grid leak". Current flows from the grid to the cathode on each positive half cycle, and this develops a negative voltage across the resistance. The condenser C is connected in parallel with the resistance in order to provide a path of low impedance to radio-frequency.

The method of keying shown in Fig. 7 is the simplest possible way, and the key here acts merely as a switch in the anode circuit. It is also possible to key a transmitter in the grid circuit or in grid and anode circuits simultaneously, the latter scheme being very common.

Fig. 8. The application of negative bias economises in high-tension current.
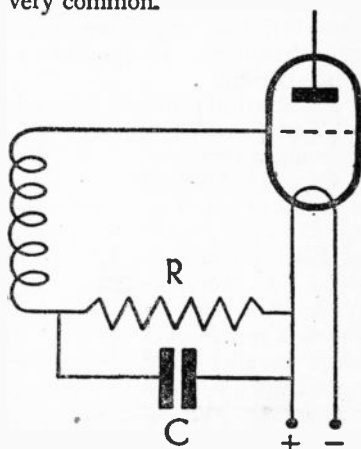
Fig. 9. Inclusion of the grid leak, R, makes an oscillating valve self-biasing.

Fig. 10 shows a simple series-feed transmitter keyed in anode and grid circuits simultaneously. The cut-off of anode current when
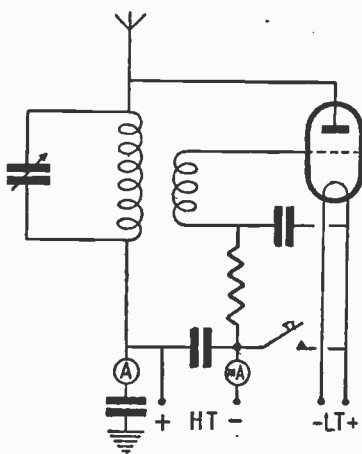
Fig. 10. Simple series feed circuit with key breaking anode and grid circuits simultaneously.

the key is raised is very sharp and assists in the production of clear-cut Morse.

In ground radio stations the transmitter itself is usually at some distance from the operator, who has only his receiver in front of him. The Morse key must, therefore, be connected to the transmitter by land lines, and the method is called "remote control". In this case the Morse key is in a low-tension circuit and
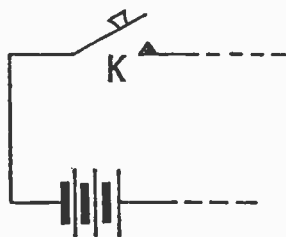
operates the actual keying circuit of the transmitter through a magnetic relay.

Fig. 11 shows the principle involved. When the key K is pressed the circuit is complete, and the electro-magnet M closes the contacts C against the tension of the spring S. On releasing the key the contacts C are pulled open by the spring, so that the movements of the Morse key are repeated at the transmitter.

Wavemeters

To adjust a transmitter to radiate on the required frequency, some form of frequency measuring instrument is necessary. This is called a wavemeter, and consists essentially of a calibrated oscillatory circuit—*i.e.*, the dial of the tuning device is marked in either kilocycles or metres, so that the resonant frequency of the wavemeter is known for any setting.

It remains to provide some means of observing when the transmitter and wavemeter are resonant to each other, and there are several ways of doing this. Fig. 12 shows the circuit of one
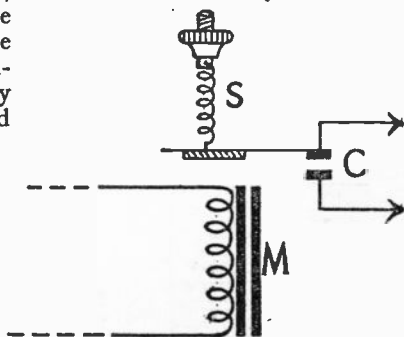
Fig. 11. Remote keying of a transmitter. When the operator closes K, the relay M closes contact C at the transmitter.

method, the valve voltmeter. *LC* is the calibrated oscillatory circuit, and the triode valve is biased to the cut-off point of anode current. A microammeter is in series with the valve anode circuit.
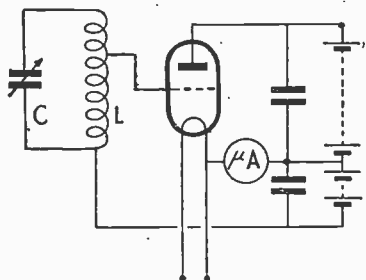
Fig. 12. The frequency of a transmitter may be measured by a wavemeter. The calibrated tuning condenser *C* is adjusted for maximum reading on the microammeter.

To measure the frequency of a transmitter, the wavemeter is placed fairly close to it (depending on the power of the transmitter) and the key pressed. The wavemeter tuning condenser *C* is then adjusted until a maximum reading is obtained in the microammeter.

Fig. 13 shows the action of the valve. At the resonant point

Fig. 14. A heterodyne wavemeter using a reactive valve. It is adjusted for "zero beat" on the headphones.

maximum current is induced in the circuit *LC*, and hence the radio-frequency EMF applied to the grid is at maximum, this in turn causing maximum anode current. A very small amount of mistuning will cause an observable drop in the anode current of the valve voltmeter, so that quite reasonably accurate frequency measurement is possible.

A second method is provided by the heterodyne wavemeter. Fig. 14 shows the circuit of a simple type. It is merely a one-valve reacting receiver using, in this case, anode bend rectification.

By tuning the wavemeter to the transmitter and finding the "dead space" of the heterodyne note, the transmitter frequency can be read off the wavemeter calibrated circuit.

The simple transmitting circuits of Figs. 7 and 10 would be workable on low powers and medium frequencies, but they would not be really suitable for modern conditions, on

ANODE CURRENT

− GRID VOLTS

+ GRID VOLTS

Fig. 13. How the oscillatory current picked up by the wavetrap produces unidirectional current pulses in the valve.

account of their inherent lack of stability as regards frequency. Being self-oscillators, the frequency is governed mainly by the aerial circuit, and is liable to "wander" appreciably. On high frequencies (short waves) this frequency wandering would be serious.

Frequency Control

All modern transmitters have some form of frequency control, the object of which is to ensure that the radiated frequency conforms closely to that desired, and also remains at that figure. Some form of self-oscillator must still be used to generate the radio-frequency, but the feature of all frequency controlled transmitters is that the self-oscillating circuit is not the aerial.

The amplifier valve V_2 is parallel-fed to the aerial circuit L_3-C_3, and the grid circuit of this valve is coupled magnetically by the coil L_2 to the master oscillator, thus deriving its exciting voltage at the frequency of the master circuit.

Being a closed oscillator and not having to deliver much power, the master circuit is largely free from the causes of frequency variation prevalent in the aerial, thus rendering the frequency of the transmitter more stable. R_2 is the grid leak for the master oscillator valve V_1, which is not keyed, but works continuously once the transmitter is switched on.

R_1 and R_3 in series form the grid biasing arrangement for the valve V_2 and keying is effected by
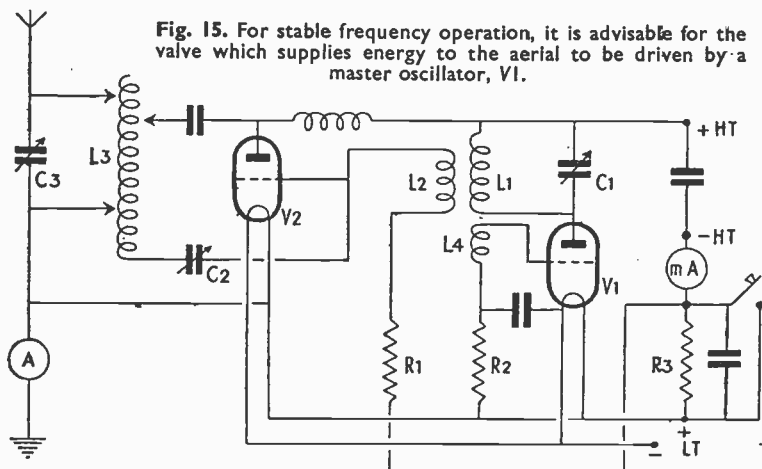
Fig. 15. For stable frequency operation, it is advisable for the valve which supplies energy to the aerial to be driven by a master oscillator, V1.

Fig. 15 shows a simple transmitter with a "master" oscillator circuit followed by an amplifying valve driving the aerial. The master oscillator is the circuit L_1-C_1, which, in association with the valve V_1 and the grid coil L_4, forms a self-oscillator. L_1-C_1 is calibrated in kilocycles or metres.

short-circuiting R_3, thus removing sufficient bias to permit the valve to function.

Crystal Effects

Certain crystalline substances, notably quartz, exhibit the phenomenon known as the piezo-electric effect. Briefly this means

that when a slice of the material is compressed, an EMF is developed across it, and also that if an EMF is applied to the slice, expansion or contraction takes place.

The crystal is, therefore, capable of mechanical vibration, and has a natural resonant frequency which is determined mainly by its thickness—the thinner the slice the higher its frequency. Quartz crystals are quite cheap, and are in very general use as frequency controlling devices, especially on short waves. They cannot, however, handle much power, so that amplifying stages between the crystal and the aerial are always necessary.

Fig. 17. A crystal in plug-in holder.

adjusted to give a maximum reading in the radio-frequency ammeter A, which occurs when the resonant frequency of LC is slightly above that of the crystal. The actual frequency is, of course, the crystal frequency—not that of LC.

Fig. 17 shows an example of a totally enclosed crystal holder. The two pins plug into a corresponding socket so that the crystals for different frequencies can be changed very quickly.

When a frequency control is used, it is very important to ensure that self-oscillation of the aerial is impossible. If self-oscillation occurs, the object of the frequency-control device is defeated.

Fig. 16. For accurate maintenance of a given frequency, an oscillator may be controlled by a crystal, Q.

Fig. 16 shows a typical crystal oscillator. The crystal Q is connected between grid and cathode of the valve, and the necessary feedback of energy to maintain oscillation is obtained by virtue of the anode–grid capacity of the valve which, on high frequencies, is quite sufficient.

The oscillating circuit LC is

Neutralising

On the higher frequencies the coupling between anode and grid circuits of the power valve due to anode-grid capacity may be sufficient to cause self-oscillation. This is counteracted by means of a
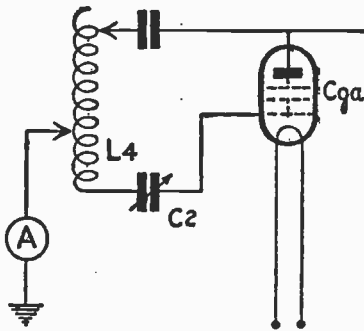
Fig. 18. Feed-back through the internal capacity of the valve, C_{ga}, is opposed by feed-back through the neutralising condenser C_2.

neutralising circuit, an example of which is shown in Fig. 15.

Fig. 18 shows the neutralising circuit re-drawn. The grid is now connected to both ends of the aerial coil, on one side via the valve capacity C_{ga}, and on the other side via the neutralising condenser C_2 and the coil L_4.

By adjusting C_2 the EMFs fed to the grid via these two paths can be made equal, and since they are inherently opposite, they will be mutually cancelling. Other circuit arrangements are possible for neutralising a valve amplifier, but the general principle is much the same.

CW, ICW and Telephony

A continuous wave, being of radio-frequency, does not cause a note in a receiver unless it is broken up into pulses of audible frequency or unless the receiver itself generates a "local" oscillation which is made to "beat" with the received CW and so produce an audible beat note. For example, if the received CW had a frequency of 300 kc., a local oscillation of, say, 301 kc. would coincide with this once every

1,000 cycles and, after demodulation in the set, would produce a 1,000 cycle audio note. This type of CW morse transmission, therefore, necessitates the "beat frequency" method of reception.

Sometimes, it is thought preferable to interrupt the wave before transmission, so that it is audible in any conventional receiver. This is done by inserting an automatic device in the keying circuit, which makes and breaks this circuit at an audible frequency—*e.g.*, 900 times per second.

A common method is to use an interrupter wheel driven by a small electric motor. The wheel is brass, with a number of insulating segments, so that if a copper brush rests on the wheel, the circuit will be made and broken as the wheel rotates. For example, if the wheel rotates 3,600 rpm—*i.e.*, 60 revolutions per second—and has 15 segments, the interruption frequency will be $60 \times 15 = 900$ per second.
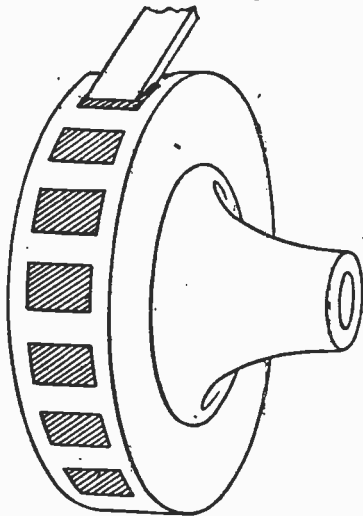
Fig. 19. An interrupter wheel which breaks a transmitted wave into pulses of audio frequency.

A Morse dash lasting 0·2 second will consist of $\dfrac{900 \times 2}{10} = 180$ short bursts of aerial oscillation, and can be received without a beat-frequency oscillator.

Fig. 19 shows the appearance of an interrupter wheel, also called a tone wheel.

Radio-telephony, including broadcasting, means the reproduction at the receiver of sounds made at the transmitter or conveyed to the transmitter from some other place. A continuous-wave transmitter is used, and keying, of course, is unnecessary. This continuous wave is called the "carrier" wave, and the sound is impressed on it in such a way that its amplitude rises and falls in correspondence with the sound vibrations. The sound must first be translated into electrical terms, and this is done by means of a microphone.

Carbon-Granule Microphone

The principle of the carbon-granule microphone is shown in Fig. 20. The disc D is free to vibrate within small limits, and the carbon granules C form part of the circuit through the microphone. If sound waves strike the diaphragm D the carbon granules experience a varying pressure.

The action of the microphone is based on the fact that the contact resistance between two pieces of carbon is proportional to the pressure applied to them. The resistance of the microphone, and hence the current in the circuit, therefore varies in accordance with the sound waves. By including a step-up transformer in the circuit, the sound is readily converted into voltages across the secondary winding.

The basic object of all microphones is to secure an EMF which is an accurate reproduction of the sound wave, and many problems arise

Fig. 21. Section of a carbon-granule microphone for use in aircraft.

Fig. 20. Principle of the carbon-granule microphone. Current from the battery is modulated by the change in resistance of the granules, C, due to sound waves striking against diaphragm, D.

in achieving this. The high standard of reproduction in broadcasting shows how far these problems have been solved. Other types of microphone have been developed, notably the electro-magnetic, the principle of which is the same as that of the headphone earpiece, but reversed in action. A very light conductor is suspended in a strong magnetic field. Sound waves impinging on the conductor cause it to move in the field, and hence to have corresponding EMFs induced in it.

Fig. 21 shows a sectional view of a carbon-granule microphone for
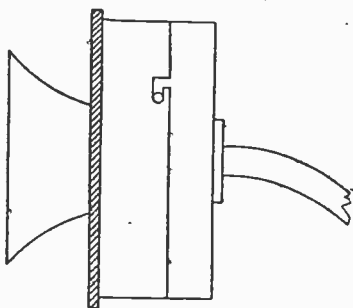
Fig. 22. External view of the carbon-granule microphone shown in Fig. 21.

use in aircraft, and Fig. 22 shows the external appearance of the complete microphone.

The output voltage from the microphone circuit can be impressed on the carrier wave in various ways, this process being called "modulation". As the microphone output is quite small, the amount of amplification required between the microphone and the power-valves will increase progres-

sively with the power of the transmitter.

Fig. 23 shows the principle of one well-known method of modulation. It is called "anode voltage modulation", the "constant current method", or the "Heising system"—after the inventor.

The microphone transformer of large step-up ratio is in series with the power-valve anode circuit, so that the EMFs across the secondary winding either increase or decrease the anode voltage, according to the variations of microphone current. The carrier wave is therefore modulated by the sounds occurring in front of the microphone.

Small Power Circuit

In Fig. 24 is a development of the circuit of Fig. 23, which would be suitable only for very small power. The microphone output is applied to the grid and cathode of an amplifying valve, and the iron-cored choke L is in series with the anode circuit of this valve and also that of the power-valve. Modulation takes place in the same way as before.

Fig. 25 illustrates modulation of a carrier wave by a pure sound, such as that of a tuning-fork. Audible frequencies are, of course,
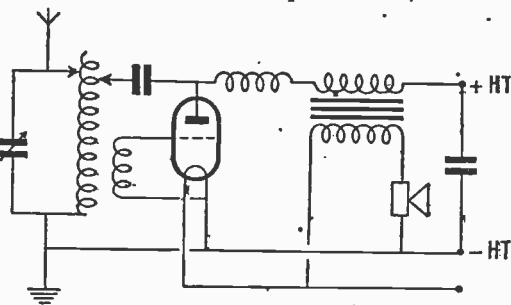
Fig. 23. Anode voltage method of applying speech modulation to a transmitting valve.
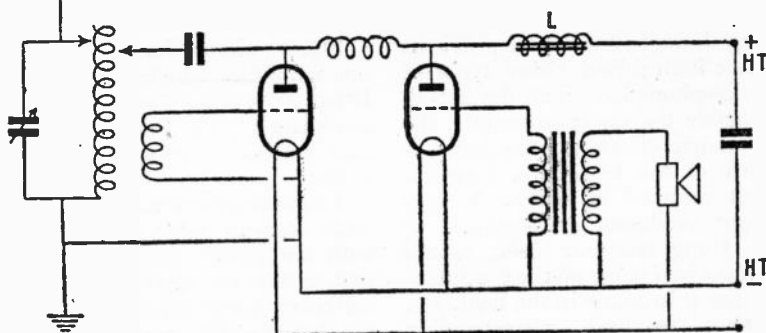
Fig. 24. A development of the system shown in Fig. 23. The amplified speech vóltages produced across L modulate the HT to the oscillator valve.

very low compared to radio-frequencies in general use. For first-quality broadcasting, all audible frequencies between about 50 and 8,000 cps are impressed on the carrier wave. If the carrier frequency is, say, 600 kc. (500 m.) each separate modulation for the highest modulation frequency of 8,000 cps is spread over $\frac{600}{8} = 75$ oscillations of the aerial.

Transmitting Aerials

Transmitting aerials can be broadly classified in terms of the wavelengths on which they operate. Thus medium- or long-wave aerials are necessarily small compared to a wavelength. The dimensions of a short-wave aerial will be comparable to a wavelength, and in the case of ultra-short waves or micro waves the aerial may be quite large in comparison with a wavelength.

The radiating efficiency of the Marconi-type earthed aerial is approximately proportional to the square of the height. A high aerial is necessary if it is desired to radiate a large amount of power or to cover long ranges. Unfortunately, the cost of masts rises so rapidly with height that about 850 feet is an approximate economic limit.

Every aerial has a "natural" wavelength—*i.e.*, the wavelength to which it is resonant without the addition of any extra inductance or capacity.

Fig. 26 shows the three usual types of earthed Marconi aerial. The length of the aerial is the distance *AB* measured along the wire and the natural wavelength is about 4·2 times this length. This is known as a quarter-wave aerial. Fig. 27 shows the addition of a loading inductance *L* in the aerial circuit.

Fig. 25. The amplitude of the radio-frequency oscillations is varied at the slower audio frequency.
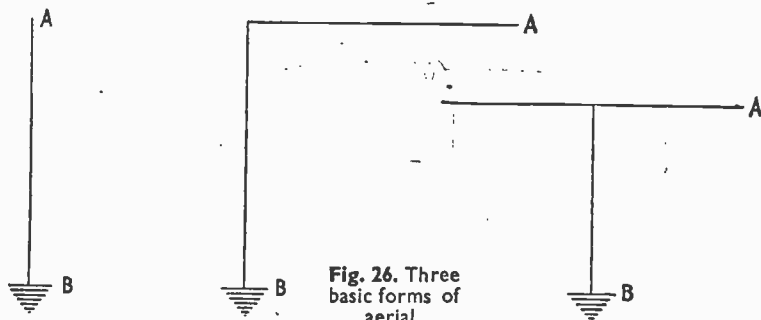
Fig. 26. Three basic forms of aerial.

By selecting the proper value for this inductance, the aerial can be tuned to resonance with some longer wave.

Short- and Long-Wave Aerials

For high powers—*i.e.*, large aerial currents—the capacity of the aerial must be increased, which is done by using a number of separate parallel wires mounted on spreaders. The construction of a long-wave transmitting aerial for a high-power station presents many problems, and the masts and aerial form a large proportion of the total cost of the station.

A straight length of wire in-sulated at each end is resonant to a natural wavelength approx. 2·1 times the length of the wire. If used on this wavelength it is called a half-wave aerial.

When used as a half-wave aerial, the length of the wire is approximately 0·47 of the wavelength.

With short waves between, say, 10 and 100 metres, it is quite easy to erect a quarter or half-wave aerial. No loading inductance is required, and the aerial is much more efficient than the long-wave types previously described.

Fig. 28 shows a typical short-wave transmitting aerial suitable for use on or close to one par-
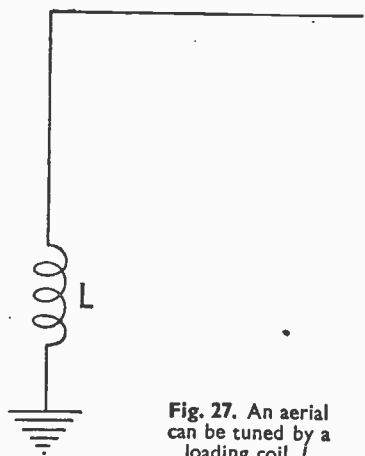
Fig. 27. An aerial can be tuned by a loading coil, *L*.
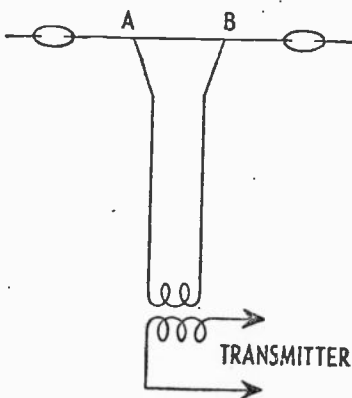
Fig. 28. Circuit of a typical short-wave transmitting aerial for use on or about one particular wavelength.

133
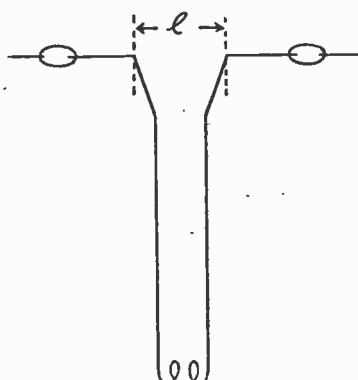
Fig. 29. An aerial, slightly less efficient than Fig. 28, but suitable for operation over about 15–100 metres.

0·1 to 0·125 of the wavelength, according to the height of the aerial above the ground—*i.e.*, the length of the feeders. The feeder lines merely serve the purpose of conveying energy to the horizontal aerial, and they do not radiate appreciably.

In Fig. 29 is a similar type of aerial which is slightly less efficient, but which can cover a wide band of frequencies, about 15 to 100 metres (20 to 3 megacycles).

The length of each horizontal limb is about 9 metres, the feeder length is 18 metres, and the distance l is about 10 inches. The feeder spacing in both cases is about 5 cms., but this is not critical.

ticular frequency. The length of the aerial is 0·47 of the wavelength, and the distance AB is about

LEARNING MORSE
THE MORSE CODE

A · —	N — ·	Full Stop · — · — · —
B — · · ·	O — — —	Apostrophe · — — — — ·
C — · — ·	P · — — ·	Inverted Commas ː — · · — ·
D — · ·	Q — — · —	Brackets — · — — · —
E ·	R · — ·	Question · · — — · ·
F · · — ·	S · · ·	Hyphen — · · · · —
G — — ·	T —	Oblique Stroke — · · — ·
H · · · ·	U · · —	Underline · · — — · —
I · ·	V · · · —	Long Break — · · · —
J · — — —	W · — —	Short Break · · · ·
K — · —	X — · · —	
L · — · ·	Y — · — —	
M — —	Z — — · ·	

Ä · — · —	1 · — — — —	6 — · · · ·
Å or À · — — · —	2 · · — — —	7 — — · · ·
È É or E · · — · ·	3 · · · — —	8 — — — · ·
Ñ — — · — —	4 · · · · —	9 — — — — ·
Ö — — — ·	5 · · · · ·	0 — — — — —
Ü · · — —		
CH — — — —		

The morse code was invented by Samuel Morse in 1872. Each letter of the alphabet is represented by a combination of long and short transmissions—*i.e.*, dashes and dots—and the inventor designed the code so that the letters occurring most frequently in the English language are represented in the shortest way. Figures, punctuation marks and certain accented letters of foreign languages are also provided for. The complete code is given on the opposite page.

Speed Factors

The speed at which morse is sent and read for practical purposes varies with a number of factors. The skill and experience of the operators, the nature of the message (*i.e.*, whether plain language, code or cypher), strength of the signal, atmospheric conditions, and even to some extent the quality of the transmitter note and the action of keying relays, all may affect the speed of working.

For most kinds of work, 20 words or 100 letters per minute is a representative average speed. It is a comfortable writing speed, and requires no great effort of concentration to read for a person who has really mastered morse code. It is also a comfortable sending speed, and represents a "natural" rate of sending for the great majority of operators.

Under favourable conditions of good signal strength, with little or no interference, expert operators often work up to about 25 words or 125 letters per minute, or even a little more when work presses. On the other hand, if the matter to be dealt with is code or cypher, or contains letters and figures mixed, or is in a language strange to the

operators, the speed must inevitably drop in the interests of accuracy and the avoidance of frequent requests for repetitions.

A great deal of nonsense is talked about morse speed, but it will almost invariably be found that the people who claim the ability to send or read morse at fantastic speeds could always do so "years ago" but are now out of practice!

Reading morse at practical working speeds is an automatic process. That is to say, the fully competent reader does not have to *think* what a particular dot-dash combination means—his pencil automatically writes it. The action is just as quick as that of a trained boxer in dodging a blow, and just as certain, perhaps more so.

In reading plain language in his native tongue, a morse reader nearly always follows the sense of the message as well—*i.e.*, he reads the words and sentences as well as the letters. Experienced operators often write several letters behind the sound, and, in exceptional cases, several words behind.

Expert Morse-Readers

All expert operators can read morse faster than it is possible to write. Automatic transmissions at 40–50 words (200–250 letters) per minute are quite readable, but of course they cannot be written down at this speed by any normal writer. Typing is a possible solution, but the noise of the typewriter may drown the signal, and in any case only a very exceptional person could perform the feat for any length of time. Such things have been done, but they are more in the nature of freak records than practical propositions.

Sending morse is more difficult

than reading it. There is only one criterion of good sending, and that is its readability. To be able to send 30 words per minute is a meaningless achievement if it is sent in such a way that no one on earth could read it.

As with all operations which depend on manual dexterity for their execution, economy of effort is the hall-mark of the expert. Only a very small exercise of muscle is needed to operate a morse key, and a good operator should be able to send continuously for at least half an hour without feeling any aches or pains.

Correct Key Adjustment

Correct key adjustment is important. Contact gap and spring tension are always adjustable, and every operator has his own best settings. A very small gap is usually preferred, but the smallness of the gap is limited to some extent by other factors. If the gap is closed up too much there will be a tendency to sparking in some cases, and the quality of the contacts themselves will affect the possible limits.

Again, in aircraft the gap will often have to be somewhat larger, because otherwise it would be impossible to work the key in rough weather, when the operator is being pitched about in his seat and perhaps leaving it altogether when the aircraft drops. In these circumstances the key has to be "punched", and morse-sending degenerates from a delicate art to a rather hit-and-miss process.

The American type of morse key known as the "bug" allows rather higher speeds, mainly because dots are sent automatically by means of a vibrating spring con-

tact. The key movement is sideways instead of up and down, one side giving a continuous transmission for dashes, and the other side a series of automatic dots. Bug keys require careful handling and setting, and inexpertness on a bug key is productive of even worse results than with an ordinary key.

Learning morse consists of three processes:

1. Learning the code.
2. Reading morse.
3. Sending morse.

Stages 2 and 3 involve reversed mental processes, and if a beginner decides to learn sending first, it is quite possible for him to attain a sending speed of 20 words a minute or more and not be able to read a letter without prolonged thought. As a rule, the two are taught together and the speed of each is developed gradually.

Learning to Read

Learning to read morse is a very tedious process, which is aggravated by the fact that a pupil is rarely conscious of any progress. Various methods have been put forward as aids in learning to read morse, but it is extremely doubtful whether any of them have the slightest effect in accelerating the desired result.

The beginner is always over-anxious. Missing a letter flusters him to such an extent that he misses the next two or three as well. He then recovers from his temporary paralysis and starts again. This recovering process gradually becomes more rapid, and after a time he automatically rejects a missed letter and reads the next one.

Progress can only be made by

sending morse to a pupil at a speed slightly in excess of what he can actually read, and it is this fact which makes the learning period so discouraging. The pupil is eternally chasing the letters, and they seem eternally to elude him.

A rough calculation shows that an average person has to hear every letter about 40,000 times before he recognises it without much effort. At this stage he can probably read about 20 words a minute by dint of considerable concentration. It takes longer than this before the reading of morse becomes possible without much concentration.

There is one compensating fact —once morse is really mastered, it stays. Experienced operators can change their work, not hear any morse for months or even years, and then sit down and read 20 words per minute, almost as if they had been doing it only yesterday.

Aids to Learning

As regards the preliminary learning of the code, the following analysis is useful:

Dot Letters.	Dash Letters.
E ·	T —
I ··	M — —
S ···	O — — —
H ····	

Reversed Pairs.

A · —	N — ·
B — ··	V ··· —
D — ··	U ·· —
F ·· — ·	L · — ··
G — — ·	W · — —
Q — — · —	Y — · — —

Letters which are the same Reversed.	Remaining Letters.
K — · —	C — · — ·
P · — — ·	J · — — —
R · — ·	Z — — ··
X — ·· —	

In the figures, the number of dots in 1, 2, 3, 4, and 5 corresponds to the figure, and then decreases progressively from 6 to 9.

Certain of the punctuation symbols are usually regarded as made up of a combination of two or three letters sent as one.

Full Stop	· — · — · —	$\overline{AAA}$
Inverted commas	· — ·· — ·	$\overline{RR}$
Brackets	— · — — · —	$\overline{KK}$
Question	·· — — ··	$\overline{IMI}$
Underline	·· — — · —	$\overline{UK}$
Long Break	— ··· —	$\overline{BT}$

The signal $\overline{CT}$ — · — · — is sent first when making a transmission, and is universally recognised as the preliminary warning. Completion of a transmission is indicated by $\overline{AR}$ · — · — ·, which announces that the operator has finished for the moment. The finish of work for an indefinite period is indicated by $\overline{VA}$ ··· — · —

Certain combinations of letters are of such frequent occurrence that they can almost be regarded as morse "phrases". For example, the beginner very soon recognises — ···· · as "the", without consciously reading the three separate letters. Similar examples are ·· — · — — · "ing", — — · — · "ment", ·· — · — — — · — · "for", — — · — — — ··· — · "of", and so on.

In the long and laborious process of reaching 20 w.p.m. in reading, pupils who worry the least usually get on best. The nervous, highly-strung type often takes longer than a more stolid individual, who seems to be less affected by the apparently unending mishaps which accompany early efforts. Cases are known in which a pupil fails to progress and finally withdraws from the contest, but they are comparatively rare. The exact causes of a definite inability to read morse are obscure, but tone-deafness is probably one of them.

Importance of Good Start

In learning to send morse, a good start is vitally important, and unfortunately this is frequently neglected. Because a morse key is a very simple piece of mechanism, the mistake is often made of supposing it to be docile. The unhappy pupil soon discovers that a morse key can be a most intractable, obstinate and infuriating device, apparently capable of making every possible signal except that desired, and possessing an evil volition of its own.

Essential Qualifications

To send first-class morse requires a delicate touch, perfect co-ordination of brain and hand, a keen sense of rhythm, plus, of course, a complete mastery of the code itself. The beginner is almost certain to adopt a bad position at the key unless guided, and very few will hold a key properly by instinct. It is true that some excellent operators use eccentric postures and hold the key in an apparently uncomfortable way, but these exceptions do not disprove the rule that a relaxed attitude is correct and that the pressure on the key should come from the tips of the fingers.

The key gap is very small, so that for all intents and purposes the fingers do not move. The elbow should also be stationary, the movement being limited to a slight up and down flexing of the wrist.

Spring Tension

One of a beginner's difficulties is that he does not and cannot at first know what spring tension suits him. An eighth of a turn on the adjusting screw may make quite a lot of difference to the handling of the key, and all skilled operators "fiddle" with their keys before settling down.

As a general guide, a tendency to miss dots is often due to too much spring tension, and a tendency to slur a dot into a preceding dash may be due to too little.

Letter formation and spacing are, of course, vitally important. The characteristics of good morse are as follows:

(1) All dots are the same length.
(2) All dashes are the same length.
(3) Consecutive dots are equally spaced.
(4) Consecutive dashes are equally spaced and very close together.
(5) Letters are equally spaced.
(6) Words are equally spaced.
(7) Every letter or figure is perfectly formed as a connected whole.

These are obviously the attributes of morse sent by an automatic machine. While few operators can reach the perfection of

machine morse, many approach it. Musical instinct and a sense of rhythm will be found in all good operators—the drummer of a dance band ought to make a fine telegraphist.

Machine Morse Standard

The desirability of machine-like morse is sometimes debated, and it is a fact that some very good operators send morse which breaks more than one of the foregoing rules, but is nevertheless "good" in the sense that it is consistent, rhythmic and easy to read. Such styles are known variously as "Bagdad morse", "Chinese morse" or "Tiddly morse" and are acquired only by operators of much experience. Whether or not this individuality is desirable is a difficult question, but on the whole it seems preferable to aim at machine morse as the recognised standard.

One of the difficulties with beginners is invariably their unconscious mental dishonesty when practising sending. Knowing that nobody is reading it, they make mistakes without bothering to correct them, and at a later stage it will often be found that they do the same thing when someone *is* reading it. To read badly sent morse with continual blunders and erasures is one of the most maddening tasks imaginable, but it is a pleasure to read first-class morse sent with the beautiful precision, slickness and accuracy of the rhythm of a good dance band.

Origin of Mistakes

The following statement should be absorbed by all who use morse: When a mistake occurs in a message, it is nearly always the fault of the sending operator.

There are various morse practice outfits on the market; most of them consisting of a small mechanical buzzer on the electric-bell principle and a key, the buzzer being worked from a dry battery. These are quite suitable for the earlier stages of learning the code, but they are open to the objections that the key is usually a poor one and that the note of a mechanical buzzer is often harsh and not very clear-cut.

Second-hand Keys

The wireless operator is, of course, trained on proper apparatus in his radio school. Anyone, however, who wishes to practise morse seriously in the absence of such facilities would be well-advised to make a simple valve buzzer and buy a good morse key. Quite a good morse key can be purchased for about 7s. 6d. new, and it is often possible to get second-hand keys of even better quality for very little more.
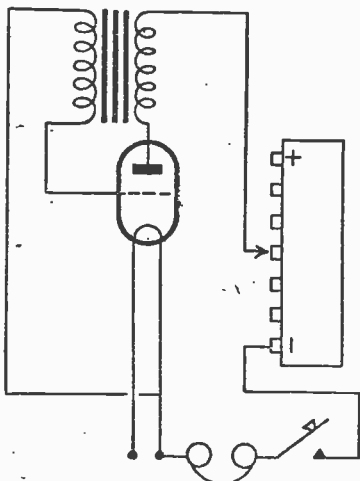
Fig. 30. How a simple valve buzzer can be made up for morse practice.

Second-hand keys should be over-hauled before use by someone who understands the job.

A valve buzzer is very simple, and comprises the following components:

  1 General purpose triode (almost any kind will do).

  1 LF transformer (about 3–1 or 4–1).

  1 Valveholder.

  1 pair headphones.

  1 9-volt or 18-volt GB battery.

  1 2 volt accumulator (for valve filament).

Fig. 30 shows the wiring employed. The pitch of the note varies with both anode and filament voltage, but it is quite easy to find a tapping on the battery which gives satisfactory results. The note is clear and musical and the morse is very clear-cut. Total cost, including the key, should not be much over 30s. While this is rather more than the simpler types of mechanical buzzer outfits, the results are superior, and well worth the extra outlay.

One form in which this practice outfit may be made up is illustrated in Fig. 31.
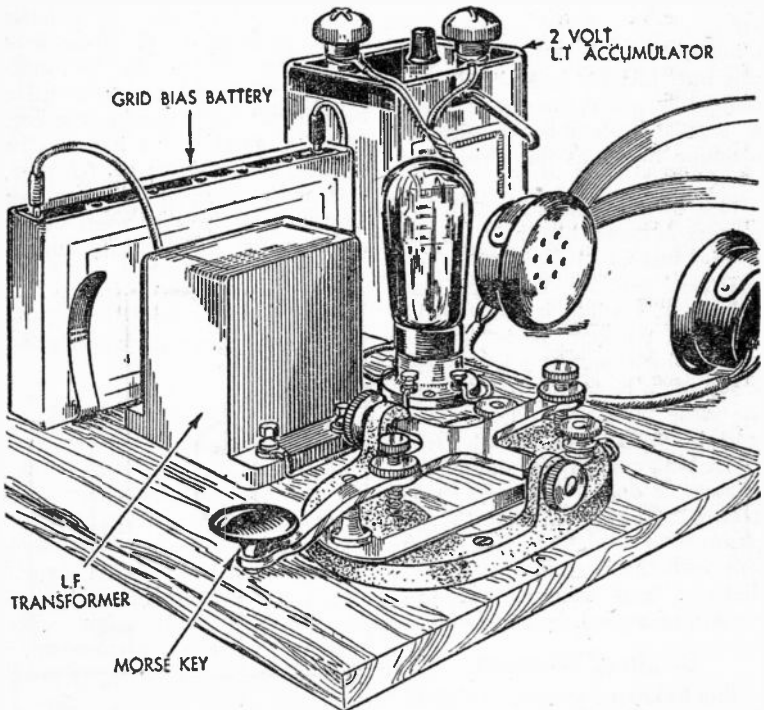
Fig. 31. A simple Morse practice outfit made up using the circuit which is shown in Fig. 30. The arrangement of parts is not critical and the layout can embody the constructor's own ideas affording scope for his ingenuity.

RADIO IN AVIATION

MAIN OBJECTS. WAVELENGTHS. WEIGHT. AIRCRAFT AERIALS AND EARTHING. POWER SUPPLIES. DIRECTION FINDING. BEARINGS. SCALES. BELLINI-TOSI SYSTEM. THE GONIOMETER. ACCURACY OF RADIO FIXING. ERRORS IN DF. ADCOCK SYSTEM. SETTING OF SCALES. QUADRANTAL ERROR. HOMING. BLIND APPROACH. MARKER BEACONS. INTERFERENCE.

RADIO is more essential to aviation than to perhaps any other means of transport, and it is only by the development and organisation of a comprehensive radio service that commercial air lines, running to schedules almost regardless of weather, have become possible.

A car, train or ship encountering fog can reduce speed to a crawl and stop at any moment. An aeroplane flying in fog or cloud has no such choice, but must continue to travel at an enormous speed compared to ground transport. An emergency landing may be either impossible or extremely dangerous, and all landmarks or points of reference may be invisible.

In these circumstances communication with the ground, and possibly with other aircraft, is a matter of vital necessity. The objects of radio in aviation can thus be summarised as follows, in order of importance:

(1) Navigational service—*i.e.*, direction-finding and blind approach systems.

(2) Giving of meteorological information.

(3) Passing instructions to the captains of aircraft.

(4) Routine messages dealing with organisation.

(5) Public correspondence, *i.e.*, radiotelegrams.

As a site for a radio installation an aeroplane has almost every possible disadvantage. Space is usually cramped, permissible weight is strictly limited, the power available is small, an efficient aerial is difficult to realise, electrical interference is high and must be suppressed, and even on aeroplanes designated as "quiet" the noise during flight is appalling compared to what is desirable in a radio cabin. Nevertheless, all these difficulties have been overcome, and the modern aircraft installation provides efficient and reliable communication.

Wavelengths Employed

Both medium and short waves are used, and in the larger types of aircraft the radio installation covers a band of frequencies on both the medium- and short-wave sections. The standard wavelength for civilian aviation in Europe is 900 metres (333·3 kc.) together with a number of other wavelengths in this neighbourhood—*e.g.*, 870 and 930 metres.

The short-wave band covered depends on requirements, 40–80 metres (7·5 mc.–3·75 mc.) being a commonly used section. Typical

wavelength coverage for an aircraft installation is:

550–1100 m. (545·4 kc.–272·4 kc.).
40–80 m. (7·5 mc.–3·75 mc.)

Weight of Equipment

In the small types of private or club aeroplane the fitting of extra equipment immediately raises weight questions, and the designer of radio sets for small aircraft has to think in lbs. A quite different technique is therefore required compared with, for example, ship radio where an extra cwt. or so is of little importance. Even on the largest aircraft yet constructed the weight of supplementary equipment remains important and must be kept down as much as is consistent with durability. The following figures show typical weights for aircraft sets:

Example 1. Marconi AD 49/50. Low-power (65-watts) installation for small private or commercial aircraft of types such as the Leopard Moth, Percival Gull, or Monospar. Medium waveband only. Weight approx. 64 lb.

Example 2. Marconi AD 41/42. Medium power (100–150-watts) installation for larger types of aircraft. Medium waveband only. Weight approx. 100 lb.

Example 3. Standard ATR 2. Medium power installation (100-watts) for larger type of aircraft. Medium and short wavebands. Weight approx. 87 lb.

Example 4. Marconi AD 57/58. Medium power (130-watts) installation for larger types of aircraft. Medium and short wavebands. Weight approx. 130 lb.

Bonding

The "earth" on an aircraft is formed by arranging electrical continuity through all metal in the aircraft structure, this being termed "bonding" the aircraft.

In the older types of wooden aircraft, bonding was a tedious and troublesome process, on account of the very large number of separate connections required to the internal bracing wires in the wings and fuselage. With modern all-metal aircraft, bonding is comparatively simple, because the main structure of the aircraft needs no attention. Any part, however, which is or may be electrically discontinuous from the main structure must be bonded by means of a flexible connection across the point of discontinuity. This includes control surfaces, which are bonded across their hinges, any detachable metal fittings, and also the engines themselves if they are mounted on rubber suspension brackets.

Connections are made by a special type of braided copper flex, known as bonding wire, which does not break with repeated bending or vibration. Incom-
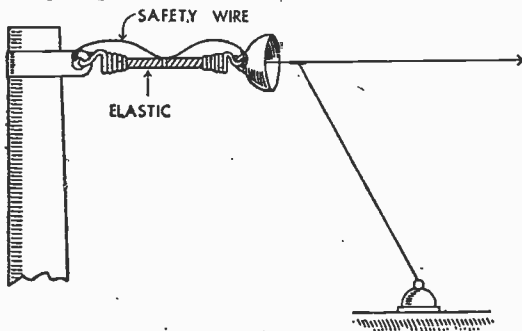
Fig. 1. A fixed aerial mounting including a de-icing cone.

plete or defective bonding may result in rubbing or intermittent contact between two parts, and this is liable to cause scraping and crackling noises in the radio receiver.

A main earth terminal is provided at some point close to the radio installation, and the aircraft bonding is checked by means of a simple continuity test between this earth terminal and any point on the aircraft.

Aerials

The aircraft aerial may be either a "fixed" or "trailing" type. The fixed aerial consists of one or more wires rigged between any two convenient points. The wire is kept taut by means of elastic cord, which is bridged with a slack safety wire, so that should the elastic break, the aerial will not have a free end.

Fig. 1 shows details of a fixed aerial mounting, including a de-icing cone. This cone prevents the aerial being short circuited to earth by ice formation. Fig. 2 shows two typical fixed aerials: *a* represents the layout on a small biplane, and *b* is the usual arrangement on large aircraft.

The trailing aerial, as its name implies, consists of a length of wire which is reeled out in flight and allowed to hang down below the
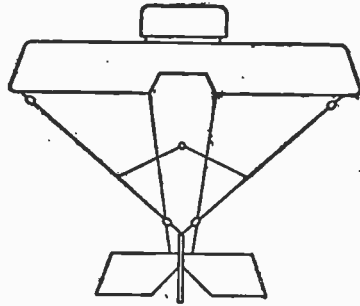
Fig. 2a. Typical arrangement of aerial on a small biplane.

aircraft. The length of wire varies from about 40 feet for short waves to a maximum of about 250 feet for medium waves. The chief advantage of the trailing aerial is that it is large compared to any aerial which could be rigged on the aircraft, and gives better ranges of transmission and reception.

A long trailing aerial prohibits any of the more violent aerial manœuvres, but this is of no consequence on commercial aircraft. With very fast aircraft, the trailing aerial drops noticeably in efficiency, because it tends to stream behind the machine in flight rather than to hang down, which has the result of reducing its height.

The components used with a trailing aerial are indicated in Fig. 3a. The aerial is weighted by means of lead beads (about $1\frac{1}{2}$ lb. total)
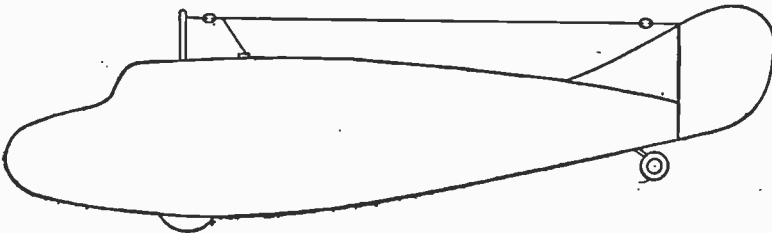
Fig. 2b. Usual situation of main fixed aerial on large aircraft and flying-boats.

attached to its free end. It is brought into the aircraft through a "fair-lead", consisting of a paxolin tube suitably mounted under the winch. An earthing device is provided by the plunger-type switch S which, when pushed in, earths the aerial via bottom metal fitting M and the contacts C.

Direct earthing of the trailing aerial at a point outside the aircraft protects the apparatus from damage during electrical storms, and also enables the wireless operator to wind in the aerial in comparative safety.

Fig. 3b is a side view of the aerial winch. The lever L has two positions, marked "Free" and "Fixed". In the "Free" position the aerial runs out, the speed of run-out being checked by an automatic centrifugal brake incor-

porated in the winch mechanism. The aerial is allowed to run out to its full extent, at which point a small pear-shaped brass connection engages with a corresponding bell-mouthed fitting at the top of the lead-in tube, thus connecting the aerial to the transmitter.

For winding-in, the lever L is put to the "Fixed" position, and a pawl and ratchet come into operation. This prevents the aerial from running out when the handle is released. Winding-in is continued until the bead weight just appears above the lead-in tube.

Power Supplies

The power supplies for an aircraft radio installation are as follows:

(1) Low-tension supply, for the filaments or heaters of the trans-
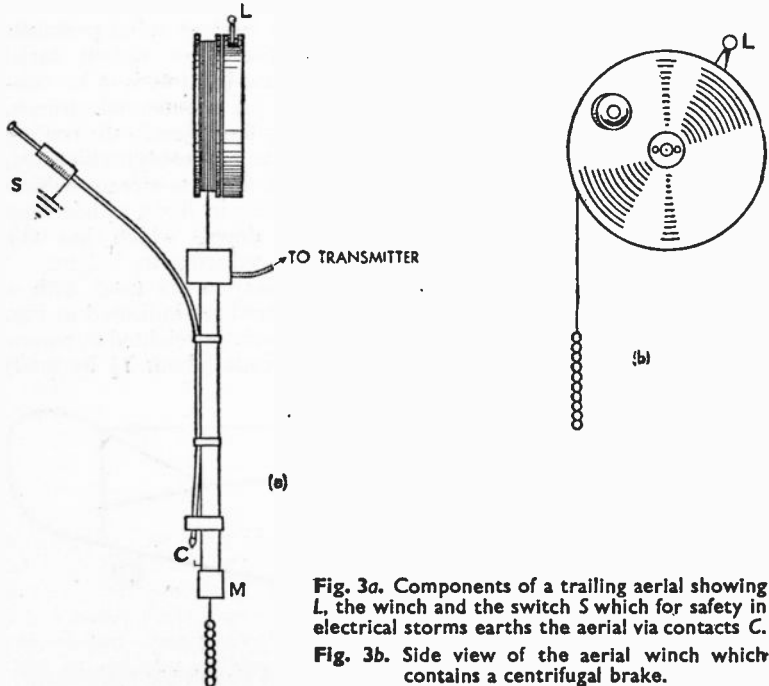
Fig. 3a. Components of a trailing aerial showing L, the winch and the switch S which for safety in electrical storms earths the aerial via contacts C.

Fig. 3b. Side view of the aerial winch which contains a centrifugal brake.
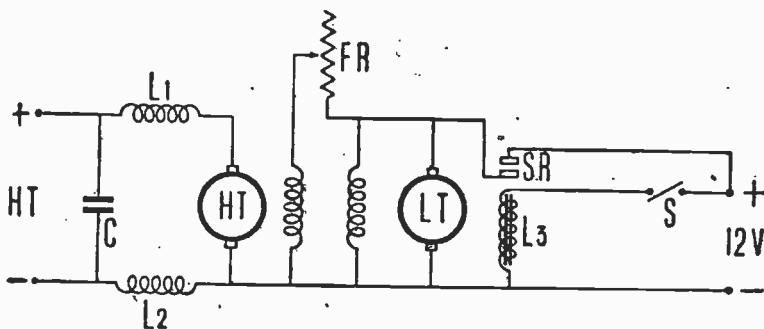
Fig. 4. Circuit of a rotary transformer used for obtaining transmitter high tension from 12 volt accumulator input.

mitting and receiving valves. This is derived from an accumulator, which may be the main battery of the aircraft, or a separate battery for the radio alone. In some cases separate batteries may be provided for transmitter and receiver. The current taken will naturally depend on size of the radio equipment, typical average figures being 6 volts 4 amps for the transmitter and 6 volts 0·5 amp. for the receiver.

(2) High-tension supply for the transmitter. A rotary transformer is the usual method in modern practice and Fig. 4 is the circuit diagram of a typical arrangement.

When the switch S is closed, the coil L_3 is energised and closes the starting relay (SR) which completes the supply to the LT side of the rotary transformer.

The field resistance (FR) is in series with the high-tension field and provides a pre-set control over HT volts. The HF chokes L_1 and L_2 with the condenser C prevent radio-frequency currents from entering the HT armature.

As a typical figure, the HT output required is 1,200 volts at 150 ma.—i.e., 180 watts. Taking the overall efficiency of the rotary

transformer as 60 per cent., this means that the input will be $\dfrac{100 \times 180}{60} = 300$ watts, giving an input current of $\dfrac{300}{12} = 25$ amps.

The load on the battery is, therefore, heavy during transmission, but the scheme has been found preferable to the use of wind-driven generators for transmitter HT. These are generally inaccessible, they decrease the speed of the aircraft slightly, and the windmills are subject to ice formation.

(3) High-tension supply for the receiver. About 120 volts at 15–20 ma. represents an average figure for a general-purpose aircraft receiver, and this could be supplied from a dry battery. There is a good deal to be said in favour of dry battery HT for aircraft receivers, mainly on the score of simplicity, reliability, and the fact that receiver HT is then independent of any other source of power.

On the other hand, the cost of electrical power derived from dry batteries is high, and perhaps for this reason the tendency is to use another rotary transformer. Such machines take up no more
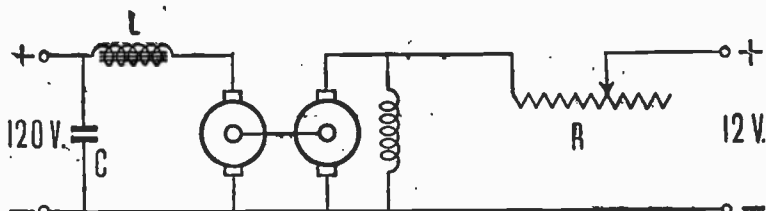
Fig. 5. Circuit of a rotary transformer for securing high tension for aircraft receivers. The complete unit is no larger than an HT battery.

space or weight than an equivalent dry battery, and they have proved very reliable over long periods.

Fig. 5 shows the circuit diagram of a typical machine. The resistance R is a starting device, an "Off" position being provided. The choke L and condenser C form a smoothing circuit which reduces the HT commutator ripple to negligible proportions. Input
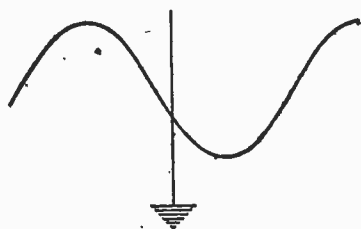
Fig. 6. The EMF induced in an aerial is in phase with the wave.

on load would be $\frac{1}{2}$ to 1 amp. in the case considered, representing only a light load on the accumulator.

Aid to Navigation

As has been mentioned, the use of radio as an aid to navigation is

its most important application in the aviation field. The methods employed can be broadly classified under three headings:

(1) DF apparatus at the ground stations, but no special equipment on the aircraft other than the ordinary general-purpose transmitter and receiver.

(2) DF apparatus on the aircraft, but no special ground equipment.

(3) Special apparatus both on the aircraft and at the ground stations, the two sets being complementary to each other. This scheme is always associated with some form of automatic indication, and is exemplified in blind approach systems and the "Radio Compass".

All three methods will be explained in the following pages, but it is first necessary to deal with the principles of DF apparatus and the various special phenomena which make its practical uses possible.

Considering the case of an ordinary vertical wire aerial under

a

Fig. 7. If A and B represent two aerials the greatest phase difference between their EMFs occurs when they are in line with the transmitter as in b.
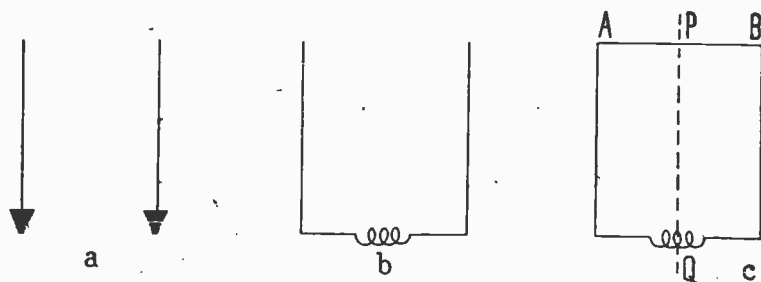
Fig. 8. The three stages by which the two separate aerials of Fig. 7 evolve into the loop or frame aerial used for direction finding.

the influence of an ether wave as in Fig. 6, it is clear that the EMF induced in the aerial will rise, fall and reverse according to the strength and polarity of the wave at any instant—*i.e.*, the EMF induced in the aerial will be in phase with the wave.

If two such aerials are erected near one another, the phase relationship between the EMFs in them will depend on: (*a*) the spacing of the aerials, and (*b*) the difference between their distances from the transmitter.

In Fig. 7 *a A* and *B* represent two vertical aerials equidistant from the transmitter X. It follows that the EMF in each aerial will be the same at any instant in both direction and magnitude, and also since $XA = XB$, that AB is at

90° to the direction of propagation XY passing through the point midway between A and B. Fig. 7 *b* shows that the greatest phase difference between the two EMFs will occur when the line joining the aerials passes through the transmitter.

Fig. 8 shows the development of a pair of spaced vertical aerials into a "frame" or "loop" aerial. If the loop in Fig. 8 *c* is mounted so that it can be rotated about a vertical axis PQ, the possibility of wireless direction-finding arises.

Fig. 9 is a plan view of the frame which is assumed to be rotated about the vertical axis O. In the position AB the frame is at 90° to the direction of the signal from the transmitter X, as in Fig. 7 *a*, and since the EMFs in the vertical
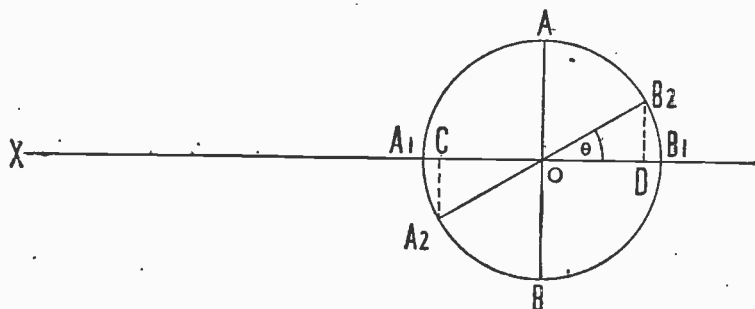
Fig. 9. If XO is the direction of the wave and A2–B2 the position of the frame aerial, the voltage induced is equal to that in a smaller loop CD.

147
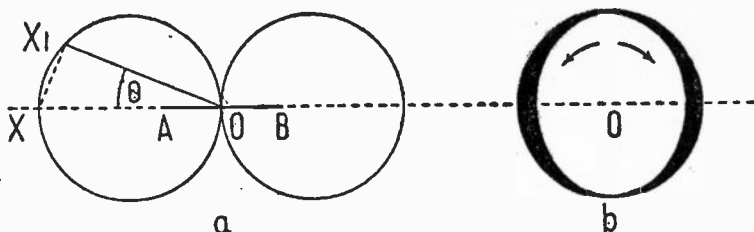
Fig. 10. In *a* the two circles represent the way the signal strength varies as the frame aerial *AB* is rotated. Another way of representing the signal—by the width of the line—gives the diagram illustrated in *b*.

limbs *A* and *B* are identical in value and in phase, their resultant is clearly zero in the loop. In this position, therefore, no signal will be received on the loop aerial.

In position A_1–B_1 maximum phase difference will occur and the resultant loop EMF will also be a maximum, giving the position of greatest signal strength.

For any intermediate position such as A_2–B_2 the frame is equivalent to a smaller frame in the maximum position. The diameter of this equivalent smaller frame is the projection of A_2–B_2 upon the direction of the transmitter—*i.e.*, *CD* in Fig. 9. It is also clear that

$$CD = AB \cos \theta$$

where θ is the angle between the plane of the frame and the path of the signal. These facts enable the horizontal polar diagram of a frame aerial to be deduced.
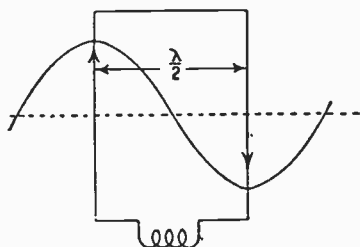
Fig. 11. Maximum EMF is obtained when the diameter of the frame is half the wavelength of the received wave.

In Fig. 10 *a AB* represents the plan view of a frame aerial. For a given transmitter at a given distance, maximum strength will be received when *AB* is in the direction of the transmitter. Let *OX* in Fig. 10 *a* represent this signal strength. If the same signal comes from any other direction, such as OX_1, the new signal strength will be proportional to cos θ—that is to say

$$OX_1 = OX \cos \theta$$

This is true for any direction. The angle OX_1X is therefore a right angle, and the locus of *X* becomes the circumference of two circles which touch at *O*. This is called the figure-8 polar diagram, and this property of a frame aerial is the basis of all apparatus used for directional reception. Fig. 10 *b* shows the implication of the figure-8 polar diagram when a signal is received and the frame rotated about *O*, the thickness of the outline indicating the signal strength for any position of the frame.

From Fig. 11 it will be seen that maximum resultant EMF occurs when the frame diameter is half a wavelength. In this case the resultant frame EMF is the arithmetical sum of the individual EMFs in the vertical limbs, and can be no larger. If the frame diameter is less than

or greater than half a wavelength, the resultant EMF is reduced. The true figure-8 polar diagram of Fig. 10 is given only when the frame diameter is less than about one-eighth of a wavelength, but it is clear that for wavelengths of several hundred metres, the frame diameter will necessarily be only a small fraction of a wavelength. In short wave DF the effect of frame diameters greater than $\frac{\lambda}{8}$ may assume some importance, and this will be referred to later. As a matter of interest, the polar diagrams for frames having diameters of $\frac{\lambda}{4}$, $\frac{\lambda}{2}$, $\frac{3}{4}\lambda$ and λ are shown in Fig. 12.

It will be seen from Fig. 10 that the position of maximum signal strength in a loop is not critical. The frame can be turned 20° or more on either side of the true maximum position without much change in signal strength. The true maximum position could not therefore be determined with any accuracy, and is unsuitable for DF.

If, however, the frame is in the minimum position, a very slight movement either way will bring in the signal. Moreover, the normal ear is very sensitive to small changes in the intensity of a *weak*
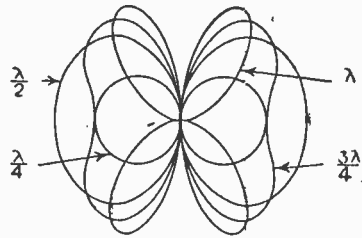
Fig. 12. Superimposed polar diagrams for loop aerials having diameters of quarter, half, three-quarters and whole unit wavelengths.

sound. The minimum position can therefore be accurately located—under favourable conditions to a fraction of a degree—and is always used for DF.

It only remains to arrange a scale and pointer associated with the frame, and the direction finder is complete in essentials.

The direction of one object from another must be stated with reference to some fixed direction, and for DF purposes this is taken as True North—*i.e.*, the direction of the meridian passing through the point of observation.

Bearings are stated in degrees East of North, and the mutual bearings of two points are reciprocals of each other.

For example, in Fig. 13 if the angle x is 70°, the *True Bearing* of B from A is 70° True and the *True Bearing* of A from B is 70° plus 180° = 250° True.

Magnetic North is the direction in which a compass needle points, and except in certain parts of the world, this direction is not the same as True North. The angle between these two directions is called the Magnetic Variation for that particular place, and is ascertained from an Ordnance Survey map or, in the case of positions at sea, from an Admiralty chart.

If the Magnetic Variation is
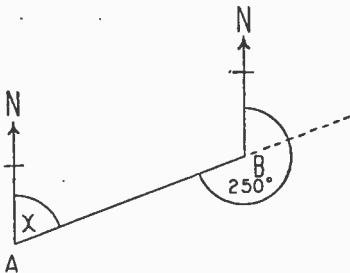
Fig. 13. If the true bearing of B from A is x, the bearing of A from B is x plus half a circle, *i.e.*, 180°.
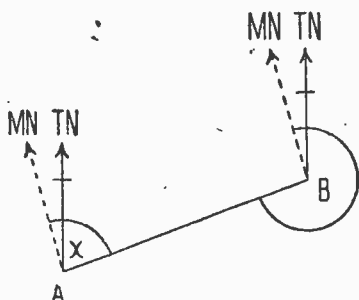
Fig. 14. If A is a ground station, its Magnetic Reciprocal Bearing from the aircraft B is x (including magnetic variation from true North) plus 180°.

Westerly, the compass reading will be greater than a True bearing by this amount, and less if the Magnetic Variation is Easterly. A "magnetic bearing" is therefore the True Bearing plus or minus the local magnetic variation. For example, the magnetic variation may be 14° West. If some object has a True Bearing of 70°, its magnetic bearing will be 84°.

A "Magnetic Reciprocal Bearing" is the kind most commonly used in aircraft work. In Fig. 14 if A represents a ground DF station and B an aircraft, the magnetic bearing of the aircraft from the DF station will be the angle x—*i.e.*, the True Bearing plus an assumed West variation. Suppose this is

84°. The magnetic bearing of the DF station from the aircraft is therefore 84° plus 180° = 264°, and this is called the Magnetic Reciprocal Bearing. It represents the compass course on which the aircraft must fly in order to reach the DF station (in the absence of any cross wind).

Since the polar diagram of a frame aerial is symmetrical, a minimum position will be found at two points 180° apart, so that with a simple frame the absolute direction of a signal cannot be determined. In some cases this does not matter, but more often it is desirable to remove the uncertainty and determine which of the mutually reciprocal minima is correct. Such a process is called "Sensing" the bearing, and involves the use of an aerial system which gives a polar diagram having only one minimum. A polar diagram of this kind can be obtained by the use of a frame aerial together with an open aerial feeding into the same receiver.

The principle is shown in the circuit diagram of Fig. 15. It is clear that there will be two EMFs in the intermediate circuit, due to the loop aerial and open aerial respectively, as shown by the arrows. If it is assumed that in (a) these
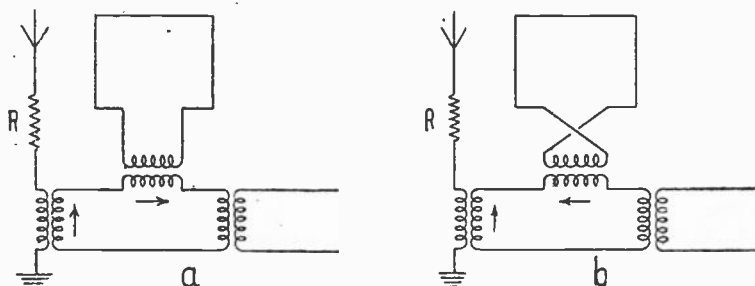
Fig. 15. How an open aerial is coupled to a loop aerial to "sense" the direction of the wave. In *a* the two signals add, but in *b*, with the loop in the reverse position, the signals subtract. The figure 8 polar becomes heart-shape.
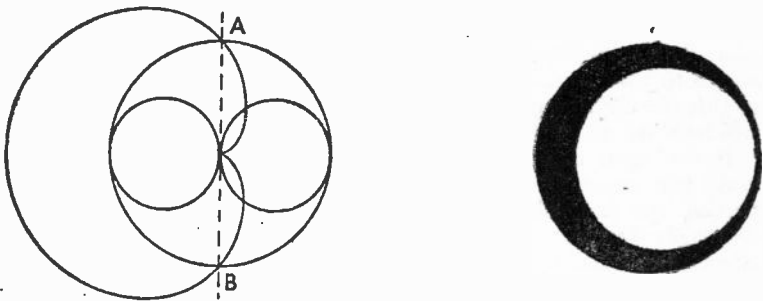
Fig. 16. The circle represents open-aerial pick-up and the figure-eight the loop pick-up. The two are added to the left of *AB* and subtracted to the right, giving the resulting heart-shape polar diagram. *Right:* another representation of signal strength.

two EMFs are in the same direction then, if the frame is turned through 180° as in (*b*), frame current will be reversed, and hence the two EMFs will oppose one another.

The purpose of the resistance *R* is to obtain the correct phase relationship between current and voltage in the open aerial, so that the two EMFs in the intermediate circuit are actually in phase or anti-phase. Other methods of securing this condition are possible, and any DF receiver will be found to contain some phasing arrangement for the sense position.

The polar diagram for the aerial combination of Fig. 15 is as shown in Fig. 16. It is assumed that the open aerial and the frame have equal receptive properties —*i.e.*, that the signal strength due to the open aerial is exactly equal to the signal strength received on the frame when the latter is in the maximum position.

The resultant signal strength in any direction is represented by adding the radii of the two polar diagrams on one side of the diameter *AB* and subtracting them on the other. The polar diagram thus formed is called the cardioid or heart-shape diagram, and clearly has one maximum and one minimum.

By arranging a sense pointer in line with the heart-shape minimum, the absolute direction of a signal can be determined. From
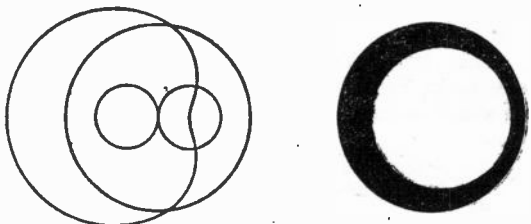
Fig. 17a. Effect of too much open aerial.
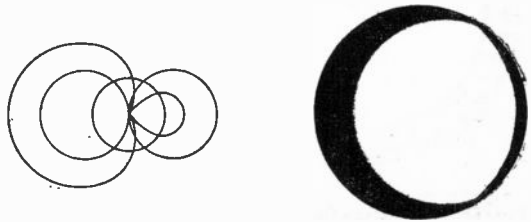
Fig. 17b. Effect of too big a loop signal.

Fig. 16 it will be seen that the heart-shape minimum is at right angles to the figure-8 minimum, so that the DF and sense pointers will be at 90° to each other.

If the open aerial and frame aerial have unequal receptive properties, the heart-shape will be distorted. Fig. 17a shows the effect of too much open aerial and b the effect of too great a signal from the frame ; b is sometimes called a cottage-loaf diagram, and gives two minimum positions less than 180° apart. A heart-shape "balance" means the obtaining of a sharp heart minimum as in Fig. 16, and means are usually provided in the shape of a variable coupling between the open aerial and the intermediate tuned circuit.

Arrangement of DF Scale

The DF scale may be arranged in one of two ways:

1. Fixed scale and moving pointer.
2. Fixed pointer and moving scale.

The two arrangements are shown in Fig. 18 a and b, both of which indicate a bearing of 40°.

It should be noted that in a the scale is engraved clockwise, and in b anti-clockwise.

The position of the scale or pointer relative to the frame aerial is quite immaterial, and can be arranged for convenience. The only condition required is that the scale reading must be 000° when the frame is lying True East–West, and therefore at the minimum position for a signal coming from True North or South.

Bellini–Tosi System

In 1907 the research workers Bellini and Tosi developed a DF system using fixed frames. The advantage of this method is that the frames can be much larger than practicable with a rotating loop, while bearings are taken by moving a small "search coil".

These advantages are so important that the Bellini–Tosi system is now practically standardised on all ground DF stations of a permanent nature and is also widely used on ships. Attempts have been made to apply it to aircraft, but the simple rotating frame continues to find more favour, partly because BT aerials do not lend themselves very well to installation in air-

a

b
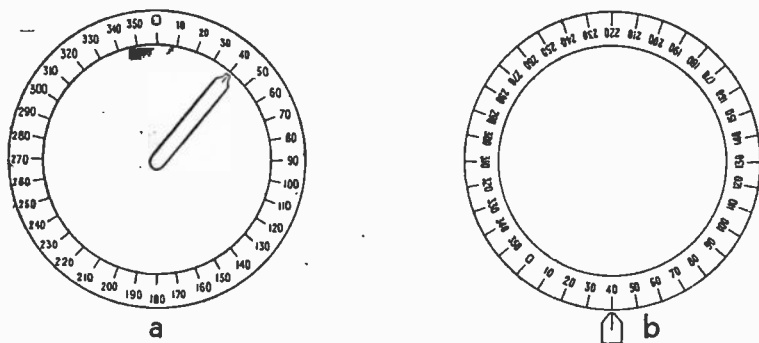
Fig. 18. A direction-finding degree scale may have either a fixed scale and moving pointer, a, or a fixed pointer and rotating dial, b.

craft and partly be-
cause DF service for
aircraft is provided
more by means of
ground DF stations
than by aircraft doing
their own DF.

The principle of
the BT system is as
follows.

Two frame aerials
are erected at 90° to
each other. Their
exact orientation is
not important, but
they are usually
fixed so that one is
in a True North–South direction
and the other one therefore True
East–West.

Fig. 19. Simplified representation of the constructional
arrangement of a radio-goniometer, a, and the equiva-
lent circuit shown as a diagram, b.

The Goniometer

The frame circuits are com-
pleted through two coils, also at
90° to each other, and mounted
coaxially with these coils is a
small rotatable "search coil". Fig.
19 a shows the general arrange-
ment, which is called a "radio-
goniometer", and b is the method
of representing it on diagrams.

When a signal influences the
frames, a current will flow in each
coil, and produce a certain total
magnetic field inside the gonio-
meter. The search coil, being
simply a small frame aerial, will
have an EMF induced in it
depending on its position relative
to this field. In other words, the
search coil has a figure-8 polar
diagram, and by turning it to the
minimum position, the direction
of the resultant field of the two
fixed frames can be determined.

It only remains to ensure that
the direction of this field relative
to the goniometer coils is the same
as the direction of the signal relative
to the fixed frames. This involves

only one main condition: that the
two frames be accurately matched.
That is to say, they must have the
same resistance, inductance and
capacity and be tuned to exactly
the same frequency.

It is difficult to ensure suffi-
ciently accurate tuning if an
attempt is made to tune each
frame to resonance with the signal
being received, and in modern
practice this is not done.

Sensing a bearing with BT
aerials is done in the same way as
with a rotating loop—i.e., by
coupling an open aerial to the
search coil circuit, thus convert-
ing the figure-8 polar diagram into
a heart-shape. Fig. 20 shows a
simple sense circuit for a BT
system. L_3 is the search coil, and
the variable coupling between L_1
and L_2 provides an adjustment for
obtaining a heart-shape balance.

Typical Scale

Fig. 21 shows the appearance of
a typical goniometer. Three poin-
ters are fitted. The DF pointer
indicates true bearings, the Sense
pointer is at 90° to the DF
pointer, and somewhat shorter,
because scale readings are not
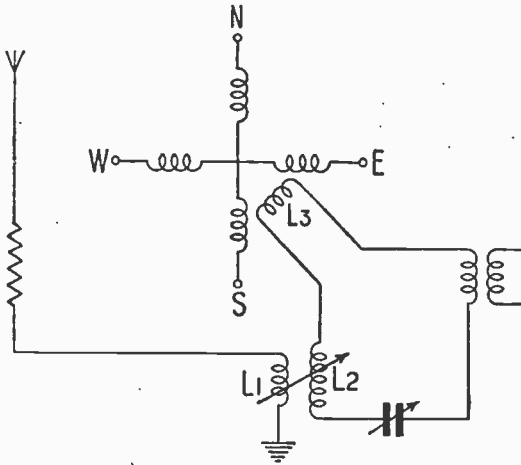
Fig. 20. How an open aerial is linked to a Bellini–Tosi system for sensing a bearing.

open aerial is brought in again through a phasing device—*e.g.*, a resistance—and coupled to the tuned circuit for heart-shape.

Steps in the taking of a Sensed bearing are as follows:

(1) Ship or air-craft calls and re-quests bearing.

(2) DF station asks ship or aircraft to transmit a series of long dashes.

(3) DF operator switches to "DF", and locates mini-mum roughly.

required when sensing a bearing, and the Magnetic Reciprocal Pointer is set according to the local magnetic variation, so as to give direct readings of magnetic reciprocal bearings. Fig. 21 shows the setting of this pointer for a magnetic variation of 12° West. Connections to the search coil are made by means of slip-rings and spring contacts, so that no stops are necessary, and the search coil can be turned through any angle in either direction.

For DF watchkeeping the aerial system must be non-directional, so that a ship or aircraft calling the DF station will be heard, no matter what its direction. This is called the stand-by position, and is provided by the use of an ordinary vertical aerial, which may also be used as the Sense aerial for heart-shape reception.

In the DF position this open aerial is earthed, and reception takes place on the frame aerial or search coil alone, giving figure-8 diagram. In the Sense position the

(4) Operator switches to "Sense" and determines which of the DF minima corresponds to the heart-shape minimum.

(5) Operator switches back to "DF" and takes accurate bear-ing on the correct minimum.

(6) Operator passes bearing to ship or aircraft.
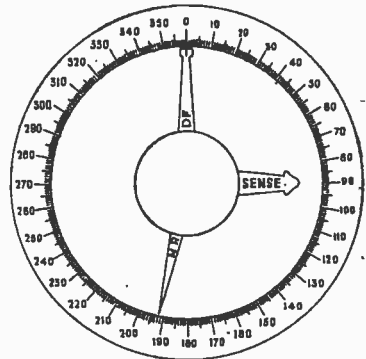
Fig. 21. The dial of a goniometer. The DF pointer, at right-angles to the Sense pointer, gives true bearings and the Magnetic Reciprocal pointer is set ac-cording to the local magnetic variation.

Under favourable conditions, steps 3–5 can be completed by a skilled operator in about 10 seconds using a goniometer.

Due to a number of causes, the figure-8 minimum is not always needle sharp. In general, this means that either the signal does not fall to zero at any point, or—especially in the case of a weak signal—it may be zero over several degrees of search coil movement.

Fig. 23. The accuracy of DF fixing progressively deteriorates with distance. The black area, called the area of doubt, in which the aircraft may be, increases the further the plane is from ground stations ABC.

It is not, therefore, possible to place the DF pointer "dead on", and recourse is had to "swing" bearings. A swing bearing is taken by rotating the pointer backwards and forwards through the minimum position and noting two points of equal signal strength. The bearing is then taken as halfway between these two points.

In practice, all bearings are

Fig. 22. The position of an aircraft within the triangle at x can be determined from the bearings obtained by three ground DF stations ABC.

taken by swinging the search coil, but when conditions are good and the minimum is very sharp, the extent of the swing becomes very small.

The classification of bearings is to some extent left to the discretion of DF operators, but a commonly accepted working basis is as follows:

First-class bearing, when minimum can be located by a swing not exceeding 2°.

Second-class bearing, when a swing not exceeding 5° is necessary.

Third-class bearing when the swing exceeds 5°.

If, however, the minimum is so flat that a swing exceeding about 20° is necessary, the bearing would probably not be given, or at any rate given as doubtful.

If three DF stations take bearings simultaneously on a ship or aircraft, and the bearings are accurate, it is clear that such bearings would intersect at a point when applied to a map. A means

of position-finding by radio is therefore available, and a position found in this way is called a wireless fix.

In Fig. 22 A, B and C represent DF stations which have taken bearings on a ship or aircraft X. One of them acts as "control" station and actually communicates with the ship or aircraft. The other two pass their observed bearings to the control station, either by radio or by telephone, and the control station applies all three bearings to a plotting map.

With modern DF apparatus and under average conditions, the three bearings usually intersect at a point, which is then communicated by the control station either in terms of latitude or longitude or by some other agreed method. If the bearings do not intersect at a point, but form a *small* triangle, as in Fig. 22, the position is taken as the centre of the triangle.

Accuracy of DF

The accuracy of DF fixing deteriorates progressively with distance. This is because no DF bearing is absolutely accurate, and instead of being regarded as a geometrical line, it should really be considered as anywhere between two lines diverging by about 2°. This is shown in Fig. 23. The fix is not therefore a point, but a small, closed figure, shown shaded. This is called the area of doubt, and in long-range DF it may become so large that even though an

intersection is obtained the result is practically valueless.

Calculation shows that with first-class bearings having a possible error of $\pm$ 1° the area of doubt at 100 miles is 12 square miles, but at 500 miles the area of doubt is 300 square miles. With aircraft, an area of doubt of even 300 square miles is not as serious as it might appear to be, because the side of a square with this area is only about 17 miles, and a modern aircraft will have covered this distance in a few minutes. When, however, the bearings are not first class, and have a larger margin of possible error—say $\pm$ 5°—the area of doubt becomes 300 square miles at 100 miles and 7,600 square miles at 500 miles.

Radio fixing must therefore always be carried out with proper regard to its limitations as the distance increases, but at the shorter ranges a high degree of accuracy can be realised.

Fixing in the ordinary sense cannot be carried out by a single DF station, but it is possible for one DF station to determine the approximate position of an aircraft which is flying towards it by the following method.

In Fig. 24, OX represents the track of an aircraft flying towards a DF station at X. At the point A the aircraft changes course 45° to a point B, so that BP (the distance of B from the original track) is some known value—say, 4 miles. Course is then changed to BC, so that CQ is also 4 miles. The air-
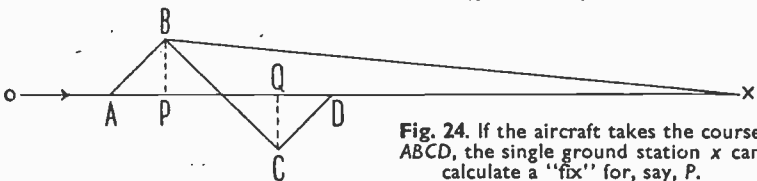
Fig. 24. If the aircraft takes the course ABCD, the single ground station x can calculate a "fix" for, say, P.

craft then returns to the original track via *CD*.

The DF station takes bearings when the aircraft is at *A*, *B*, *C* and *D*. Assume that the following results are obtained:

Bearing at *A* . . . 260°
Bearing at *B* . . . 264°
Bearing at *C* . . . 255°
Bearing at *D* . . . 260°

The average change in bearing is $4\frac{1}{2}°$ for a four-mile deviation from track. From the figures:

$$\text{Tan } BXP = \frac{BP}{PX}$$
$$PX = \frac{BP}{\tan BXP}$$
$$= \frac{4}{\cdot 0787}$$
$$PX = 51 \text{ miles approx.}$$

The method is only approximate, and not suitable for distances of much over 100 miles, because the deviation required to give a measurable change in bearing would become too large for convenience in the case of greater distances.

Causes of DF Error

There are many possible causes of failure to obtain perfect figure-8 or heart-shape polar diagrams, and it will be appreciated that whereas some distortion of the heart-shape will probably not prevent the sensing of a bearing, distortion of the figure-8 is much more serious, because it may cause considerable errors in bearings. If such errors are unknown and unsuspected, the DF information becomes a menace instead of a guide.

Fortunately, all the sources of error inherent in the DF apparatus itself are well known, and can
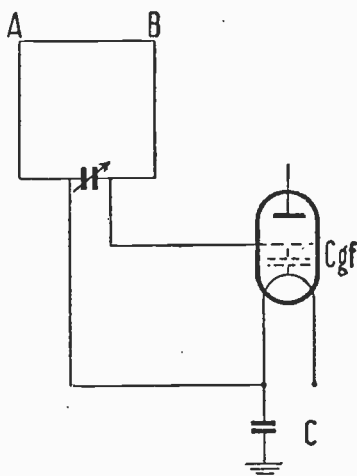
Fig. 25. Vertical error in DF is introduced because loop arms *A* and *B* are not balanced with respect to earth. The side *B* contains the impedance of the grid-to-earth capacity, C_{gf}, of the first valve in the receiver.

be almost entirely eliminated by proper precautions. There are, however, other causes of error which are due to natural phenomena and are not subject to control.

1. *Vertical Error.* An extreme case of vertical error would occur in the circuit of Fig. 25.

No matter what the position of a frame aerial relative to the signal, there are always the same signal voltages in the vertical limbs, and even if the frame in Fig. 25 is actually at 90° to the direction of the signal, the points *A* and *B* will be at the same potential above earth.

The impedance of *A* to earth, however, is much less than the impedance of *B* to earth, because the grid-to-cathode capacity (C_{gf}) of the first valve in the receiver is in series with the *B* side of the frame. Thus, although the result-
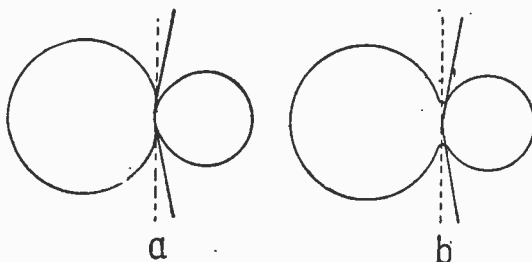
Fig. 26. Polar diagrams showing the possible effects of vertical error, in phase in case *a* and out-of-phase in *b*.

an earthed metal screen S interposed between the windings. This screen is thin copper foil. Copper being a non-magnetic material, normal transformer action is unaffected, but capacity between L_1 and L_2 is zero, thus isolating the capacity unbalance of the valve from the frame circuit.

ant current in the frame is zero, there will still be a signal on account of this capacity unbalance. The minima may be extremely vague and would almost certainly be displaced.

Fig. 26 shows the possible effects upon the figure-8 polar diagram ; *a* is the effect of in-phase vertical giving a "cottage-loaf" diagram with sharp but misplaced minima, and *b* shows the "woolly" and displaced minima caused by out-of-phase vertical.

The cures for vertical error have one common aim—the elimination of the capacity unbalance associated with the input to the first valve of the receiver.

Fig. 27 shows a common method. The centre point of the frame is earthed, thus equalising the impedances to earth of the points A and B. This would be completely effective were it not for the capacity between the coupling coils in the frame circuit and intermediate tuned circuit. In order to deal with this, coupling to the receiver via coils L_1 and L_2 is made through a shielded transformer having

A further extension of vertical compensation may be provided by means of a screened loop as in Fig. 28. This is applicable to rotating loop DF or to a pair of crossed loops forming BT aerials.

Weatherproof Housing

The loop is enclosed in a metal tube (the circular shape is usual) and the tube is broken at the top by an insulator A. The tube then serves the double purpose of forming a convenient, rigid and weatherproof housing for the frame aerial, and of largely nullifying the capacity unbalance elsewhere, because the capacity to earth of the two sides of the frame
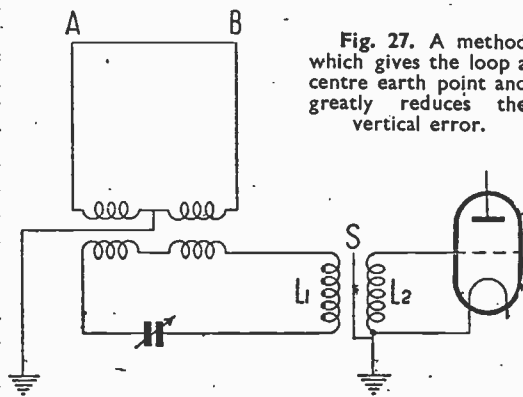
Fig. 27. A method which gives the loop a centre earth point and greatly reduces the vertical error.

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now consists almost entirely of their capacities to the earthed metal tube. The insulator is necessary in order to prevent the great loss of signal strength which would occur if the loop were completely screened.

· 2. *Direct Pick-up*. Since the directional properties of DF apparatus are dependent solely on the aerial system, it is imperative that no other part of the equipment should be influenced by the wave. If it is, a circle polar diagram will be superimposed on the figure 8 and the effect will be similar to Vertical. Precautions against direct pick-up must therefore be taken by completely screening the whole of the DF apparatus other than the aerials.

3. *Quadrantal Error*. This is the error peculiar to the particular DF station, and may be called "site error". It is due to re-radiation of the signal from surrounding objects, such as trees, wire fences, telegraph or telephone lines, railway lines, underground pipes or sewers, or even from metalled roads in the vicinity.

The choice of site for a permanent DF station is therefore an important matter, and on a really good site the quadrantal error may be negligible. After erection, the station is carefully calibrated by means of a portable transmitter, which is taken round the station at a convenient distance of a few miles, and bearings are taken with the transmitter in a series of known positions. Any errors are provided for by means of a calibration chart showing the corrections to be applied to observed bearings.

For DF stations intended to work with aircraft, the calibration process is usually completed by
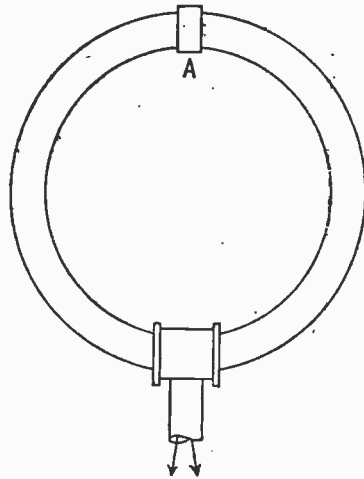
Fig. 28. Further reduction of vertical error is secured by screening. The screen, which is broken by a non-conductor at A, forms a convenient weatherproof housing for the loop.

taking check bearings on an aircraft flying over a series of known pin-points at a distance of about 20 miles from the DF station.

4. *Night Effect*. Very early in the history of DF it was observed that the bearings of fixed stations varied to an extraordinary degree during the hours between dusk and dawn. The medium frequencies (up to 1,000 kc.) are mainly affected during these hours, and this gave rise to the term "night effect".

Research has shown that at varying heights above the surface of the earth there are layers of partially conducting air, and the conductivity of these layers is sufficient to cause reflection of an electric wave which approaches their lower surface at a sufficiently acute angle (see Chapter 7). Radiation from a transmitting aerial may therefore reach a distant receiver by reflection from the upper atmosphere (see Fig. 29).

On arrival at the receiver, the wave will have a downward angle of approach, and owing to the reflection it may also be abnormally polarised—*i.e.*, the "appearance" of the wavefront may be as in *b*, in which the lines of magnetic force are not horizontal. Where abnormal polarisation accompanies a downward angle of incidence, an error always occurs in DF with a simple rotating frame or BT loops.

Briefly, the cause of this error is the fact that EMFs are induced in the horizontal limbs of the DF
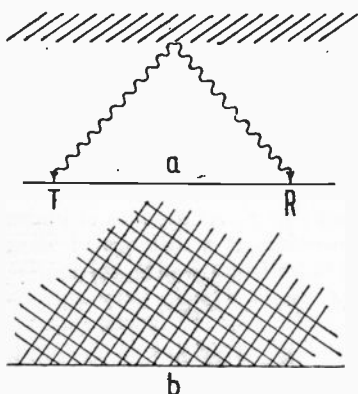
Fig. 29. "Night effect" errors are due to the reception of reflected waves as in *a* and to polarisation of the wave, *b*.

frames as well as in the vertical limbs. As an illustration of the effect, if the downward angle of approach and the angle of tilt due to polarisation are both 45°, all bearings on a rotating frame will be displaced by about 35°. On medium frequencies it follows that DF with a simple frame or BT loops is unreliable at night except at very short ranges, when the presence of a reflected wave is practically ruled out.

On high frequencies—*i.e.*, short waves—such reflections may take

place at any time, thereby aggravating the situation still further.

Since the trouble is due to the influence of EMFs in the horizontal limbs of the DF aerials, the most obvious line of attack is to eliminate the horizontal limbs. This scheme was suggested by Adcock during 1914–1918, and has now been almost universally adopted for permanent DF stations, whether working on medium or short waves.

Although the Adcock system is theoretically applicable to a rotating frame, it is more usually associated with a BT system, rotating frame DF being practically confined to aircraft, small ships and portable DF apparatus.

Fig. 30 shows the general scheme for one pair of Adcock aerials constituting one "frame" of a BT system. There is no top horizontal portion, and the lower horizontal portion is completely screened and buried to a depth which varies from 2 to 6 feet. Only the vertical portion can be influenced by the wave, and the effect previously described is very largely eliminated.

The type of Adcock aerial shown in Fig. 30 is called the buried-U type. The height of the aerials and the spacing *d* in Fig. 30 are determined by the frequency band to be covered. For medium frequencies, 100-feet masts with 200-feet spacing are common dimensions, but for short waves the masts do not as a rule exceed 30 feet, and the spacing may be as little as 20 feet.

Fig. 31 shows the general appearance of a short-wave Adcock DF station. The Sense aerial, which also serves for "standby" reception, is suspended at the centre from crossed triatics.

The symptoms of "night effect" —*i.e.*, the presence of a reflected and abnormally polarised wave— are as follows:

(*a*) Minima suddenly become flat.

(*b*) Minima are sharp, but displaced. This, of course, is not really a symptom, because it is not detectable, and would be very dangerous if it occurred alone.

(*c*) Distortion of broadcast programmes, in which music and speech may become almost unrecognisable.

(*d*) Fading, which may be slow or rapid, but unless very slow it will be noticeable.

(*e*) Distortion of the heart-shape. This is a valuable method of detecting irregularities, and a DF operator who is thoroughly conversant with the "sound" of a normal heart-shape on his particular apparatus is able to observe quite small deviations from it.

Basis of DF Service

The provision of permanent DF stations, usually at aerodromes, is the basis of the DF service for commercial aircraft. On regular air routes, services are maintained in practically any weather, cancellation being comparatively rare.

The captains of commercial aircraft know their routes extremely well, and even a fleeting glimpse of the ground through a "hole" in the clouds is often sufficient for them to recognise their position. DF, however, remains the principal aid to navigation, and confers the additional advantage that the movements of aircraft can be controlled by the aerodrome authorities via the
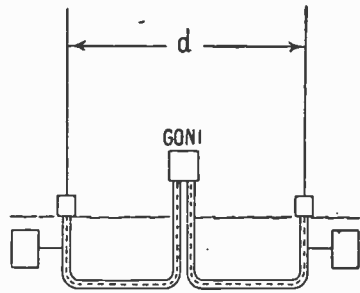
Fig. 30. In the Adcock aerial the top of the loop is dispensed with and the bottom effectively eliminated by screening and burying from 2–6 feet.

radio. This is most essential in the interests of safety when—as frequently happens—a number of aircraft are converging on to an airport in thick weather.

The use of DF apparatus on the aircraft itself is supplementary to the above organisation, but the majority of the larger aircraft are fitted with rotating loop DF. In some cases the general-purpose receiver is used in conjunction with the loop, plus an additional ampli-
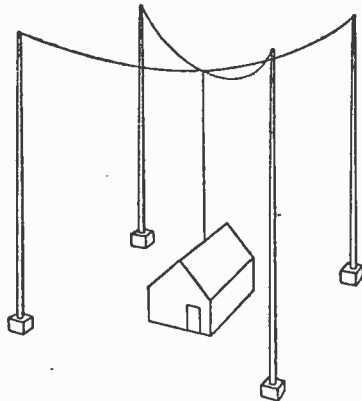
Fig. 31. Practical layout of a short-wave Adcock DF station. The uprights constitute the two "loops" at right-angles and the open sense aerial is suspended in the centre from insulated lines.

F   (R.E.)
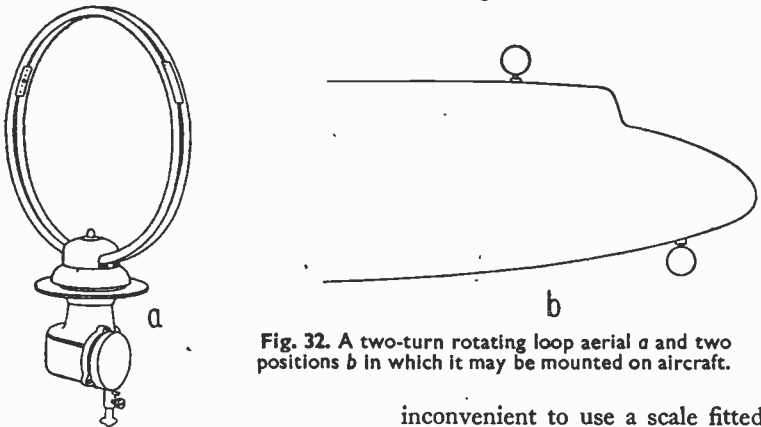
Fig. 32. A two-turn rotating loop aerial *a* and two positions *b* in which it may be mounted on aircraft.

fier, but in larger aircraft the DF receiver may be entirely separate.

Fig. 32 *a* shows the general appearance of a two-turn rotating loop for aircraft, and *b* illustrates two possible positions when mounted. It is important, of course, that the loop spindle shall be vertical when the aircraft is in level flight. In most cases it is

Fig. 33. A type of scale for a remote-controlled rotating loop.

inconvenient to use a scale fitted to the loop spindle, and it is necessary to employ mechanical remote control to operate the loop. The DF scale is then fitted at the remote control end.

Fig. 33 shows a type of scale for a remotely controlled loop and another is shown in Fig. 35 *b*.

Since the aircraft may be heading in any direction, bearings must be taken with reference to the fore-and-aft lines of the machine. The scale is therefore set to read 000° when the loop is at right angles to this line—*i.e.*, athwartships. When a bearing is taken, the scale reading gives the bearing of the distant transmitter from the head of the aircraft. The magnetic bearing is obtained by adding the compass course to this figure. If a true bearing is desired, the local magnetic variation must then be subtracted, if westerly, or added, if easterly.

A heart-shape polar diagram can be obtained by bringing either the trailing or fixed aerial into circuit through a suitable switch and phasing arrangement, thus enabling a bearing to be sensed, but in many cases sense is not provided.

It is much less important in an

aircraft, because in few cases would the crew be so hopelessly lost as to be uncertain whether they were, say, North or South of a known transmitting station. Taking average conditions, this would imply that their position was uncertain to the extent of perhaps 100 miles—an unlikely state of affairs on routine flights.

An aircraft loop should be as small as possible. About 13 inches used to be a common diameter, but modern loops are usually smaller, in some cases only 5 or 6 inches in diameter. These small loops are enclosed in a stream-lined housing which remains fixed, the loop rotating inside.

From a wireless aspect the small loop is a disadvantage, because its pick-up is correspondingly small, but this can be effectively combated by the use of more turns on the loop, whilst modern receivers give very great signal amplification. Larger loops not only give rise to structural problems on account of wind pressure in flight, but quite naturally raise protests from the aircraft designers. The speed of modern aircraft is such that even a comparatively small excrescence has an effect on the performance.

As has been previously mentioned, an aeroplane is a poor site for a radio station, and for DF it is even worse. The DF aerial is perforce surrounded by masses of metal, the noise in flight masks the figure-8 minimum, the whole apparatus is subject to vibration, and in rough weather it is almost impossible to keep the machine on an even keel even for a few seconds whilst a bearing is being taken. In spite of the difficulties, however, DF in aircraft is a practical proposition, although the quadrantal error is always large, and corrections of 10° or more may have to be applied for some directions.

Determining Quadrantal Error

In order to determine the quadrantal error, the aircraft is placed on a compass base in flying position—*i.e.*, with the tail raised to the correct height on a trestle. The compass base is a level circle of concrete marked with eight positions: True North, North-East, East, South-East, South, South-West, West, and North-West. Plumb-lines are hung from exact central positions at the nose and tail of the aircraft and aligned on these marked diameters on the compass base (Fig. 34).
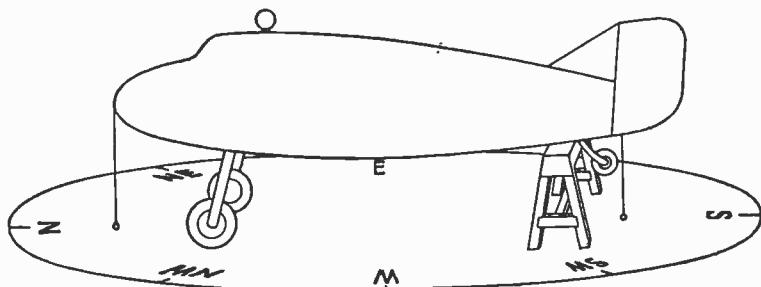
Fig. 34. To determine the quadrantal error, the aircraft is placed in flying position on a compass base. The aircraft DF is then calibrated as the plane is rotated during reception of a station of accurately known bearing.

For intermediate positions, the plumb-lines are aligned by means of a compass having sights, placed about 20 to 30 yards from the aircraft on a tripod stand.

Calibrating Aircraft DF

In order to calibrate the aircraft DF, a signal from some known direction must be available. A broadcasting station is ideal for the purpose. The exact bearing of the transmitting aerial from the compass base must be ascertained and the aircraft placed on this bearing. It will be remembered that the loop aerial is arranged so that the scale reading is 000° when the loop is at right angles to the fore-and-aft line. It follows that the apparent bearing of the transmitter should be 000° with the aircraft in this position. The aircraft is then moved round a few degrees at a time, and the observed DF bearings compared with the correct bearings. This process is called swinging the aircraft, and occupies a considerable time. It is greatly facilitated if the compass base takes the form of a turntable. Flying-boats can be swung on the water, but unless a dead calm prevails it is extremely difficult to hold the machine still during observations. The results

obtained on the ground should be checked by similar observations in the air, but these need not be so numerous unless discrepancies are noted.

The final correction table is sometimes incorporated in the loop scale, as shown in Fig. 35. In *a* a correction graph is added to the scale, and bearings are read at the point where the line engraved in the fixed transparent strip *X* cuts the scale. The correction to be applied is shown by the point where the correction graph cuts the vertical strip, on which the correction scale is also engraved. This method is suitable for directly operated loops. The reading in the figure is 6°, with a correction of + 2° = 8°.
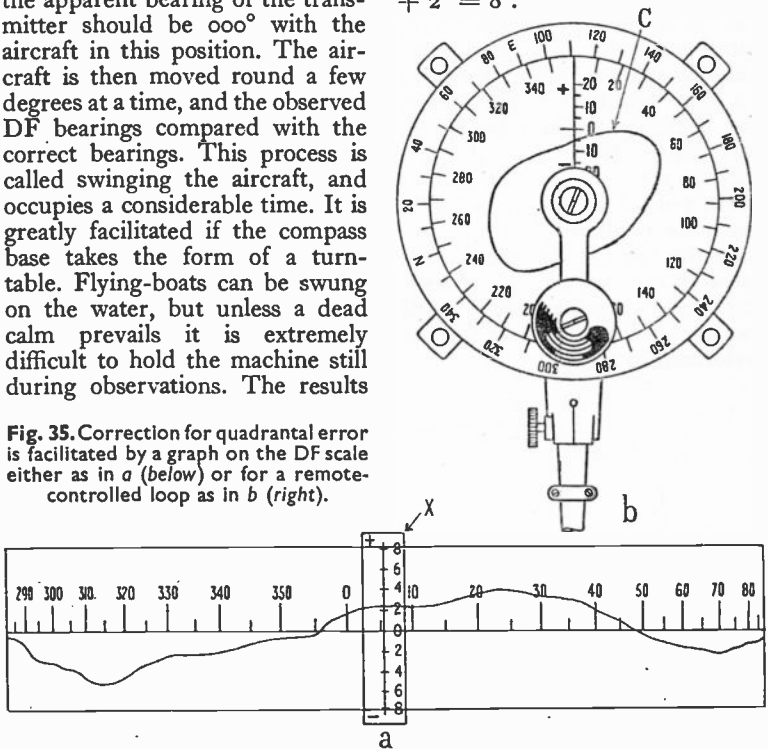
Fig. 35. Correction for quadrantal error is facilitated by a graph on the DF scale either as in *a* (below) or for a remote-controlled loop as in *b* (right).

In *b* is a scheme for a remote controlled loop. The correction curve *C* is engraved on the fixed dial of the loop control. On rotating the handle, a transparent circular disc carrying a correction scale moves over the dial and gives the correction for any bearing. The outer ring is adjustable, and is used in applying observed bearings to navigational purposes.

Homing

The term homing applies to any scheme in which some form of DF is used to enable the aircraft to fly directly towards a distant aerodrome.

The simplest method of homing is for a DF station at the aerodrome to give the aircraft a series of magnetic reciprocal bearings—in other words, telling the captain the compass course on which he should fly to reach the DF station. This may not be the compass course on which he actually does fly, because the presence of a cross-wind will necessitate a correction for drift, but this, of course, is not a matter for the DF station.

A point against this method is that only one aircraft can be dealt with at a time, especially during the latter stages of the approach, when bearings are passed at the rate of four or six a minute, but as only one aircraft would be allowed to land at a time, this is not always a serious objection.

Aural System

Another form of homing is when a special kind of apparatus is used on the aircraft to enable the pilot to fly towards a particular transmitter, which must radiate continuously. Such a transmitter would normally be at, or very close to, the aerodrome. If a broad-
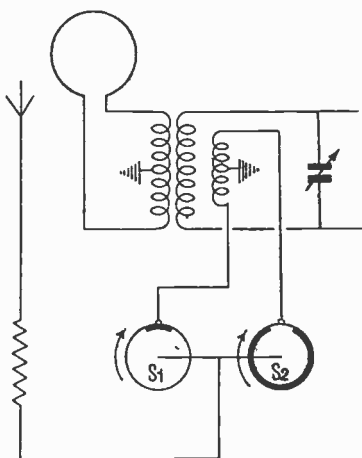
Fig. 36. Aural indication of direction can be obtained by mechanical reversing of the open aerial connection by rotating switches S1, S2. These turn a steady signal into dots or dashes at either side of the correct course.

casting station happens to be in the required direction, this, of course, provides an ideal signal for the purpose.

The essential conditions required for a homing device are the following two:

(1) Indication must be given that the aircraft is on course or off course.

(2) If off course, indication must also be given on which side of the correct course the deviation has occurred.

DF apparatus used in this way is often called a Radio-compass, and there are two main methods of securing these indications, each of which can be carried out in different ways.

1. *Aural Homing.* In this method the "on course" indication is a continuous unbroken signal. If the aircraft is off course to the left, a morse letter is heard,
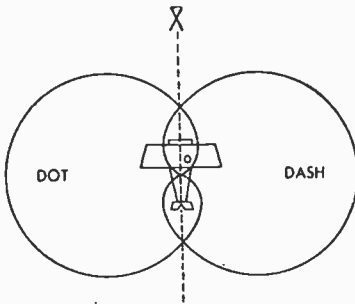
Fig. 37. The effect of the aural arrangement of Fig. 36 in terms of polar diagrams.

and if off course to the right, a different morse letter is heard. The letters chosen must "interlock"— *i.e.*, the spaces of one must correspond to the dots and dashes of the other. E (·) and T (—), A (· —) and N (— ·), F (· · — ·) and L (· — · ·) have been used, E and T being the simplest combination.

Fig. 36 shows the principle by which these results are obtained. The loop aerial is set at 90° to the line of flight (scale reading 000°) when homing. The open aerial is brought into circuit to give heart-shape reception, but the phase of the open aerial input is mechanically reversed by the rotary
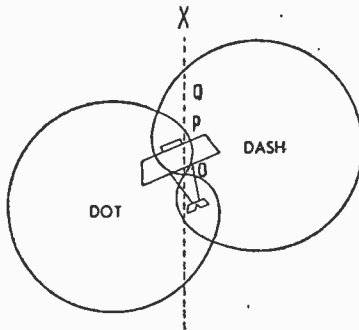
Fig. 38. When the aircraft goes off course to the left, the signal on the dash cardioid *OQ* exceeds that on the dot cardioid *OP* and vice versa.

switches S_1, S_2. The contacts are shaped so that one switch produces a series of "dots" and the other a series of "dashes", the dots and dashes interlocking.

Fig. 37 shows the effect in terms of polar diagrams. Reception takes place on one heart-shape or the other, according to the operation of the switches S_1, S_2. If the aircraft is on the correct course OX, the same strength of signal will be heard on both heart-shapes, and since the switching interlocks, the result is a continuous signal of unvarying strength.

Fig. 38 shows what occurs when the aircraft is off course to the left. OX is the correct course. OP represents the strength of signal received on the "dot" cardioid, and OQ the signal strength on the "dash" cardioid. It is clear that OQ is greater than OP, and the effect will be a series of Morse dashes instead of a continuous signal. Similarly, if the aircraft is off course to the right, a series of dots will be heard.

Exactly the same result can be secured without any special apparatus in the aircraft other than the general-purpose receiver. In this scheme the course indication is given by directional transmission on the ground at the aerodrome.

Fig. 39 shows the principle. Two fixed frame aerials transmit the interlocked morse letters E and T and the course indicated is the line OX, which bisects the angle between them. An aircraft on course would therefore hear the E and T at equal strength, and thus receive a continuous signal. If the aircraft is off course on the line OY, it is clear that cos EOY is greater than cos TOY, and consequently the E signal will predominate, giving a series of dots.

Morse dashes will occur on the other side of *OX*.

This arrangement is called an equisignal course beacon. It is extensively used in America, but has not so far been used much in Europe.

2. *Visual Homing.* The aural method of homing is open to the objection that it involves continuous listening to a signal on the part of the pilot. This is not only irksome, but distracting, and to some extent prevents the pilot from listening to his engines or

tions being arranged so that a signal received on the left-hand heart-shape deflects the instrument needle to the left, and a signal received on the right-hand heart-shape deflects it to the right. This gives the result that when off course to the *left* the instrument needle moves to the right, indicating the direction in which the aircraft must be steered to get back on course.

When on course, the instrument receives equal alternate impulses in opposite directions at the frequency of switching—about 12 per second—and its damping is sufficient to result in no movement from the central position.
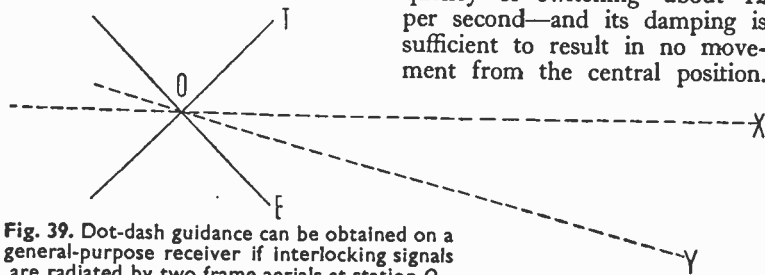
Fig. 39. Dot-dash guidance can be obtained on a general-purpose receiver if interlocking signals are radiated by two frame aerials at station *O*.

attending to remarks from his captain or co-pilot.

A demand has therefore arisen for an instrumental indication of course. The principle of switched heart-shapes as in Fig. 36 is used, but morse letters are no longer required, and the contacts give equal switching periods. The output from the receiver is taken to a centre-zero moving coil instrument through a reversing switch and a pair of rectifiers, this second reversing switch synchronising with the heart-shape switch.

S_1, Fig. 40, is the heart-shape switch and S_2 switches the instrument I through one or other of the metal rectifiers W_1 and W_2.

These rotary switches are on a common shaft, and the switching operations synchronise, connec-

When off course, the instrument will receive unequal impulses and the needle will move away from the central position.

Instrument Flying

Blind flying means keeping the aircraft on a level course, together with the execution of ordinary manœuvres—including, perhaps, take-off—under conditions of zero visibility. A more appropriate term is "instrument flying", because the basis of the art is complete reliance on instruments.

Instrument-flying has been developed to a high state of efficiency, and flying in cloud does not to-day cause any concern to a properly trained pilot, but the problem of finding the aerodrome, approaching in the correct direction at the

Fig. 43. Vertical polar diagram of the main beacon.

illustrated in Fig. 44. Having picked up the main beacon signal and got on to the equi-signal course, the aeroplane approaches the aerodrome at a height of about 600 feet. On hearing the outer marker beacon, the pilot starts to lose height at a rate which will bring him down to about 100 feet in 3 miles—*i.e.*, by the time he passes the inner marker.
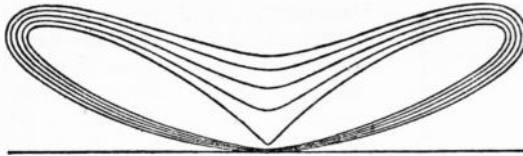
of radiation and provides a special distinguishing signal lasting for a few seconds as the aircraft flies over the beacon and passes through the "fan". The distinguishing signals are as follows:

Outer Marker.—This transmitter sends dashes lasting 0·4 seconds with 0·1 second intervals. The wave is modulated at 700 cps. The effect is long dashes with a fairly deep note.

Inner Marker.—This transmitter sends dots lasting 0·066 second with 0·1 second intervals. The wave is modulated at 1,700 cps. The effect is short dots with a fairly high-pitched note. The markers are thus readily distinguishable.

Glide Path

The vertical polar diagram of the main beacon is shown in Fig. 43. The lines represent paths of equal signal strength, and, although curved, it is possible to use this property to hold the aeroplane on a definite glide-path.

The method of approach is

The Landing

On hearing the inner marker he throttles right back and proceeds to land. As previously explained, the ground would normally come into view almost immediately after passing the inner marker, at which point the blind-approach apparatus has fulfilled its functions. The process sounds simple when thus described, but it will be realised that in practice it is by no means easy, and calls for great skill and experience in the handling of the aircraft.

If a blind landing is being attempted, use is made of the glide-path indication, and this is shown on a visual instrument which will now be described.

Fig. 45 represents the visual indicator in the aircraft. *A* and *B*
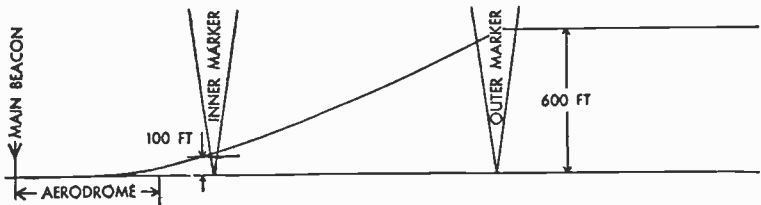
Fig. 44. On passing the outer marker at 600 ft. the pilot glides down at a rate which brings him to 100 ft. by the time he hears the inner marker.

are small neon tubes which act as visual warnings when the aircraft passes over the marker beacons. It has been mentioned that the marker-beacon transmitters employ different modulation frequencies (700 and 1,700 cps.) The neon tubes are connected through filter circuits to the receiver output, so that tube A lights up when passing the outer marker showing the long dashes visually, and tube B acts similarly when passing the inner marker.

Course Pointer

The lower pointer $P2$ moves over the horizontal scale and provides a visual indication of on-course or off-course conditions. It is a moving coil instrument, and so designed that the needle is heavily damped at the central position but lightly damped at a small distance on either side. This gives the result that the needle will swing in a different direction, according to whether the dots or dashes
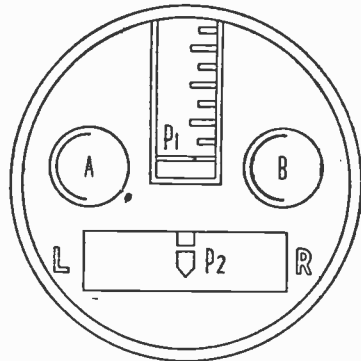
Fig. 45. Visual blind approach instruments. A and B are neon lamps which light as the marker beacons are passed. P1 is a glide-path indicator and P2 a left-right course indicator.

predominate. The circuit arrangement is such that the needle deflects towards the correct course— *i.e.*, the pilot "follows" the needle.

Glide Indicator

The upper pointer $P1$ is the glide-path indicator and moves over a vertical scale. It is operated by the main beacon signal, and
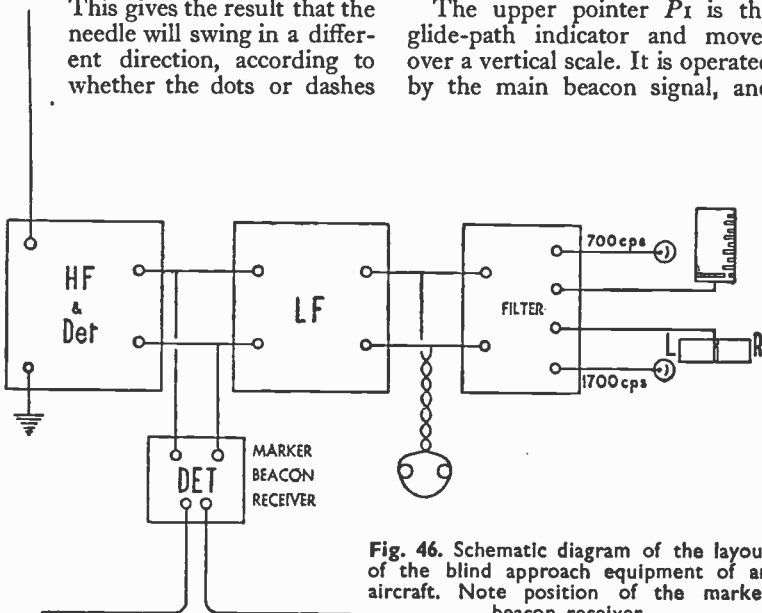
Fig. 46. Schematic diagram of the layout of the blind approach equipment of an aircraft. Note position of the marker beacon receiver.

when the aircraft is on the correct course will take up a definite position. By holding this position, the pilot can follow the glide-path for a blind touch-down.

The visual indicator is, of course, additional to the aural indication already , described. When using the system the pilot wears headphones, and so can both hear and see the information given by the equipment.

Fig. 46 shows a schematic diagram of the aircraft equipment for blind approach. The marker beacon receiver contains a detector only, the output from which is fed to the post detector stages of the Main Beacon receiver. All tuning is done by means of pre-set condensers, and the only con-trols used in the air are the on/off switch and a remote volume control. HT can be supplied from a 120 volt dry battery, but in some models from a rotary transformer.

Receiving Aerials

Two aerials are required on the aircraft. A vertical rod aerial about 3-4 feet long for reception of the Main Beacon signal, and a horizontal dipole mounted in the line of flight for reception of the marker beacons. Each half of the dipole is about 3 feet long, and it is usually mounted on small stand-off insulators underneath the aircraft. It is important that the marker beacon receiver should be situated as close as possible to the dipole.
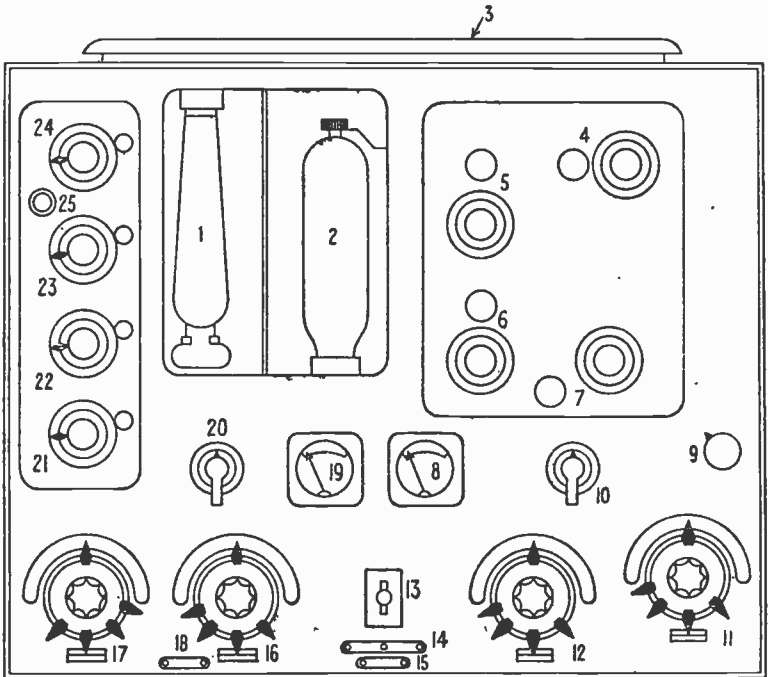
Fig. 47. Front of an aircraft transmitter showing the controls. The key to the numbers is in the text on the opposite page.

The Marconi AD 67/6872* aircraft radio equipment is typical of modern practice in large passenger carrying aircraft.

Transmission and reception on both short and medium waves are provided, and either CW, MCW, or RT can be used.

DF on the medium waveband is carried out by means of a rotating loop aerial using the same receiver, but if visual homing is required, a separate DF receiver must be included.

Transmitter Wavebands

The transmitter covers the following wavebands, in six ranges:

	Metres.	Kcs.
(1)	15–22	(20,000–13,636)
(2)	21–32	(14,286–9,376)
(3)	30–42	(10,000–7,143)
(4)	40–90	(7,500–3,333)
(5)	80–200	(3,750–1,500)
(6)	550–1,100	(545–272·7)

The range in use is selected by a six-position wave-selector switch, so that six spot-waves are immediately available by the operation of this one switch. On ranges 5 and 6 three additional spot-waves can be selected by setting click-stop devices on the tuning controls. This will be referred to again shortly.

The filament heating current is derived from a 12 volt accumulator and requires about 4·2 amps for the four valves. HT is supplied by a rotary transformer driven from a 12 volt accumulator and providing an output of 1,200 volts at 200 ma. The power at the anodes of the two amplifier valves is approximately 145 watts on CW.

The transmitter controls are

* The data regarding the AD 67/6872 and diagrams 47 and 49 have been supplied by the courtesy of Marconi's Wireless Telegraph Co., Ltd.

actually very simple, although they appear numerous owing to the six frequency ranges. Fig. 47 is a diagram of the front of the transmitter, the key being as follows:

(1) Master oscillator valve.
(2) Power amplifier valves.
(3) Ventilator.
(4) Range 1 of power amplifier tuning control and aerial tap coupling switch.
(5) Range 2 ditto.
(6) Range 3 ditto.
(7) Range 4 ditto.
(8) Aerial ammeter.
(9) Extra aerial inductance switch (medium wave ranges).
(10) Range 5 aerial taps.
(11) Range 6 power amplifier tuning control.
(12) Range 5 Ditto.
(13) CW/MCW/RT switch.
(14) Microphone socket.
(15) Headphones socket.
(16) Range 6 master oscillator tuning.
(17) Range 5 Ditto.
(18) Key socket.
(19) Milliammeter (HT feed).
(20) Waverange selector switch.
(21) Range 1 master oscillator tuning and locking device.
(22) Range 2 Ditto.
(23) Range 3 Ditto.
(24) Range 4 Ditto.
(25) HT fuse.

Fig. 48 gives details of the click-stop device fitted to items 11, 12, 16 and 17. The small V-edged stop can be set at any point on the periphery of the dial by means of the locking screws. On engaging with the slot in the spring-loaded block, the dial is stopped at a predetermined point. A little extra pressure will, of course, enable the dial movement to be continued if this is not the desired point.

It will be seen that this trans-
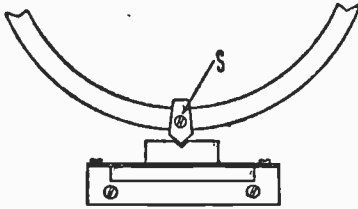
Fig. 48. Detail drawing of the click-stop device fitted to the tuning controls to facilitate selection of predetermined positions.

mitter is essentially designed for very rapid wave-changing between a number of pre-set waves.

The transmitter circuit consists of a triode master oscillator which drives two pentode power-valves in parallel. A further valve is used for the double purpose of modulation when radiotelephony is required and as an audio-frequency oscillator for MCW.

Relay Connection

No Send-Receive switch is fitted. The HT rotary transformer is switched on separately for transmission by a control on the main power-control unit, and the aerial is connected to the receiver through a relay which switches it over to the transmitter when either the key or the microphone button is pressed. "Listening-through" is thus automatically provided.

The weight of the transmitter itself is approximately 55 lb.

The receiver covers the following wavebands:

600–2000 m. (500–150 kcs) in 2
· ranges, for use with DF
300–450 m. (1000–667 kcs)
  183 m. (1639 kcs)
15–100 m. (20,000–3,000 kcs)
  in 4 ranges.

All valves are indirectly heated from a 12 volt accumulator, taking

2·4 amps total. HT is usually supplied from a rotary transformer having an output of 200 volts at 30 ma.

There is only one tuning control for any particular wave, so that receiver tuning is very simple.

Fig. 49 is a diagram of the receiver front panel, key being as follows:

(1) On/off switch.
(2) Power-plug for LT and HT.
(3) Telephone socket.
(4) Medium-wave/short - wave range switch.
(5) Local oscillator switch for CW.
(6) Short-wave range switch.
(7) Short-wave tuning.
(8) Medium-wave tuning.
(9) Medium-wave range switch.
(10) DF tuning.
(11) Plain aerial/DF switch.
(12) Volume control.
(13) Zero-clearing for DF (differential condenser).

The receiver is a superheterodyne and has six valves; one triode-hexode as HF amplifier and frequency changer for medium waves; one triode-hexode as HF amplifier and frequency changer for short waves; one pentode as intermediate frequency amplifier; one double-diode pentode as second IF amplifier, second detector and first LF amplifier; one triode output valve; and one triode oscillator for CW reception.

The approximate weight of the receiver complete is 19 lb.

Number of Aerials

A modern commercial aircraft has five aerials: a trailing, a fixed, a loop for DF and homing, a vertical rod aerial for blind approach main beacon · and a horizontal
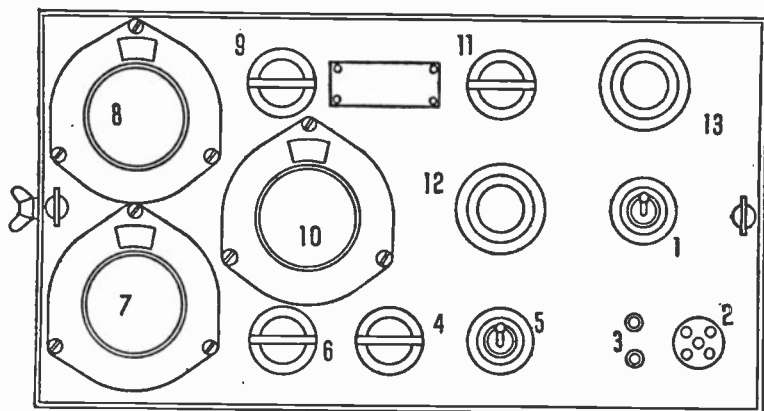
Fig. 49. A receiver front panel. The key to the numbers is given in the text.

dipole for blind approach marker beacons.

Fig. 50 shows a typical lay-out for these aerials on a medium-sized passenger carrying plane.

The trailing aerial winch and fairlead are fitted on the port side of the bulkhead under the operating bench. This is convenient for operation of the winch. The short mast acts as a point of support for the fixed aerial, and contains the vertical aerial for reception of the blind approach main beacon signal.
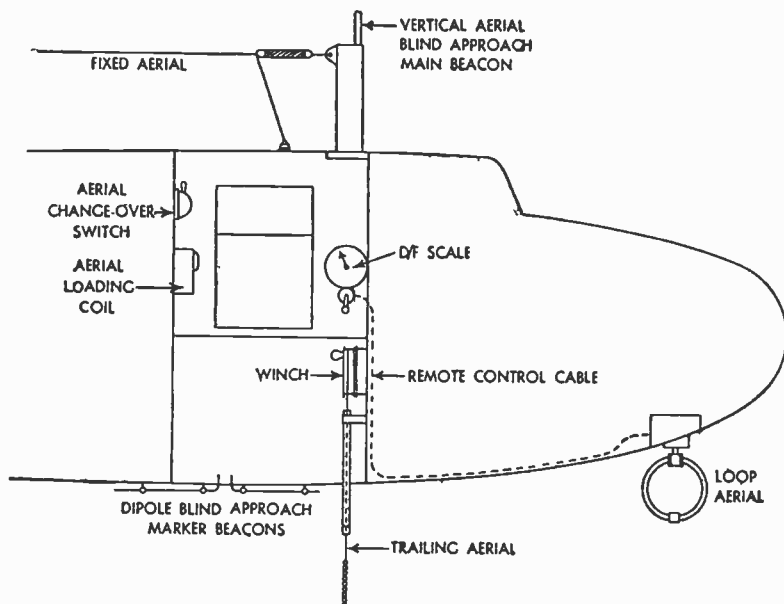
Fig. 50. Typical layout of the five aerials of a fully equipped commercial air liner.

Fig. 51 gives a general view of another aircraft installation, excluding the wiring and connections between the components. Key to the diagram is as follows:

(1) DF loop tuning.

(2) Change-over switch from open aerial to DF loop.

(3) Phasing resistance for homing.

(4) Change-over switch for homing. (This performs the same function as the switches S_1 and S_2 of Fig. 36, the off course indication being a louder signal in one position of the switch—*see* Fig. 38.)

(5) Extra HF amplifier valve for use with loop.

(6) Receiver tuning.

(7) Receiver volume control.

(8) Receiver reaction control.

(9) Receiver power-plug for HT and LT.

(10) Master oscillator valve.

(11) Power valves.

(12) CW/MCW/RT switch.

(13) Send-off/receive switch.

(14) Filament switch for power amplifier valves. (Off when neutralising.)

(15) Aerial ammeter.

(16) Anode current milliammeter.

(17) Neutralising condenser (adjustable by coin or screwdriver).

(18) Master oscillator tuning.

(19) Anode taps.

(20) Aerial taps.

(21) Aerial variometer.

(22) Change-over switch. Fixed and trailing aerial.

(23) Fixed aerial loading coil.

(24) Rotary transformer for receiver HT.

(25) Morse key.

(26) DF loop scale and remote control.

(27) Aerial winch.

(28) Fairlead.

(29) Blind approach marker beacon receiver.

(30) Rotary transformer for transmitter HT.

(31) Blind approach main beacon receiver.

(32) HT battery for blind approach equipment.

Interference in Aircraft

Hindrances to reception in aircraft can be classified under two main headings: (*a*) noise of the aircraft itself, and (*b*) electrical interference.

The effect of noise made by the aircraft varies considerably. In small open-cockpit machines it is severe, and conditions are extremely bad for radio communication. A tight-fitting helmet with ear-holes over which the headphones rest is one solution, or, alternatively, the headphones may be built into the helmet. Soft Sorbo rubber ear-pads fitted to the headphones can also be used.

In modern passenger carrying aircraft sound-proofing has been more developed, and the passenger cabin is often reasonably quiet, the noise being about on a level with that in a railway train travelling at 60 to 70 m.p.h. Unfortunately the radio operator is not situated in the passenger cabin, and the fore part of the aircraft is rarely as quiet. It is a remarkable proof of the selectivity of the human hearing apparatus that radio-communication, including DF, can be carried out efficiently under such conditions.

Electrical interference on aircraft is attributable mainly to the ignition system of the engines. Every time a plug fires, the HT leads radiate a short pulse of high-
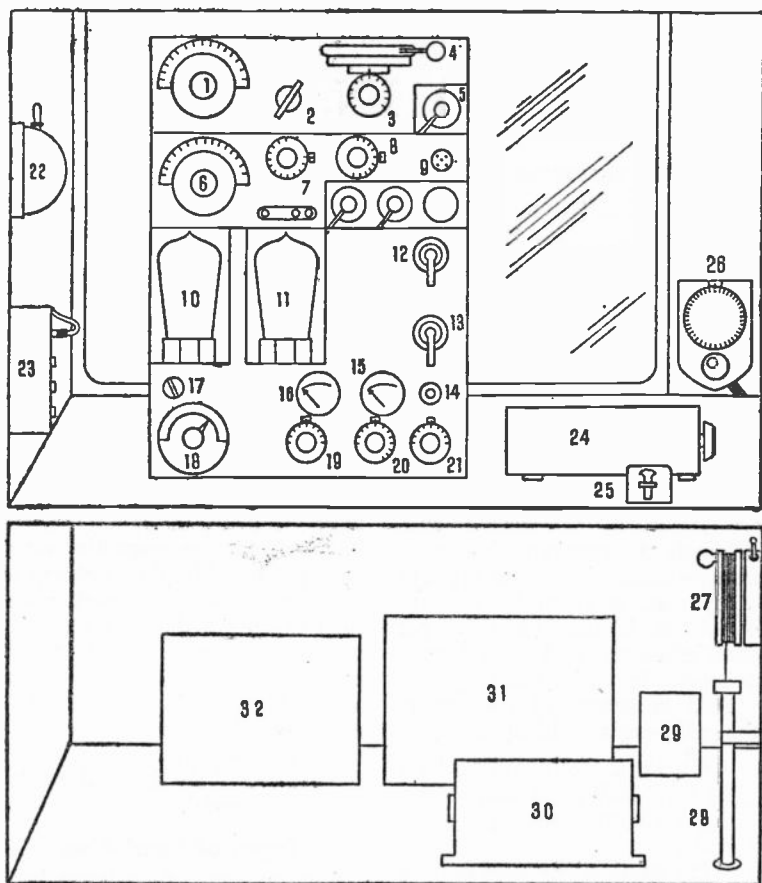
Fig. 51. General view of an aircraft radio installation. See key on opposite page.

frequency electric waves, and each pulse is liable to cause a cracking sound in the receiver. As several thousand sparks occur per minute reception would be impossible.

The usual method is to screen all parts of the ignition system completely. This means that the magnetos are enclosed in earthed metal cases, HT and LT leads are screened cable with the metal braiding earthed, and the sparking-plugs are specially designed with earthed metal screens.

The charging circuits may cause interference if a constant voltage regulator of the vibrating contact type is used. Suppression can be achieved by screening or by the use of chokes and condensers arranged as filter circuits.

Interference may also occur from the electric motors used to operate retracting undercarts, flaps, de-icing pumps and windscreen wipers. Filter circuits are employed as a rule to deal with these items.

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RADIO IN SHIPS

APPARATUS. TRANSMISSION. RECEIVING CIRCUITS. CRYSTAL RECEIVERS. GRID CONTROL. ANODE CONTROL. DEPTH SOUNDING. SIGNAL RADIATION AND RECEPTION METHODS. ULTRASONIC FREQUENCIES. OPTICAL SYSTEM. MARINE DIRECTION FINDERS. SENSING BEARINGS. AUTO-CALL ALARMS. EMERGENCY AND ANCILLARY APPARATUS. PUBLIC ADDRESS EQUIPMENT.

BESIDES normal communications on board ship, radio principles are used as the basis of many instruments that safeguard the vessels. In this chapter some of these instruments are described in outline and, although the apparatus has some features common to other types of equipment, it is to be remembered that it must have 100 per cent. efficiency, and must remain in service for many years.

Ship apparatus of concern to the radio engineer includes:

(1) Transmitters and receivers for CW, ICW, and telephony,
(2) Depth-sounding apparatus,
(3) Marine direction finders,
(4) Distress auto-call alarms,
(5) Life boat and emergency apparatus,
(6) Ancillary apparatus such as aerials, battery and mains supplies,
(7) Public address or relay service.

Marine radio can be roughly subdivided into two main divisions: that used for naval purposes and that for passenger and cargo vessels. Some knowledge of equipment of the second type will be of considerable assistance to the reader who subsequently becomes concerned with naval equipment, which, of course, may not be described at the present time.

In the early days of transmission, thermionic valves were not available, and other means of creating high frequency radiation had to be used. Electro-magnetic waves were produced by the discharge of a condenser across a spark-gap thus causing a damped wave. It was necessary to have: (a) a tuned circuit comprising of a condenser and inductance; (b) a method of charging the condenser; (c) a spark-gap, and (d) an RF transformer to feed the damped oscillation to the aerial.

Types of Spark-Gap

Various types of spark-gap have been used, but as power output requirements of transmitters increased, the older open and quenched types were ousted by the synchronous rotating pattern.

The open type can only be used for low-power transmitters, because of the heat generated at the gap. Although large electrodes are used and finning is provided, the power available is so small that this type is now obsolete.

The synchronous rotary gap is shown in Fig. 1, from which it will be seen that at the end of a shaft is a metal disc that carries a number

of contacts which are in electrical connection with each other.

The voltage from the condenser flows to an insulated contact on the stator, across the gap to one contact on the disc, through the disc to another contact opposite the second insulated stator contact. The speed of the rotor is adjusted so that the contacts come opposite each other when positive or negative peaks of the LF cycle are reached, thus causing the discharge once every half-cycle.

When the discharge takes place, the oscillatory circuit produces a damped waveform as represented in Fig. 2. This type of gap can handle far greater power than the open gap. Fig. 3 gives a typical circuit of a half-kilowatt transmitter using a rotary gap and constructed by the Radio Communication Co. This transmitter has a range of reliable communication of about 500–700 miles under all conditions.

Fig. 1. Diagrammatic representation of a synchronous rotary spark-gap. This type of gap can handle much greater power than is possible with an open gap.

Fig. 2. Type of discharge curve obtained with a rotary gap. The frequency of the wave, as completed by the dotted line, is determined by the number of contacts on the rotor and its speed.

It will be seen that the frequency of the transmitter is determined by the stud positions on the tapped inductances, and these are set at 450, 600, 700 and 800 metres. The rotary controls are brought out on the front of a vertical insulated panel so that rapid changes can be made.

The aerial circuit is loose-coupled to the transmitter. Due to the large power carried by the tuning inductances, they are constructed from copper strip or tube mounted on skeleton insulated formers. The condenser is of the oil-and-mica dielectric type, and is capable of withstanding a pressure of 15,000 v. The ammeter in the earth-lead indicates the value of the aerial current, and it will be noticed that two discharge circuits are provided and selected by means of a knife-switch.

The main transmitter is usually operated from the ship's AC or DC supply via a motor-generator delivering 100 v. 500 cps. If the ship's supply fails, the operator makes use of an emergency accu-
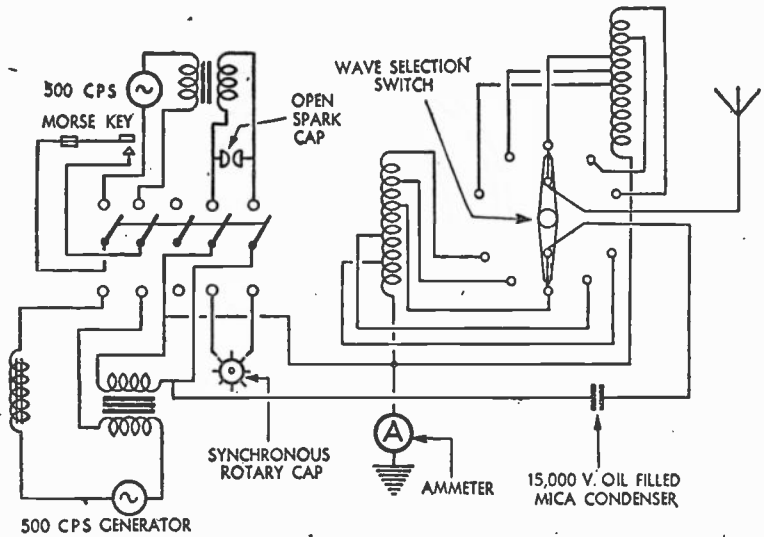
Fig. 3. Circuit of a rotary gap transmitter by the Radio Communication Co. operating at a power of half a kilowatt and possessing a range of 500–700 miles.

mulator supply which drives a smaller motor-generator delivering a quarter of a kilowatt at 100 v. 500 cps. When the emergency supply is switched on an open spark-gap is brought into operation to save the power which would be needed to operate the rotary gap.

The whole of the apparatus is built into a rack carrying the motor-generators in the base and the transmitter proper on the vertical panel.

With a simple transmitter of this type it is only possible to radiate code signals. This is achieved by the use of a morse or tapping key that completes the primary winding of the transformer and the 500 cps generator.

Crystal Receivers

In the early days, simple receiving sets of the crystal type were used. It was found that various minerals allowed current to pass in one direction with little

opposition while flow in the opposite direction was greatly reduced. Natural minerals such as zincite, silicon, galena, molybdenite, bornite and tellerium all possess this characteristic of rectifying AC.

Rectification takes place at the point of contact with either another crystal or with a sharp metallic point such as the pointed end of phosphor-bronze wire. Unfortunately the crystal rectifier is unstable, and often much time is taken in finding a sensitive point.

It was found that carborundum, which is made from silica and carbon, offered far more stable operation when used with a flat spring exerting a small pressure. The carborundum is mounted in a brass cup with the aid of low-temperature solder, and a small potential is applied by means of a potentiometer and battery.

Fig. 4 shows a simple type of receiving circuit in which the

tuned circuit L_1–C_1 is loosely coupled to the aerial–earth system by the coil L_2. The condenser C_1 is variable so that the circuit can be tuned to any wavelength, and the HF voltage developed across the tuned circuit is applied to the crystal detector D.
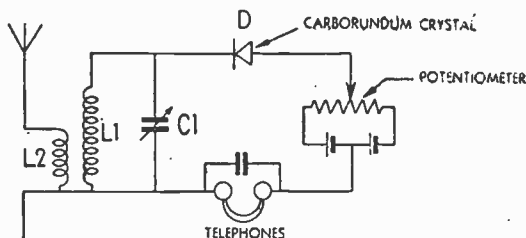
Fig. 4. Simple receiver using a carborundum rectifier and giving headphone reception.

The unidirectional audio current that results from the type of rectification which is characteristic of the crystal then flows through the telephones back to the tuned circuit.

The characteristic curve of a typical carborundum rectifier is given in Fig. 5, and it will be seen that it requires a negative potential of 1 v. if it is to operate at the most sensitive point.

As the "forward" resistance of the crystal is of the order of 40,000–70,000 ohms, it imposes considerable damping on the tuned circuit, and hence highly efficient tuned circuits are unnecessary. The tuning coil can be wound with relatively thin-gauge wire such as 28 SWG, the number of turns being dictated by the wave-band coverage required.

If a morse transmission is being
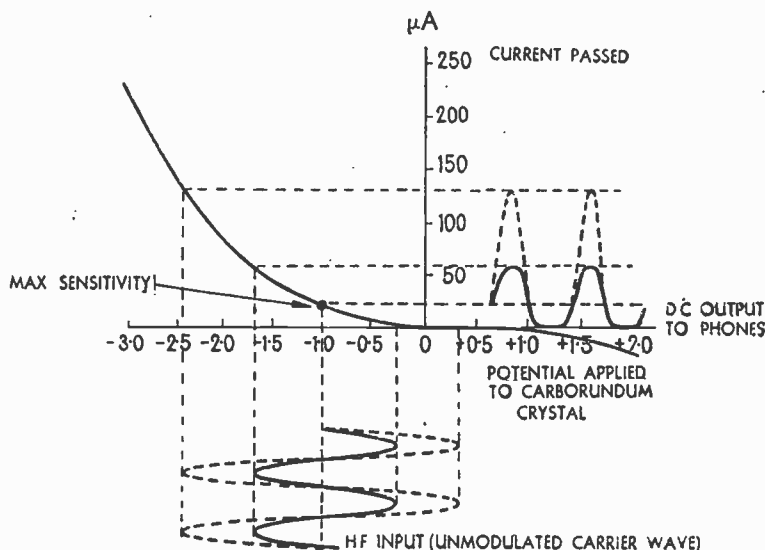
Fig. 5. Rectification curve of a carborundum crystal showing how HF pulses in one direction produce greater current pulses than in the opposite direction. A standing bias must be applied to secure operation at the point of maximum sensitivity.
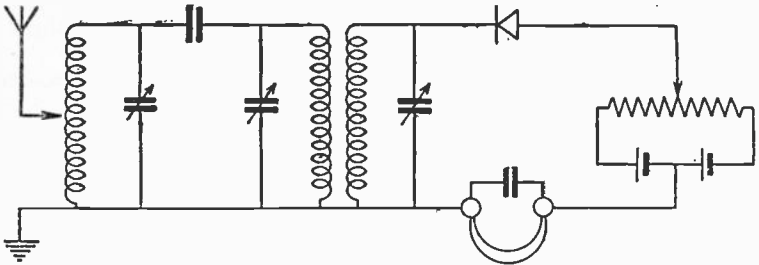
Fig. 6. To increase selectivity a number of tuned circuits must be used. In this circuit there are three. The first two are coupled by capacity and the third tuned circuit is coupled inductively.

received, the crystal rectifies the HF carrier and causes the rectified intermittent pulses to operate the telephones, thus causing a note to occur at the pitch of the transmitter spark frequency.

Tuned Circuits

To increase the selectivity of the simple crystal receiver, and to prevent it picking up harmonics of an unwanted transmission, several tuned circuits are used as successive filters (Fig. 6).

The advent of the valve caused many changes in the design of transmitters, for not only was the distance of effective transmission increased, but the selectivity of the tuning circuits was vastly improved, thus allowing a greater number of transmissions to be made within the allotted channels for marine broadcasts.

Transmitters are dealt with in Chapter 4, and so here we will proceed straight to consider the fundamental circuit of a simplified continuous wave (CW) transmitter.

If the oscillating valve circuit is coupled to an aerial–earth system, as shown on the left of Fig. 7, and the degree of coupling is accurately chosen, the aerial will radiate the continuous wave or any sequence

of starts or stops that are created by the operation of the morse key. In this simple diagram the necessary filament, HT and bias supplies are shown as being obtained from batteries, but in practice it is necessary to use DC generators or rectified AC.

This method of transmission does not create any sounds in an ordinary receiver except clicks at the starting and stopping of the transmitter. To make the signals audible a special receiving circuit that includes a "beat-frequency oscillator" must be used. The set
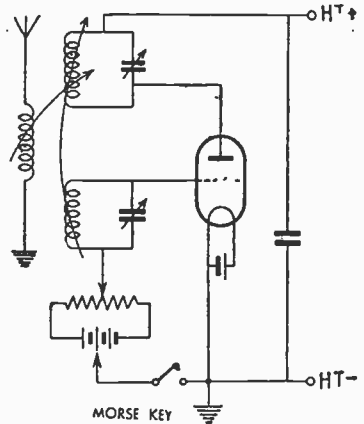
Fig. 7. Simple oscillating valve transmitter. Oscillation is controlled by means of the key in the grid circuit.
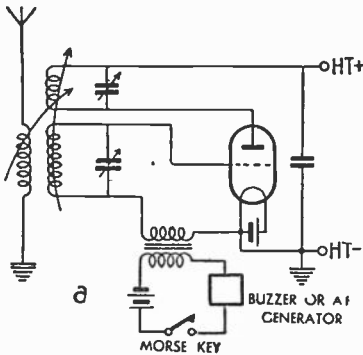
Fig. 8a. Comparison with Fig. 7 shows that little modification is needed to secure modulation of the transmitted wave. The audio frequency from the buzzer or other device is injected to the grid circuit of the oscillating valve by means of the transformer.

contains an oscillator valve, rather similar to that in a superhet, and the frequency generated by this valve is selected so that it "beats" with the received transmission at a rate producing an audio note.

If it is desired to transmit so that ordinary receivers can receive the transmission, it is necessary to make use of the interrupted continuous wave (ICW) system. In this a buzzer or audio-frequency generator is used to modulate the transmitter, and is operated by a morse key. The buzzer is connected so that it splits the CW into

a regular number of pulses, which are controlled by the frequency of the buzzer.

Figs. 8a and b show that the CW transmitter circuit in the previous diagram requires only slight alteration in order to be converted to ICW transmission. The potentiometer and its battery have been replaced by the secondary of an AF transformer, the primary circuit of which includes the buzzer, the battery and the morse key.

Fig. 9 shows the waveform of a a CW transmitter and b an ICW transmitter. In a it will be seen that as long as the key is depressed the waveform which is emitted is a "sine" wave of constant amplitude. On releasing the key, either the wave is completely stopped or it is reduced to a much lesser amplitude. In b the waveform of the buzzer-modulated oscillation is shown. It must be remembered that the number of HF oscillations produced during each LF wave is far greater than the number given in the diagram.

When it is necessary to use speech transmission, which is the fastest method of conveying intelligence, the simple transmitter indicated in Fig. 8a is amended again as in Fig. 10.
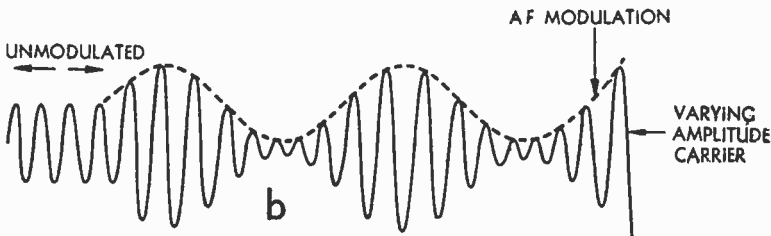
Fig. 8b. A modulated carrier wave showing how the amplitude or strength of the radio-frequency waves varies at the slower audio-frequency rate. Actually the number of RF waves to an LF wave is much greater than indicated.
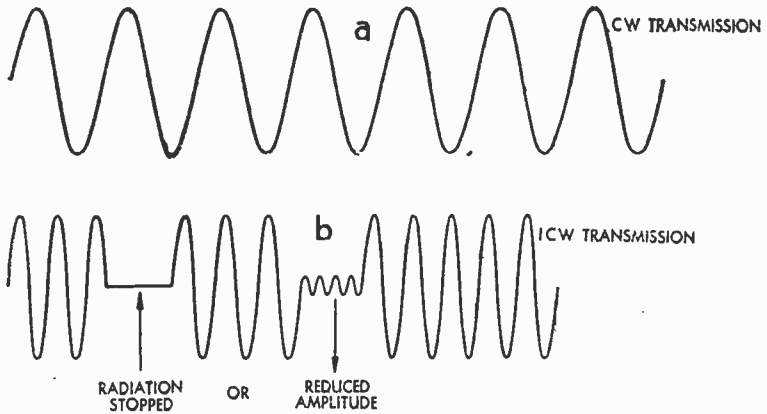
Fig. 9. In *a* is represented a continuous wave transmission which is not audible in a receiver without the application of special methods. In *b* is an interrupted continuous wave of the buzzer-modulated oscillation—the occurrence of the RF pulses at LF intervals produces an audible note after rectification.

The microphone is of the carbon type—that is, the changing air pressure on the face of the microphone causes the resistance of the carbon granules to alter. As a battery is connected in series with the microphone and the transformer primary, any changes in the resistance of the granule formation causes changes in the flow of current. Thus a change of magnetic flux is produced in the transformer, and this induces a voltage across the secondary wind-

Fig. 10. Simple arrangement showing the method by which speech modulation can be applied to an oscillating valve.

ing and, finally, across the grid of the valve.

This method of coupling the audio-frequencies to the valve is known as "grid control", and it effectively alters the amplitude of the continuous-wave transmission.

Anode Control

Another method makes use of "anode control", and a circuit using this method is presented in Fig. 11. In this case the microphone causes varying potentials to be applied to the grid of V_2, and these are amplified by the valve to a larger amplitude. The anode load of this valve is the anode AF choke, and the anode current for the valve V_1 also flows through the same choke.

A high-frequency choke prevents the HF signal entering the AF amplifier, but permits the latter to modulate the anode supply of V_1, thereby causing a similar change in the amplitude of the continuous wave radiation.

By the use of suitable switching

Fig. 11. A more advanced telephony transmitter. The microphone has an amplifier valve, V2, and its magnified signal controls the anode voltage of the oscillator, V1.
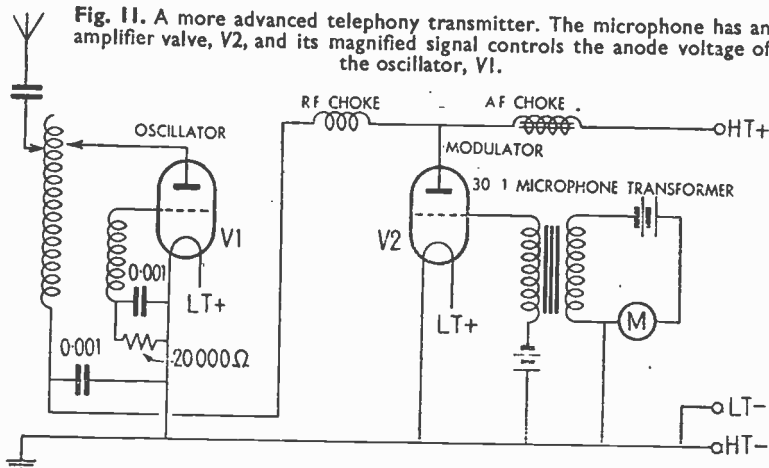
it is possible for a composite transmitter to be built that enables the operator to transmit on CW and ICW with code messages or to use radio-telephony for ordinary communication. A typical composite transmitter is shown in Fig. 12a, and a complete cabin installation is illustrated in Fig. 12b.

Modern methods of depth-sounding have completely superseded the older method of dropping a weighted line over the side of the vessel, with its unavoidable inaccuracies and time lag. We now make use of an electro-acoustical system by which a sound-wave is radiated from the bottom of the
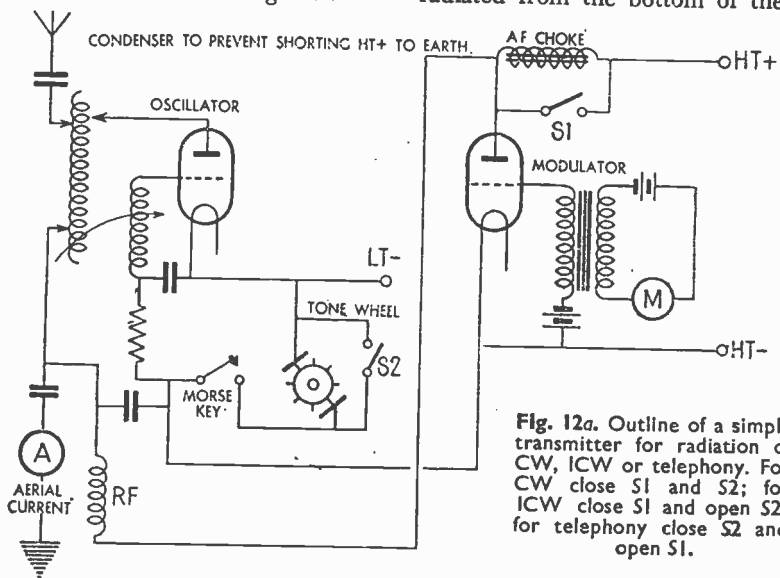
Fig. 12a. Outline of a simple transmitter for radiation of CW, ICW or telephony. For CW close S1 and S2; for ICW close S1 and open S2; for telephony close S2 and open S1.
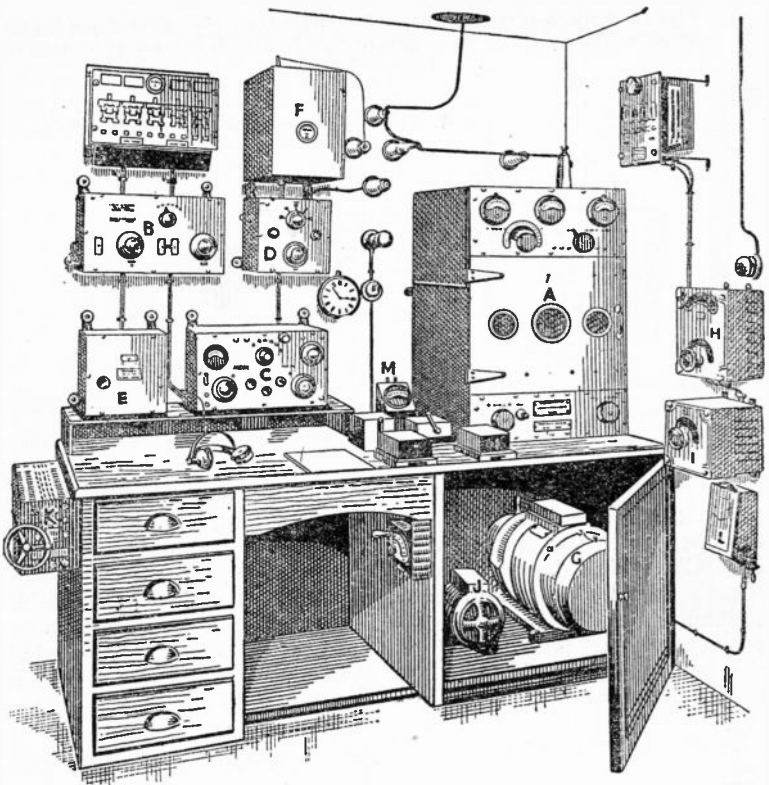
Fig. 12b. A Marconi 1·5 kw. valve transmitter as installed in a ship's cabin. A, main transmitter; B, high-frequency amplifier; C, receiver; D, local oscillation generator; E, note filter; F, emergency transmitter; G, main motor alternator; H, main motor alternator starter; I, main motor alternator regulator; J, emergency motor alternator; K, main power regulator; L, main switch, M, aerial ammeter.

ship and the reflected wave from the sea-bed is picked up by a receiver also mounted in the hull.

Knowing the speed of sound in water, and measuring the time between the radiation and reception of the acoustic wave, it is easy to calculate the distance travelled. The resultant figure, when divided by two, gives the depth of the sea.

There are two principal methods of radiation and reception of the signals, using piezo and magnetostriction effects respectively.

Certain crystals, such as quartz, Rochelle salt and tourmaline, possess unusual properties when cut along a certain axis. If pressure is applied to two opposite facets of the crystal, an electrical potential is produced across the two other facets at right-angles. Also, conversely, if a potential is applied, then the crystal distorts in proportion to the voltage (Fig. 13).

A crystal of this type can be used as a microphone—air pressure
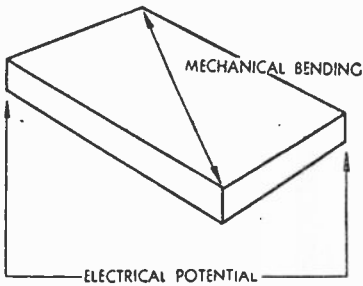
Fig. 13. The reversible electro-mechanical properties of the piezo crystal.

The earliest means of depth-sounding were crude compared with the modern methods, and usually consisted of a hammer striking the hull of the ship and a hydrophone (water microphone) picking up the reflected signal. This system works at low audio-frequencies, and the sound-waves spread spherically from the hull, not having any directional properties.

being applied to the facets and electrical facsimiles obtained—and also as a loudspeaker, electrical potentials being applied, and the resultant mechanical distortion being coupled to a diaphragm, and so creating sound-waves.

In the case of magneto-striction it has been found that certain materials change their length when subjected to magnetic fields of varying intensity. For example, a bar of nickel in a magnetic field contracts as the flux increases.

Other materials, such as steel, expand first, and then, as the field is increased, contract.

The modern transmitter makes use of ultrasonic (above audible) frequencies, which are far more directional in their propagation and reflection, thus saving a considerable amount of power and giving a more precise indication.

The projector of the sound impulse is represented in Figs. 14a and b. · It is mounted flush with the plates of the hull, with the diaphragm assembly pointing vertically downward. The distance the wave travels is given thus:

$$d = \frac{Vt}{2}$$

where d = depth in metres or feet, V = velocity of wave in the sea in

LEADS TO PIEZO CRYSTAL

MARCONI SOUND PROJECTOR FITTED INTO HULL

DIAPHRAGM OF QUARTZ BETWEEN TWO STEEL PLATES

HULL OF SHIP
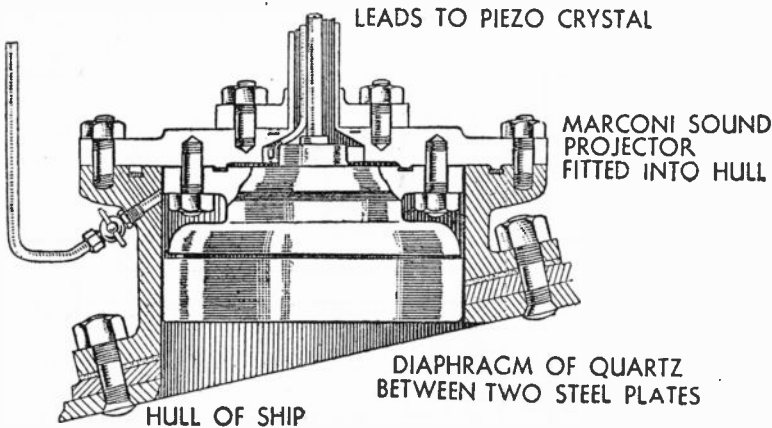
Fig. 14a. A piezo crystal ultrasonic wave projector, mounted flush with the plates of the hull of a ship for the purpose of depth sounding.

Fig. 17b. An optical depth indicator (*left*) and an electrolytic recorder (*right*) as installed in a large vessel.

bearings from several stations and plot them on a map. By a process of triangulation the position of the ship can be accurately determined.

The "radiocompass", as it is sometimes termed, operates owing to the tendency of a loop or frame aerial to pick up signals only when they pass the loop in a certain direction. The loop consists of several turns of wire wound into a large coil, circular or rectangular in shape. Signals of the maximum intensity are picked up when the loop points to-

from rocks and very irregular-shaped beds. When thick mud is encountered the reflected response curve is very flattened, *c*.

Radio Compass

One of the greatest contributions to the safety of those who travel by water is the direction finder, that enables the operator to determine the exact position of the ship, irrespective of weather conditions. Fog, mist, heavy seas no longer prevent bearings.

The marine direction finder enables the operator to take radio

Fig. 18. Typical impulses as seen on an optical indicator. Experience enables the type of sea bed to be identified by the "shape" of the signal reflected on the paper or the screen.
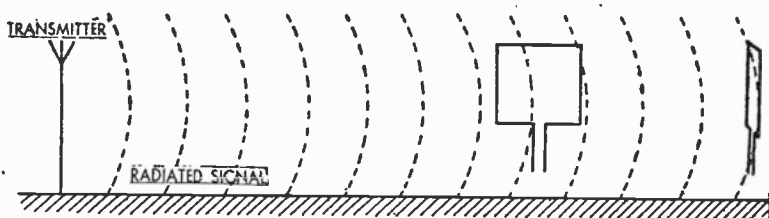
Fig. 19. A loop aerial picks up the greatest signal when edge-on to the wave. When it is broadside the equal signals in the two vertical sides cancel out.

wards the transmitting station (Fig. 19).

As Fig. 20 shows, the signal is picked up when the loop is pointing to the station, but when the side of the loop is parallel to the incoming waves, the currents in each side of the aerial cancel out and the point of minimum signal is obtained. As the minimum position is more accurate than the maximum, it is the one that is always used.

Many types of radio-compass have been developed both in Britain and in the U.S.A. It is legally necessary for all ships exceeding 5,000 gross tons to carry such apparatus.

The input circuit of a representative radio-compass is shown in Fig. 21. The variable condenser C_1 forms the tuned circuit in conjunction with the loop aerial, connections to the rotatable frame being made by slip-rings having the least possible HF resistance.

Across the condenser C_1 is connected the tuned HF receiver with demodulator and audio-frequency amplifier. To prevent interaction between the telephones and the radio-compass, it is necessary to keep them at some

CURRENT DIRECTION

DIRECTION OF
SIGNAL ⟶

DIRECTION OF SIGNAL
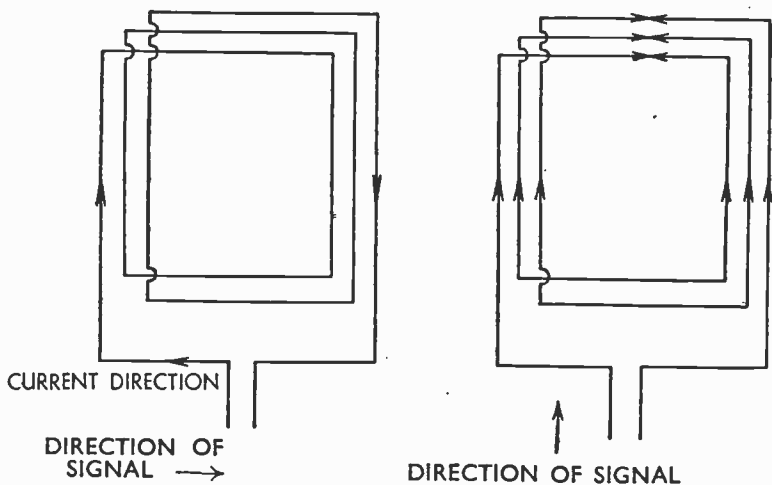
Fig. 20. How currents add up (*left*), and cancel out (*right*), in a loop aerial depending on the direction of the wave relative to the winding.
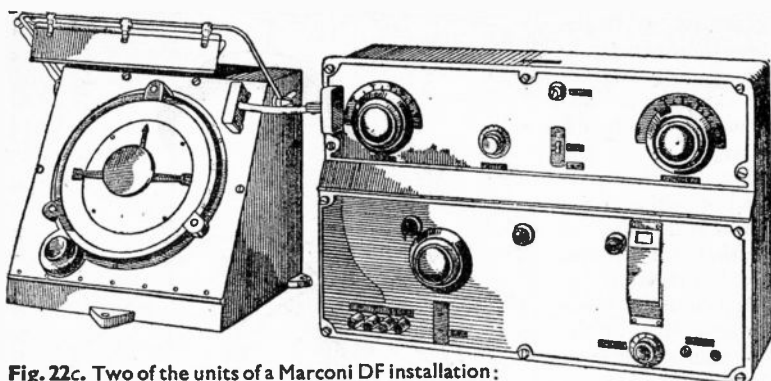
Fig. 22c. Two of the units of a Marconi DF installation: (*left*) the Radiogoniometer and (*right*) the receiver.

junction with the navigator, takes the following readings:

1. Ship's direction as taken from magnetic bearing = 45°
   Variation obtained from chart = 10° E = 10°
   Deviation obtained from correction chart = 2° E = 2°

   57°

2. Radio beacon T_1 as read on radio-compass = 272°
   Correction due to quadrantal error from chart = − 1·5°
   Therefore radio bearing on T_1 relative to ship's reading = 270·5°

Thus the bearing on T_1 relative to the true North = true ship's head + corrected radio bearing = 57° + 270·5° = 327·5°. From this information the line T_1–OY can be drawn through the radio beacon T_1.

3. Radio bearing from T_2 as read on radio compass = 223·5°
   Correction due to quadrantal error from chart = + 9·5°
   Radio bearing on T_2 relative to the ship's line = 233°

The bearing on T_2 relative to true North = True ship's head and corrected radio bearings = 57° + 233° = 290°. This gives the position of line T_2–OX from the radio beacon T_2 and the intersection of the two lines at O gives the position of the ship.

Distress Signals

An automatic alarm is a device used to ensure that radio distress signals are received even when operators are not actually "on watch". Regulations govern the distress signal and the number of operators on duty.

The function of the distress signal is to operate an automatic receiving device on any vessel in the vicinity of the ship in distress, and by means of electric bells to call attention to the receiver. The special signal transmitted is not the SOS, but is known as the auto-alarm signal, and is transmitted just prior to the sending of the SOS.

The signal consists of a series of dashes and spaces, each dash having a duration of four seconds, and each space a duration of one second. Twelve such dashes and spaces can be transmitted during
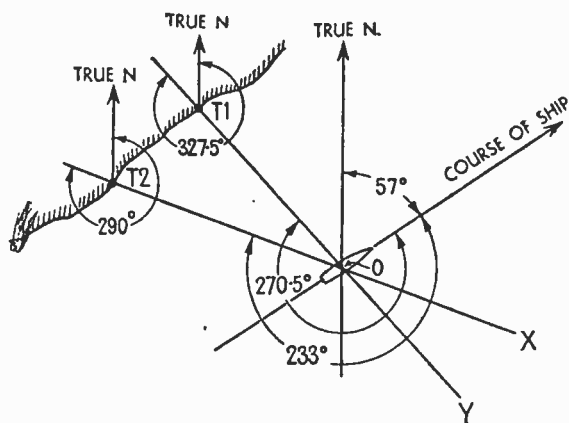
Fig. 23. How two bearings obtained on shore radio beacons of known position enable the position of a ship to be calculated, as described in detail in the text.

one minute. Fig. 24 shows this sequence.

In some countries the alarm bell rings after three consecutive dashes and spaces have been received, but in the U.S.A. they have standardised four dashes and spaces, as it greatly reduces the number of false alarms. The normal distress signal is radiated on a frequency of 500 kc. (600 m.), and as it is radiated for twelve dashes and spaces, it will operate both European and American apparatus.

Life-Boat Apparatus

At the International Convention for the Safety of Life at Sea in 1929, it was decided that where ships carry more than thirteen lifeboats, one of these must be driven by internal-combustion engines and equipped with a wireless telegraph installation. Obviously the apparatus must be very easy to operate, as unskilled operators may have to use it, and it must be able to withstand the severest weather conditions.

Power for the transmitter and receiver is obtained from accumulators which are capable of running on continuous load, together with that of a small searchlight, for six hours. The battery is usually ten 2 v. cells connected in series and has a capacity of some 150 amp.-hours. The aerial is strung between two masts preferably higher than 23 feet, and the earth consists of a metal plate 6 feet square on the underside of the hull. The transmitter is normally tuned to 600 m.

As it is necessary to obtain the greatest range of transmission with the minimum battery consumption, the quenched spark transmitter is normally used. A motor alternator is operated from the accumulator giving an output of about 0·25 kw. at 50 v. 500 cps. This power is supplied to the
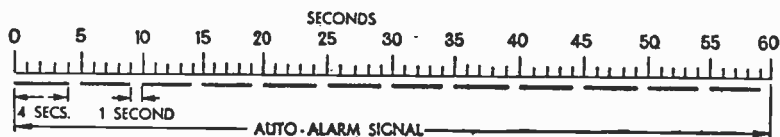
Fig. 24. Illustrating the spacing of the four-second dashes comprising the standard form of auto alarm for distress signals.

direction-finding apparatus makes use of its own rotatable loop aerial, plus another small vertical one to give the signal for the "sense" reading.

One of the greatest problems is the design of suitable insulators. Many types are available, each designed to keep the insulation path as long as possible. In order to prevent dirt and soot adhering to the insulator, the surface is highly glazed. If mounted in a vertical position a hood prevents water from running down the insulator and partially short-circuiting the signal to earth.

Where it is necessary to carry the aerial through a deck or roof in order to reach the transmitting room, aerial "trunks" are used. These are constructed from porcelain tubes into the end of which fit moulded flat discs. Through the centre of the porcelain discs is fed a screwed rod that finally terminates through finned insulators (Fig. 27).

Extreme care must be taken at any joint in the aerial to see that

the radiation resistance is kept as low as possible. This can be ensured by using a suitable gauge wire and confirming that the joint is thoroughly soldered and taped.

Where steel guy-wires are used to support the aerial mast or other apparatus, it is necessary to place insulators at each end to limit induced currents.

Loudspeaker Systems

In many ships to-day loudspeakers are placed at "strategic" points to relay news and entertainment programmes and to enable the ship's officers to talk to the passengers or crew.

To perform these various duties it is necessary to have:

(1) A radio receiver.
(2) Microphone(s).
(3) Gramophone pick-up(s).
(4) Audio-frequency amplifier(s), and
(5) Loudspeakers.

It is usual on passenger ships for the whole of the apparatus to be housed in the concert-room, with the exception of the radio receiver, which is connected from the radio control room via a low-impedance transformer coupling.

The gramophone pick-ups may be of the piezo-crystal or electro-magnetic type. If they are located a considerable distance from the amplifier, the magnetic type is preferable, as it can be used with a step-down transformer, thus preventing the introduction of hum.

Normally on board ship the loudspeakers are of the short directional horn baffle type, although the box baffle is used for indoors, where the atmospheric conditions are less severe.
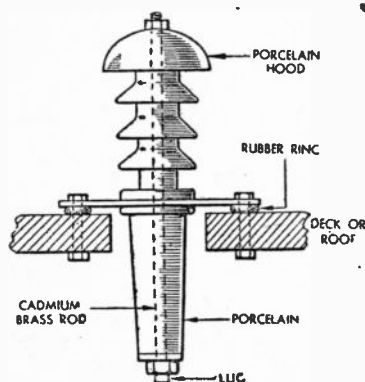
Fig. 27. Section of a "trunk" leading the aerial connection into the radio cabin through a deck or roof.

SHORT WAVES.

RADIATION OF WAVES. REFLECTING LAYERS. EFFECT OF FREQUENCY. SKIP
DISTANCE. ULTRA SHORT WAVES. FADING. DIVERSITY RECEPTION. SHORT-
WAVE AERIALS. FEEDERS AND REFLECTORS. BEAM ARRAYS. MICRO WAVES.

ONE of the problems which puzzled the early investigators of radio transmission was the fact that it was possible to receive radio signals at a range of many hundreds of miles. According to the knowledge then possessed, this ought to have been impossible, because waves travel in straight lines and, since the earth's surface is curved, they ought to leave the earth soon after they were initially produced. This point will be clear from Fig. 1.

The waves are actually radiated in all directions, some going straight up into the air, some horizontally along the earth's surface at the transmitter and some of them down into the ground, where they are very quickly absorbed. Therefore a receiver at the point B should not obtain any signals from the transmitter at A.

There is a certain dragging of the "feet" of the waves, because they do not travel so easily or so quickly through the earth. This point is easily demonstrated by tying a light weight (only a fraction of an ounce) on the end of a piece of cotton. If you walk along with this in your hand, it will travel with you without difficulty, but if the bottom end is dropped into a trough of water, the extra friction caused by the water will cause the end of the cotton to drag behind, and we shall get the effect illustrated in Fig. 2.

Diffraction

The scientific name for this effect in connection with electromagnetic waves is "diffraction" (Fig. 3), but this in itself was by no means sufficient to account for the strength of the signal which was obtained in practice.

After some time it was dis-
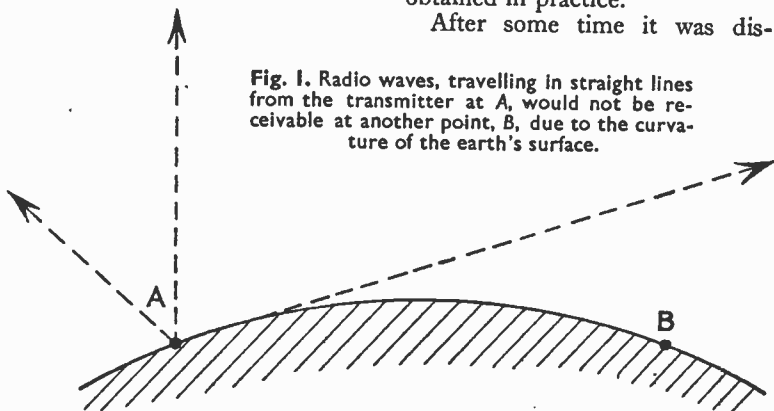
Fig. I. Radio waves, travelling in straight lines from the transmitter at A, would not be receivable at another point, B, due to the curvature of the earth's surface.
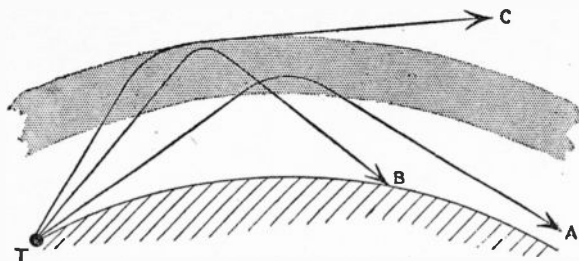
Fig. 6 (*above*). Wave A is reflected but passes over the receiver. Wave B enters the layer at a steeper angle and returns to earth successfully. C enters at too steep an angle and passes through the layer before being bent sufficiently for reflection back to earth again.

Fig. 7 (*right*) shows a simple illustration of inertia. A series of rapid blows on the sides of a heavy weight will not produce any movement.

large that the wave is completely lost.

This particular frequency coincides with the natural period of oscillation of the electrons, and the energy absorbed under these conditions is very large. Because of this it seemed at first as if this frequency (which corresponds into a wavelength around 200 m.) constituted a complete barrier and that wavelengths shorter than this were quite useless for any long-distance transmissions. The authorities therefore allocated wavelengths below 200 m. to amateurs for experimental purposes.

Amateurs' Discoveries

It was not long before the amateurs completely disproved the accepted theories by transmitting farther with these so-called useless short waves than the professional engineers could do with their high-power transmitters on the longer wavelengths. And this opened up an entirely new field.

Actually, as the frequency is increased we pass through the resonant period, and the impulses generated by the radio waves recur too quickly for the electrons to take any notice.

If we have a heavy weight on the end of a rod and give it a light push in one direction and then a light push in the reverse direction, it will swing to and fro, but if the impulses follow one another with extreme rapidity, the weight has no time to move in one direction before it has received an impulse in the reverse direction, and we can administer quite strong impulses without causing any movement of the weight. (Fig. 7).

The action of the high-frequency waves on the electrons in the electrified belt is much the same. They have, in fact, come and gone before the electron has had time to move, so that these very high-frequency (short wave) oscillations are able to travel through the electrified layer with practically no loss.

They are still subjected to the bending action, so that the reflection takes place, and we have all the advantages of the mechanism which we have just discussed without the disadvantage of considerable loss of energy.

There are several belts of electrified atmosphere, and the one which has the greatest influence on the short wavelengths used in commercial practice is called the "F" layer, which is some 200 miles above the earth's surface. Short waves travel through the first or "E" layer with a slight deviation in their route, and then reach the "F" layer, where they are reflected as illustrated in Figs. 8 and 9. Owing to the much greater height of this layer and the much lower gas pressure, the ionisation is much more stable.

Fig. 8. Short waves are slightly bent by the lower "E" layer and fully reflected by the "F" layer which lies about 200 miles above the earth's surface.

With the lower layer the ionisation varies considerably with the time of day. The effect of the sun's rays is to increase the ionisation and to cause the effective height of the layer to become appreciably less. At night-time the ions recombine and the electrification disappears, at any rate at the lower levels.

With the "F" layer the time taken by the ions to re-combine with their electrons is many hours, because of the very low pressure of gas, which means that there are relatively large distances between the molecules, so that the electrons and ions can wander about for a long time before meeting each other.

Consequently this upper layer is in a state of more or less permanent electrification, and it does not change its state of ionisation anything like so seriously with time of day.

The longer short waves are more affected by the "E" layer and, therefore, more variable in their action, while the shorter wavelengths travel considerable distances (actually many times around the earth) before they are so greatly reduced in strength as to become quite useless.
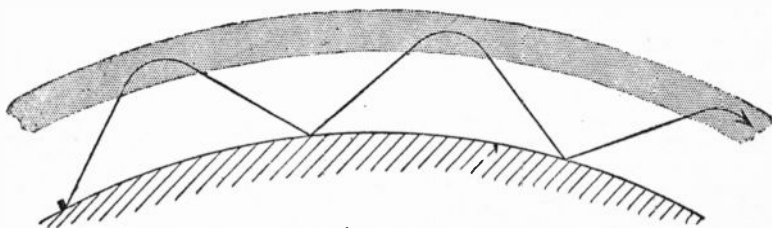
Fig. 9. Waves may be reflected between the earth and ionised layers many times. This makes it possible to transmit communication to any part of the world provided that suitable wavelengths and powers are employed.
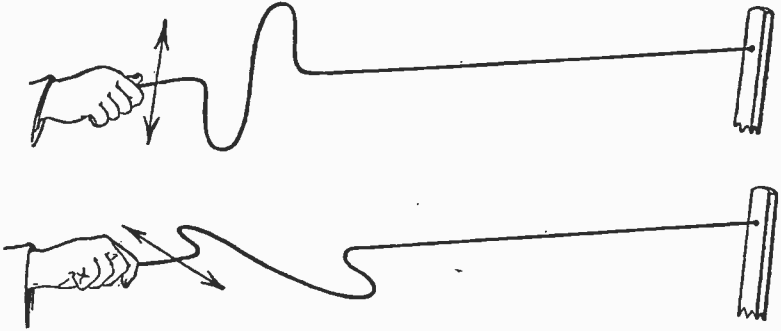
Fig. 12. A mechanical analogy to the difference between vertical and horizontal polarisation. Polarisation of radio waves contributes to the effect known as fading.

adhered to, so that everyone shall have a fair share.

This is particularly troublesome on short waves, because these waves travel so extremely well that a station in this country may quite easily be interfered with by one operating 10,000 miles away. The strictly limited zone of the effectiveness of ultra short waves means that the same wavelengths can be used over and over again in different parts of the world without danger of interference. There is a further marked advantage in the almost complete absence of the phenomenon known as fading.

Fading is the name given to the gradual variations in the strength of the received signal due to a dis-

turbance of the wave during its reflection at the Heaviside layers. This change in strength may be very slow, first causing the signal gradually to become weaker until perhaps it vanishes altogether, after which it will increase again until it becomes quite strong. The whole cycle of change may last for many minutes. This form of fading is more usually noticed on the medium waves around 300–600 m., where reflection is principally obtained from the "E" layer.

The other form of fading is a very rapid fading, in which the strength varies, often quite erratically, over a period of a few seconds. Both types of fading are
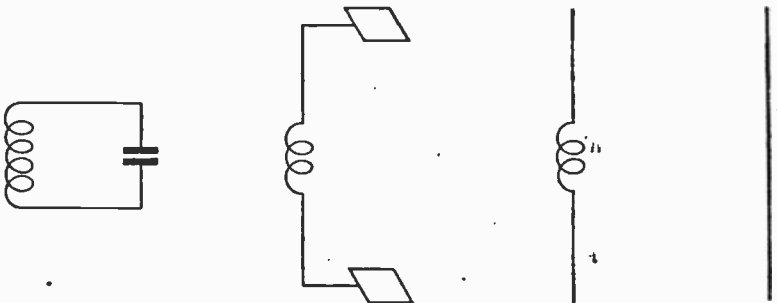
Fig. 13. If we take a simple oscillatory circuit (*left*) and open it out we reduce the capacity and inductance, but even the straight wire indicated on the extreme right of the diagram possesses sufficient of both still to form an oscillatory circuit.

due to a rotation of the "plane of polarisation" of the wave.

We can best understand this by considering once again the analogy of the ripple in the rope (see page 10). This is reproduced in Fig. 12 for convenience. If the hand holding the free end of the rope is jerked vertically up and down, then the ripple will be vertical, and we should say such a wave was vertically polarised.

If the hand is jerked sideways, however, the ripple produced will be horizontal, and it is obvious that we can have many kinds of waves having any plane of polarisation from horizontal to vertical.

Now, the customary radio receiver is designed to respond to vertically polarised waves. The waves are generated by a vertical wire, along which the electrons are caused to oscillate, and at the receiver we erect a similar vertical wire. The wave passing this wire causes the electrons to oscillate and, as we know, the strength of this oscillation is increased by the process of tuning, followed by valve amplification.

If we erect a horizontal wire at the receiving end, a vertical wave going by will have very little effect, and practically no signal will be picked up. Similarly if we have a vertical wire a horizontally polarised wave will have little effect.

Now, the reflection at the Heaviside layer is not always a completely straightforward business. The surface of the layer is not smooth and highly polished like a mirror, but is rather like the underside of a cloud, and the wave is liable to be twisted. Actually we find that the wave is sent on its downward path, spinning round and round, so that at one instant the wavefront is vertically polarised and shortly afterwards horizontally polarised.

The effect of this on a normal aerial will easily be understood. When the wave arrives vertically polarised, the aerial will receive normally. As the wavefront twists, the signal received will get less and less, until it falls away to zero, when the wavefront has twisted completely horizontal. Then it will gradually increase again, and so the signal will
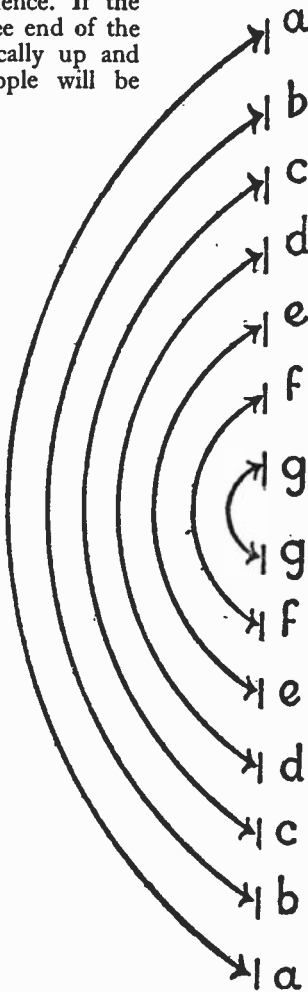
Fig. 14. Consideration of the behaviour of current and distribution of EMF in an aerial is simplified if it is thought of as a number of short, charged conductors.
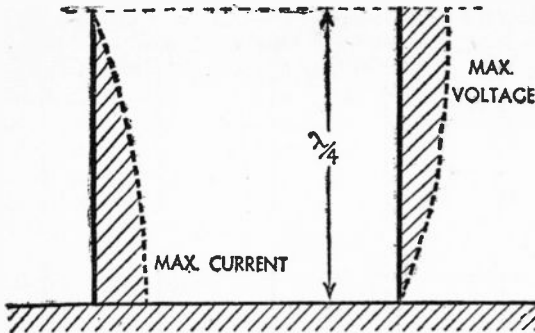
Fig. 17. Distribution of current and voltage as they appear in a quarter-wave aerial.

also rise to the maximum in the opposite direction and then fall to zero. (See also Fig. 16). A simple wire such as this is called a half-wave or dipole aerial, and the wavelength of the wave generated if such a wire is caused to oscillate is approximately twice its actual length.

the wire near the end will only carry those currents which come from the outside portion, and obviously the portions at the extreme ends of the wire will carry no current at all.

Consequently, the current distribution over the wire is not the same all over, the current being the greatest in the centre and falling off towards the extremes. The distribution can be illustrated diagrammatically as in Fig. 15.

By a similar reasoning it will be clear that there is no voltage in the centre of the wire, but that the voltage gradually increases as we go away from the centre until it is a maximum at the extremes, which gives us a distribution of voltage which can be illustrated as shown (Fig. 15).

It will be seen that the distribution corresponds to half a wavelength. The voltage at the two ends of the wire is exactly reversed, and the current has increased to its maximum and fallen to zero again, whereas in a full cycle it will

If we cut the aerial in two and connect the middle point to earth, we then get a quarter-wave aerial, as shown in Fig. 17. If we make the aerial longer, the current reverses in certain parts of the wire.

Fig. 18 illustrates a three-quarter wave aerial, from which it will be seen that the current is flowing in one direction at the bottom of the aerial and is flowing in the exact opposite direction two-thirds of the way up.

The radiation produced by the bottom section will be in the opposite direction from that produced by the upper portion.

Arrangements like this are sometimes employed because the can-
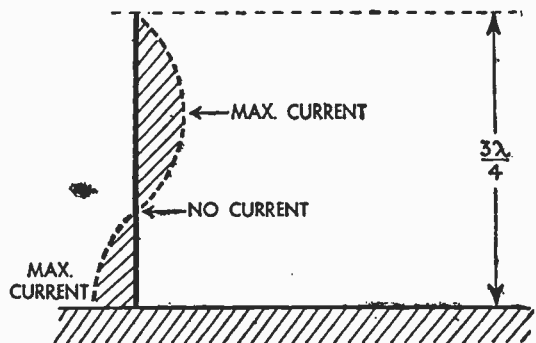
Fig. 18. Instantaneous current in a three-quarter wave aerial. Note change of direction of current.

celling out of the radiation from top and bottom portions is not the same at all angles to the ground, and therefore a certain directional property is obtained causing the wave to start in an upward direction.

The manner in which we feed the aerial is interesting. If we have an ordinary tuned circuit and we wish to induce current in it, one simple method is to wind a few turns of wire close to the coil in question and to pass current through this coupling coil. Instead of actually winding a second coil, as in Fig. 19 *a*, it is possible to use some of the turns of the main coil itself by taking a tapping on the coil, as illustrated in Fig. 19 *b*.

We have seen that a straight wire is equivalent to an oscillating

mitter itself to the aerial over quite long distances through special transmission lines, which are really simply a pair of wires, though for convenience they are usually made concentric—*i.e.*, with one conductor inside the other as illustrated in Fig. 20. (A simpler arrangement for a receiver feeder is shown in Fig. 21.)

If these transmission lines are properly designed it is possible to conduct the energy from the transmitter to the aerial over a distance of a mile or more without appreciable loss (Fig. 22).

The advantage of this is that it enables us to build what are called "arrays", which increase the effectiveness of the transmitter.
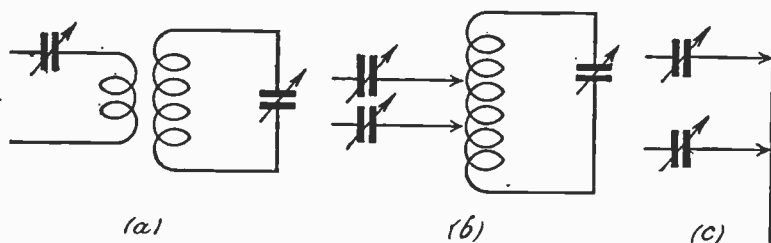
Fig. 19. Three stages in the development of the aerial feeder. The theoretical arrangement is shown in (*a*). But part of the oscillatory circuit can be used instead of the second winding (*b*) and the aerial itself is the oscillatory circuit (*c*).

circuit, so that if we simply connect our source of current across part of the wire, it has the same effect as tapping across the coil of the circuit in Fig. 19 *b*. The arrangement is illustrated in Fig. 19 *c*, and it will be clear that we must tune the input circuit so that a variable condenser is introduced in each of the feed-wires in order to obtain the maximum current into the arrangement.

It is, indeed, possible to transmit the current from the trans-

One way of increasing the effective height of the transmitting aerial is shown in Fig. 23, where a long wire has been folded up so that all its currents are in the same direction. The portion *AB* is a half wavelength long, and the current is therefore all in the same direction over this section.

Over the portion *BC*, however, the current is reversed. To prevent this from doing any harm, this section of the wire is folded in the particular form shown, and it will
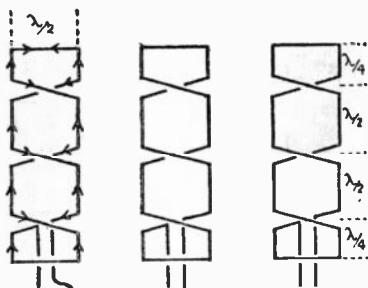
Fig. 24. In the "Sterba" method of increasing the effective size of an aerial the successive half-wave sections are alternately vertical and horizontal. It will be seen the currents in the vertical sections are all in the same direction but those in the horizontal portions neutralise each other.

have to be used which have a "low loss".

Valves of very small size and with correspondingly reduced internal capacities are sometimes employed (Fig. 27).

It has already been pointed out that although a material may not conduct current, the electrons of which it is composed will oscillate from side to side under the influence of the alternating fields.

This movement of electrons is accompanied by some dissipation of energy (a sort of electrical friction), and when the oscillations are extremely rapid this loss may become serious. It may even cause so much heat to be generated that the insulator itself catches fire, or perhaps splits and breaks to pieces. As a result, special materials, usually of a ceramic (porcelain)
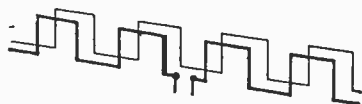
Fig. 26. A zig-zag aerial with reflector, suitable for transmission or reception. Each side is a quarter wavelength and the arrangement acts as a broadside array of quarter-wave height.

Fig. 25. A second resonant wire placed near the aerial becomes energised and acts as a radiator. If the spacing is quarter-wave the two transmissions add in the forward direction but cancel behind the reflector.

type, have been developed for ultra short wave purposes.

We can conclude this chapter with a reference to the very short waves known as micro-waves. These are generated by frequencies of the order of hundreds of megacycles, which produce for us wavelengths of a few centimetres only.

Such waves are very similar to light waves in their general character. They will go through fog and can be focussed into beams (Fig. 28).
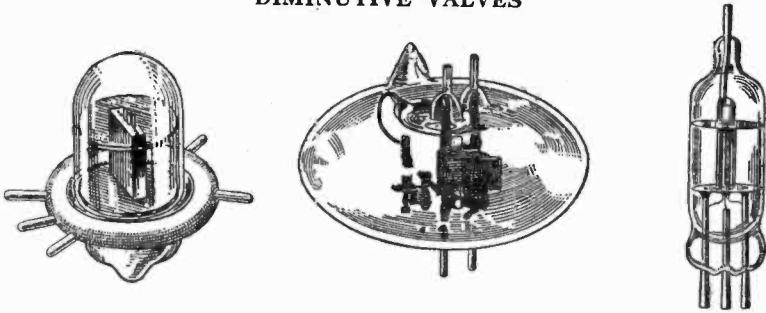
Fig. 27. Three typical valves developed for short-wave work and variously described as "acorns" and "peanuts", which suggests their small size. They are small in order to reduce internal capacities and electron paths. The lead wires co-operate with clips, there being no valveholder in the usual sense.

Fig. 28. A remote-controlled centi-metre wave transmitter (housed in weatherproof box) with its tiny aerial and large reflector array. Such a com-munication system can be used only between points little more than visual distance apart.

REFLECTOR

DIPOLE AERIAL

TRANSMITTER
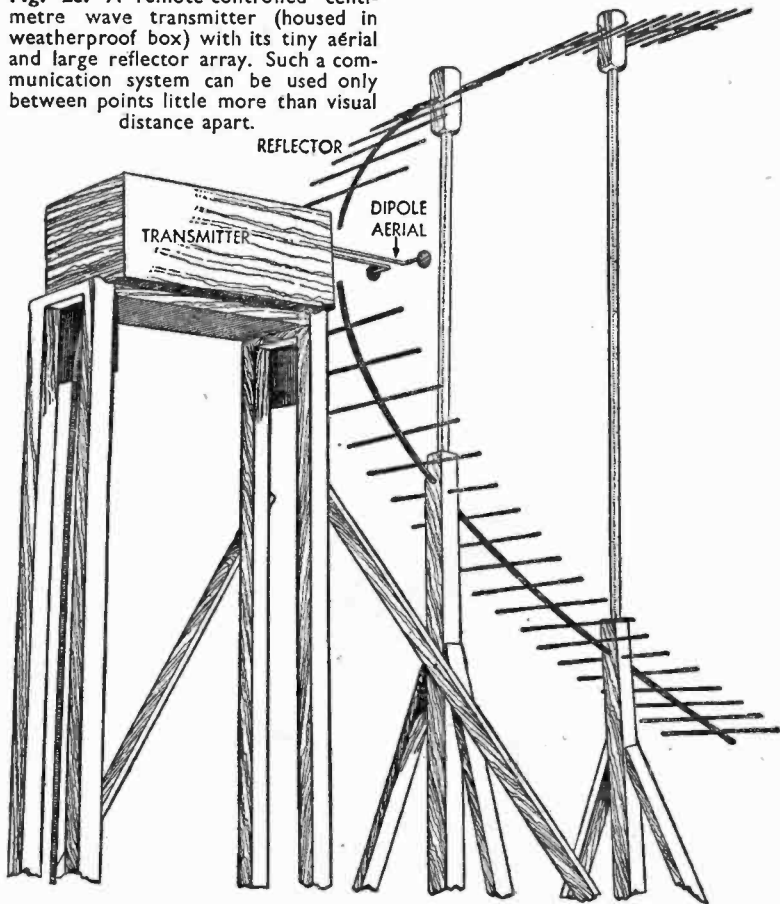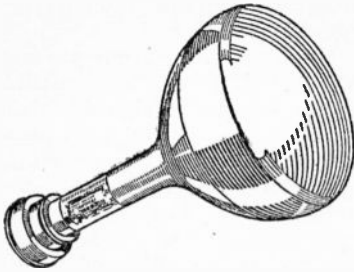
Fig. 3. A cathode-ray tube. On the flat end the television picture appears. Air is exhausted from the tube which has to be very strong to withstand atmospheric pressure. In large types the diameter may be 16 ins.

ever, has a far more difficult problem, because he has to build up his picture completely in that very short space of time, whereas the cinematograph engineer has his pictures already printed on a transparent strip of celluloid, and has merely to arrange that they come in front of the lens at the right moment.

What do we mean by building up a picture? Any reproduction, whether it be a photograph, an illustration in a paper or an image on a television screen, is composed of a series of very small dots.

Where there is a large amount of light in the subject, the dots are very small or practically non-existent, while in the deepest shadow the dots are full-size and very black. The illustration in Fig. 2 shows this process.

Even the eye operates in the same way, because the retina is made up of a large number of very tiny dot-like cells.

We can build up an image, therefore, by using a sufficient number of small elements of different degrees of blackness arranged in the right order. We call these "picture points".

Now, obviously, if we have a scene containing a large amount of detail, such as a procession or a football match, it will be necessary to divide the image up into a very large number of these picture points or detail will be lost.

Face Detail

To take an obvious example : If a scene contains a crowd of people and each man's head occupies one five-hundredth of the total area, then, if we only had 500 picture points, it would be quite impossible to show any detail on the individual faces. The best we could do would be to have a very light picture element where there was a face, and dark ones where there were no faces. Viewed from a considerable distance, this might give the impression of men's faces, but if one come closer to the image and found that the detail did not get better, one would be dissatisfied.

Every one of those faces would in itself require to be composed of perhaps 1,000 picture points, mean-
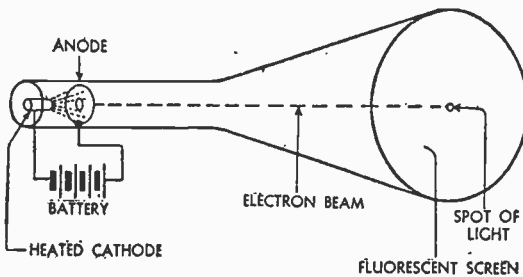
Fig. 4. The main elements of a CR tube are an electron-emitting cathode, an anode and the fluorescent material forming the screen. Where the electrons hit the screen a spot of light appears.

ing that the whole scene would need to be made up of half a million elements.

Now, practical experience shows that it is not necessary to go higher than about 200,000 picture points in a scene. If the eye is to view the scene as a whole, it cannot appreciate any better detail than this.

Fig. 5. To focus the electrons in a narrow beam and accelerate them, the anode is developed into an assembly of electrodes called an "electron gun".

But even this number is quite large enough, for our method of operation is to assemble these picture points in rows or lines arranged one above the other, and the time available for the reproduction of each individual element is one five-millionth of a second!

It is not surprising that television made very little headway until the cathode-ray tube was brought to a reasonable state of efficiency.

This device (Fig. 3), the big brother of the valve, is a truly remarkable piece of equipment. It consists of a heated cathode coated with certain oxides which have the property of giving off electrical particles or "electrons" in great profusion when the cathode is heated to a dull red. In front of the cathode (Fig. 4) we place an anode with a small hole in the centre, and to this anode we apply a fairly high voltage. This voltage attracts the

electrons emitted by the cathode, and, because of the high voltage, it actually draws them across the intervening space at high speed.
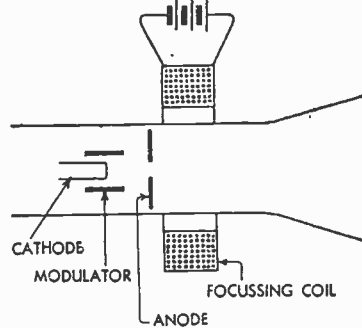
Fig. 6. An alternative method of focussing is to use a magnetic field set up by a coil placed round the neck of the tube.

Those electrons which hit the anode return through the external circuit back to the cathode, but those in the centre shoot straight through the hole and continue in a straight line, at a high velocity.

We mount this structure inside a long glass tube, and some inches farther on we place a screen coated with certain chemicals. For convenience this screen is usually made the end of the tube itself, which is coated on the inside with a fine crystalline powder.

When the electrons reach this
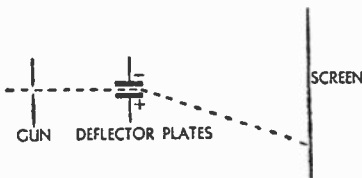
Fig. 7. The electro-static field between plates carrying a potential serves to deflect the electron stream.

modulator. This is an instantaneous process, so that we have a source of light of which we can vary the intensity at incredibly rapid rates—far more quickly than we need for our particular purpose.

But this electron beam has further advantages. We can cause it to move easily. If we place a pair of plates on either side of the beam and make one plate positive and the other negative, the positive plate will attract the electrons, and the negative plate will repel them. Consequently, the beam, instead of travelling straight down the centre of the tube, will deflect to one side (Fig. 7), and the spot will not appear in the same place on the screen.

Here again, by the mere application of electrical voltages on the deflector plates we have been able to move the spot from one
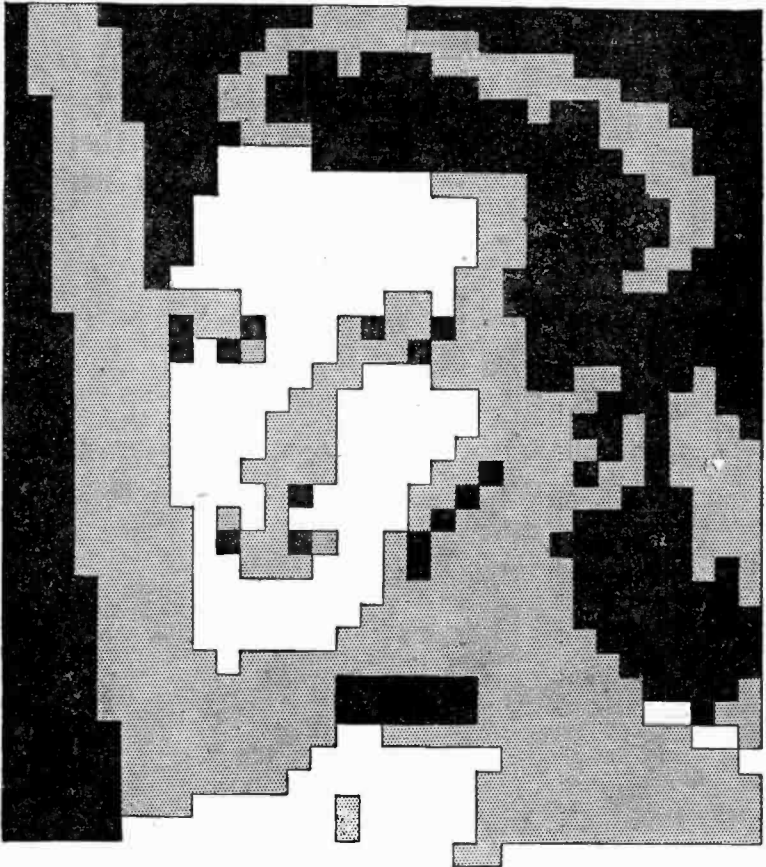
Fig. 12. An extreme example of how a picture can be assembled from separate elements—in this case an eighth of an inch square. Viewed at a distance of 6 ft., the picture appears to have some detail and appreciable depth. In a television picture the elements may be a fiftieth of an inch or less square and in all degrees of brilliance instead of only three gradations as in this illustration.

point to another instantaneously. Actually this process is not quite as instantaneous as the other, but it is still practically instantaneous for our purposes.

Placing the Spot

If we use a similar pair of plates at right angles to the first pair, we can cause the spot to move in a vertical direction, and, by placing the appropriate voltage on both pairs of plates, we can make the spot take up any position we like on the screen (Fig. 8).

It is possible to produce this deflection magnetically by arranging coils on either side of the tube, as shown in Fig. 9. The direction of deflection in this instance is at right angles to the magnetic field, so that if we want to move the spot vertically, we place the coils on a horizontal axis, and vice versa. In practice, to get the coils as close to the beam as possible, they are usually shaped to fit closely round the neck of the tube (Fig. 10).

With this mechanism we are now able to build up a picture, and the process we use is known a "scanning". Suppose we start the spot at the top left-hand corner of the screen and we cause it to move
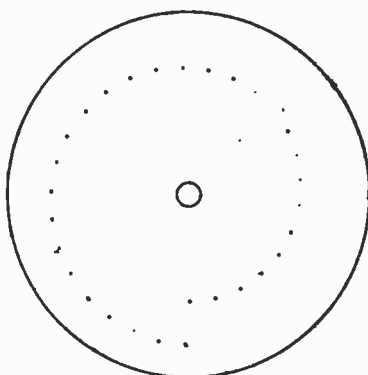
Fig. 13a. The principle of scanning was first utilised in the scanning disc used for low-definition (30-line) television. The disc contains 30 holes arranged in spiral formation.

across the screen in a horizontal line until it comes to the other side. Let us now move it back again very quickly to the starting point, and cause it to move across the screen again in a second line slightly below the first.

We can do this by arranging that all the time the spot is moving across the screen it is also being caused to move downwards, very slowly, so that it finishes the first line a little lower than it started. Consequently, when it flies back
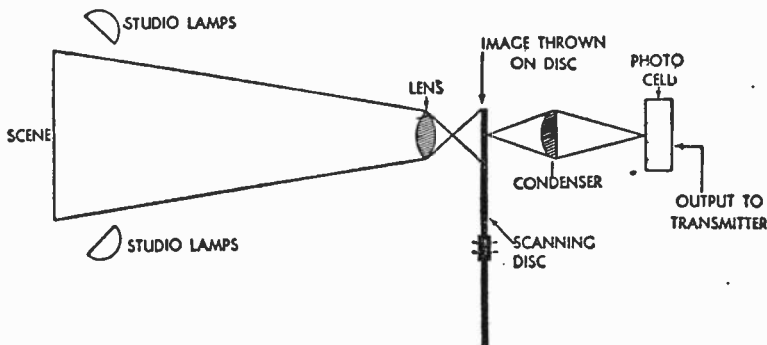
Fig. 13b. The scene is focussed on the disc and is "seen", strip by strip, by the photo cell as the holes in the rotating disc swing by.

PHOTO-SENSITIVE
CATHODE DEPOSITED
ON INSIDE OF GLASS

RING-SHAPED
ANODE

MICROAMMETER
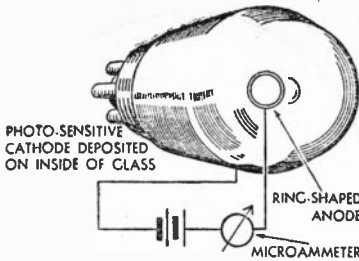
Fig. 14. Diagrammatic representation of a photo cell. Light waves striking the photo sensitive material release electrons which are gathered by the anode.

and commences the second line it does so just below the first line, and so on until we can produce a screen or raster of lines, as shown in Fig. 11.

Moreover, if we do this whole process in one twenty-fifth of a second, and then send the spot back to the starting point and go over the whole ground again, the eye will not be able to follow the movement of the spot, but will see the whole image as a complete

picture. In other words, the eye will just see a series of lines of light on the screen, and if we make these lines sufficiently large in number and sufficiently close together, the effect obtained will be of a rectangular patch of light, even though it has really been traced out by only one tiny spot.

Reading of it, one may find it difficult to imagine how a minute spot of light, simply by rapid movement over the area, can appear to create a large luminous rectangle. The persistence of vision characteristic of the eye, already explained, is what produces the illusion. The effect is the same as that which we have all noticed at some time when a match or cigarette end, moving suddenly in the dark, has appeared as a red streak.

Actually, the fluorescent material of the screen glows for a fraction of a second after the impact of the electrons has ceased and
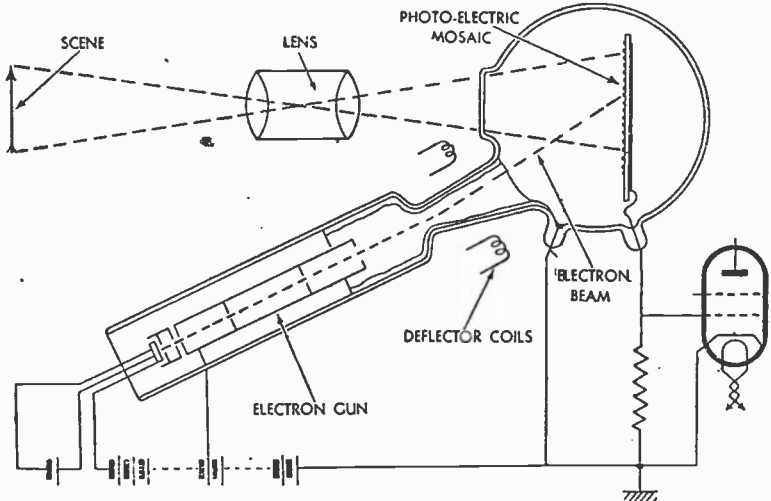
Fig. 15a. Elements of an electron camera. The scene produces electric charges on the photo-cell mosaic, and the strength of light at each point determines the amount of charge. When scanned by the electron beam, the mosaic discharges, producing voltages across the amplifier valve.

this aids the illusion. It will be realised that to produce a large bright area, the tiny spot of light must itself be extremely brilliant.

Remembering now that we said that the intensity of the spot could be varied as required, it will be clear that if, while the spot is travelling along the line, we can cause it to change its brightness, we have all the mechanism for building up a picture. By causing the spot to brighten in certain parts, to become dimmer in others, and perhaps go out altogether at other places, we can get a succession of picture points of light and shade, which, when the picture has been completely finished, gives us an image of whatever we wish.

Detail and Distance

The process is illustrated very crudely in Fig. 12, where, for the artist's benefit we have restricted the number of picture points very severely. We have also used only three grades of intensity, black, half white and white, whereas in the television picture we have a complete range.

Viewed closely, this image does not appear anything spectacular, but if you will regard it at a distance of 6 feet you will find that it
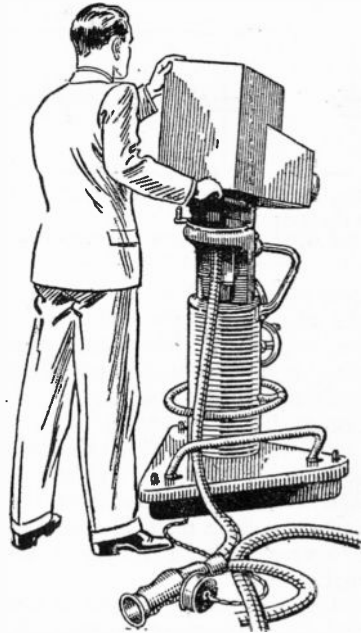
Fig. 15b. An electron camera as used by the BBC for pick-ups.

gives you a simple imitation of the subject.

On a cathode-ray tube we use something like 400 lines, and each one of these lines is divided up into about 500 picture points—in other words, the spot changes its intensity something like 500 times as it
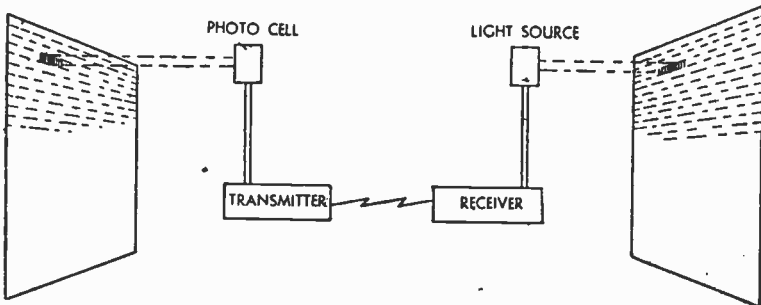
Fig. 16. Illustrating how, element by element, the receiver recreates the transmitted scene provided the elements are correctly located. To ensure this, transmitter and receiver scanning must be synchronised.
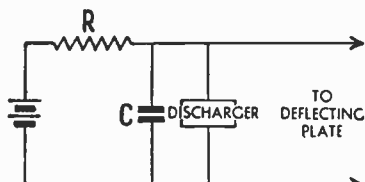
Fig. 17. The essence of a time base is a charging condenser with a discharger that comes into operation when a certain voltage is reached.

goes along each line. This gives us the 200,000 picture points which we originally decided were necessary, and in practice an image built up in this manner gives a remarkably fine picture.

The tiny size to which this light spot must be focussed will be realised when it is appreciated that some 400 lines must be traced on a screen only, perhaps, a few inches deep.

Our next query is how to control the brilliance of the spot. We shall discuss later the circuits used for causing it to move sideways and vertically in the particular manner necessary to build up the framework.

Applying Modulation

The modulation of its intensity is accomplished by applying voltages to the modulator of the tube, and these are the voltages we pick up from the transmitter.

Actually if one applies the ordinary signals from a radio set to the modulator of a cathode-ray

tube it will cause the spot to modulate its intensity, and will result in a bewildering variety of meaningless patterns.

If we are to produce a picture, we must have some similar scanning arrangement at the transmitter which will split up the scene into picture points in a suitable order and number. In the early days a "scanning" disc was used, and in much-improved forms it is still used sometimes for transmitting films. It consists essentially of a rotating disc containing a spiral series of holes arranged as in Figs. 13a and b. At present, however, the scanning arrangement used for all studio and outdoor television is the "electron camera".
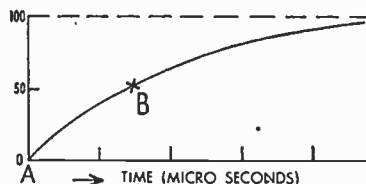
Fig. 18. The discharge point, B, has to be located so that the straightest part of the charging curve, A–B, is utilised.

The electron camera, or Iconoscope, is an arrangement somewhat like the cathode-ray tube, in that it contains a beam of electrons which are focussed and caused to move from side to side in the same way as the receiving tube. Instead of the fluorescent screen, however, we have a photo-electric mosaic.

This is made in the form of a plate containing on its surface hundreds of thousands of very tiny globules of photo-electric material. This is a chemical which gives off electrons in pro-

Fig. 19. The saw-tooth waveform of the output of a lime base is represented by this graph.

portion to the amount of light which falls on it.

Fig. 14 illustrates a photo-electric cell which consists of a surface coated with this photo-electric material and an anode in the centre on which we place a positive potential. If we shine a light on the cell, the photo-electric material gives off electrons which are attracted to the anode and produce a current in an external circuit. This current is proportional to the amount of light flowing, and devices like this are used for many purposes (Chapter 15).

In the electron camera (Fig. 15) each individual tiny photo cell in the mosaic is activated by the amount of light which falls on it. But since there is nowhere for the electrons to go, they accumulate as a charge on the cell. Consequently, if we focus an image on to the whole mosaic, each of the tiny photo cells acquires a charge proportional to the amount of illumination at that point.

We now scan this plate with an electron beam which moves from side to side in a series of lines, just as it does in the receiving tube. When the beam reaches each individual photo-cell in turn, it discharges it and causes a current to flow through the external circuit. This current will obviously be proportional to the charge at that point, so that the current which flows varies continually, and is at any instant proportional to the light-value at that part of

FRAME TIME BASE WITH WAVE FORM LIKE Ⓐ
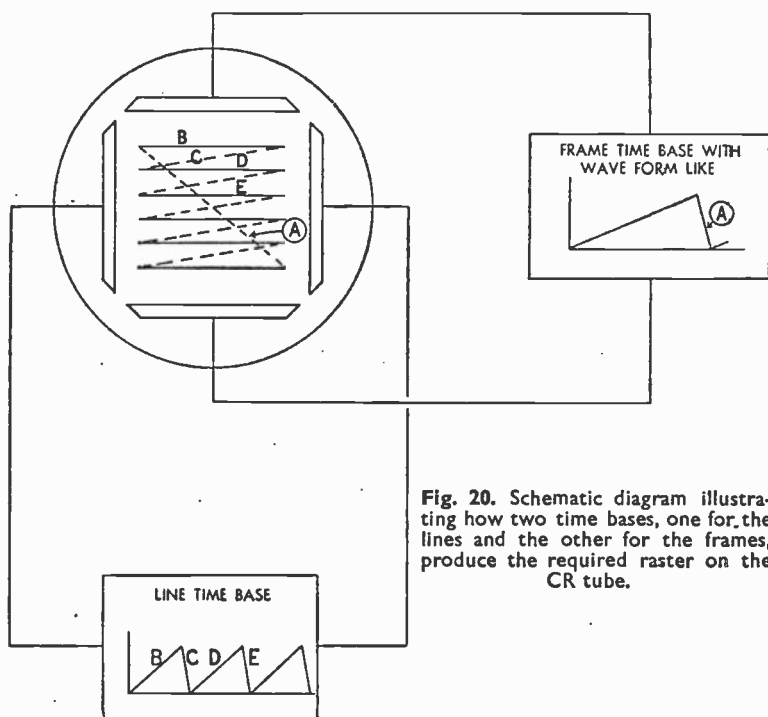
LINE TIME BASE

Fig. 20. Schematic diagram illustrating how two time bases, one for the lines and the other for the frames, produce the required raster on the CR tube.

the picture on which the beam is resting at the time.

All we have to do to reproduce the image on a cathode-ray receiving tube, therefore, is to produce a voltage which is proportional to this current generated by the electron camera. When the image is bright we shall have a large voltage on the modulator of the receiving tube which will cause the beam to glow brightly. At points where there is no illumination there will be no current, and the intensity of the spot on the receiving tube will be cut off.

Obviously, we can connect the transmitter and the receiver directly by a wire or through a radio link, in the same way as we transmit speech and music by radio (Fig. 16), the only essential requirements being that the scanning beam and the transmitter and the receiver shall move absolutely in step.

Synchronisation

This requirement is clearly of primary importance, because obviously if the beam at the transmitter scanned the image quicker than that at the receiver, the picture points would appear in the wrong sequence. At the end of the first line we should get into difficulties, because the transmitter would have flashed back and commenced to scan the second line of the picture while the receiver was still operating at the end of the first line.

This lack of agreement would become steadily worse and, remembering that the whole operation is completed in about one twenty-fifth of a second, and is then repeated over and over again, it will be clear that the successive images built up would not correspond at all, and we should simply get a meaningless jumble.

If, however, we can arrange that strict synchronism be maintained, then not only will the receiver build up a faithful reproduction of the image at the transmitter, but it will continue to do so over and over again, so that we are left with the impression of a continuous and steady image, in much the same way as in the cinema.

Time Base

To understand how this synchronism is arranged we must first consider the manner in which the spot is caused to deflect across the screen. This is accomplished by a device known as a time base, which in its simplest form is shown in Fig. 17.

Here we have a condenser which is charged through a high resistance. Now, if we connect the battery to a condenser through a resistance, the condenser does not immediately charge up to the full voltage of the battery.

It takes a little time to do so, and the higher the resistance the longer will be the time taken. Similarly, with a given value of resistance, the larger the condenser the longer will be the time taken. Consequently, the voltage across the condenser, which is proportional to the amount of charge on it at any instant, will gradually build up to its full value. Fig. 18 shows the particular manner in which a condenser charges, and it will be seen that the rise in voltage is fairly steady at first, then afterwards trails off.

Now, it is this first part of the charging cycle that we are interested in, for obviously over the portion *AB* the voltage on the condenser is increasing at a more

or less steady rate, and moreover we can alter this rate by changing either the value of the capacity or the resistance. If the terminals of this condenser were connected to the deflector plates of a cathode-ray tube, the beam would be deflected from one side to the other at a rate depending on the charging rate of the condenser.

Saw-Tooth Wave

Moreover, if we had some arrangement which would discharge the condenser when it reached the voltage corresponding to the point B, the operation would recommence, and we should obtain a series of relatively slow and steady charging, followed by a rapid discharge giving us the effect illustrated in Fig. 19. This is called a saw-tooth wave, for obvious reasons, and it will be clear that it gives us exactly what we need for scanning.

The relatively slow charge of the condenser first generates a voltage which moves the spot from one side of the screen to the other, while on the rapid discharge it flies back to the starting point and proceeds to traverse the same route again.

As we have seen, in producing a television scan we also arrange that a similar voltage is supplied to the vertical deflector plates, but operated at a much slower rate, so that the successive lines produced by the travel of the spot are spaced slightly from one another.

The time taken by the vertical travel is equal to the time which we allot to the picture—e.g., one twenty-fifth of a second, while the time taken for the horizontal traverse must be shorter than this by the number of lines we require. If we want 200 lines, then the time of travel from one side of the screen to the other would have to be one five-thousandth of a second (Fig. 20).

The question is, of course, how we are going to discharge the condenser when required at the end of each line and "frame". Fortunately there are circuits which will do this. One of the simplest and easiest to explain is the gas-relay, which is a triode valve containing a small amount of gas, such as neon, argon or helium.

Suppose we imagine an ordinary valve with a fairly large negative voltage on the grid and no voltage on the anode. Obviously there will be no anode current. As we increase the anode voltage there will still be no anode current, because the electrons emitted by the cathode are being held in check by the negative voltage on the grid, and not until the anode voltage reaches some value fairly large relative to the grid voltage will its effect be sufficient to overcome this throttling action by the grid.

Valve Control Ratio

The point at which anode current begins to flow is dependent on the "control ratio" of the valve, which is a factor somewhat similar to the amplification factor, being dependent on the closeness of the grid wires and the relative distances between the various electrodes. It is usually something between 10 and 20 times, so that if we have 5 v. negative on the grid, we shall not obtain any anode current until the anode voltage reaches something in the neighbourhood of 100.

Now, with an ordinary valve, if we reach this point, a little current will flow; and if we increase the

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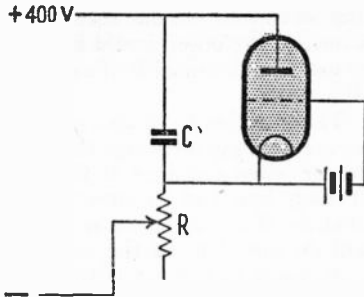
Fig. 21a. The special properties of a gas-relay valve, or thyratron, enable it to be used as a time-base discharge device. The voltage at which the discharge occurs is controlled by the grid bias.

anode voltage, more current will flow, while if we decrease it below the critical value again, the current will stop. If there is any gas in the valve, however, the electrons moving in the space between cathode and anode encounter some molecules of gas and "ionise" them.

These heavy positive ions drift back towards the negatively charged control grid, and tend to nullify its effect, so that still more electrons are released. These in their turn produce more ions, with the result that in a very short space of time a very large current is flowing.

Moreover, this current continues to flow as long as there is any voltage on the anode, and we can reduce the voltage practically to zero without stopping the current. Once the current has started to flow, therefore, it builds up immediately to a large value, which cannot be stopped until the voltage is removed from the anode.

Figs. 21a and b illustrate such a valve connected across the condenser of the time-base circuit of Fig. 16. It will be seen that we have here all the requirements necessary.

We start with a small negative voltage on the grid, and this holds the valve in a non-conducting condition. As the condenser charges, the voltage on the anode rises, until ultimately a point is reached at which it overcomes the effect of the grid, and current commences to flow.

At this point, as we have just
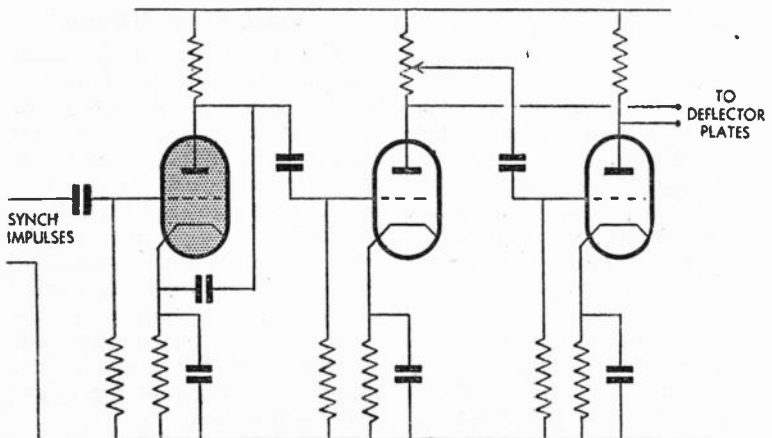
Fig. 21b. A complete thyratron time base showing the saw-tooth generator followed by two amplifier stages as described in the text.

seen, the current rapidly builds up to a very high value, and this discharges the condenser. As the condenser discharges, the voltage falls, and consequently so does the voltage on the anode of the valve. We have seen that this has practically no influence on the discharge current and, therefore, the condenser discharges completely (or very nearly so).

When the voltage has fallen to zero, the ions in the gas re-combine and the whole valve becomes inert once again, so that the condenser is free to charge up once more. It goes on in this manner, charging up slowly to a critical value and discharging extremely rapidly, giving us the saw-tooth wave which we need. The point at which the discharge commences is easily controlled by adjusting the value of the grid bias on the valve.

Because the arrangement is so sensitive to grid bias, it provides us with an easy method of achieving the synchronism we require. We can always arrange that, provided the voltage on the condenser is somewhere near the correct triggering value, the application of a small positive voltage to the grid causes instantaneous operation of the relay.

For example, suppose we have a valve with a control ratio of 20. If we had 3 v. on the grid, then the valve would "fire" when the anode voltage reached 60. If we have 5 v.

on the grid, the anode voltage must rise to 100 before firing commences.

Let us suppose that we are operating the valve with 5 v. on the grid, but that when the anode voltage has reached 90 we suddenly reduce the voltage on the grid from 5 to 3. The anode voltage is now well above the "firing" point for 3 v. bias, so that the valve immediately fires and the condenser discharges.

Synchronising Impulses

Now, at the transmitter we arrange that when the scanning spot comes to the end of each line, a synchronising impulse is produced. This synchronising impulse is in the form of a sharp increase in voltage. At the receiver we apply the corresponding voltage to the grid of the time-base valve so that it produces the triggering action just described.

Actually, the synchronising impulses are generated independently of the scanning in a separate unit, and they are applied to the time-bases which operate the transmitter, and they are also mixed with the signals which are generated by the transmitter itself, so that they are transmitted and picked up by the receiver, where they trigger the receiving time-bases at the correct instants (Fig. 22).

By this simple expedient we are able to ensure that the time-bases
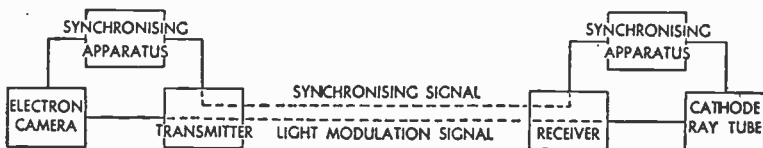
Fig. 22. Transmitter and receiver must be linked by both light-modulation and synchronising signals. Both signals are radiated on the same carrier wave.
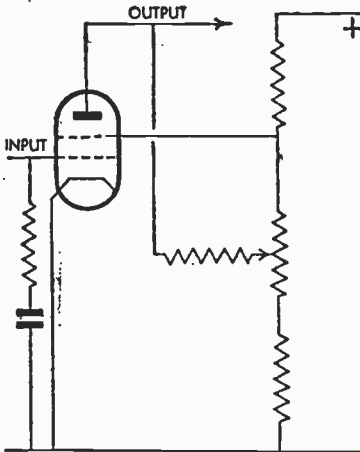
Fig. 23a. One form of limiting circuit which separates the synchronising signals from the light signals.

brilliance in the picture. Various intermediate shades of illumination produce smaller amplitudes of signal down to about 30 per cent. of the maximum, which corresponds to complete black.

"Blacker than Black"

The whole range of picture brightness is obtained within this compass from full value down to 30 per cent. For the synchronising signal, however, the strength is momentarily reduced to zero, so that we have a signal correspondng to "blacker than black".

At the receiver, conditions are arranged so that with a signal 30 per cent. of the maximum the cathode-ray tube is just blacked out. The synchronising impulse, therefore, cannot make it any blacker, and consequently there is no apparent influence on the picture. Because of the selecting circuit just mentioned, the time-base can make use of this synchronising pulse to keep in step.

There are many other types of

at both transmitter and receiver are maintained strictly in step, the only requirement being that they must be arranged to run at approximately the right speed beforehand. It will be seen that this does not involve any extra channel, because the synchronising signal is mixed with the modulation or vision signal. All that is necessary is that some discriminator circuit shall be adopted to separate the synchronising signal from the normal modulation.

To facilitate this, the synchronising signal is made stronger than the strongest signal normally radiated, and we then pass it through a special form of limiting valve (Fig. 23), which takes no notice of the ordinary vision signals, but responds immediately to the large synchronising pulse.

So that the synchronising signal shall not interfere with the picture, it is usually made "blacker than black". Fig. 24 shows the form of a television signal. The maximum strength of signal is with full

Fig. 23b. Synchronising separation is also obtainable by a diode which conducts only when the anode becomes more positive than the cathode.
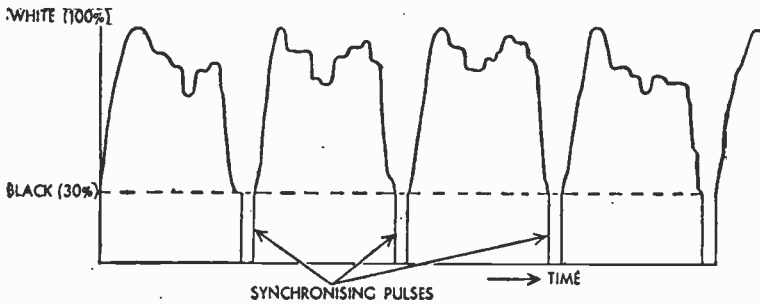
Fig. 24. Typical waveform of a television signal. The synchronising pulses are the "blacker than black" portions where the signal drops below 30 per cent.

time-base. The gas relay described has one disadvantage—namely, that it tends to be a little erratic. Its operation depends on atmospheric conditions, on the number of hours that it has been in use and various other factors. Circuits which have an equivalent operation (*see* Fig. 25) have been devised using valves of the ordinary high-vacuum type, which are more reliable in their operation. The principle, however, remains the same, and the differences are only in detail.

A point which is worth mentioning is that of the brightness level of the picture. We have seen that the range of light and shade is all contained within the limits of maximum signal down to 30 per cent. of the maximum.

At the receiver we must arrange that at 30 per cent. signal we have blacked out, and at full signal we have the tube giving the maximum brightness which it can stand without de-focussing. If we have too much current in the beam the sharp focus of the spot deteriorates, and we get a blurred image.

We have two things to do at the receiver to comply with this. The first is to adjust the strength of the
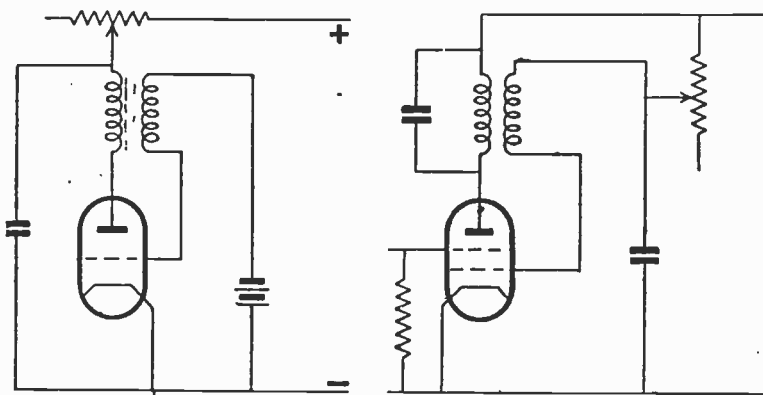
Fig. 25. Illustrating two other forms of saw-tooth generators. The type shown on the right, is known as a "squigger" circuit.

modulation signal which is received from the transmitter so that its range of values just fits into the required scale, and the second is to see that the average value of the voltage on the modulator electrode of the receiving tube is correct.
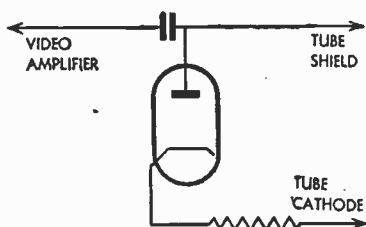
Fig. 26. The DC restorer preserves a correct average value of lighting for the image as a whole, so that bright and dull scenes are not "levelled out" by the amplification of the receiver.

If this voltage is too little, then the image will be, as a whole, too bright, and the blacks will not appear fully black, while the whites will be over-bright and distorted. If, on the other hand, the steady bias is too much, then we shall reach black level before the right moment, and we shall only see the high lights of the picture, while all the detail in the shadows will be lost.

This adjustment is partly effected by hand operation when the picture is first tuned in, but, in addition to this, special circuits are incorporated which generate a steady voltage proportional to the average brightness of the picture, and these automatically preserve the correct relationship between transmitter and receiver. It is not possible to discuss these circuits in detail, but their necessity will be obvious if we consider a simple black out.

Suppose the producer at the transmitter wishes to black out his scene. He simply cuts off his light, and the scene goes dark. At the receiving end, however, the circuits will tend to restore themselves to the mean or average value. And after a momentary black out the picture will brighten up and give us the effect of a light grey—half-way between black and white. The presence of the "DC restoring" circuit (Fig. 26) avoids this, and makes sure that as long as black signals are being transmitted, then the receiving tube correctly gives black indication.

It remains to consider the mechanism by which we transmit the vision signal. This is done by modulating a radio-frequency carrier in exactly the same manner as with speech and music of an ordinary radio transmission.

The principal difficulty arises from the greatly increased bandwidth required. We have seen that the time of one picture point is something like one two-millionth of a second, which means that our modulation frequency extends to something over 2 megacycles.

Carrying Modulation

Now, if we are to carry modulation on the carrier wave, it is essential that the rate at which we vary the amplitude of the carrier shall be slow compared with the rate at which the carrier oscillations change. In other words, the carrier frequency must be many times greater than the highest modulation frequency.

The normal broadcast band operates at frequencies around 1 megacycle with the highest modulation frequency about 10 kc.—a ratio of 100-1, and consequently, to preserve the same ratio, we should need a carrier frequency
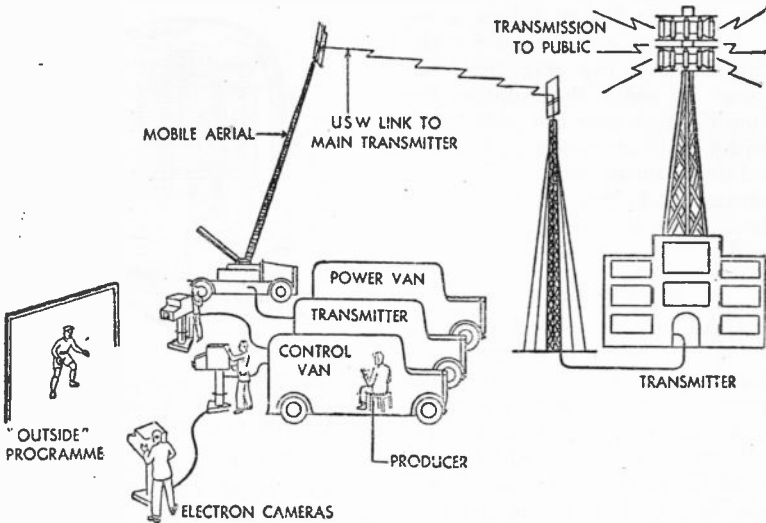
Fig. 27a. An outside broadcast, or OB, is frequently relayed to the main transmitter by a mobile unit operating on an ultra-short wavelength.

for television of something above 200 megacycles.

Fortunately, we find that it is not necessary to go quite as high as this, and the frequencies customarily used are around 40 to 60 mc. corresponding to wavelengths between 5 and 7 m.

This, of course, is within the ultra short wave band, so that we are at once confronted with the limitations of this type of transmission—the strictly limited range being the major disadvantage, as discussed in the chapter on Short Waves.

At first this seems a disadvantage, but it does not necessarily follow that it is an insuperable one. It is possible to transmit the very high frequency modulation signals over special types of cable known as coaxial cable, and this leads to the idea of a chain of stations located in the principal cities of the country, fed with transmissions from a central point.

Moreover, it is possible to have special cables led from the central studio to various points of vantage, such as football grounds and other places of interest, and for mobile work to have special short wave links operating on a few metres only, which link up the scene to be televised with the central transmitter (Figs. 27a and b).

Ultra-Short Waves

For the television receivers, ordinary ultra-short wave technique is adopted. Owing to the high frequencies involved, special valves having very small clearances between electrodes are used (Fig. 28), and the circuits employed have to be designed to accommodate a relatively much larger band-width than with ordinary broadcasting technique.

These, however, are points of circuit design which are capable of solution, and have been very successfully solved. At the moment

a larger number of valves is required than is the case for the equivalent sound reception, because in order to maintain the amplification over the wide bandwidth it is necessary to use low values of anode resistances, which means that the stage gain is limited to something between 5 and 10 with normal practice.

Improved Types

Gradually, improved types of valve are being developed, and these will in time enable the number of stages to be cut down.

Various complete television receivers of the type which were available in Britain up to the war are illustrated in Figs. 29–31. That in Fig. 31 is a large screen type which was the only one on the market to use a mechanical system instead of a cathode-ray tube system.

Fig. 32 shows the optical arrangement of this Scophony system, and it will be seen that the cathode-ray tube is replaced by two rotating drums which deflect a

Fig. 28. One of the smaller types of valve developed for operation on the short waves employed for television.

beam of light from side to side for the "lines" and up and down for the "frame". The intensity of the light is modulated by a special crystal "gate".

One final word may be said regarding a form of scanning which was adopted by the BBC. It was desired to use 400-line images, and it was found that if these were repeated only 25 times per second the eye was conscious of a distinct flicker.

Rate of Flicker

In the cinema the light is cut off not only when the picture is changed, but also twice while the picture is actually on the screen, and this raises the flicker rate to 72 per second, which is fast enough to cause no discomfort.

To avoid the influence of flicker in television, it was found that a picture repetition rate of at least 50 pictures per second was desirable, but to repeat a 400-line picture in one fiftieth of a second demanded modula-

Fig. 27b. When the Alexandra Palace television transmitter was in operation, the BBC used the ladder of a fire escape to carry the aerial used for OB relays.
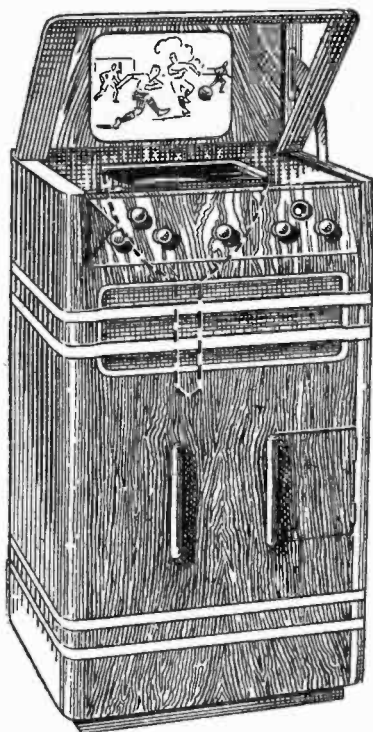
Fig. 29. With the largest tubes it is sometimes more convenient to mount them vertically and view the picture through a mirror in the lid.

Fig. 30. With the smaller tubes a complete receiver, covering ordinary sound broadcasts as well, can be arranged in a table type cabinet.
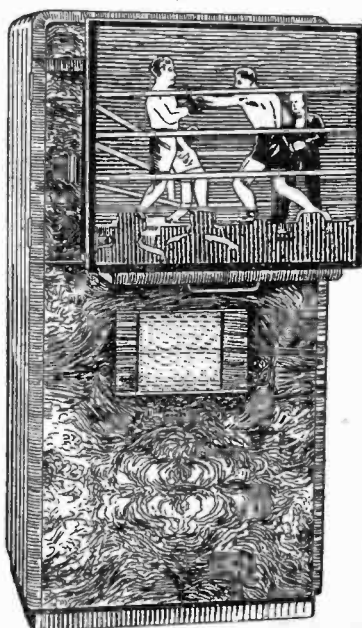
Fig. 31. A large-screen receiver suitable for large rooms and small public gatherings. This model used the Scophony mechanical mirror system.

tion frequencies as high as 5 megacycles.

Interlacing System

As a compromise the interlacing system was devised in which half the number of lines was transmitted in one fiftieth of a second. The next image, however, was arranged not to fall exactly over the first picture, but to lie in between the previous set of lines.

The point is illustrated in Fig. 33 on a small scale, where the full lines A–B, C–D, etc., represent the first scan. It will be seen that

Fig. 32. The Scophony receiver employs a special device to modulate the light from a powerful source, and scanning is obtained by two rotating mirror drums.

the bottom line finishes in the middle of its scan, and the spot then flies to the top of the picture and commences on the dotted lines *K–L*, *M–N*. When the spot reaches the point *T* it flies back to point *A* and re-commences the process. It thus covers the screen in two successive travels interlacing with one another.
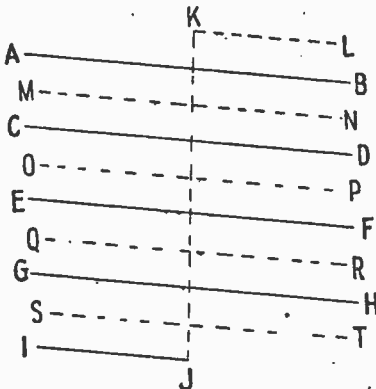
Fig. 33. To obtain simple interlacing it is necessary for the raster to consist of an odd number of lines with the frame fly-back occurring between the points J and K as shown.

Such an arrangement can very easily be obtained by using an odd number of lines, and the BBC transmission used 405 lines, 202½ on each scan.

Preventing Flicker

In this way we have 405 lines repeated in one twenty-fifth of a second, but because of the division into two successive half scans occupying half the time, the flicker rate was equivalent to 50 per second, and in actual practice the effect was very satisfactory.

The transmissions at present taking place in America also use this interlacing, and it appears likely to be generally adopted as a device to increase the flicker rate without making too severe a demand on the band-width to be transmitted.

Television had definitely proved its entertainment value when the B.B.C. service had to be suspended in 1939. There can be no doubt that technical advances now being made will result in almost perfect pictures in the future.

INTERFERENCE
SUPPRESSION

CAUSES OF INTERFERENCE. IMPORTANCE OF SUPPRESSION. SIGNAL-INTER-
FERENCE RATIO. HOW INTERFERENCE IS GENERATED. WIDE WAVE-RANGE.
METHODS OF PROPAGATION. TRACING THE SOURCE. CHARACTERISTIC
NOISES. IDENTIFYING THE CHANNEL. METHODS OF SUPPRESSION. CON-
DENSERS AND CHOKES. SUITABLE SUPPRESSOR CIRCUITS. SUPPRESSION AT
THE RECEIVER. FILTERS. ANTI-STATIC AERIALS. HETERODYNE INTERFERENCE.

INTERFERENCE is the name given to those crackles, bangs, whirr-ings and whistles which mar radio reception and which are due to causes outside the receiver itself. Noises almost indistinguishable from interference may be caused by loose connections in a set or by faulty adjustment, but, beyond the fact that the engineer must know how to identify them for what they are, they have nothing to do with the subject of this Chapter.

Forms of Interference

The specialist in interference suppression does not include in his province even those forms of interference caused by overlapping of transmissions or interaction be-tween receivers. As this chapter, however, is intended for the general radio technician rather than the specialist, these hetero-dyne forms of interference are dealt with on page 261.

Interference always enters a set electrically, and in many cases it arrives in the form of radio waves, similar to ordinary programme transmissions.

Some interference is generated wherever electrical disturbances take place. Everyone has evidence of this—the "sputter" heard in sets when there is lightning.

Various electric discharges take place in the air, particularly at high altitudes, without lightning being visible. The crackles these cause are called atmospherics. In the early days of radio, atmo-spherics were thought to be due to electrostatic discharges in the aerial, and were given the name "static".

Natural electrical disturbances, in these latitudes at least, cause little interference—which is for-tunate, since little can be done to suppress them.

Round our receivers, however, are electrical machines and appli-ances, most of them setting up electrical disturbances and pour-ing interference, as a kind of by-product, into the ether. This "man-made static" is the sphere of interference suppression.

These two facts—that inter-ference is a radio wave and is generated by electrical machinery —enable us to appreciate the vital importance of suppression.

The first means that required

transmissions cannot be separated from interference waves. Both must be received together. For the stations to be worth listening to, they must be strong with respect to the interference, so that they are loud in the speaker while the static is negligible. The "signal-interference" ratio, must be high.

This ratio determines what can be heard. Increasing the amplification of a set will not lift a transmission out of the "mush", but only bring in more interference.

This is not the worst of the story. We are constantly extending the use of electrical apparatus in houses, shops, factories and streets and thereby reducing the signal-interference ratio.

It is no exaggeration to say that both the further development of receivers and the extension of radio's service to the public depend on a parallel development of interference suppression. The ether must be made "clean"—and made ever cleaner as the performance of receivers improves.

Suppression technique is now well advanced. Seldom need interference remain at such a level that reception is impossible. In most cases suppression can be carried out at a reasonable cost—possibly a few shillings, a few pounds at the most. Suppression is not always a simple matter, however, and a good deal depends on the skill of the engineer.

Special Preventive Methods

Complexity arises because, in the first place, interference can be generated in numerous ways, each needing its own suppression methods and, secondly, because it can enter a receiver in various ways each, again, requiring special preventive methods.

Suppression at the source is best, but cannot always be applied, since the owner of the apparatus is not necessarily the suffering listener. In any event, suppression at the source is never 100 per cent. effective. We have to use also, therefore, methods of suppression at the receiver.

Before he can take any practical steps, the engineer must know: (1) how to locate the source of interference; and (2) how to identify the channels by which it enters the receiver. This means he must
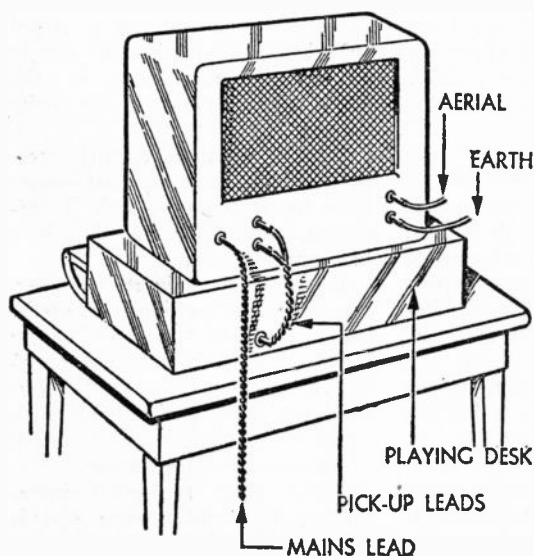
Fig. 1. The hum which may occur when unscreened pick-up wires run near the mains lead is an example of a simple form of interference.

have a reasonable knowledge of how interference is generated and how it travels from source to set.

Interference may be set up whenever a current changes in strength. A current is surrounded by magnetic and electrostatic fields, and these change in strength with any alteration of the current. Any conductor in a changing field has currents induced in it (see Chapter 17).

This explains one form of interference—that caused by "direct induction".

An AC mains wire will induce hum in a receiver if placed within an inch or two of, say, the grid lead to the first LF valve (Fig. 1).

High Voltage Cables

With cables carrying high voltages and large currents, such as used in the Grid system, the effects can be experienced up to distances of several yards, particularly when the cables are parallel to the aerial. The aerial may have a current induced in it by the magnetic field (Fig. 2), and there can also be a current in the lead-in due to the electrostatic field (Fig. 3).

By far the greater part of interference, however, is of the radiofrequency type. This is also due to changes in current flow, but is set up when these changes produce high-frequency oscillating currents in the distributed inductance and capacity (Fig. 4) of the machine or appliance. The properties of inductance and capacity and how oscillatory currents are produced in them are explained in Chapter 17.

These oscillatory currents, unable to flow through the machine because of the circuit interruption,
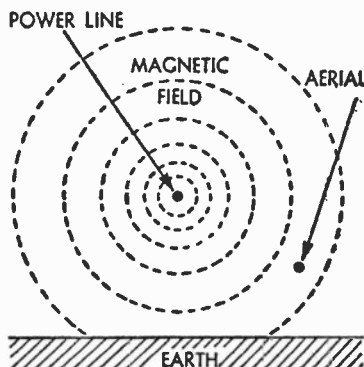
Fig. 2. Electromagnetic field.
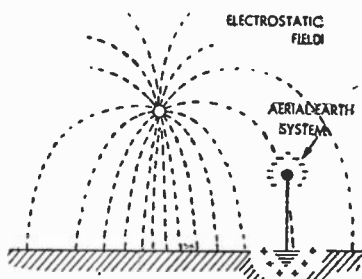
Fig. 3. Electrostatic field.

Both electromagnetic and electrostatic fields may induce interference currents in an aerial. The magnetic field has little effect unless the aerial is parallel to the power line. The electrostatic field sets up an alternating current in the lead-down since polarity of the aerial changes with every change of polarity of the power line.

flow back into the mains in an endeavour to find alternative routes (Fig. 5). Being of high-frequency they are able to discharge into the capacity between the mains wires and between the mains and earth.

When the interference currents are equal and opposite in the two mains wires they balance out as far as earth is concerned, and are called "symmetrical". If, however, one main carries more interference current than the other, the two

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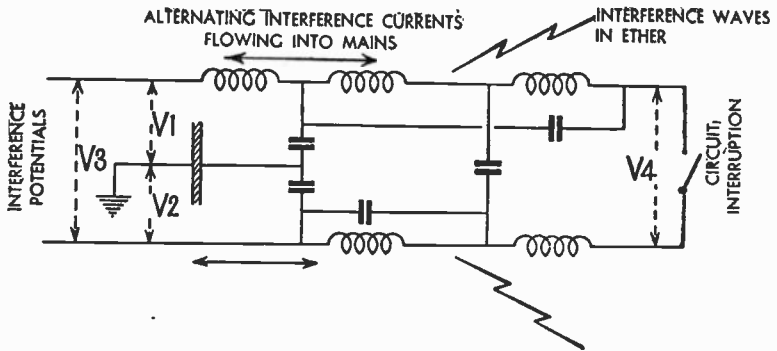
Fig. 4. Theoretical diagram representing a few of the innumerable inductances and capacities into which an interference-generating device may be analysed. Symmetrical interference voltages appear at V3 and V4 and voltages to earth appear at VI and V2.

wires together have an "asymmetrical" potential with respect to earth (Fig. 6).

As the inductance and capacity of a machine are usually widely distributed, they correspond to innumerable separate capacities and inductances. A large number of oscillatory currents of different frequencies (wavelengths) are set up in these. For this reason interference generally extends over a very wide wave-range, possibly from 5 to 2,000 m.

Interference is generally produced in the form of very rapid pulses (Fig. 7). These are called "transients", and can be resolved into a large number of waves of increasing frequency and diminishing power.

The capacities between the mains and between mains and earth offer least opposition to the higher frequencies present in an interference pulse. Consequently *radiated* interference is strongest on medium and short waves, while long-wave static is mostly *conducted*.

We can now distinguish three types of interference and four ways they can pass between source and receiver.

The first two are the magnetic and electrostatic and both travel by:

(1) *Direct induction* as described above.

The third, radio-wave type, can travel by:
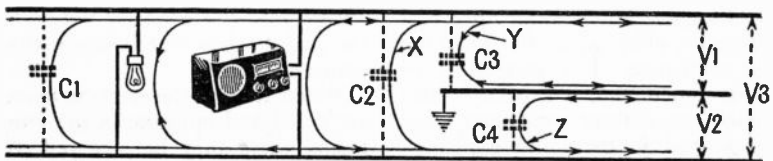
Fig. 5. Interference voltages, VI, V2 and V3 drive HF currents through appliances connected to the mains, such as nearby receivers, and into the capacities existing between the wiring and between wiring and earth. These capacities, represented by CI, C2, C3 and C4, are actually distributed throughout the whole mains system.
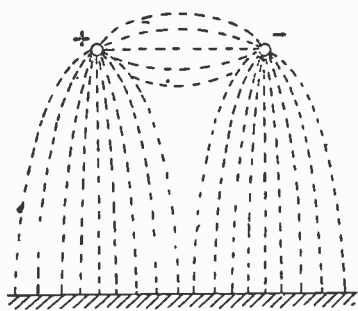
Fig. 6. When the conductors of a circuit carry equal and opposite interference currents the fields to earth cancel out. If one current is stronger than the other, however, there is a predominant asymmetrical field set up between the lines and earth.

Fig. 7. Interference pulses are generally large in amplitude but last only a few microseconds. This diagram shows the waveform as it may appear in the tuned circuit of a receiver.

(2) *Radiation* direct from the interference generator to the receiver or its aerial–earth system. Direct radiation is generally not effective at more than 10 yards from the source, but is most severe near trams, trolley buses and factories, and has been known to energise aerials up to 40 yards.

For a given power, waves of high-frequency travel further. The effect of this is that radiated interference is generally strongest below 250 m.

(3) *Conduction.* Interference currents travel along conductors, usually those forming the supply system. The characteristics of the mains quickly weaken medium- and short-wave currents, but long-waves ones may travel a mile or more.

Conducted interference may enter a receiver through its mains section.

(4) *Re-radiation.* This is a combination of (2) and (3) and accounts for 80–90 per cent. of interference. It occurs when wires conduct interference and also radiate it.

Re-radiation is a frequent cause of trouble, not because it spreads interference a long way, but because it conducts the "noise" all over the mains network and releases it in close proximity to receivers and aerials.

Power cables, telephone lines and other wires not connected to the source pick-up radiated interference, conduct it and re-radiate it. Metal objects, such as guttering, cause trouble in this way. These four ways of travel are illustrated in Fig. 8.

Characteristic Sounds

We have seen that interference is produced solely electrically. The origin does not necessarily produce a noise similar to that heard in the loudspeaker. In practice, however, most types of interference have a characteristic sound.

Interference waves, when converted into electrical currents in a receiver, are much too rapid to be audible. Each "train" of waves produces a voltage at the demodulator or detector stage, however, and a succession of them produces a series of impulses which can operate a loudspeaker and become audible as sound (Fig. 9).

The speed at which the "trains"

are emitted depends on the rate of circuit interruption in the appliance. When these interruptions are caused in some way which produces a noise—for example, the whine of a commutator and its brushes, or the click of a dial telephone—the impulses, occurring in the receiver at the same rate, produce an obvious correspondence in sound.

The following tables give a list of interference sources and their characteristic noises. Each list is arranged alphabetically for convenient reference.

CHARACTERISTIC NOISES

Whirring and Crackling

These noises are generally due to electric motors and other

apparatus in which a circuit interruption occurs continuously and rapidly.

Addressographs	Hair dryers
Air conditioning apparatus	Laundry plant
	Lifts
Bakers' and Butchers' machinery	Lighting generator plants
Beauty parlour equipment	Mixers, drink
	Motors
Cash registers	Portable tools
Calculating machines	Printing machines
	Razors
Dentists' equipment	Refrigerators
	Rotary converters
Dishwashers	Sausage machines
Drills	Sewing machines
Fans	Toy trains
Floor polishers	Vacuum cleaners
Garage equipment	Washing machines
Generators	
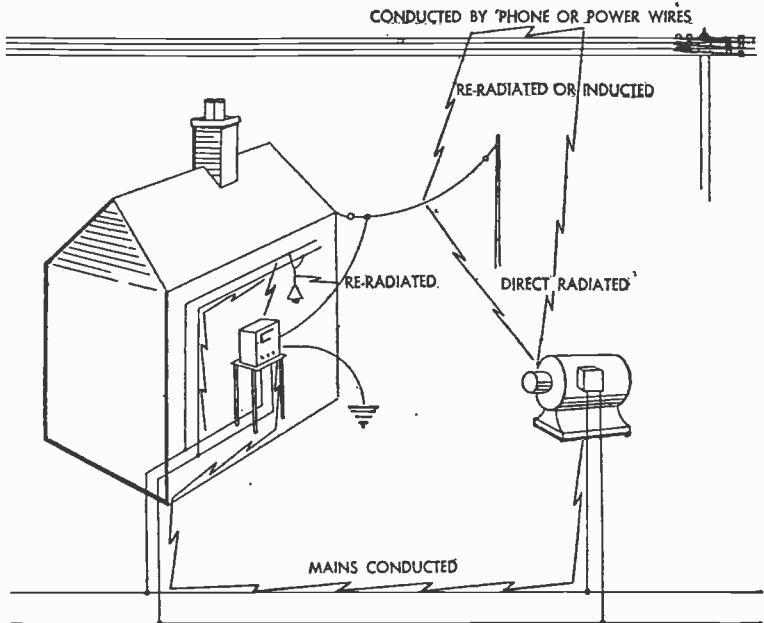
Fig. 8. Interference may reach a receiver by any of four channels, either singly or in combination. The four ways are (1) direct radiation, (2) conduction by the mains, (3) re-radiation from the mains wiring, and (4) re-radiation, from energised conductors, such as phone and power lines.

Clicking, generally due to intermittent switching.

Car ignition	Lifts
Clocks	Ovens
Dial telephones	Switches and
Electric type-	switchgear
writers	Telegraph relays
Flashing signs	Traffic signs
Incubators	

Buzzing

Air purifiers	Power lines
Arc lighting	Sewing machines
Battery chargers	Switchgear
Bells	Telephones
Buzzers	Traction systems
Car ignition	Vibratory recti-
Discharge lamps	fiers
Dust precipitators	Violet-ray equip-
Flour bleachers	ment
Mercury rectifiers	Water - heating
Neon signs	equipment
Oil burning igni-	X-ray equipment
tion systems	

Spluttering

Bad connections in	Control Gear
wires, earthing,	Lifts
plug connec-	Power lines
tions.	Traction systems

Rushing Sounds

Air purifiers	Neon signs
Dust precipitators	Power lines
Flour bleachers	Ultra-violet ray
High - frequency	equipment
apparatus, in-	X-ray apparaus
dustrial and	
medical	

The location of the source of interference is aided by recognition of characteristic sounds and also by the predominant wavelength. Frequently guidance can be obtained from the times at which noise occurs—for example, it may be found to begin soon after "clocking-on" time at a nearby factory, or it may coincide with the operation of a lift.

An interference locator can be obtained by utilising the directional properties of a frame aerial. This type of aerial picks up maximum signal when edge-on to a

INTERFERENCE CURRENTS IN AERIAL

RECTIFIED AUDIO PULSES AT DETECTOR
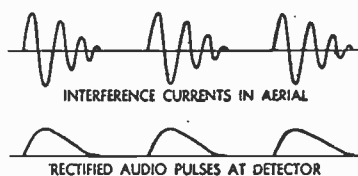
Fig. 9. The actual interference currents produced in the aerial circuits of a receiver are of high-frequency and do not get beyond the detector stage of a set. A series of them, however, produces a succession of pulses at the detector and these are slow enough to operate the loud-speaker and become audible.

radio-wave. When broadside, the pick-up is at a minimum, as the currents produced in opposite sides of the loop cancel out.

An ordinary battery portable can be used as a pointer to interference sources, but it helps if the frame is mounted on a short rod, as shown in Fig. 10, so that it can be moved with greater freedom than the whole set. A three waveband set is advisable and, as it may be operated where there is considerable external noise, headphones should be provided. It must, of course, be battery operated.

When suppression is to be applied at the receiver, there are two ways the static may be entering: (a) by pick-up on the aerial–earth system and, possibly, on the wires in the set itself, and (b) by conduction via the mains connection.

Conducted interference is most common, and there is usually associated radiation from the mains wires. Pick-up of interference on the aerial only is comparatively rare. Normally, the engineer applies suppression to the mains, and follows this up, if it does not prove adequate, by fitting an antistatic aerial system.

Fig. 10. The directional properties of a frame aerial can be used to locate interference-generating machines. An ordinary battery portable can be employed, but a separate aerial on a rod and headphones are of great assistance, particularly where, as in a factory, there may be a number of sources and considerable acoustic noise.

could be connected together by wires, there would be no HF currents fed into the mains and no radiation into the ether. The potentials would drive currents through the shorting strips, thus dissipating the energy in heat, and that would be that.

Such a simple remedy is not practicable, because the shorting strips would simultaneously short-circuit the normal operating voltages of the machine. Fortunately, however, in the condenser (Chapter 17) we have a device which will, to a large extent, short circuit high-frequency potentials while having negligible effect on currents of mains frequency and providing a complete stoppage to direct current.

Fig. 11 reproduces Fig. 4 with suppression condenser connected across points of interference potential.

By disconnecting the aerial and earth of a receiver, a rough indication of the relative amounts of conducted and radiated interference can be obtained. Occasionally it may be found that practically all the noise disappears when the aerial is disconnected. Suppression of the mains is then unnecessary, and attention can be devoted to the aerial–earth system.

If the points across which interference voltages occur in a machine

The resistance of a condenser, or "reactance" as it is called, depends on its capacity and on the frequency of the applied current. The larger the capacity of a condenser, the better it will short-circuit the interference currents; however, expense and other factors set a limit to the actual capacity that can be used. For this
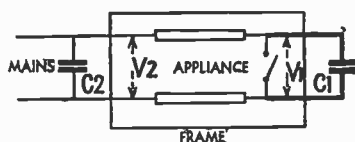
Fig. 11. As condensers conduct HF current but pass very little low-frequency AC and no DC, they can be connected as at $C1$ and $C2$ to "short-circuit" the interference voltages V1, V2.

reason condenser suppression may not be as effective on the long waves (low frequencies) as on the short waves.

Another point is this: the suppression condenser is in parallel with the interference paths. The lower the impedance (resistance) of these other paths, the larger the suppression condenser must be if a considerable proportion of the interference is to flow through it.

As the practical size of the condenser is limited, an additional way of achieving the object is sometimes necessary. Instead of trying to lower the reactance of the condenser still further, the impedance of the alternative paths is increased. This is done by inserting inductances or choke coils.

Fig. 12 illustrates how these two complementary methods of suppression may be applied. Across the main source of HF potential a "short-circuit" condenser is connected, $C1$. Assuming this is not completely effective, an interference voltage still remains across the points at V.

It will be seen,

however, that across these points are three impedances in series —two choke-coils and a further suppression condenser. The chokes present high impedances to the passage of the HF currents, but the condenser presents a low impedance. Practically all the interference voltage V will, therefore, be divided between the two chokes, and very little will appear across the condenser. It is across the condenser that the mains are connected.

Actually, the mains themselves possess inductance as well as capacity, and this further increases the effectiveness of the condenser.

Asymmetrical Currents

Suppression condensers and chokes fitted as shown in Fig. 12 would do all that is required as far as symmetrical interference is concerned. As we have seen, however, there are also asymmetrical currents between the system and earth. These can be by-passed by condensers as in Fig. 13a or b, but it is quite possible for the same condenser to deal with both symmetrical and asymmetrical components.
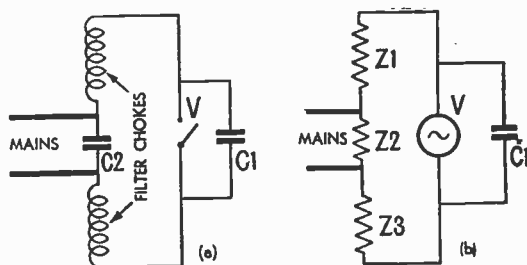
Fig. 12. Illustrating the principle of the use of HF chokes with suppression condensers. In (a) is a simplified practical arrangement and in (b) the theoretical equivalent. The interference voltage V is partly short-circuited by $C1$. The remaining voltage is applied across $Z1$, $Z2$, $Z3$ in series. $Z1$ and $Z3$ are of high value and practically all the voltage is developed across them.

Fig. 13. Two ways condensers can be connected to by-pass asymmetrical currents to ground.

This is arranged for as shown in Fig. 14. The condensers across the circuit are each replaced by two condensers in series, and the centre-point is taken to earth. A parallel single condenser for symmetrical suppression only may also be used.
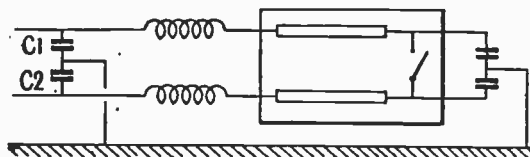
Fig. 14. Illustrating two condensers arranged in series: for example C1, C2, provide a symmetrical path between mains and at the same time offer asymmetrical paths from each main to earth.

The asymmetrical interference voltage appears between the appliance itself and its frame or housing (Fig. 15). Normally, the frame is earthed, and hence the asymmetrical voltage appears between mains and earth.

. If the frame was disconnected from earth, this would have the same effect as connecting a small capacity between the machine and earth. This small capacity would have a high reactance and would have the beneficial

effect of reducing the asymmetrical interference current.

For reasons of safety, however, the frame should be earthed, particularly with large machines. In the case of small appliances, an earth connection can be retained and the asymmetrical current limited by the use of a choke (Fig. 15).

With large machines this method is not generally favoured, since a break in or burn-out of the choke might leave the frame at a dangerous potential.

When the frame is not earthed (for example, with a domestic appliance), the return side of an asymmetrical suppressor from the mains should be connected to the frame, and not to earth (Fig. 16). With this arrangement anyone touching the appliance will be in series with the condenser between earth and the mains and to prevent the flow of a current sufficient to give a shock, a condenser in this
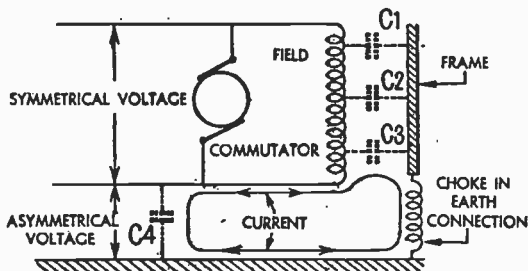
Fig. 15. Asymmetrical interference current flows first through the capacity between the machine and its frame (C1, C2, C3) and then via earth and the distributed capacity C4 back to the machine. The insertion of a choke between the frame and earth opposes the flow of this current and reduces asymmetrical interference.

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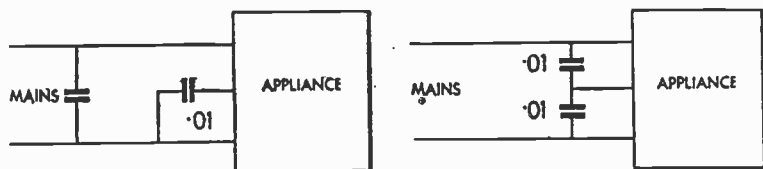
Figs. 16 and **17.** When the frame of an appliance—usually an item of domestic equipment—is not earthed, asymmetrical suppression must be taken to the frame and, to avoid shocks, the capacities should not exceed the value shown.

position must not exceed 0·01 mfd.

Where the centre-point of two condensers across the mains is taken to the frame (Fig. 17), the arrangement acts as a potential divider and the frame is raised to half mains voltage. Here again, therefore, the capacities must be kept down to 0·01 or lower to prevent the passage of a current sufficient to give a shock.

If both the shorting and blocking methods do not give sufficient suppression of radiated interference, it is sometimes possible to arrest this by earthed metal screens surrounding the source. These may convert the ether waves to currents and lead these down to earth (Fig. 18).

Condensers and chokes for suppression work must be carefully constructed and rated, since any failure may affect the operation of the machine. In particular, components in parallel with operating voltages should be fused whenever possible. Major requirements are set out below.

The capacity used depends on the nature of the source and the
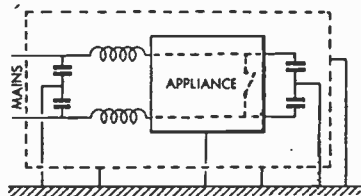
Fig. 18. Extreme cases may call for the application of all the methods of suppression shown here, condensers, chokes and screening. Screening must completely surround the equipment and be thoroughly earthed at several points if of fair size.

circuit, and is generally between 0·005 and 2 mfds. The voltage rating should meet the requirements set out in a British Standard Specification as follows:

Working Voltage	Test Voltages		Condensers Prefix Type No.
	Between Terminals.	Between Terminals and Metal Case	
250 AC 450 DC	1,500 DC	1,500 AC	X
250 AC 750 DC	2,250 DC or 1,500 AC	1,500 AC	Y
500 AC 900 DC	3,000 DC or 2,000 AC	2,000 AC	XX

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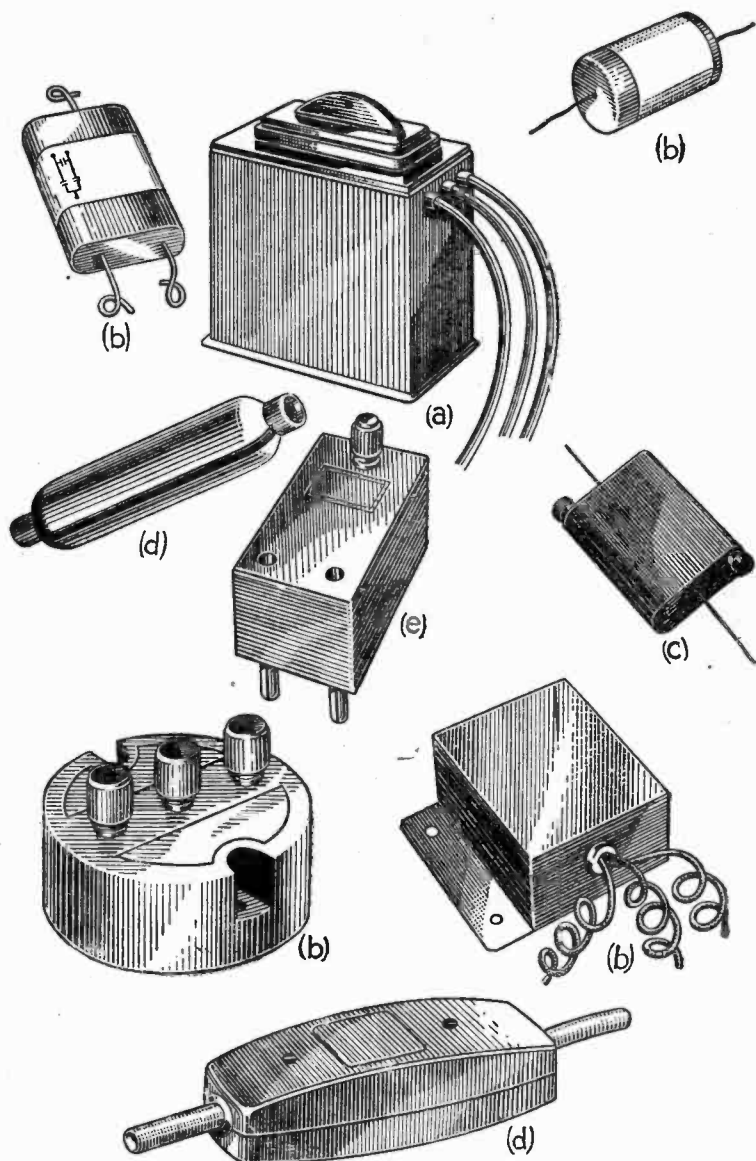
Fig. 19. Representative suppression condensers: (a) a twin unit in moulded case with fuses, (b) impregnated paper types, (c) high-voltage mica dielectric type, (d) flex lead suppressors in moulded cases and (e) a unit for insertion between power point and appliance plug. Suitable condenser units are available for practically all suppression purposes, fitted with fuses and shock proof cases where these are considered necessary.

(a)

(b)
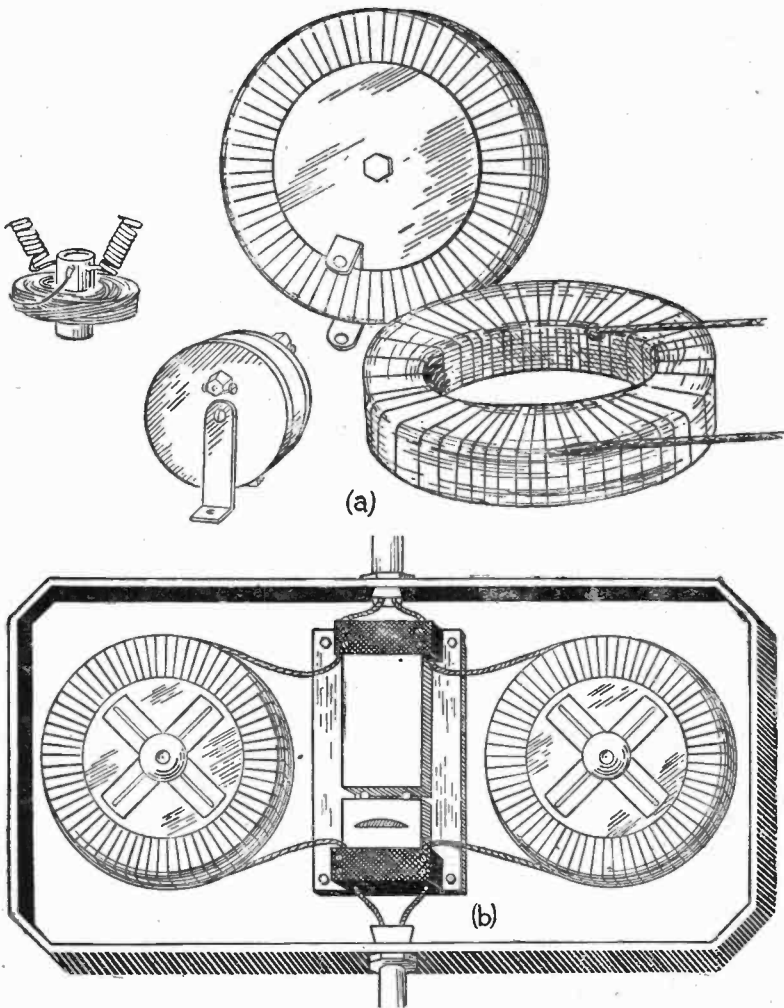
Fig. 20. Chokes are made in many types, from those fitted in flex lead suppressors to others carrying 300 amps or more and suitable for fitting to trolley buses and large industrial plant. For industrial purposes combined choke-condenser units (b) are made up into screening boxes which can be inserted in conduit runs.

Suitable condenser units are available for practically all suppression purposes. These are fitted with fuses and shockproof cases where necessary. Typical units are illustrated in Fig. 19.

Chokes are available in many types for currents from a fraction of an ampere to 300 amps or more. Those below 50 amps rating are generally pancake wound, and those for higher currents are of

flat strip construction. They are available with and without cases and in units combined with condensers (Fig. 20).

The heavy-duty type of choke-condenser filter may be in a metal housing suitable for insertion in conduit. Small types for connection in the wires to domestic appliances, and called "flex lead suppressors", are assembled into neat moulded cases (type *d* in Fig. 19).

The development of iron-cores suitable for operation at radio frequencies has permitted the production of very compact choke units for low-current circuits.

Except when fitted inside an appliance, suppressors should be fused. Where a condenser is not accessible and cannot be fused, a mica dielectric type should be fitted. With waxed types, the local temperature must not be forgotten, but standard BSS types will withstand 120° F. or 50° C.

Chokes must be chosen with operating temperatures, humidity, vibration and so on kept in mind.

Suppressors must always be fitted so that the leads are as straight and short as possible. Any inductance in the leads to a condenser will reduce the effectiveness of the unit, particularly at high frequencies.

Below are described the types of suppressor circuit suitable for various common sources. Where values are not indicated, they must be arrived at by experiment, by experience, or in consultation with a specialist manufacturing concern.

Small Motors. As these are widely used in domestic appliances, such as vacuum cleaners, they are a common source of static. Sup-
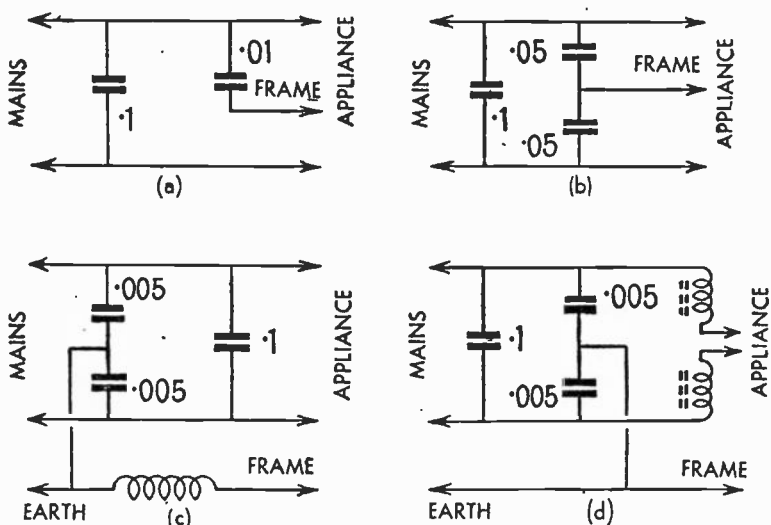
Fig. 21. Four suppressor arrangements for application to small domestic appliances and generally fitted in the form of flex-lead suppressors. Types (a) and (b) are for use from two socket outlets, and types (c) and (d) provide more effective treatment where there is an earth socket or where an earth can be provided.
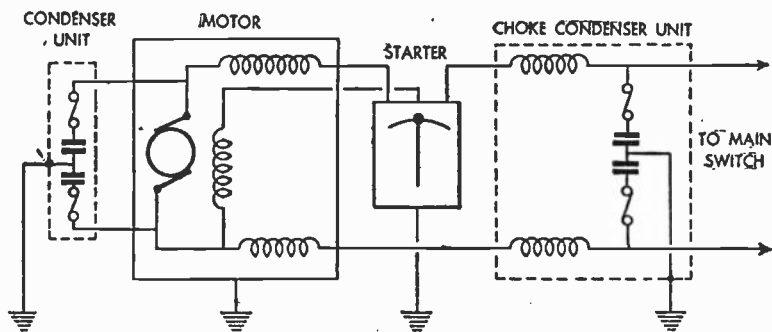
Fig. 22. Condensers of 0.1 to 2 mfd. from each brush to frame are the first remedy for DC and certain AC motors. A choke-condenser mains filter may also be necessary with, perhaps, screening and earthing of the starter and wiring.

pression is best applied in the form of a "flex-lead" unit within a few inches of the appliance. Various arrangements may be tried.

In Fig. 21(a) is a simple unit with one by-pass for the symmetrical component and one for the asymmetrical. Another type is illustrated in (b).

Where a device is operated from a three-pin plug, a more effective arrangement, (c), can be used. This includes a choke in the frame-to-earth lead. Compact suppressors with chokes in each main (d), and suitable for currents up to 2 amps, have recently been evolved.

DC Motors and Generators and AC Series Motors. Condensers from brushes to frame provide for both symmetrical and asymmetrical components. The capacity necessary ranges up to 2 mfd., according to the machine (Fig. 22).

When there is a large asymmetrical component from frame to earth, a choke between frame and earth is effective. It should be able to carry about a third of the full-load current of the machine. A choke should not be fitted in this position without expert advice,

however, as a break in the coil or a breakdown of insulation in the machine leading to a burn-out may result in the frame having a dangerous potential.

If condensers from the brushes to frame or earth are not effective, a choke-condenser unit between the starting gear and main switch should be tried (Fig. 22).

Induction AC Motors. These do not generate interference themselves, but trouble is caused by the associated switching. This may entail chokes in each main with 0·1-mfd. condensers down to earth.

Repulsion AC Motors. Condensers across the brushes serve no purpose with these motors, and a filter must be fitted at the mains input.

Rotary Converters. These often embody both AC and DC motors and, moreover, are frequently used to supply receivers. All the following may be necessary: 0·1-2-mfd. condensers from DC brushes to frame; 0·1-mfd. from AC brushes to frame; choke condenser filters in input and output leads; complete screening and earthing of the whole unit.

Rotary converters with me-

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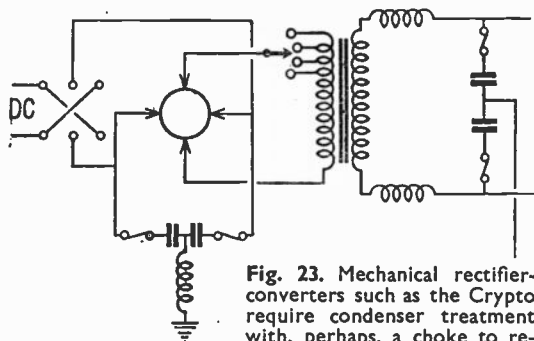
Fig. 23. Mechanical rectifier-converters such as the Crypto require condenser treatment with, perhaps, a choke to reduce the asymmetrical current.

chanical rectification, such as the Crypto require comprehensive treatment, as in Fig. 23.

Battery Charging equipment. Large valve rectifiers (mercury-vapour types) may require 0·1-mfd. condensers between anodes and cathode with, possibly, chokes in the anode leads (Fig. 24).

Switches and Thermostats. These are also frequently used in domestic appliances. If the contacts are accessible, a small condenser with a series "quench" resistor may be very effective (Fig. 25). The value of resistor is critical, and experiments should be made. A choke-condenser filter may be necessary
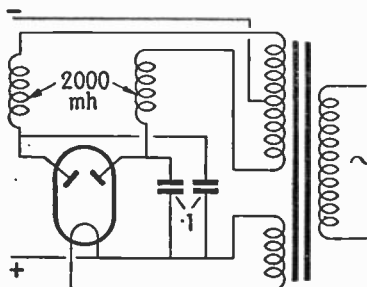
Fig. 24. Rectifiers as used for battery charging equipments frequently need suppressors from each anode to cathode. Chokes of 2,000 microhenries may sometimes also be called for.

with, perhaps, complete screening of all wires and units.

Flashing Signs. Here each contact cannot be suppressed individually. The whole "flasher" should be placed in an earthed metal box and the lamp-leads run in screened cable. A condenser should be taken from each main to the screening.

Neon Signs. A choke of about 50 henries should be included in the HT circuit—a special type insulated to withstand the high voltage is necessary. Condenser suppression is required across the mains transformer, and all units and wiring must be effectively screened and earthed (Fig. 26).

Lifts. Condensers may be fitted to the motor brushes and a choke–condenser filter to the mains input. The contactor panel may require screening and earthing.

The principal cause of trouble is the trailing cable, and special choke-filters are available for application to this. No suppression work should be carried out on lifts without expert supervision, and the co-operation of the people responsible for the maintenance of the lift.

Ignition Systems. The ignition systems of cars require 10,000–15,000-ohm resistors, of special design to withstand the temperature and vibration, in each HT lead as close to the spark plug as possible. A resistance of 5,000–15,000 ohms is inserted where the HT lead from the coil enters the distributor.

The low-tension make-and-break requires a 0·5-mfd. condenser in shunt (Figs. 27 and 28).

The coil-case should be bonded to the engine frame and the HT leads be as short as possible. In extreme cases the complete ignition system may be screened and bonded to frame.

Fig. 25. Devices using simple make-and-breaks such as thermostats and "flashers" often need a quench resistance in series with the suppression capacity. The resistance prevents a too rapid charging and discharging of the condenser and its exact value should be arrived at by experiment. Complete screening of all the wiring and equipment is generally necessary.

A generator on the car with third-brush regulation may be suppressed by a shunt 0·5-mfd. condenser mounted on the frame. For windscreen wipers, special choke-condenser filters for fitting in the lead are available.

Medical Apparatus. Certain equipments generate very powerful high-frequency voltages. Ordinary suppression methods are not applicable, and the most practicable remedy may be complete screening of the room containing the apparatus. A wire-mesh may be used. It must be complete, covering doors and windows, and well bonded and earthed. Condensers should be fitted across the mains to prevent HF being conducted outside the screening.

When suppression at the source cannot be applied, or is not sufficiently effective, steps must be taken to prevent interference entering the receiver. This it may do, as we have seen by:

(1) Radiation, both direct and re-radiated.
(2) Direct induction.
(3) Conduction.

Radiated and direct-induction types are usually picked up by the aerial–earth system, although in exceptionally strong fields they may also be picked up by wires in the receiver itself.

The conducted type enters mains sets via the mains transformer and rectifier system, and generally also creates re-radiation, which is picked up in the same way as direct radiation (Fig. 8).

The conducted type, with its associated re-radiated field, is the most common form of interference. The radiated field is usually limited to within about 25 feet horizontally and 10 feet vertically. This means that where the wiring of a house is carrying interference a field rather as in Fig. 29 is set up.

Filtering HF Currents

The engineer's first object, obviously, is to filter the HF currents out of the mains. Logically a condenser unit mounted as near as possible to the mains entry into the house—*i.e.*, on the meter board—is the best way of achieving this.

Before taking this step, however, it must be remembered that if there is present a radiated field either from the actual source or from nearby wiring, the mains
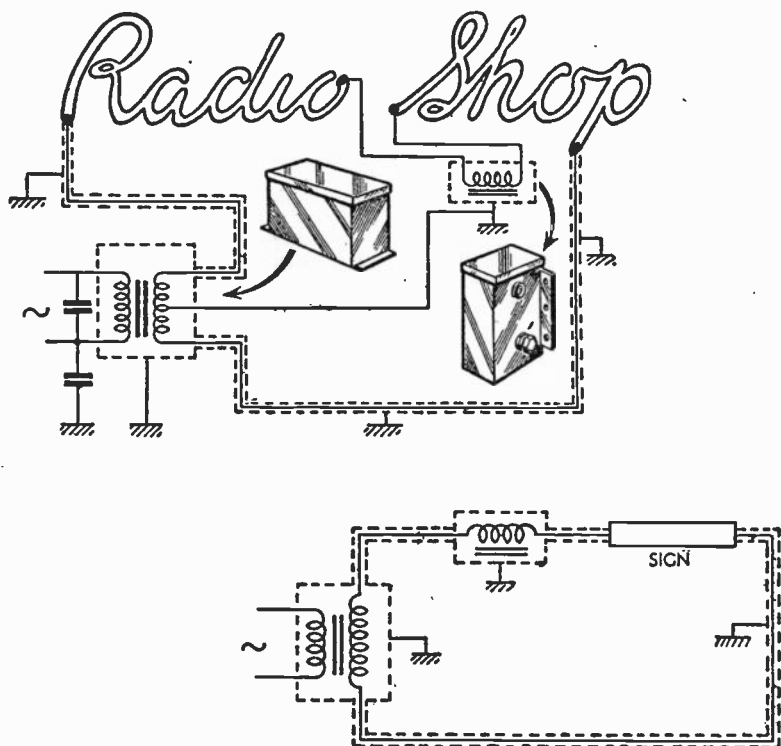
Fig. 26. It is not practicable to apply condenser suppression to neon signs, and HF currents are reduced by the inclusion of a choke. This must be a type of about 50 henries specially designed to withstand the high voltage and exposure to weather. With a split unit the high tension potential is reduced by means of a centre-point earthing arrangement.

system in the house concerned may be re-energised between the entry and the receiver. With semi-detached houses this is almost a probability, and it is often advisable to see if an "input" filter cannot also be fitted next door.

A check on re-radiation from outside can be obtained by using a battery set on the aerial and earth concerned and "cutting" the main switches of the house.

Where re-energisation cannot be avoided, a filter situated as close to the receiver as possible is necessary. It may then be found that a meter-board filter serves no useful purpose.

The filter at the set may be of the type shown in Fig. 30. It should be located at the power point from which the set is operated and, if possible, the mains wiring to the power point should be run in earthed conduit. The earth connection from the mains-point filter should be separate from the earth used for the receiver.

To minimise the transfer of

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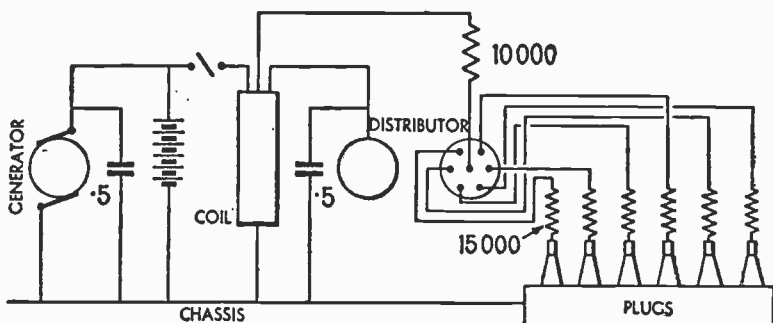
Fig. 27. Suppression of ignition interference calls chiefly for resistances in the HT leads and capacity across the distributor make-and-break. The high tension leads should be as short as possible and the coil can be well bonded to chassis or engine. A suppressor may also be put across the dynamo.

static from the mains to the receiver, transformers frequently include an earthed screen (Fig. 31). AC–DC sets as a class are recognised as being "noisier" than AC types; this is because they do not oppose even a transformer as a barrier to HF currents from the mains. Nowadays, however, many of these sets include suppression chokes and capacity in their mains section (Fig. 32).

A special form of interference which strictly is not due to the type of conducted interference now under review, but which is, all the same, due to HF in the mains, is known as "modulation hum". It appears only when a strong station is tuned in. There are two reme-

dies: (1) a 0·1-mfd. condenser between the live main and earth; and (2) 0·1-mfd. condensers across each half of the mains transformer HT secondary (Fig. 31).

With conducted and associated re-radiated interference reduced to a minimum, remaining noise must be due to pick-up of radiated, re-radiated or direct-induced interference on the aerial–earth system and, possibly, the set itself.

The approach here is to collect the "cleanest" signal possible by erecting the aerial where the interference field is weakest, and then to prevent the pick-up of static on the lead-in by running it through an earthed metal screening tube.
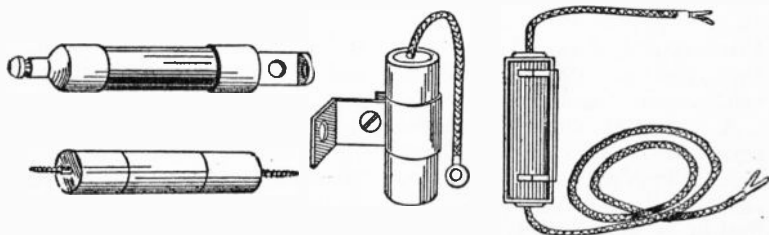
Fig. 28. Ignition resistances have to be specially made to withstand heat and vibration. Special condenser units and windscreen wiper suppressors are also made.
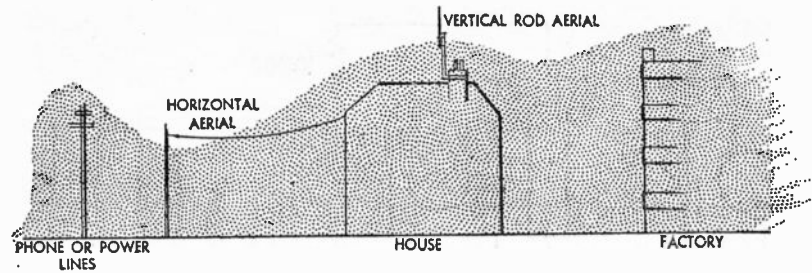
Fig. 29. Interference generally travels further horizontally than vertically, is densest near its source and clings to near-by wiring. The shading represents the possible shape of an interference field and indicates that a vertical aerial may be the only really satisfactory way of picking up a "clean" signal.

This method inevitably reduces the signal fed to the set because, normally, the lead-in acts as a collector; but as long as the signal-interference ratio is increased, the loss of signal can be compensated by increased amplification in the set. An arrangement of a collector portion of the aerial outside the interference field is shown in Fig. 33.

The lead-in and its earthed screen form a condenser. This capacity is across the input of the set and offers an alternative path to the signal. A further loss of signal, therefore, cannot be avoided. It is, however, kept as low as possible by the use of "transmission-line" technique.

Use of Transformers

The effect of the screened lead-in as a condenser can be minimised by reducing the voltage between the lead-in and its screening. The use of transformers enables this to be done.

A screened anti-static aerial equipment, in this case the Belling–Lee "Eliminoise", is designed as shown in Fig. 34. At the top of the lead-in is an aerial transformer unit, the primary winding of which is connected to earth via the screening of the cable. The voltages induced in the secondary are led down a twin transmission line to another transformer at the receiver end.

The aerial transformer steps the voltage down. Apart from losses in the transformer, the energy remains the same, and the lower voltage is compensated by increased current. At the receiver transformer, the voltage is stepped up to practically its original level.

It will be noted that an earthed screen in the receiver transformer shields the secondary from any electrostatic field (see Fig. 3), which may cause currents in the transmission system as a whole.

To be ideal, the transformers should be designed to match the aerial to the particular electrical characteristics of the receiver. This would entail special equipment for each make of set, and both aerial and earth transformers would have to contain waveband switching. In practice a compromise design is generally achieved.

An aerial system of this kind is excellent for where a number of receivers have to be run from one aerial. The transformers reduce the coupling between the sets.

Directly induced interference

waves in both electromagnetic and electrostatic forms are mostly of a horizontal nature, or are "horizontally polarised". Waves have least effect on conductors at right angles to them; where directly induced interference is present, therefore, a vertical aerial picks up least noise. This has led to the development of the "rod" aerial.

For mechanical reasons, a metal rod of convenient dimensions must be limited to 12 or 18 feet in length. This is a poor collector in comparison with a 60-foot horizontal aerial. On the other hand, a rod collector is non-directional, and it can usually be mounted

Fig. 30. When the mains wiring of a house is energised by radiated interference, conducted HF should be barred from the receiver by a unit of this type (Belling–Lee) fitted at the power socket near the set.

on a chimney-stack some 10 or 15 feet higher than a horizontal wire from the eaves.

As Fig. 29 indicates, it is often easier to mount an aerial of this type above a radiated field than to arrange an L-type beyond it, and consequently the rod aerial is not limited to where interference is of the directly induced type.

Designers have partly offset the small pick up of the rod aerial, which has, of course, to be used with a screened transmission line, by arranging the whole system to resonate over the wavebands covered. As a result, when installing these systems the lead-down should not be altered in length if this can be avoided. The circuit arrangement for a Belling–Lee "Skyrod" is shown in Fig. 35.

A special type of rod aerial is the dipole as used for ultra short wave

and television reception (see Chapters 7 and 8). In this case the whole system is designed to match some particular wavelength and the aerial itself is "tuned". An additional anti-interference measure is
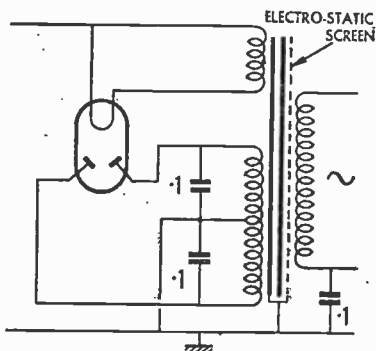
Fig. 31. A screen between the primary and secondary windings of a transformer reduces the electrostatic transference of interference. To reduce modulation hum 0·1 mfd. condensers may be fitted across the HT secondary or from live main to chassis.
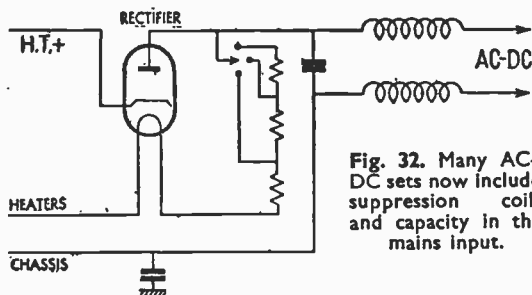
Fig. 32. Many AC–DC sets now include suppression coils and capacity in the mains input.

practicable in this case, as the aerial can be screened by resonant reflector rods (Fig. 36).

Some all-wave aerials have anti-static properties on the short waves. These are usually of the "doublet" type—that is, the horizontal collector is in two parts, proportioned so as to have a resonant effect over certain wave-ranges. These two portions are connected to the receiver by an unscreened transmission line, and the centre point of the primary of the transformer is taken down to earth.

Alternative Circuits

With this arrangement the short wave signals are developed across the ends of the transformer primary, and energise the secondary in the usual way.

Any interference currents induced in the twin down wires flow to earth via the centre connection and cancel each other out in the transformer.

On medium and long waves, these aerials are generally switched so that the transformer is cut out and the transmission line becomes in effect a single down wire. It then has no anti-static properties.

In very strong interference fields, noise may enter a set by means of exposed wires in the chassis itself. These wires should be run through low-capacity screened leads if possible, or, alternatively, the whole receiver may be screened by covering the interior of the cabinet with metal foil connected to earth. In all cases of interference the earth connection must be the best possible.

Noises which are not due to electrical machines, but are every bit as annoying, may occur as a result of (a) interaction between transmissions, (b) incorrect opera-
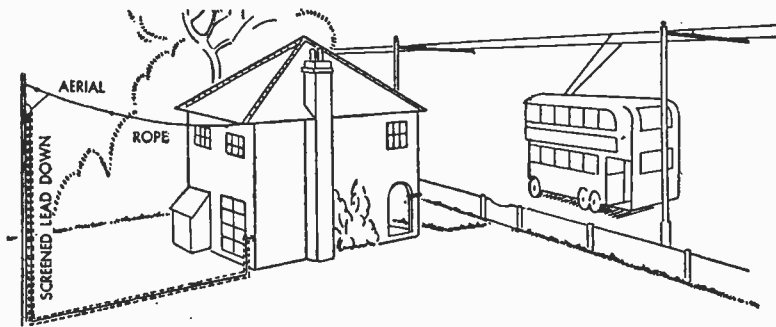
Fig. 33. When the interference field does not include the whole of the garden, a clean signal may be picked up by this arrangement. A screened anti-static lead-in must be employed as shown on the left of the illustration.
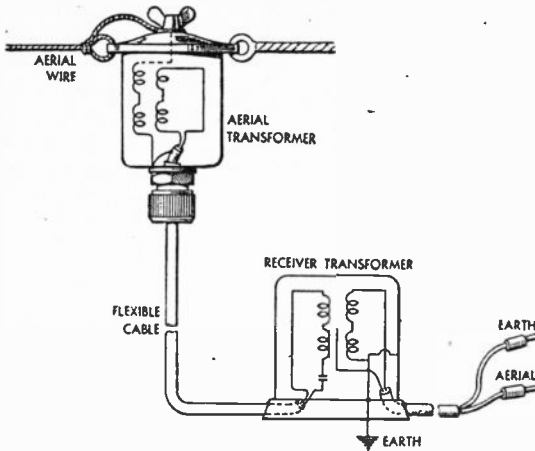
Fig. 34. To reduce loss of signal through the capacity between lead-in and the screening cable, transmission line technique is employed. This entails a step-down transformer at the top of the lead and a step-up transformer at the receiver end.

tion of the receiver, or (c) interaction between receivers.

When two transmitters are so close together in the frequency band that their carrier waves overlap, the result may be a whistle, chattering noises or background talk. Most transmissions occupy at least 4·5 kc. each side of the carrier frequency, and so, if there is less than 9 kc. between two transmissions, interference may occur, and little can be done about it at the receiving end.

Any efforts made to eliminate these noises must be directed to reducing the band width received (increasing the selectivity) and to filtering out the whistle by means of a filter circuit in the low-frequency portion of the receiver.

When interference is heard between two stations which are a reasonable distance apart in wavelength, the fault is lack of selectivity. It should be ascertained that the tuned circuits of the receiver are properly aligned, and some improvement may be obtained by reducing the size of the aerial. In particular, efforts should be made to reduce the

capacity between the lead-in and earth.

Where trouble is caused by a powerful local transmission
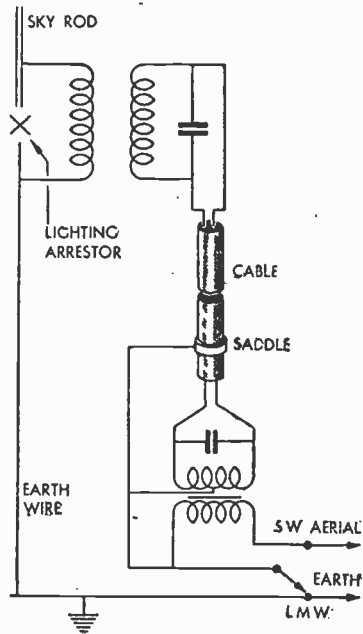
Fig. 35. Transmission line technique is also employed with the rod type collector such as the above.

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DIPOLE AS FAR FROM HOUSE AS POSSIBLE.

TO TRANSMITTER
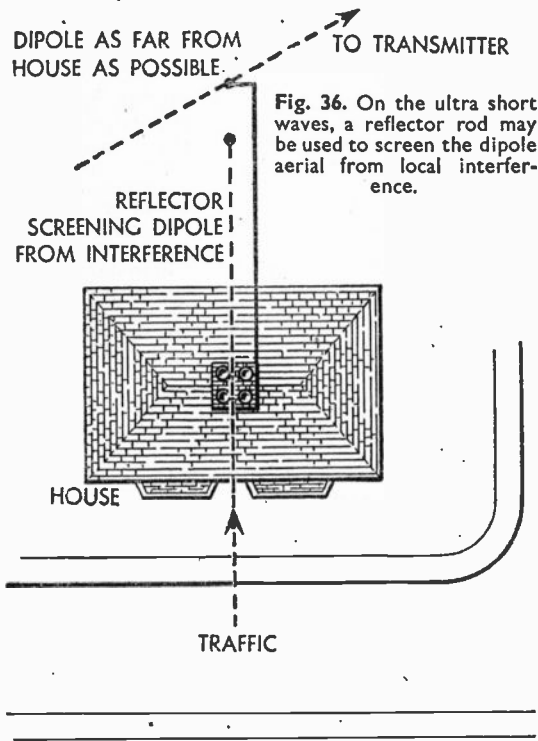
Fig. 36. On the ultra short waves, a reflector rod may be used to screen the dipole aerial from local interference.

REFLECTOR SCREENING DIPOLE FROM INTERFERENCE

HOUSE

TRAFFIC

The rejector type seeks to prevent the unwanted signal passing from the aerial to the set, while the acceptor type provides a by-pass route.

With superhet receivers, a strong local signal may produce whistles at several parts of the dial. This may be due to overloading of the first valve and to heterodynes with the oscillator frequency and its harmonics. Once it has been proved that the tuned circuits of the set are properly adjusted and that the oscillator stage is operating with the correct voltages and components values, the only remedy is the use of a wavetrap.

swamping a large part of the dial, remedy may be found in the use of a wavetrap. This may be either a rejector type, *a* in Fig. 37, or an acceptor, *b*.

Interaction between receivers is comparatively rare now that the old type of set with reaction is out of fashion.

SET

(a)

SET

(b)
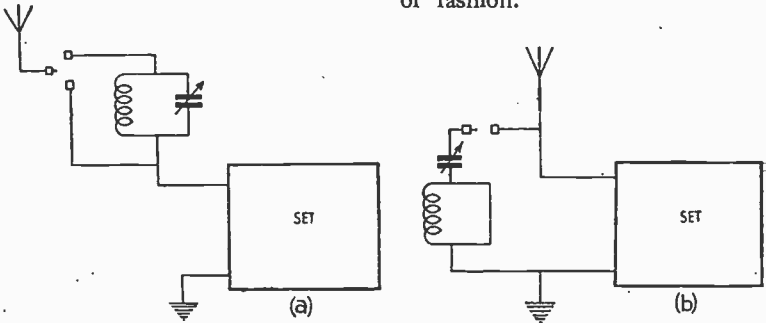
Fig. 37. "Swamping" by a strong local transmission may produce several forms of interference. The signal can be reduced by means of either a rejector wavetrap as in (a) or by using an acceptor type (b).

BATTERIES AND CHARGING

ALTHOUGH modern radio equipment tends to the use of the electric mains for supplying the necessary power, there are many occasions when batteries must be used. Such instruments as portable receivers, microphone amplifiers, police transceivers all operate from batteries.

Electric cells can be divided into two groups—namely, primary and secondary. The primary cell produces electrical energy by chemical action and, after the energy is discharged through a circuit, the original chemical characteristics of the elements of the cell are changed. Generally, the cell is destroyed.

Secondary Cell

The secondary cell, commonly known as an accumulator, also functions due to chemical action, but after it is discharged it can be recharged by passing current through it.

The primary cell can be subdivided into two classes: dry and wet. The original elements in the first battery made in A.D. 1800 by Volta, in Italy, comprised copper and zinc discs separated by cloth moistened with a salt solution. Later he invented a cell using copper and zinc plates in the form of cups connected in series to form a battery of cells.

Electrodes and Electrolytes

Modern cells are made from two dissimilar metals, called electrodes or plates, and an electrolyte or conducting liquid which can combine chemically with the metal of one of the electrodes. The addition of a "depolarising agent" is necessary if the cell has to supply a continuous discharge.

In the case of the wet cell, the inert electrode is normally made from copper or carbon, and is surrounded by the depolarising agent in the form of a pot or sack. The sack is placed in a glass jar containing the electrolyte and the other electrode, which is usually a zinc rod. The depolariser may be either liquid or solid.

In the dry cell the depolariser is solid, being in the form of a paste around the inert electrode or compressed carbon. The depolariser and carbon rod are placed in a sack, which is surrounded by electrolyte made up into a thin paste or jelly. Sack and paste are

then put inside a zinc pot, and finally, to retard evaporation, the cell is sealed with pitch.

If a cell were made without a depolarising agent, the voltage would rapidly drop and the cell would "polarise". After the load was removed the voltage would slowly rise to its original value. Although such a cell might be used for very intermittent purposes, its practical uses would be very limited.

Polarisation is caused by the production of hydrogen bubbles on the surface of the carbon electrode. The space occupied by the bubbles reduces the active area of the electrode, and the polarisation causes an EMF in opposition to the original EMF of the cell.

The hydrogen bubbles are the result of voltaic action due to the chemical changes which take place when the cell is being discharged.

The depolarising agent, usually made from manganese-dioxide or manganese-peroxide and carbon, is placed in the cell to absorb the hydrogen before it reaches the carbon electrode. Thus the opposition EMF is prevented, the whole of the carbon area remains active and the voltage stays approximately constant.

A cell of this type, whether of the dry or wet type, suffers from "local action"—that is, it slowly discharges itself, even if it is not connected to a circuit. This effect is due to chemical impurities in the electrodes, and it can be greatly reduced by coating the surface of the zinc electrode with a film of mercury.

The Léclanché Cell

Of the many cells that have been invented, the Léclanché type is chiefly used today, being made in both dry and wet forms. The wet type is used primarily for intermittent service, as for bells, alarms and telephones (Fig. 1). In its dry form it is used for high-tension, low-tension and grid-bias batteries (Fig. 2).

The general construction of the dry type follows the lines described, consisting of a zinc container inside which is a canvas sack or "dolly" containing the carbon electrode and depolarising agent (Fig. 3). The agent is made in accordance with trade secrets, and, although it varies considerably, the general results are similar. The carbon rod is electroplated at one end so that a copper cap can be soldered on to form a good contact.

Each of the cells, where more than one are used, is contained in an insulating section of the impregnated cardboard container.

Each dry Léclanché cell gives
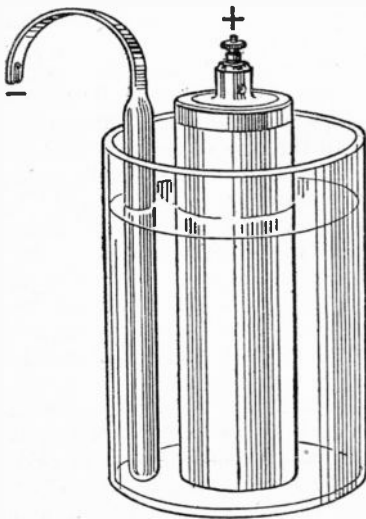
Fig. 1. The wet Léclanché cell is used for operating bells, alarms and other devices used only intermittently.

an EMF of approximately 1·5 v. The carbon rod is the positive and the zinc container the negative. Where more than 1·5 v. are required the cells are connected in series. Each cell has a small internal resistance when it is new, and this gradually increases as the battery is used.

Fig. 2. Typical "dry" batteries. The cells are Léclanché type but the electrolyte is made up in paste form. HT and GB units consist of numerous cells in series.

If 60 v. are required, the battery must contain $60 \div 1·5 = 40$ cells. In practice manufacturers supply a few cells in excess of the calculated number, in order to offset the gradual running down of the battery before it comes into use. The contacts to the cells are made by brass tapping points to the positive and negative ends of the battery and to intermediate positive points.

If the slightest leakage of current takes place through the insulating compound used to seal the top of the waxed container, or through the inter-cell divisions, the battery will gradually discharge. This effect leads to the term "shelf life", which is the time the battery takes to discharge when "on the shelf" and not actually in use.

The discharge and recovery curves of the dry cell are shown in Fig. 4. It will be seen that the voltage starts high but rapidly falls to a steady value, and during the subsequent discharge period the rate of fall is fairly constant. When the load is removed the depolariser clears the cell of hydrogen and the voltage recovers, starting the next discharge period again with a high value. However, the average

value of the voltage is gradually reduced, due to the growth of the internal resistance.

Chemical Action

For readers who wish to study the primary cell more closely we give in the next few paragraphs a more technical description of the processes just outlined, indicating the exact chemical action.

A simple wet primary cell may consist of plates of zinc and carbon in a solution of ammonium chloride—commonly known as
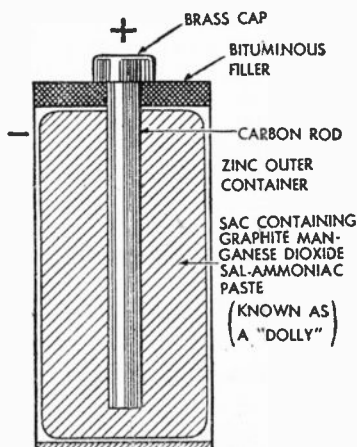
Fig. 3. Section of a dry cell showing the zinc can, the paste and the "dolly" containing the depolariser and the positive carbon electrode.
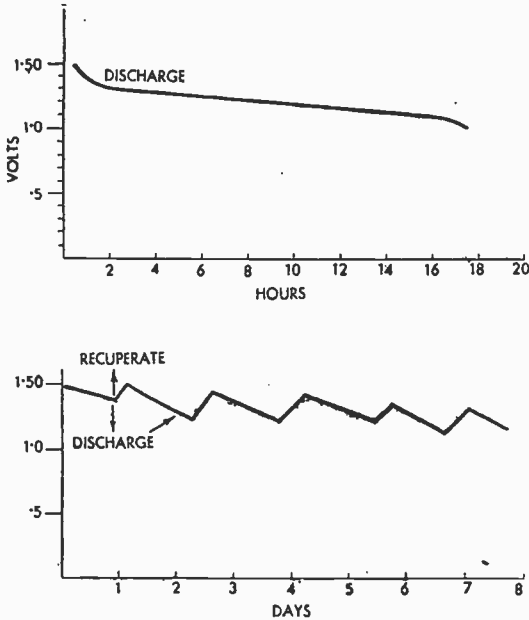
Fig. 4. Typical discharge curves for a dry cell. The top curve shows the steady fall of voltage on continuous load. On a heavier but intermittent discharge (second curve) the voltage rises during each recuperative period.

sal-ammoniac (NH_4Cl). Fig. 5 shows the chemical action that takes place when a current is taken from the cell. The electrolyte (the sal-ammoniac solution) is composed of ions of ammonia, NH_4, and chlorine, Cl. When the zinc plate is immersed in the solution, positive zinc ions are produced (Zn^{++}). These are positive because each has left behind two electrons on the plate. The excess of electrons on the plate gives it negative polarity.

Action of Zinc Ions

The zinc ions in the solution repel the hydrogen ions, and the ammonia ions already present drive them to the carbon plate, forming bubbles of hydrogen and ammonia. The bubbles are created by the loss of electrons by the carbon plate, which thereby becomes positive. The zinc ions combine with the chlorine and form a white deposit, zinc chloride. This action gradually eats up the zinc electrode, the zinc chloride staying in the solution.

The formation of bubbles on the positive plate reduces the area exposed to the solution and has the effect of reducing the voltage and current output. This increases the internal resistance of the cell and explains why, if a short circuit is put across a cell, the current is not infinitely great, as Ohm's Law may lead the unwary to expect.

Polarisation can be reduced by the addition of a chemical rich in oxygen, so that the oxygen combines with the hydrogen and forms water. As in the dry cell, manganese dioxide is used (MnO_2), and is placed in a porous container around the carbon electrode.

Due to impurities in the zinc electrode, minute local actions take place and cause the zinc to be eaten away, even when no current is taken from the cell. Pure zinc cannot be used, due to its high cost, but it has been found that local action is considerably reduced if the surface of the zinc is amalgamated with mercury.

The chemical action in the

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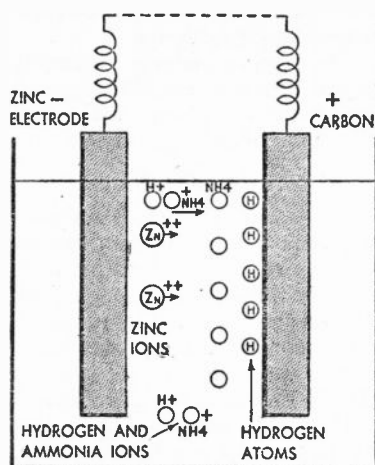
Fig. 5. Illustrating the electro-chemical action in a wet primary cell. Electrons are left on the zinc plate, making it negative, and are taken from the carbon, making it positive.

popular type of dry cell is as follows:

$$Zn + 2MnO_2 + 2NH_4Cl =$$
$$Mn_2O_3 + H_2O + 2NH_3 + ZnCl_2$$
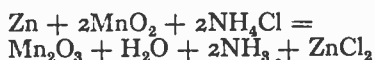
The result is that zinc chloride, $ZnCl_2$, water, H_2O, and ammonia gas, NH_3, are formed. As in the wet cell, due to the impurities in the zinc, local action takes place, and the zinc is slowly eaten away.

As the active area is reduced the internal resistance increases. Failure of the depolarising agent to completely neutralise the hydrogen bubbles also increases the resistance and the resistance of the cell limits the discharge current. Internal leakage continues until the EMF is insufficient to overcome the growing resistance.

With large cells the electrode area is larger and a heavier current can be obtained. Manufacturers state the maximum discharge rate of any particular size cell. If this rate is exceeded the cell not only raises its internal resistance due to the creation of excessive bubbles, but its life is prematurely shortened. The dry cell is not generally designed for continuous rating, and requires rest periods to recuperate the depolariser.

Where dry cells are used to supply the filament power for a receiver, it is necessary to use large cells, and they usually have a height of 5 to 6 inches and a diameter of 2 inches. Such a cell can give a discharge of up to 0·5 amp. for several hours on end.

HT Batteries

Special valves have been designed to operate from dry cells. They have a filament voltage of 1·4 and, therefore, one cell is adequate. Most "battery" valves, however, are 2 v. types for running from accumulators. If these are used with dry cells, two batteries must be used in series with a resistance to reduce the 3 v. so obtained to 2 v.

As described earlier, HT and GB batteries are built up from many individual cells connected in series, each cell being insulated from its neighbours by waxed cardboard separators (Fig. 6).
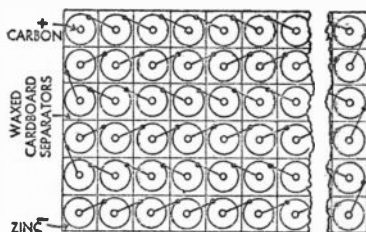
Fig. 6. HT and GB batteries consist of numerous cells connected in series, their zinc cases spaced and insulated from their neighbours by waxed cardboard and bituminous (pitch) filling.

Normally, the cells have tappings brought out through the bituminous compound that covers the tops.

The current rating is about 6 ma. for the smallest types and 30 ma. for the largest.

HT batteries are rated in a capacity unit called the milliampere-hour, meaning that a battery is capable of delivering so many milliamperes for a given number of hours. The small cells deliver about 450 milliampere-hours and the largest about 4,500 milliampere-hours. It is generally much cheaper to use the larger type.

When a dry cell is discharged to about $1 \cdot 1$ v. its life can be regarded as finished. As the zinc has been practically eaten away, the battery cannot be reactivated.

Accumulators

We have seen that the dry or "primary" cell is capable of supplying power to a circuit, but that it gradually becomes exhausted, and finally has to be discarded. The secondary cell, or accumulator or storage battery, as it is variously known, is so designed that after a discharge period it can be restored to its original state by passing a current through it in the opposite direction to that of the discharge. The storage battery can be divided into two classes: (1) the lead-acid accumulator; and (2) the alkaline cell.

The modern lead-acid cell is nearly always constructed on the Fauré principle—that is, the plates are made from a lead and antimony alloy in the form of a grid, and a paste of oxide of lead and red lead is forced into the grid mesh. In the case of heavy traction and large-capacity stationary batteries, the Planté or unpasted plate is regaining popularity.

The positive plates are normally pasted with red lead (Pb_3O_4), and the negative plates with lead monoxide or litharge (PbO).

Forming the Plates

To "form" the plates for subsequent use it is necessary to convert the red lead to lead peroxide and the litharge to spongy lead. This is accomplished by passing a direct current through the cell, a dilute sulphuric acid solution (H_2SO_4) forming the electrolyte.

It will be seen in Fig. 7 that hydrogen ions are transferred to the cathode (or negative plate), where they give up their electrical charge, become normal hydrogen, and react with the litharge, forming spongy lead and water:

$$H_2 + PbO = Pb + H_2O$$
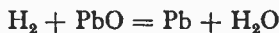
Sulphur ions are attracted to the positive plate, give up their charge, and react with the water, producing sulphuric acid and liberating oxygen. This combines with the red lead and produces lead peroxide:

$$2SO_4 + 2H_2O = 2H_2SO_4 + O_2$$
$$\text{and } O_2 + Pb_3O_4 = 3PbO_2$$
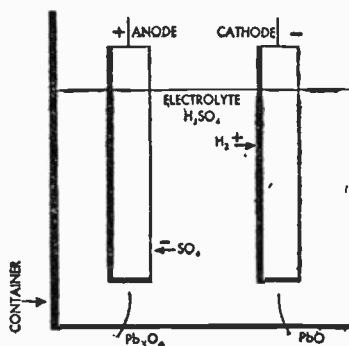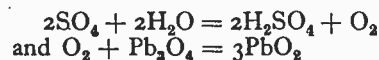
Fig. 7. Chemical reactions in an accumulator during formation of the plates.
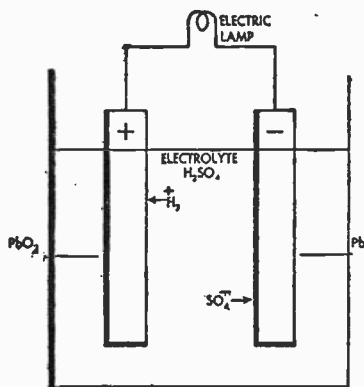
Fig. 8. The accumulator action during discharge. Note the flow of current in the opposite direction compared with charging as in Fig. 7.

Let us assume that a charged accumulator is to light a lamp and this is connected across the terminals (Fig. 8). The cell now drives through the lamp a current, which is in the opposite direction to the original charging current.

Hydrogen is liberated from the positive peroxide plate and sulphur ions from the negative plate. The chemical equations are:

$$PbO_2 + H_2 \rightarrow PbO + H_2O$$
$$PbO + H_2SO_4 \rightarrow PbSO_4 + H_2O$$
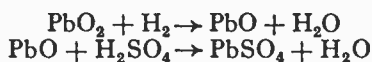
This change in the chemical constitution of the plate results in the formation of lead sulphate, which reduces the effective area of the active plates and, if left for any period, causes permanent damage. The specific gravity of the electrolyte is reduced due to the additional water content. This change of specific gravity enables one to check the state of discharge of the cell.

The lead plate also undergoes a chemical change, namely:

$$SO_4 + Pb = PbSO_4$$
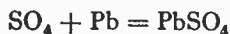
i.e., lead sulphate has formed also on this plate. When the cell is completely discharged, the grid-paste is reduced to lead sulphate in each case. The cell is now completely inoperative, but may be recharged by passing DC through the cell in a direction opposite to the discharge.

The chemical changes that take place (see Fig. 9) are:

Positive plate. $SO_4 + PbSO_4 + 2H_2O = 2H_2SO_4 + PbO_2$, showing that the lead peroxide is obtained and that the dilute sulphuric acid electrolyte has its specific gravity raised.

Negative plate. $PbSO_4 + H_2 = H_2SO_4 + Pb$. Thus the spongy lead is reformed and the cell becomes recharged. This process of discharge and charge can be continued many times, and provided that the maximum current rates stated by the manufacturer are not exceeded, a normal cell usually lasts at least two years.

During the change of the state of charge to discharge the specific gravity of the dilute sulphuric
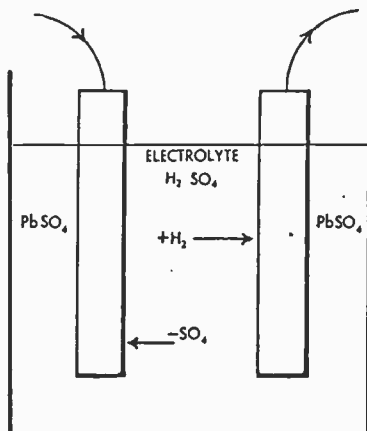
Fig. 9. Chemical action in an accumulator during the process of charging.

acid changes. The specific gravity of a liquid is the ratio of weight of a volume of it to the weight of an equal volume of pure water, at a given temperature.

Specific gravity can be measured by means of a hydrometer. From Fig. 10 it will be seen a hydrometer consists of an outer glass container, having a flexible rubber tube at one end and a rubber bulb at the other. Inside the glass container is a calibrated float (Fig. 11), which is adjusted, usually by means of lead shot, to float vertically. To prevent the float sticking to the inside of the glass container,

Fig. 11. This drawing gives details of the float contained in the glass tube of the hydrometer. The float is balanced by lead shot and prevented from sticking to the tube by glass pips. The denser the liquid, the higher the float rises.

the latter is made with small raised pips.

The "denser" the liquid the higher the float rides, and so the float can carry a scale calibrated to read specific gravity.

To use the hydrometer, the flexible rubber tube is first inserted into the acid. The rubber bulb is squeezed and released, so drawing acid into the glass container. The float rises, and the specific gravity is read from the scale.

Care must be taken to see that the float rises freely, and the eye should be on a level with the acid surface to avoid parallax errors in making the reading.

In accumulators made for the non-technical public, automatic charge indicators are sometimes provided. These usually take the form of two or three coloured balls or a pointer showing "charged — half charged — discharged". In both cases the indi-

Fig. 10. Specific gravity is measured with a hydrometer. Air is expelled by means of the rubber bulb. The tube is inserted in the accumulator and the bulb released. Atmospheric pressure half fills the tube and raises the float.

cator is operated by the specific gravity. Provided the cell is originally filled with the correct specific gravity acid, these indicators are fairly accurate.

State of Charge

As an accumulator is discharged the specific gravity falls and, in a reciprocal sense, it rises during recharging. When recharging is complete no further change of specific gravity occurs.

Due to the gradual evaporation of the water of the dilute sulphuric acid solution, the specific gravity rises during the life of a cell, and it is imperative to maintain the acid at the level specified by the manufacturers. Unless electrolyte has been spilled, the fall in level must be made good by the addition of distilled water only, and not with an acid solution.

The colours of the positive and negative plates are a further check on the state of charge. When charged, the positive is deep chocolate brown, and the negative a slate grey. As a cell discharges, the lead sulphate that forms on the plates changes the colour of both until the positive plate is only a little darker than the negative.

As by-products of the charging process both oxygen and hydrogen are liberated, bubbling through the electrolyte to the surface. This "gassing" only commences when the cell is near a state of complete charge, and acts as an additional pointer as to when to stop charging.

During the chemical changes, electrical changes also occur, being reflected in the voltage of the cell. Together with the specific gravity, therefore, the voltage indicates the state of charge. When the cell is being charged the voltage rises to
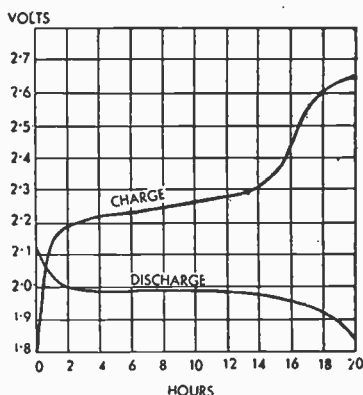
Fig. 12. Change in voltage during charge and discharge plotted against time.

around 2·2 fairly rapidly, and then slows during a further rise to 2·3, when the charge is practically complete. Gassing now commences, and the voltage may rise to as high as 2·6.

When a cell is placed on discharge, the voltage rapidly falls to about 2·05 or 2·1, then more gradually to 2 v. It remains steady around 2 v. until the charge is nearly exhausted, when it falls to about 1·8.

The graph shown in Fig. 12 indicates the change in voltage for charge and discharge plotted against time and Fig. 13 shows
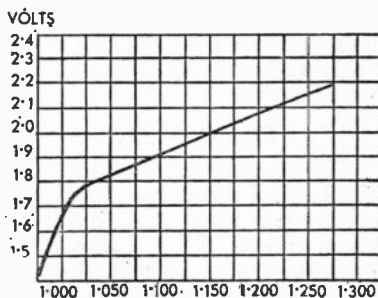
Fig. 13. Showing the change of specific gravity with the change of voltage.

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Fig. 14. Types of radio accumulator. *Top:* an LT mass-plate slow-discharge cell with charge indicator; a non-spill celluloid unit for portable sets (*centre*); and a standard celluloid type. *Left:* a 10-volt accumulator forming part of an HT unit.

the change of specific gravity with the change of voltage.

A cell should be recharged as soon as possible, for the lead sulphate tends to attack the plates, and may severely damage them.

The type of cell and rate of discharge determine how many hours an accumulator may be used. The unit used to express capacity is the "ampere-hour"—usually abbreviated to AH.

Cell Capacity

The capacity can be found by discharging a cell by a constant current and noting the number of hours it lasts before being fully discharged. If a cell is discharged for 50 hours at 1 amp. it has a capacity of 50 AH and could be expected to give 2 amps for 25 hours, or 5 amps for 10 hours. In each case the product of the number of hours and the constant current is equal to 50.

While this theoretically suggests that 50 amps could be taken from the cell for 1 hour, in practice a much smaller maximum rate would be indicated by the manufacturers.

Two discharge-current ratings for accumulators are used:

(*a*) the continuous and
(*b*) the intermittent.

The intermittent rating is used when the cell is required for very short periods, such as for ringing a bell or starting a car. This rating is about half the continuous capacity rating. Thus the same cell can have a continuous capacity of 20 AH or an intermittent of 40 AH. Where cells are to be used for long periods, as for providing the filament power for a battery-operated receiver, the continuous discharge current rating is applicable.
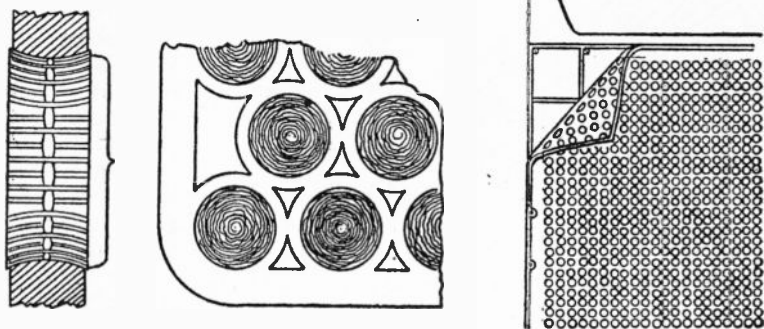
Discharge rate is primarily dependent on the thickness of the plates. If too heavy a discharge is attempted, the gas liberated forces the paste out of the lead-alloy grids. The cell disintegrates and the loose paste falls to the bottom and forms a conducting sludge. Eventually the layer of sludge may short the positive and negative plates and complete the ruin of the cell.

The capacity of a cell depends on the effective area of the plates which may be obtained by having (a) a number of thin plates in parallel, or (b) one very thick plate. In the case of cells for heavy intermittent currents design (a) is employed, and (b) is used for long-period, light-discharge rates.

Constructional Parts

After many reversals of the chemical composition the plates become less effective. This is due to the loss of paste and the gradual creepage of lead sulphate.
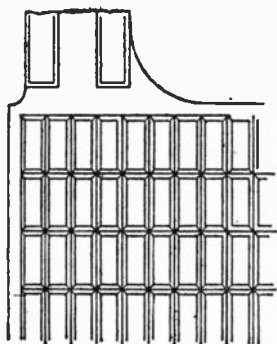
Every type of accumulator, whether for radio LT and HT supplies, for starting petrol or diesel engines, or for lighting or driving other electrical apparatus, must consist of the following parts:

Container. This may be fabricated in glass, celluloid or vulcanised rubber (Fig. 14), according to the type of service for which it is to be used. Celluloid is employed for light portable batteries and is transparent when new but becomes opaque in time. The vulcanised rubber type is used primarily for starter batteries, due to its toughness, and its ability to withstand wide temperature changes.

The glass type is employed for house-lighting plants and radio accumulators. Being transparent, the acid level can be readily inspected and the glass acts as an excellent insulator.

Plates. The majority of accumulators make use of the pasted or
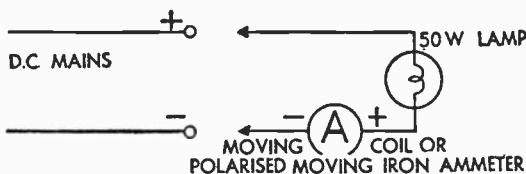
Fig. 20. An ammeter can be used in order to indicate polarity if the current is limited by a series lamp.

rate circuits where large variations of charging rate are desired, as this lengthens the life of the accumulator.

Figs. 24 and 25 illustrate how banks of accumulators can be connected to DC mains.

In Fig. 24 a variable rheostat is placed in series with an ammeter and the cells, the whole circuit being connected across the mains. By adjusting the resistance of the rheostat, the current can be regulated throughout the charge to the maker's specification.

and one negative terminal. When a number of batteries are to be charged they may be connected in parallel or in series.

In the series connection the same current flows through all the cells and must not exceed the maximum rated value for the smallest cell if a mixed batch of batteries is connected. The voltage required to charge a bank of cells is the number of cells multiplied by 2·4. Fig. 22 illustrates this series mode of connection.

When the parallel method is used, a constant voltage is applied to each cell, and the current is divided between the cells according to their internal resistances. Fig. 23 shows this method of connection, but it is not recommended, for the most discharged cell will take longer to recharge than the remainder.

It is advisable to provide sepa-

Fig. 21. If two lead strips are put in acidulated water, the negative produces more bubbles than the positive.

This is called constant current charging.

The rheostat has to be adjusted in order to maintain the current at the same value because the back-EMF of the accumulators increases as they become charged. This reduces the charging voltage and, consequently, the current tends to decrease.

Fig. 22. Series connection of accumulators. The current is limited by the maximum charging note of the smallest cell, if a mixed batch of batteries is connected.
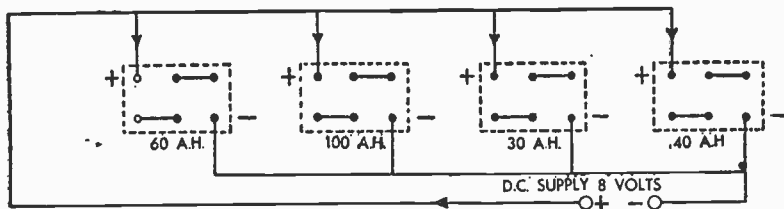
Fig. 23. The parallel arrangement must be used carefully or those units which are least run down may be overcharged.

As we shall see later in this chapter, in some chargers a constant voltage is utilised. This results in a heavy current at the start of charging and the amperage decreases to a small value when the charge is near completion.

The ammeter indicates the current passing through each cell, and any number of cells can be connected as long as their total voltage does not exceed the mains supply. The more cells that are charged at once the less is the amount of energy lost in the form of heat in the rheostat. The cost of charging is the same whatever the number of cells.

Value of the Rheostat

The value of the rheostat is calculated with the aid of Ohm's Law. Let us assume that 20 cells are to be charged from 200-v. DC mains at a rate of 2 amps. The total required voltage is $20 \times 2 \cdot 4 = 48$ v. The voltage to be dropped in the rheostat is 200 v. — 48 v. = 152 v.

The value of rheostat is given by

$$R = \frac{E}{I} = \frac{152}{2} = 76 \text{ ohms.}$$

The gauge of wire used for winding the resistance must be capable of dissipating 2 amps without appreciable temperature rise,

and 18 or 19 SWG Eureka wire is very suitable for the purpose.

Sometimes carbon lamps are used in place of the slider rheostat, as in Fig. 25. Several are connected in parallel when greater current ranges are required. The following table gives candle power
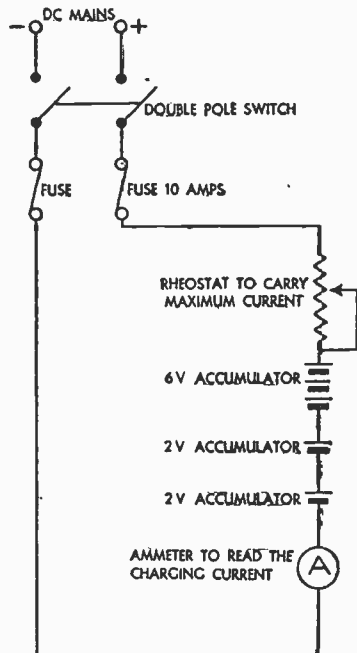
Fig. 24. How a bank of cells is connected for charging from DC mains. Current is controlled by the rheostat and measured by the ammeter which is at the earth end of the circuit.

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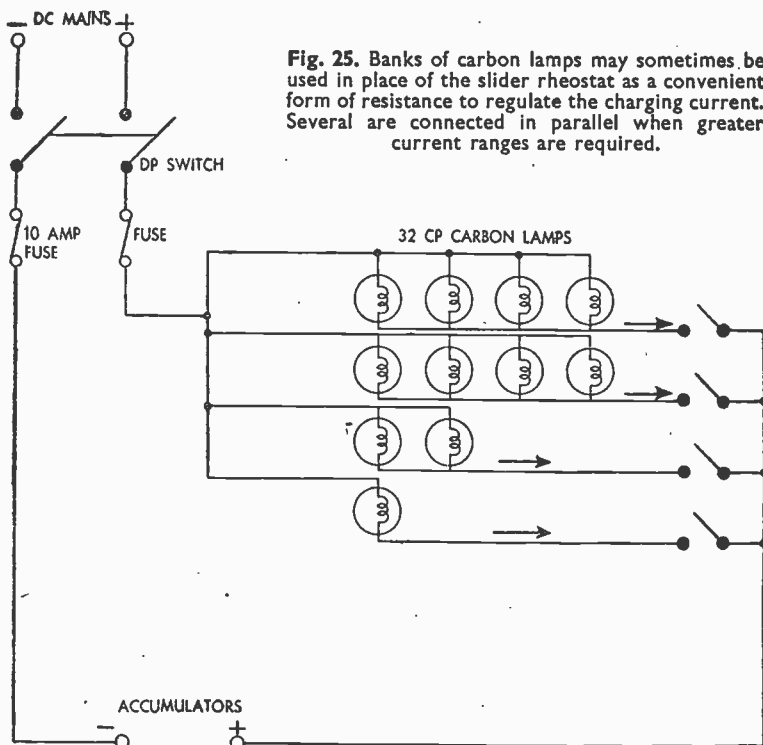
Fig. 25. Banks of carbon lamps may sometimes be used in place of the slider rheostat as a convenient form of resistance to regulate the charging current. Several are connected in parallel when greater current ranges are required.

of carbon lamps, or lamps required for certain charging rates with various voltage drops.

CARBON LAMPS AS RESISTANCES

Current in Amps.	Candle Power			
	Volts to be dropped			
	25 v.	50 v.	100 v.	200 v.
·25	—	—	8	16
·5	—	8	16	32
1	8	16	32	60
2	16	32	60	120

As a constant current is desirable, the operator only needs to switch in a number of lamps so that the correct charging current is indicated on the ammeter. Where several charging rates are desired at the same time, several banks of lamps or rheostats, each with its own ammeter, can be connected as shown in Fig. 26.

Maximum Current

The maximum current that can be obtained is limited only by the number of carbon lamps in circuit. Usually a maximum current of 10 to 12 amps is suitable. Separate branch lines accommodate banks of cells to be charged at various rates. To operate the charger in the most economical way each bank should have, if possible, its maximum number of cells on charge, thus reducing losses in the form of heat.

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Fig. 26. Where several different charging rates are required at the same time, separate circuits with different values of rheostat (or banks of lamps) are used. Each circuit has its separate switch, fuse and ammeter. There may also be, if desired, an ammeter to record the total current.
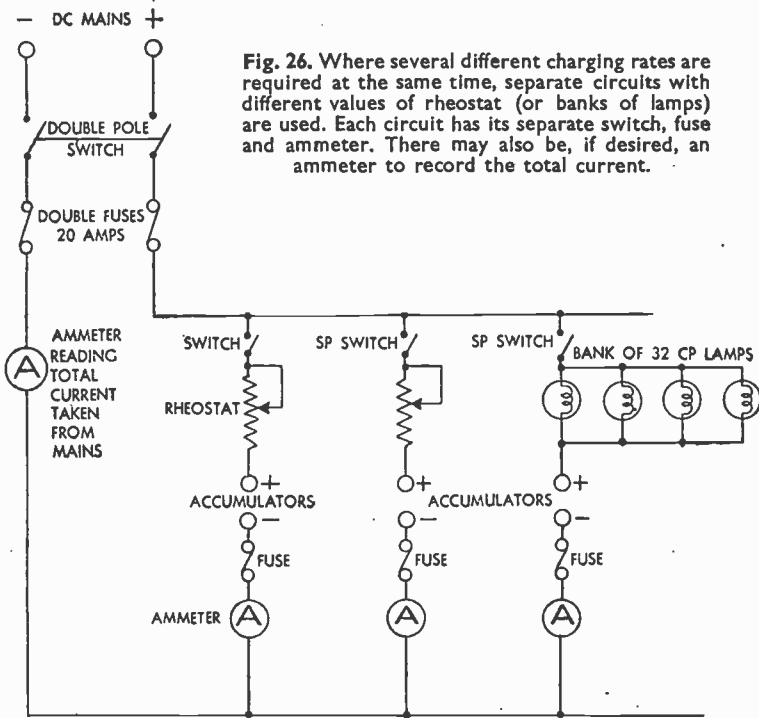
It will be seen that fuses are connected in each main lead, so that if an accidental short circuit takes place, it only puts that particular circuit out of action. Again, a switch is provided so that the whole of the apparatus can be completely disconnected from the mains.

It is essential that personal danger from shock be minimised by connecting the batteries to the earthed main. The earth main can be ascertained by means of a voltmeter, as shown in Fig. 27. Connect one side to the earthed conduit, a water tap or a metal tube driven into the ground, and connect the other side to each main in turn. The one that does not indicate any voltage or but little vol-
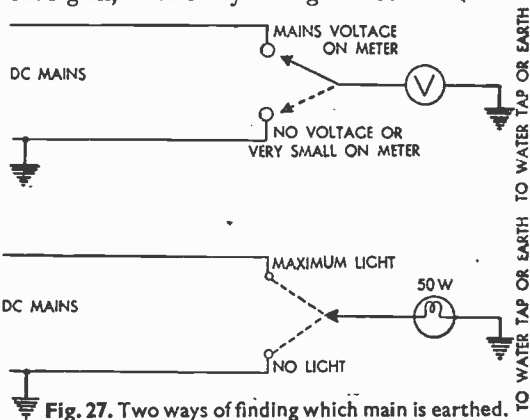
Fig. 27. Two ways of finding which main is earthed.

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tage is the main at earth potential, and this one should be connected direct to the batteries.

Either positive or negative main may be earthed, and in the former case the rheostats or lamps will be placed between the batteries and the negative main.

In large accumulator charging plants operated from DC mains it is usual for the 3-wire system to be used. Fig. 28 illustrates this
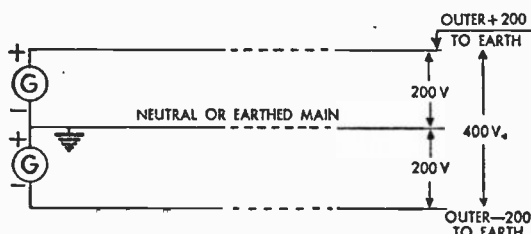
Fig. 28. A three-wire mains system provides a low voltage for domestic use and double the voltage for commercial power requirements, as described on this page.

method of distribution. The pressure of the supply is about 400 v. between the two outer cables, and a neutral or third cable is electrically between the two outers and is connected at the generator station to earth. Thus a 400 v. supply is available across the two outers for driving electric motors and other power devices, and a safer pressure of 200 v. is available between neutral and either outer for domestic use.

As the pressure of 400 v. is dangerous, it is essential to use the 200-v. connections (neutral to outer) for battery charging. If the batteries are connected through the ammeter to the earthed main, no severe shock will be felt. The fuse and switch in each lead enable the operator to isolate the live main when any alteration is required in any individual circuit.

Although it is not ideal, there are occasions where it is necessary to connect accumulators in parallel. It will be realised that as the same potential difference is across each cell, those with the lowest resistance will pass the greatest current and be recharged first. However, provided that the operator does not allow a cell to become overcharged, thus driving the paste from the plates, charging can be satisfactorily achieved.

Fig. 29 illustrates the method that can be adopted when many types of cells of differing voltage and capacity are to be recharged. Each group is arranged so that its total current is divided between the cells in such a way that no individual cell carries more than its normal charging rate.

Checking by Hydrometer

As each particular cell becomes charged it is checked by means of a hydrometer, taken from the charger, and replaced by a similar cell, or the circuit is amended and re-grouped.

Due to the differences in the capacities of accumulators, there is the possibility of charging a cell at either too high or too low a rate. Although the pasted type of plate does not mind a very slow charge and, in fact benefits by it if it has been left in a discharged condition for some time, the Planté plate is damaged if the rate is less than half what it should be.

Normally plates are designed for recharging at one-tenth to one-

twelfth of the ·AH rating. As the charge is being completed it is advisable to gradually reduce the rate, especially when the cell begins to gas.

The number of hours a cell requires for recharging depends on the state of discharge. It is dangerous to assume that a cell has been fully discharged, and then proceed to charge at a fixed rate for so many hours. To do so may result in over-charging, which, besides being costly, increases the temperature of the cell. If the temperature rises much above 100° F. the cell will shed its paste.

Consistent under-charging will also ruin a cell, for the plates become coated with insoluble lead sulphate.

Recognising State of Charge: When a cell is gradually discharged, both the terminal voltage and the specific gravity are reduced. If neither voltmeter nor a hydrometer is available, the colour of the plates will give a fair indication.

An accumulator must be considered as discharged if the voltage is less than 1·85 v. per cell and the specific gravity is less that 1·150. Care must be taken to measure the voltage while the cell is connected to a discharge circuit; open-voltage conditions do not give any reliable indication of the state of the cell. In a discharged

Fig. 29. The skilled charger forms the accumulators into a series-parallel arrangement so that no individual cell receives more than its correct charging current, which would shorten life.
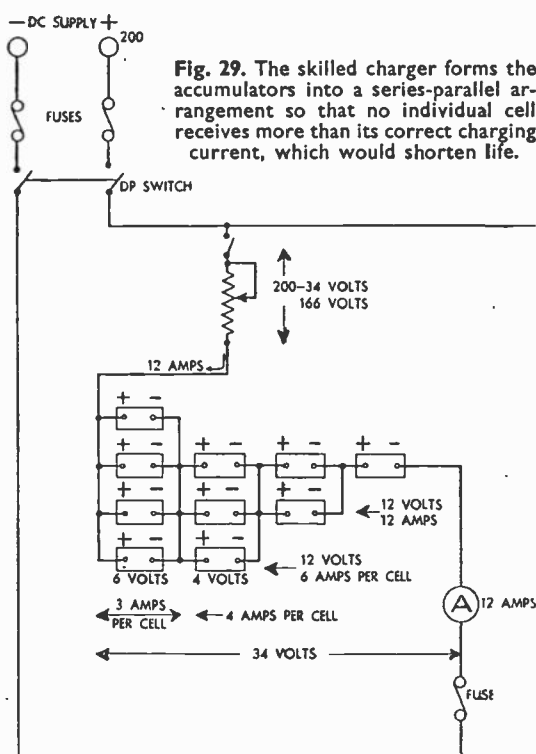
cell, both plates are of a slate-grey colour.

Colour When Charged

When a cell is fully charged the voltage rises to around 2·2 per cell and the specific gravity to a value of from 1·250 to 1·280, dependent on the type of cell. The colour of the positive plate changes to a deep rich chocolate and the negative plate remains a slate grey.

Evaporation of the Electrolyte: When a cell is to be charged, the acid level must be checked. If it is below the marking on the case, the level must be raised by the addition of distilled water. Under no account must dilute sulphuric acid be used, for it is only the water

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content of the electrolyte that evaporates. When water has evaporated the specific gravity may become high enough to indicate that the cell is not fully discharged when, in actual fact, it is.

Usually the acid level is about half an inch above the top of the plates. Only distilled water should be used, for ordinary tap-water contains chemicals that are ruinous to the plates. In an emergency, rain-water may be used.

Correct Specific Gravity

When a new cell is to be placed in commission, or where the electrolyte has been spilled, new electrolyte of the correct specific gravity must be prepared. The acid is generally supplied in concentrated form, having a specific gravity of about 1·800. This must be reduced to the manufacturer's rating for the cell by the addition of distilled water.

Great care must be taken to see that the acid is added to the water and not vice versa. The water should be placed in a vessel that will not be attacked by the acid—glass or porcelain is suitable—and very slowly the acid added. The solution should be stirred to produce good mixing. Tests with a hydrometer will show when the necessary strength is reached.

Too much emphasis cannot be laid on the personal danger that results if water is poured into the acid. Not only is great heat produced, but the solution may explode, covering everything in the vicinity with burning acid.

The following table will enable the operator to calculate the approximate volumes of distilled water and concentrated acid which are required to produce certain values of specific gravity.

Required specific gravity at 70° F.	Distilled Water by volume	Acid 1·800 by volume
1·350	15	10
1·300	25	10
1·280	27	10
1·260	29	10
1·240	33	10
1·220	38	10

It will be seen that the final specific gravity is rated when measured at 70° F., and the diluted acid should be allowed to cool to this temperature before the specific gravity is taken.

First Charge Effects

When a new accumulator is receiving its first charge the maker's instructions should be faithfully followed, for, although the plates have been "formed", the first charge influences the life of the cell. Generally the first charge is a fairly long one at less than the normal rate, and when the gassing of the cell, together with the specific gravity reading, indicate that charging is completed, the electrolyte must be emptied and thrown away. The acid should be poured down a sink with a good volume of water running.

The cell must be re-filled with new electrolyte at a specific gravity of the normal value of a fully-charged cell. The cell is then placed on charge until the plates readily gas, and then left until the temperature of the acid falls to 70°. The specific gravity is checked, and, by the use of distilled water, amended to conform with the maker's recommended value. The acid level should be checked.

Constant Voltage Charging: During the past few years there has been

a tendency to use constant-voltage charging sets. If a constant potential is applied to a cell the charging rate will be high initially, and gradually, as the voltage of the cell rises, the rate of charge will decrease. This method of charging has the advantage that it shortens the time required, and this is of importance for commercial plants handling large accumulators.

To obtain a constant voltage it is usual, where the mains are DC, to employ a mains-driven DC generator constructed to provide 7·5, 15 or 30 volts at a high current.

In the case of the 7·5 v. generator set, three cells are connected in series and placed across the busbars. When the cells are fully discharged their voltage is around $3 \times 1·8 = 5·4$ volts. The generator has a pressure 2·1 volts greater. This causes a heavy initial current to flow through the three cells but, as the voltage difference decreases, the current diminishes.

Automatic Current Regulation

This method overcomes one of the difficulties of the constant current system, in which the operator has to continuously check the specific gravity of the acid to prevent over-charging. In the constant-voltage system the current gradually tails off, thus following theoretical requirements.

Fig. 30 illustrates a typical constant-voltage system. An AC motor is connected to the mains through a double-pole on-off switch and a pair of fuses. The motor operates at constant speed, despite the varying load of the generator, which is generally compound wound. This type of generator keeps the voltage output fairly constant in spite of the varying current demands.

The DC output from the generator is fed through a cut-out, so that if the polarity of the supply is reversed—a condition which would ruin the cells—the circuit is automatically opened. A voltmeter and ammeter are provided, and the field regulator enables the operator to set the output to 7·5, 15 or 30 volts. The ammeter shows the total charging current, and the maximum rating of the generator should not be exceeded.

Car Starter Cells

Where car starter cells are to be charged, they are either of the 6 or 12 volt type, and thus the 15 volt setting is desirable. The diagram shows that any combination of cells can be accommodated, but each series circuit should consist of cells which require the same charging rate. The final checking of the cells is conducted in the same manner as already described.

Although an AC motor has been illustrated, the motor generator set can be operated by means of a DC motor and in this case a motor starter is placed in series with the DC mains to limit the starting current.

Where no mains exist there are several alternative methods of obtaining the motive-power. Probably the most reliable is the use of a petrol engine which is governor controlled, so that any reduction of load, which would normally increase the speed of the engine, reduces the amount of petrol fed to the carburettor. Such petrol-generator sets are largely used by the ground staffs of airfields and army units.

The petrol engine is either of the two- or four-stroke type, with an air-cooled cylinder-block. Wind-
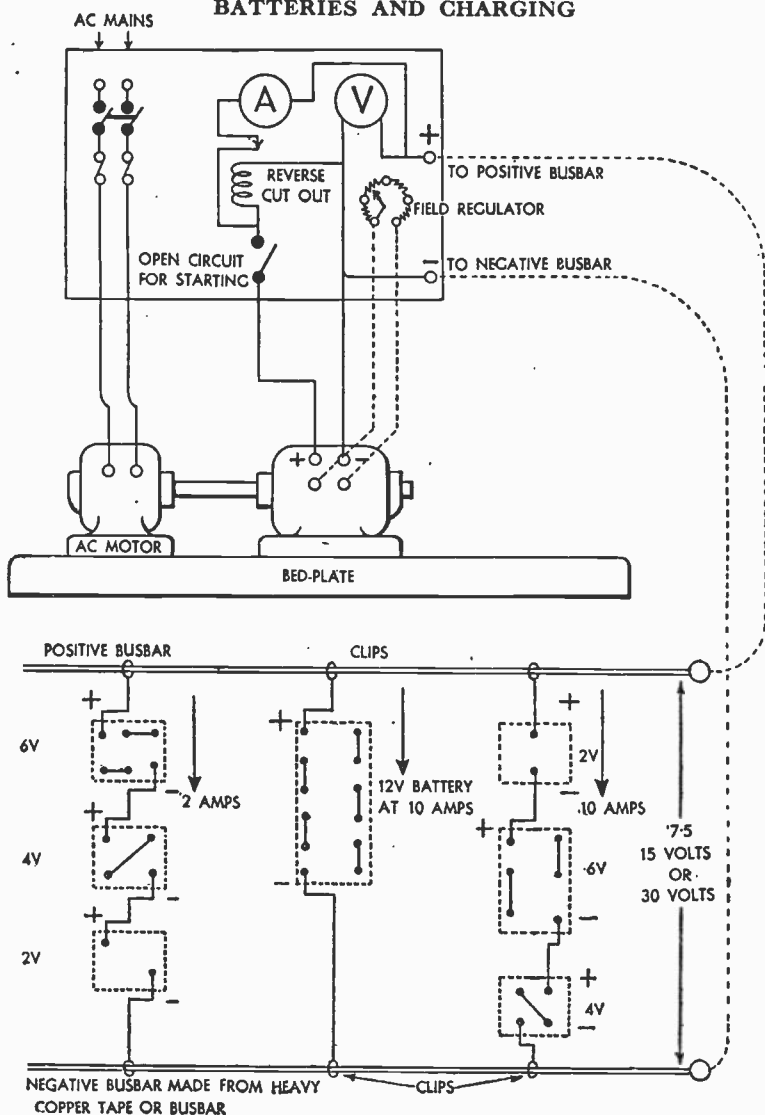
Fig. 30. Typical constant-voltage charging system employing a rotary converter. In the event of failure of the AC supply, the reverse cut-out prevents the accumulators discharging back through the generator, which would ruin the cells.

driven generators can be used at high altitudes, but the variations in rotor speed due to gusty wind operate against accurate charging. In the case of a permanent installa-tion, as might be made in a village, a gas or oil engine can be used as the prime mover.

AC Rectifiers: Where the mains supply is AC, several methods are
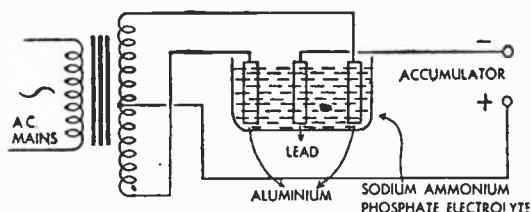
Fig. 31. Two electrodes of aluminium and one electrode of lead in a solution of sodium ammonium phosphate form an electrolytic rectifier.

available for converting it to the necessary DC for charging. An AC–DC motor-generator similar, except for the motor, to the generator just described can be used, but the following static chargers are also available:

Electrolytic,
Westinghouse and Standard metal rectifiers,
Half- and full-wave vacuum valve rectifiers,
Mercury-vapour rectifiers, and
Tungar or argon-filled rectifiers.

Certain metals when immersed in an electrolyte allow current to pass freely in one direction only. In Fig. 31 two electrodes of aluminium are seen in a solution of sodium ammonium phosphate and are connected to the ends of a mains transformer. The other electrode is of lead.

Full-wave Rectification

If the cell is connected as shown, current will flow from the lead to the aluminium, but not in the reverse direction. Thus the accumulator receives two half-cycle pulses for each AC cycle (Fig. 32), rectification having been achieved due to the centre tapped transformer.

This type of rectifier is not very

efficient and, due to temperature rise, the maximum current obtainable is rather low. If means of cooling the cell are available the latter disadvantage can be reduced, but the device remains suitable for only the smallest charger system. Tantalum metal and lead act as a more efficient rectifier, but the free liquid still makes the method undesirable.

Westinghouse Rectifier

During the last few years the Westinghouse metal rectifier has achieved great popularity. This rectifier is of the static type (does not employ moving parts), and appears, if not grossly overloaded, to be "everlasting".

The rectifying action is electronic in nature, and takes place at the junction of copper and copper-oxide surfaces. Current passes from the copper oxide to the copper without much resistance, but in the reverse direction a resistance about 1,000 times greater is presented.
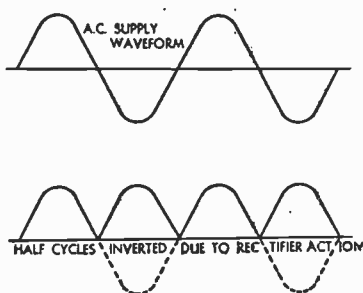
Fig. 32. With full-wave rectification, charging current is obtained from both positive and negative halves of each cycle of mains current.
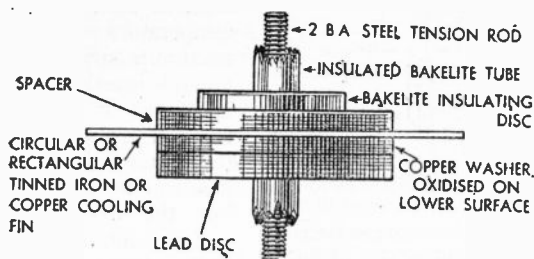
Fig. 33. Construction of a metal rectifier element.

Fig. 33 illustrates the construction of the rectifier element, and this general assembly is used for both low- and high-voltage rectifiers. Elements are made up into assemblies, as in Fig. 34. The current that can be taken from the rectifier is limited by the temperature rise, and this is in turn limited by the area of the disc. Where larger currents than about 5 amps are required, the Westinghouse plate rectifier is used.

It will be appreciated that not only are there no mechanically moving parts to the metal rectifier, but there is not even a heated filament as in the valve rectifier. This contributes to the "everlasting" life of this unit. To offset against this advantage is the fact that the initial cost is rather higher than with valve rectifiers of comparable output.

The full-wave bridge rectifier is probably the most usual for battery charging circuits, as it gives high efficiency and requires an AC voltage supply of approximately the same value as the required DC output.

In Fig. 35 the bridge rectifier is connected to an AC supply across opposite members of the bridge. The elements are numbered, and full-wave rectification takes place as follows: Assume that the upper end of the winding is positive relative to the lower end at a certain time. Then current flows through No. 1 rectifier to the ballast resistance, through the accumulator, back through No. 4 rectifier to the negative end of the winding. It cannot traverse any other path, as 2 and 3 are connected in the non-conducting direction.

On the next half-cycle the conditions are reversed. The lower end of the winding is positive, and the upper end is made negative. Thus the current flows through rectifier 3 to the ballast resistance, through the accumulator, and back through rectifier No. 2. Thus on both half-cycles the current travels through the accumulator in the same direction. Fig. 36 shows the mechanical method of assembly of the elements and serves as a practical wiring diagram.

When it is desired to adjust the voltage output of the rectifier, it is necessary to arrange for this in one
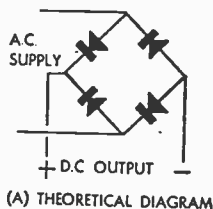
(A) THEORETICAL DIAGRAM
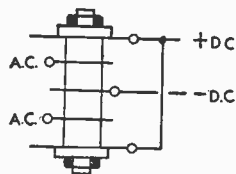
(B) MECHANICAL ARRANGEMENT OF ELEMENTS SHOWING TERMINALS

Fig. 34. A number of elements are assembled together to form a practical metal rectifier.
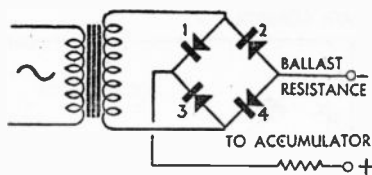
Fig. 35. Bridge connection of metal units for full-wave rectification.

producing approximately twice the voltage across the output circuit compared with the AC input to the rectifier. Each rectifier charges its own condenser when it is in its conducting direction. The two condensers are connected in series, and the sum of their voltage discharges into the load.

The circuit diagram in Fig. 40 is typical of a complete charger using Westinghouse or Standard Telephone electronic rectifiers. The primary of the mains transformer is tapped, so it can be adjusted to the local mains voltage. Two secondaries are provided, each with tappings for voltage regulation. The first rectifier is used for charging HT accumu-

of three methods. Firstly, by means of the voltage drop in a simple resistance, as shown in Fig. 36; secondly, by the use of a tapped choke in series with the transformer, as in Fig. 37; or thirdly, by the use of a tapped transformer secondary winding (Fig. 38).

The latter method is the most economical. It is advisable to insert a small resistance of a fraction of an ohm, so that in the event of a short circuit the output current will be limited and damage to the rectifier prevented.

A half-wave rectifier is normally used for high-voltage, low-current chargers. It is very useful for charging HT accumulators, where the current is usually not above .0·5 amp., but the voltage may be quite high.

The "voltage doubler" system (Fig. 39) has the advantage of

Fig. 36. One way of regulating the current is by means of the voltage drop in a series resistance.

lators, the second for low-current charging rates, the third for medium rates, and the last for heavy rating.

Where low-current charging rates are required, the hard vacuum-valve rectifier is widely used. In this case a filament heat-

TAPPED CHOKE COIL METHOD OF VOLTAGE CONTROL

Fig. 37. If a tapped choke is employed, the applied voltage and hence the current can be adjusted without loss of power as in a resistance.

TAPPED TRANSFORMER METHOD OF OUTPUT VOLTAGE CONTROL
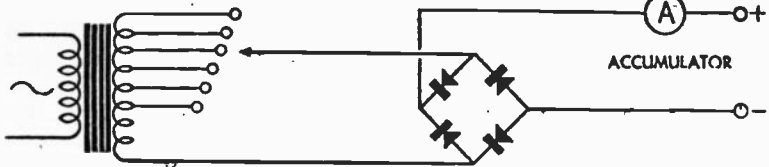
Fig. 38. Tappings on the transformer enable the voltage, and hence the current, to be regulated, and make an appreciable difference to running costs.

ing winding on the mains transformer is necessary. The valve can be of the half-wave type, as shown in Fig. 41, or the full-wave type, as in Fig. 42. During the negative half-cycle no current flows through the accumulator in the half-wave type, but on the full-wave type current flows during both half-cycles.

The Argon or Tungar rectifier (Fig. 43) is used for relatively high currents of the order of 5 amps. The operation of the tube relies on the ionisation of the gas molecules. A filament is heated by means of a separate transformer winding, and a positive potential applied to a carbon anode which attracts the electrons emitted from the filament at a high velocity.

On their way to the anode the electrons collide with atoms of argon gas, hitting them with sufficient velocity to release electrons. Thus an increased number of electrons flows to the anode, constituting a greater external current.

The atoms, having lost one or more of their electrons, are now "positive ions" and, being relatively heavy, they drift to the most negative part of the circuit, the

filament. Thus the internal resistance of the tube is considerably lower than that of the hard vacuum valve, and larger currents can be drawn from the filament.

Where large DC currents are required the mercury-vapour rectifier is invaluable. Fig. 44 shows a typical circuit in its simplest form. The rectifier operates in a similar way to the Tungar rectifier—that is, it relies on the collision of molecules and allows a very low resistance path for the current flow.

When a mercury arc is started between the pool of mercury and the anode, electrons can only flow when the mercury pool or cathode is negative in respect to the anode. The mercury pool is partly vaporised, and acts as a carrier of the rectified current.

On single-phase supplies two anodes are provided, so that full-wave rectification can be obtained. A small starting arc is provided to commence the discharge. The electrons leave the cathode when either of the anodes is positive.
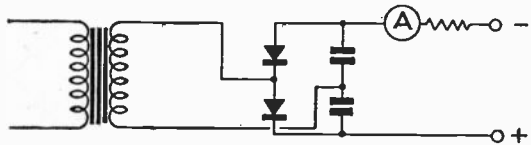
Fig. 39. By the voltage doubler system, an output voltage of approximately twice that of the input is secured.

VOLTAGE ADJUSTMENT
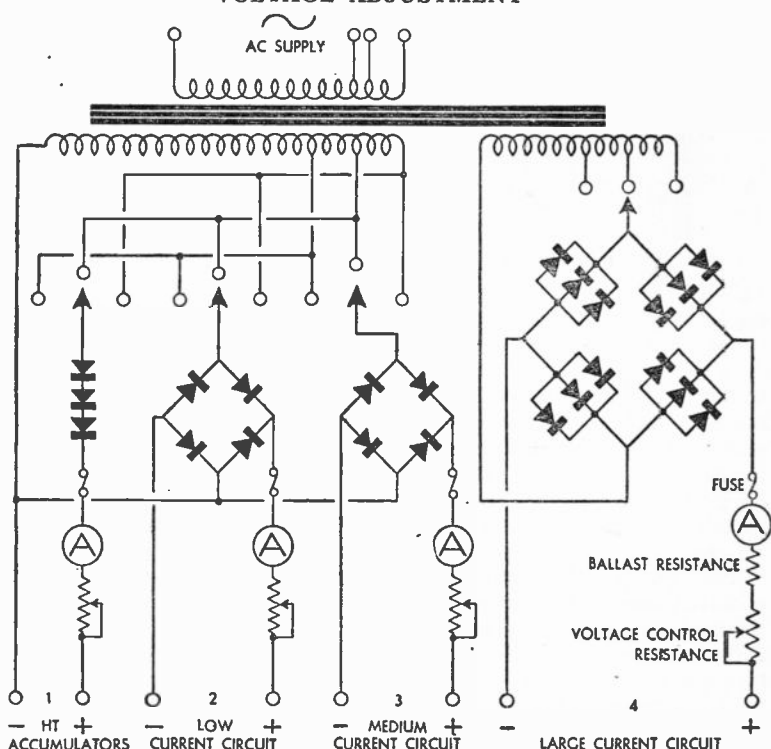
Fig. 40. Circuit of a complete metal rectifier charging unit with four circuits providing different charging rates. The valve may be either half-wave or full-wave.

Because the electrons have left it, the cathode becomes more positive than it was, and it is the positive side of the battery charger. Voltage adjustment is provided by means of tappings on the transformer secondary.

Alkaline Cells: During the past twenty years, cells have been constructed which are not only different from the lead-acid type, but are in some ways superior. There are two main types: the Edison, which makes use of nickel and iron, and the Nife, which employs nickel and cadmium.

In the Edison the plates are built up from steel tubes which
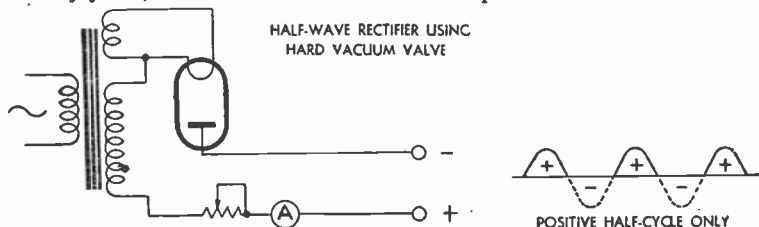
Fig. 41. Half-wave valve rectifier and (*right*) diagram representing the AC wave.

K   289   (R.E.)
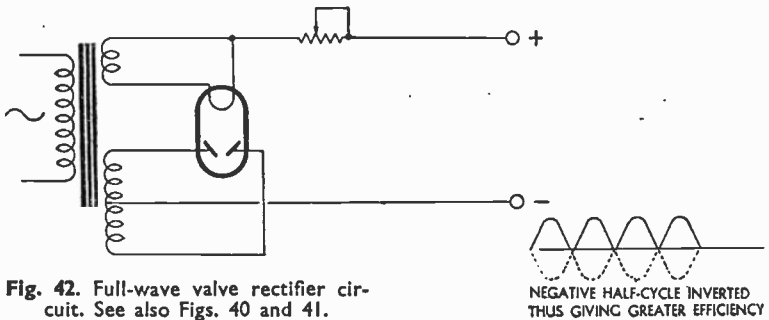
Fig. 42. Full-wave valve rectifier circuit. See also Figs. 40 and 41.

NEGATIVE HALF-CYCLE INVERTED
THUS GIVING GREATER EFFICIENCY

contain nickel hydroxide and flaked metallic nickel for the positive plates and powdered iron oxide for the negative plates. The tubes are perforated so that the caustic potash has access to the active material.

The groups of negative and positive plates are bonded together by steel bolts and spacing pieces, and stout steel lugs are brought through the top of the welded steel outer case. Rubber separators are used between the plates and the outer case and the groups of plates. The specific gravity of the alkaline solution is 1·190 to 1·200, and differs from the lead-acid cell in that the specific gravity remains constant during the whole of the charge–discharge cycle.

As the electrolyte has no chemical action on the steel plates or container, there is no internal corrosion. But the solution will absorb carbon dioxide from the air, and it is necessary to hermetically seal the cell by an efficient filler cap. The electrolyte is made by the addition of distilled water.

The steel cells are usually assembled in hardwood cases, such as teak or oak, and are located by an external suspension boss welded to the outer side of the steel case. Ebonite insulators fit over the steel bosses, and thus insulate the cells from the case and prevent local leakage.

One of the features of the Edison cell is that compared with the lead-acid cell it has about 50
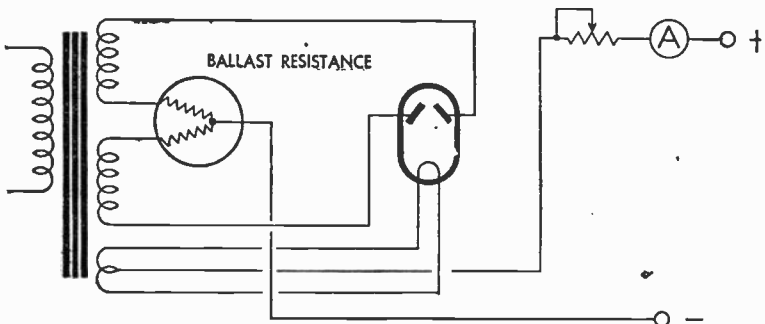
Fig. 43. For charging currents of the order of 5 amps Argon or Tungar rectifiers are employed. They are efficient and give good service.
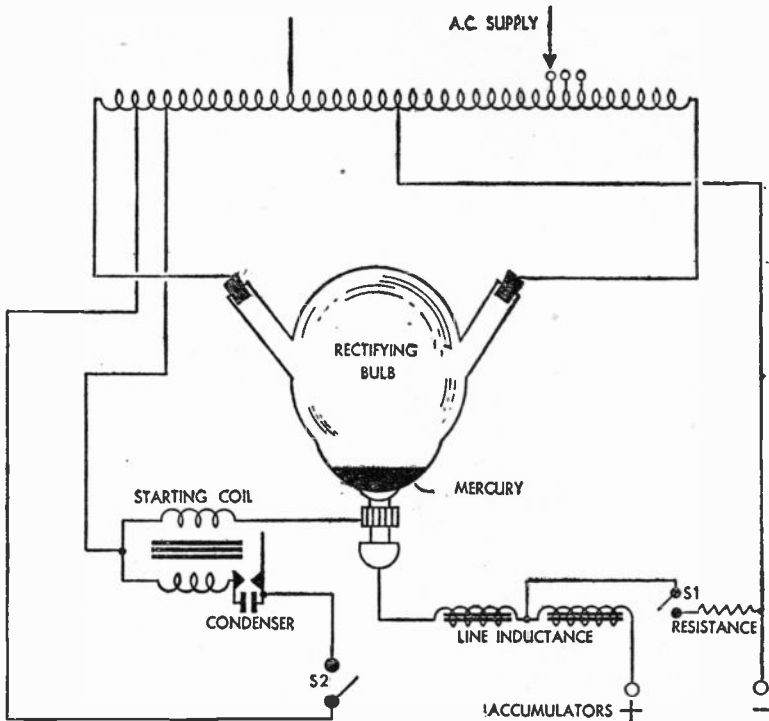
Fig. 44. Large currents are obtainable from the mercury-arc rectifier. Here is a typical circuit in its simplest form. Its operation is similar to the Tungar rectifier.

per cent. greater capacity for a given weight.

The terminal voltage under load is 1·2. Thus for a 6 volt circuit five cells are necessary compared to three of the 2-volt lead-acid type.

No matter how badly the cell is treated it appears to be indestructible. Not only can dead short circuits be made with impunity, but the cell can be left without fear of subsequent failure due to corrosion or leakage. It is extremely robust mechanically, and no paste is shed from its plates if it is charged at too high a rate or for too long a period. With the exception of replacing the electrolyte

after every 12 months, no replacements are necessary.

As the Edison cell gasses during the whole charging period, and as the specific gravity is constant, these cannot be used as indications of state of charge. The operator must rely on the voltage indication only. When the cell is fully charged it gives about 1·75 volts; the discharged reading is 1·2 volts.

The charging rate of any particular cell can be exceeded above the standard rate, providing the temperature does not rise above 115° F.

When a cell is to be left for any long period, it should be half discharged and the filler caps securely

FILLER CAP

COPPER ROD PRESSED INTO STEEL LUG

TAPERED POLE
FILLER CUP
CELL COVER (WELDED JOINT)
HARD RUBBER GLAND RING
COLLECTING BAR
POSITIVE PLATE FRAME
POSITIVE PLATE
NEGATIVE PLATE

STEEL GLAND NUT
GAS RELEASE VALVE
STUFFING BOX
SOFT RUBBER GLAND RING
SPACING WASHER
LOCKED NUT
NEGATIVE PLATE FRAME
POSITIVE ACTIVE MATERIAL
NEGATIVE ACTIVE MATERIAL
EBONITE SEPARATORS

STEEL CONTAINER (SPECIALLY RUST PROOFED)

FINELY PERFORATED POCKET ENVELOPES

SUSPENSION BOSS

CELL BOTTOM (WELDED JOINTS)

Fig. 45. In the Nife cell, the plates consist of finely perforated steel tubes containing nickel hydrate for the positive and cadmium and iron oxides in the negative.

screwed down with the electrolyte left in the container. The cell should be stored in a clean, dry place. When brought back into commission, a cell should be recharged at its normal rate for 12 hours.

Although this cell has many advantages, it has a higher internal resistance than the lead-acid cell, and there are; therefore, certain jobs for which it is not suitable.

In the Nife alkaline cell, illustrated in Fig. 45, the active material of the positive plate is a specially prepared nickel hydrate mixed with other chemicals that increase the conductivity and porosity of the plate. The negative plate is filled with cadmium and iron oxides. The electrolyte is mainly potassium hydrate in a solution of distilled water, and has a specific gravity of 1·170.

The mechanical construction of the positive and negative plates is practically identical, and it will be seen from Fig. 45 that they consist of a finely perforated steel strip formed into flattened tubes containing the chemicals. The tubes are sealed and cut to standard lengths, then mounted into steel frames and locked into position by means of ingenious interlocking seams.

It is impossible for the tubes to burst, and the internal resistance of the plate is lower than any other type of construction. The plates are pressed under great pressure, and then completed groups are mounted, together with the aid of steel bolts with suitable spacing washers.

Containers are constructed from steel sheet cadmium, nickel-plated to ensure freedom from rust and external corrosion. Steel bosses are welded to the sides of the cells to act as supports when the complete unit is mounted into a strong wood crate.

The terminals are passed through the upper plate and insulated from each other by means of a rubber seal, that not only acts as an electrical insulator, but also a hermetic seal. The smaller cells have a hinged filler porcelain valve, and the large cells have a hinged filler cap that incorporates a gas-valve.

One of the outstanding features of the Nife cell is that it can be

recharged in 6 hours, but if necessary this rate can be varied over a very wide range. No corrosive gasses are given off, and the cell can be charged at very high rates, known as "boosting", provided its temperature does not exceed 120° F. or 50° C. The cell can be quite satisfactorily trickle charged, with a voltage as low as 1·47 volts per cell.

During discharge the Nife cell gives an average of 1·2 volts and, due to the low internal resistance, this voltage remains substantially constant. Contrary to the lead-acid cell, the ampere-hour capacity is practically constant, irrespective of the rate of discharge.

The cells are delivered in a discharged state, but they are filled with the alkaline electrolyte, and the filler vents plugged with wood to prevent spilling. The level of the electrolyte must be checked, and should be compared with the maker's figures for that particular cell. The final specific gravity of the electrolyte after any distilled water has been added should be between 1·170 and 1·190.

Rating of Cells

The cells are rated at a certain discharge rate, and the AH capacity is based on this rate. However, as stated previously, much greater loads can be imposed provided the temperature does not rise above 120° F. The battery should be considered as fully discharged when the terminal voltage on normal load falls to 1·1 volts per cell.

On routine charging the cell should be charged at the maker's rate, irrespective of the discharge condition. A fully discharged battery must be given a full charge before it is placed into commission again. If the state of discharge is in doubt, a generous charge can be given without any harm.

It is important to note that the filler caps must be kept *closed* at all times except when specific gravity measurement or topping up is being undertaken. The electrolyte tends to absorb carbon dioxide from the air, which ruins it, forming potassium carbonate.

Charge–Discharge Cycle

After about every twenty-fifth charge–discharge cycle it is advisable to discharge the battery fully to 1·1 volts per cell, and then recharge at the normal rate for 12 hours. This over-charge compensates for any variation in the number of ampere-hours taken from the cell compared with those replaced during charging.

The voltage must be brought down to 0·8 volt per cell at normal discharge rate and the cells removed from their crates. They are then vigorously shaken to loosen any sediment, emptied, and rinsed out with several applications of tap-water until the cells are quite clear.

After leaving the cells inverted for half an hour to let the water drain away, the cells are refilled with new electrolyte, of 1·19 specific gravity, to the correct level. In no circumstances must the plates be exposed for longer than half an hour, for they will absorb the air, which will later contaminate the electrolyte, with most unfortunate results.

The electrolyte of the alkaline cell is corrosive to the skin, and if the operator is burned, the pain can be relieved by the application of a 10 per cent. solution of citric acid in distilled water. If the solution affects the eyes, a 1 per cent. solution should be used.

CHAPTER 11

RADIO SERVICE EQUIPMENT

THE ANALYSER. MILLIAMMETERS, VOLTMETERS AND OHMMETERS. THE BY-
PASS OR SHUNT. RESISTANCE MEASUREMENTS. AC METERS. MOVING-IRON
TYPE. VALVE TESTERS AND THEIR CIRCUITS. CAPACITY TESTERS. ELECTRO-
LYTIC CONDENSERS. THE SERVICE OSCILLATOR. OUTPUT METERS. AUDIO-
FREQUENCY OSCILLATORS. VALVE VOLTMETERS. CATHODE-RAY OSCILLO-
GRAPHS. TOOLS AND THE WORKSHOP.

BEFORE the repairing of a radio
receiver can be attempted, or
really even discussed, a know-
ledge of the principles underlying
service equipment is essential.
Whenever we talk about any par-
ticular fault, it is generally in
relation to tests which must be
carried out with instruments. It is
not much good talking about
using a milliammeter to measure
the anode current of a valve or the
application of an ohmmeter to
check up resistances, or a service
oscillator to trim up circuits, un-
less we have a fairly good idea of
these instruments and how they
are applied in general practice.

The Analyser

The most-used instrument
either in the service workshop or
in the field (the term "field" is
applied to all service work carried
on outside the workshop and in
customer's houses, ·factories and
so on) is the analyser. This
instrument is a very comprehen-
sive and rather complicated-look-
ing piece of equipment, but it is in
fact a simple milliammeter, which
is made to work in as many
different ways as possible.

We will, therefore, trace the
evolution of the modern analyser,
building it up circuit by circuit
from its simple source, as by so
doing we shall gain an understand-
ing of the operations of the milli-
ammeter, voltmeter and ohmmeter.

Moving-Coil Meter

There are two types of milli-
ammeter which concern us; one is
termed a moving-coil instrument,
and the other a moving-iron. As
the former is the more sensitive
and is in practically universal use,
we will build our analyser round
it, and refer to the moving-iron
type later.

When a varying current is
passed through a coil of wire sus-
pended in a strong magnetic field,
interaction between the field of
force surrounding the coil and the
field of force created by the magnet
causes the coil to move in sym-
pathy with the current flowing
through it. Fig. 1 shows how this
principle is applied to meters. It
will be seen that the small coil acts
like an electro-magnet when cur-
rent flows through its windings.

The North Pole of the coil is
attracted by the South Pole of the

permanent magnet which surrounds the coil, and the South Pole of the coil is attracted by the North Pole of the magnet. As the coil is pivoted, it rotates in the direction indicated by the arrows, and we have, therefore, the basic movement of a meter.

A very small current flowing through the moving-coil generates only a weak field, and the coil moves only a small amount against the action of the hair springs which are mounted on the axis of the coil. A larger current flowing through the coil creates a stronger field, causing a greater interaction with the field of the magnet, and so moving the coil round further.

By having a very light pointer fixed to the coil system and a graduated scale arranged behind the pointer, the amount of movement may be noted. This movement is a measure of the strength of the current flowing through the coil. By calibrating the scale behind the pointer by comparison with a standard meter, the value of the current which has caused the pointer to move along the scale can be determined and the scale marked accordingly.

A moving-coil meter may cost a few shillings or many pounds, but the fundamental principle of operation is the same. The difference in price is accounted for by the detail design and workmanship. Thus a milliamp. of current flowing through a cheap meter may cause the needle to move only a quarter of an inch, but the same current applied to a high-quality meter may be sufficient to make the needle to go the full length of a long scale.

When a current ceases to flow, the moving coil must be brought back to the normal "zero" position, ready for the next measurement. This is effected by means of small hair-springs, two of which are used so that they may also be employed to convey the current from the terminals of the meter to the ends of the winding.

The springs are mounted one at each end of the coil pivot, and are in opposition, so that as one unwinds the other winds. This action
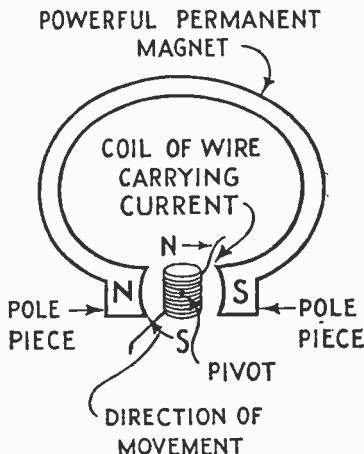
Fig. I. The interaction of two magnetic fields, one produced by a magnet and the other by a coil, is the principle of the moving-coil meter.

prevents the needle being deflected across the full scale for only a very small current, and also steadies the movement.

The springs absorb, in the form of mechanical energy, the electrical energy of the current moving the coil. The more the springs are moved from their normal position, the greater is their effort to retard the movement. When the electrical energy acting upon the moving coil is equal to the energy stored up in the springs, and which is acting against the coil movement, then the needle comes to rest.

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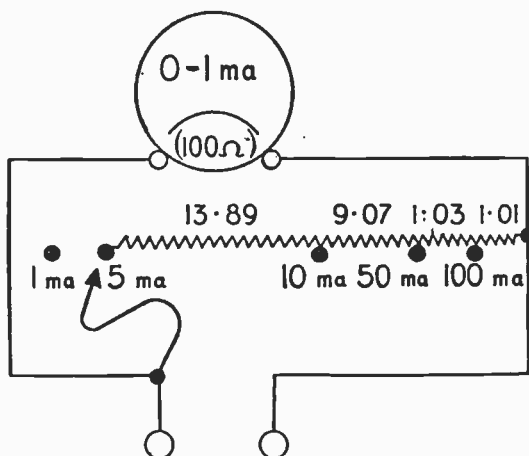
Fig. 4. The current measurable with a meter can be increased by providing shunt (parallel) resistances.

amp. would flow, and the needle would register this amount of current on the scale, and this point could be marked "0·5 v."

Thus we have the underlying principle of multi - voltage ranges and the reason for various sets of markings on a single scale. Fig. 5 shows how a number of resistances may be connected so that any one may be selected for a particular voltage range.

meter circuit, and if we know what resistance is in that circuit, then we have two of three quantities involved in Ohm's Law.

This law states in one of its forms that $E = IR$, where E is volts, I is current (in amps) and R is resistance (in ohms). If we put a resistance of 10,000 ohms in series with the meter, connect the two across a battery and get a reading of 1 ma., Ohm's Law tells us that the potential must be 10 volts. Therefore, we can mark on the scale at the 1 ma. calibration point "10 v."

Obviously, with this voltage any resistance less than 10,000 ohms will cause too much current to flow through the meter and may burn it out. But supposing we want to measure 1 v.; then we must use a 1,000-ohms resistance in series with the meter, and this necessitates 1 v. to force 1 ma. through the circuit, and we can mark 1 v. against the 1 ma. point on the scale.

If we were to apply only 0·5 v. to this circuit, then only half a milli-

For general service work it is not essential to take into account the resistance of the meter when adding series resistances for voltage ranges. For example, for a 10 v. range, the series resistance should be 9,900 ohms, as this value, when added to the 100 ohms of the meter, gives the required total of
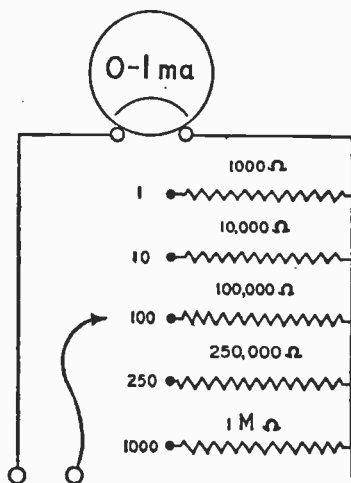
Fig. 5. How resistances can be selected for various ranges of voltage readings.

10,000 ohms. For home-built analysers a good-quality resistance of 10,000 ohms may be used.

The next step is to combine the shunt and the series resistances so that they may be easily selected by a simple switching arrangement. Two ways of doing this are shown in Fig. 6. At *a* we have a simple switch and three terminals. The test-leads are connected either to the terminals marked "Common" and "ma." for reading current, or to the terminals marked "Common" and "v.", when it is desired to read volts.

To overcome this changing of leads, a double-pole rotary switch may be employed and wired up as shown in Fig. 6b. Where there are a great number of ranges, a combination of the two arrangements is often used, otherwise too many pairs of contacts on the switch would be needed. This would complicate wiring and necessitate a large switch.

The final purpose for which we wish to use our meter is for resistance measurements. Meters that measure resistances are often termed ohmmeters, and just as in the case of the voltmeter, they are milliammeters which apply Ohm's Law. The designer arranges for a battery of known voltage to be incorporated in the meter, and when a certain current flows, as indicated by the meter, it is known what resistance must be in circuit to allow that amount of current to flow. The scale may thus be marked in ohms at the various current readings.

Simple Ohmmeter

Fig. 7 shows a simple arrangement for an ohmmeter; the first step is to have the battery and resistance (*R*) so that only 1 ma.

will flow when the circuit is complete.

The next step is to provide two terminals for test-leads. This will break the circuit, but we know that if we short the leads, the milliammeter needle will fly over to full scale, and the position may be marked "Zero ohms". The other end of the scale will be "Infinity ohms"—that is, with the test-leads not joined together. If we apply the test-leads to anything which has a resistance, this resistance will prevent the needle from passing
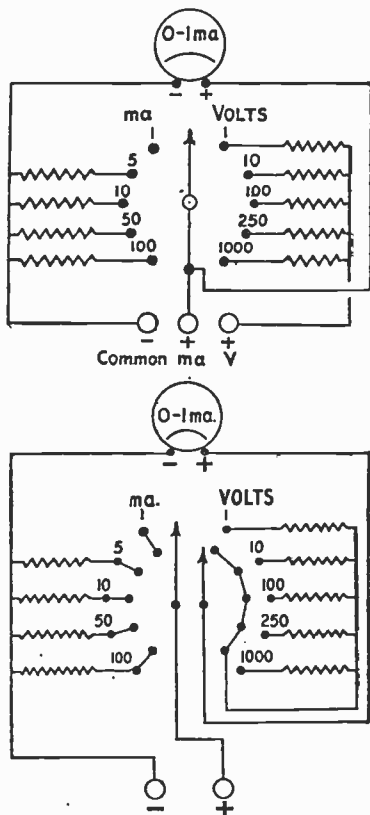
Fig. 6a (top) and b. Two ways of switching both shunt and series resistances for a combined current and voltage measuring instrument.
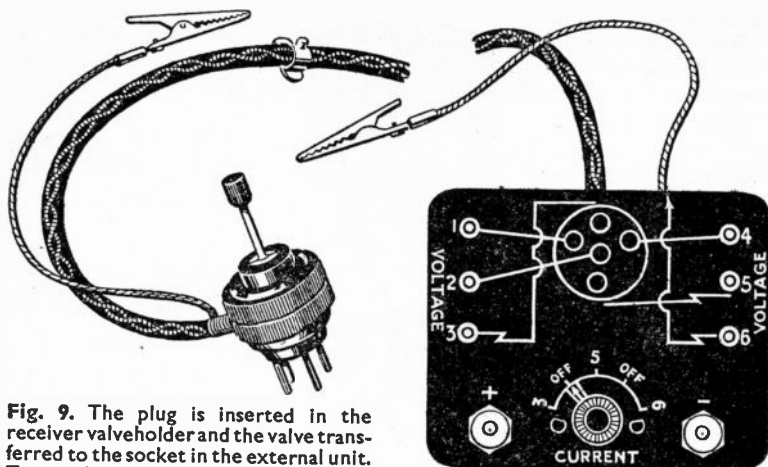
Fig. 9. The plug is inserted in the receiver valveholder and the valve transferred to the socket in the external unit. Terminals enable the current and voltages in each lead to be measured.

adopted for checking a faulty receiver. In this country, however, valve-testers are usually separate instruments. For theoretical considerations, however, it will be found easier to appreciate their functioning by incorporating a simple valve-tester into the analyser circuits we have described.

In its simplest form the valve-tester is nothing more than an adaptor which is plugged into the valveholder so that the anode circuit is broken, enabling a milliammeter to be connected so as to read the anode current. Fig 8 illustrates this simple plug-in adaptor arrangement.

To guard against a faulty diagnosis, other data should be checked, and for this reason the arrangement shown in Fig. 9 is often used. As will be seen, it comprises an adaptor which plugs into the valveholder and a multi-core cable connecting the pins in the adaptor to corresponding sockets on an external valveholder panel. The valveholder has contacts wired in series with each socket, which

enable a meter to be connected. A similar adaptor is also shown in Fig. 10 and it is seen in use in Fig. 11.

We thus have a means of measuring the current flowing in each electrode circuit and also, by applying the leads of the analyser between the various electrodes, the voltages can be measured. Measurements taken will provide evidence as to whether, for example, a low anode current is due to a faulty valve or to a fault in the anode circuit in the receiver.

If the anode voltage is normal or higher than normal, while the anode current is very low, then this will indicate a faulty valve. If, however, the anode current is low and also the anode voltage is much lower than it should be, then this will show that the low voltage is the cause of the low current flowing and will indicate some fault in the HT supply circuit.

Valve analysis along these lines will often more rapidly locate a fault in the receiver than will the use of a separate valve-tester,

which will only indicate whether a valve is faulty. If the valves are not faulty, then they have to be replaced in the receiver and investigations carried out by checking up the valve voltages and current as outlined above.

Modern receivers are very sensitive, and will most likely be forced into instability if any of the HF or IF valves are removed and replaced by the plugs of an analyser with its long leads. Nevertheless the analyser plug and the valveholder on the analyser to which the cable is connected forms a very convenient method of testing anode, grid and heater voltages, which, perhaps, could not have been undertaken without removing the receiver chassis from the cabinet.

To get thoroughly used to the various ranges and to obtain practice in reading the scale of the particular instrument with which he is to work, the engineer should spend an hour or two measuring
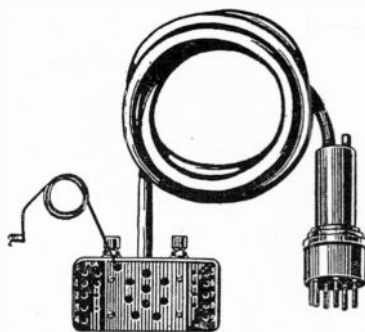
Fig. 10. An adaptor similar in principle to that in Fig. 9. The meter connections are made by plugs and sockets on the extension valveholder unit.

resistances of known value, checking the voltages of HT batteries, accumulators, and so on, and taking current readings by measuring valve emissions with the aid of a valve-adaptor, or by breaking the circuit of the valve to be tested and connecting the meter in series with the anode or cathode circuits. This is described more fully later.
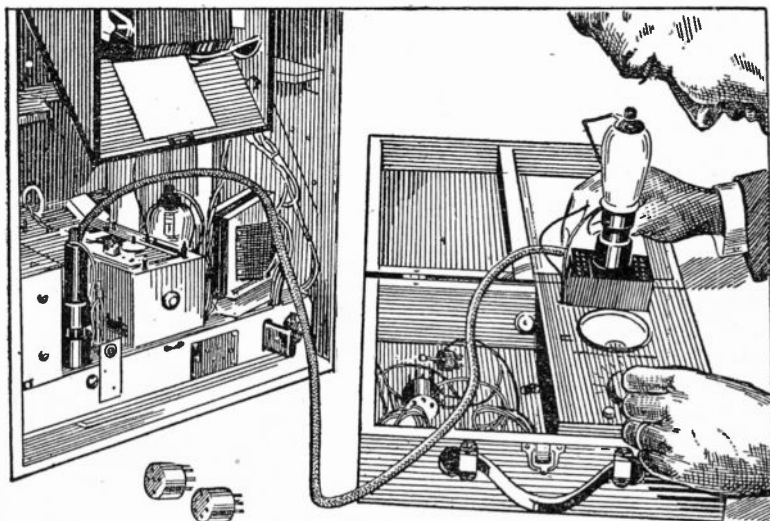
Fig. 11. The adaptor of the kind shown in Fig. 10 in actual use. It is known as the Weston Analyser. Various plugs provide for different valves.

Fig. 12. The Mullard valve-tester. The valve is inserted in a holder, a special card is inserted at the top and all the necessary test connections are made either by pulling the lever or by pressing the buttons.

Always leave the analyser adjusted to the highest voltage range if there is no "Off" position of the switch. This will prevent accidents should one absent-mindedly apply the leads to a high-voltage circuit. Also this will prevent the analyser being left on a low-resistance measuring range, which, as pointed out, will entail a heavy drain upon the internal battery in the analyser.

When taking high-resistance measurements do not hold the bare metal parts of the meter test-prods, otherwise readings will not be accurate. This is because the human body has a resistance which varies with different people, but has an average value of about 50,000 ohms when

When the meter is to be applied to a circuit in which it is not known just what values of current or voltage may be expected, great care should be taken to set the meter to its highest range.

For example, take the case of measuring a voltage between the anode and cathode of a valve. The meter should be set to the highest range, which may be 0-1,000 volts; if the needle of the meter gives only a slight movement, then the analyser can be adjusted to the next voltage range which may be 0-500 volts. This will, no doubt, bring the needle well along the scale to perhaps, the 100-v. mark, but if there is a voltage range on the meter of 0-250 v. the meter should be switched to this range.

The needle will then swing up to the middle of the scale, where it will be easily read and where, as a matter of fact, the calibration of most meters is more accurate than along the first half of the scale.

Fig. 13. A neat portable valve-tester (Norman Rose) which when operating draws from the mains.

measured from one hand to the other. If the prods are held while the resistance of 50,000 ohms is being measured, the meter will only indicate a value of 25,000 ohms, which is the resultant value of two 50,000-ohms resistances in parallel.

Lastly, treat analysers gently. Modern instruments are robust and stand up to a lot of hard usage, but if they are handled sympathetically they will give much better service and have a long life, and will prove themselves to be one of the best friends of the service engineer.

A valve-tester which can measure the efficiency of a valve is extremely useful in the service workshop. They are really very simple in their basic principles, although many of them appear to be bulky and complicated. This is merely because there are so many different types of valve with so many different forms of bases that a great part of the instrument is taken up in making room for all the various holders required.

Some popular valve-testers are shown in Figs. 12, 13 and 14.

Most testers operate from the mains and the mains transformer supplies HT for the anode and screens of the valves, while there will be several LT windings of different voltages to apply to the filaments or heaters of 2, 4, 6·3, etc., voltage ratings.

Battery valves can operate quite happily from AC of the required voltage for the particular test which is the proof of their efficiency. The method by which the test is

applied in most instruments is to measure the change in the anode current which occurs when the grid voltage is varied a definite amount.

This change of milliamps divided by the change of grid volts is the "mutual conductance" of a valve, and is a measure of its amplifying power. A valve is often referred to as having a certain "slope" of so many ma.-per-volt, and this means that for a change

Fig.14.The Avometer valve-tester utilises add-on units.

of one volt applied to the grid the anode current will change by the value given.

Other tests are applied to the valve for insulation or short circuits between the electrodes. Another test generally provided is for softness. When a valve gets old a certain amount of gas is liberated from the metal electrodes, and this reduces the vacuum and causes a high anode current. When a normal receiving valve is very soft, a blue glow may be observed, and this is always a sign that the valve is not up to standard.

A test for softness is to have a high resistance in the grid circuit and to connect a switch across the

resistance. The anode current of the valve is observed when the switch is closed, and then the switch is opened, and the anode current read again. This is because the grid of a soft valve becomes positive due to having acquired positive ions from the gas molecules, and therefore current flows through the grid circuit back to the filament or cathode.

When current flows through the grid resistance, a voltage is produced across it and alters the bias of the valve. When the resistance is short-circuited, the self-biasing

common in certain types of small tubular condenser, and is exceeding difficult to find without a capacity tester. An open circuit has no effect upon the voltage or current flowing in a receiver circuit, but, if the condenser is a coupling between one stage and the next, signals will be very weak.

A capacity tester should also be capable of measuring the leakage current in an electrolyte condenser. This type of condenser cannot be checked for insulation.

Fig. 16a gives a simple circuit for the measurement of capacity and,
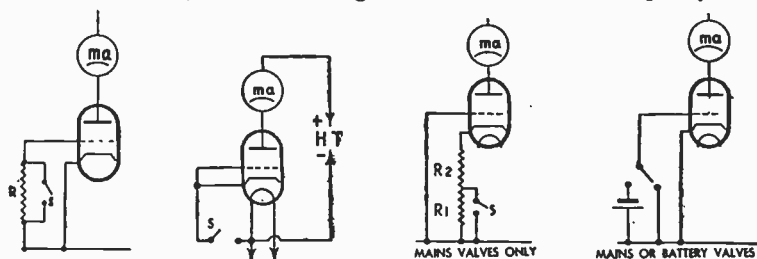
Fig. 15. Fundamental valve-test circuits. *Left to right*: A test for "soft" valves; a method of switching the anode circuit; and ways of introducing a change of bias to mains and battery valves respectively.

voltage disappears and the change of anode current occurs.

Some of the fundamental circuits of valve-testers are shown in Fig. 15. It must be appreciated that various manufacturers of testers have their own designs and individual methods of obtaining meter indications which can be tabulated in the form of "efficiency readings".

Testing Condensers

A capacity tester should not only measure the capacity of a condenser; it should also be capable of checking the insulation of the dielectric and indicating whether there is a "short" or an "open" circuit. The latter fault is very

in this case, of resistances also. A straight-forward mains transformer and rectifier arrangement provides HT which is broken down by a potentiometer for providing different voltages for testing the insulation of various types of condenser.

Many faulty condensers do not show up on insulation tests when a low voltage is applied to them, and insulation tests should always be made with a voltage equal to the working voltage of the unit.

Conversely, to apply a high voltage to a condenser which is only designed to work on a much lower voltage will quite likely break down the insulation. Therefore, before a test is made make
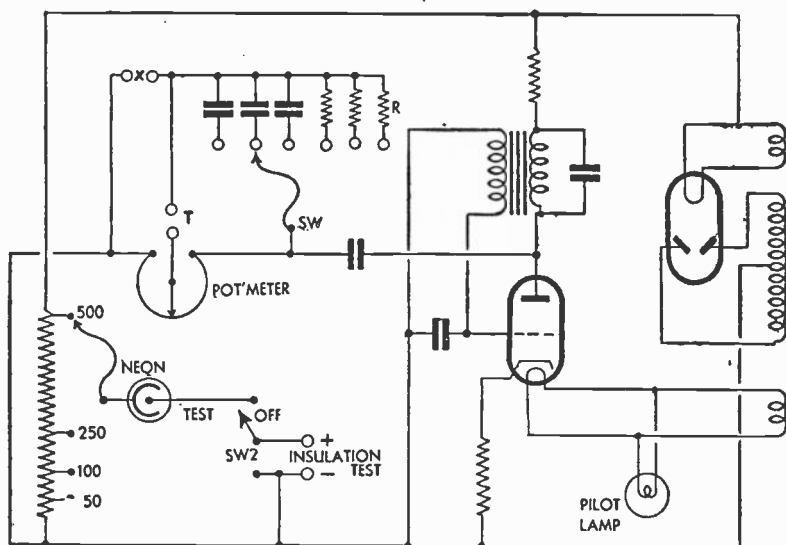
Fig. 16a. Simple circuit for the testing of capacities and resistances.

quite sure of the particular type of condenser and what voltage is normally applied to it under working conditions. All condensers should be tested for insulation before they are tested for capacity.

For capacity tests a simple bridge circuit is often employed using a low-frequency note which can be heard on a pair of head-

phones, or a voltage which is applied to the control grid of a visual indicator or magic eye. In the circuit shown in Fig. 16a a simple triode valve is made to oscillate at a low frequency by coupling the anode circuit to the grid by an inter-valve transformer.

The output from this arrange-
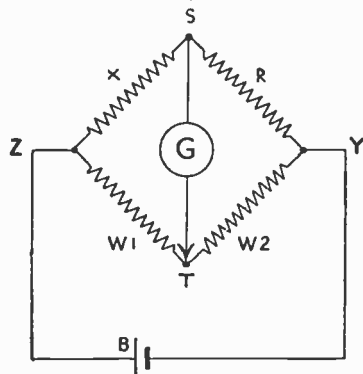
Fig. 16b. The bridge circuit which forms the basis of the capacity tester.
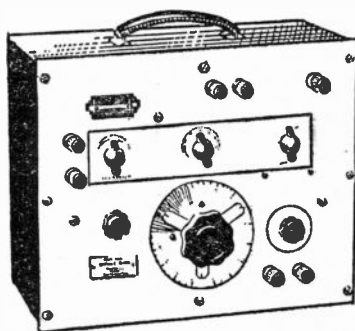
Fig. 16c. Cossor AC impedance bridge for capacity, inductance and for taking resistance measurements.

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the two condensers are equal in value, then the voltage at point S will be half the applied voltage, and to balance the bridge the slider of the potentiometer will have to be half-way along its travel, to divide the voltage across its windings, so that the voltage at T equals that at S. The bridge is then balanced.

A Cossor bridge instrument for measuring capacity, inductance and resistance is shown in Fig. 16c.

Electrolytic condensers, as we have already stated, cannot be tested on the bridge circuit just described, as a small leakage current always flows in one direction and a much larger current in the opposite direction. Therefore, capacity testers have a separate circuit which measures the leakage current in milliamps when the correct working voltage is applied.

Visual Indicator

The current is either indicated on a milliammeter or is made to operate a visual indicator of the magic-eye type so that the eye closes when the correct current is flowing. If the leakage current of the electrolytic condenser is normal its capacity can also be assumed to be up to standard.

When large condensers are first connected to a circuit to which a voltage is applied there is always a very heavy surge as the condenser accepts the first charge. Therefore, experiments in this direction by using HT batteries and a milliammeter should always be carried out with a series resistance of a few thousand ohms and the milliammeter set for measuring very high current. After a few minutes the resistance may be shorted and the meter switched to the appropriate range when the current falls to its normal leakage value.

Leakage current is referred to in ma. per microfarad, and although all types of electrolytic condenser have not the same ratio of leakage current to capacity, an average *maximum* figure is about 0·5 ma. per mfd.

The exact figure cannot be given, as the age of a condenser has quite a good deal to do with the leakage current. A typical smoothing condenser of the 8-mfd. 450-v. working type would have a leakage current of about 1·8 ma. when new, but if this same condenser was tested after it had been in use for two or three years and measured about 4 ma. on test, it could be accepted as being satisfactory if there was no undue hum in the circuit in which it was incorporated. For the very low voltage types as used across cathode biasing resistances a leakage current of about 0·1 ma. per mfd. would be the limit when the condenser was new.

A simple method of ascertaining the approximate capacity of a condenser not of the electrolytic type is often employed in universal analysers, and is based on the simple circuit inlet in Fig. 17. If an AC voltmeter is applied to a source of AC voltage, it will indicate a certain value. If a condenser is placed in series with one of the leads of the voltmeter, the condenser will act as an impedance, and will so cut down the current, and a voltage will be developed across the condenser.

Calibration Method

The latter voltage is dependent upon the capacity of the condenser; the smaller the capacity the higher will be the impedance to alternating current and the greater will be the voltage developed across the

condenser. We therefore have a method of calibrating the AC voltmeter scale with capacity readings, which may be obtained either by calculations or by a series of measurements using condensers of known value.

Service Oscillator

The service oscillator is one of the chief pieces of equipment in the service department; its importance is only second to that of the analyser. Without an oscillator no modern superheterodyne receiver can be properly overhauled or repaired. The service oscillator is

known under several names, such as, test oscillator, signal generator and modulated oscillator, but if it is sold for radio servicing purposes it is fundamentally the same thing whatever its name.

Essentially it is a miniature transmitter which derives its power either from internal batteries or from the mains. Its output, instead of being broadcast, is confined to a twin shielded lead, by which it may be injected into any part of the receiver circuit.

The wavelength or frequency of the output may be varied by means of a tuning control to cover all the
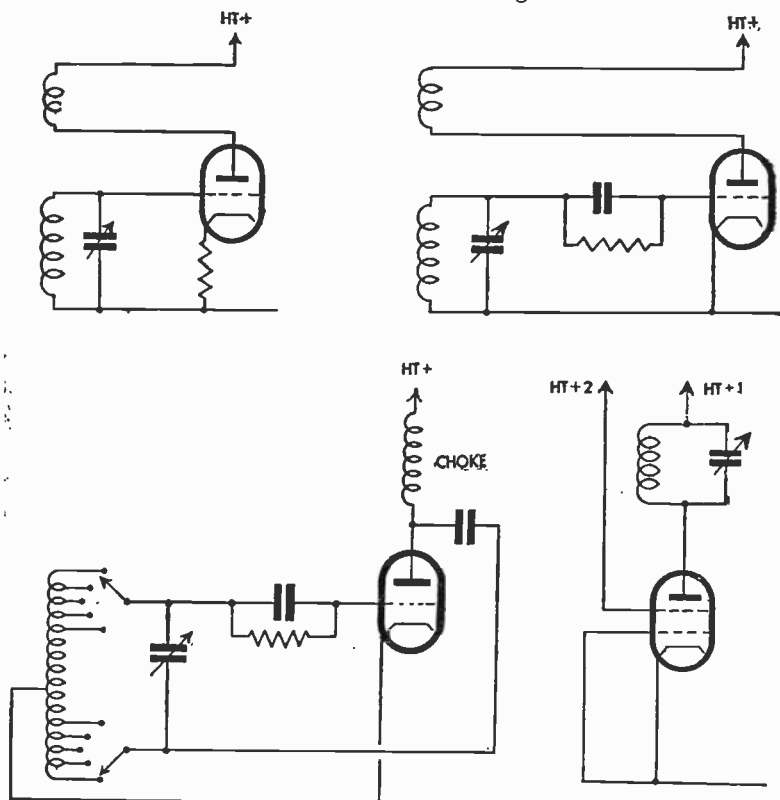
Fig. 18. Four common circuits for the generation of HF oscillations. Three use the triode but the fourth shows a screen-grid valve dynatron circuit.
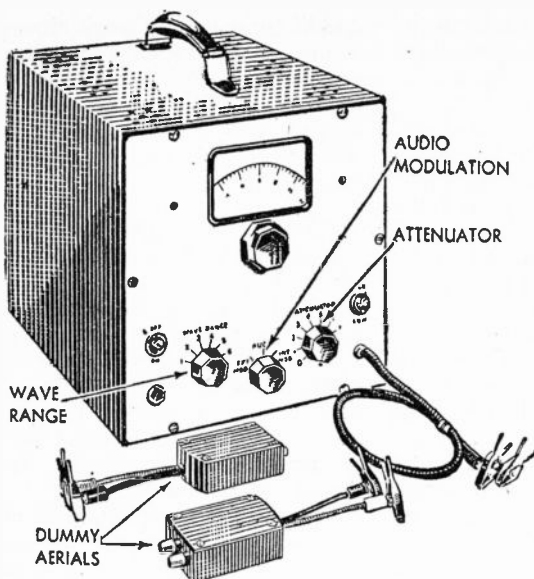
Fig. 20a. The E.M.I. Service signal generator. The "dummy aerials" in the foreground duplicate the effect of the normal aerial upon the receiver.

fact, an AC voltmeter, or universal analyser adjusted to operate as an AC voltmeter, will work just as effectively as an output meter. For trimming operations it is connected across the loudspeaker. If the latter has a high impedance, the AC voltmeter must be adjusted to a high voltage range, whereas if the speaker has a low impedance, the voltmeter must be adjusted to a voltage range of about 0–5 v.

The A.F. generator is an oscillator which gives an output of which the frequency is well within the audible range. It is very useful for checking up the frequency response of an amplifier or loudspeaker, and provides a steady signal of any audible frequency which may be injected into the input of an amplifier, or into the pick-up sockets of a radiogramophone, while investigations are carried out.

These oscillators are often termed beat-frequency oscillators, and this describes the circuit which is used in them. Briefly, it comprises two HF oscillators the outputs of which are mixed together. One of the oscillators operates at a fixed frequency, and the other oscillator may be varied very slightly with regard to the first. By this means "beats" are obtained in the output varying from zero when the two circuits are

sary, however, to have these trimmers correctly tuned to obtain maximum selectivity as well as sensitivity. The output meter enables every slight change of a trimmer condenser to be seen as a movement of the needle.

The output meter is nothing more than an AC voltmeter. In

Fig. 20b. A ganging oscillator as manufactured by Cossor.

exactly in tune and rising in frequency as the oscillators get more and more out of step.

The valve voltmeter (Fig. 22a) permits measurement of the voltages on very sensitive receiver circuits without affecting them in any way. The ordinary voltmeter or analyser, as we have seen, is a resistance, and this resistance can

vided by the coil. If, however, it is desired to measure the voltage across a circuit which has already a high standing voltage on it, or if the circuit to be tested involves a condenser which would break the circuit between the grid of the valve and its cathode, then a grid condenser and a grid resistance must be used in the
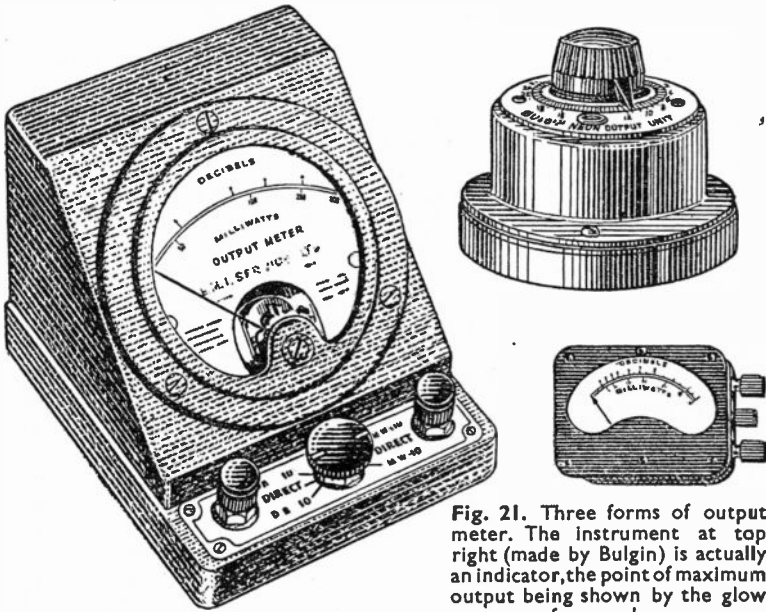
Fig. 21. Three forms of output meter. The instrument at top right (made by Bulgin) is actually an indicator, the point of maximum output being shown by the glow of a neon lamp.

upset HF and IF circuits. Valve voltmeters have very little effect, as only the very high resistance between the grid and the cathode of the valve is imposed.

The principle of operation is quite simple. When the voltage on the grid of a valve is varied the anode current changes, and this characteristic is taken advantage of when designing a valve voltmeter. There must always be a circuit between the grid of the valve and its cathode, and when measuring coils this circuit is pro-

input circuit of the valve voltmeter.

This, of course, imposes a certain load upon the circuit being tested. Even so, as the grid resistance can be of the very high value of 1 or 2 megohms, the load is generally far less than that imposed by even the most sensitive analyser or voltmeter.

Even valve voltmeters with a comparatively low resistance input circuit have advantages over the usual type of voltmeter, because they are not what is termed fre-
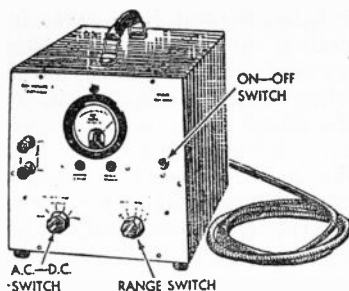
Fig. 22a. A valve voltmeter by E.M.I Service, Ltd.

quency conscious. Ordinary AC voltmeters are calibrated at a certain frequency, generally 50 cycles. With a valve voltmeter, however, practically any frequency whether LF, HF, or even right up into the television frequencies can be applied without loss of accuracy.

A typical valve voltmeter circuit is shown in Fig. 22b. In the circuit shown a modification is made to the anode circuit of the valve, which considerably extends the voltage range.

In a simple valve voltmeter circuit the milliammeter in the

anode circuit would show a reading of the standing anode current, and quite a large part of the scale would not be available for voltage measurements. A modification is therefore provided which develops a voltage across the milliammeter and provides reverse current to counteract the standing current, and so brings the meter needle back to zero.

Checking Voltage Gain

A valve voltmeter is very useful for checking the voltage gain between one stage and another. Coils can be matched by connecting the valve voltmeter across a fixed condenser and then connecting the coil to be matched across the condenser and noting the voltage developed when a signal is fed from an oscillator. Coils can have their turns removed or spaced in order to produce the same voltage as any other similar coil. Coils can be compared for efficiency in the same way.

Conversely, condensers may be compared by connecting them
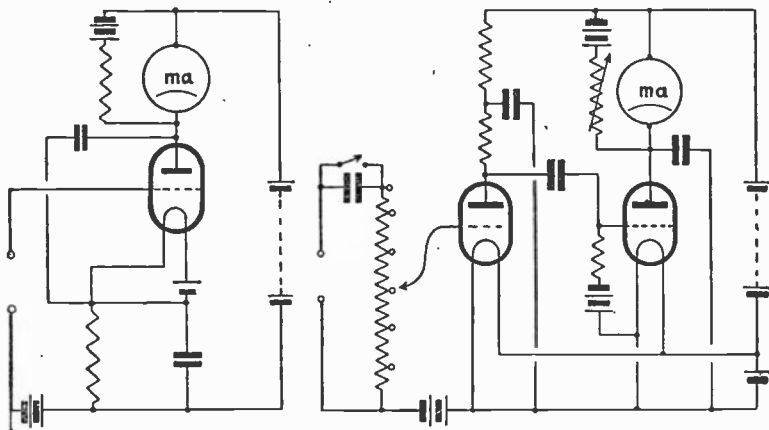
Fig. 22b. Two basic valve voltmeter circuits. Note the arrangement for providing a reverse current to bring the meter to zero despite the steady valve current.
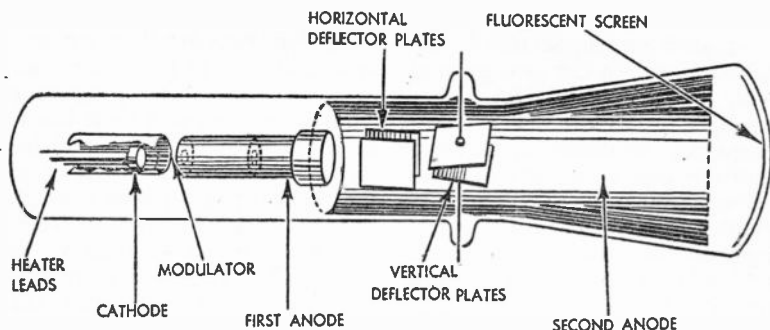
Fig. 23. Sectional and X-ray view showing the arrangement of electrodes in a cathode-ray tube which is the principal component in the oscillograph.

across a standard coil. The separate sections of a ganged condenser may be matched up in the same way. The valve voltmeter may be employed as an indicator for tuning a circuit, especially wave-traps.

Cathode-ray Oscillograph

The cathode-ray oscillograph has become very popular for receiver circuit analysis. The advent of television made this instrument practically the only means of finding out what was going on in the very high-frequency circuits.

One of its features which is of great importance is that it imposes practically no load upon a circuit and, within exceptionally wide limits, it cannot be overloaded by excessive voltage application.

The cathode-ray tube, which is the principal component in the oscillograph, is described in Chapter 8, but for convenience a sectional diagram is given in Fig. 23. In Fig. 24 the way the beam is controlled is indicated.

It is impossible here to deal thoroughly with all the applications of cathode-ray oscillographs in radio design and servicing. Briefly, the instrument enables one or more cycles of alternating current, whether of low frequency or
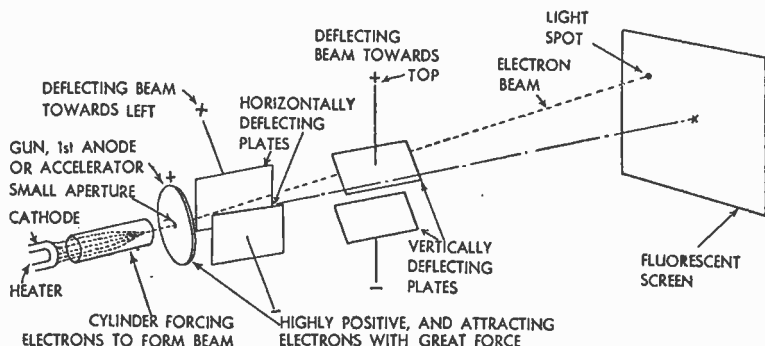
Fig. 24. This diagram illustrates how the electron beam in a cathode-ray tube is condensed and deflected. The principle is explained in the text.

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high frequency, to be traced on the fluorescent screen, so that a distorted waveform can be compared with the original waveform. For example, if the output of an audio-frequency oscillator is injected into the pick-up sockets of a receiver, the cathode-ray oscillograph can be connected across this input and the waveform examined; it should, of course, appear as a pure sine wave.

A typical service oscillograph is shown in Fig. 25. The controls appear at first to be rather complex, but they each perform a simple function, and their use is soon mastered. In the actual instrument illustrated the input of the vertical plates passes through an amplifier which can be switched off when direct connection is desired. The degree of amplification may be varied when the amplifier is used, by adjusting a left-hand knob marked "Gain". Similarly the input to the horizontal plates can be controlled. There are knobs for controlling the intensity of the beam to alter the biasing on the modulator electrode, and the beam itself may be focussed.

In the centre of the instrument may be observed a knob marked "Range". This is for adjusting

Fig. 25. A portable cathode-ray oscillograph.

Next the oscillograph leads are connected across the anode load (which may be a resistance or a normal inter-valve transformer) in the anode circuit of the first LF amplifier valve. The waveform should appear very much larger, but of exactly the same shape, with no kinks or other distortion. If there are imperfections, then this indicates that the stage is distorting and, with the image then being shown on the tube of the oscillograph, adjustments may be made or components changed, biasing altered and so on, and the effect of these changes observed.

the input to the vertical deflecting plates, so that the curve does not fly off the end of the tube when the voltage is too high. The remaining controls are concerned with adjusting the image in various ways, so that it is nicely positioned on the screen.

Fig. 26 depicts the internal view of a cathode-ray oscillograph, showing the valves used for amplifying the input to the vertical and horizontal plates and also the valves comprising what is termed the time base.

Time base circuits cause the beam to swing across the tube

horizontally, and can be adjusted so that the beam effects its passage from one side of the tube to the other in the time taken by one cycle of the waveform it is desired to examine.

For example, take the case of the examination of a 50-cycle mains supply. In this case the beam is adjusted by the controls so that it

Fig. 27. A neat portable insulation tester with fold-up generator handle and flap to protect the scale glass.

will travel from one side of the tube to the other in one-fiftieth of a second. While it is doing this, the voltage of the mains supply which is applied to the vertical deflecting plates will cause the spot of light on the screen to move up as the voltage increases to its maximum in the positive direction, then to fall right down to the maximum voltage in the negative direction,

and then to come back to the zero volts position again. If a little thought is given to this, it will be seen that one complete cycle will be shown traced over and over again in the same position on the screen, so as to appear quite stationary.

By altering the controls of the time-base, the time taken to move the beam across the tube may be varied up to many thousands or even million times a second, so hat H F cycles can be traced.

Another rather special instru-
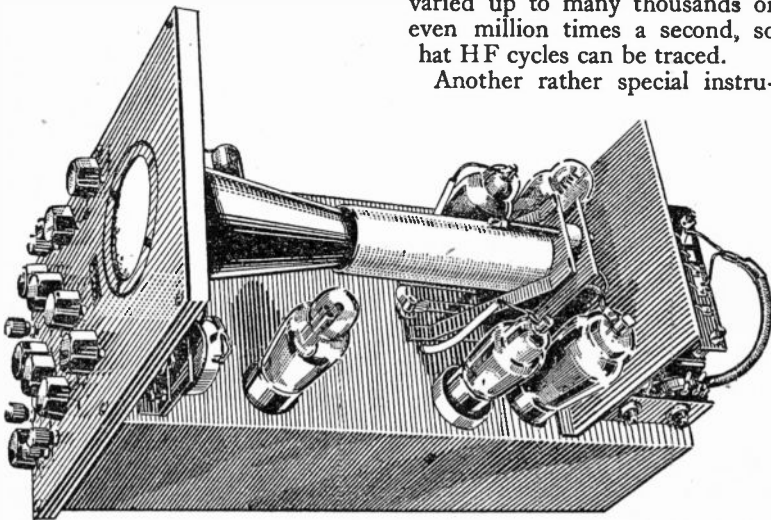
Fig. 26. Internal view of the oscillograph illustrated in Fig. 25 showing the valves employed in the amplifiers and the time bases.
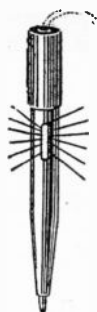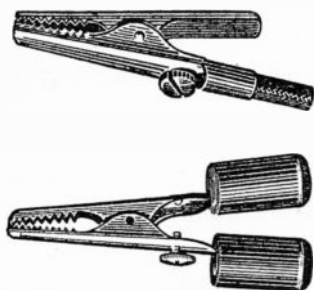
Fig. 30. Useful clips which, when attached to meter leads, save much time in making connections. A neon tester (*right*) provides simple indication of the presence of voltage.

should have a drawer in which he can keep his own small tools and meters. At the back of the bench

large, should be kept tidy and the various items which comprise the furniture should be arranged in an orderly manner. Fig. 33 illustrates a well-laid-out service workshop.

The service bench itself should be sturdy, and each engineer

there should be a shelf to accommodate the larger pieces of test equipment. There they are less liable to be damaged, more easily inspected when readings are taken, and more convenient as regards test-leads connected to them.

Supply Points

Points should be arranged at the back of the bench for supplying power to chassis. On the inside of the legs of the bench there should be a supply point into which soldering irons may be plugged, thus preventing the leads trailing over the work on the bench.

A shelf a few inches from the floor is a convenient place for storing cabinets while the chassis are being worked on. Some engineers prefer to use adaptors to enable any type of plug or lamp adaptor which they may find on the mains lead of a customer's receiver to be connected to the supply socket on the bench. Other engineers prefer to wire up a number of different sockets and a batten-type lamp-holder in parallel on the bench.

If the area covered by the service department includes a district supplied by DC mains, while the service department itself is sup-
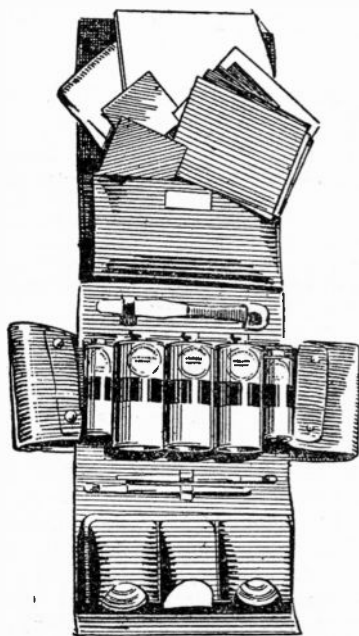
Fig. 31. A kit such as this enables the cabinets of repaired sets to be polished and generally smartened up.

plied with AC, provision must be made for an alternative supply to test DC instruments. A convenient method is to have a rotary converter such as that shown in Fig. 32. One having an output of about 250 watts will cater for the largest radio-gramophone, or will provide sufficient output for several small chassis to be tested or demonstrated at the same time.

Under the conditions which we have mentioned the converter will be driven by AC and will deliver DC. Where the reverse conditions prevail, and it is desired to operate an AC receiver in a workshop that is on a DC supply, then the converter must work from this supply and deliver the required AC output.

An important item is the bench-lamp. This should be of a type which will allow the light to be directed into any awkward corners either of a chassis or in the interior of a radio-gramophone, without blinding the eyes of the engineer working with it. A convenient type will be seen on the bench in Fig. 33

For easy inspection and repair of radio-gramophones and console models a cabinet stand is very useful. It raises the instrument to a position where lengthy periods can be spent working on it without too much back-bending.

Chassis, auto-mechanism and motor boards are sometimes very awkward things to support on the bench. Chassis are generally satisfactory when they stand upright, but in this position many of the components are inaccessible. Some manufacturers sell suitable metal cradles to which the chassis may be bolted and which allow them to be supported in any position on the bench.

Useful Folding Tray

A very convenient arrangement is to make up four pieces of square wood about 8 in. long and ½ in.
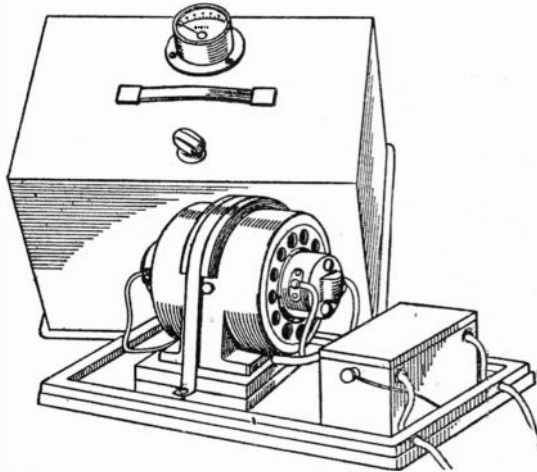
Fig. 32. A rotary converter is a valuable adjunct to the workshop in an AC–DC district.

square, each fitted into a base two or three inches square. Three or four of these may be positioned on the bench so that they support the chassis, motor board or auto-mechanism, clear of the bench.

In Fig. 33 a stand will be seen for supporting an auto-mechanism or motor board; a folding tray at the side is useful for holding tools and parts of the mechanism when they have been taken down. A shelf at the bottom of the stand accommodates test records.

A job-card should be available

TESTING COMPONENTS

CHOKES. CONDENSERS. COILS. FRAME AERIALS. FUSES. INTER-VALVE TRANS-
FORMERS. LOUDSPEAKERS. MAINS TRANSFORMERS. MOTORS. PICK-UPS.
PLUGS AND SOCKETS. POTENTIOMETERS. REACTION CONDENSERS. RESIST-
ANCES. SWITCHES. VALVES. TESTING WITHOUT INSTRUMENTS.

THE beginner in radio servic-
ing will find that testing any
components he can lay his
hands on will not only help him
to become thoroughly acquainted
with the use of his servicing equip-
ment and to acquire a practical
insight into the construction of
components and what faults can
occur in them, but the knowledge
so gained will be invaluable when
he comes to servicing a faulty
radio receiver. After all, with the
exception of a few types of faults,
such as badly soldered joints, and
instability or insensitivity due to
wires being misplaced, nearly all
troubles in radio receivers are
due to faulty components.

Alphabetical Review

Actual values of components
cannot be given here as they vary
widely according to the manu-
facturer's particular design. All
service departments should have
a complete set of manufacturer's
service manuals or the service
sheets compiled by trade papers.

The following is a review in
alphabetical order of the compo-
nents which will be found in a
modern radio receiver, together
with hints on the types of faults
which can occur in them and how
to locate and cure them.

Chokes (*HF*) (*see* Fig. 1). The
chief troubles with HF chokes are
breaks in the winding or at each
end of the winding, where the fine
wire is soldered to terminals or
tags. If the coupling condenser
between the anode of the valve and
the next valve develops a short
circuit the HF choke will probably
be burnt out, because the HT cur-
rent will rise to a high value and flow
through the condenser to earth.

Sometimes HF chokes develop
a fault which nullifies their effec-
tiveness, producing weak signals
or instability. This occurs when
several layers of the winding be-
come shorted out due to a break-
down of the insulation covering
the wire. Such a fault will lower
the total resistance of the winding,
so that when an ohmmeter is used
to check up the value of the wind-
ing, a low reading will be obtained
compared with the value in ohms
given in the service manual.

If the fault is anything more
than a broken connection to a tag,
which can be resoldered, the HF
choke should be discarded.

Chokes (*LF and Smoothing*)
(*see* Fig. 2). These can break down
due to either a break in the wind-
ing or to a failure of the insulation
between the winding and the iron
laminations. This latter fault may
cause the winding to burn out. To
test a choke, check its resistance
between one end of the winding
and the other with an ohmmeter,

and compare the values obtained with the data in the service manual. If no reading is obtained, then there is a disconnection in the winding and rewinding is necessary. Specialist repair firms undertake this work.

Before condemning the choke, however, examine the connection between the actual wire ends and the terminals or soldering tags. A pair of tweezers is useful with which to grip the wire in order to make sure that it is properly connected.

Leakage Test

An insulation test should next be applied by connecting an ohmmeter on its highest resistance range between one of the ends of the winding and the laminations. There should be "infinity" resistance reading. If an insulation tester is available, this should be used, so that the choke is subjected to a voltage at least equal to that at which it operates.

If a choke is buzzing when it is in a receiver, this is generally due to loose laminations. Tightening up the bolts which clamp the
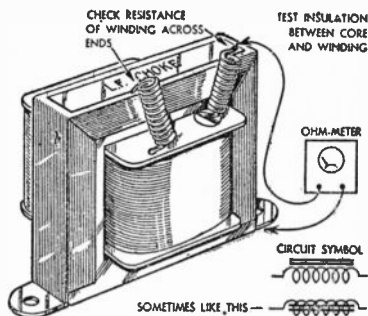
Fig. 2. The LF choke is distinguished by its iron core. The resistance of the winding and the insulation between winding and core must be checked.

laminations together or wedging them with small splinters of wood, is generally effective.

Checking Coils

Coils (*see* Fig. 3). The term "coils" covers any winding of wire upon a former and, in fact, a mains transformer or a smoothing choke can well come within the category of coils which are used for testing purposes.

Coils should be checked for their resistance. If there is no continuity between the ends of the
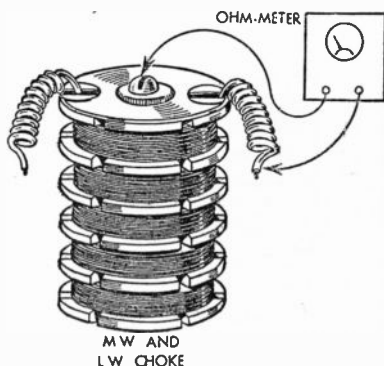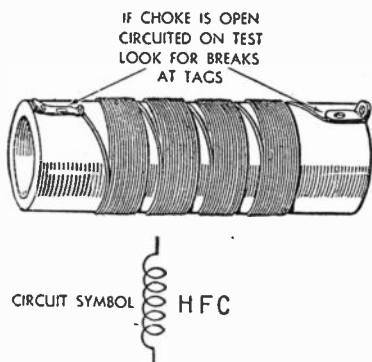
Fig. I. Two forms of HF choke. Besides checking the resistance of the winding, test between winding and mounting bolt for any leakage. If a choke is burnt out look for a short to chassis elsewhere in the circuit.
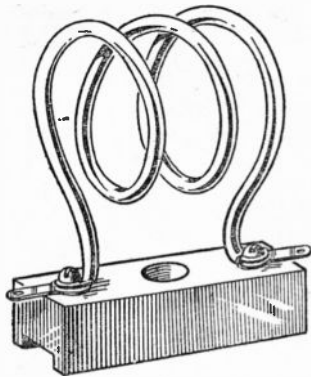
Short wave coils are generally of thick wire and often "self-supporting" like the one shown here. A break is unlikely but good connections and high insulation across the holder are important.

CIRCUIT SYMBOLS

SINGLE COIL —

L1
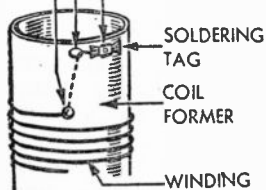
3-WAVE BAND COIL —

In coils for medium and long waves a fairly fine insulated wire is employed, and when a continuity test indicates a break this should be looked for where the wire passes through the former, and also where it joins the connection tags.

LOOK FOR
BREAKS HERE

SOLDERING
TAG

COIL
FORMER

WINDING

L W.   L1

M W.   L2

S.W.   L3

M.W WINDING
(SINGLE LAYER)

REACTION
WINDING

L.W. WINDING
(THIN WIRE
PILE WOUND)

S.W. WINDING
(THICK WIRE)
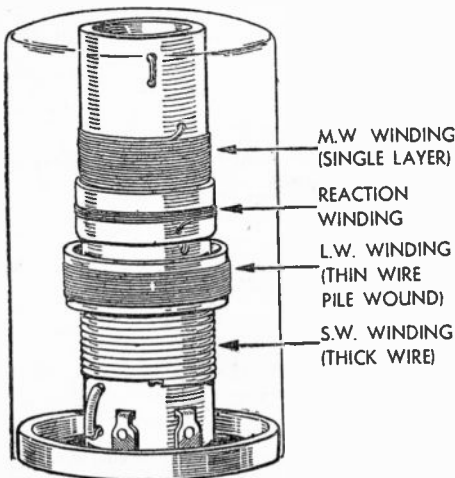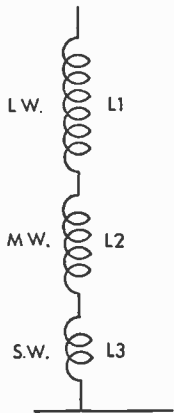
Coil screening cans must be firmly earthed to chassis. Low insulation due to dampness may prevent a coil functioning correctly.
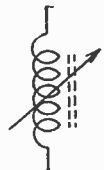
COIL WITH
IRON-DUST
CORE

Fig. 3. A short-wave coil and a three-waveband screened type.

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windings, this points to a break in the coil, and the connections to the terminals should be examined. If these appear O.K. and the repair is urgent, then it is often possible, in the case of simple single-layer coils, to unwind the layer, locate the break and repair it.

Oscillator Coil Faults

Oscillator coils in the oscillator stage of a superhet sometimes develop a fault which prevents the circuit from oscillating; this is due to damp. Drying out a coil may effect a cure, but generally they have to be replaced.

Coils which comprise several sections wound on a long former with tappings made at various points sometimes develop a break where the thin wire goes through a hole in the former and is bent towards its terminal or tags. A coil showing an open circuit should be examined in these places, where a break may often be discovered and rectified. Generally speaking, however, a faulty coil is best substituted by a new one.

Condensers (Fixed) (see Fig. 4). These should be tested on a capacity tester, first for insulation and then for capacity. If no capacity meter is available an ohmmeter test will tell whether the condenser is short circuited or not, but it will not indicate any internal discon-
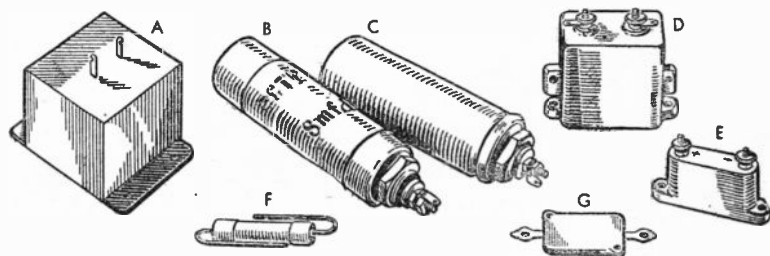
(A) 4 mfd. paper condenser. Tested 1500 v. DC, normal working 450 v.; (B) 8 mfd. wet electrolytic, max. continuous working voltage of 440, peak voltage of 460; (C) 8 mfd. dry electrolytic, max. continuous working voltage of 500, peak voltage of 550; (D) 2 mfd. non-inductive paper condenser. Tested 400 v. DC, working voltage of 200; (E) 25 mfd. dry electrolytic, max. working voltage of 25 DC; (F) 0·01 mfd. tubular paper condenser. Tested to 1500 v. DC for 400 v. DC working; (G) 0·0025 mfd. mica condenser. Tested to 500 v. DC for 250 v. DC working.

CONSTRUCTION

TIN FOIL

PAPER OR MICA

TAG OR TERMINAL

GAUZE SATURATED WITH ELECTROLYTE

ALUMINIUM FOIL
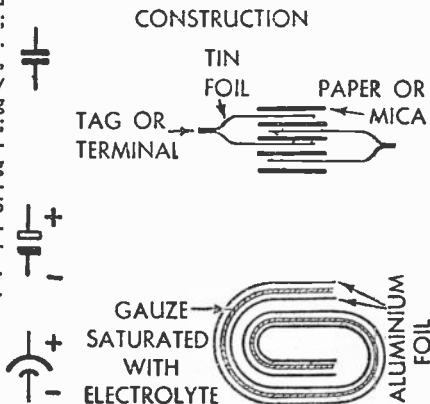
Fig. 4. A selection of condensers with their circuit symbols and also details of construction. A description of how condensers are manufactured is contained in Chapter 16 on "Production Methods".

nection. Faulty condensers must be replaced.

Condensers (*Electrolytic*) (*see* Fig. 4). Electrolytic condensers generally give ample evidence of their breakdown, due to the fact that they are employed mostly in HT circuits. When they fail they may develop an internal short circuit which provides a direct path to earth for the HT current, thus overloading the mains transformer and rectifying valve.

Electrolytic condensers should be tested on a capacity bridge for short circuits, leakage and also for capacity, as this latter test will indicate whether there is any internal disconnection. Faulty electrolytics must be replaced, but where only one section of a block containing several sections has "gone", only this one part need be by a new external unit.

Condensers (*Variable*) (*see* Fig. 5). The chief faults which can occur in variable condensers are the moving vanes touching the fixed vanes and noisiness in operation. The first fault gives rise to dead points in the tuning range, unless, of course, the fault is so bad that the moving vanes foul the fixed vanes all the way round. An ohm-meter test between the two terminals will show whether any shorting is taking place.

Noisiness may be due either to dirt or metal filings fouling the two sets of plates of the condenser, or to corroded or oxidised surfaces

SINGLE VARIABLE CONDENSER:— GANGED CONDENSERS:— HOLE IN SHAFT LOCKNUT
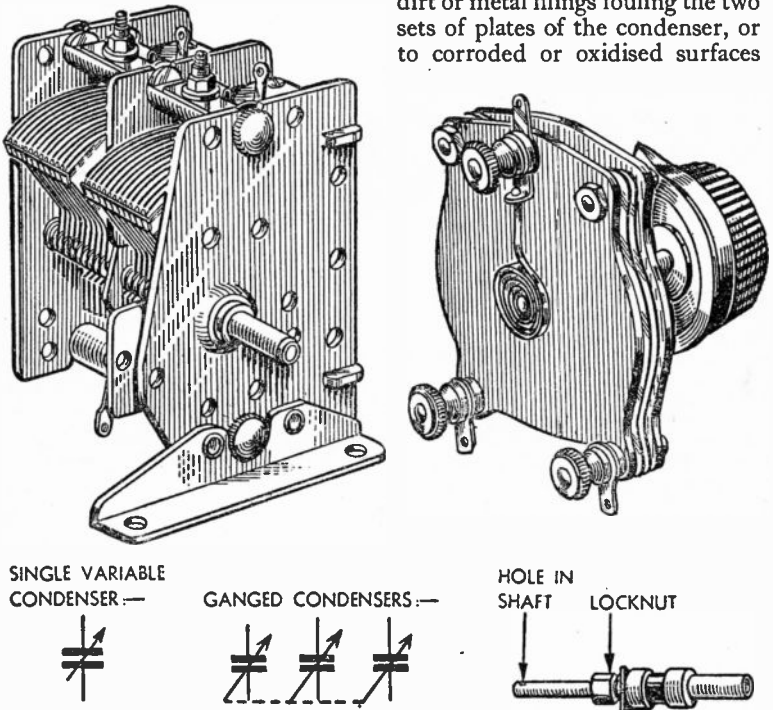
Fig. 5. A two-gang air spaced condenser for tuning and a solid dielectric type used in reaction circuits. The earthing clip of the two gang and the "pigtail" of the reaction type are suspect when reception is noisy.

OHM-METER

CHECK INSULATION BETWEEN WINDING AND CORE

MEASURE RESISTANCE OF EACH WINDING

Fig. 6. Two LF transformers. One has a tapped secondary for energising the grids of two valves used in push-pull.
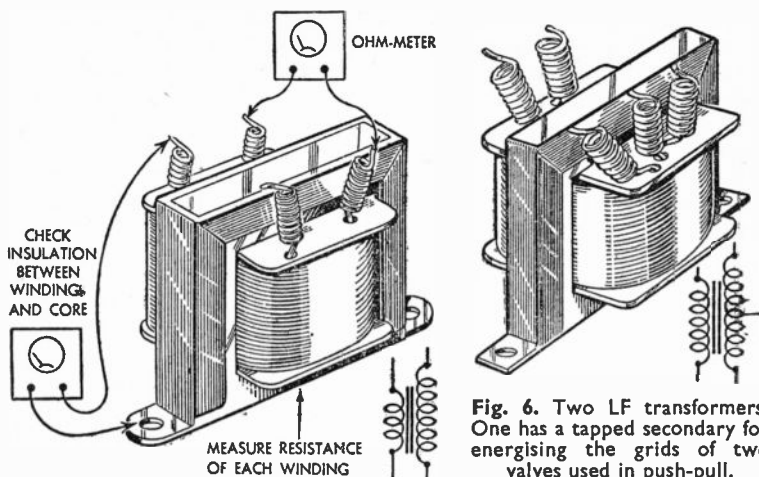
between the moving vanes and the clip which makes contact with the spindle and the terminal of the condenser.

In a ganged condenser, where there are several sections, each section will have its own clip for making contact with its own particular set of moving vanes, and it is very essential, especially in short-wave circuits, that the spring-clips make efficient contact both where they touch the bearings and where they are soldered to their part of the circuit or to the chassis.

' Cleaning Condensers

Dirt can be removed from condensers by blowing or by use of a pipe-cleaner or plasticine. Corrosion should be removed with fine emery paper and/or one of the proprietary cleaning fluids.

Frame Aerials. Frame aerials develop similar faults to, and they may be tested as, coils. Frame aerials are used mostly in battery portable receivers and, because of this, they are susceptible to corrosion due to acid fumes which are given off from the accumulator.

An insulation test should always be carried out on frame aerials between the winding itself and the former (which is often the lid of the portable).

Fuses. When fuses are fitted in the HT circuits they can cause crackling if loose in their holders.' If a fuse is suspected of having blown, care must be taken when testing it to make sure that a heavier current than the fuse can carry is not forced through it by the ohmmeter. It is advisable to fit a high resistance in series with the fuse to limit the current.

Inter-valve Transformers (see Fig. 6). Test each winding for continuity and for insulation between the windings and the core. It is advisable also to test for insulation between the windings, as if the transformer is of the type in which the primary winding is connected in the anode circuit of the LF amplifying valve, low insulation between the two windings of the transformer may allow a high positive voltage to be applied to the grid of the following valve. This will give rise to excessive

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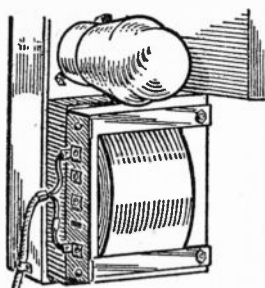
Mains transformer near its rectifier valve on the chassis.

In a service manual the underneath of the transformer would be shown as in sketch on right.
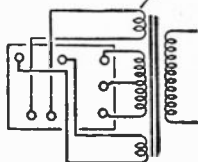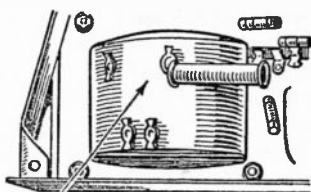
This sketch in a service manual would tell the engineer which soldering tags were connected to the various windings. Another way of giving this information is shown in the drawings at the bottom of the page where the tag numbers are given on the circuit diagram.
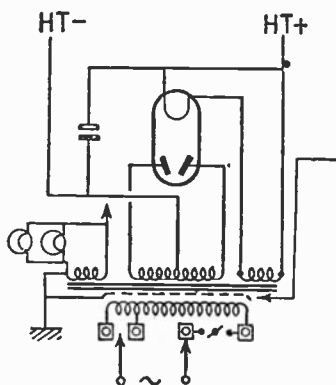
The dotted line represents a layer of copper foil which acts as a screen between the mains supply and the receiver circuits. If the screen is not earthed, modulation hum and noisy reception may result. The screen is between the primary and secondary windings, but must not form a complete ring or it would act as a short-circuited turn.
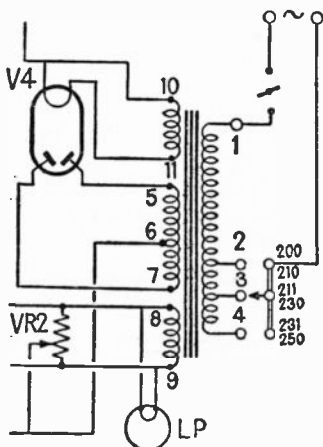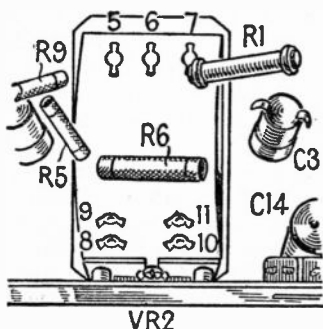
Fig. 9. Ways in which mains transformers are indicated in circuits and in practical diagrams as given in service manuals issued by manufacturers.

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generally due to lack of lubrication, and can be located by switching off the motor and turning the various spindles by hand to see whether they appear stiff.

The motor gears should have grease applied, but other bearings, such as the main turntable bearing, the bottom bearings of the turntable spindle and governor assemblies, should be lubricated with high-quality, thin oil.

Series Resistance

In the case of motors which operate on a low voltage and have a series resistance to enable them to operate from a mains supply, it is advisable to check the voltage across the motor terminals while the motor is running. It is often found that lack of power is due to the resistance being incorrectly adjusted. The correct voltage is generally between 40 v. and 60 v.,

but the value will be found in the manufacturer's service manual.

Motors which operate from DC or which are also suitable for use in AC/DC instruments have an armature winding which is connected to a commutator on the shaft. By means of carbon brushes, contact is maintained between the armature winding and the motor terminals. In time the brushes and commutator require attention. The carbon brushes must be an easy but not "sloppy" fit in their holders. Otherwise they will not wear down evenly, and excessive sparking will occur, which will burn and pit the surface of the commutator.

The Commutator

It is practically impossible to clean a badly burnt commutator, and the armature should be completely removed from the motor,

BRUSH LEVER
BEARING BOLTS

BRUSH
TENSION
SPRINGS

COMMUTATOR

FIELD
COIL

MAGNET
FRAME

MAGNET
SECURING
BOLTS

MAGNET
SECURING
BOLT

BRAKE PAD
ASSEMBLY FIXING
SCREW

TERMINAL
BLOCK

BRAKE PAD

GOVERNOR
BEARING

BRUSHES

GEAR WHEEL GRUB SCREW

CONDENSER

GOVERNOR
BEARING SCREWS
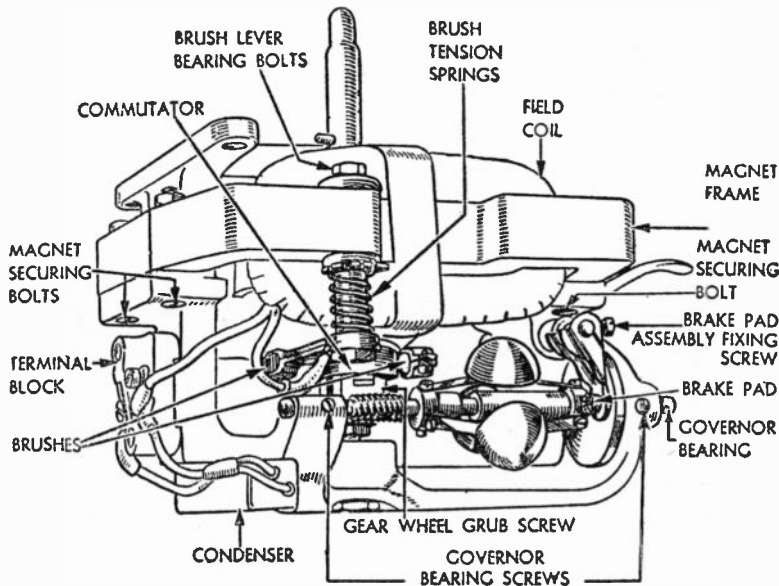
Fig. 10. A gramophone motor for operation from either AC or DC mains.

REACTION
CONDENSER

REACTION
COIL

GRID
COILS

HT+
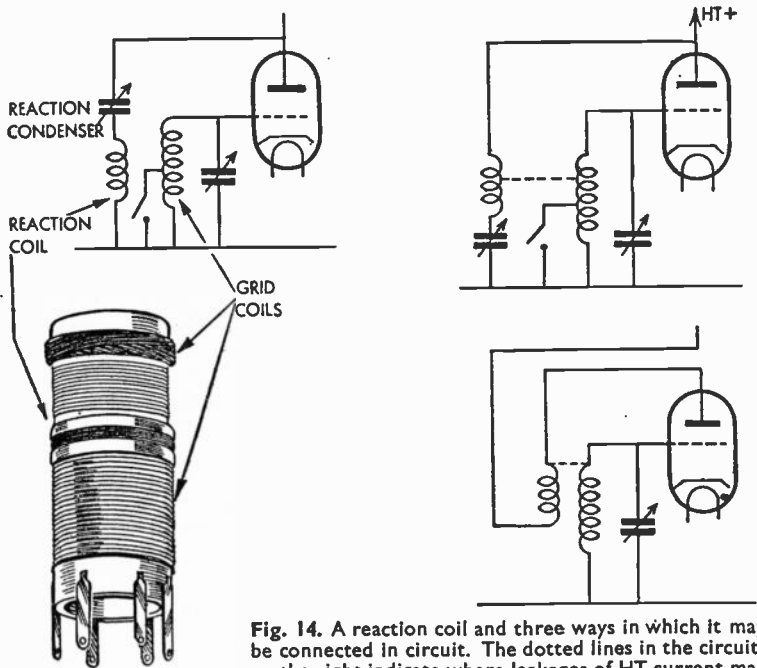
Fig. 14. A reaction coil and three ways in which it may
be connected in circuit. The dotted lines in the circuits
on the right indicate where leakages of HT current may
occur from anode to chassis.

CRACKLING AND INTERMITTENT
RESULTS OCCUR IF THESE END
CONNECTIONS WORK LOOSE

WIRE WOUND RESISTANCE FOR
CARRYING A HEAVIER CURRENT
THAN THE TYPE ABOVE
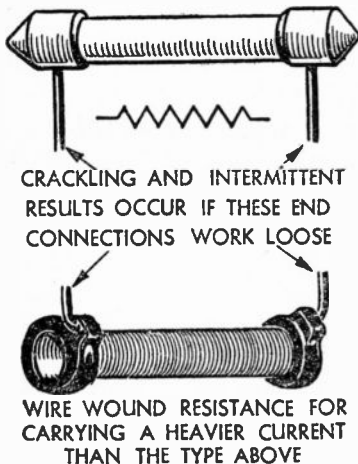
Fig. 15. Two forms of resistance or "re-
sistor". These light units are suspended
in the circuit wiring or soldered to tags
on assembly strips.

If reproduction is distorted but not weak, this points to perished rubbers, which, however, are not so soft as to allow the armature to "freeze". The reproduction from a pick-up is perfectly audible in a pair of headphones, and this is useful for testing purposes. Reproduction should be clear and bright, and if these sort of signals are obtained on the headphones, any distortion from equipment using the pick-up must be looked for in the amplifier or loudspeaker.

Plugs and Sockets. These small items can cause a lot of trouble. Whenever the complaint regarding a receiver is of crackling or intermittent reproduction, all plugs and sockets should be exam-

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ined. They should be cleaned and, if at all slack, opened up so as to ensure that the plugs are a tight fit in their sockets. Crackling can, of course, be brought about by a bad connection between the plugs and the wires which lead into them.

Potentiometers. See Resistances (Variable).

Reaction Coils (see Fig. 14). Failure to obtain oscillation may be due to insufficient coupling to the grid coil or reverse connection of the windings. A burnt out coil may be due to a shorting reaction condenser or to a short to another winding.

Reaction Condensers (see Fig. 5). These control the amount of feed-back between the anode and grid circuits. Nowadays they are to be found only in small battery receivers, and the control is often termed a sensitivity, or volume control.

To obtain greater capacity and
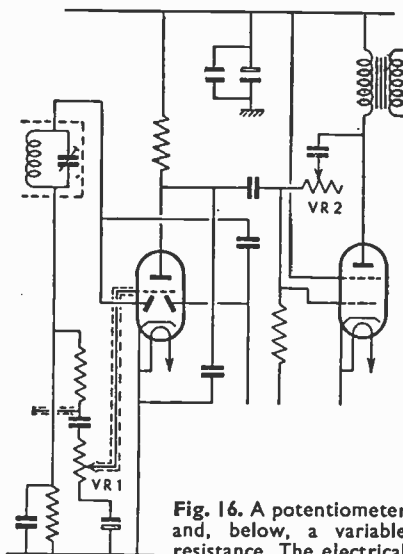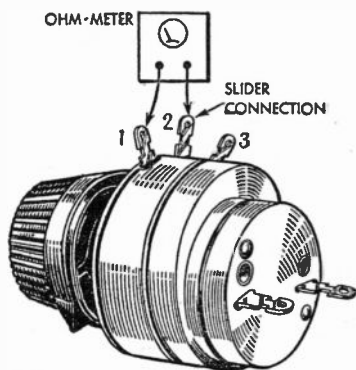
Fig. 16. A potentiometer and, below, a variable resistance. The electrical arrangement of the two is the same but the latter is usually designed to carry a fairly heavy current and dissipate the consequent heat. The circuit shows the two positions, VR1 and VR2, in which a potentiometer is usually employed. VR1 is the volume control of a superhet and VR2 the tone control.
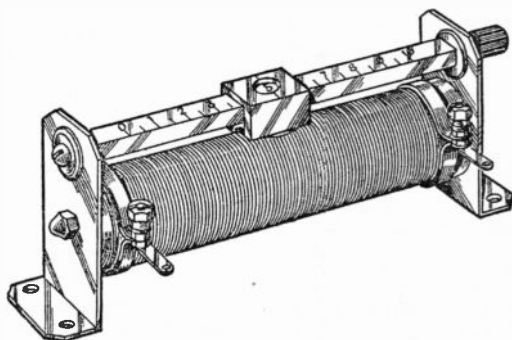
to make the condenser as small as possible, many types have discs of mica separating the fixed and moving vanes. This is also to guard against shorting between the vanes, because if this fault does occur, there will be a direct path to earth for the HT current, as will be seen from Fig. 14. Therefore, if it is found that the reaction coil is

METAL FILINGS WILL SHORT THE PLATES OF THE TRIMMERS

IN SOME TYPES OF IF TRANSFORMERS THESE WIRES CAN SHORT TOGETHER SEE THAT THEY ARE WELL SPACED

IF TRANSFORMER WITH TRIMMERS ON TOP

CIRCUIT SYMBOL FOR AN IFT WITH IRON-DUST CORE

CIRCUIT OF AN AIR CORE IFT
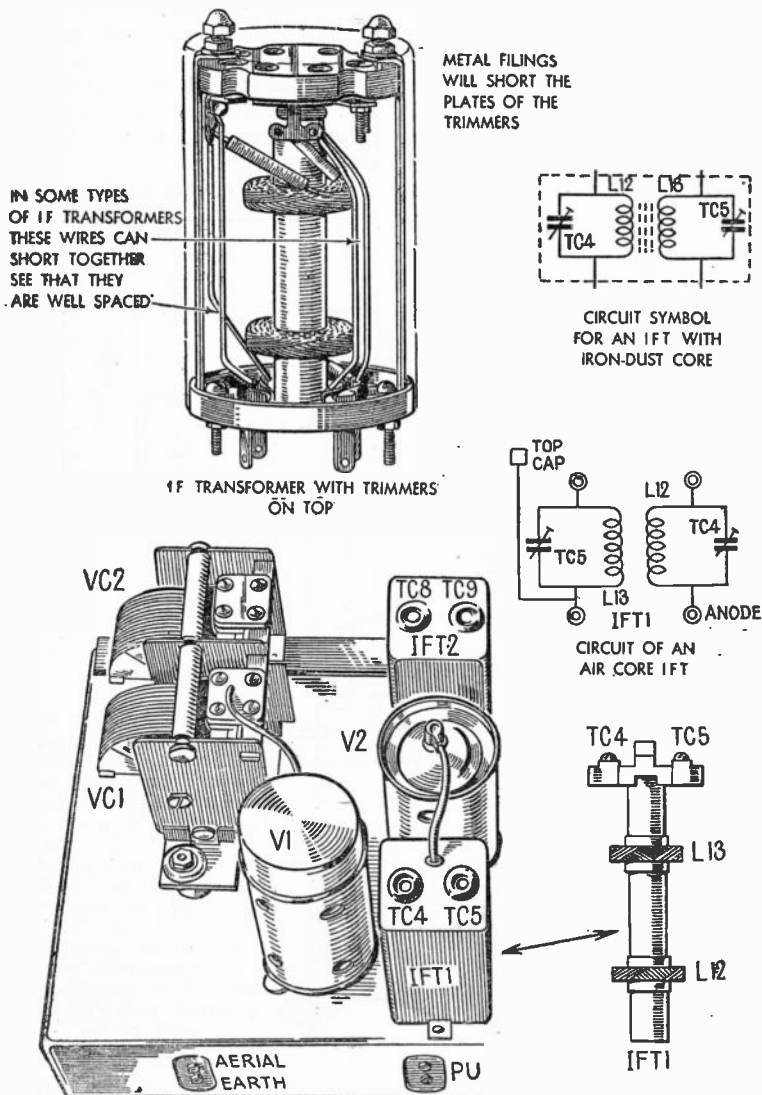
Fig. 17. A drawing of an IF transformer with the screening can "ghosted" and ways in which such a transformer may be represented in circuit and chassis diagrams.

burnt out, the cause of the fault should be looked for in the reaction condenser, which may be shorting during its movement. Test as for Condensers (Variable).

Resistances (Fixed) (see Fig. 15). These little components are very numerous in the modern receiver and seldom give trouble unless abused. They are simple to check by means of an ohm-meter.

If a resistance has been put into a circuit to drop the HT from 200 to 100 v. on the anode of a valve, and it is found that the voltage is only 10 v. with a low anode current, whereas the voltage is still 200 v. at the HT end, then the resistance has obviously become faulty and developed a high value.

Resistances which do not carry current, such as those in grid or AVC circuits, can cause trouble after a lengthy period by giving rise to crackling. The only sure way of proving them to be faulty in this respect is replacement. Sometimes tapping will aggravate the crackling. This point is discussed later when dealing with fault location in receivers.

Resistances (Variable) (see Fig. 16). Volume controls are the most used of all the controls on a receiver. They generally consist of a variable resistance (but see *Reaction Condensers*), and it is only to be expected that in time they will require replacement, or repair.
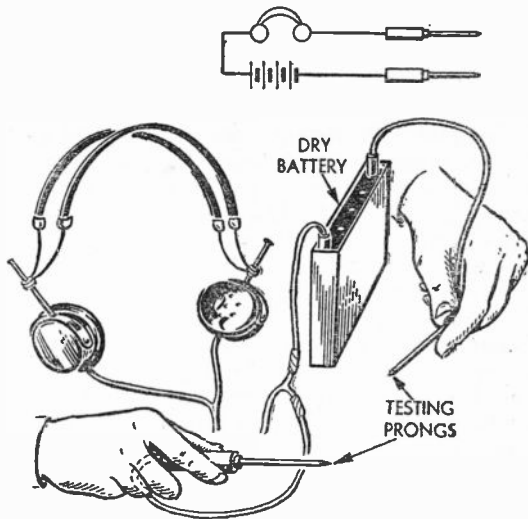
Fig. 18. How a pair of headphones and a dry battery may be wired up as a simple continuity tester. When the prods are applied to a component, a click indicates continuity.

There are two types of variable resistance; one has an element made up of wire wound on a strip of insulated material, while the element in the second type comprises a high-resistance layer of some such material as graphite on a card or paper base. In both types a slider, attached to the control, makes contact with the element.

There is no real difference between a potentiometer and a variable resistance. Fig. 16 shows a variable resistance in the position VR2 and a similar unit with potentiometer connections in VR1.

The potentiometer connection provides a fixed potential across the resistance element, and the sliding arm of the component can pick off the desired potential. For example, if 10 v. is being dropped across the element and the slider is half-way between the two ends, then the voltage which is being applied to the next part of the circuit would be 5 v.

A variable resistance is generally used in series when there is current flowing in the circuit. If it is of a high value it can be used to control LF current, such as when it is used as a tone control by shorting out the condenser in a tone-control circuit. These points are illustrated in Fig. 16.

. The chief faults which can occur in variable resistances are: intermittent operation due to dirt between the element and the slider, and a worn element. Dirt can be removed from wire elements either with very fine glass-paper or with a paint brush, but when an element is badly worn it is generally not possible to effect a satisfactory repair.

Variable resistances may be tested by connecting an ohm-meter to one end of the winding and to the slider. When the latter is slowly moved along the element, the readings on the meter should vary gradually from minimum to maximum, or vice versa, and the meter needle should not exhibit a series of eccentric movements. The resistance element itself can be checked for continuity and resistance by connecting an ohm-meter between the two terminals which make connection with the two ends of the elements.

Adjusting Volume Control

If a volume control is unsatisfactory in operation but its element appears to be quite clean and unworn, then the bearings and connections between the slider and its terminal should be examined and cleaned if necessary.

Switches. Dirty contacts and weak contact pressure give rise to crackling or "no results". In the case of the wavechange switch, it can generally be definitely estab-

lished that the switch is the cause of faulty reception by gently rotating the switch from side to side. This aggravates the crackling or will cause the reproduction to be intermittent.

In the case of dirty contacts, and especially when the switch is rather inaccessible, the contacts may be cleaned by applying a drop or two of one of the switch-cleaning liquids which are extensively advertised. If this does not effect a permanent cure, then the switch must be adjusted to increase the pressure between contacts. This is where the switch adjusting tool, illustrated in Fig. 29 of Chapter 11, will be used when dealing with flat-bladed spring contacts.

Rotary Switches

Rotary switches have a self-cleaning action and seldom give trouble, and the application of a switch-cleaning liquid generally cures any crackling or intermittency.

Transformers. See Inter-valve Transformers *and* Mains transformer.

IF Transformers may be dealt with as for coils and chokes (HF). See that the leads in the IF transformer are not touching and shorting (*see* Fig. 17).

Valves. The chief tests for valves were discussed under the heading of "Valve Testers", and the only points to be looked for in addition to those given are dirty pin contacts, microphonic valves and noisy valves.

Valves with dirty legs can cause crackling and intermittent results. In some types the wiring of the internal electrodes is passed through the hollow legs and soldered to the ends. Care should be taken not to disturb this soldering,

otherwise open circuits will occur, or worse, intermittent operation.

Microphonic valves give symptoms often mistaken for mains hum, but which become intolerable when the valve is badly microphonic. The symptom is howling, which, starting quietly, builds up to a volume that often reaches such a stage that the set has to be switched off.

It is generally easy to find a microphonic valve, as by slightly tapping each valve the faulty one will at once start to give rise to the howling, or at least cause a microphonic sound from the speaker. The reason a valve sometimes does not present its fault during tests is that the back of the receiver is opened, and this releases pressure of the sound waves.

·It may sometimes befall an engineer to endeavour to trace a fault without any instruments, and the following notes may be of value to him should he find himself in this predicament.
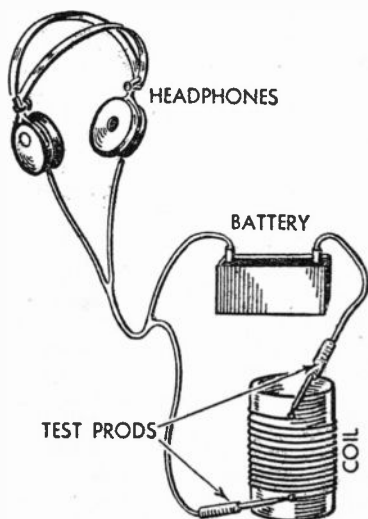
Fig. 19. Phones test applied to a coil.
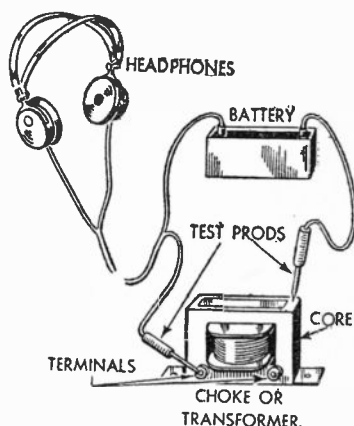
Fig. 20. Testing the insulation between a winding of a transformer or choke and its iron core.

A great deal of work can be carried out by means of a pair of headphones and a dry battery. A 1·5 v. or 3 v. battery is all that is required, and this arrangement may be wired up with a pair of test-prods as shown in Fig. 18. The test may be omitted so long as the wire is insulated except for the very ends.

When the battery is wired up with the headphones and the latter are being worn, a loud decisive click will be heard in the 'phones when the test-prods are touched together or shorted. This state of affairs will indicate continuity. For example, in Fig. 19 a coil is being tested for continuity by applying the test-prods to the soldering tags on the coil-former. These tags should, of course, be connected to the windings of the coil, and a click will be heard in the headphones if the coil has a continuous winding which is connected properly to its tags.

If the coil is faulty—in other words, open circuited—or has what many engineers term, a "dis" in it,
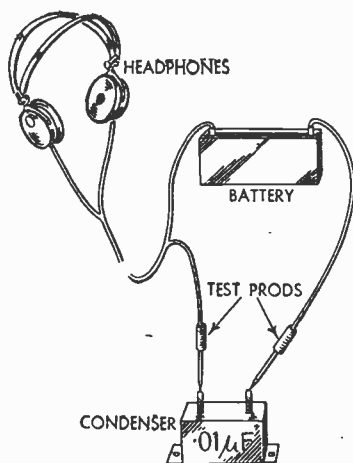
Fig. 21. The phone test is suitable for application to small condensers.

there will be no click in the headphones when the test-prods are applied to the ends of the windings. If the coil being tested is a multiple arrangement having SW, MW, and LW windings on it, each separate winding may be checked for continuity by applying the test-prods to the appropriate pair of soldering tags. In addition, a test for insulation between the various windings may be made by applying one test-prod to the soldering tag of one winding and the other test-prod to one of the tags of the adjacent winding.

Testing Oscillator Coils

This is a useful test to apply in the case of oscillator coils, which often have fine reaction windings over the grid tuning winding. A short of HT to earth may sometimes be located in this way, due to the breakdown of the insulation between the reaction winding and its corresponding grid tuning winding. IF and HF transformers and chokes may be tested in a similar

way, but it must be appreciated that this simple test will not show up such unusual faults as shorted turns.

LF transformers, smoothing chokes and mains transformers may be checked in the same way by applying the test-prods to the tags or terminals of each winding. In addition, the insulation between the windings and the core or laminations of the transformer or choke may be checked as shown in Fig. 20. In the latter case there should be no click, showing that the insulation between the windings and the core is satisfactory. A very slight scratching noise in the 'phones when the test is applied may be ignored; a decisive click is indicative of a breakdown.

Small fixed condensers may be tested for insulation or short circuit, as shown in Fig. 21. When the test-prods are first applied to a good condenser there will be a click as the condenser charges up from the battery, but any further touching of the test-prods on the condenser terminals should not provide any click in the 'phones. If there is a loud click every time the test-prods are touched on to the condenser terminals, then the condenser is short circuited. If there is no click on first application of the test-prods, then the condenser is probably internally disconnected from its terminals.

Condensers of large capacity may be checked as follows. First the condenser is charged by applying a voltage to it from an HT battery. A screwdriver should be held against one of the terminals and slid along until the tip of the screwdriver blade nearly touches the other terminal.

A large spark should occur as the condenser discharges. No spark indicates a faulty condenser.

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FAULT FINDING IN RECEIVERS

VOLTAGE DANGERS. PLANNED PROCEDURE. PRELIMINARY TESTS. VOLTAGE ANALYSIS. METER EFFECTS. RESISTANCE ANALYSIS. DYNAMIC TESTING. TESTING THE OSCILLATOR VALVE. MISCELLANEOUS FAULTS. HUM. HOWLING AND INSTABILITY. INTERMITTENT RESULTS. MOTOR BOATING. WHISTLING. WEAK REPRODUCTION. CIRCUIT ALIGNMENT. OUTDOOR AND INDOOR AERIALS. EARTHS. LOUDSPEAKER WIRING.

IF a faulty receiver was taken and every component in it tested by the methods described in the previous chapter, the cause of the trouble would be found. The testing would take a very long time, however, and fortunately there are ways of finding the particular region of a set in which a fault lies so that detail tests need only be carried out on one or two components.

To understand the ideas behind these fault-localising tests which are applied to the set as a whole, the engineer must have a fair knowledge of how a set works and, in particular, of how each receiver consists of a series of "stages" like links in a chain. The reader should refer again if necessary to Chapter 2, "How Receivers Work", before proceeding further with this chapter.

Two Main Faults

Various kinds of fault occur in receivers—from complete silence to howling and other queer noises. To some extent the tests to be applied depend on the nature of the fault, but fundamentally all failures are caused in one of two ways. Appreciating this, we can

work out logical testing systems which will find any fault in a minimum of time.

All faults are caused by either (a) the "opening" or partial interruption of a necessary circuit path or (b) the creation of an unwanted path. Basically, then, testing is a matter of checking continuity, *i.e.*, whether a required path remains or an unwanted path has come into existence.

Correct Continuity

If receivers used DC only, this testing would mean simply carrying out resistance measurements. The DC currents in a set, however, are only vehicles for the transference of the signals which, whether of radio or audible frequency, are alternating currents. We have, therefore, to make sure that the continuity is correct for AC as well as DC.

Most faults affect both DC and AC continuity—in other words, when the signal ceases to pass through the set, or does so inadequately or distortedly, there is at the same time a change in the circuit so far as DC is concerned. A current path has "opened" or a "short" or high-resistance circuit
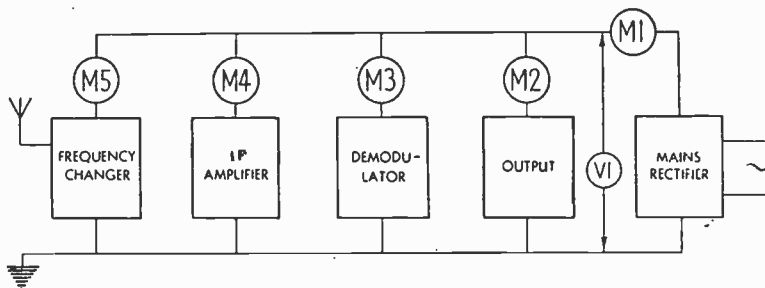
Fig. I. Current measurements show which stage contains a DC fault. A meter at MI shows the total HT current and with the voltage at VI indicates whether the mains section or the rest of the set is at fault. Tests at M2, M3, etc., then check the separate stages by measuring the valve anode currents.

has occurred, and this change of path or resistance is reflected by a change in the DC voltages and currents flowing to the valves.

By testing the voltages and currents at selected "key" points, and comparing the measurements obtained with the correct values given in the technical information issued by the manufacturers, we can pin down the point where the resistance has changed to some particular stage (Figs. 1 and 2). We can then test the components in this stage individually (Fig. 3).

Modern Testing Methods

Voltage and current testing of this kind is the backbone of radio servicing, but in recent years properly equipped professional engineers have developed a second test method which forms, it may be said, a very strong "right-arm".

As we have indicated, a fault may possibly only affect AC continuity. In this case voltage and current measurements are of no value. The only way to locate such a fault (apart from the random substitution of parts) is to put each stage of the set to work in turn, starting at the last valve and working back to the aerial (Fig. 4).

Mains-operated receivers use voltages of 350 and even more, and the greatest care must be exercised when handling chassis if the mains lead is connected. For this reason no attempt should be made to repair a mains set until experience has been acquired in handling battery receivers and service equipment generally.

When working on a "live" chassis the engineer must stand on a dry floor, preferably a rubber mat. He should touch the set only when holding insulated test-prods or other insulated tools (a metal screwdriver is dangerous to set and user).

The learner is well advised to wear rubber gloves. Every engineer should acquire the habit of touching chassis with one hand only; this eliminates the risk of shock through both arms and across the heart.

With AC/DC sets, the chassis is connected to one of the mains and, as this may be the "live" main, the chassis must not be touched.

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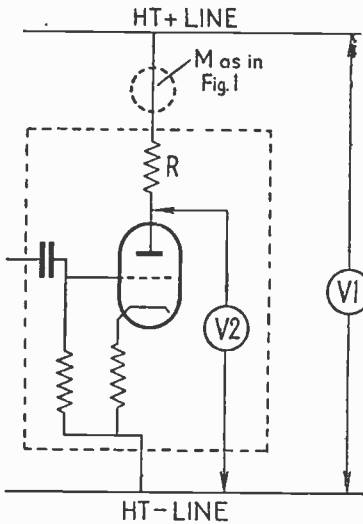
Fig. 2. Instead of breaking the circuit for current measurements, it is often easier to measure the voltages V1 and V2 and obtain the current through R by Ohm's Law.

Fig. 3. Typical stage showing the points at which resistance and insulation tests are made across individual components.

Testing each stage in this way is extremely simple when the engineer is equipped with a service oscillator (see Chapter 11) of the kind which is necessary for ganging superhets. With one of these, a low-frequency signal can be injected to the output valve and then the first LF amplifier; next the intermediate-frequency can be applied to the IF valve and, finally
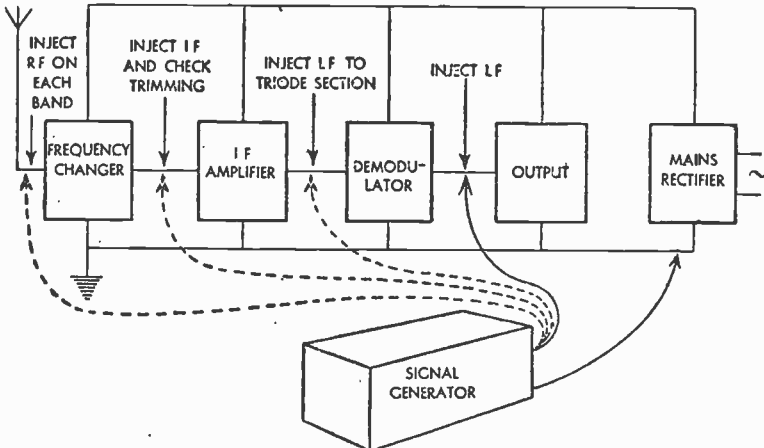
Fig. 4. Signal continuity is tested by injecting LF, IF and RF at points working back from output to aerial. Each stage is made to operate in turn.
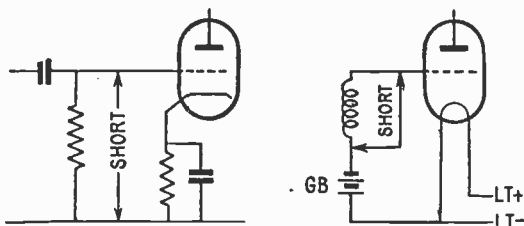
Fig. 8. An actual shorting strip can be used instead of a condenser provided it is taken to the bias point.

stages. Should the receiver be an all-wave model, each band should be tested, as this may localise the fault to the circuits used on one particular band. If signals come through on one band, this will eliminate the IF stages, which must be satisfactory.

and the output, LF and rectifier stages are up to standard.

If there is no reproduction from the record, the parts mentioned may be suspected, but the pick-up and its leads must not be overlooked.

Wavebands Check

Where record reproduction is satisfactory but radio is not, the fault must lie in the IF or HF

A table model can be checked in much the same way if pick-up sockets are available. The set should be switched to gram and a moistened finger touched on the pick-up sockets. If a loud "plop" is heard the LF circuits are satisfactory as regards the passing of signals—but, of course, may not necessarily be equally satisfactory as regards distortion.
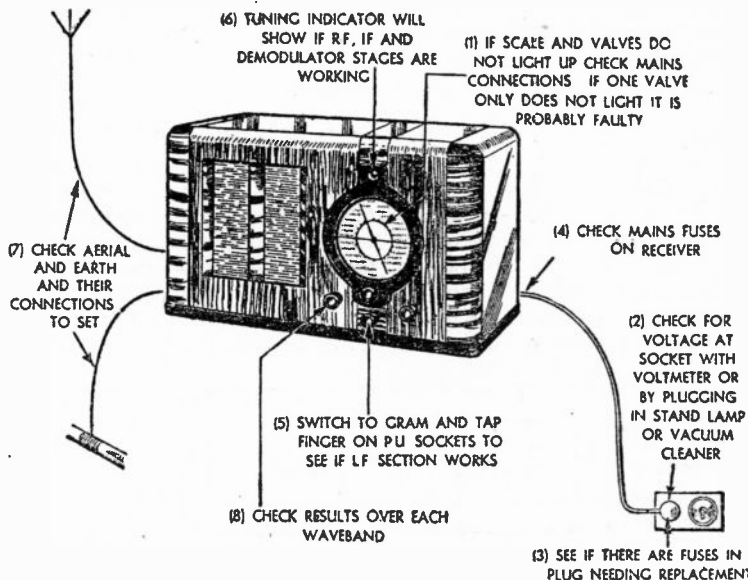
Fig. 9. Before disconnecting a set, possible external faults must be checked. Observation of how the set reacts to simple tests may obviate a great deal of detail checking. Tests should be made in the order shown.

Visual tuning indicators also provide useful guidance. As has been explained in Chapter 2, these operate from the signal voltages developed by the second detector valve or the AVC diode. If the indicator does not fluctuate when the tuning control is rotated, no signals are reaching the second detector valve, or the AVC valve is not functioning.

On the other hand, if no signals are heard and yet the indicator moves every time a station is passed, this shows signals are reaching the second detector and AVC valve, but not getting through to the LF part of the chassis.

The back of the set should now be removed and a search made for any obvious faults, such as a loose lead to the top cap of a valve or a blown fuse (Fig. 10). If one valve is cold it has probably failed, and a replacement may be tried. If all the valves are cold the main source of low-tension will be suspect—

i.e., the accumulator, the mains connection and the mains transformer.

Many receivers are fitted with extension and/or pick-up sockets which contain switches controlled by the position of the plug. If the plug is in the wrong position, or if the contacts have become faulty, a receiver which is blameless will appear "dead". It should be made a rule always to check the position of these plug-switches.

Voltage Analysis

If no cause becomes evident, it is time to reach for the meters and begin a voltage analysis. As many measurements as possible should be made before taking the chassis out of the cabinet, as this may prove unnecessary. With mains sets the HT voltage can often be measured between chassis and one of the tags on the back of the loudspeaker. If the speaker is an energised type another tag will give the

CHECK MAIN HT VOLTAGES BETWEEN FIELD TAGS AND CHASSIS

IF MAINS TRANSFORMERS OR OTHER PARTS ARE OVER HEATING SWITCH OFF AND CHECK FOR SHORT CIRCUITS

LOOK FOR MECHANICAL FAULTS, DISCONNECTED VALVE CAP LEADS, LOOSE VALVES

CHECK MAINS VOLTAGE ADJUSTMENT

CHECK EXTENSION SPEAKER SWITCH

CHECK PU SWITCH IS IN RADIO POSITION
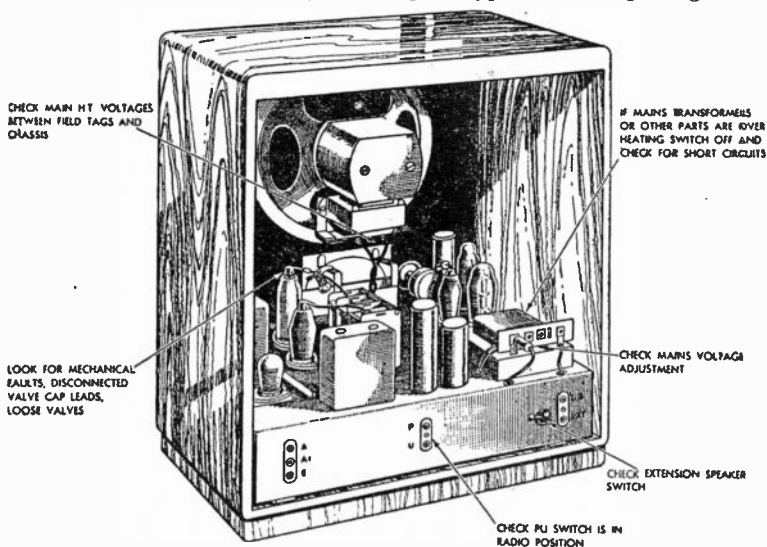
Fig. 10. When the back has been removed, check the "obvious" possible sources of trouble before removing the chassis from the cabinet.
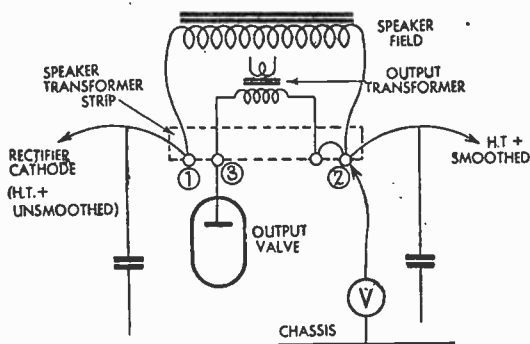
Fig. 11.—With most mains sets the terminal strip on the loudspeaker enables the principal voltages to be measured without the chassis being removed. By Ohm's Law the HT current can be calculated, thus providing a pointer to any rectifier, output valve or main HT line fault.

voltage after the HT has passed through the field coil (Fig. 11).

But to take things in their proper order: First, measure the voltage at the HT source, which may be either a battery, mains supply (in the case of DC instruments) or the output from the rectifying valve in an AC receiver. We will consider the AC instrument, as the first two are very similar, with the exception that there is no mains transformer and rectifying valve. A voltage reading, therefore, is taken of the output from the rectifying valve and, if this is low, the current from the valve should be measured.

If the current is also low, the rectifier is either faulty and has a low emission, or it is not getting the proper voltages from the mains transformer. These points should be checked by trying a new valve or, what is safer, measuring the AC voltages across the heater and anode sockets of the valveholder.

Reverting to our initial test on the HT supply point, if the voltage is low but the current of the valve is very high, this points to a

"short" somewhere on the HT circuit— *i.e.*, a smoothing condenser which has broken down, an output valve running without bias, a short in the smoothing choke or any HT wire shorting to chassis.

If the voltage and current delivered by the HT supply are up to standard, then the voltages on the anodes and screens of all the valves may be checked. If the first valve anode, for example, shows no HT voltage, this points to a break in the HT path to this point.

For these tests the negative voltmeter lead may be clipped to the chassis or to the HT negative point while the positive lead is used as a test-prod. The meter should be set to the highest DC voltage range giving a clear indication.

In Fig. 12 a representative stage circuit is shown. If no voltage appears at the anode socket of the valveholder, the positive voltmeter lead should be touched on the anode end of the resistance R_1, which is the coupling resistance. If there is no voltage here, then the lead must be connected to the other end of the resistance. Should the voltage appear here, this indicates either that the resistance has developed an open circuit internally, or that the soldered connections to it are bad.

Should there be no voltage on the second test, then the voltmeter lead should be touched on to the lower end of R_2, which is the

decoupling resistance, and again at the other end of R_2 if no voltage is indicated. The same remarks apply as before, but as we know that the main HT feed-line (which has been checked in the first tests) is O.K., we may assume that we shall get a voltage on this last check, thus indicating that R_2 or its connections are faulty.

Quite possibly voltages will be measured at the anode and between R_1 and R_2, but found higher or lower than they should be. This may be due to the valve being faulty (an alternative, known to be good, should be tried), or it may be caused by incorrect bias.

R_3, the automatic bias resistor, may have changed in value or be short-circuited. It must be remembered, too, that bias will not be applied to the valve if the grid circuit is open—*i.e.*, the grid-leak, R_4, and its leads must be checked.

Short circuits or high-resistance leakages in the decoupling condenser, C_1, or the coupling condenser, C_2, will cause heavy currents through R_2 and R_1 and, therefore, low voltages at the two test-points. A short of the bias decoupler, C_3, will operate the valve without bias, while an "open" C_3 will give reduced amplification, particularly of low notes.

Effect of Meter

When measuring circuit voltages we have always to remember that the meter itself consumes power and that the voltages measured are not exactly those present when the meter is not connected. The current passed by the meter flows through the circuit resistances and causes increased voltage drop across them—con-
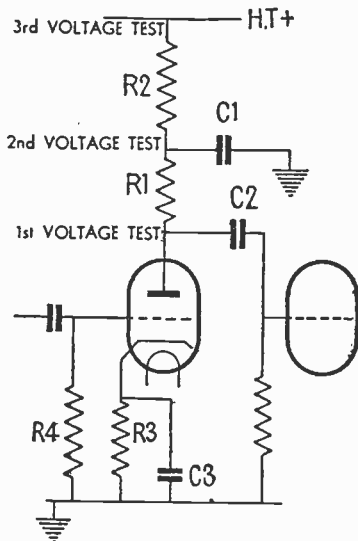
Fig. 12. Circuit of a simple LF stage with points for checking its anode circuit by voltage analysis.

sequently, the measured voltages are lower than the correct values.

If the circuit resistances are very high, the current taken by even the most efficient of ordinary meters may cause such a large voltage drop that a completely useless measurement is obtained. This often occurs in stages, as shown in Fig. 12, when R_1 has a value of anything from 50,000 to 250,000 ohms. This point is made clear by Fig. 13.

With AVC and demodulation stages it is generally impossible to obtain useful voltage readings, because the circuit resistances are so high and the power in these circuits is so small. AVC is best checked by connecting a milliammeter in the cathode circuit of a controlled valve and watching for a decrease of current as the set is tuned through a powerful station.
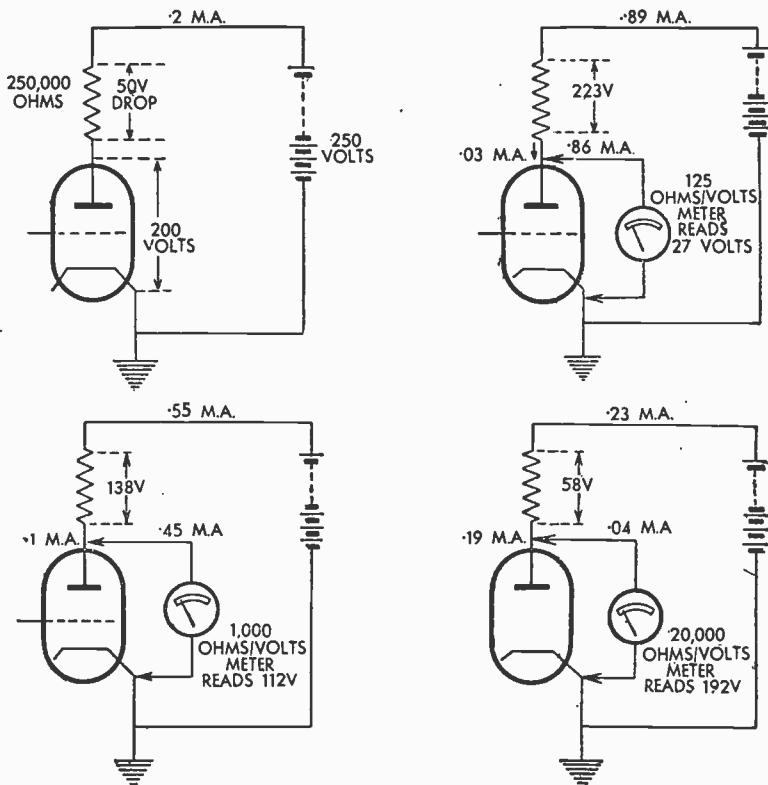
Fig. 13. These four diagrams illustrate the considerable effect the meter itself may have upon the voltages it is measuring. Generally speaking, a meter of less than 1,000 ohms per volt or equivalent sensitivity should not be employed.

Valves and components are generally made with a "tolerance" of error up to 10 per cent. high or low. These variations mean that any small errors due to the meter itself are not of importance and, generally speaking, any reading within 25 per cent. of the "correct" value can be passed.

Tests of resistance instead of voltage or current are useful when there are short circuits which blow the fuses or cause the mains transformer to smoke. These symptoms give a guide to the type of trouble to be looked for (short-ing smoothing condensers, faulty windings on mains transformer, and so on), and then it is only a matter of checking the resistances of the various components, the receiver being "off" and disconnected from the mains.

A glance at a circuit diagram will show that the anodes of all the valves are connected to the HT supply through circuits of various resistance values and, therefore, if one lead of an ohmmeter is connected to the source of HT, then the other lead may be tapped on to the various valve electrodes to see

whether they are properly connected to the HT supply.

For example, if, when applying the test-lead to the anode socket of the valveholder in the intermediate frequency position, it is found that no reading is obtained, this points to a break in that valve's anode circuit. The test-lead can be taken back lead by lead, and component by component, until the disconnection is found.

In normal service work, voltage and resistance tests proceed hand in hand. For example, a suspicious voltage reading would be followed up by switching off the receiver and measuring the resistance of the suspected components or checking the continuity of the wiring and joints.

Dynamic Testing

We now reach the third testing method, that by which a signal is injected into every circuit of a receiver in logical sequence.

Let us assume that we have a 6-valve superhet with a circuit similar to Fig. 14, and that the preliminary tests have been carried out as have been described to establish the fact that the principal HT voltages are present.

Signal tracing is carried out as follows. The AF (audio-frequency) output from the oscillator is injected between chassis and testing point No. 1, the grid of the output valve, V_5. If the signal of the oscillator cannot be heard in the loudspeaker, there is evidently a fault either in V_5, in the grid or anode circuits of it, or in the speaker.

Thus, the location of the fault is narrowed down to a very small part of the receiver. The anode voltage and current of V_5 should be checked, and if they are not

right, the primary of the output transformer L_1, the bias components R_1 and C_1 and any parallel tone components such as C_2, R_2 and C_3 should be checked.

Testing the Loudspeaker

The loudspeaker should next be examined and the speech-coil (L_3) resistance measured, when it will probably be found that a disconnection has occurred in this or in the secondary winding (L_2) of the output transformer. These windings will be of only a few ohms resistance, and it may be found easier to test the speaker simply by connecting a substitute permanent magnet type in parallel with the primary L_1.

It will be noted in the circuit there is a third small winding (L_4) in series with the speech-coil. This is the "hum-bucking" coil, which performs the same function as the "hum-neutralising" coil mentioned under the heading of Pick-ups in Chapter 12.

Finally, it must be seen that the grid circuit, R_3, is not shorted.

If signals are reproduced from the speaker when injection No. 1 is made the oscillator lead can be transferred to point No. 2. It may be necessary to insert a 0·1-mfd. condenser to isolate the oscillator from the HT. This will check R_4, the anode load, C_4, the coupling condenser, and any parallel components. Next, still injecting LF, we transfer the oscillator lead back to point No. 3.

If V_4 and the volume control, R_6, are satisfactory, signals will be heard from the loudspeaker. If not the voltages on V_4, and the bias resistance, R_5, and decoupling condenser, C_5, should be checked. If the anode current is low while the voltage on the anode is normal
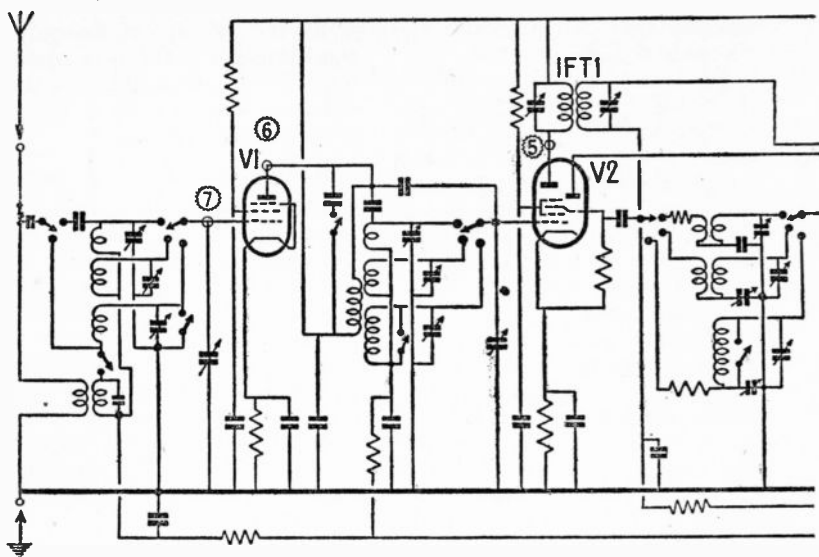
Fig. 14. Circuit of a typical six-valve superhet showing the points at which signals should be injected for dynamic testing. Each stage is tested separately, working from V5 back to V1, by injecting suitable frequencies from a signal generator. When the faulty stage is located, resistance or voltage measurements are taken and these reveal the component responsible.

or higher than normal, then a replacement valve should be tried.

Assuming that signals are received from test-point No. 3, the next step is to switch the oscillator to give a modulated signal at the intermediate frequency of the receiver. The output is then applied to test-point No. 4, which is the anode circuit of the IF amplifying valve, V_3. As there is HT here, it may be necessary to use a condenser of about 0·0001 mfd. in series with the test lead.

No output will indicate a faulty IF transformer (IFT_2) or a faulty demodulation diode. The various diode-load resistances and condensers, R_7, R_8, C_6, C_7, C_8, should be checked and the connections to them inspected.

If signals are satisfactory, the next test may be made at point No. 5, with the service oscillator

still adjusted to the intermediate frequency. The same considerations outlined above will prevail as to whether the circuit is O.K. or not, and if conditions are satisfactory, the next test will be at point No. 6.

This is the anode circuit of the HF valve, V_1, and the service oscillator must be adjusted to the medium wavelength—say, 250 metres—and the tuning of the receiver adjusted to this wavelength. All wavebands should be tested in this way as mentioned earlier.

If the test at No. 6 point gives no results, the oscillator stage should be checked to see whether or not it is oscillating. One way is to tune the receiver to a station and then inject the frequency of this station plus the IF to the oscillator grid, thus substituting

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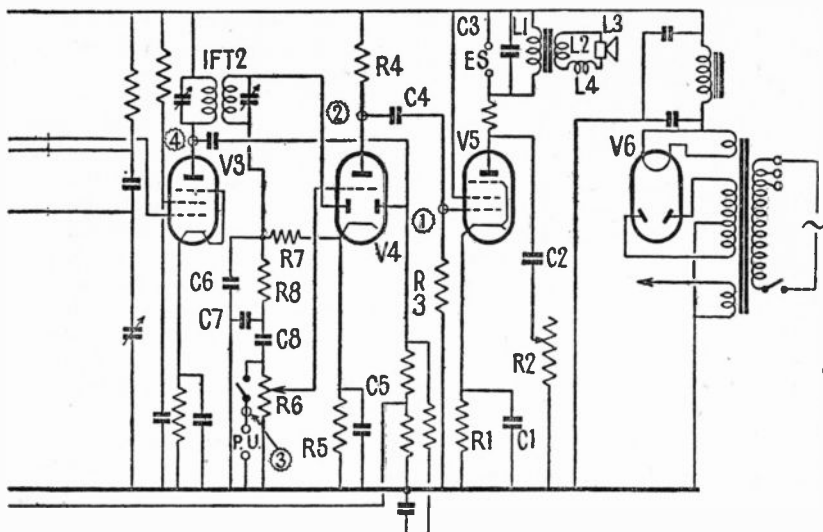
the oscillator circuits. If the station is heard, obviously everything is correct except the oscillator; if nothing comes through, the reason can only be that the signal is not reaching the frequency-changer valve (Fig. 15).

In oscillator circuits employing a grid condenser, C_1, and resistance, R_2 (Fig. 16), the current will rise when the grid-circuit is shorted. In circuits not employing a condenser and resistance (Fig. 17) the current will fall when the valve is made to stop oscillating.

To connect a milliammeter in series with the anode or cathode circuit of the valve may upset the stability of the circuit. To overcome this, a voltage test may be made across one of the feed resistances, R_3, in the anode circuit.

This test should be made on all wavebands and on two or three widely separated wavelengths on each band. If results are intermittent, watch the voltage readings when reproduction ceases; if

the voltage fluctuates, the oscillator valve or its associated components should be suspected and carefully tested individually.

Eliminating Tests

If results at No. 6, Fig. 14, point are satisfactory on all wavebands, then a test should be made at test-point No. 7, Fig. 14, which is the very first circuit of the receiver, and if results are then obtained, it will indicate that the fault is in the aerial circuit and its coils. If there is no signal, then the fault must lie between points No. 6 and 7.

This procedure appears more complex than it really is. The testing of the circuits from point No. 3, Fig. 14, back towards the aerial will be complied with automatically when aligning the IF and HF circuits of a receiver as fully described in the manufacturer's service manual.

The condition "no results" is easier to deal with, and is generally
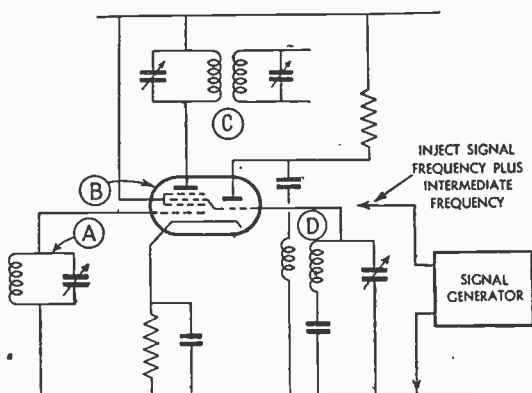
Fig. 15. A signal generator can be used to test the oscillator stage by substitution. When a signal plus IF frequency is injected to the oscillator grid, failure to get an output shows either A, B (the valve) or C is at fault. If the signal is heard, then D is incorrect.

INJECT SIGNAL FREQUENCY PLUS INTERMEDIATE FREQUENCY

SIGNAL GENERATOR

otherwise crackling will appear, due to chassis vibration.

Where difficulties are experienced in locating the cause of the trouble, the circuit must be carefully analysed stage by stage, shorting various components, such as resistances or chokes, to see whether the crackling ceases.

Condensers, of course, must not be shorted, and if they do not respond to gentle prodding they should be replaced by good components and the results noted.

The object of shorting the various anode and grid circuits is to see whether the crackling is being passed on to that stage from

more rare, than complaints of crackling, distortion and intermittency, and now that the reader has been shown how to thoroughly examine a chassis, these various faults will be discussed.

Miscellaneous Tests

Crackling. This may be due to broken aerial and earth wires, or frayed battery leads. When it is decided that the fault is in the set, preliminary tests should be undertaken, as already described, to see whether the fault lies in the HF or LF parts of the circuit.

Crackling may be due to bad connections, partial breaks in the windings of coils, chokes or transformers and faulty resistances. Valves also can give rise to crackling when they have faulty electrodes.

Prodding the components and suspected joints in the wiring with a wire dressing-tool (page 321) will often assist in localising the cause of the crackling, but care must be taken not to prod too vigorously,

Fig. 16. With the grid-leak type of oscillator, the voltage across R3 should rise when L1 or L2 is shorted to stop oscillation and the current rises.

358
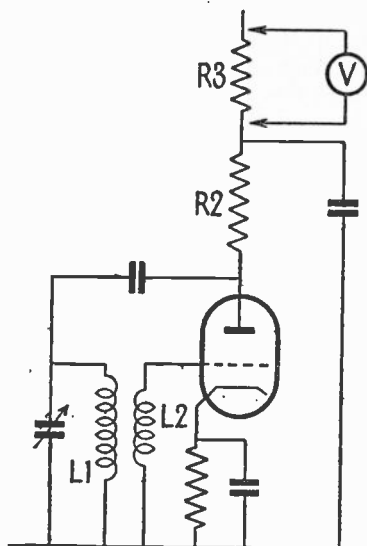
Fig. 17. With the anode bend oscillator, the voltage across *R3* should decrease when oscillation is stopped. If it does not, the valve was not previously in a state of oscillation.

the previous stage. For example, referring to Fig. 14, if, with no station tuned in, the grid circuit of V_5 is shorted, but the crackling persists, then the cause of it must be in V_5 or the wiring and components between it and the loudspeaker. The shorted grid circuit will prevent any signals or crackling from the previous stages affecting V_5.

Shorting of the Grid

If the crackling stops when V_5 is put out of action by shorting its grid to the chassis, then this indicates that the crackling is either in the grid resistance of V_5 or is being passed on to it from the previous stage. The next test, therefore, would be the shorting of the grid of V_4, and if the crackling was in evidence on this

test, this would show that the cause was in the circuit between these two test-points.

Hum. The stage in which hum is being generated or picked up may be found by a similar method of stage analysis as described for crackling. Instead, however, of placing a direct short circuit across the various components, a large-capacity condenser may be used, having a value of about 1 mfd. By using a condenser to short the hum "signal" the DC voltage applied to the valves is not affected and misleading results due to this obviated.

The condenser can be connected across a biasing resistance to see whether the original condenser is open-circuited. If, when the tests are carried out, the signal being reproduced ceases but the hum continues, this indicates the cause of the hum is between the loudspeaker and the test-point.

Excessive Hum

Excessive hum of a deep-throated type is generally associated with faulty HT smoothing, and the condensers and smoothing choke (or loudspeaker field coil) should be checked. Hum due to trouble in these components will be evident on both radio and gram.

If the hum is not so deep and is not heard on gram, the cause may be a faulty valve in the HF or IF circuit. With a radiogram, hum may be introduced by the leads to the pick-up and these should be as short as possible and run through earthed screening cable (Fig. 18).

Hum may be picked up by grid wiring from adjacent AC heater wiring, and careful re-positioning the wire with a wire dressing-tool should be tried. If no cure is effected when any particular wire

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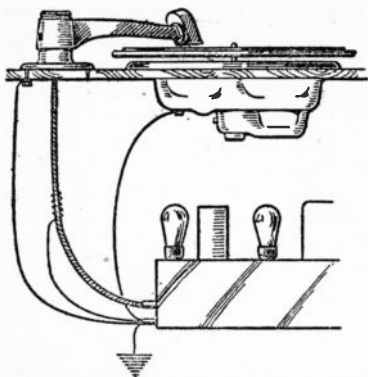
Fig. 18. Pick-up leads must be short and screened to avoid the introduction of hum from the mains leads.

is moved, the wire should be returned to exactly the same position in which it was found, so as to prevent other troubles occurring, such as lack of tuning range, or loss of sensitivity, especially in short-wave circuits.

Howling and Instability. Howling may sometimes be due to microphonic valves, microphonic wiring in short-wave circuits, or instability due to open-circuited decoupling condensers. Removal of the chassis from its cabinet will prove whether the trouble is due to microphonic components or instability because, out of the cabinet, microphonic components very seldom give rise to the complaint, as they are not subjected so much to the vibrations of the loudspeaker. Microphonic valves should · be changed and microphonic wiring should be given extra supports so that it cannot vibrate.

If the howling continues with the chassis out of the cabinet, tests must be made on the various decoupling condensers, or for interaction between the anode and grid wiring. The set should first be tried on all its wavebands. If the fault occurs only on one waveband this will narrow the search down to the components of that part of the circuit.

If the howling is apparent on all wavelengths but not when the receiver is switched to gram, then look for the cause in the HF or IF circuits. If the howling occurs on radio and gram, the root may be looked for in the second detector or LF stages.

Faulty Connection

Bad connection to earthing points can cause howling due to instability, and so also may excessive voltage on the anodes or screens of the valves. The latter can be checked by voltage measurements to see whether any feed resistances have changed in value or been shorted by some wiring fault or stray piece of solder.

To check for an internally faulty decoupling condenser, a good condenser with two test-leads attached may be connected across suspected condensers (Fig. 19). If the instability ceases, the condenser across which the test condenser is connected is faulty and should be replaced.

Intermittent Results. This fault is one of the worst the engineer can come up against, because very often, as soon as an attempt is made to locate the trouble, reception becomes normal again.

Practically any of the troubles discussed under "Components" will give rise to intermittent results when the fault itself is not complete but only partial. For example, a broken soldered joint or a badly made one may hang together sufficiently to give reception until some vibration of the

receiver causes the fracture to part and break the circuit; another vibration may be sufficient to bring the surfaces together again, so that the circuit is renewed.

Bad connections inside fixed . condensers, partial breaks on'the soldering tags of HF and LF chokes, can be responsible for intermittent faults, and these have to be looked for with great patience, using a wire dressing-tool as a prod or probe to investigate all the likely joints and the suspected components.

Fig. 19. Decoupling condensers, C1, C2 and C3 can be checked by connecting in parallel a substitute permanently wired to a clip and test prod.

Many types of intermittent fault are only apparent when the receiver has thoroughly warmed up and is enclosed in its cabinet. The mere fact of taking the chassis out of its cabinet for test on the bench upsets the operating conditions, so that the fault does not occur. This point should not be overlooked when investigating elusive intermittent faults, and an upturned box may be put over the chassis or loudspeaker to retain the heat, and so duplicate normal working conditions.

"Crackling"

Where intermittent faults occur frequently and are easily provoked by vibrating the chassis, the stage in which the fault occurs may be localised in a similar way to the method described under "Crack-ling." A close watch should be kept on the visual indicator if one is fitted in the receiver, because if this fluctuates when the fault occurs it will prove that the trouble has occurred in the IF or HF stages.

Comparing Readings

Voltmeters or milliammeters may be connected in the various valve circuits and their readings noted while reception is satisfactory, and then, when reproduction ceases, the readings should be compared with the original notes.

Motor Boating. Motor boating is a term applied to a form of instability which occurs at such a low frequency that each individual cycle or pop can be heard. It is

usually due to open decoupling condensers or low-capacity smoothing electrolytics.

Whistling. If the whistling is of a continuous nature when the tuning knob of the receiver is rotated, the cause is one of those given above for instability.

Curing Whistling

If, however, the whistling varies in pitch as the tuner is rotated, it may be put down to interference from a station with a wavelength close to that of the required programme. Sometimes, commercial or government stations on about 600 metres are received direct on the wiring of the IF circuits, or force their way through the HF circuits and cause whistling to be heard on every station as it is tuned through.

The cure is to first re-trim the HF and IF circuits as carefully as possible. If this does not sufficiently minimise the annoyance, a wavetrap should be inserted in the aerial lead (*see* page 262).

In the case of the 600-metres transmission referred to, an old IF coil and trimmer may be used.
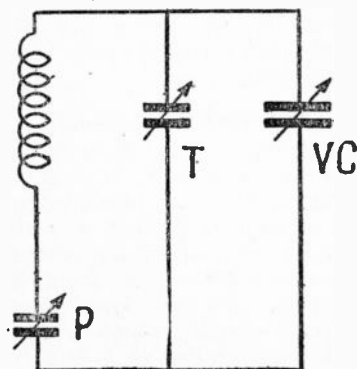
Fig. 20a. The elements of an oscillator circuit showing the parallel trimmer and series padder for correct tracking.

Weak Reproduction. If the usual tests on valves, voltages and currents do not reveal the reason, coupling condensers between the detector stage and LF or output stage should be checked for capacity. If the tags of the condensers are not touching the foils inside, the condensers will be open-circuited and have no capacity. There may, however, be sufficient capacity in the wiring and the faulty components to hand on a weak signal from one stage to another.

Circuit Alignment

As explained in Chapter 2, "How Receivers Work", the tuned circuits in receivers are provided with small parallel "trimmer" capacities, so that inequalities between circuits due to variations in manufacture and ageing can be compensated.

The oscillator circuits also include series "padding" condensers (Figs. 20a and b) to secure correct tracking (the maintenance of the right frequency difference with respect to the RF stages) over the whole waveband (page 70).

When sets have been in use for a considerable time or after valves, coils or wiring have been altered, these trimmers and padders need readjusting, and the process is variously known as "trimming", "ganging" and "circuit re-alignment".

With simple "straight" or tuned radio-frequency sets it is quite satisfactory to adjust the trimmers for maximum volume on some station at about 275 metres.

Experiments may show that the trimming is somewhat out of adjustment at each end of the waveband. This will affect both sensitivity and selectivity. The

only solution is to arrive at a compromise adjustment, so that the trimmers are not exactly accurate at any point, but give the best average performance over the waveband.

Fig. 20b. Trimmers T1 and T2 are adjusted towards the low wavelength end of the band and T3 is the padder adjusted to preserve tracking at the upper end.

The trimmers should be set to the least capacity possible, or the minimum tuning capacity will be unnecessarily increased and the tuning range correspondingly decreased. These TRF sets usually have reaction, and this control should be kept at just below oscillation point throughout trimming.

The alignment of superhet circuits cannot be undertaken without the use of a signal generator, and without this item of equipment it is making trouble to start altering trimmers. The signal generator is described on page 311. It is also advisable to connect an output meter (page 313) across the loudspeaker or the speaker extension sockets;

this will give far more reliable and sensitive indication of the effect of adjustments than the ear.

Throughout alignment, volume and tone controls should be at maximum and the selectivity adjustment, if any, at "sharp". Except when injecting to them, the aerial and earth-sockets should be shorted together.

IF Circuits

The intermediate-frequency circuits are first aligned (Fig. 21). The generator is adjusted to give a modulated signal of the intermediate frequency of the set (this frequency is given in the maker's service information), and its output leads are connected to the
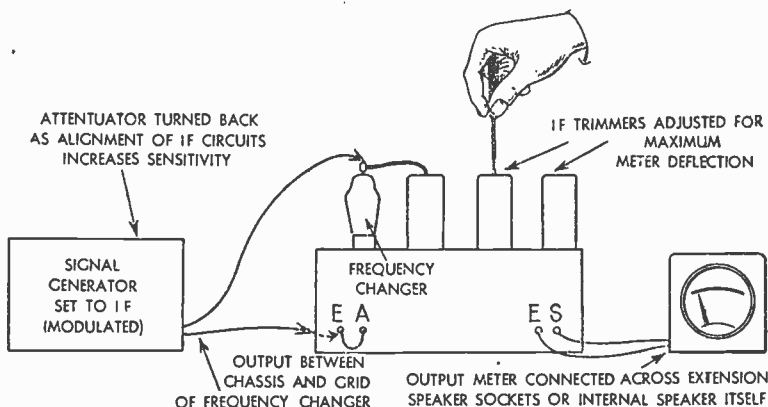
Fig. 21. IF circuits are lined up first. Modulated IF is injected to the frequency-changer signal grid and the IF trimmers adjusted for maximum response on the output meter. The input is kept as low as possible to prevent operation of AVC.
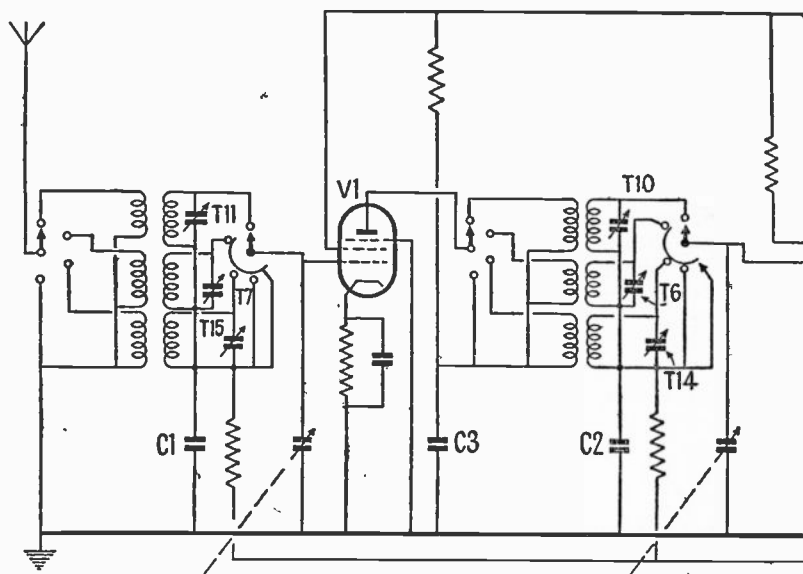
Fig. 22. Circuit of RF, frequency-changer and IF stages showing the trimmers that are adjusted during the operation of circuit alignment. The procedure is described below.

chassis and the signal grid of the frequency-changer valve.

The IF trimmers ($T1$, $T2$, $T3$ and $T4$ in Fig 22) are then adjusted several times over until a given indication on the output meter is obtained with the least possible input. Throughout the process the input from the generator should be constantly decreased as the circuits come into line, so that the AVC does not operate.

All modern sets have their scales marked with station names, metres and, sometimes, kilocycles and megacycles, and the trimmers have to be set so that the stations are received at the right points on the dial. Before beginning alignment, therefore, it must be checked that the dial is horizontal and central in its mounting, and the pointer registering with its lowest marking when the gang is full out.

The parallel trimmers are adjusted towards the bottom end of each band, the oscillator trimmer being adjusted first. For example, the receiver is tuned to 220 metres, a modulated signal of this wavelength is injected across aerial and earth, and $T5$, $T6$ and $T7$ (Fig. 22) are adjusted for maximum output in the order given.

Padding

The "padding" frequency is then injected. This is always towards the top end of the band. The set is tuned to, say 500 metres, 500 metres is injected, and the series padder, $T8$, adjusted. It is often advisable to "rock" the gang condenser (dial backwards and forwards over a few degrees), in such a way that both gang and padder are adjusted simultaneously.

Generally, the different wavebands are independent and can

GANGED CONDENSER

be ganged in any order. Occasionally, however, the short-wave trimmers are in circuit on other bands; in this event they must be adjusted first and then left alone.

On the short-waves it will be found that the oscillator trimmer (T_9) gives more than one peak. This, unless otherwise stated in the maker's instructions, should be set to the peak obtained with the · trimmer farthest out.

Fig. 23 summarises in diagrammatic form the complete alignment procedure.

With RF circuits as with the IF stages, the injected signal must be kept as low as possible, so that the AVC circuits do not come into action and cause misleading effects. If the signal is allowed to exceed the AVC delay (*see* Chapter 2), the amplification of the RF and IF valves will keep altering in an endeavour to offset the effects caused by the trimming adjustments.

The actual trimming and padding frequencies with each set depend on the particular design, and are always given in the maker's service information. When they are not available, however, the following will not be far wrong:

Short Waves. Trim at 20 metres, pad at 40 metres.

Medium Waves. Trim at 214 metres, pad at 500 metres.

Long Waves. Trim at 1,000 metres, pad at 1,800 metres.

Inductance Trimming

In modern sets the padding condensers are sometimes fixed and not adjustable. In others such as in Fig. 24, the inductances of the coils are adjusted either by altering the spacing of a turn or two or by adjusting iron-dust cores. In both cases the effects and the procedure are the same as in the case of capacity trimmers.
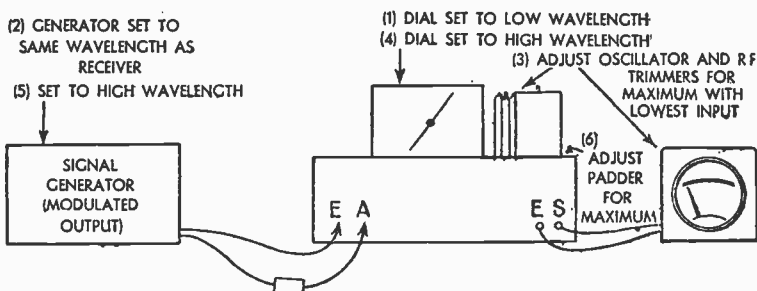
Fig. 23. Schematic summary of the complete procedure for ganging the signal and oscillator circuits of a superhet receiver.

Where a receiver has a frame aerial, the signals are injected from the signal generator simply by picking them up on the frame aerial, the generator having a foot or two of wire connected to it and laid on the bench some inches from the receiver. With self-contained sets, particularly battery portables, the chassis, frame aerial and batteries should all be in their normal relative positions when adjusting the trimming.

Wherever possible, an outdoor
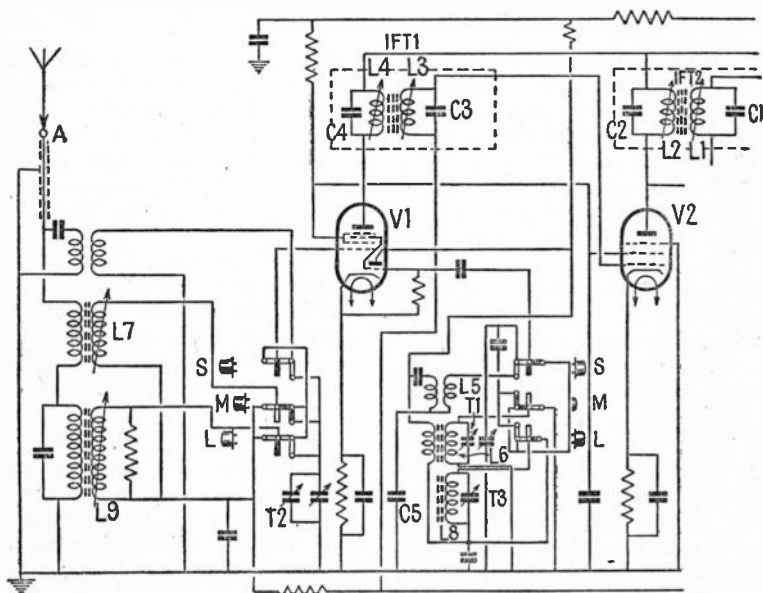
Fig. 24. A frequency-changer stage in which inductances as well as capacities are adjusted for alignment purposes. The IF circuits are trimmed by the cores of L1–L4. SW padding is fixed (C5) and tracking is obtained by adjusting the turns of L5. On MW, T1 and T2 are adjusted at 220m. and L6 and L7 at 500m. On LW T3 is set at 1,000 and L8, L9 at 1,750m.
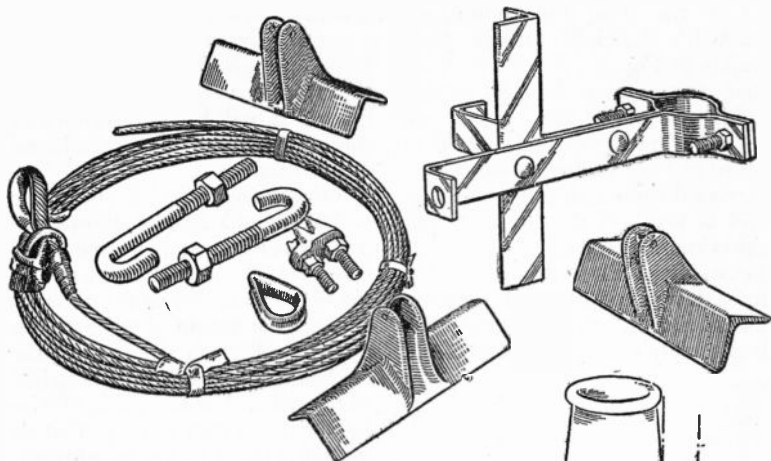
Fig. 26. Chimney straps and mast brackets for use where brickwork is not suitable for screw-fixed brackets.

aerial should be used, no matter how sensitive the receiver. In fact, the more sensitive the set the better should be the aerial, because a high-amplification receiver working on an indoor aerial will pick up all sorts of electrical interferences from far around.

Installation

If a good outdoor aerial is used, the signal handed to the receiver is so strong that the AVC circuits provide a large bias which desensitises the HF and IF valves and automatically makes them less sensitive to "noise" from nearby electrical wiring.
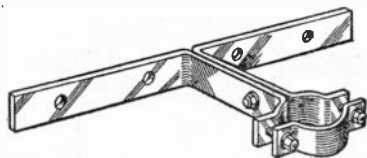
Fig. 25. A mast supporting bracket for fixing to walls or chimneys where brickwork is sound.
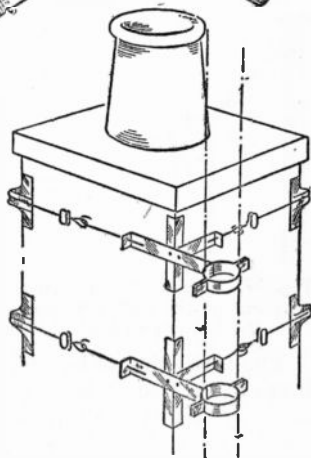
Fitting a mast is not very difficult if proper equipment is used for fastening it to the building. If the house is comparatively new and the bricks are hard and sound, the type of bracket shown in Fig. 25 may be used. The holes for fixing the bracket should be fitted with plugs into which large coach-screws will fix firmly. Care should be taken to see that the holes are in the brickwork and not the mortar between the bricks.

When the brickwork is old, fixing brackets of this type should not be used without the advice of a builder. It is generally safer to

attach the mast to a chimney-stack by means of fittings illustrated in Fig 26. It will be seen that the actual bracket which holds the mast fits on to one corner of the stack and is held in position by a strong cable, which is passed right round the chimney and is kept off the brickwork at the corners by means of the corner pieces. Strainers enable the cable to be drawn up tight, and when the job is finished the chimney-stack is probably stronger than before.
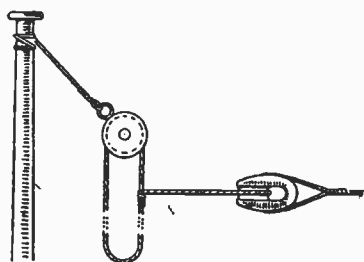
Fig. 27. To prevent the halyard running out of the pulley it should be in the form of an endless loop.

The aerial should be supported between the two points of suspension by pulleys. The halyard should be endless (Fig. 27), so that if it slips out of the hand when putting the aerial up, it will not run through the pulleys. Also, an endless halyard provides a downhaul which is very useful when lowering the aerial during a periodic overhaul.

Fig. 28 illustrates the right and wrong methods of wiring up of insulators between the aerial wire and the halyard. In the first method the insulator is under a state of compression, and should it fail, the aerial and halyard wires will still be connected and will not come down. In the second, and wrong, method the insulator experiences a pulling strain. Should

it break, the aerial will come down and the halyard will probably run back through the pulley, so that the insulator, or a broken remnant of it, will become jammed in the pulley at the top of the house or the mast.

The heavy cable of anti-static aerials should not be allowed to pull directly away from the aerial transformer unless provision is made in the design of the aerial to support the weight of 60 or 70 feet of cable. Fig. 29 shows how the cable may be looped up and lashed to the halyard or to a piece of wire between two insulators, so that no weight is taken by the aerial transformer itself.

Most people feel safer if they know that their outside aerials are fitted with a lightning arrestor, and one of the many forms now available can be fitted when installing the aerial (Fig. 30). In some types a switch has to be manipulated to short the aerial to earth when desired, but the gas-discharge type of lightning arrestor or the simple spark-gap arrangement is more convenient, as it is automatic.

The spark-gap type should be periodically attended to, to make sure that dirt has not collected in
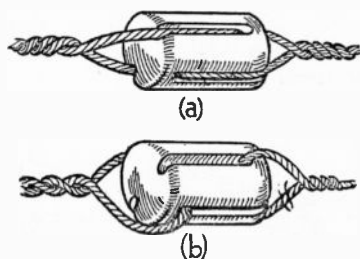
Fig. 28. The correct method of using an insulator (a) provides compression and leaves the wires aloft even if the insulator breaks; (b) is incorrect.
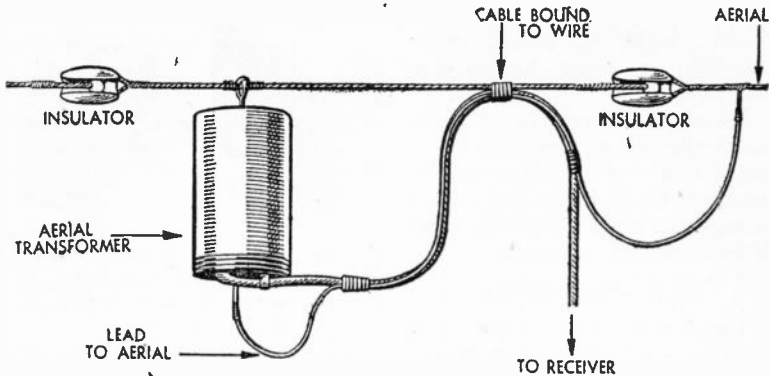
Fig. 29. With anti-static systems the weight of the screened lead-down should be taken by the span as shown here and not by the transformer.

the gap, so causing a leakage to earth, which will weaken signals.

When an indoor aerial is necessary either by the insistence of the customer or force of circumstances, then, wherever possible, it should be located beneath the roof. There are generally many places under the gutter where a down-lead may be brought out. Where there is no length of garden, an aerial in the roof is quite effective.

The wire should be run round the rafters as high as possible, to keep it away from any electrical wiring in the ceiling above the upper floors. If a good-quality insulated wire is used, it may be fastened to the rafters by means of insulated staples.

In flats where there is no access to a loft, a wire round the picture-rail must be neatly stapled into position between the top of the picture-rail and the wall, where it will not be seen.

Engineers should make it quite clear to clients that with an indoor aerial, especially of the latter type, results cannot be as satisfactory as with an outdoor aerial. Definite statements of this nature, courte-
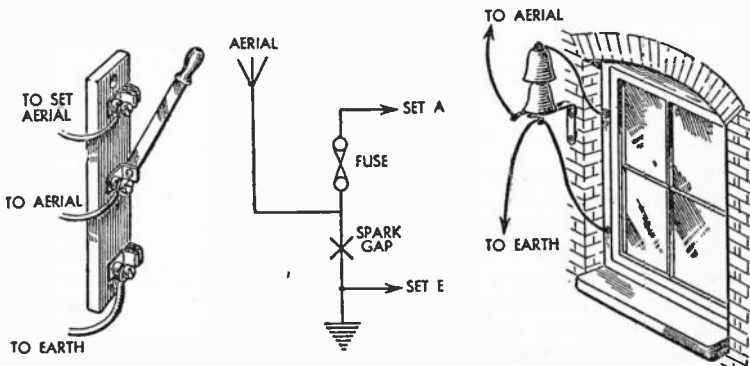
Fig. 30. A simple aerial earthing switch and a device (*right*) incorporating a safety spark-gap and fuse. The latter gives automatic lightning protection.

ously expressed, prevent future "service calls" for unsatisfactory reception or noisy background interference.

Wherever convenient, a short earth-wire to an earth-tube inserted into moist earth should be used, and the customer instructed to keep the earth round the tube moist during dry weather.

Water-Pipe Earths

The next most satisfactory type of earth is the water-pipe, where it enters from the mains into the house. The wire should be attached to an earth-clip, which should be fastened round the pipe, after the latter has been thoroughly cleaned.

When it is not possible to connect up to the earth or a main water-pipe, other earths must be tried, to see which gives the best results. In modern houses, three-pin electricity mains sockets are provided on the skirting-board, and the thick earth-pin may be used for the radio. The third socket of the supply point is connected to the conduit, and this, if the installation has been properly approved, will connect to an earthed water-pipe somewhere on the system.

The pipes of hot-water radiator systems may sometimes prove effective as a "capacity" earth, even if there is no direct connection to earth.

Extra Loudspeaker Wiring

The distribution of loudspeaker points for large installations is dealt with in Chapter 14. Points for the service engineer to attend to when installing extra or "extension" speakers for domestic receivers are concerned mostly with the type of wire and with the problem of matching the speaker to the output of the receiver.
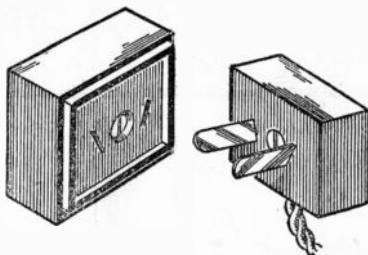
Fig. 31. A neat way of connecting extension speakers. The special plug and socket prevents accidental connection to power points.

The wiring may be carried out with twin flex run between the picture-rail and the wall or along the skirting-board (Fig. 31).

Generally, the wiring should not carry HT. With receivers which have a high-impedance output (Fig. 32) the anode of the output valve should be connected to one side of a 1-mfd. condenser (500 v. working), one of the speaker leads going to the other side of the condenser (Fig. 33). The remaining speaker lead should be connected to earth or chassis of the receiver (but not to chassis in the case of DC or AC/DC instruments, where the chassis may be at full mains potential above earth).

Loudspeaker Impedance

This arrangement uses the output transformer as a choke, while the condenser blocks the HT but permits speech currents to flow through to the extra loudspeaker. This method is also very suitable for using a high-impedance speaker where only a low-impedance circuit is provided at the extension sockets of a receiver.

Wherever possible, employ a loudspeaker whose impedance is similar to that in the receiver. For example, if the extra speaker sockets of the receiver are connected across the speech coil of a
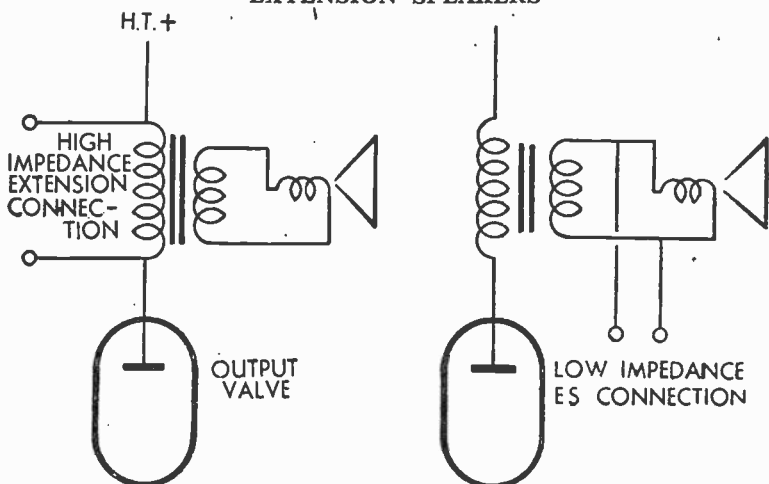
Fig. 32. High-impedance (*left*) and low-impedance connections for extension loudspeaker. With the former connection the extension speaker requires its own matching transformer, and part of the HT current to the output valve flows through the wiring. With the low-impedance connection on the secondary of the transformer, the leads must be direct to the speech coil of the extension speaker.

4-ohm loudspeaker, then the external speaker should have a speech coil resistance of, say, 3 to 5 ohms.

With low-impedance extensions the connecting wires must be as short and thick as possible, because the current is large and a small resistance can absorb a lot of the power. If, for instance, the extension speaker had an impedance of 4 ohms and the resistance of the leads was 4 ohms, half the "volume" would be lost in them.

Switching-off Loudspeaker

A simple method of switching off the internal loudspeaker when of the moving-coil type (as is usual these days) is to cut one of the leads between the speech coil and the secondary of the output transformer and to connect the two cut ends so formed to the ends of a length of twin flex, carefully insulating the joins. The other ends of the twin flex may be then connected to the two terminals of a single on-off switch. When this switch is in the open position the internal loudspeaker will be switched-off.

Now-a-days, most commercial receivers have extension-speaker switches fitted to them in the course of manufacture.
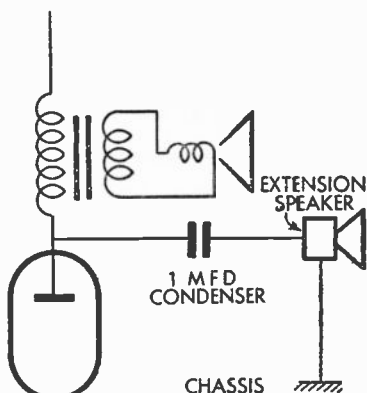
Fig. 33. By inserting a capacity large enough to pass the audio frequencies, the HT voltage can be kept from the extension circuit.

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SOUND AMPLIFICATION

PUBLIC ADDRESS. TYPES OF MICROPHONES. AMPLIFIERS. SAFEGUARD CIR-
CUITS. LOUDSPEAKER EQUIPMENT. MONITORING METERS. TONE CORRECTION.
DUAL CHANNEL RACKS. DC INSTALLATION. HF SYSTEMS IN FLATS. CONCEALED
LOUDSPEAKERS. LAYOUT OF WIRING. FACTORY, HOSPITAL AND SCHOOL
INSTALLATIONS. DEAF-AID AMPLIFIERS. MOBILE EQUIPMENT. ADVANTAGES
OF PUBLIC RELAY SYSTEMS. MAINTENANCE.

NOT long after the advent of broadcasting a number of enterprising spirits realised that progress in valve amplifiers and loudspeakers made it possible to magnify voices, music and records so that they could be heard by far larger audiences than previously. Early endeavours in this direction generally took the form of weird looking hook-ups amplifying the voice of some ambitious political speaker addressing an open-air public meeting.

In this way the science and industry of "public address" was founded. The apparatus used was the same as for amplifying broadcast programmes, and the enterprising people who developed this new application were radio dealers and engineers.

Public Address

"Public address" has remained a branch of the radio industry, and most retail businesses of any size have a public-address department. The radio engineer in such a firm, and in other branches of the trade also, is often required to be a PA expert.

The development of PA since those early days has been on a scale no one could have visualised. To list even a fraction of the duties

it now performs would be wearisome. It is so much a part of modern life that we now seldom realise that the voice that says "stand clear of the gates" in the Underground, or the film-star's dulcet tones, come to us by permission of the thermionic valve.

Amplification Apparatus

So many are the uses, that "public address" is quite inadequate as a name, and "sound amplification" is now felt to be more appropriate. War has found applications, from control systems on aerodromes and warships to intercommunicators in aircraft. In the future, the entertainment, commercial and public-service (such as traffic and passenger control) uses of amplification will be enormously expanded.

The operating principles of sound distribution will become evident to the reader through other chapters of this book, such as those on "Foundations of Radio" and "How Receivers Work". In this chapter we describe actual amplification apparatus and how it can be arranged to meet various requirements.

Carbon Microphones. Fig. 1 illustrates the principal components of a carbon microphone. It

will be appreciated that when sound-waves strike the diaphragm the carbon granules move and alter the electrical resistance between the metal diaphragm and the back of the microphone.

As the carbon granules comprise part of an electrical circuit (Fig. 1), the varying resistance due to the moving granules causes a fluctuating current, and by means of the transformer, voltages are set up across the input terminals of the amplifier.

Transverse Current Type

Another popular type of carbon microphone is the Transverse-Current type (Fig. 2). The carbon granules are in a shallow cavity, in a block of insulation material which forms the body of the instrument. At each side of this cavity electrodes are fitted and connected to their respective terminals. The diaphragm is of insulating material such as mica, and when it is moved by the air vibrations it compresses the carbon granules and alters the resistance of the path between the two electrodes, thus varying the circuit current.

Carbon microphones should be operated with the diaphragm in a vertical position, and some types must be suspended one way up.

As will be seen from Fig. 1 b, a battery is in circuit with the microphone. The voltage must never exceed that specified by the makers. Generally, 4·5 v. to 6 v. is supplied by an accumulator.

Excessive voltage does not give better results, but causes trouble due to pitting of the carbon electrodes and the packing of the granules, both of which tend to produce a noisy background to reproduction.

There is always slight back-
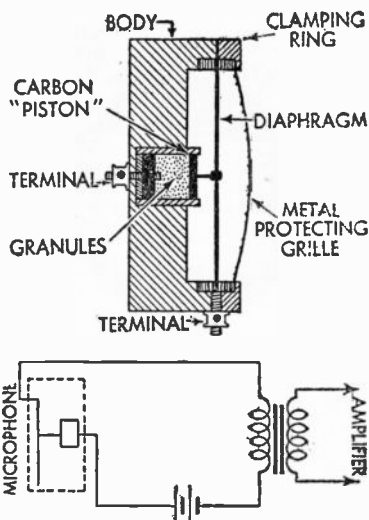
Fig. I. A sectional diagram illustrating the principle of the button type carbon microphone and (*below*), how it is connected to an amplifier.

ground hiss from carbon microphones, and this is one of the disadvantages of the type. As the microphone ages the granules tend to "pack". This lowers the resistance, allowing more current to flow. When this condition cannot be remedied by tapping the microphone, it should be replaced or new granules fitted.

Condenser Microphones. Fig. 3 depicts the general arrangement of a condenser microphone. It will be seen that the diaphragm forms one plate of a condenser, with a solid electrode close to it to form the second plate. When this arrangement is wired up as shown, the sound-waves striking the diaphragm alter the capacity. As the amount of charge which the condenser can hold is varied, current flows in and out from the battery and causes fluctuating voltages across the resistance R.

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SPRING PULLING MICROPHONE DOWN ON TO CUSHION

SORBO RUBBER CUSHION

ENDLESS RUBBER BAND

TERMINALS

CAVITY IN SOLID BODY OF MICROPHONE

CARBON ELECTRODES

CARBON GRANULES

SILK GRILLE   MICA DIAPHRAGM
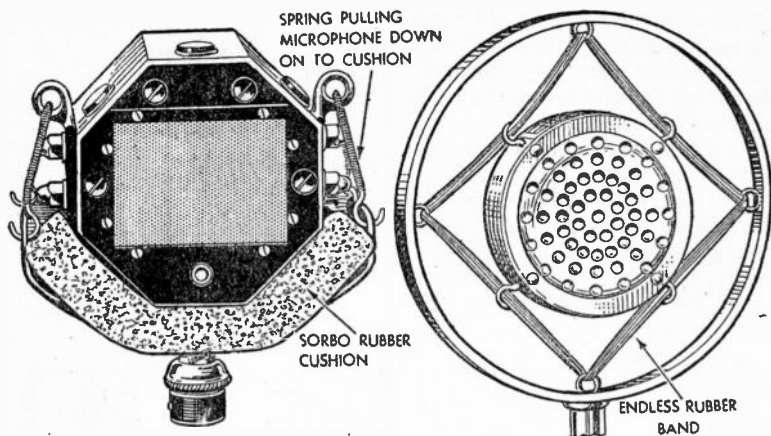
Fig. 2. Two examples of transverse-current microphone, the Marconi–Reisz (*left*) and the type PM202 by E.M.I. Service, Ltd. At the side is a sectional diagram illustrating the construction of these microphones.
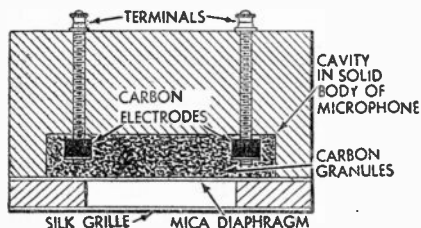
Condenser microphones must have a potential of about 100 v. applied between the electrodes.

An advantage of condenser microphones is that they may be operated in any position. They have lower sensitivity than the carbon type and are quickly affected by damp, which causes crackling, due to electrostatic charges building up on the electrodes.

Moving-coil Microphones. This type operates in a reverse way to the moving-coil loudspeaker, which is explained on page 67. The general arrangements of the microphone are shown in Figs. 4a and 4b.

When the diaphragm is vibrated by the sound-waves the coil moves in the gap in the magnet system. The magnetic field induces voltages in the coil and these are applied via a suitable matching transformer to the input of an amplifier.

Low Impedance

The moving-coil microphone generally has a low impedance of about 15 ohms, and the construction lends itself to a sturdy arrangement. It is very sensitive and has a good frequency response; it is not very susceptible to damp and may be operated in any position. As no polarising current is required, there is no background noise.

One form of moving-coil microphone is the "ribbon" type. The

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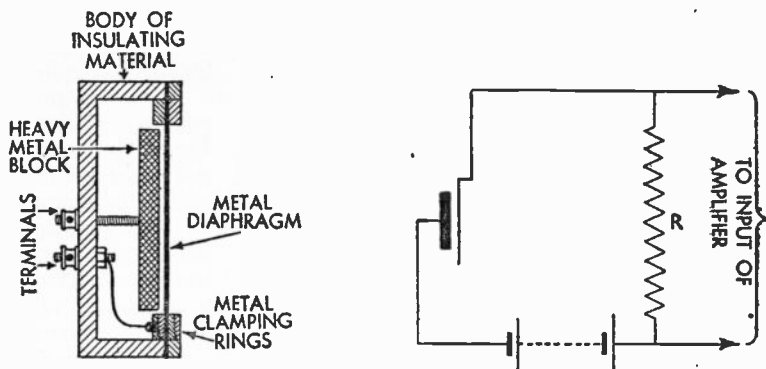
Fig. 3. Simplified arrangement of a condenser microphone and the theoretical method of connection. Movement of the diaphragm alters the capacity of the condenser, and the current, flowing in and out, produces a voltage across R.

general construction is seen in Fig. 5. The ribbon is, in effect, a single conductor within a magnetic field. When it is vibrated by sound-waves, currents are induced in it.

Crystal Microphones. Crystals of Rochelle salt develop a voltage when compressed. In some microphones a small diaphragm is fastened to a crystal assembly, as shown in Fig. 6, so that when sound impinges on to the diaphragm, a varying pressure is exerted across the crystal and corresponding voltages are thus produced.

A less sensitive but more satisfactory arrangement with regard to frequency response employs only a thin layer of crystal between
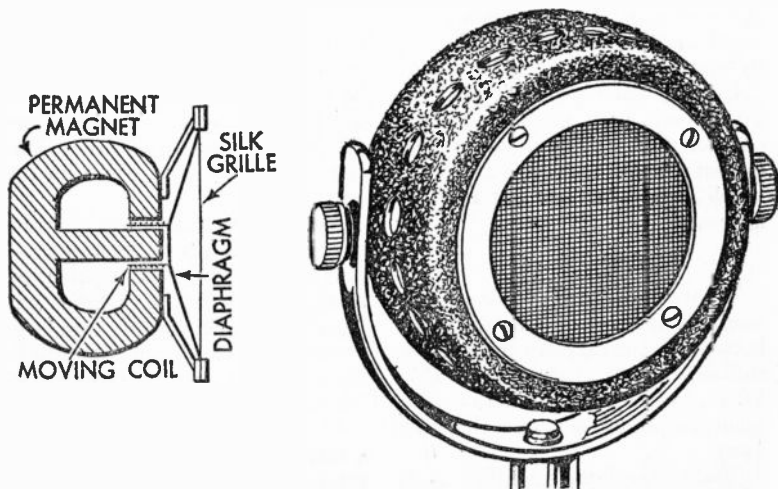
Fig. 4a. The close resemblance between moving-coil microphones and loud-speakers is evident from this section diagram and picture of an MC "mike".

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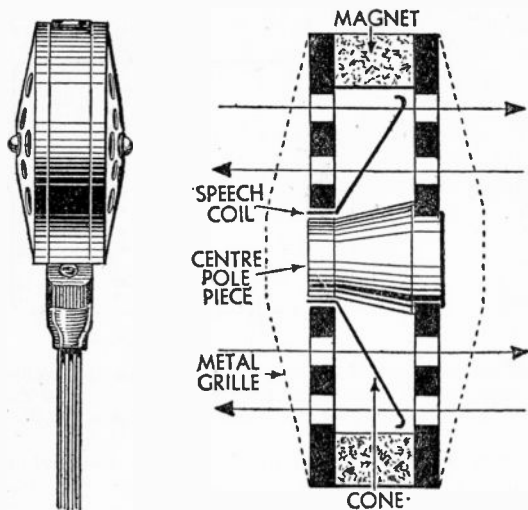
Fig. 4b. The Celestion moving-coil microphone is of unusual design. The cone is suspended within a ring magnet and is actuated by sound waves from either side.

foil electrodes, so that the sound-waves themselves impinge on the face of the crystal and develop voltages due to the mechanical strain set up. The crystals are encased in wax, as they are affected by moisture.

Crystal microphones can be made with very good frequency characteristics. Their rather low output often necessitates a "local" amplifier within a few feet and this is sometimes a drawback.

Amplifiers

Where low-output "mikes" are used, a small microphone amplifier is employed to step-up the voltage sufficiently to overcome cable losses, as in many installations the main amplifier is some distance away.

The microphone amplifier often includes fading and mixer controls to enable the output from two or more microphones to be controlled and blended as required.

A typical mixer circuit is shown in Fig. 7. Such a control panel would be useful, for example, in theatre work. Each volume control is connected to a separate valve. This is necessary because if the controls were simply connected in parallel, the correct resistances would no longer be obtained.

A very simple mixer for using two similar microphones is shown in Fig. 8. As the arm of the potentiometer is swung round from A towards B, No. 1 microphone has a decreasing resistance put across it and its output falls, while microphone No. 2 has an increasing resistance applied across it, so that its output rises. When the arm of the potentiometer rests on terminal B, No. 1 microphone is short circuited and No. 2 gives its full output.

Very large amplifiers require smaller amplifiers to drive them—that is, to build up the input signal voltage to a value which will "swing" the grids of the large power valves. These pre-amplifiers are often termed "swinger" or "driver" amplifiers.

On the driver amplifier there is a master volume control which is set, depending on the input signal, so that the output valves are operated without overloading. Also,
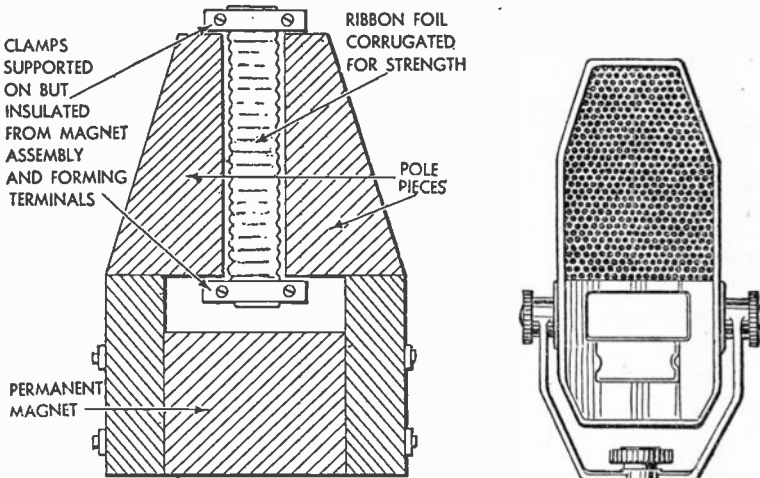
Fig. 5. Internal arrangement and external appearance of a ribbon type microphone. (*Right*) the Shaftesbury "Velodyne" microphone. Ribbon types are often termed velocity microphones because the movements of the ribbon depend on the velocity of the air particles striking the ribbon.

tone control circuits are incorporated in the driver stage, as the large output valves, with their hundreds of volts, cannot economically be tone corrected by the usual methods.

A typical driver amplifier circuit is shown in Fig. 9.

Large installations are generally made up of units mounted in a rack. The rack is housed in some small room or cupboard, and is fitted with remote controls which enable it to be switched on from a distant point, perhaps the microphone or gramophone position.

Safety Arrangements

Large rectifying and output valves cannot be treated in the same way as the smaller types used in radio receivers and small amplifiers. It is essential, for example, that the grid-bias supply circuits be in operation before the HT is applied. Arrangements are incor-

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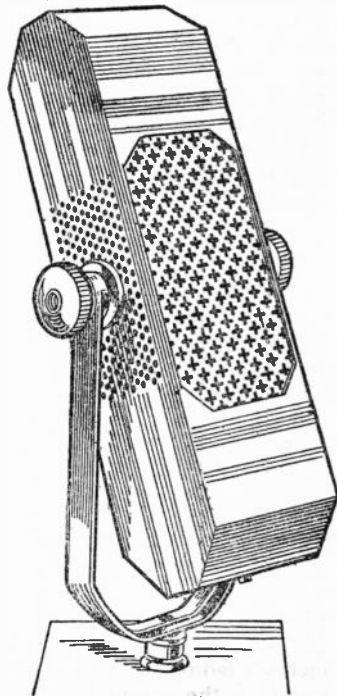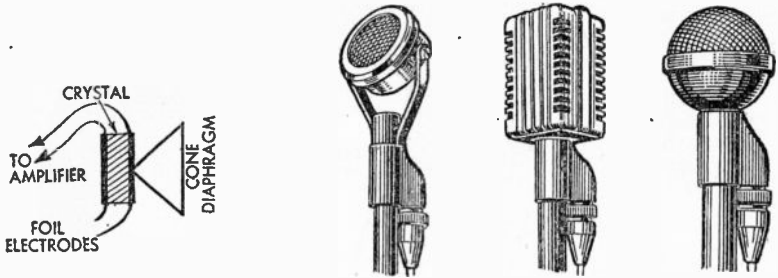
Fig. 6. Principle of construction and three examples of crystal microphone. The two microphones on the right are non-directional.

porated which shut off the amplifier if the grid-biasing circuits fail.

Similarly, expensive mains transformers must be fully protected by fuses and cut-outs. A representative circuit employing these precautionary devices is shown in Fig. 10.

Often several comparatively small mains transformers are used instead of one large component with many windings. This arrangement reduces the amount of insulation required and keeps down the cost of replacements should a breakdown occur.

In large amplifiers, grid-bias for the output stages may require to be well over 100 v., and separate small rectifier circuits are used to provide the potential.

As shown in Fig. 10, the winding of a relay is often placed across the grid-bias supply circuit, so that the current flows through the winding all the time the bias-circuit is alive. When it is energised, the relay holds up the contacts which maintain the main HT circuit, but, should the bias fail, the relay lets the contacts open and by this means breaks the HT circuit to the output valves.
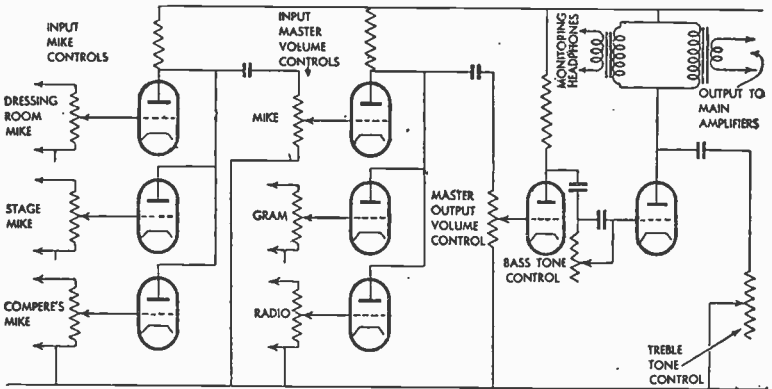
Fig. 7. A fader, mixer and tone control unit suitable for play productions and large hotels. The valves prevent the controls affecting each other, and mixing takes place in the common anode circuits.

The main high-tension circuits of large output amplifiers require rectifiers which provide potentials up to 2,000 v. and more. Mercury vapour valves (Fig. 11) are generally used with about 1,500 v. on their anodes. Four in a bridge circuit is a common arrangement. These valves glow blue while in operation, and are quite easily recognised.

It is essential, with this type of valve, that the filament be allowed to heat up before the HT is applied to the anodes. Should the HT be applied to the anodes before the filament has properly warmed up, the emissive properties of the latter will be ruined.

It is necessary, therefore, to employ an additional circuit to delay the application of the HT while the filaments are heating up. The
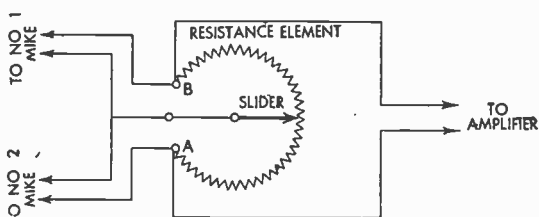
Fig. 8. Two-microphone fader switch. With the slide in the position shown the programmes on both the microphones are heard at equal strength.

delay action may be performed by various means, such as a large capacity condenser being charged across a neon lamp, or by a clockwork mechanism.

Use of Delay Valves

An often-used circuit is that shown in Fig. 10, which uses a delay "valve". This is not a valve in the accepted sense of the word, but is really a heat operated relay.

Within its glass envelope is arranged a bi-metal strip with a filament close to it, as shown in Fig. 12. A contact is arranged close to
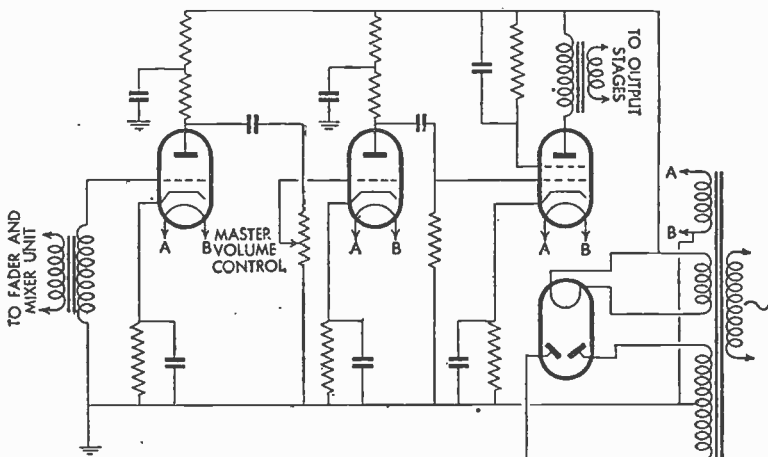
Fig. 9. A driver amplifier with its own HT supply. If a fader tone unit was used, the tone control circuits in Fig. 7 would be incorporated in the output stage. Normally the master volume control would be set to load fully the output stage, and subsequent adjustments made at the fader unit.
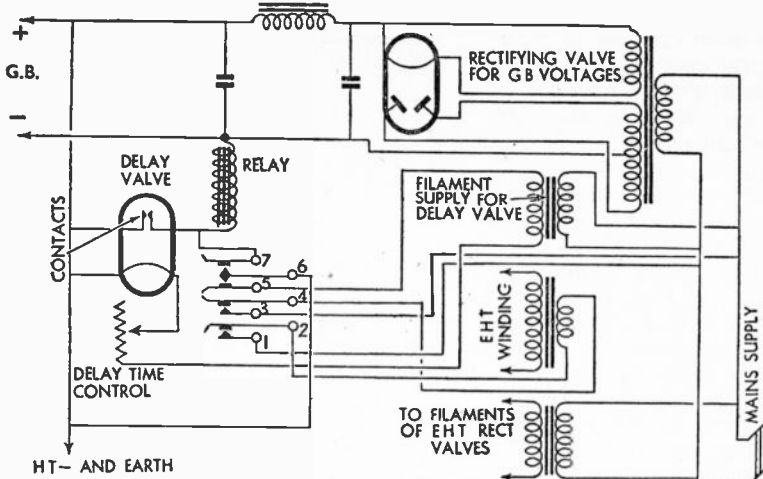
Fig. 10. HT circuit control by a DLS10 delay action valve. Note the adjustable series resistance which regulates the delay by controlling the rate at which the bi-metal strip is heated.

the bi-metal strip, so that when the latter bends, as it does under the action of the heat from the filament, connection is established between the strip and the contact.
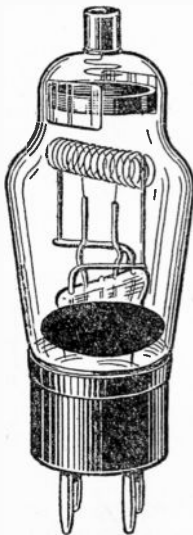
Fig. 11. A 1,500 v. half-wave mercury vapour rectifier—the Marconi GU5.

The usual arrangement is that shown in Fig. 10, which incorporates the grid-bias circuit previously described. The filament voltage for the delay valve is controlled by a variable resistance which is set to determine the time taken for the bi-metal strip to heat up to the temperature at which it bends. The return path of the filament circuit is through the contacts 5 and 6 of the relay switch, which are closed when the valve is not operating.

Providing GB Voltage

When the mains are switched on the filaments of the grid-bias rectifier and the delay valve heat up. The rectifier and its smoothing circuits provide the necessary GB voltage, and the bi-metal strip in the delay valve begins to get hot.

After the pre-determined period the strip bends and the contacts touch each other. Current then flows through the relay. Directly this happens the relay is energised

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CONTACTS

BI-METAL STRIP
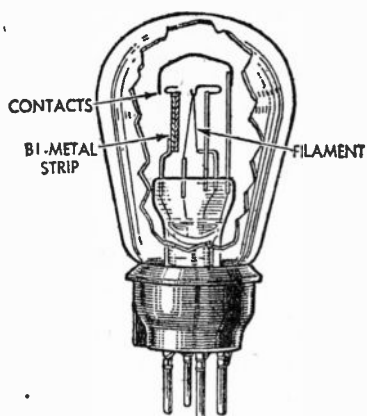
FILAMENT

Fig. 12. The Ediswan DLS10 delay action valve as used in Fig. 10.

and pulls up the contacts 1,3, and 6. Contact 6 thus parts from contact 5, and the filament circuit to the delay valve is broken. As, however, contact 6 goes over to con-

tact 7, the relay is still connected to the positive side of the GB circuit.

Simultaneously with the above action contact 3, shorts on to contact 4, while contact 1 closes on to contact 2, so switching on the mains supply to the primary of the HT transformer.

Feeding Loudspeakers

Equipment for feeding a small number of loudspeakers and having an output of, say, 10–20 watts, is often incorporated in one amplifier unit with all the fader controls, mixers and tone controls on the front panel, as in Fig 13. These units are handy for ARP call systems and general purpose PA work. They are no more complicated, in many cases less so, than the amplifier to be found in a large radio-gramophone.

Larger installations requiring 30 watts or more are made up in units and fitted to racks. These racks are, by international agreement, 19 inches wide, and can be as high as convenient. Two or
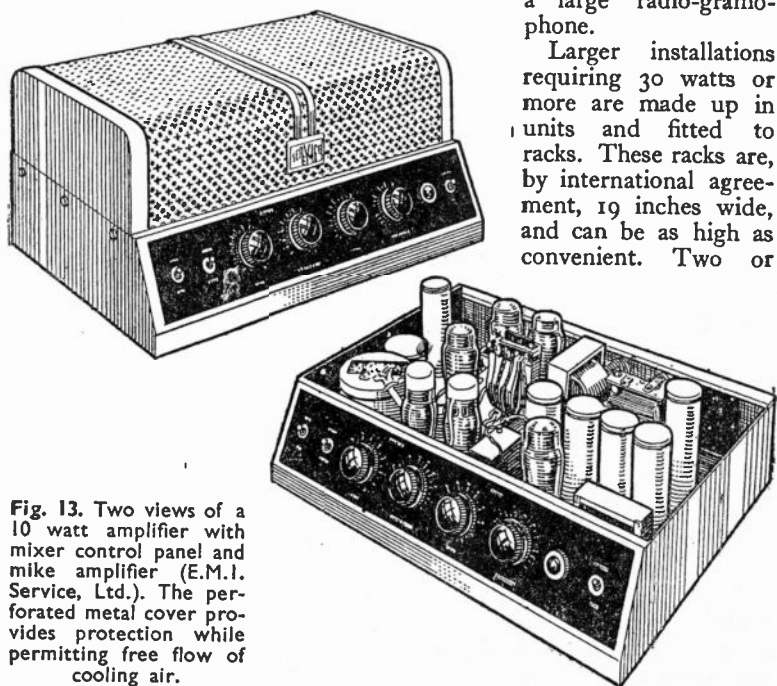
Fig. 13. Two views of a 10 watt amplifier with mixer control panel and mike amplifier (E.M.I. Service, Ltd.). The perforated metal cover provides protection while permitting free flow of cooling air.

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RECEIVER

VOLUME
CONTROLS
FOR LOUD
SPEAKERS

FADER AND
MIXER
PANEL

AUTOMATIC
RECORD
PLAYER

PILOT
LOUD
SPEAKER

VOLUME
CONTROL
FOR PILOT
LOUD SPEAKER

AMPLIFIER UNIT
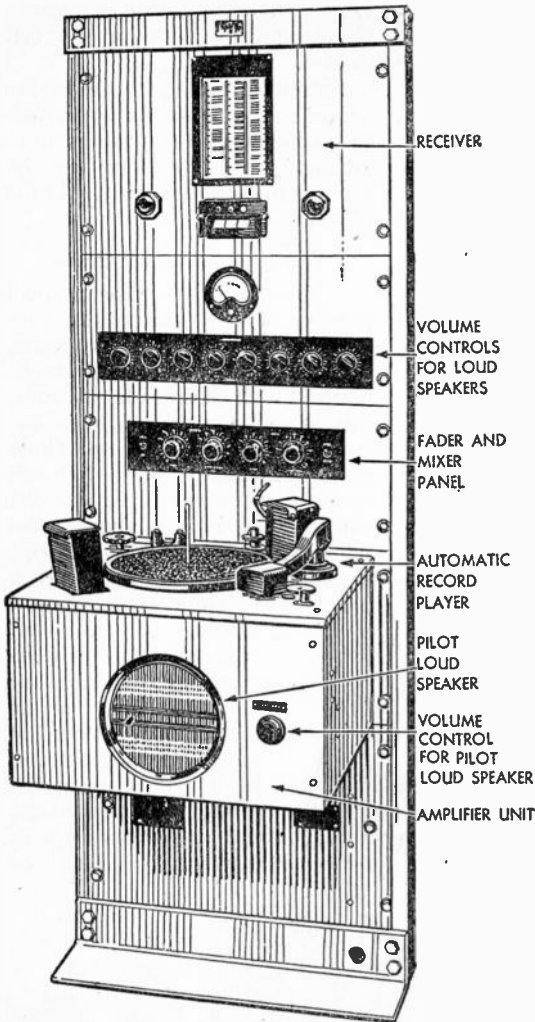
Fig. 14. General purpose medium power output rack.

more may be accommodated side by side.

A typical medium-output rack equipment is shown in Fig. 14. The top section is a normal broadcasting receiver chassis with push-button wavechange switching, and beneath it is a panel which enables the volume of each of eight

speakers to be controlled.

This is a variation on the method often employed whereby the volume controls are incorporated in the speaker cabinets. Which method is chosen depends on the personnel employed in the factory.

It can happen that a particular workshop might turn its loud-speaker off by means of the local volume control, so that any urgent message would not be reproduced. The central control panel as shown on the rack in Fig. 14 ensures that the operator can put all speakers on full volume when putting over an urgent message.

For the preservation of good quality at all volumes, the normal type of potentiometer is unsatisfactory, and what is termed a "constant impedance" network is used. Fig. 15 shows the circuit of a constant-impedance volume control. It will be seen that the unit comprises three variable resistances ganged on a single spindle.

The underlying principle is that there is always the same impedance on both sides of the control,

no matter to what position the slider is adjusted. In Fig. 15 three positions of the control are shown, and it will be observed that in all three — maximum, half, and "off" volume—the resistance network between input and output sides is the same.

Reverting to our consideration of the rack equipment illustrated in 'Fig. 14, there will be seen beneath the volume-control panel, a mixer panel comprising a master volume control for the microphone input and a master volume control for the radio and gramophone inputs. Two tone controls are for use on all inputs, and both bass and brilliance may be varied as desired.

Two toggle switches control the input to the mixer panel, and so decide whether microphone, radio or gramophone is fed to the output stages.

In front of the automatic record mechanism will be seen the grille of a pilot or monitor loudspeaker, with its own volume control at the right. This enables the operator to keep an audio check on output.

The bottom section of the rack contains a 30 w. amplifier which does not require any separate driver section, as it includes its own LF stages feeding the output valves.

Where a very large loudspeaker network is to be fed, the rack we have just described could be used as a driver unit for feeding another rack similar to that shown in
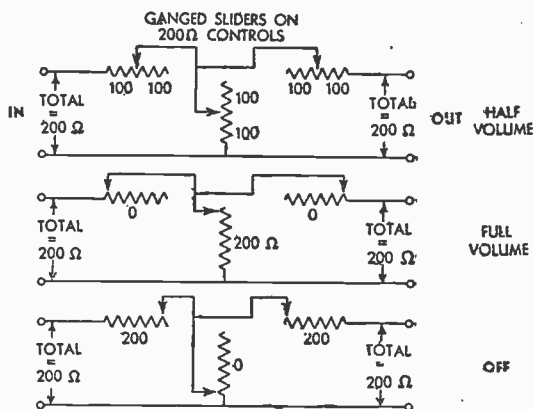
Fig. 15. How constant impedance volume controls operate. The sliders are ganged together and the arrangement ensures that the microphone or pick-up always works into the same impedance.

Fig. 16. This rack is almost entirely devoted to circuits associated with the large output valves which give a total output of some 400 w.

Monitoring Meters

In large amplifiers there will always be found a milliammeter associated with a multi-point switch or a wander-plug and lead and a number of sockets. By means of the switch or plug-and-socket arrangement the meter may be connected into any of the valve anode or cathode circuits to check the currents.

This is useful not only for fault-finding in the case of a breakdown, but also for maintenance work, to see whether the valves are ageing and require replacing. An amplifier unit with a milliammeter for this purpose is shown in Fig. 17.

In large single, and dual-channel installations a loudspeaker is built into the rack equipment for monitoring on all outgoing lines or on any of the amplifiers. The monitor loudspeaker is useful both in maintenance work while the instal-

LINE PROTECTION DEVICE

DRIVER AMPLIFIER

400W OUTPUT STAGE

MILLIAMMETERS AND G.B. CONTROLS FOR MATCHING OUTPUT VALVES

MAINS SWITCH

CAGE PROTECTING MERCURY VAPOUR EHT RECTIFIERS
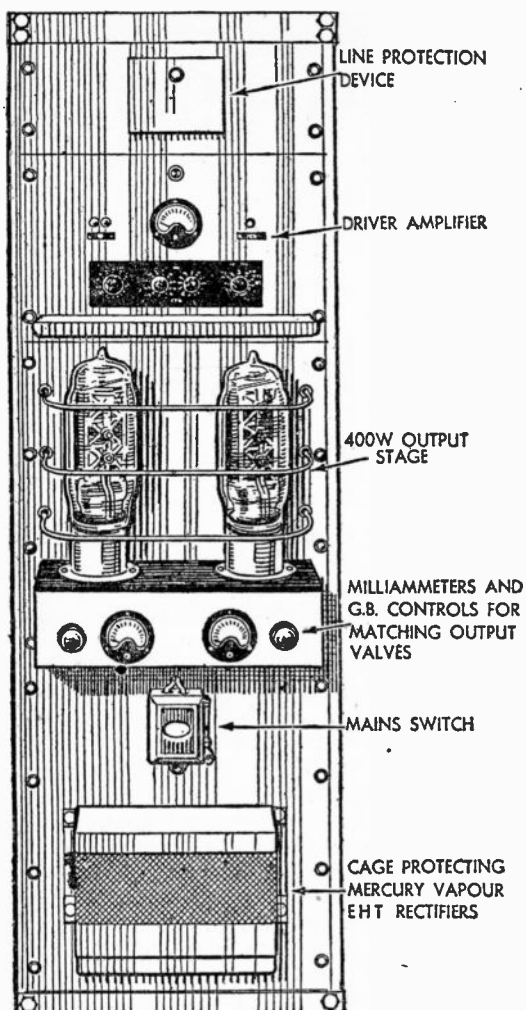
Fig. 16. A 400w. rack for relay and flat installations.

tion, and the extra stages are necessary to make up for this.

This reduction in apparent volume is specially noticeable in cases where it is necessary to reduce the brilliance, as most of the "volume" is due to the middle and upper frequencies. When the latter are attenuated, the apparent sound output is reduced, and it is generally necessary to increase the volume by means of the master volume control.

Sometimes the tone correction circuits are incorporated with the mixing panel arrangements in one unit.

Provision of an alternative programme entails the duplication of all the main amplifying equipment. The distribution network is in duplicate and the two channels must be thoroughly screened from each other to prevent interference.

lation is in operation or as an aid in fault location.

In large installations control of tone reproduction is often carried out in a separate unit comprising two or three valves with the tone correction circuits between them. This is because tone correction results in a reduction in amplification is in a reduction in amplifica-

In the case of small equipment providing up to 30 or 50 watts a single rack can be used as shown in Fig. 18. Beneath the playing-desk will be noted two identical amplifier units, and each one of these would feed into its own particular loudspeaker network.

One of these amplifiers can be fed by radio and the other by gramophone records, or by music from an orchestra picked up by a microphone, as is often arranged in hotels and large restaurants.

The control of such an amplifier in the case of hotels and large boarding-houses is probably in the manager's office, where there can also be the gramophone records and playing desk, and possibly the radio receiver.

Fig. 17. An amplifier incorporating a milliammeter which may be switched into any valve circuit for testing.

Connection between the control point and the rack can be made by relay circuits, so that the amplifier can be switched on and off as desired from the office.

Installations that require a large amplifier to be operated from DC mains supply are generally designed for AC operation and fed from a rotary convertor. This piece of apparatus is merely a combined motor and generator which runs on DC and gives out AC at the required voltage.

HF Systems in Flats

In some blocks of flats an HF instead of an audio signal is provided in all suites of rooms, so that tenants may employ their own radio or television receivers, instead of being confined to programmes emanating from a dual-channel audio system. The technical arrangement is similar to that described for relay systems later in this section, and comprises an aerial amplifier, generally located in a top-floor room, and fed from a first-class anti-static aerial covering all wavebands.

In the case of television signals, the usual dipole and mast would be used, with a special amplifier, built solely for amplifying signals at the television frequency. Special low-loss lead-covered cable would be wired throughout the building, with suitable outlets on the skirting-boards in the various suites of rooms.

Often the skirting-board point comprises a mains supply socket, a special output socket for the television aerial and a normal aerial and earth twin socket for radio.

When it is desired to erect a mast and other aerial equipment on a conspicuous building, the engineer should get in touch with the owners or their agents to obtain permission, otherwise a lot of unnecessary work may be carried out with wastage of material and time.

The final link in every sound

FADER AND
MIXER PANEL
FOR FOUR
MICROPHONES

PUSH BUTTON
RECEIVER

RECORD PLAYER

PILOT
LOUD SPEAKER

30W AMPLIFIER
FOR PROGRAMME
CHANNEL "A"

30W AMPLIFIER
FOR PROGRAMME
CHANNEL "B"
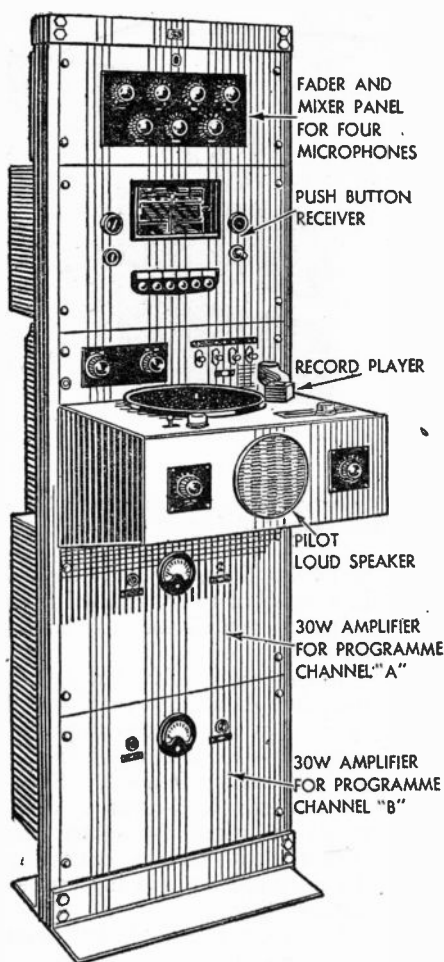
Fig. 18. Single rack for dual-channel work. Microphones, radio set or pick-up can be connected to feed two different programmes to two circuits.

amplification system is the loud-speaker. There are several special types for particular purposes.

For factories where there may be a dirty atmosphere and where there is a possibility of metal filings flying about, the industrial type, as seen in Fig. 19, is often used. In nearly all cases permanent magnet units are employed, so as to dispense with the rectifying units necessary where energised speakers are employed.

Owing to the strong field surrounding powerful permanent magnets, such units must be shielded from metal filings. Industrial type loudspeakers are often very heavily protected by layers of material behind the grille and at the back of the unit.

Some of these units are so fully protected that they have been approved for use in mines and powder factories. It is only to be expected that a certain amount of quality is sacrificed by reason of the precautions adopted, but in view of the class of work for which they are used, this is a small disadvantage.

Horn or "projector" loud-speakers are used where it is desired to concentrate the reproduction over a comparatively small area. For example, in machine-shops with high belting which causes the speakers to be located high up in the ceiling, projectors can be used to concentrate the sound down and towards any particular group of operatives.

The horn type loudspeaker is generally chosen for outdoor work, as it can be made weatherproof.

An interesting type is that often termed the "directional baffle". This loudspeaker comprises a moving-coil unit, such as may be found in a normal cabinet loudspeaker, with a wide metal flare bolted to the periphery of the cone assembly. In this way good-quality

reproduction is obtained which can be directed over a given area as desired.

The very long projector loud-speakers, often having a length of some 7 ft., are useful for address-ing large crowds from a central position when it is impossible to lay-out cables supplying a large number of small loudspeakers. Some typical horn loudspeakers are shown in Fig. 20.

Another interesting type is shown in Fig. 21. This uses a single moving-coil unit and reproduction is made to cover a very wide area by means of a special deflector arrangement in which the unit is housed. Such loudspeakers are sus-pended from the ceiling and are useful for providing music at dances in large ballrooms, where, due to the severity of the wall decoration, it may be found im-possible to mount small units all round the room.

To try to supply sound to a large crowd from a speaker at one end of a hall would make the noise intolerable to people near the loud-speaker while yet being insufficient for dancers at the remote end. A central suspended unit solves the problem.

Concealed Loudspeakers

Ventilating grilles, false plaster ornamentations on ceilings, corn-ices and friezes, may all be made to serve the purpose of a grille in front of one or more loudspeaker units.

A certain amount of tone con-trol may be effected by the choice of loudspeakers, especially in factory installations. For example, if some speakers are operating in a work-shop having a high-pitched back-ground noise due to lathes, others are in a shop with rumbling noises
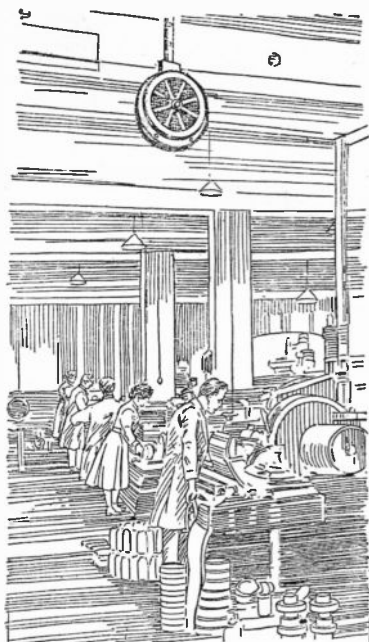
Fig. 19. A loudspeaker installed in a workshop. Industrial types must be fully protected from dust, metal filings, and damp.

due to heavy presses, and yet more are in a quiet assembly bay, it may not be possible to effect satis-factory tone correction on the amplifier to meet all requirements.

In the workshop having a high-pitched background noise a low-note loudspeaker of the directional baffle type would be more easily heard, whereas in the workshop with a rumbling background a higher-pitched speaker, such as a narrow-throated horn projector, would make itself heard better above the machinery. The quiet assembly bay would be best served by small cabinet loudspeakers of the domestic type.

For loudspeakers in normal liv-ing-rooms a power of 1 to 2 watts may be allowed and for very large

THREE SECTIONS
BOLTED TOGETHER

7' PROJECTOR
SPEAKER ON A
TRIPOD MOUNTING
FOR ADDRESSING
LARGE CROWDS
FROM A DISTANCE

DIRECTIONAL
BAFFLE LOUD SPEAKER

NARROW THROATED
RECTANGULAR FLARE
SPEAKER ESPECIALLY
SUITED FOR FITTING
TO A P.A VAN
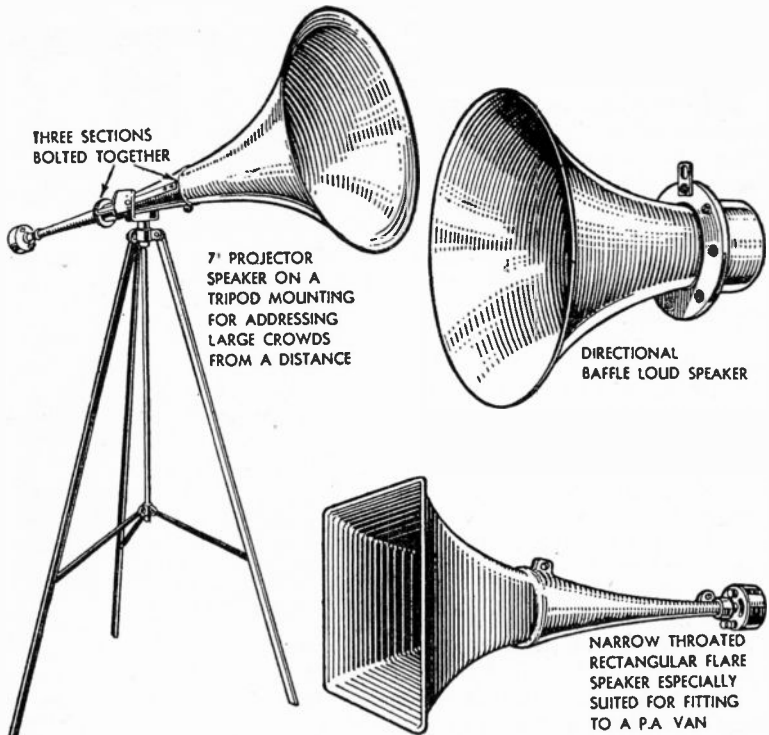
Fig. 20. Three projector type speakers for use outdoors and in large halls. Public address on the present-day scale would be impossible without the use of these types of loudspeaker.

rooms or factory workshops 5 watts for each loudspeaker is not too much.

Speakers may be installed about 50 ft. apart in large workshops with the units about 12 ft. above floor level. Square-shaped rooms or workshops can often be served by a group of loudspeakers in the centre, one pointing towards each corner. By this means, interaction of the sound-waves in the centre of the room is obviated.

For hospital installations a power of 10 milliwatts may be allowed for each headphone point and 1 watt for the loudspeakers. It is better to operate what is known as a low-diffusion arrangement with several loudspeakers each at a low volume level, rather than a small number operating at high volume. With the latter arrangement people near the loudspeakers are inconvenienced, and this is not advisable, especially in the case of convalescence wards.

Layout of Wiring

All microphone cables should be screened, and should have rubber covering over the screening, to prevent the sheath rubbing on metallic earthed objects. This would give rise to crackling noises which would be amplified considerably. When the installation is a permanent one, good-class cables should be used, run in conduit.

Loudspeaker wiring of twisted flex may be run without conduit if the mains wiring in the building is properly screened. For permanent installations, however, VIR cables should be used in conduit, as considerable voltages can be set up, and local regulations should be observed so as to be on the safe side.

Mains wiring between the control point and the microphone amplifier, rotary convertor, etc., must be carried out to the specification of the local electricity authorities.

Although many amplifiers incorporate fuses, the latter should be checked to see that they conform with local regulations and, if they do not, the supply point to the amplifier or any other equipment should be provided with fuses of the required rating, and, as is generally the case, fitted in a cast-iron fuse-box.

The wiring for a comprehensive distribution network should not comprise one single main cable with branches for each loudspeaker point. If a break should occur in the early part of the main cable, then the greater part of the
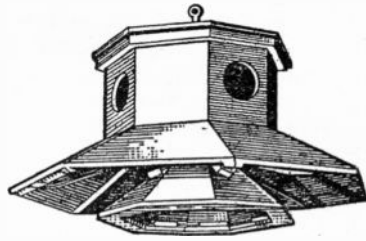
Fig. 21. The G.E.C. omni-directional speaker for hanging in the centre of an auditorium for dance music, etc.

system would be out of service while the fault was located and repaired.

It is advisable to break up the network into a number of sub-networks, each fed direct from an outlet on the main distribution board, which is either a unit on the amplifier rack or is situated close to the amplifier and connected to it by a short run of cable.

For example, in the case of a block of flats with five floors, the network for each could be terminated at a junction box, and this junction box connected to the main distribution board by a separate cable. The layout would be on somewhat similar lines to that shown in Fig. 22.
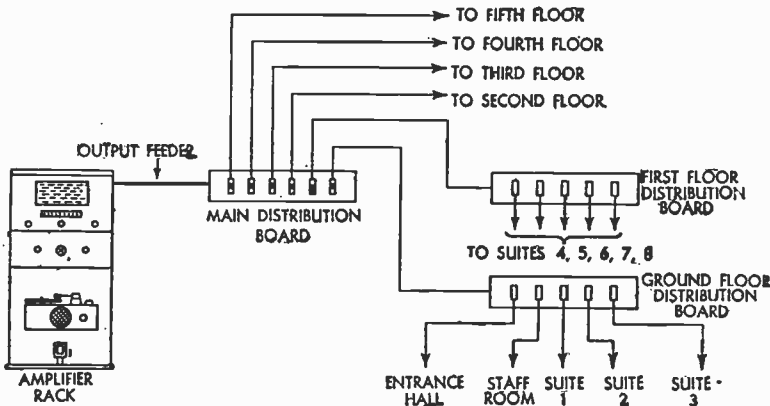
Fig. 22. Wiring plan for a block of flats, permitting easy isolation of faults.
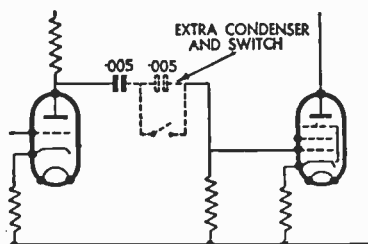
Fig. 24. How bass reproduction can be reduced to prevent boominess on speech. The two condensers in series provide less coupling than one alone.

the reproduction of music is desired.

Fig. 24 illustrates this modification, which is well worth trying with any receiver which gives "boomy" reproduction. Another simple modification which can be made to achieve the same end, but which is effective on music as well as speech, is to draw back the loudspeaker from its baffle-board so that a slight gap exists. This has the effect of reducing the output of the lower frequencies.

Church Bell Effects

In normal times, a small chiming equipment, together with an amplifier and loudspeakers, is sometimes used as an inexpensive way of providing a church or chapel with a set of "bells".

The method is to hang a set of tubular bells in front of a microphone so that the sound may be fed into an amplifier, which in turn feeds the loudspeakers.

Another method employs a very small dulcima arrangement comprising a number of steel rods, each of which is adjacent to a small magnet system, like that of a pickup. When a particular rod is struck with a small mallet, the steel rod vibrates at its natural frequency and, being steel, varies the field of

force surrounding the magnet system. Voltages set up in the windings are then applied to an amplifier in the usual way.

These two methods enable churches to have individuality with regard to their chimes or hymntunes. When this is not required, an ordinary playing-desk installation will serve, using any of the available gramophone records of church chimes. A typical rack installation comprising both these arrangements is seen in Fig. 25.

Large churches and cathedrals which suffer from poor acoustics may be provided with normal sound amplification equipment comprising a large amplifier and loudspeakers. When it is desired merely to fit up a few pews with headphones for people who are deaf, similar equipment to that in cinemas may be employed.
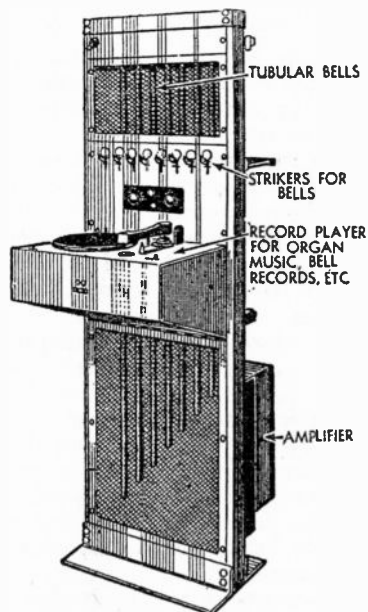
Fig. 25. Bell chimes and amplifier as frequently used in small churches.

As the output is fed only to earphones taking very little power, a single output valve, as used in a normal radio amplifier, is sufficient to feed up to thirty or forty headphones. The amplifier is generally made up on a small chassis with its own power supply for rectifying AC mains or for breaking down DC mains to the required voltage. The chassis may be mounted in a totally enclosed metal case fixed to a wall or to the back of a pew.

The only external controls are an on-off switch and a master volume control, so that an operator can adjust the output when plugging his own headphones into a test-point provided. The headphone positions generally have individual volume controls.

Special Equipment

For general work at political meetings, dances and so on, portable equipment is very useful, and it may be obtained in various forms to suit the type of work or locality.

Where the district to be covered has both AC and DC mains supplies, the equipment should be of the universal type for use on either supply with very little adjustment. A typical arrangement is shown in Fig. 26a; the loudspeaker is in a weather-proof cabinet, while the amplifier and control units are in a separate carrying-case.

In the equipment shown, a turntable is provided for record reproduction and, although this is not essential, it is a very useful feature to fill in a gap in the programme. An output of about 10 watts is usual for this type of equipment, and this provides sufficient energy to operate two speakers requiring 5 watts each or a larger

number of small speakers for indoor work. When desired, of course, portable amplifiers may be used with projector-type loudspeakers for outdoor work.

Cable used with portable equipment should be robust, and preferably armoured with a rubber-covered metal sheathing. The sheathing should be earthed at the amplifier end, to prevent transference of electrical disturbances.

Power Supply

The equipment derives its power from the car accumulator and types for 6 v. or 12 v. are available. Where a 12 v. equipment is to work from a car having only a 6 v. battery, an additional 6 v. accumulator may be wired up in series.

There are two methods of obtaining the HT voltages necessary for the amplifying valves. One is to use a vibrator unit which breaks up the DC current from the accumulator into pulsating uni-directional current. This is fed to the primary of a transformer from the secondaries of which the required HT voltage is obtained. The HT is, of course, AC, and has to be rectified (Figs. 26b and c).

Rotary Converter

The second method is to employ a small rotary converter which operates on 12 v. DC and gives out 300 v. or so DC for the HT circuits. The LT circuits for the valve-heaters are supplied direct from the accumulator in both methods.

A variation of the two methods is to use a converter giving an AC output which may be stepped up by a transformer to the required voltage, using normal HT rectifying circuits for the purpose of obtaining the anode potentials.

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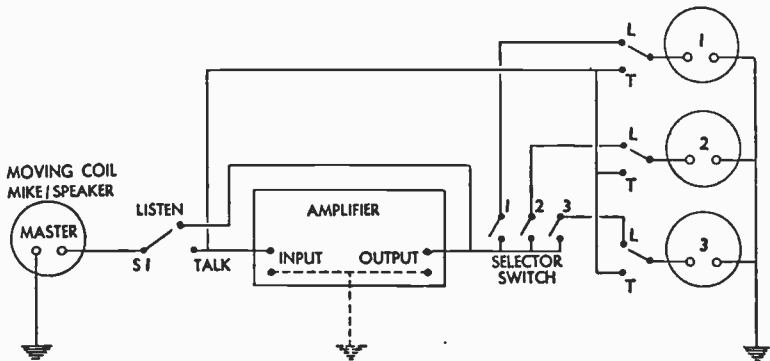
Fig. 27. Simplified schematic diagram of an office inter-communication system. To operate, set selector switch, depress S1, talk, and let go S1, and 1, 2 or 3. Then depress "T–L" switch and answer. All "T–L" switches spring back to listen position when not depressed by operator.

the loudspeaker at the subordinate position is connected to the output of the amplifier. The manager can then speak to the subordinate.

When the manager releases his key, the subordinate can depress the key on his own loudspeaker, thereby putting his unit on to the input of the amplifier.

There is no possibility of the manager's unit being left in the "speaking" position and so providing unintentional broadcasts.

Very modern systems operate without a "Talk-Listen" switch by utilising a type of AVC circuit which is familar to amateur transmitters and others who use it on duplex operation.

Automatic Switching

During quiet periods the loudspeaker is connected to the output of the amplifier through a relay. Directly the speaker is spoken into, the voltages generated are applied to an AVC diode, which generates a bias voltage, which in turn is applied to the grid of an amplifying valve. The sudden change of anode current in this valve when the bias is applied is

made to operate a relay in the anode circuit. The contacts of the relay are so arranged that they immediately switch the loudspeaker to the input side of the amplifier.

When the speech-currents in the loudspeaker cease, the relay resets itself to its previous position, so that the loudspeaker is connected to the output of the amplifier ready to reproduce the answer from the subordinate position.

A slight "delay" voltage on the AVC diode keeps the loudspeaker connected as a microphone during short pauses in talking, but a few seconds' silence suffices to return the loudspeaker to the output of the amplifier. So that the first few words are not lost, a preliminary call of "Hallo" is sometimes necessary to make the AVC circuit switch the loudspeaker to the microphone position.

"Broadcasting Re-diffusion"

Although not strictly coming under the heading of sound amplification, "broadcasting re-diffusion" or relay systems cannot very well be left out of this chapter, as

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they are very closely allied to the subject, and the equipment is in many respects the same.

One of the great advantages of the relay is that it can provide radio programmes in areas where reception conditions are extremely poor.

Improving Poor Reception

For example, in certain parts of Wales and Scotland towns may be a long way from the nearest BBC transmitting station, and at the same time may be badly screened from it by nearby mountains. By erecting a first-class aerial on a high point and employing a local aerial amplifier, strong signals may be fed down the mountain-side through special high-frequency cable to a powerful receiver and amplifying rack in the relay system headquarters. This is similar to the HF distribution in blocks of flats already described.

This arrangement is also very suitable for industrial districts where local interference is so severe that even individual anti-static aerials do not clear up reception sufficiently to enable programmes to be heard satisfactorily. By placing the aerial outside the town, a good clean signal can be obtained for feeding to the relay network. These advantages, of course, are outside any financial advantages which can be claimed for relay systems.

The aerial amplifiers include circuits which cover a very wide band of frequencies, so that signals on practically all broadcasting wavelengths are amplified to the same degree and passed on to the cable feeding the main receiver.

The chassis on which the amplifier is built is often housed in a weatherproof cast-iron box, which may be locked and installed at the aerial location. The mains supply is fed to it by a cable, running together with the output cable, to the relay station, so that the unit can be switched on and off from the station when required. Fig. 28 shows a typical aerial amplifier, in which the mains rectifier will be seen at the top of the cast-iron box with the amplifier beneath it.

In a screened box to the left of the mains transformer are located the filtering circuits for the mains supply into the amplifier. These circuits are not only necessary to prevent mains interference in the amplifier, but also to prevent HF signals reaching the mains wiring, and thus becoming distributed over the mains wiring in the town. This would cause interference in receivers.

Only under very favourable conditions will an ordinary anti-static aerial suffice to give a good steady signal without excessive fading. Signals in two aerials separated by a fair distance rarely fade at the same time, however; also, if one aerial is horizontal and the other vertical, the two may be placed closer together, and still give signals of different strength.

Maintaining Signal Output

This feature is made use of in order to maintain a more level signal input into the relay receivers. The outputs from the two aerials are brought to two receivers, and the outputs are fed to a mixer panel, where they are blended into one steady signal which is fed to the main amplifiers.

The receivers used in relay equipment have to conform with Post Office requirements with regard to sensitivity and selectivity. Many types do not have normal tuning-scales, but are adjusted to

H.T. RECTIFIER AND
MAINS TRANSFORMER

MAINS
SUPPLY

H.F. FILTER
CIRCUITS
FOR MAINS

AERIAL
SIGNAL
AMPLIFIER

OUTPUT
TO RELAY
STATION

INPUT FROM AERIAL
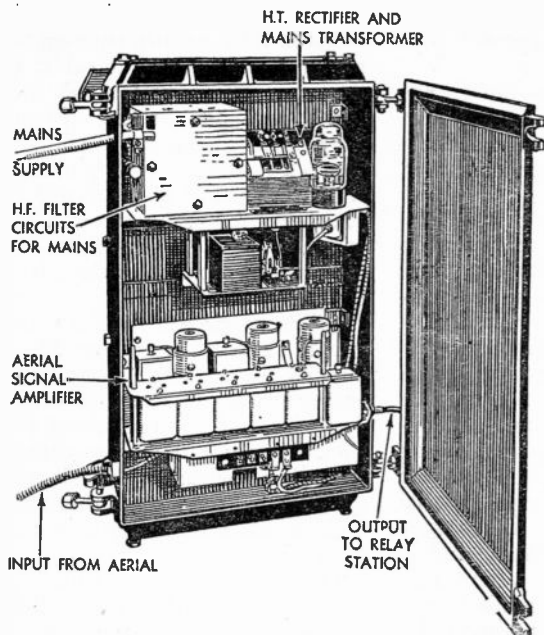
Fig. 28. An aerial amplifier for feeding a relay station from a remote aerial (E.M.I. Service, Ltd.). As the unit may be in an outside position without attention for long periods very robust construction is called for.

receive only one station. Four or more receivers may be mounted in a rack, so that the reception of any one station may instantly be got by switching the output of a particular receiver into the amplifier.

Receivers with normal tuning-scales are often employed as reserve units for picking up any less common station. The receivers may be tuned in by means of visual tuners and monitor loudspeakers before the output is fed into the main amplifiers.

Apart from the receiver and aerials, relay equipment is very similar to sound-amplification gear as used in flats and other large establishments, except that the output wiring is generally external, supported like telegraph wires.

Because of this there is often incorporated in the output stages of the amplifier a line protecting device. This is a form of lightning arrestor of the gap type or gaseous discharge variety. The object is to take care of any surges which may occur on the overhead lines due to atmospheric conditions, and to pass excessive charges to earth without affecting the outgoing programme signals.

Radio-frequency transmissions can be distributed over electric mains wiring or Post Office telephone lines, so that any person who is on the supply or telephone network can plug his receiver into the system.

The method is often referred to as "wired wireless", and the programmes emanate from normal transmitting equipment, just as they do in broadcasting. Instead of the output being connected to an aerial and earth, it is connected through filter circuits to the existing wiring network.

The high-frequency current travels along the wiring and actuates any tuned radio circuit connected to the system, and adjusted to the frequency of the signal. The signals are thus introduced to normal types of receiver, which amplify, rectify and reproduce them through loudspeakers.

A large number of "channels" of different frequency can be passed through the wiring without interfering with each other, so that subscribers to the system can have a choice of several programmes.

Due to the wiring of the system being carried out in twin conductors, the equal and opposite fields surrounding the wires cancel out, thus reducing any tendency for the signals to be radiated.

The servicing of sound-amplifying equipment is generally far easier than fault location on radio receivers. As has already been stated, many amplifiers incorporate meters with switches which enable circuits to be quickly tested for current and voltage when a breakdown occurs. Also, many large installations have spare amplifier units available on the rack, and these may be instantly connected into circuit when a unit breaks down.

A very useful piece of service equipment for the location of faults in sound-amplifying equipment is the audio-frequency oscillator. This has been described in the radio-servicing section of this book, and with its aid, sections of cable may be tested out during a period when the main amplifying equipment is not in operation.

Plugging Oscillator Output

By plugging the output from the oscillator into the various connecting points in the distribution boxes a note of the desired frequency may be passed through the network for testing purposes, frequency distortion investigation, or for tracing a breakdown.

In the amplifier room or the control-desk location there should be a cupboard or steel cabinet, which should be kept under lock and key, and in which spare valves, rolls of emergency cable and other suchlike spares may be kept available in case of a breakdown.

A portable kit of tools should be handy, comprising pliers, insulation tape, loudspeaker connecting plugs, and so on, and should also be kept locked, not so much as a precaution against theft, but as a guard against the borrowing of the tools, so that they are not to hand when an emergency arises.

The various arrangements of amplification equipment we have discussed will enable readers readily to appreciate details of the many interesting applications of unusual form with which he may come in contact.

Bomb Detector Devices

Bomb detector devices are but one of many forms of standard equipment in which the microphone (for HE bombs) or photo-electric cells (for incendiary bombs) take the place of the normal input. Large numbers of microphones or photo-electric cells are arranged over a given area, with the cables coming to the central listening post via an amplifier and indicator, which shows immediately, by means of a red light or similar warning signals, which location has received the bomb.

Another interesting application using standard equipment is for the training of ARP Rescue squads. Small but robust loudspeaker units are hidden under masses of debris, and are fed from a microphone and amplifier with various weak sounds imitating the moans and faint calls of trapped people.

It is the task of the Rescue squads to locate these sounds and dig down as quickly as possible to the loudspeaker unit.

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ELECTRONICS

CONTROL OF ELECTRONS. THREE MAIN APPLICATIONS: (1) CONTROL
DEVICES; (2) SAFETY DEVICES; (3) MEASUREMENTS. PHOTO-CELLS AND
THEIR USES. GAS-FILLED RELAYS. THE INVERTER. THYRATRON CON-
TROL. ELECTRONIC INSTRUMENTS. FREQUENCY METERS. OSCILLATORS.
CATHODE-RAY TUBES. GAS DISCHARGE LAMPS. STROBOTRON.

ELECTRONICS or "electron en-
gineering" is a term applied
to the use of valves and other
thermionic devices in industry.
Although electronic engineering
has grown out of radio, it can now
be said that radio is one of the
branches of electronics.

Electronics has been called the
science of the "free electron".
This may seem a curious term, in
view of the fact that all electrons
are free in their movement, but the
freedom is only relative. In an
ordinary electrical circuit this free-
dom is within the conductor, and
there is no tendency for the elec-
trons to leave the wire.

Free Electrons

Once an electron does leave a
conducting path for the surround-
ing space, however, it becomes
"free" and is capable of being
used in new ways. To give it this
freedom special conditions must
be created. It is usually necessary
to remove the barrier of the sur-
rounding air and to provide an
attractive positive force near the
conductor (Fig. 1). The electrons
may also be helped to leave by
heating the conductor.

Once liberated, electrons can be
used in a variety of ways. They can
be controlled by external fields,
magnetic or electric (Fig. 2). They

can be used to amplify small
changes of potential, as in the
ordinary valve, or to liberate other
electrons by knocking them out of
the surface of materials, as in the
"secondary emission tube" (Fig.
3). By allowing electrons to strike
atoms, we can produce ions, which
serve to carry comparatively heavy
charges of electricity, and in a
beam of free electrons we have the
basis of the most versatile research
instrument—the cathode-ray tube.

All these properties and uses of
free electrons have been found by
radio engineers, and their dis-
covery has enabled the electron
tube to be applied to every branch
of engineering industry helping
manufacturing processes, ensur-
ing accuracy in production, and
even saving life. In war, electronics
plays a vital part in maintaining
communications, controlling gun-
fire, detecting hostile aircraft and
other ways which for the present
may not be disclosed.

If we attempt to classify the
ways in which electrons are of use
to industry, we may do so under
three broad headings:

(1) Control devices.
(2) Safety devices.
(3) Measurements.

In addition, electronics can be
used in general communications,
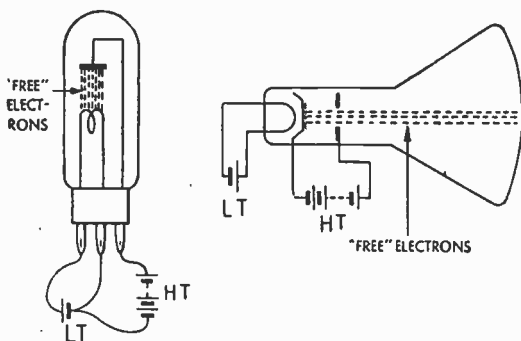
Fig. 1. In the simple diode valve, the anode draws electrons away from the filament across the evacuated space. The cathode-ray tube, shown in principle on the right, is a further development of electronic technique, the electrons being used to excite fluorescent material on the inner surface of the end of the tube.

such as telegraphy and telephony, apart from radio broadcasting.

(1) *Control Devices.* One of the advantages of the ordinary thermionic valve is the ease with which a small change in potential can be made to control a larger change in potential or current (*see* Chapter 17). In the case of the "gas-filled valve" in particular, a heavy current can be started or stopped by the application of a small potential to one of the electrodes. This means that this type of valve or "gas relay" can be used in place of a more cumbersome mechanical relay to stop or start a machine or process.

A favourite application of the
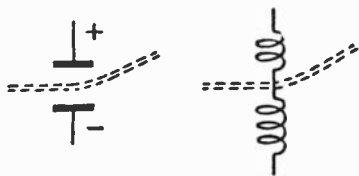
Fig. 2. Electrons, once they have been liberated, can be controlled by both electric and magnetic external fields.

gas-relay is in the accurate control of current in welding plant, where the duration of the current flow is of great importance.

In photo-cell devices, where the action of a beam of light is caused to liberate electrons, the application is even wider. Machines fitted with photo-cell control are stopped automatically in the event of any abnormal conditions, or can be altered in speed or production rate as the material or process varies.

Checking Packing Machines

In packing machines the contents of cartons or jars and the positioning of wrappers (Fig. 4) can be automatically checked, and the time of operators saved for more important work. Production can be automatically counted, and rejects separated from the main flow of work.

Another wide electronics field
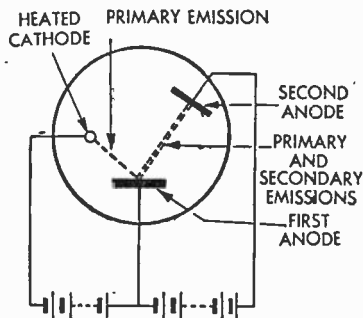
Fig. 3. Liberated electrons can be employed to free other electrons by knocking them out of metal anodes.

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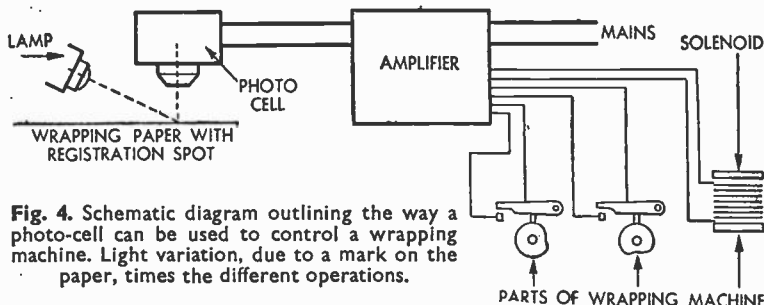
Fig. 4. Schematic diagram outlining the way a photo-cell can be used to control a wrapping machine. Light variation, due to a mark on the paper, times the different operations.

PARTS OF WRAPPING MACHINE

is in unattended stations for supplying the three main services of water, gas, and electricity. Street-lighting can be switched on at a pre-determined time (which alters from summer to winter) without the necessity of continual adjustment.

Water-tanks can be kept constantly replenished, and impurities in the supply noted and the control station warned. A continuous record can be kept of the quality of domestic supply and the apparatus can be set to compensate for any abnormal load which may occur.

Blind Landing Apparatus

One of the most important contributions which electronics has made to aviation is the blind landing apparatus, in which an aeroplane is guided to the runway in thick weather solely by indications on the pilot's instrument (*see* page 168). In addition, aeroplanes may be fitted with an electronic altimeter which gives the correct height above ground level throughout the flight.

(2) *Safety Devices*. As the last example illustrates, there is sometimes only a very slight difference between control and safety devices, but electronics can be applied to numerous cases for protection of operators where mechanical safety

arrangements would be clumsy or unreliable.

Among the most common causes of industrial accidents are heavy power presses or metal-cutting machines, where the operator's fingers or arm are liable to be trapped. A photo-cell and light-ray apparatus forms an ideal protection for such machines, as it can be arranged to prevent operation while the mechanic is in a dangerous position or has his hands in the path of the press (Fig. 5).

Before the introduction of electronic protection a form of mechanical guard was widely used, in which the operator's arm was brushed aside as the press came down. This sometimes produced slight injuries, and in any case distracted the operator from the work in hand. The photo-cell device is unobtrusive and certain in operation, and can be applied without alteration to the machine.

Photo-cell Control

One of the most striking applications of the photo-cell control to safety is in a bridge installation completed some years ago by the General Electric Co. A large swing-bridge over the River Forth at Kincardine, Scotland, is automatically controlled in movement by an arrangement of photo-cells which prevent over-running of the
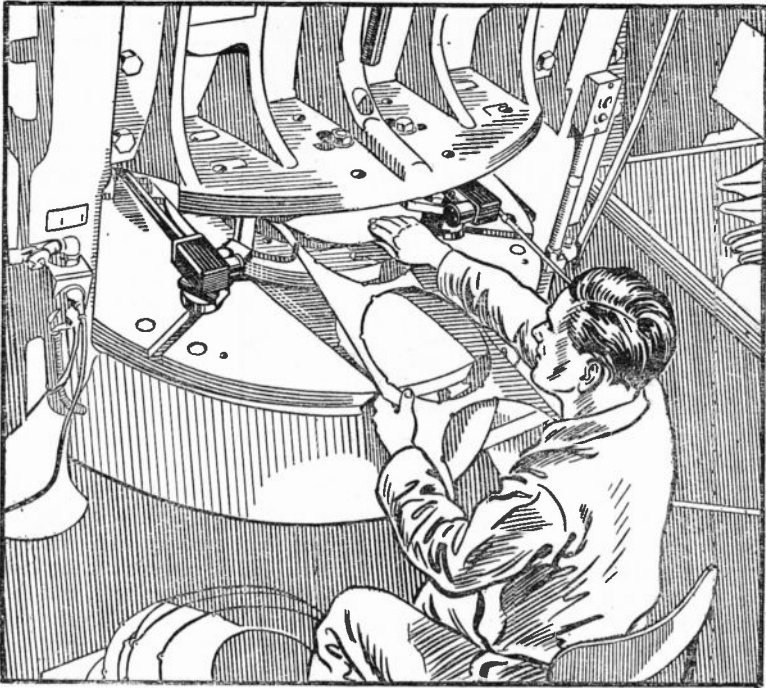
Fig. 5. Typical of safety applications of electronic technique is this installation controlling a press. As long as the man's hands interrupt the beam between the lamp and the photo-cell, the press cannot be operated.

stops and ensure its correct position before the traffic is permitted to cross. Similar installations have been used in passenger lifts as a precaution against over-running the floors (Fig. 6).

Hospital Safeguards

Electronic apparatus has also been devised to safeguard patients in hospitals (Fig. 7) and for burglar alarms and fire prevention or warning. The latest applications have been in connection with incendiary bombs (Fig. 8), and the photo-cell warning device can be made to sound an alarm and turn on sprinklers if necessary, thus dispensing with a number of fire-watchers in large premises.

(3) *Measurements.* The field of accurate measurement in electrical engineering has been enormously increased by the use of thermionic valves and apparatus. Currents as small as one billionth of an ampere can be measured with ease, which almost corresponds to counting the movement of individual electrons! Apart from purely electrical measurements, there are determinations of physical quantities such as light and heat which have been rendered much more accurate by the use of electronic measuring instruments.

Electronic Lightmeter

The simplest example of the electronic instrument is the "lightmeter" (Fig. 9), in which the intensity of light is measured directly
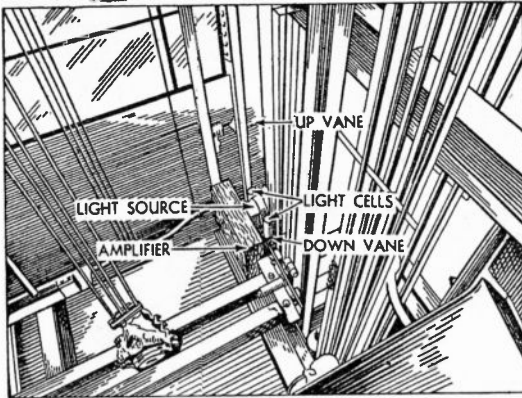
Fig. 6. Photo-cell equipment on the top of a lift. When the lift reaches the required floor, a vane exposes a photo-cell and results in stoppage at the exact level.

The cathode-ray tube itself, which is described on page 219, is one of the most valuable aids to measurement and research which has been developed, and a description of its applications alone would fill a book.

In the remaining part of this chapter, we examine in detail some of the applications of electronics to industry, and study the fundamental circuits used. The adaptation of these circuits to a particular machine or research is the task of the electronic engineer, and the success of the device largely depends on his understanding of the fundamental circuits involved.

in terms of the electrons liberated from a metal, and one of the most complicated is a harmonic analyser for determining the magnitude and frequency of the various components in an audio-frequency waveform. It is even possible to analyse colours (Fig. 10) and a more mundane use is checking electricity meters (Fig. 11).

Before dealing with the subject in detail, it is advisable to give a word of warning to radio engineers
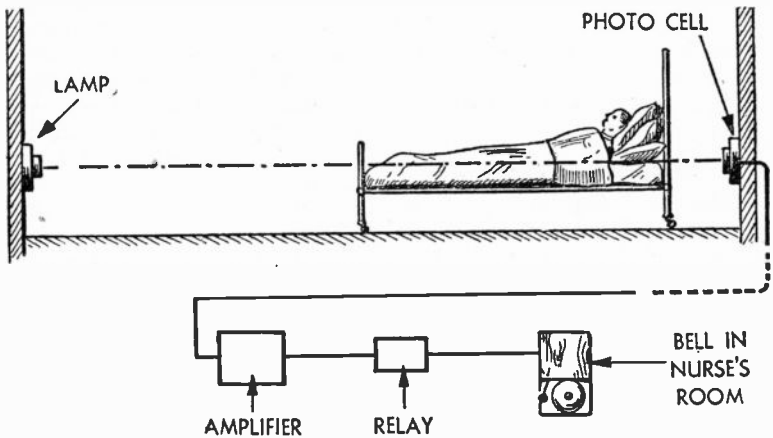
Fig. 7. Light-ray equipment may be utilised to guard delirious patients. If the patient gets out of bed, the ray is interrupted and a bell rings in the nurses' quarters. A similar system can be employed as a burglar alarm for the protection of safes, jewellers' windows, private houses, etc.
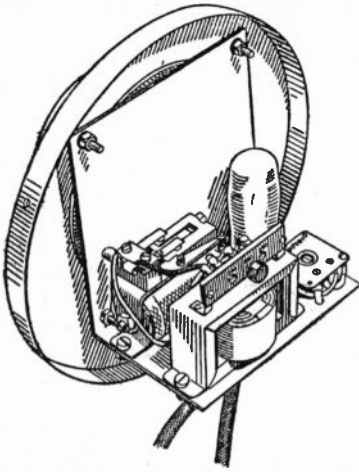
Fig. 8. Interior view of an incendiary bomb detector. When a bomb lights up, the output of a photo-cell is amplified by the valve and made to operate a relay which closes an electric circuit and rings an alarm bell.

who may be called on to advise an industrial firm on the installation of electronic devices. There exists a prejudice among certain industrial engineers against the use of thermionic apparatus on the grounds of its complexity and unreliability. This prejudice should be overcome by pointing out the many cases in which valves and valve apparatus have been installed and left to work unattended for months with perfectly satisfactory results.

The Post Office uses hundreds of valve amplifiers all over the vast network of telephone and telegraph communications in this country, and many of the stations are left unattended for

long periods. The fact that they have sufficient confidence in the reliability of electronic apparatus to use it in this way should refute any argument against its adoption in industrial plant.

The photo-cell is one of the most important links in the application of electronics to industrial purposes, since it provides a means of obtaining electrical energy from light energy.

The majority of control and safety devices depend for their operation on the interruption of a beam of light by the object under control, and the consequent movement of a relay or counting device by the current generated in a photo-cell.

Photo-cells at present available are of three types:

(1) Photo-conducting cells,

(2) Photo - emissive cells, and

(3) Photronic or Photo-voltaic cells.

Photo-conducting cells are usually made of selenium, which has the property of varying its resistance when exposed to light. They are manufactured by forming a very thin layer of metallic selenium on the surface of two foil electrodes fixed on a base of glass or other
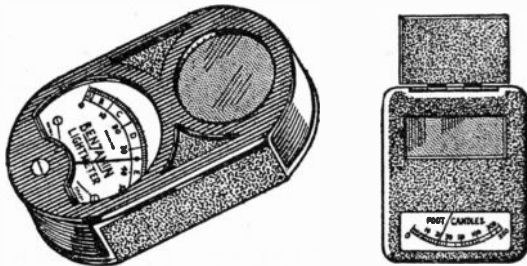
Fig. 9. Two examples of the "light meter"—the simplest form of electronic measuring device.

age and reduces the bias of the valve. The anode current rises and the relay closes.

To produce the maximum change in voltage across R for a given emission, it must be as high a resistance as possible, and values of 5–10 megohms are not unusual.

To enable the circuit to operate in the reverse sense—*i.e.*, with the cell normally illuminated and an interruption of light to operate the relay—it is necessary to reverse the connections of the cell and battery as shown in Fig 15 *b*.

In this case the direction of the electron flow is such that the grid bias of the valve is increased when the cell is illuminated and the anode current increases when the illumination is cut off.

It is not necessary to use a separate battery for supplying the cell, and Fig. 16 shows the connections with a common battery.

If the circuit is supplied from an HT unit there is a possibility of "hum" interference in the

Fig. 14. A small type of caesium photo-electric cell with a plate cathode.

cell circuit producing "noise" in the output, but this is not of importance if the cell is used in a simple relay circuit such as that shown. For acoustic reproduction in sound-film work great care has to be taken in smoothing the HT supply.

Photo-voltaic cells differ from either of the foregoing types in that they actually produce a voltage when light falls on them.

Their action depends on the fact that when light strikes certain semi-conducting substances electrons leave them and pass to the adjoining metal. The metals used in this type of cell are those which also act as rectifiers, such as copper oxide and copper or selenium and iron.

The use of selenium in photronic cells may lead to confusion between them and the true selenium cell, and it is important to remember that the selenium cell alters its resistance but does not produce a voltage, but that the selenium

Fig. 15. The basic circuit for using the photo-cell. When the battery voltage applied to the cell is reversed as in *b*, control operates in the reverse "sense".

"rectifier" cell produces a voltage between the selenium coating and the iron plate backing.

Photo-voltaic Selenium Cell

The output of such cells is higher than that of the gas-filled caesium cell, and they are generally more responsive to green light. Some of their disadvantages are their comparatively low resistance (200–2,000 ohms), which makes it difficult to use them with high-gain amplifiers, and their large area, which limits the range of frequency over which they will operate.

The sectional sketch of Fig. 17 shows the composition of one of these cells. A thin film of selenium is formed on the surface of an iron plate, and a transparent metal film is pressed into contact with the upper surface of the selenium.

When light penetrates the selenium layer, electrons are liberated at the junction of the selenium and the iron (usually termed the "barrier layer"). Some of these electrons circulate between the selenium and the iron as shown by the dotted arrows, but a greater part will flow out of the iron, returning by way of the top electrode.

Light Meters

If a sensitive microammeter is connected to the electrodes of the cell it will indicate the current flow, which will be proportional to the illumination on the cell.

This suggests one of the simplest applications of this cell—as a light
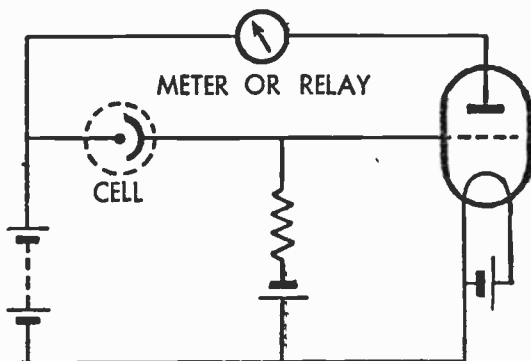
Fig. 16. How a single battery can be used to energise both the cell and the amplifier.

measurer, and it is marketed in various commercial forms of "light meter" and photographic exposure meter (Fig. 9).

Most people have seen these instruments. They consist simply of a photo-voltaic selenium cell, coupled internally to a small sensitive current meter. When light strikes the cell current flows and the pointer travels across the face of the meter.

The meter is not calibrated to read current (which is actually, of course, what it indicates). By the use of the standard light intensities, it is calibrated to read directly in foot-candles or, in the case of exposure meters, in special terms devised to aid the photographer. Light meters have made it possible to introduce legal standards of lighting in factories and offices.

The current output of a cell is even sufficient to operate a sensitive relay directly connected across its terminals, and to obtain the best results it is necessary to make the resistance of the relay coil the same value as that of the cell.

Over a hundred applications of
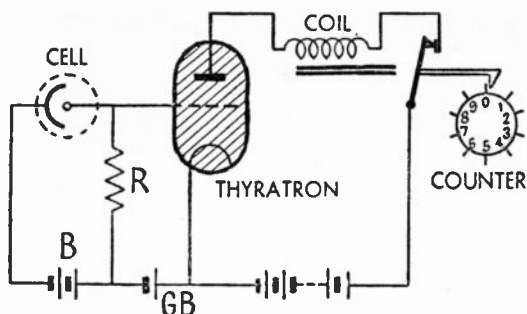
Fig. 19. Fundamental circuit of a photo-cell and gas-filled relay employed for automatic counting. The relay operates an anode-circuit switch as well as the counter, and this resets the circuit for the next impulse.

slight momentary alteration in the applied voltage to the grid.

A simple application is in the counting of articles in conjunction with the photo-cell apparatus described above. The arrangement is shown in Fig. 19.

The grid of the relay is biased by the battery *GB*, and in the anode circuit of the relay is connected the counting mechanism, actuated by a magnetic coil. An extra contact is fitted to the moving arm which is arranged to break the anode circuit as soon as the ratchet has pulled the counting train forward. This makes the relay self-resetting after the momentary impulse has been applied to the grid.

An elaborate series of such relay circuits is used to count very rapidly occurring impulses up to 1,000 per second in special research on cosmic rays.

The Inverter

Another important application of the gas-filled relay is in the inverter, an arrangement for converting direct current to alternating current for high-voltage rectification circuits or power supplies.

It often happens that the only

supply available for radio receivers or transmitters is a low-voltage DC — say 110 v. To obtain DC at a higher voltage it is necessary to interrupt the low-voltage DC, transform the voltage up and then rectify the resulting AC. This can be done by a motor-converter or form of vibrator circuit, both of which have certain disadvantages. The inverter circuit, however, enables the conversion to be done electrically and efficiently.

The principle of operation is shown in Fig. 20. Two gas-filled relays have a condenser C connected between their anodes and load resistances R_1 and R_2 in each anode circuit, the grids being biased by the batteries GB.

The action is as follows: Assume an impulse is applied to the grid of V_1, causing the current to flow in the anode circuit and resistance R_1. The condenser C also charges through the other load resistance R_2 till its potential is nearly equal to that of the HT supply, since the resistance of the relay V_1 is very low.
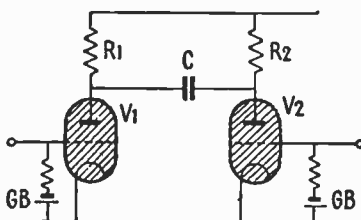
Fig. 20. The principle of the inverter circuit by which increased voltage can be secured from a DC supply.

Now suppose that a second impulse is applied to the grid of V_2, causing it to pass current. The condenser then discharges through V_2, and its potential is applied between the anode and cathode of V_1 in such a direction as to oppose the HT voltage applied to V_1. The current through V_1 therefore ceases and the grid regains control.

C is then charged in the opposite direction through the anode resistance of V_1. The next impulse applied to the grid of V_1 causes it to pass current again, the condenser this time discharges through V_1, and so extinguishes the current in V_2. This alternate action will continue as long as impulses are applied to each grid in turn.

The complete inverter circuit is shown in Fig. 21. DC is applied to the anodes through the centre-tapped transformer T_1, from the secondary winding of which the AC supply is obtained. A second transformer, T_2, connected to the grids of the relays serves to apply timed impulses to each grid in turn, the frequency of the impulses being determined by the constants of the condenser C_1 and the resistance R_1.

The condenser C_2 is necessary to ensure that the voltage applied to the grids is in correct phase relationship with the voltage applied to the anodes.

Small inverter circuits using gas-filled relays of the Osram GT.1 or Mazda T.11 type are very efficient for HT supply for power amplifiers

and apparatus, the output from the transformer being rectified and smoothed in the usual way.

Thyratron Control

The British Thompson-Houston Co., whose gas-filled relays are manufactured under the name "Thyratron", have applied them to the control of welding processes in industry, and by their use enable very accurate control of welding time to be obtained.

The success of welding operations depends on the duration of the current flow, among other factors, and this duration is beyond the accurate control of an operator using a foot-switch. By using a thyratron as a relay the timing of the current is made independent of the operator and uniform results are obtained.

Thyratrons are also used in the control of small motors and in the regulation of temperature for furnaces.

A number of instruments used in modern radio practice and in research utilise thermionic valves for their operation and have shown that they are capable of
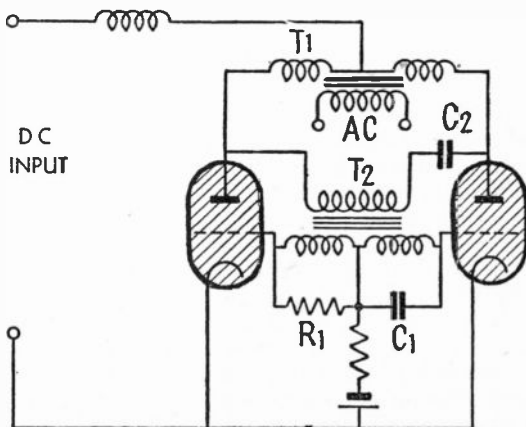
Fig. 21. Simplified form of complete inverter circuit.
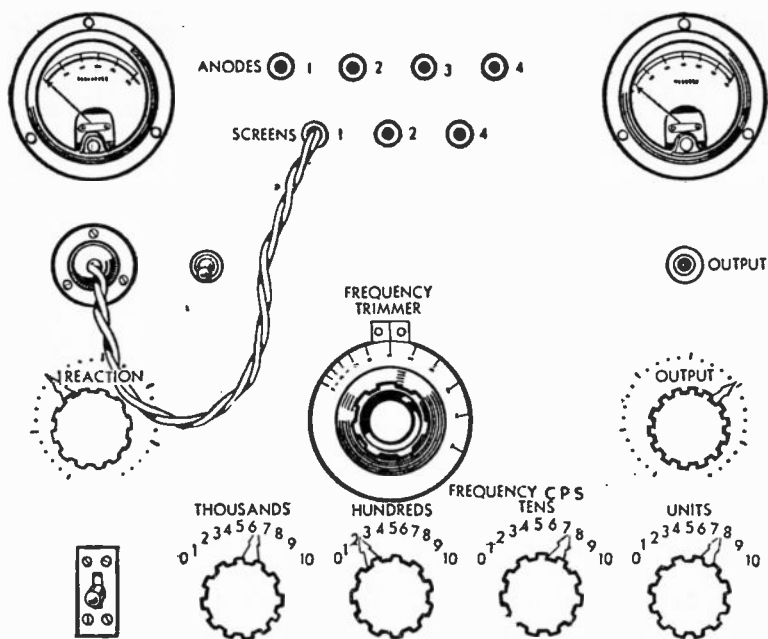
Fig. 25. The front panel of the Muirhead oscillator in which required audio frequencies for test purposes are obtained at the turn of switches.

duce a "beat", which is then amplified.

The latest type of audio-frequency oscillator utilises the properties of "negative feed-back", and has a circuit arranged so that energy is fed-back to the input at a given frequency, which is governed by values of resistance and capacity in the circuit. Oscillators of this type have the advantage that they are more stable in use and require less elaborate components. Fig. 25 illustrates the Muirhead Co.'s oscillator, in which the frequency is selected by ordinary dial switches in the same way as a resistance box is set for a given value of resistance.

The use of the cathode-ray tube in television is a comparatively recent application of this important electronic instrument, and before the development of the high-definition television systems it was in use as a laboratory instrument for research and general testing.

One of the most important advantages of the cathode-ray tube is its extreme flexibility. The beam acts as a weightless pointer which can be deflected in any direction by the application of magnetic fields or by the use of deflecting voltages, and in consequence the spot can be made to trace a pattern on the screen corresponding to any variation in two electrical quantities.

A common application of the tube is in the comparison of two

frequencies, one of which is known accurately. To do this the deflecting plates of the tube are connected to the oscillator under test and to the standard oscillator respectively. The trace of the spot on the screen will then be determined by the instantaneous deflecting forces applied to the beam.

Suppose that one frequency is twice the other, as shown by the waves in Fig. 26. The position of the spot at any moment is proportional to the instantaneous values of the voltage waves, the point P corresponding to the values E_1 and E_2. If successive deflecting voltages are plotted in a similar manner, the spot will be seen to move over the screen in a figure 8, moving up and down twice to each horizontal movement to and fro. The formation of the figure 8 indicates that one frequency is exactly twice the other, and similar figures can be formed

from other multiples of the standard frequency.

Fig. 27 shows some of the patterns obtained in this way.

A slight deviation from the exact proportion between the frequencies gives an irregular pattern or result in the slow changing of the pattern on the screen.

Another use of the cathode-ray tube is in the automatic plotting of response curves of tuned circuits, such as the tuned circuits in the RF stages of radio-receivers. To do this, the horizontal movement of the beam is made proportional to frequency, while the vertical movement is controlled by the output from the tuned circuit.

An oscillator of the type in Fig. 28, sometimes called a "wobbulator", is connected to the circuit under test, and its frequency is varied between fixed values on either side of the mean frequency to which the RF circuit is tuned.
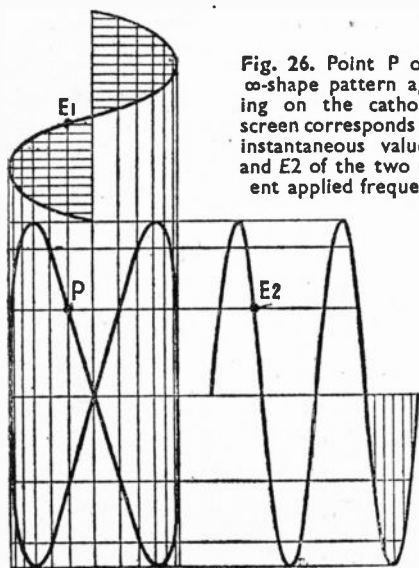
Fig. 26. Point P on the ∞-shape pattern appearing on the cathode-ray screen corresponds to the instantaneous values E_1 and E_2 of the two different applied frequencies.

6:4

7:5

5:3

3:2
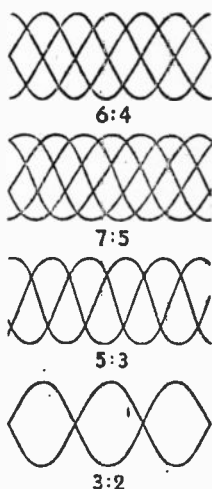
Fig. 27. Four typical wave shapes with the ratios of the two applied frequencies.

(R.E.)

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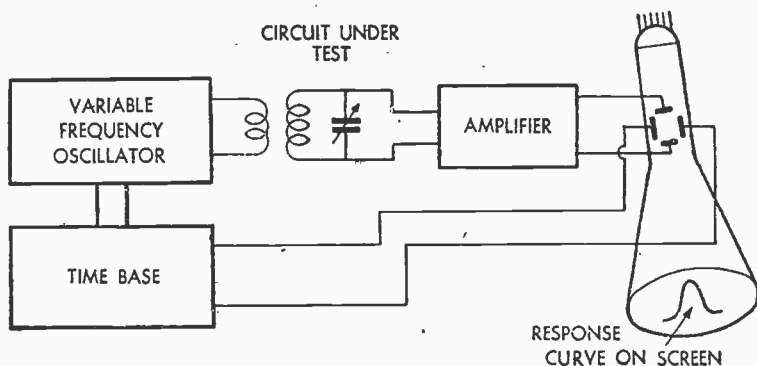
Fig. 28. Block diagram illustrating how a frequency "wobbulator" is used in conjunction with a cathode-ray tube to see the shape of the response curve of a tuned circuit. The frequency is rapidly "swung" across the tune point of the circuit under test. The time base of the CR tube is in step with the "swing".

This frequency variation is controlled by a time base which deflects the beam in the horizontal direction at a rate proportional to the change in frequency in the oscillator, so that a definite position of the spot corresponds to a definite value of frequency.

The output of the tuned circuit is applied to the vertical plates after amplification. By repeating the variation of frequency several times per second the curve is traced over and over again and appears quite steady on the screen.

Direction Finding by Radio

Another important application of the cathode-ray tube, particularly at the present time, is in direction finding by means of radio signals.

Two aerials are used, mounted at right angles, as in Fig. 29, and the incoming signal from the station is detected and amplified in the usual way. The output of the amplifiers is connected to the deflector plates of the tube, so that the beam experiences a deflecting force which is proportional to the signal strength in each aerial.

If the frame aerial system is turned so that the aerial marked N.-S. is directly facing the station, maximum signal is induced in it and there is no signal in the aerial E.-W. The voltage output of the N.-S. amplifier will then cause the beam to deflect in the vertical direction on the screen. If the aerials are turned so that the signal is arriving at an angle of 45° to the N.-S. aerial, the E.-W. aerial will receive a signal of equal strength. The beam will then be deflected by two equal forces at an angle of 45° and will swing over on the screen to a corresponding angle.

The advantage of the cathode-ray tube as an indicator is that the screen may be marked in degrees and compass bearings and the direction of the line drawn on the screen gives the exact bearing of the station. A full description of the cathode-ray tube in direction-finding is given in a book published by H.M. Stationery Office under the title "The Cathode Ray Oscillograph in Radio Research".

The gas-discharge lamp is one of the latest applications of the "free electron", and apart from its
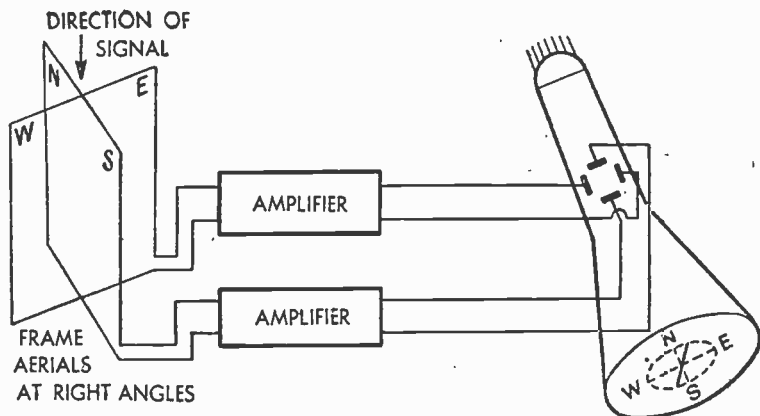
Fig. 29. Schematic of the use of a cathode-ray tube to give visual direction finding from radio signals. Directional properties of the frame aerials produce different voltages across the amplifiers according to the direction of the signal.

uses in illumination has been of great use in research on rapidly moving machinery.

Geissler's Vacuum Tube

The history of the gas-discharge lamp dates back to 1880, when Geissler produced ornamental vacuum tubes in which the passage of electrons from the cathode at one end to the anode at the other produced fluorescent effects on. substances in their path (Fig. 30).

A later form of the Geissler tube is the familar "neon tube", which is used for advertising and other purposes, in which the colour of the light is governed by the nature of the gas present in the tube. The commoner colour effects are produced by using neon (red), mercury vapour (bluish-white) or helium (blue).

The action taking place in the gas-discharge tube is due to the emission of electrons from a cold electrode (the cathode) under the influence of strong positive potential applied to. a second electrode (the anode) a little distance away.

The electrons leave the cathode with sufficient velocity to collide with the particles of gas in the tube, and dislodge more electrons and positive ions by impact. This breaking up of the gas molecules is accompanied by the giving off of energy in the form of light, so that the luminous glow which

Fig. 30. The Geissler tube, the forerunner of the gas-discharge lamp.

forms in the column of gas is evidence of the bombardment which is taking place.

A considerable potential is required to start the discharge (about 6,000–10,000 v.), but when once the discharge is established it may be maintained by the application of a lower voltage (1,500–3,000 v.).

This property of the tube requires special design of transformers for starting and maintaining the discharge.

With the object of reducing the high voltage required for the tube (and the attendant danger), the "hot-cathode" discharge tube has been developed, in which the electrons are emitted from a heated cathode in a similar manner to a thermionic valve. The voltage for the discharge is reduced to a few hundreds instead of thousands.

A sketch of a modern gas-discharge tube is given in Fig. 31. The lamp consists of an inner tube surrounded by an outer jacket, the space between them being evacuated as in a vacuum flask. The inner tube contains a mixture of neon or argon gas and mercury vapour, which assists in starting the discharge. The electrodes are of alkaline-earth material and are heated by the passage of the discharge itself.

Heating the Electrodes

On switching on the lamp the discharge starts as a faint glow, which grows more vivid as the electrodes heat up and emit more electrons, until the whole inner

Fig. 31 (*left*). A modern gas discharge lamp containing two heated electrodes within an inner tube.
Fig. 32 (*right*). In the fluorescent tubular lamp the rays from the gas discharge excite fluorescent powders which produce a close approximation to daylight.
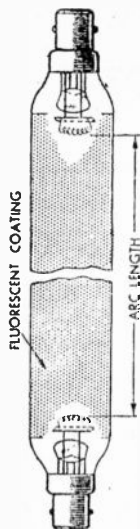
tube is filled with a bright column of light. These discharge lamps are very efficient, and have a life comparable with that of the ordinary gas-filled lamp.

More recently the discharge lamp has been developed to the stage where it is possible to obtain long tubes of 5 ft. or more, lined with fluorescent coating. The material is so chosen that in conjunction with the colour of the discharge it is possible to obtain an illumination comparable with that of daylight (Fig. 32.)

A neon type of discharge tube is shown in Fig. 33 and a further development of the principle, applied to rectification, instead of lighting, is seen in Fig. 34.

A special form of discharge tube, known as the Strobotron, has been developed for use in high-speed photography, and is capable of giving a very intense flash of light, lasting for only a few thousandths of a second. It is a cold cathode tube, and the construction of the electrodes is shown in Fig. 35. The cathode is in the form of a cup containing a caesium compound and surrounded by a ceramic insulator.

Above the cathode is a gauze grid and a second "grid" in the form of a graphite ring. The anode

STROBOTRON DISCHARGE TUBE
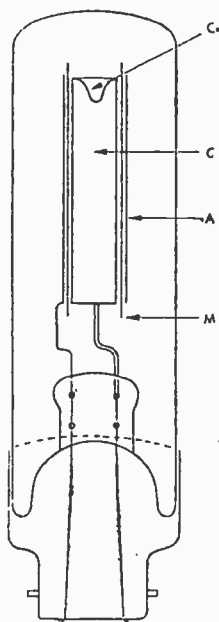
Fig. 33 (*left*). A neon lamp intended for use as a source of light of small area. A central cathode C has a mica insulator surrounding it M which separates it from the cylindrical anode A. The discharge between C and A is confined to the crater Cr. at the top of the cathode rod.
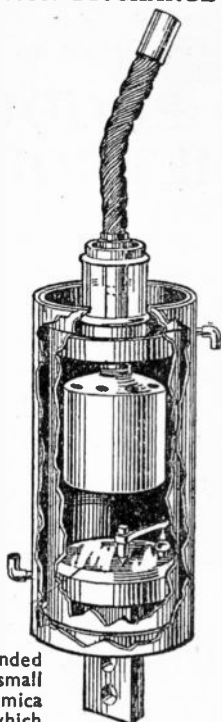
Fig. 34 (*right*). The Ignitron, a form of arc rectifier. A cathode spot forms when current passes between an "igniter" and a pool of mercury. An arc then flows to this spot when the anode potential has become sufficiently high.

is a little distance above this ring. The tube is filled with neon or argon gas, and, when switched on, a local discharge takes place between the grids, which forms an arc discharge when potential is applied to the anode.

This arc discharge is exceedingly brilliant, and during its formation a peak current of several hundred amperes passes momentarily through the tube. The discharge is usually formed by allowing a condenser to charge and dis-

charge through the tube when its voltage reaches a predetermined value. Tubes of this type have been developed to give a flash discharge lasting only 1/30,000th second.

The Strobotron, is used in scientific research work of every variety, and it constitutes an appropriate apparatus with which to close this chapter on electronics—a subject which, although it already concerns nearly every aspect of modern life, is barely 20 years old, and has hardly left the exploratory stage of growth. When this new science is able to play its full part, it will be one of the main instruments of progress.
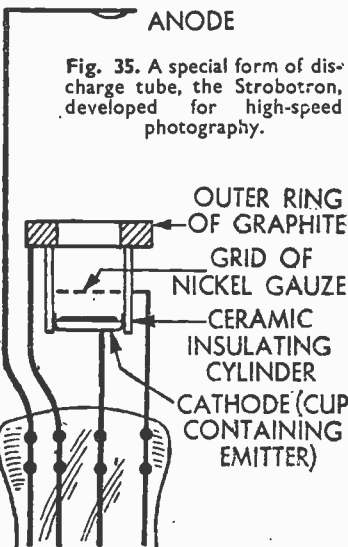
Fig. 35. A special form of discharge tube, the Strobotron, developed for high-speed photography.

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RADIO PRODUCTION METHODS

TECHNICAL MANAGEMENT. PRODUCTION PLANNING, SALES AND RESEARCH DEPARTMENTS. INSPECTING AND TESTING. TEST EQUIPMENT. PRODUCTION, SOAK AND TRANSPORT TESTS. MAKING COMPONENTS. LABORATORY TESTS. MAKING CONDENSERS. ETCHED PLATES. VALVE MANUFACTURE. ANODE-STAMPING. GRID WINDING. ANNEALING VALVE GLASS.

FOR anyone with the slightest interest in radio, whether from the practical or theoretical view-point, a modern radio factory organisation has some niche into which he can fit.

All aspects of normal commercial life have their places in the organisation, such as advertising, publicity, accountancy and general clerical office work. With the ever-present background of radio, these offer the amateur radio enthusiast many opportunities for getting into close touch with the commercial side of his hobby, even should he not wish to enter the technical side of the business.

Varied Opportunities

Here, however, we are concerned with the design, production and servicing of radio receivers, and so in this review of the great opportunities which exist in the radio industry we will leave out of consideration general office routine, and concentrate on the productive side with its problems.

Chemists, draughtsmen, designers, inspectors, storekeepers, and the large numbers of assemblers all have to be co-ordinated under a board of technical management which can visualise and plan for the production of instruments a long way ahead. The board must also supervise the inventive work going on in the laboratories.

Scientific Research

For example, in the Research Department alone there will be many experienced scientists, each an expert on his particular subject, such as condensers, transformers, motors and loudspeakers. All of these might at some time or other refer to the chemical laboratory for advice on the type of impregnation for a particular job of coil winding on one of their components, or for a report on some paper to see that it is free from acid, so that it may be used in transformers.

The chemist would want to know from the receiver designers what were the conditions under which the materials would be used—*i.e.*, climate, voltages applied to them, and so on.

The designers would give this information from theory, but they would probably enquire from the Service Department as to whether any trouble had been encountered in the past when using certain components or material under such and such conditions. Did the

paper insulation in inter-valve transformers stand up to the moisture-laden atmosphere of the Manchester districts, or were coastal areas responsible for trouble in this direction?

So, throughout the organisation, liaison must be established between all departments, and periodic meetings convened for the purpose of airing troubles and passing on information.

Production Charts

In order to appreciate the interrelationship between all these branches, the table shown in Fig. 1 should be studied. It shows the organisation of a large radio-factory in terms of committees which decide the progress of the work through the factory.

Fig. 2 is a chart of the factory production personnel who are involved in the carrying out of the decisions made at the various meetings charted in Fig. 1. In small firms, of course, many of the functions will be the concern of only one man or one department.

For example, in a factory which might assemble on to a chassis components made up by other manufacturers, there will be no meeting of the component designers; discussions with regard to these items will be carried out between the receiver designer and the representatives of the component manufacturers.

In a similar way the woodwork may be handled by an outside firm, which would submit two or three samples of cabinets after having received a blue print or an early production or hand-made chassis for fitting purposes. However, by assuming that all the various functions are carried out in the one factory, the overall

routine may be more thoroughly appreciated.

For the continuity of our review it will be assumed that the models for the next season are to be decided upon and put into production. The first decisions are often made nearly a year before marketing, but the work entailed in getting a big programme into full production takes up all this time, as we shall see.

The first meeting will be concerned with a review of the popularity of the firm's present range of models, to see whether any of them should be retained. If one of them is very good it may be continued with slight exterior alterations advised by the Sales Department. Perhaps a new-style cabinet with a change of tuning scale may meet their requirements.

Details as to the appearance of new receivers (or other products under consideration) would be discussed by the meeting, which, as shown in Fig. 1, would include representatives of the Production, Planning, Sales and Research departments.

Sales Organisation

The sales side of the organisation have to "sell" the public on the merits of the new products, and they have a considerable say in the matter of performance and the external appearance of the instruments, and this is why they are represented at many of the more technical production meetings.

It will be appreciated that, in addition to the main committee meetings charted in Fig. 1, there are always in progress more or less informal discussions between designers and others concerning new ideas and modifications to improve existing arrangements. The fruits

FACTORY

Chief Store-Keeper.	Factory Manager.		
Stock Control of Parts and Material	Chief of Test.	Machine Work-shop Manager	Assembly Shop Manager.
Sub-Stores Foremen.	Designers of Test Equip.	Shop Fore-man.	Fore-man. (Chassis assembly) — Fore-man. (Component assembly). — Fore-man. (Sub-assemblies).
Charge-hands.		Charge hands.	
Checkers.	Test Equip. Calibrators.	Operatives.	Charge-hands. — Charge-hands. — Charge-hands.
	Test Equip. Maintenance Staff.		Operatives. — Operatives. — Operatives.

floor in case a query should arise. The value of these will be shown later when the "assembly line" is under consideration.

Another set of drawings is required by the Service Department for them to check up on their spare parts and to refer to when dealers order parts as replacements.

Planning Production

Reverting to the progress of the receiver through the factory, the Planning Engineer and his staff examine the whole job with a view to laying it out for mass production. They also see that the Tool-making Department is provided with the drawings of any metal parts which are to be made.

Any metal-turning work, chassis-pressing, special condenser-drive mechanisms, screws, etc., are given over to the Machine Work-shop, which houses the lathes and presses (Figs. 3a, b and c).

Apart from the winding of coils and the manufacture of fixed electrolytic condensers and the valves, practically the whole of the commercial mass-produced radio receiver chassis is manufactured on mechanical engineering lines.

Loudspeaker cradles are punched out and shaped in one operation by powerful punches which exert a pressure of hundreds of tons, and chassis are also produced in a similar way with the sides bent and the holes punched out all in one action of the press.

In the cabinet workshop many operations which were previously carried out singly can now be completed in one operation, as may be seen in Fig. 3d. This illustrates the motor-board of a radiogramophone having all the holes drilled in it, including the large one for the motor turntable spindle by one machine, simultaneously.

Even such items as variable con-

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SUPERINTENDENT

Production Planning Engineer.

Chief Planner.

Chief Inspector.

Chief Draughtsman.

Preparation of Drawings and Plans for Production.

Draughtsmen (Specialists for Cabinets, Chassis, Components, etc.).

Preparation of Manufacturing Orders to fulfil Production Requirements.

Progress Manager and Chasers.

Foreman Inspector.

Inspectors.
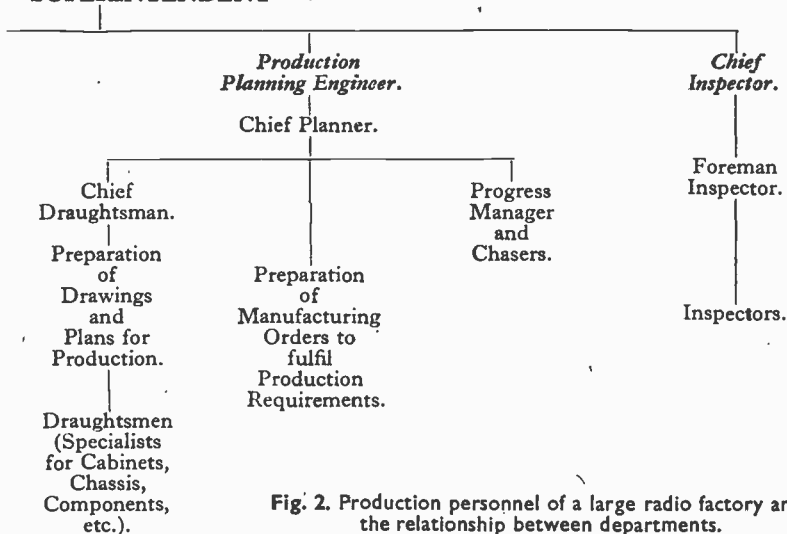
Fig. 2. Production personnel of a large radio factory and the relationship between departments.

densers come within the scope of the mechanical engineer, because the frames are generally castings, and the vanes are also stamped out by the thousand by a simple punch-press. It is not until the vanes are assembled into sections, and the sections are built up into frames, that the component passes from the mechanical stage to the electrical inspection. Fig. 4 shows operatives examining variable condensers for freedom of movement and proper spacing between the moving and fixed vanes, prior to electrical tests.

The work in the machine shops follow usual mechanical engineering practice, and details of the various operations and machines employed are dealt with in Odhams "General Engineering Workshop Practice". We are concentrating here on the electrical and radio aspects of the factory.

The Production Planning Department's work is so bound up with the smooth running of the assembly line that we must examine them both together, and come back to our consideration of the committee chart when we have reached the stage of the completed chassis. Inspection and test are also closely linked with assembly, and the work of these departments will be referred to as and when they affect assembly progress.

Engineering Plan

The Production Planning Engineer knows from the first meetings the general make-up of the instrument, and decides upon what components should be bolted direct on to the chassis, or which components should be connected or made-up in the works into a sub-assembly, which in turn would be fixed to the chassis.

Many parts of a radio receiver cannot be fitted to the chassis

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without interfering with the fitting of other parts. This aspect of assembly must be visualised by the Planning Engineer when he has one of the hand-made sample models in front of him, together with all the designer's rough sketches or blue prints of the various components.

It will be his aim to introduce a bare chassis on to one end of the long assembly line of operatives, and for the chassis to pass evenly down the line without any long delay at one particular stage.

For example, the chassis when first passed into the assembly shop might be a bare metal contrivance straight from the heavy presses in the machine shop. The first job would be to rivet valve-holders into the holes provided for them (*see* Fig. 5) and fix such small items as aerial and earth panels, pick-up socket panels, and so on.

The chassis would then be passed along by one girl to the next who would mount the chassis on to a metal cradle of the type shown in Fig. 5, so that it may be rested in any position on the bench without damage to the components and wiring.

The next assembly stage might be the fixing of the mains transformer and then the ganged con-
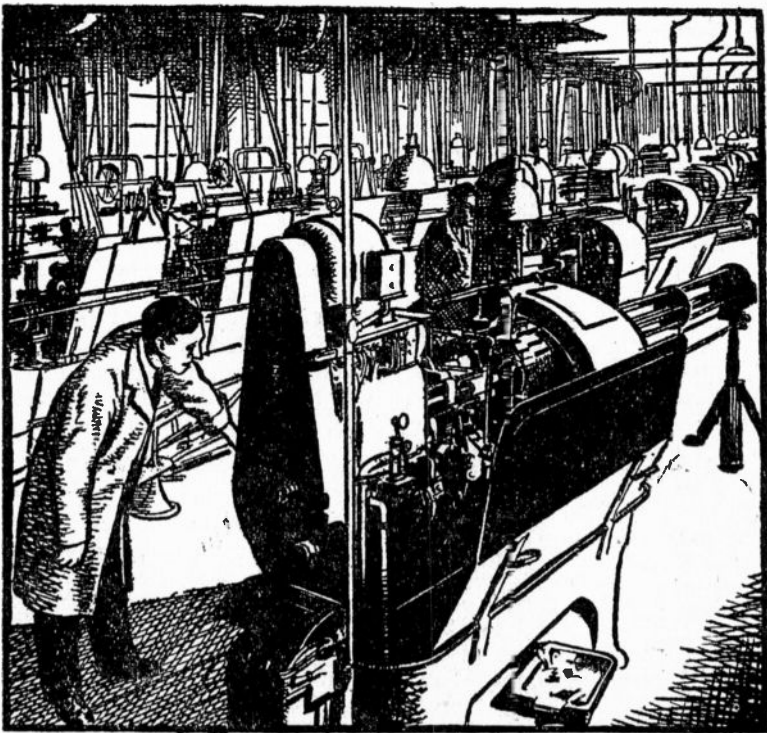
Fig. 3a. Automatic lathes turning, shaping and cutting loudspeaker bolts, governor balls, loudspeaker centre pole-pieces and similar items.
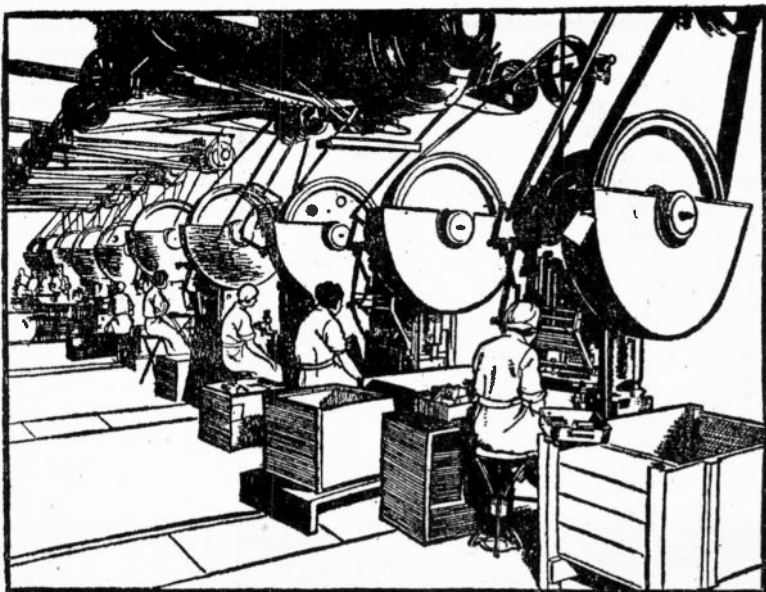
Fig. 3b. A line of punch presses used for stamping out transformers, laminations, coil cans and other metal parts of a similar nature.

denser, to be followed by the aerial coils.

From the first few operations it will be seen that the Planning Engineer has to make each operation take the same amount of time, in order that all the operatives pass along the chassis to their neighbour at the same instant. He has to see which operation takes the longest time and make all the other stages equal that time.

This means that in some stages two or three small components can be mounted on to the chassis or, towards the end of the line, a certain number of wires soldered into position by one operative.

In addition to the planning of the assembly line, other planning engineers, in association with the chief Planning Engineer, examine the production question of what are termed "sub-assemblies".

Time can be saved by mounting up certain components into an assembly for easy fixing on to the chassis. Banks of resistances on paxolin decks and condenser banks are typical examples.

In a large organisation these are made up separately by small groups of girls, sitting near the main assembly line. The sub-assemblies made are put into boxes, which are fed to those whose job it is to fit them to the chassis on the assembly line.

The charge-hands, whose job is to keep the line of assembly running smoothly, see that these boxes are kept well supplied, so that production does not have to cease owing to a shortage of any particular component.

In some types of receiver, especially short-wave models, wir-
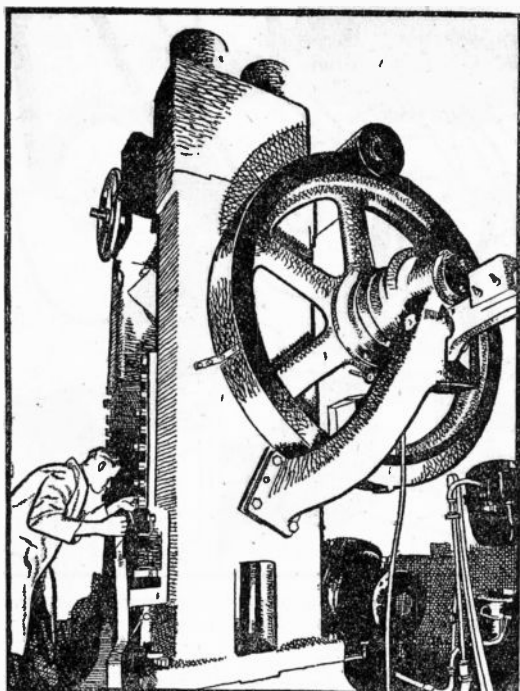
Fig. 3c. A huge 1,000-ton press for punching out heavy items such as steel gramophone turntables.

the work of charge-hands, testers and inspectors. As will be seen from a glance at Fig. 2, charge-hands are an essential link in the organisation. One charge-hand is in charge of about six to twelve operatives. He knows exactly what their job comprises, and has had several hours' experience in doing each of the operative's jobs before the assembly line starts up in full production—that is, while the assembly planning is in progress.

Some charge-hands supervise sub-assembly groups, and others are all along the main assembly line, where they are ready to advise any girl in the difficulties with which she may have to contend.

ing is direct from point to point, and is carried out by girls on the assembly line, who cut their own wire to the correct length and solder it into position.

Where, however, a very large number of receivers is in production and the receiver is designed so that many HT and LF wires may be bunched together, sub-assembly groups are formed for cutting wires to the correct length, trimming and bending them into the position and binding them together into what are called cable-forms. Fig. 6 shows this work in progress. The assembly girls then fit these cable-forms quickly into position on the chassis.

We must mention at this point

Inspecting and Testing

Perhaps the holes in the flange of a component are not quite the right size and the operative finds difficulty in forcing the screws through them. A few seconds' delay with each screw may add up to half a minute or more on that particular operation, and when this is multiplied by the number of chassis passing through her hands, many hours' delay can occur.

The charge-hand, directly the girl draws his attention to the trouble, investigates the difficulty and, if he finds that he cannot

help, he takes the component to his foreman. The foreman has the blue-prints (referred to earlier in this chapter) in his office, and the component is compared with its drawing.

If the component is wrong, the floor manager takes it up with the manager of the component assembly floor, thrashes the matter out and has a new supply of components sent along immediately.

If there are a number of components already on the assembly line, then the assembly foreman may have to put operatives on reaming out the holes to the correct size, so as to bring back the rate of production to the proper figure pending the arrival of the new and correct components.

Inspectors also supervise the work, but they are there to reject faulty workmanship and material. As will be seen from Fig. 2, inspectors are responsible only to their foreman inspector, and thence to the Chief Inspector, whose status is level with that of the Factory Manager. There is no connection between the inspectors on the assembly floor and the assembly staff, although, of course, they are all subject to the same factory discipline.

When the planning of the assembly line is in progress, the various inspection points have to be considered. It may happen that when a certain component is placed in position, wiring or connections to another component are obscured and could not be seen by an inspector examining the complete chassis.

At this point on the assembly line, therefore, an inspector is located, and he sees that the work up to that point is up to standard. He stamps the chassis with his particular coded stamp, indicating that that inspection has been car-

Fig. 3d. All the holes in the motorboard of a radiogramophone being drilled in one operation.
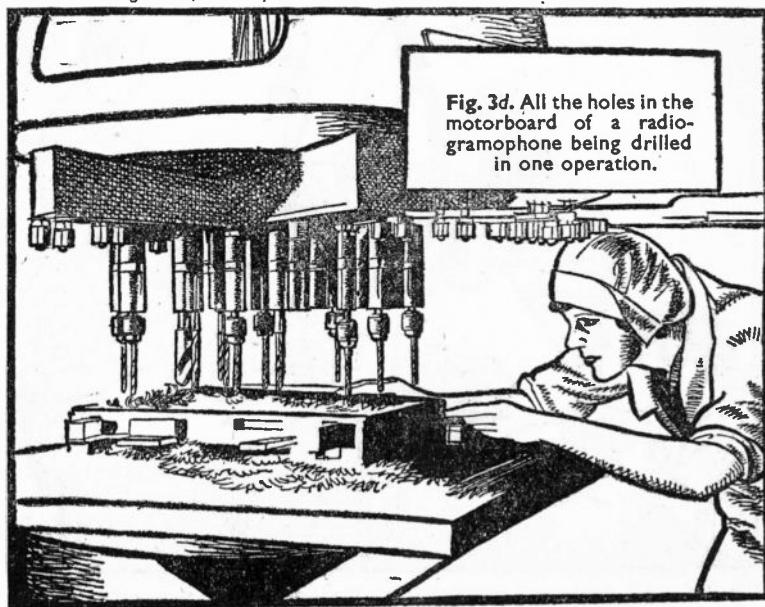
ried out. The next operative is instructed not to accept any chassis that does not bear that stamp-mark.

Inspectors also examine the sub-assemblies, and stamp them before passing them to the assembly line.

In many factories the inspection staff wear an overall of a different colour from that of the production staff, so that assembly foremen know who are responsible to them and who are not.

The work on the assembly floor is only a part of the activities of the inspection staff, and they will be found throughout the factory and stores, machine shops and repair shops inspecting and examining at all stages in production.

We now come to the testers. These men are on the production or assembly staff, and they test the various components and chassis to see that electrically and mec-.

hanically they do their job. The difference between the inspectors and the testers may be better appreciated, perhaps, by an example or two of their work.

Testing the Chassis

A tester may put a chassis through its paces, finding it quite up to standard in sensitivity, selectivity and quality of reproduction, but an inspector might reject it afterwards because of stiffness in the condenser drive, which could cause a cord-drive to break after the receiver had been in use.

A tester might pass a mains transformer as O.K. because all the secondary windings gave the correct voltages when a certain voltage was applied to the primary winding, but an inspector would reject the component if he saw that a lamination had partially cut through the insulation of a wind-

Fig. 4. Ganged condensers being mechanically inspected and their vanes adjusted.
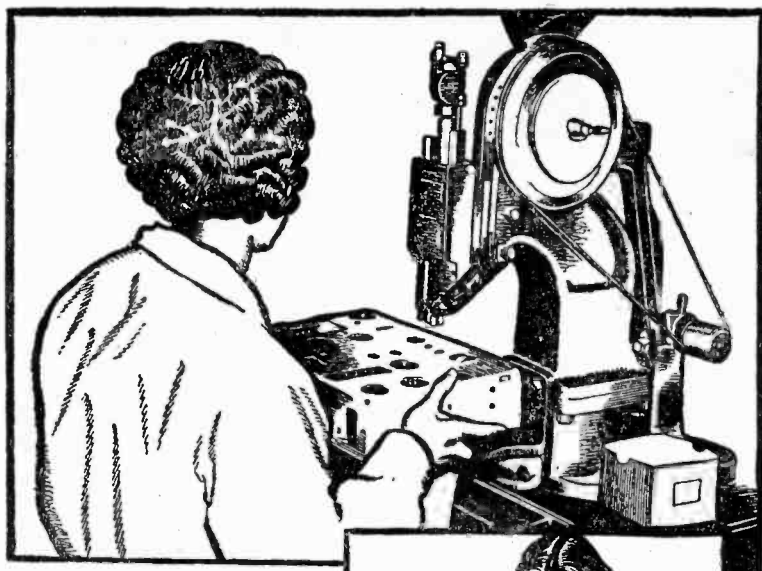
Fig. 5. The first stage in assembly. Riveting valveholders on to a chassis which has come straight from the punch presses. (*Right*) a girl operative assembling parts on to a chassis. Note the metal cradle which facilitates the work and protects the chassis.

ing, since this might lead to a complete breakdown after a period.

As the chassis leaves the last assembly operation it passes through the hands cf an inspector, who examines it thoroughly from a mechanical point of view. It is his job to see that the soldered points are good, and he tests by pulling the wires firmly with pliers.

He may then pass the chassis on to another inspector, who sees that there are no pieces of loose solder lodging in the awkward places or splashes of solder adhering to the chassis.

These splashes of solder can work loose in transit and cause short circuits to occur when the set is installed, although the set has passed through the test stages satisfactorily. Where the rate of production is not very high, both these inspections can be carried out by one man.
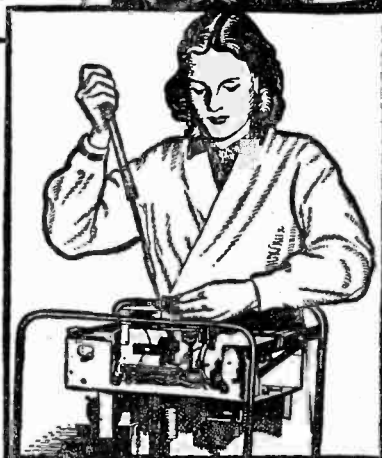
The next stage is an examination of the wiring by a more technical inspector, who has drawings of the "dressing" of the leads to
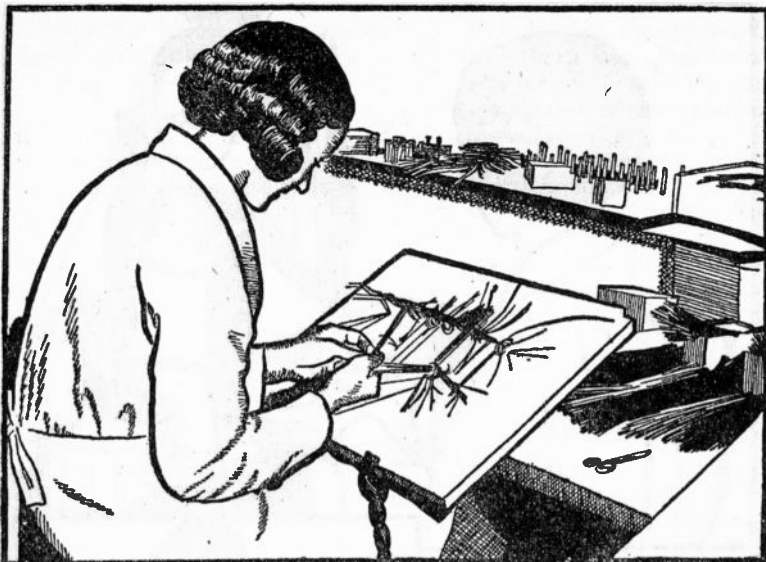
Fig. 6. Wiring to components is generally made up into "cable forms". The operative here is cutting wire and bending it to shape around nails·on a board which is marked out as a guide. The various wires are then bound together with thin twine.

guide him. The term "dressing" is used in radio factories to indicate the positions of wires, as this is important in modern all-wave receivers. Instability, insensitivity and microphony can all be caused by wires not being in the positions which the designer has found best for them.

The sequence of the above inspection stages should not be overlooked by the reader. It would be useless to dress the wiring first and then have people prodding about and pulling suspected faulty joints.

At the stage along the line where the wiring is completed and has been inspected, the planning engineer must co-operate with the department concerned with the equipment for testing the complete chassis.

The testing of chassis in a large

factory can only be satisfactorily carried out by means of test equipment mounted in racks and arranged so that the chassis may be quickly connected.

In the chart in Fig. 1 it is shown that after the review of the complete sample models a meeting of the set designer, inspection, assembly and test equipment engineers is held. The meeting has before it one of the hand-made sample models and copies of the designer's rough drawings and specification or performance figures.

From the discussion there evolves the type of test gear required, where it is to go along the assembly line and how many of each type are required.

The latter depends upon the rate of production. It is no good having a rapidly moving assembly

line if a bottle-neck is to occur at the test-points. The time for each test must be estimated, and if, for example, this is four times as long as the longest assembly operation, then four sets of test equipment must be made up, so that each one can cope with one quarter of the output from the assembly line.

After the preliminary meeting, the test equipment designer works out circuits and apparatus which, by means of a few plugs or clips, can be applied to the chassis by the tester, and enables the test to be made automatically by pressing buttons and reading the meters.

The first test is probably to apply a high voltage to all the various circuits in the set (with no valves in the receiver), in order to make sure that the insulation of the components and wires is correct and that there is no "short" to earth or chassis.

After the first electrical test, the chassis may be passed to a tester in charge of a rack in which anode current, anode voltage, heater voltage and grid-bias voltage are given by means of meters with a standard set of valves operating in the instrument. This will show that all the circuits are working and complete and that the chassis is ready to be passed along for IF and RF alignment.

In order that unskilled labour may be utilised as much as possible, the various meters are not graduated in actual voltages or milliamps, but have marks or indicators on them, so that all that the operator has to watch is that the needle moves over to the mark.

Use of Meter Scales

When a different kind of receiver is to be tested the test-equipment engineer merely makes new marks on the meter scales. He knows the range of the meter, and probably has the standard calibration scale for that meter which he can press close against the blank meter scale (see Fig. 7) so as to set his marking points. Some meters have little movable metal indicators for this purpose. They can be seen on the meters in the racks illustrated in Fig. 20.

When producing huge quantities of units such as radio chassis it cannot be expected that they will
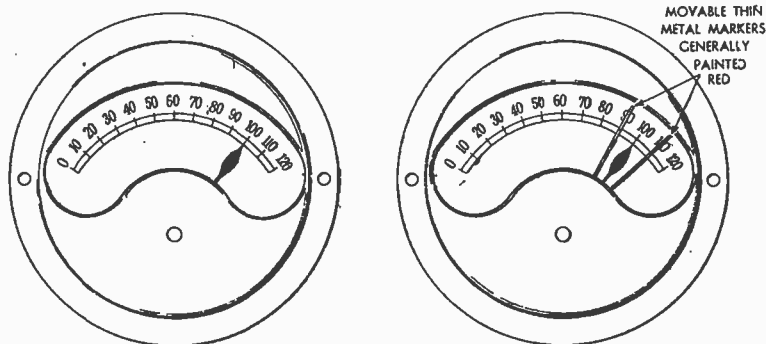
Fig. 7. A normal meter (left) and a meter used for testing during production. On the latter, two markers are set to limit positions fixed for the particular receiver which is in production. The operative, therefore, has only to see that the pointer comes somewhere between these two markers.

all behave exactly the same way. Voltages will be a little down in some cases and a little up in others, so that the test engineer must collaborate with the designer in deciding what are the "test limits" for the various stages.

Test Gear Limits

For example, the average voltage on the anode of a particular valve may be 200 v., but the designer would give the O.K. to the test-gear engineer to set limits of perhaps 190 to 210 v. for that particular test.

The test engineer can, therefore, make two marks on the scale of the meter, and as long as the needle comes to rest between these two marks the operator can pass the chassis—with regard to that particular valve reading—as being up to standard.

Limits may range from plus or minus 1 per cent. for very high-grade components used in a vital position in a short-wave circuit, to plus or minus 20 per cent. in the case of components performing a function of a more formal nature such as decoupling or voltage dropping.

It is because of these limits in component production that limits must be tolerated with regard to voltages and currents in the complete receiver.

Receiver Variations

This explains why some receivers are just that little bit better than the normal or standard instruments and why one or two receivers may be just sufficiently below standard to be noticeable.

By a mere run of chance one receiver may have incorporated in it resistances whose values are all on the low side, although within their own particular limits. If this is the case, then all the voltages to the valves will be towards the upper limits of the voltage and current standards and, therefore, the receiver will be particularly "lively" without any discernible reason to the service engineer, unless he takes the trouble of checking every resistance for its exact value.

In the majority of receivers, however, the different tolerances, being high on some components and low on others largely cancel out. All the same the point has to be remembered, in particular by the repair engineer when checking voltages, currents and resistances against the data in a manufacturer's service manual. The figures given are average, and variations of plus or minus 20 per cent. are usually regarded as passable.

In the chapter dealing with sound amplification equipment, rack amplifiers are described and illustrations (page 385) show meters which are employed for rapid testings of the valve currents. The same principle is employed in test-racks to save using large numbers of meters.

Test Equipment

One meter will be used with a switch beneath it, so that it may be connected to any of the valve-circuits in the chassis being tested. The meter switch will not only connect the meter to the appropriate part of the circuit, but will also introduce the correct series resistance in the case of voltmeters, or shunt resistance in the case of milliammeters, so that the right range for the particular measurement is obtained automatically.

In the case of the test-rack for the assembly line, the series and
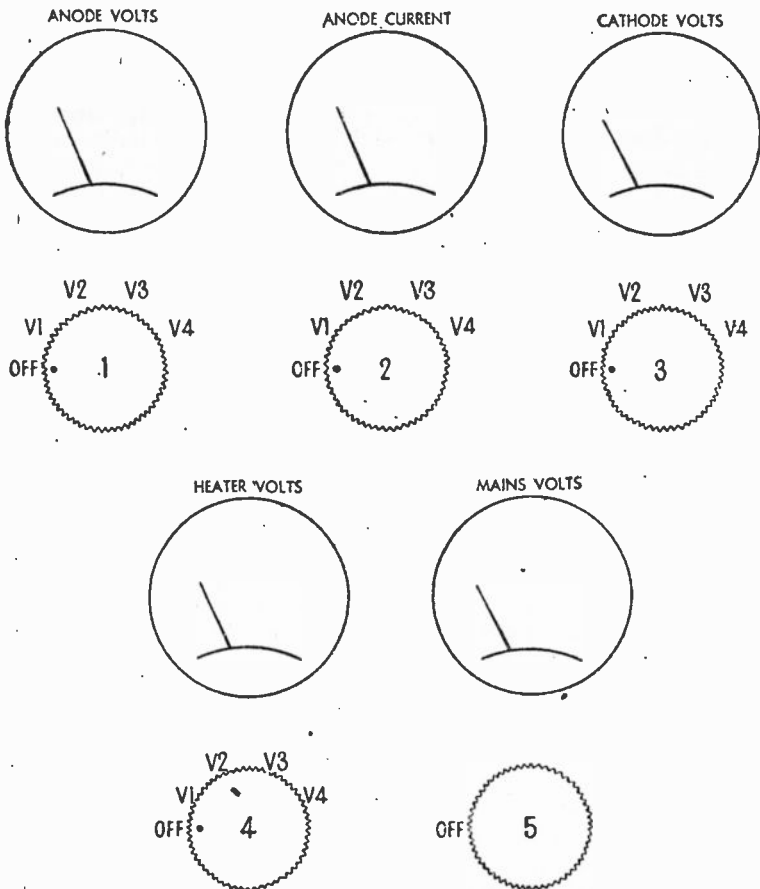
Fig. 8. Typical arrangement of meters and switches mounted on a test panel for the purpose of checking the voltages and currents of a chassis.

shunt resistance are designed not only to safeguard the meter and save an operation in manipulating a range switch, but also to bring the needle within the limit marks on the scale for every reading. Of course, for the complicated testing of all the circuits in the chassis one meter cannot be used for every measurement, so an arrangement similar to Fig. 8 is often made up.

It will be seen that there are meters for all the primary checks, and the knob below each meter connects it into each valve circuit in turn. Thus, when the chassis is fitted to the test-rack, the operator switches No. 1 knob to all positions in turn, to see that the needle takes up the correct position for all the valves. Then he repeats the operation with switch No. 2, etc.

Control No. 5 is a variable resistance which maintains the volt-

age from the mains supply at the correct potential. In big factories, especially where they generate their own electricity supply, the voltage may vary slightly according to the load on the system.

This could upset the voltages obtained during testing, so the operator adjusts the mains voltage meter to read between the limit marks before he takes the readings on the other meters.

The next test-rack, in the case of mains-driven receivers, is devoted to checking for hum; the aerial and earth terminals are shorted and the chassis connected to the mains supply.

Observing the Hum

The amount of hum is observed on an output meter, and there is also a loudspeaker to give an audible impression of the amount of hum present. In a particularly "hot" chassis one or two single wires in the grid circuit of certain valves may be likely to pick up hum from nearby heater wiring, and these wires have to be dressed to obtain minimum hum, as shown on the output meter.

The output meter may have a red mark above which the needle must not go. If it does, the wiring has to be dressed until the needle falls below the mark, or the chassis rejected for further investigation.

From this test the chassis proceeds to a rack fitted with a signal generator and an output meter. The operative here adjusts the IF trimmers and, if the production is not very great, he can also adjust the RF circuits.

During a big production run, however, he would probably pass on the chassis to another operator, who would carry out oscillator and RF testing adjustments. The oscillator would not necessarily be a complete signal generator.

The signal oscillator in a large production test-rack would be a small affair, made up in a screened box, with a knob and pointer concentric with a scale which might not be calibrated in frequencies, but only with a number of points labelled Test 1, Test 2, Test 3, etc. Alternatively, the points might be labelled $TC1$, $TC2$, $TC3$, indicating that with the controls adjusted at that position the trimmer condenser bearing that number on the circuit is to be adjusted.

Fig. 9, shows an operative lining up the circuits of a superhet. Immediately below the large dial on the test-rack, behind the radio chassis, will be observed the heavily shielded lead which injects the output from the test-rack into the receiver circuit.

The operator hears the signal from the generator in his earphones, so that he may quickly arrive at the approximate setting of the trimmers, after which he makes his final and very accurate adjustment by means of the output meter at which he is looking in the picture. His left hand is on the attenuator, which cuts down the input from the signal generator so as to keep the receiver output down to about 50 milliwatts.

Circuit Alignment

As described in Chapter 13 on Fault Finding, a very powerful signal is required to force a way through circuits which are considerably out of alignment, but as the circuits are brought more and more into tune, the input is reduced so as to keep the output from the receiver down to an easily readable figure.

When all the circuits have been
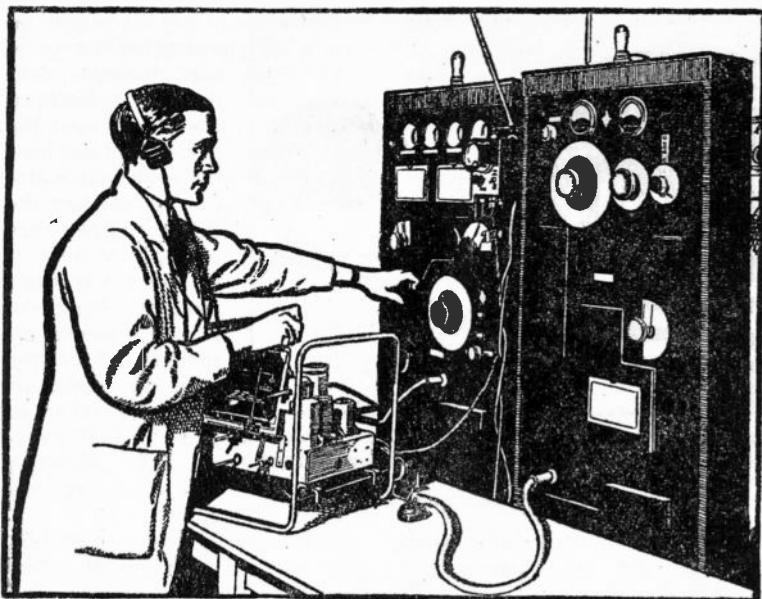
Fig. 9. A superhet chassis being lined up by means of frequencies generated in the panel instruments. Trimmer condensers are adjusted for maximum output.

corrected the attenuator should be in a position allowing only a very small voltage to be delivered to the receiver. The operative has to make sure that the attenuator goes down to the figure given by the designer for the mark on the output meter.

It will be seen that although a great deal of labour and time goes into the designing of test equipment for big productions, the expenditure involved is small compared with the gain in production which can be obtained by making the tests as automatic as possible. In this way, semi-skilled, and in some cases unskilled, labour may be employed on jobs which, it might be expected, would require the services of skilled operatives.

After the RF and IF circuits have been aligned, the chassis is ready for its pass out, and is handed on to a skilled engineer working generally in a screened room, so that the receiver is not affected by electrical interference from machinery in the factory.

By means of a signal generator or similar piece of equipment, signals of a known strength are injected into the aerial and earth circuits of the receiver. The output of the receiver is fed to an output meter and, for the set to be passed as O.K., the output must rise to the marks on the meter as set up by the designer.

This procedure is called "taking a sensitivity run", and means that the sensitivity is checked at several points on each waveband.

When the chassis has gone through this final test it is passed to girls or youths, who bolt it into its cabinet and connect up the wires to the loudspeaker and any

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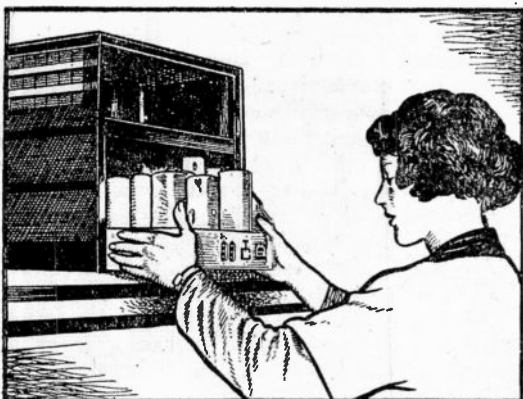
Fig. 10. A completed chassis being fitted into its cabinet. Note the height of the bench which minimises fatigue on the part of the operative when connecting up the wires to the loudspeaker, and other fittings.

Fig. 11 shows an operative making the various connections between the chassis and the automatic mechanism of an auto-radio-gramophone, as the latter passes very slowly by on an endless train of carriers. Note the height of the radiogramophone from the ground and the stool for the operative, so that the job is carried out as efficiently and easily as possible.

other fittings on the cabinet, such as aerial and earth panels and extra loudspeaker sockets. As will be seen from Fig. 10, the cabinet of the receiver is well raised, so that the operation is carried out with as little fatigue as possible to the operator during fitting up.

The complete instrument now goes into a sound-proof cabin, where it is tested under actual domestic operating conditions on an outside aerial and earth. The general performance and the quality of reproduction are noted. The input from a record player is
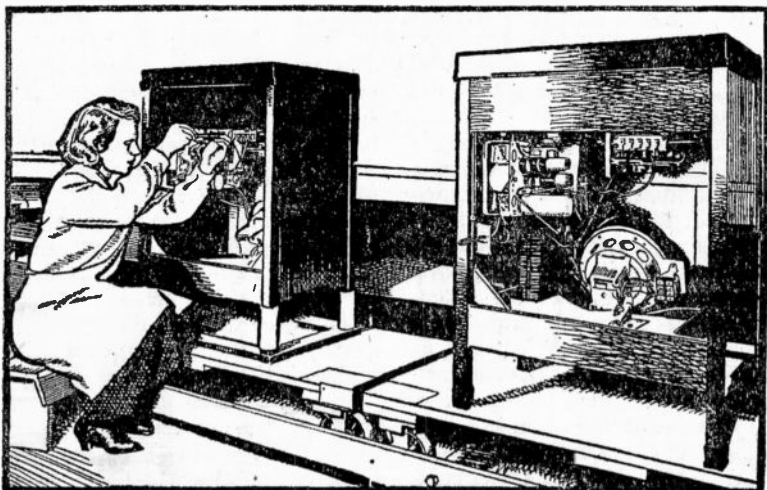
Fig. 11. An operative connecting up the chassis and mechanism of an automatic radiogram as it passes slowly by on a conveyor.

fed into the pick-up sockets, if the receiver is provided with these or, in the case of radiogramophones, a record is played to make sure that the pick-up circuit and wiring are correct. The operator also makes sure that the motor is running quietly and tests it for constant speed with a stroboscopic disc.

From this cabin the receiver passes away to the Packing Department, and thence to the stores.

Any chassis or complete instruments which are rejected are passed to expert fault-finders if the trouble is associated with electrical faults (sensitivity and selectivity), or to mechanical engineers when the trouble is due to some fault in the tuning device or other mechanical feature.

In Fig. 12 mechanical engineers are adjusting various parts on the chassis and making minor adjustments to the fitting of the chassis in the cabinet. Throughout production the cabinets are protected by cardboard coverings so as to avoid possibility of damage.
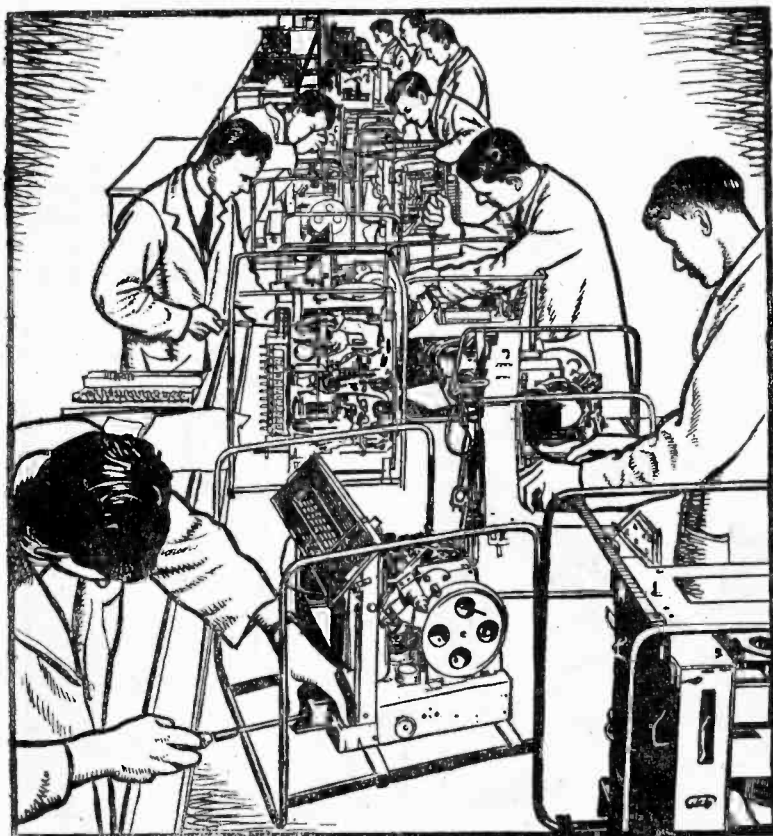
Fig. 12. Chassis undergoing mechanical inspection and repair. The cradles provide easy handling of the chassis and prevent possibility of damage.

Female labour is generally employed on assembly jobs and repetition production operations, but more and more women are being used in other work, and they can easily undertake mechanical assembly, inspection, and even electrical repairing after a short training. Fig. 13 shows one of these women inspectors giving a batch of chassis a final mechanical examination before they are fitted into their cabinets.

Before a new model is put into full production, an experimental production run of about two or three hundred chassis is made, to see what snags are encountered

Fig. 13. Girls are employed a great deal in assembly work and increasing numbers are being used on repair and inspection. This girl is checking over a batch of completed chassis prior to fitting them into cabinets.

under production conditions. The Planning Engineer has tried to foresee all difficulties, but despite his forethought trouble may occur.

It may be found, for example, that when a girl is soldering a particular joint her soldering iron comes too close to a coil, which becomes charred or burnt. The Planning Engineer will then arrange that this particular component is put on after the joint is made, instead of before.

Final Test Stages

Troubles may occur during the final test stages, and the sensitivity run may prove unsatisfactory. It may be found easy to hand-make a few chassis which give the required output for the specified number of microvolts input, but when the mass production batch is made up all sorts of troubles may occur.

Inductance limits of coils and capacity limits of padding condensers may have to be tightened up, due to the inability of the operators to maintain the exactness of the wiring as laid out by the Planning Engineer.

Valves, of course, must be treated as components, and if, as is usual in the case of valves, they are not made in the factory, but are supplied by a valve manufacturer, close contact must be maintained. It may·be found that batches of these valves differ from the samples which were used in the experimental models.

Whole batches of newly produced receivers and components are given a prolonged run under operation conditions, and these tests are generally referred to throughout the radio industry as "soak tests".

To ensure there is no fault which might pass unnoticed by a short operation, a batch of instruments is connected up to aerials and earths and run continuously for 24 hours or more under the supervision of inspectors. Fig. 14 shows a group of television receivers being soak-tested on the right, while the engineer is fitting in the cathode-ray tubes.

Some of the early experimental models are tested for any special requirements with regard to packing and their ability to withstand rough handling. In the case of table models, tests are often carried out by dropping the packed receiver from a certain height (generally four or five feet) flat on to its face and sometimes on to all sides of the packing carton in turn.

Fig. 15 shows another method of carrying out a transport test. The instrument is fixed to a platform and, by means of reciprocating arms and cams, subjected to a series of violent vibrations and periodic thuds.

Mechanical Strength

After these tests the model is examined. Quite drastic changes have sometimes to be made to the chassis when an exceptionally heavy transformer is bolted to it. The extra weight of the transformer may cause the chassis to shift or distort, thus upsetting the tuning scale and causing other troubles. These tests will show whether it is necessary to insert packing blocks to wedge the chassis tightly in the cabinet, or whether the packing carton itself should be strengthened.

As shown in the Fig. 1 Chart, heat-runs are also taken with soak tests, under the supervision of the Service Department and also that of the set designers.
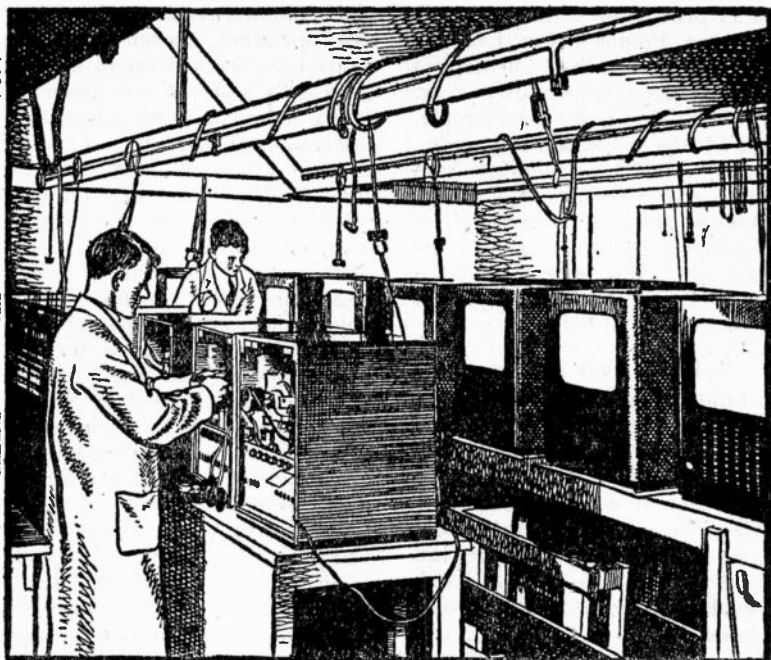
Fig. 14. A batch of television receivers undergoing a "soak" test, *i.e.*, a non-stop run of many hours' duration, to ensure against faults not observable in shorter runs.

A heat run is a test which the designer has to carry out under practical conditions. This means that the chassis or receiver is put into a box or cabin with very little ventilation and provided with a thermometer which may be read from outside the box. The set will then be switched on and left for several days at a room temperature of the highest which the receiver will have to endure.

If the model is one which will be sold for export, then, in addition to the high room temperature, the atmosphere will be moistened to represent humidity, such as may be experienced in certain foreign countries. Fig. 16 shows such tests being carried out. The percentage of humidity in the air is referred to as "HUM—98%".

To withstand these conditions the components of the receiver are often specially impregnated to keep out the moisture, and after a long heat and humidity test the components may be sawn in half and otherwise carefully examined for traces of corrosion and breakdown.

In the case of receivers for 'the home market,' the heat run will prove whether the ventilation of the cabinet is sufficient to prevent excessive temperature, which may give rise to softness of the impregnation and waxes used in the transformers and condensers.

Sometimes it is found that the heat from the output or rectifier valve is too localised, and causes excessive heating of the cabinet immediately above. If the cabinet

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is already in production the designer must get over the trouble by putting in pieces of asbestos or arranging a cowl over the valves to deflect the hot air out through the ventilation holes in the back.

The importance of ventilation should not be overlooked by the service engineer or the listener.' If the back of the receiver is too close to a wall, overheating may result, possibly leading to a burn-out.

Many of the larger components such as loudspeakers, pick-ups and motors are built up along an assembly line. One in which motors are being assembled is shown in Fig. 17. This is the assembling of the spring-driven motors of the type used in record players for mobile PA equipment.

In the mass production of coils all having similar characteristics a very intricate coil-winding machine is used which requires the attention of a skilled operative. Fig. 18 illustrates one of these machines, with which twelve coils may be wound simultaneously.

Fine Windings

Such machines are used for windings having a great number of turns of wire, such as the primaries and secondaries of inter-valve transformers, long-wave inductances, HF chokes and IF coils. The twelve reels of wire are plainly seen, and the wires from these are fed by means of spring-loaded pullies to keep an even tension on the wire, and so prevent it breaking, due to starting and stopping operations.

In the particular instrument shown, the coils are all wound on one former, and as each layer is completed a long sheet of paper
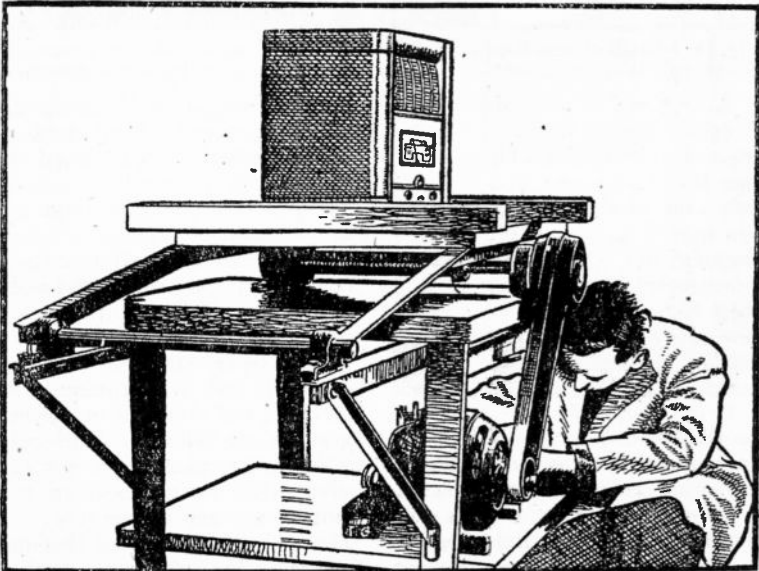
Fig. 15. A machine which vibrates and bumps a receiver to simulate transport conditions. After a test of 48 hours, the receiver is expected to give a standard performance. This test also determines the most suitable type of packing carton.
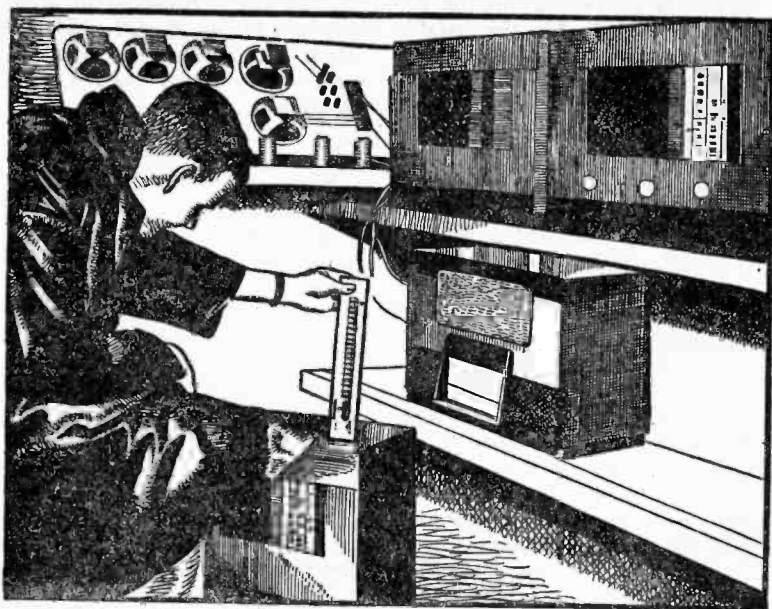
Fig. 16. Tests in oversea markets are preceded by arduous tests in the laboratory. These pictures show sets and parts inside a chamber which reproduces any extremes of temperature and humidity. The notice outside the chamber indicates that the actual climatic conditions of the tropics are being duplicated.
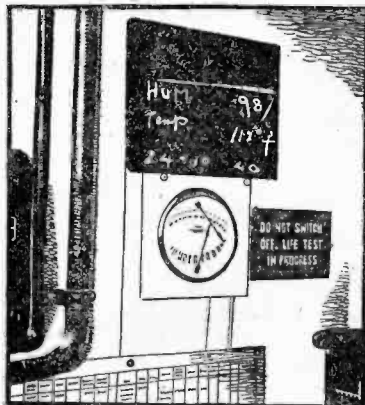
moves forward, wraps itself round the winding, and is then cut by a guillotine at the proper instant. The next layer of wire is wound, more paper is fed in, and so on.

The counter on the machine tells the operative when the correct number of layers has been wound. The wires are then cut from the spools and a certain number of layers of paper allowed to wrap themselves round the finished coil. When the paper covering is sufficient, the operative pastes it down using a non-corrosive adhesive.

It will be seen in Fig. 18 that the operative has a soldering iron available, and this is to enable her to solder on thick lead-out wires to the fine winding.

Next, she brings into action a number of small rotating circular knives which cut through the long former, and so make twelve individual coils. The mandrel is then taken from the instrument and the coils slipped off from the machine.

Single-layer coils on formers, small pile-wound coils and large sections of mains transformers are generally wound on machines which handle only one or two coils. Fig. 19 shows a small machine which is handling two bakelite formers such as are used in pick-ups or HF chokes as used in the mains circuit of a DC receiver.

The counter on the left indicates the number of turns which have been wound, the outer circle of numbers being the single turns, with the inner circle registering turns over 100. The two spools of wire are seen at the back of the machine, while at the top, left, a spool of string is seen. This is wound round the coil after it is finished to protect it from damage.

Coils and transformers are no exception to other components with regard to rigorous testing and inspection. After a transformer has been completed by assembling the laminations into and around the former, soldering the wiring on to the appropriate tag and connecting panel, the transformer is subjected to various tests.

Voltage Test

It will first pass a strict insulation test of some thousands of volts between each winding and the next winding and between all windings and the laminations.

Fig. 17. Major components are assembled on a "line" as are receiver chassis. These girls are making up spring motors for portable gramophones and PA gear.

Fig. 18. A multiple machine, winding twelve coils simultaneously. The small rotating circular knives cut through the long former, thus making the individual coils.

Because of the high voltages employed, safety precautions are used to protect the operatives, and Fig. 20 illustrates a mains transformer being tested.

The transformer is placed in a stout wood box and the various connections made to the lugs or terminals. On the inside of the box there is an electric switch, which can be seen just above the operator's right hand in the illustration. So long as the box is open the mains supply to the test equipment is cut off, but directly the box is closed, the two contacts establish the circuit.

Should any insulation be faulty, a red warning lamp will light up and the transformer is rejected by the operator. If the first test is passed satisfactorily the various voltmeters on the test-panels indicate the potentials being delivered across the secondary windings.

The voltages applied for testing the insulation between windings are much higher than those deliv-

ered by the transformer secondaries themselves. The reader should note the care taken to protect the operator engaged on this testing work and should appreciate the care he should himself use if testing or working near a mains transformer.

Fig. 21 shows the testing of an inter-valve output transformer. Here a similar procedure is adopted, except that the voltages across the secondaries are measured at various audio-frequencies, so as to check the transformer's response curve.

Tuning-coils have to be adjusted to very fine limits, so that they will operate efficiently in circuits tuned by a ganged condenser. When the coil is being made, a few extra turns will be wound on to the former separated a little distance from the main winding. The

extra turns will be well in excess of the total turns required, and an operative at a special test-rack (Fig. 22) reduces the winding turn by turn until she gets a correct reading on the meter, which indicates that the inductance of the coil is exact.

Tuning coils, in addition to testing for continuity and general appearance, are checked for inductance and efficiency. Fig. 23 shows a typical example of coil-testing apparatus, in which it will be seen that by means of long metal arms fitted with spring clips, connecting the coil to the apparatus is facilitated and, also, the coil is kept away from the coils and wiring in the test fixture.

While on the subject of coils and the miles and miles of wire used in their construction, the testing of new wire before it is
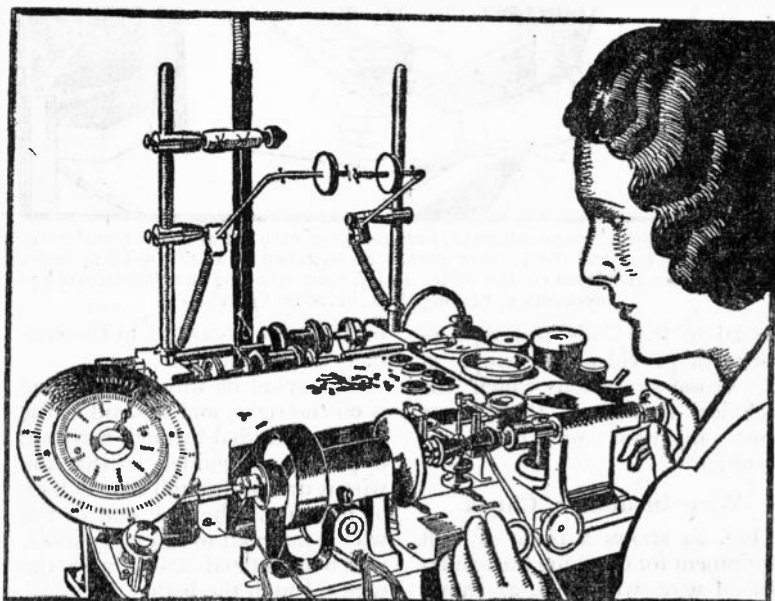
Fig. 19. Small coils are generally wound on non-automatic machines. Note the turns counter calibrated in units and hundreds to the left of the operator.
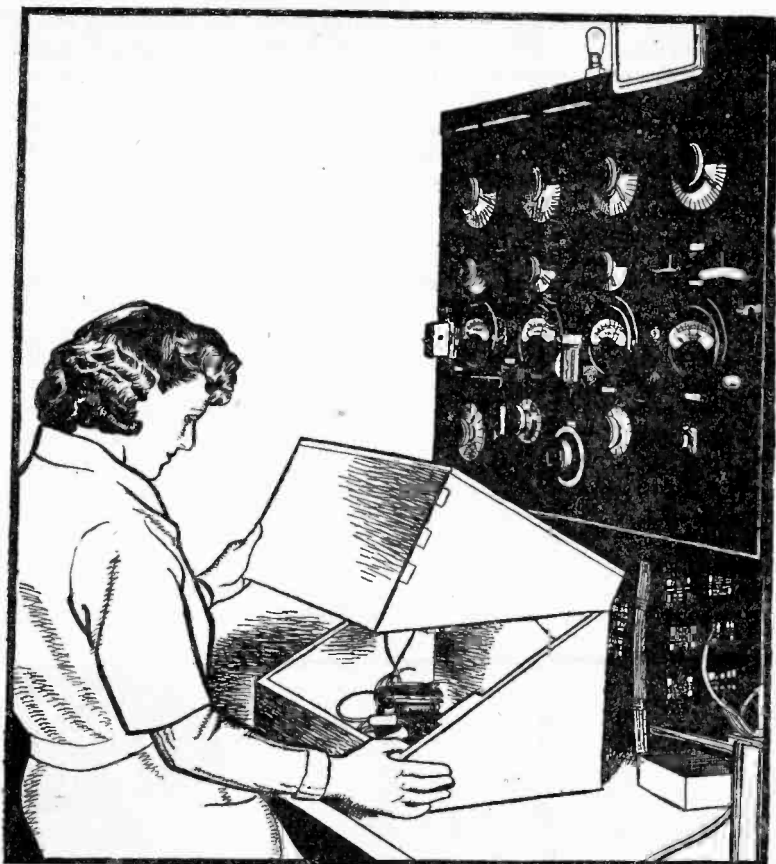
Fig. 20. Testing a mains transformer. Because of the high voltages, the transformer is placed in a box and the current cannot be switched on until the lid is down. Limit markers are fitted on the meter scales, thus relieving the operator of the necessity of reading the calibration figures.

passed to the Coil-Winding Department provides an example of the ceaseless watch which the technical section of the factory must maintain on purchased material.

Wire Insulation Check

Fig. 24 shows a piece of test equipment for checking the insulation of wire, while Fig. 25 shows the schematic layout of the apparatus. It ensures that there are no pin-holes or abrasions in the enamelled insulation.

The spool of wire to be tested is on the right, and the end of the wire is threaded through a system of pulleys and guides, so that the wire is drawn through a small bath of mercury. The free end of the wire is fastened to an empty spool, which is rotated and draws the wire through the bath.

An electrical circuit is established between the end of the wire

on the storage spool and the mercury in the bath. The voltage applied depends on the type of wire. Directly any length of faulty wire enters the mercury bath the circuit is completed between the copper wire and the mercury, and a red lamp or warning bell is ·operated. At the same time the electrical circuit actuates a relay which will stop the spool rotating.

Laboratory Tests

In addition to electrical and mechanical tests on material, a large concern maintains a chemical laboratory, whose job it is to analyse all materials. Apart from ordinary items which easily come to mind, there are less obvious jobs which have to be investigated. Soldering fluxes, pastes for sticking paper formers together in transformers and lubricating oils all have to be examined for any corrosive action.

Another activity of the chemical laboratory is to supervise the manufacture of varnishes, polishes, etc., in the cabinet factory.

It will be seen from the Chart in Fig. 1 how large is the influence which the Service Department should have in decisions affecting production. They are the technical contact with the receiver once it has left the factory. They know the difficulties that arise in servicing the model, and they have to deal with complaints.

Fig. 21. Intervalve and output transformers being checked against standards at several points on the audio-frequency scale.

These points are vitally important from the sales point of view, and therefore any new model should be reviewed by the Service Department to see that the designer has not perpetuated any errors of the past.

Service Check-up

The Service Department is given the important job of compiling information concerning new instruments and components and brings the reports to the notice of the design and factory authorities at the very earliest opportunity.

All engineers' reports must be analysed, sales or replacements of spare parts of new models must be tabulated; any conversations of an adverse nature made by the dealers to sales representatives must be explored to the utmost. The Service Department should be able to give information such as, whether one condenser is any worse than another or which resistance is giving most trouble and why.
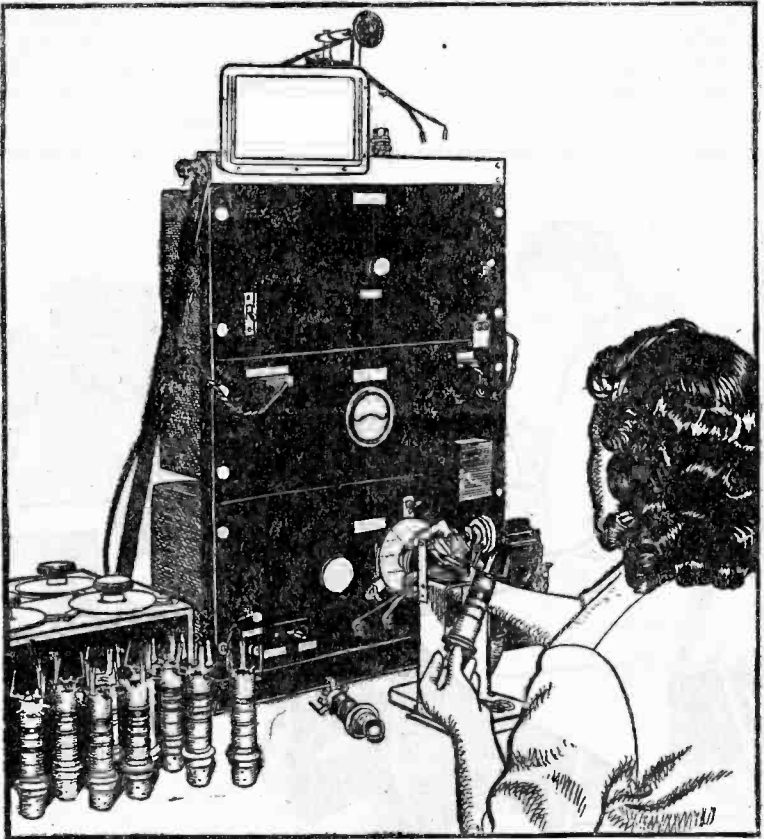
Fig. 22. Coils being adjusted to the correct inductance by removing superfluous turns. With ganged tuning, inductance must be highly accurate.
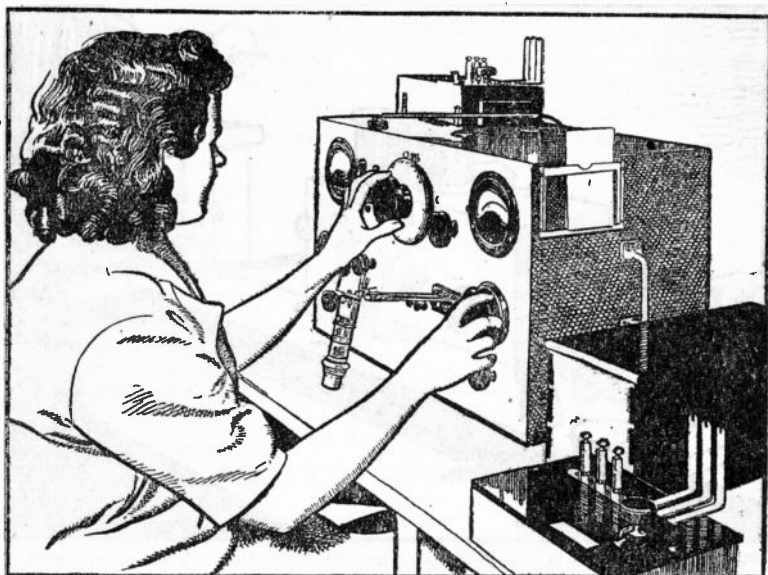
Fig. 23. Coils for the assembly line are checked on this type of inductance tester after they have been in the stores some time. Slight dampness can affect the inductance of coils quite considerably.

Samples of faulty material are collected for examination by the designs engineers with the full history as to exactly how long the component had been used, the locality from whence it was returned (in the case of corrosion by sea air), the mains voltage of the supply, with notes concerning any suspicion that the mains voltage fluctuates unduly.

One of the early models is sent to the Service Department for it to examine in the light of its previous experience on faults and troubles, to see whether they have any criticisms. In addition to this, the Department will interest itself in the ease of servicing the chassis, not only for itself, but for the service engineers.

They will see that it is easy to remove and replace valves and to replace components without too much disconnection of wires, and and they must also keep an eye on the layout of the chassis as it concerns servicing.

Manufacture of Condensers

Earlier in this chapter we mentioned that there are a few components that cannot be constructed and assembled along mechanical engineering lines. One of these is the condenser, in both solid dielectric and electrolytic types. (The theory of the condenser is explained in Chapter 17 and the practical uses referred to in various chapters—*see* Index.)

The two chief forms of solid-dielectric condenser used in domestic receivers are the mica-type, employed where exceptionally good insulation is necessary due to high applied voltages, and the waxed-paper type for general

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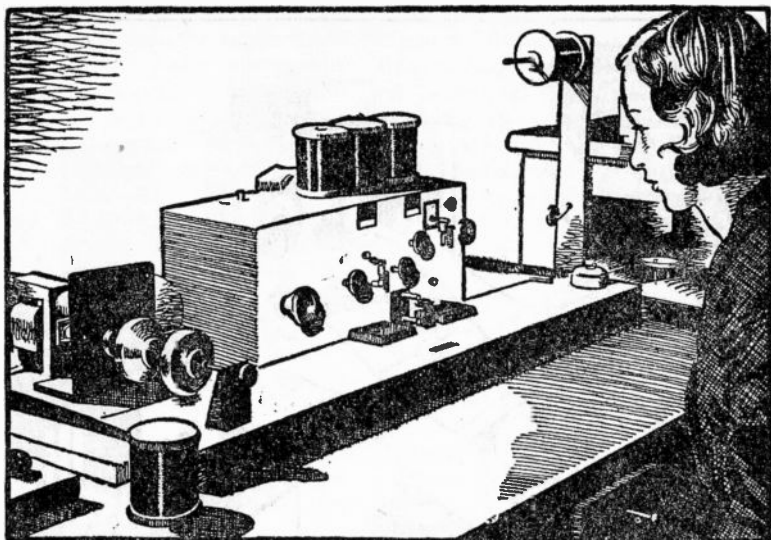
Fig. 24. Testing the insulation of wire by running it through a mercury bath. A warning is given when a fault is found. (*See also* Fig. 25).

use in decoupling, tone correction positions and so on.

For the mica-type pieces of mica of correct thickness are stamped out by a machine. Copper foils or plates are cut and the required number to obtain the desired capacity are welded together at one end. Foils and micas are then interleaved.

The material is passed to the first girl of a group, and in Fig. 26 it will be seen that a small chute feeds the material to her from a girl in the background, who is operating the stamping machine which is cutting up the sheets of mica and copper foil. Other girls, not shown, are operating a·small electric machine welding each set of plates together and connecting on to the end of each group of plates a soldering tag.

The first girl in the group probably inspects the copper foils and puts the good ones in a box beside the second girl. This girl puts one set of plates into a "jig", which keeps them in position, and she passes the jig to the next girl, who inserts the micas and interleaves the second set of plates.

The next girl might be an inspector, who would see that the micas are evenly positioned, so that there is no risk of the two sets of plates touching each other. She passes the assembly to a girl, who closes up the foils and places the condenser in a fixture, so that it can be taken along to the moulding shop, where it is inserted into a moulding of bakelite or other insulating material.

Many paper dielectric condensers of modern manufacture are made up into tubular forms, whether they are put subsequently in round containers or square ones. For example, "block" condensers, which comprise several small condensers in one container,

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are constructed of individual tubular units placed in a metal container with the spaces filled by an insulating compound to keep the units in place and prevent the entry of moisture.

Tubular condensers are mass-produced by girls operating machines which roll up metal foil interleaved with a special high-quality waxed paper. On the machines are mounted rolls of thin paper and two rolls of foil. Generally, two strips of paper are first arranged as an external covering, then comes one foil, next two sheets of paper, the other foil, and finally two more layers of paper.

When the operative has arranged this "sandwich" on her mandrel she sets the mandrel in motion and winds on as many turns as has been decided upon by the designer to give the required electrical capacity.

Before the winding is complete she stops the mandrel and inserts two lengths of thick foil to act as connecting tabs. The tabs are inserted, one between each foil and its adjacent paper insulation, so that connections are obtained at the two opposite ends of the condenser roll. The operative then wraps a few extra turns of paper round the condenser for protection.

The condenser now looks something like Fig. 27 a. This assembly is put into a cardboard cartridge, and the tags at each end are spot welded to metal caps (Fig. 27 b), which are a tight fit into the ends of the cartridge. The edges of the cartridge are then spun over the edges of the caps to prevent them coming out (Fig. 27 c).

At this point it will be of value to readers who are service engineers to learn of a fault which can occur with this type of condenser, and which gives rise to hard-to-find, intermittent troubles.
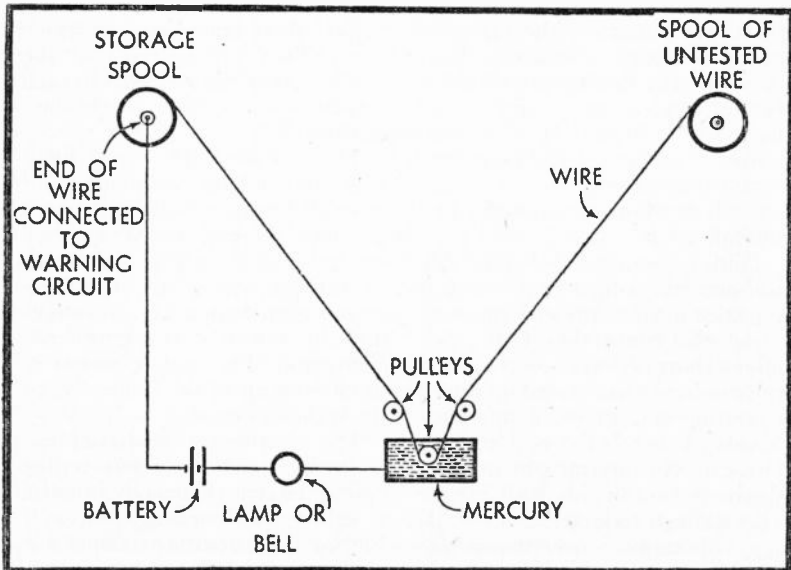
Fig. 25. A schematic diagram of the test shown in Fig. 24.

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Fig. 26. Small components requiring few assembly operations are often made up by groups of girls.

sers are impregnated with wax are connected up to vacuum pumps so that the air is drawn out of the condenser assemblies so permitting the fullest possible penetration of the wax. The impregnation preserves high electrical insulation and prevents deterioration of the foil and paper.

After the condenser has been impregnated it is tested, marked with its capacity and voltage rating and given a coating of hard varnish. It is then ready for use.

In earlier types of "tubulars" the metal connecting tabs were not spot welded to the end caps, but were folded backwards and forwards to form a "wad" which pressed against the caps when these were inserted into the ends of the cartridge. As the next process was the immersion of numbers of condensers in great vats of heated wax to seal them against moisture and air, it will be appreciated that some of the wax occasionally got between the caps and the foil wads.

With a condenser in which this has occurred, slight movement of the wire fixed to the end cap may make the connection O.K., but after a short period of use, or when the condenser has heated up under operating conditions, a film may develop between the wad and the end cap. An intermittent internal disconnection of this kind can be very difficult to locate. Spot welding, of course, overcomes this trouble.

The vats in which the conden-

Units required for the making up of "block" condensers are passed to a special assembly bench before they reach the cartridge stage. They are grouped in the various capacities required in each container and connecting wires are soldered on.

The "blocks" are then filled with hot insulating compound and proceed through a cooling tunnel as shown in Fig. 28. When they emerge, a girl stamps a code letter or number with a hot metal die against each connecting wire sticking up through the now hard compound. This coding assists in the wiring up of the "block" into the receiver chassis.

The electrolytic condenser has no visible dielectric, but builds one up electro-chemically in what is called the "forming process". Fig. 29 illustrates the principle and shows an aluminium outer can and a central aluminium electrode

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which is insulated from the can by means of an ebonite or rubber bush at the top.

The can is filled with a liquid—the "electrolyte". The electrolyte is made up from pure distilled water and salts such as boracic acid, borax and phosphates. The central electrode is termed the anode, and is the positive terminal of the condenser, while the casing is the cathode or negative terminal. When a voltage is applied to the two terminals of the condenser, a heavy current flows at first, but an oxide film soon forms over the anode and isolates it from the electrolyte. This film acts as a dielectric and the current falls to a very small steady value.

The film formed over the anode is only one or two atoms in thickness. As the capacity of a condenser increases as the distance separating the plates is reduced (see Chapter 17), it will be appreciated that this electrolytic method of bringing the two plates of a condenser close together enables very large capacities to be obtained.

The practical design of an electrolytic condenser embodies these technical principles in a commercial form. Instead of a simple rod as shown in Fig. 29, the anode may take the form of a thin plate either wound round in a spiral or in other formations.

Holes in the sheet allow the electrolyte to pass freely to all parts of the anode. Sometimes a solid casting having a star section is used instead of sheets welded to a central support.

As the capacity of a condenser depends also upon the area of the opposing plates, means have been found of increasing the area by roughening the surface of the anode. This may be done by either mechanical or chemical etching or by means of sand blasting.
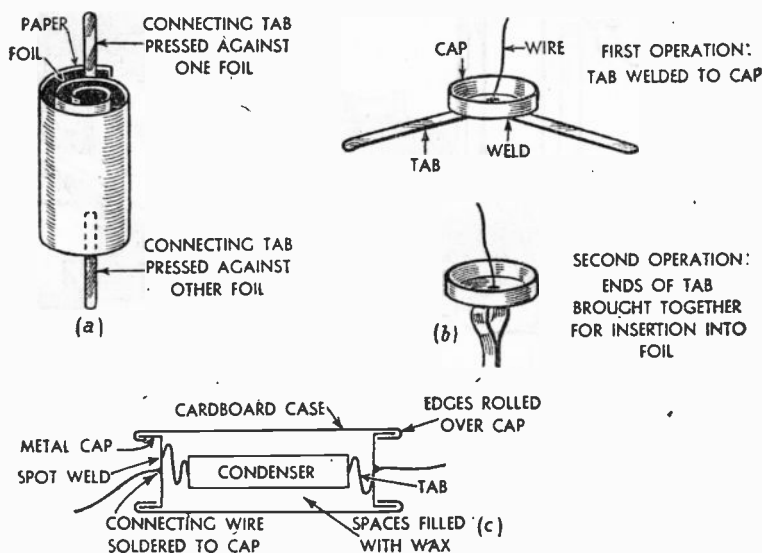
Fig. 27. Stages in the production of a paper-dielectric tubular condenser. The rolled-up condenser assembly is placed in a wax-filled cardboard tube.

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Before the anode assembly is put into the condenser it is thoroughly washed, and it often undergoes chemical treatment for oxidising the surface so as to assist the forming process.

In this process an initial low voltage is applied which gives rise to a high current until a slight film is formed, as indicated by a reduction in the current. The voltage is then increased by a further step, which results in the current rising until it again falls by reason of increased film.

Once more the voltage is raised, and this process goes on until the maximum voltage for the type of condenser being made is reached. The time taken is often 2 hours or more, although various methods are favoured by the different manufacturers.

In one method the electrolyte is boiled during the process and complete forming takes nearly the whole working day. In some cases the anode assemblies are clamped into racks and "formed" in a tank of electrolyte. They are then assembled into their cans and given a further "forming".

When a condenser is left in store for a long time it gradually becomes de-formed, due to the electrolyte attacking the aluminium oxide film. A de-formed condenser can give trouble if connected into a receiver, as it may cause a short circuit on the HT
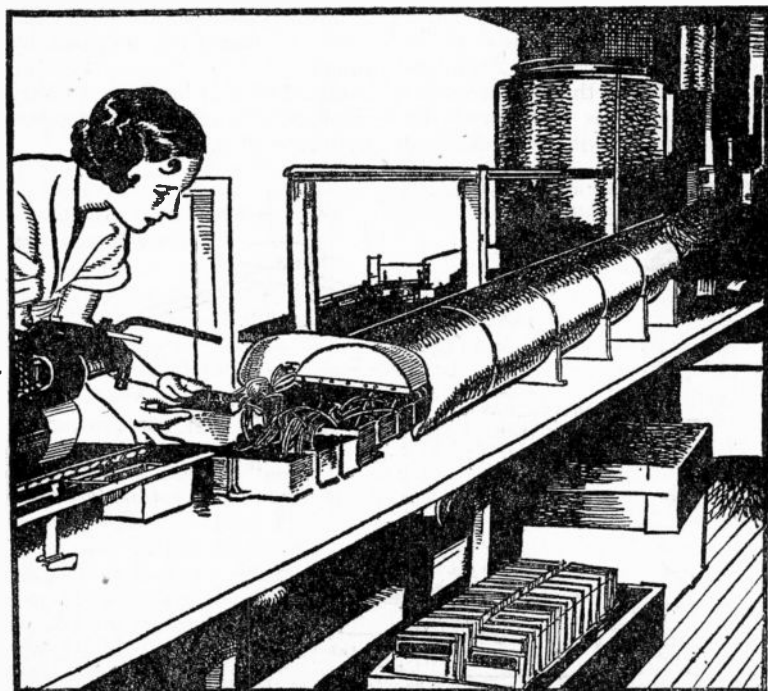
Fig. 28. "Block" condensers being filled with hot, freely-running insulating compound. They are then passed through a cooling tunnel to the next stage in manufacture. Both electrolytic and paper condensers are made into block units.

side and burn out the rectifier valve and mains transformer.

To prevent de-forming, electrolytics not in regular use should be connected up to their normal working voltage about once every six months.

Electrolytics may be marked for peak, working or surge voltages.

Peak Volts

"Peak volts" refer to the maximum voltage which should ever be applied to the condenser, and is the sum of the DC surge plus the AC peak voltage. The "maximum working voltage" is generally reckoned to be about 90 per cent. of the peak voltage rating, and includes about 5 per cent. for AC ripple. The maximum DC working voltage in the case of a condenser rated at 500 v. peak voltage would be about 425 v. DC plus 25 v. AC ripple. These two voltages together come up to 90 per cent. of the peak voltage rating.

The term "surge voltage" is generally considered to be the same as the peak voltage.

It is dangerous to apply to a condenser a voltage higher than that which it is rated to withstand. Excessive current will flow through the electrolyte, and this will result, not only in the heating up of the component, but also to the excessive generation of hydrogen and oxygen. As the excessive voltage may also cause sparking to occur between the electrodes, a state of affairs is created which is very favourable for the formation of an explosion.

Even during the normal life of a condenser electrolysis occurs. This breaks up the gases in the electrolyte to form oxygen and hydrogen. If no provision is made for these gases to escape, a high
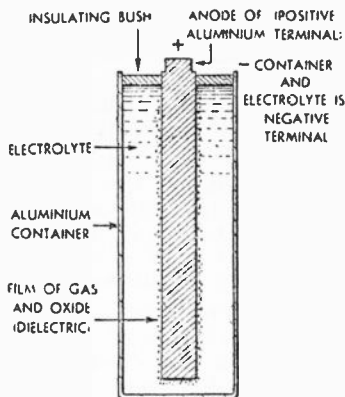
Fig. 29. Theoretical diagram showing the principle of the electrolytic condenser. The film of oxide forms the dielectric and because of its extreme thinness ensures the high capacity which is the outstanding characteristic of this type of condenser.

pressure is developed inside the condenser and the electrolyte forced out.

A rubber vent is, therefore, provided in the form of a small bladder with a needle hole in it. This hole is practically self-sealing, and will not allow the electrolyte to come out during normal storage or transport. When the condenser is mounted the correct way up on the chassis, however, gases formed are able to force their way through the hole in the rubber.

A manufacturing difficulty is often experienced in the making of a good connection between the foil and the external connecting wires. Soldering is not practical on the thin aluminium foil used in these condensers, and it is usual to rivet the wire to the foil. This riveted connection should be arranged in a part of the assembly which is entirely free of electrolyte so that a film does not form between the surfaces.

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The strips of foil metal from which the anodes are made are generally stretched out between points of suspension on large trays or racks, and the whole assembly placed in a tank of electrolyte. They are there formed by gradually increasing the voltage between the electrolyte and the anode until the maximum figure is reached.

Valve Manufacture

The first radio valve was made in the lamp factory of the Edison Swan Electric Co. at Ponders End, and for many years afterwards radio valves were looked on as small brothers of the more important electric lamp. The enormous demand which arose with the introduction of broadcasting gave the valve a status of its own, and nowadays factories are in operation which are solely devoted to the production of valves of all types, and their output runs into millions yearly.

The raw materials of the radio valve are the same as those for the electric lamp—namely, glass, mica, nickel and copper and some rarer metals. The glass bulbs used for receiving valves are generally of lead or soda glass, such as is used for small lamp bulbs, but in the case of transmitting valves, where the temperature is high, the so-called "hard" glass of the Pyrex type is generally used.

Mica is largely used for supporting the internal structure, but here again in transmitting valves a substance is required which will withstand greater heat without deformation or loss of its electrical properties, and steatite or porcelain replaces mica. Nickel is used for the supporting wires for the electrodes and for the electrodes themselves in certain cases.

Two other metals are employed in valves which are specially connected with the lamp or valve industry. These are molybdenum (pronounced mo-lȳb-denum, and often abbreviated to molly) and tungsten. Molybdenum is exceedingly tough and has a very high melting point, and hence can be operated for long periods at red heat.

Tungsten is the metal from which all lamp filaments are made and was the first metal to be used for the filaments of valves. Although it has now been displaced by nickel coated with special compound (*see* below), it is still used in some transmitting valves and for connections through the glass of high-power valves.

Valve Filaments

The heart of the valve is the filament, which is usually of nickel wire coated evenly with a compound of barium and other metals which provide the electron emission when heated to dull red. Indirectly heated valves for mains sets have the emitter in the form of a thin nickel cylinder or hollow rectangle coated on the outside in the centre of which is a separate heater made of tungsten and insulated from the nickel cylinder (Fig. 30).

The coating of emitting compound is applied to filaments by passing them through a bath, but indirectly heated emitters, or cathodes, have the compound sprayed on. The greatest care has to be taken against impurities in the emitting mixture, or the valve is spoilt, and frequent samples are made up and tested before a fresh batch of filaments is used.

In modern valves several grids are the rule rather than the excep-
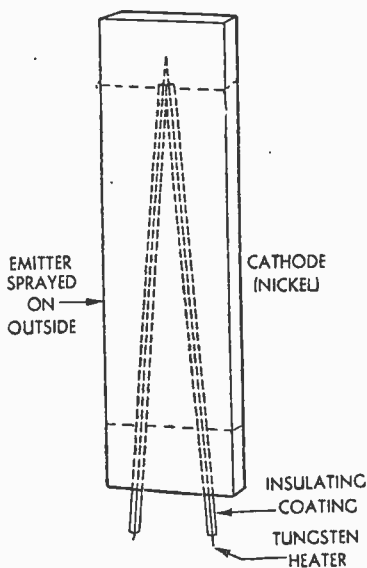
Fig. 30. Indirectly-heated mains valves employ a tubular cathode heated by an insulated tungsten filament.

such as screening plates, tags and clips.

In the preparation of all the metal components for assembly into the finished "mount", as the electrode structure is called, the utmost cleanliness is essential, and all the parts are treated in a furnace under vacuum to remove dirt from the surface and air from the inner pores of the metal.

The cleaned electrodes are assembled between mica spacing pieces, as shown in Fig. 33. The use of mica for spacing and aligning the electrodes is one of the most important improvements which have been made in valve construction over the past few years, as with its aid it is possible to mount the electrodes to an accuracy of a few thousandths of an inch, and thus maintain uniformity of characteristic, besides ensuring rigidity of the mounting under shock or vibration.

In larger and more robust types glass spacers may be used and in the latest ceramic type supports are sometimes used.

The "Pinch"

The electrodes are finally mounted on wires which are sealed into a glass "pinch" which is formed from a short length of glass tubing melted and pressed into shape round the supporting wires. The junction of the glass and metal must be vacuum tight, and for the purpose of ensuring this a special alloy is used at the point where the connecting wire passes through the glass.

tion, and these are wound in a continuous length on a lathe, the wire being welded to the support wires at each point (Fig. 31).

After winding, the grids are checked for accuracy of dimensions—a difference of less than a tenth of a millimetre will make a considerable difference to the characteristics of a valve—and are then cut up and stored ready for issue to the assembly benches.

Anodes (Fig. 32), are stamped out of previously cleaned nickel sheet by automatic presses, together with any smaller parts which are used in the assembly of the whole electrode structure,

Fig. 31. Valve grids are wound in continuous lengths on a lathe, the wire being spot welded to the two support wires at each turn.
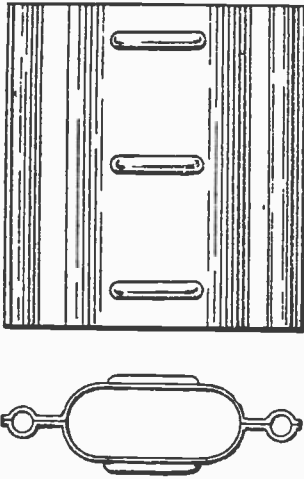
Fig. 32. Side and plan views of a typical anode. Metal parts such as this are stamped out of nickel sheet by automatic presses.

The finished mount is sealed into a glass bulb on a rotating head machine. The bulb is held in a cradle in the correct position for the stem, and a series of blowpipe flames play on it as it rotates in the cradle. As the glass softens it is drawn downwards by its own weight and inwards to form the seal at the flange of the pinch. The scrap glass which is left after the seal has been completed is collected and used again in the manufacture of the bulbs.

While the larger type of bulb are blown by hand in a mould, the receiving valve bulbs are machine blown automatically, a dab of molten glass being picked up by a hollow tube and placed in a hollow mould of the shape of the finished bulb. At the right moment an air blast is directed into the tube and the glass blob is expanded till it accurately fits the interior of the mould.

Originally this wire was of platinum (and still is in some transmitting valves), but a less expensive substitute is now used in the form of a composite wire of copper and steel with a coating of borax to make it "stick" to the glass. For heavy-current leads tungsten is used, and copper seals have been developed which form a direct joint with the glass, but these are mainly found in water-cooled valves.

In the neck of the pinch is sealed a small glass tube (the "exhaust tube"), through which the air is sucked when the valve is placed in position on the vacuum pump.

When the bulb is blown, the air supply is automatically cut off and the mould opens to release
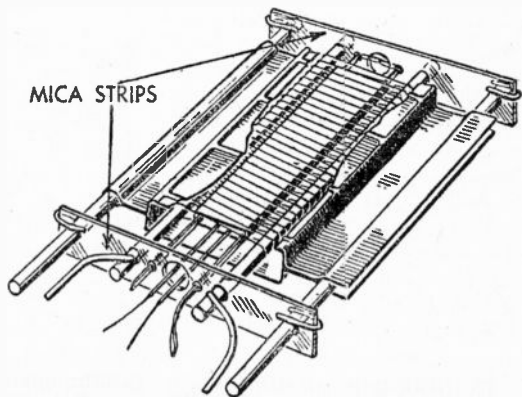
MICA STRIPS

Fig. 33. View of an assembly showing how the electrodes are mounted between mica strips which provide correct spacing and the necessary insulation. Frequently the micas are circular and fit into the glass bulb.

the finished red-hot bulb and allow it to pass to the annealing oven.

The annealing of the glass at various stages in the manufacture of the valve is of the greatest importance, as glass which has been allowed to cool too quickly is in a state of strain which may lead to cracking at a later stage or set up minute air leaks during life.

In recent years various types of valves have been produced using metal envelopes instead of glass. Greater robustness, better heat dissipation and improved screening are among the advantages of these (Fig. 34).

After the stem has been sealed into the bulb, the valve passes to the exhaust pumps, whose work is to remove all traces of air from the bulb. A simple form of pump which is used in roughly exhausting the bulb is of the piston type, which sucks air out at each stroke of the piston. The degree of vacuum produced is, however, insufficient for valves, and this form of pump is used as a "backing" for other types which are capable of reaching a higher degree of exhaust.

One of the best forms of high-vacuum pump is the so-called "condensation" type, which has no rotating parts, but depends for its action on the condensation of a jet of mercury vapour which passes through a narrow opening and carries the air with it. The complete arrangement of the pumping system is shown in Fig. 35.

Between the condensation pump and the glass tube on which the valve is mounted for pumping is a trap, which is cooled by being immersed in liquid air, and which prevents any vapour from the
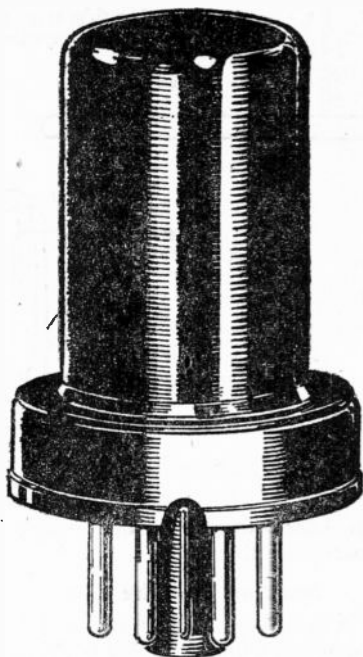
Fig. 34. An American "metal" valve with octal (eight-pin) base and special spigot which co-operates with locating dowel in the valveholder. The metal envelope dissipates the heat effectively and means a cooler electrode assembly.

pump finding its way back into the valve.

Following the vapour pump is an oil pump, which is capable of a higher suction than the piston type, and which is in turn coupled to the piston pump.

The final cleaning-up of gas inside the bulb is done by chemical-physical means by an agent termed a "getter". This is a small piece of magnesium or barium metal which is heated electrically after the valve has been exhausted, and which serves to "mop up" the remaining gas or air molecules in the bulb. The deposition of the getter on the sides of the bulb
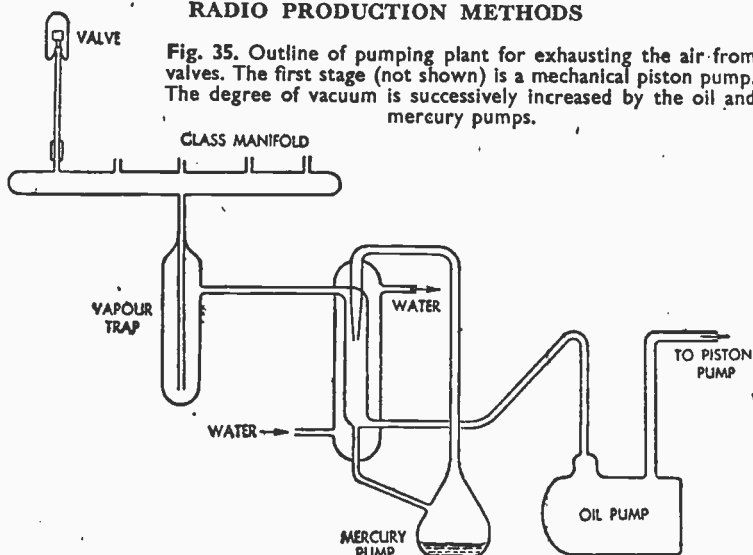
Fig. 35. Outline of pumping plant for exhausting the air from valves. The first stage (not shown) is a mechanical piston pump. The degree of vacuum is successively increased by the oil and mercury pumps.

gives the valve its familiar silvery coating on the inside.

Sucking Out the Gas

A very important process which is applied while the valve is being exhausted is the heating of the metal electrodes to drive out any gas which has been absorbed by the metal. This is done by surrounding the bulb with a coil which forms part of a high-power oscillatory circuit.

The valve is now practically completed except for branding and testing. Every valve which leaves the factory undergoes a series of tests which are designed to show up any weak points in the manufacture, and which ensure that it conforms to the published data within reasonable limits.

Before testing, however, the filament is "aged" to develop its full emission by running the valve for some hours on the racks with a definite value of filament and anode voltage.

In the test-room a certain pro-portion of each day's production is taken for life test and run continuously for several thousand hours under the conditions it would encounter in actual use. A record is kept of the batch number and the number of hours effective life, and the batches are not released for sale unless the test samples are satisfactory. A certain number of valves are also checked under operating conditions in the receivers in which they are intended to work, and from their performance in this test a great deal of useful information can be obtained for improvement in the design of the circuit or in the valve itself.

In this chapter we have studied the methods by which receivers, components, condensers and valves are manufactured. Further details of the actual nature of these products and the way they should be used and tested outside the factory are explained in other chapters. The working principles of condensers and valves in particular will be found in Chapter 17.

FOUNDATIONS OF RADIO

NATURE OF ELECTRICITY. ENERGY AND FORCE. ELECTRICAL CHARGES.
PROPERTIES OF THE ELECTRON. STATIC ELECTRICITY. CONDUCTORS. OHM'S
LAW. MAGNETISM AND AC. PRINCIPLE OF INDUCTION. INDUCTANCE AND
CAPACITY. TRANSFORMERS. CONDENSERS. IMPEDANCE. RESONANCE. THE
VALVE. HIGH-TENSION AND LOW TENSION. POWER FOR THE LOUDSPEAKER.

BESIDES providing a fascinating insight into the nature of the world we live in, even a slight acquaintance with the theory of radio is of great practical assistance in most radio jobs, particularly those, such as testing and repairing, in which a variety of problems is encountered.

To most people radio seems hard to understand because electricity is invisible. Mechanical devices, they feel, are easier to comprehend because one can see what is happening. They forget that the force driving a machine is as invisible as electricity. They do not realise that electricity can be thought of as a flow of units, "electrons", which behave in quite a commonsense way.

Electricity is subject to the same laws of energy, force, work and power as mechanics. It has its own forms of friction, inertia and springiness.

Form of Energy

Every machine, from the universe itself down to a pocket flashlamp, is driven by "energy". Energy is something that cannot be created or destroyed, but which only changes its form.

For example, energy released by burning coal may be changed to heat energy in the form of steam, then into mechanical energy in a turbine, and hence into electrical energy in a generator. This electrical energy may flow into the mains, and so be converted into heat, light and sound (radio programmes) in the homes of consumers (Fig. 1).

Force: Work: Power

Since electricity is a means of conveying energy, it is as well to get clear ideas of what is meant by the familiar words "force", "work", and "power".

Energy is not used (changed in form) unless it moves its point of application. As long as the thing to which it is applied remains stationary, the energy provides a "force". When the something moves, the force does "work". "Power" is the *rate* of doing work.

As an illustration, if a man holds a rope and supports 100 lb. of bricks, as in Fig. 2, he provides a "force". It is only when he hauls them up that he applies *force through a distance* and does work. The higher he hauls the bricks the more work he does. Multiplying weight by vertical distance gives us a measure of work in "foot-pounds".

The man may take either, say, one minute or ten to lift the bricks
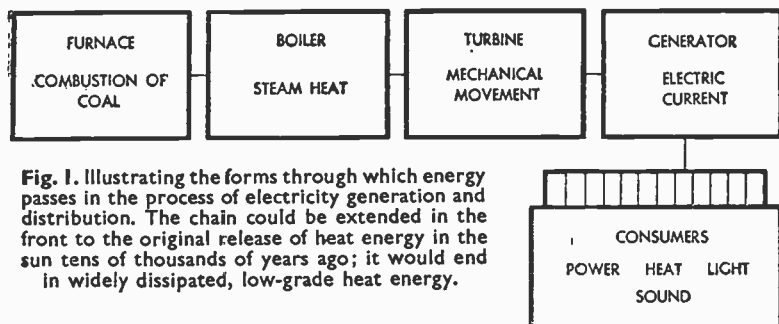
Fig. 1. Illustrating the forms through which energy passes in the process of electricity generation and distribution. The chain could be extended in the front to the original release of heat energy in the sun tens of thousands of years ago; it would end in widely dissipated, low-grade heat energy.

50 ft. In both cases the work done is 100 × 50 = 5000 ft.-lb. He will need more "power" to raise them in the shorter time. The unit of mechanical power, "horse-power", is 33,000 ft.-lb. per minute, so, in the example, our man may work at 5,000/33,000 = 0·15 h.p. or

$$\frac{5,000}{33,000 \times 10} = 0\cdot015 \text{ h.p.}$$

Electro-motive Force

Returning to electricity, we can now appreciate that when energy is applied to an electric circuit it creates a force. For obvious reasons we call this an "Electro-motive Force" (EMF). It is often termed "potential", and is measured in "volts".

When an EMF does work the something it moves is what we term "current".

In the ultimate sense, we still do not know what current is. All the same, we have learnt a good deal about its nature and properties. We know it consists of a movement of "electrons". The electron is something the imagination can play with, and once we understand its characteristics, it becomes easier to reason out what happens in radio components.

Were you able to take a fragment of this page and keep dividing it until you had the smallest particle still having the properties of paper (no microscope would show it), you would have a "molecule". On further dividing you would get a number of "atoms" of carbon, hydrogen and other elements. If you could see these atoms they would, perhaps, look rather like solar systems, each con-
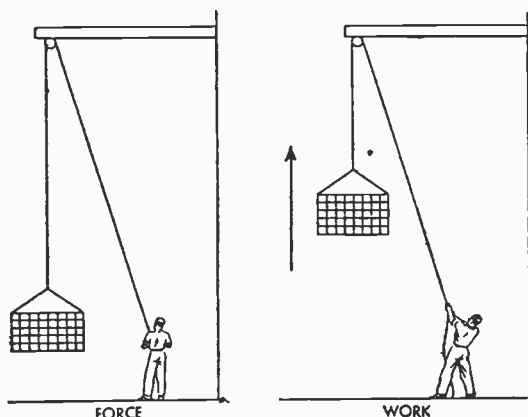
Fig. 2. Work is done when force is applied through a distance. The man on the right uses energy; the man merely supporting the load (left) does not.

sisting of a central nucleus, round which, at relatively vast distances, planet-like "electrons" would be revolving.

The Electron

The electrons are unit (indivisible) "charges" or quantities, of negative electricity. They are unimaginably small—the weight of one is about decimal point twenty-seven noughts nine of a gramme. The nucleus appears to consist of two types of unit: a "neutron" particle with zero charge and a "proton" or positive charge which is normally sufficient to balance all the electrons, so that the atom, as a whole, is electrically neutral.

Positive and negative charges attract each other, and like charges—*i.e.*, negative-negative or positive-positive—repel each other. The region round each charge in which this force of attraction or repulsion is effective is termed an "electric field". We map out fields by tracing the paths which would be taken by free electric charges. These tracks (*see* Fig. 3) are called "lines of force". The intensity of a field is indicated by saying it has so many lines of force per square centimetre.

The electron has one further important property. As it *moves* it acquires a different kind of field—a "magnetic field". This also can be plotted, but, instead of
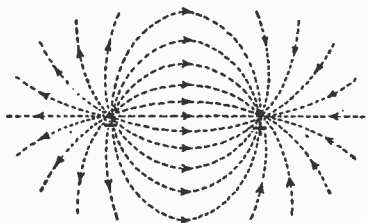
Fig. 3. Lines of force in the region of opposite electric charges.
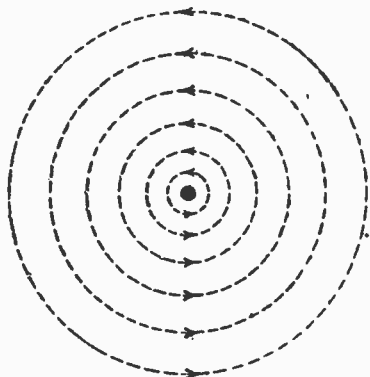
Fig. 4. Magnetic lines of force round a conductor (shown by the black spot) carrying an electric current.

tracing the paths of negative charges, we indicate the tracks of North magnetic poles. A magnetic field round a movement of electrons is shown in Fig. 4.

Electrons are not permanently attached to their atoms. In any large mass of molecules and atoms there is a wandering population of "free" electrons, some just joining atoms, some just leaving and others enjoying temporary freedom. With some substances, "conductors", electrons break away quite readily. In others, "insulators", the movement of electrons is strictly limited.

Generating Electricity

In various ways we can apply energy so as to make "free" electrons part from their atoms and flow in a definite direction. We can do it by:

1. Friction.—*i.e.*, by physical force we make the fields of two materials react on each other;
2. Mixing substances so that they react on each other chemically, as in a battery, the energy

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being abstracted from the materials themselves, and

3. Using mechanical force to make powerful magnetic fields move relative to each other (as in the most important source of current, the generator).

When electrons and atoms are forcibly separated, the former collectively make a negative charge, and the electron-deficient atoms constitute a positive charge. The electric force of attraction between these opposite charges is the Electro-motive Force to which we have already referred.

Static Charges

Charges are set up wherever friction occurs. The quantities are usually very small, even though the potential may be great (Fig. 5). More often than not the charges arise on conductors and quickly leak away; it is only on good insulators, where electron movement is very limited, that the charges have to stay put, and so become detectable. For this reason they are called "static" charges, and the force between them is often called "electro-static force".

If an insulated body, A in Fig. 6, is given a charge, and another insulated body, B, brought up, the field of A will repel electrons from the nearer end of B, and so "induce" two charges as shown.

If we connect B to the earth through a conductor, as in Fig. 7 a, the repelled electrons will travel down to earth. As the earth is so vast, however, they will not make it
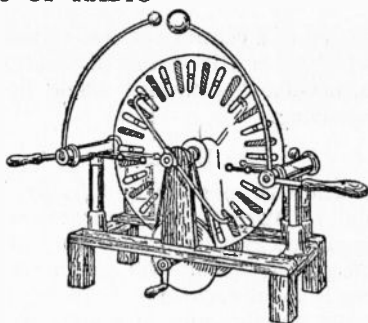
Fig. 5. This simple device, the Whimshurst machine, generates electro-static charges of sufficient EMF to spark across a gap of more than an inch.

negative. Similarly, if the charges are all of the opposite "sign" as in Fig. 7 b, the earth will not be made positive. This is why earth is regarded as zero potential and why any large conductor which can absorb electro-static charges without acquiring a noticeable charge is termed an "earth".

To make electric forces safe for everyday jobs, we use devices which provide a sustained movement of considerable quantities of electrons at low potentials. We have such devices in the primary battery (see Chapter 10) and the generator (described later).

If we have two charges created by either of these devices at each end of a conductor, as in Fig. 8, the potential between them will
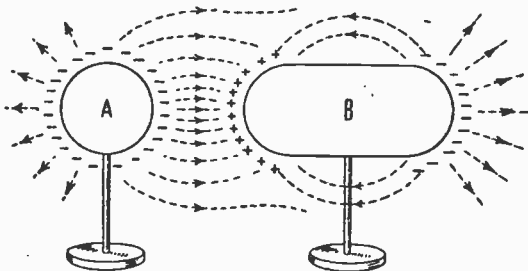
Fig. 6. How a charged body, A, induces two equal and opposite charges in a nearby object B.

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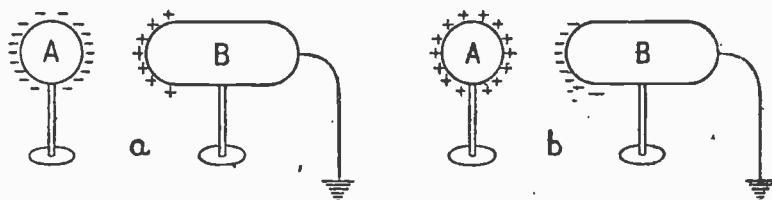
Fig. 7a and b. The earth can receive and return either positive or negative charges without any change of potential and is therefore accepted as zero potential.

make the electrons endeavour to flow to the positive.

Suppose we link them by a wire (conductor). The free electrons in the wire will be drawn in to meet the electron shortage at positive, and the surplus electrons at negative will in turn flow into the wire. If the EMF provides work, a continuous flow of electrons will result.

The Circuit

Work will be put into the "circuit"—as this roundabout path is termed—at the current source, and will be expended in the external circuit by the electrons during their journey.

Energy is taken from these electrons as they pass from atom to atom in the conductor. This opposition to current flow is termed "resistance", and is measured in "ohms". The energy expended in overcoming resistance appears as heat.

For a given substance the resistance increases with the length and decreases with an enlargement of the cross-section area (Fig. 9). For comparisons, we take the "specific resistance", which is the resistance of a centimetre cube.

Ohm's Law

A higher EMF will drive more current through a circuit of given resistance. Alternatively, by halving the resistance, we can enable a given EMF to drive twice as much current. This relationship of EMF, resistance and current, is expressed in Ohm's Law, which, since it enables us to find any one of these three quantities if the other two are known, is of the greatest practical importance.

It is written in any of three ways, according to which quantity is to be found:

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

BATTERY OR GENERATOR PRODUCING EMF

ELECTRONS FLOW ROUND "CIRCUIT"

FREE ELECTRONS SEPARATED FROM ATOMS HERE.

ENERGY USED HERE = ENERGY EXPENDED IN CIRCUIT
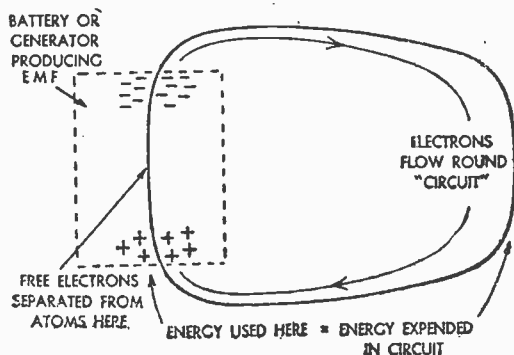
Fig. 8. A circuit is a conducting path linking the positive and negative of a current source.
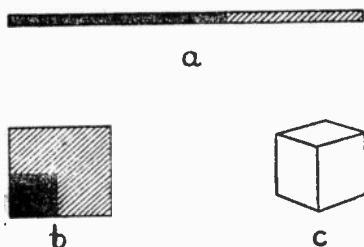
Fig. 9. Resistance is increased by increasing the length of a conductor *a* and reduced by enlarging the cross section *b*. For comparisons the resistance of a cm. cube is taken.

I stands for current, which is measured in "amperes". *E* is for EMF in volts and *R* for resistance in ohms. The quantities must be expressed in these units. For instance, 15 milliamps must be written as 0·015 or 0·5 megohm as 500,000.

Clearly, if we double the current a given EMF is drawing, twice as much work must be put into the circuit. In other words, we can express power by multiplying current and EMF. The unit of electrical power is the watt, and 746 watts equal one horsepower:

$$P \text{ (watts)} = E \text{ (volts)} \times I \text{ (amperes)}$$

Substituting *E* and *I* in turn by Ohm's Law, we also get:

$$P = I^2 R. \quad P = E^2/R.$$
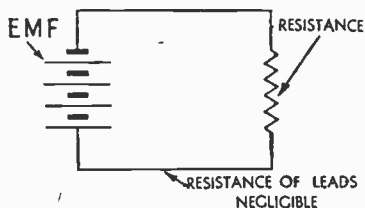
Fig. 10. Although every conductor possesses resistance, the resistance of a circuit is indicated by a symbol joined to the current-source by straight lines.

We usually require the power to be available at some particular device in a circuit. Consequently, we arrange the resistance and, perhaps, the EMF, at suitable values to give the watts required, and then, to minimise waste of power between the source and the device, make the resistance of the conductors as low as possible in relation to the resistance of the power device. If the resistance of the conductors is negligible, we can represent a circuit containing a resistive component as shown in Fig. 10.

Series and Parallel

When a circuit contains several resistances they may be connected in "series", as in Fig. 11 *a*, in "parallel", as in 11 *b*, or series-parallel, as in 11 *c*.

The series arrangement increases the opposition to current-flow:

R (total resistance)

$$= R_1 + R_2 + R_3, \text{ etc.}$$

With parallelled resistances, however, the current divides into several channels, and the smaller current in each finds it easier to pass. Where all the resistances are of the same value, the effective opposition is the resistance of one divided by the number of paths. For example, four 20 ohm resistances together present $20/4 = 5$ ohms resistance.

Where parallel resistances are of different values we must remember that the opposition of each is in proportion to the total —*i.e.*:

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \text{ etc.}$$

For example, the resistance of Fig. 11 *b* is

$$\frac{1}{R} = \frac{1}{10} + \frac{1}{5} + \frac{1}{30}$$

$$= \frac{3 + 6 + 1}{30} = \frac{10}{30} = \frac{1}{3}$$

$$\frac{1}{R} = \frac{1}{3}$$

$$\frac{R}{1} = \frac{3}{1}$$

$$R = 3$$

When a parallel path is introduced (usually by accident) of such low resistance that the other arm is virtually deprived of all current, it is said that a "short circuit" has occurred.

Some readers may have understood that the conventional direction of current flow is from positive to negative, and that positive is "live" (or dangerous) while negative is earth or neutral. The explanation above of electron flow will have surprised them. The fact is that electrical pioneers had no evidence of the actual direction of current flow and did not particularly care—all that mattered was that they should have a standard means of reference to avoid confusion in discussion and to form the basis of practical work.

Points at positive potential, and from which, by their hypothesis, current issues, they called "anodes". Negative points, by which current entered, they termed "cathodes". This led to the idea that negative was at lower potential or was the inert partner. When a circuit was to be earthed, it was usually the negative side which was selected. The term negative came to be considered almost synonymous with earth.
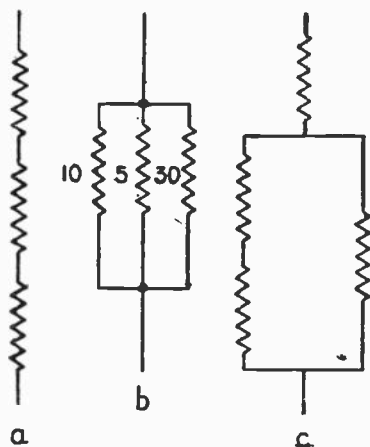
Fig. 11. Diagram showing (*a*) series, (*b*) parallel, and (*c*) series–parallel methods of connecting resistances or other components.

Now we know that the electrons flow from negative to positive (from cathode to anode), that both are equally "live" and that either can be earthed.

As practical technique was built up on the old positive-to-negative theory, it is often more convenient to continue to think of current as flowing in this way. On the other hand, valve circuits are often difficult to understand unless one thinks in terms of electrons. Most radio engineers switch mentally from "electron" to "conventional" ideas, according to whichever is most convenient at any moment.

Alternating Current

So far we have considered only "direct current" (DC)—that is, a flow of electrons in one direction in a circuit. A second type "alternating current"—in which the electrons oscillate backwards and forwards, now awaits our attention. To approach its study properly it is advisable to return

for a moment to the electron and its magnetic effects.

As we have said, an electron creates a magnetic field when it moves. Let us see how this property explains—as, obviously, it must—what a magnet is and why it is that only certain metals (those known as ferrous—*i.e.*, iron and steel and some of their alloys) can be magnetised.

Electrons spin on their axes as well as rotate round the proton. Both motions set up magnetic fields, but the one produced by the spin is most effective.

The directions of spin of the electrons in an atom may be such that their fields cancel. In the iron atom, however (Fig. 12), an odd number of electrons spin the same way and give the atom a predominate field—*i.e.*, it acts as a

magnet with North and South poles.

When atoms are combined in molecules the fields may again either cancel out or, as in the ferrous metals, have a preponderating field. In ferrous (magnetic) bodies the molecules form themselves into groups or "domains", which are equivalent to minute magnets of sub-microscopic size.

In a material which is magnetic but not magnetised, the domains are arranged so that their fields have short, internal paths (Fig. 13 *a*). When the material is magnetised by the application of a powerful field from outside, the domains are pulled into line (Fig. 13 *b*), with the result that two end poles are created. These produce an external field (Fig. 13 *c*).

Soft iron is distinguished by the fact that the domains quickly twist out of the in-line arrangement once the outside field is removed. Steel and special alloys of it, in which the molecules are closer packed, are harder to magnetise, but can be magnetised very strongly and remain in this condition for years.

When iron is placed in a field, and after the domains, as we have explained, are forced in-line, they co-operate with the field, with the result that it becomes intense in the
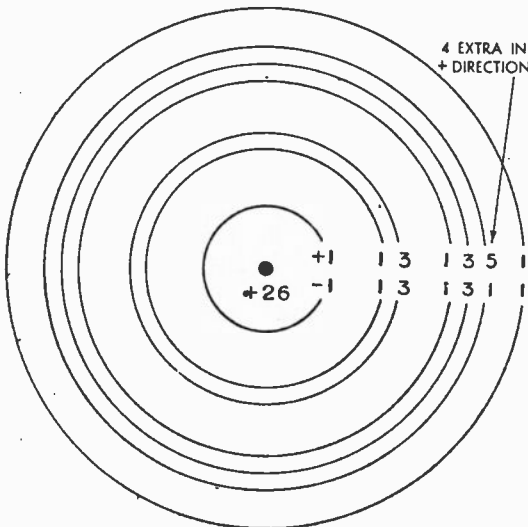
Fig. 12. Diagrammatic representation of an iron atom showing the orbits of electron groups with the numbers in each group. The proton is equal and opposite in charge to the 26 electrons. The plus and minus signs near the electron numbers indicate the direction of spin and not the polarity of the electric charge.
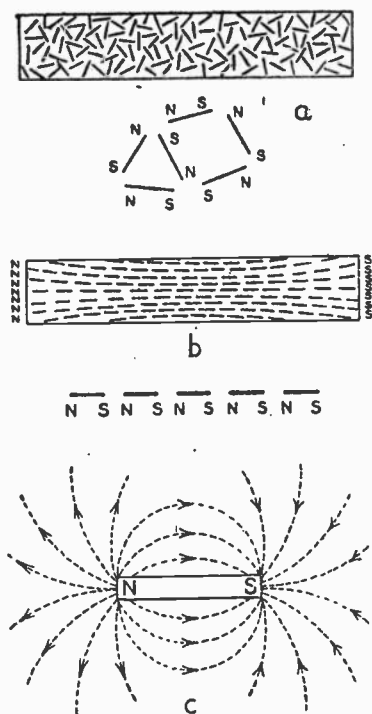
Fig. 13. In non-magnetised ferrous metals the domains arrange themselves, *a*, for short internal magnetic paths. When magnetised, *b*, the domains are forced into line so producing an external field as shown in *c*.

If a movement of current sets up a moving field, it is reasonable to expect the converse to happen. Another simple experiment shows that indeed it does. When a coil of wire is connected to a current meter, as in Fig. 16*a*, a pulse of current is shown every time a magnet is pushed in and out— *i.e.*, a field is made to "cut" the conductors. Faraday's Law states: When a conductor cuts the lines of force of a magnetic field, an EMF is induced in the conductor which is proportional to the rate of cutting.

Induced Current

This principal of "induction" is the basis of the generator in which a conductor is made to revolve in a magnetic field. The principle is illustrated in Fig. 17. At points *A* and *B* the conductor is moving with the field and no EMF is produced. As it turns towards *C* and *D* it cuts the field at an increasingly sharper angle and the "rate of cutting" grows until it reaches maximum at *C* and *D*.

If we draw a graph of the EMF during half a turn from *A* to *B*,

iron and weaker outside (Fig. 14).

As electron movement sets up a magnetic field, a wire carrying a current must exhibit magnetic effects. This is the case, as is shown by a simple experiment (Fig. 15). If a wire is placed near a small pivoted magnet (a compass), the needle will be deflected when a current is made to flow. The stronger the current, the farther the field travels outward, as can be proved by moving the compass farther back. When the current stops the magnetic field at once collapses inward to the wire.

Fig. 14. How a magnetic field concentrates in the region of a bar of soft iron.

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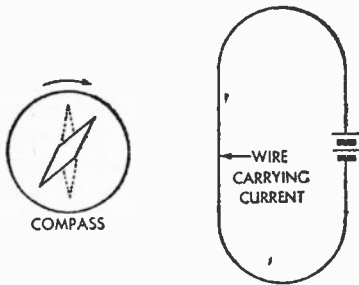
Fig. 15a. A compass is deflected when a current is passed through a wire.
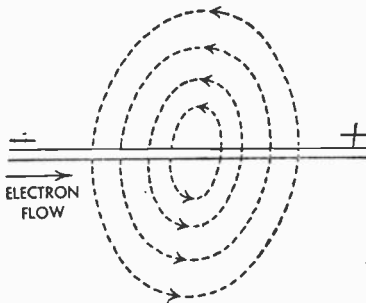
Fig. 15b. Direction of the magnetic field round a current.

we get a shape like Fig. 18. During the second half of the revolution each side of the loop cuts the field in the reverse direction, and consequently the polarity of the EMF is reversed. For a complete "cycle", therefore, we get a "waveform" as in Fig. 19. This shape is known as a "sine wave" because the EMF at any position of the conductor can be calculated by using the trigonometrical "sine" ratio.

If we connect a circuit to the rotating conductor (in practice a large coil wound on an "armature") by means of the "slip-rings" (Fig. 20) the EMF will drive an "alternating current". In a circuit containing resistance only, the current at any instant will be determined by Ohm's Law and the curve of Fig. 19 will represent it. Values above the line indicate current flow in one direction, and values below the line represent current flowing in the reverse direction.

One cycle, it will be noted, includes two peaks and extends, say, from A to E (Fig. 19), C to F, or between any other two points this distance apart. The number of cycles per second is the "frequency" or "periodicity".

Standard mains frequency in Britain is 50 cps., but 25 and 100 cps. are sometimes found. In radio circuits frequencies of millions of cycles per second are employed.

Direct current is obtained from a generator by using a "commutator" instead of slip-rings. This is, in effect, a reversing switch, and the principle is shown in Fig. 21, from which it will be seen that each "brush" is always connected to a conductor cutting the field in the same direction. A number of armature windings are employed,
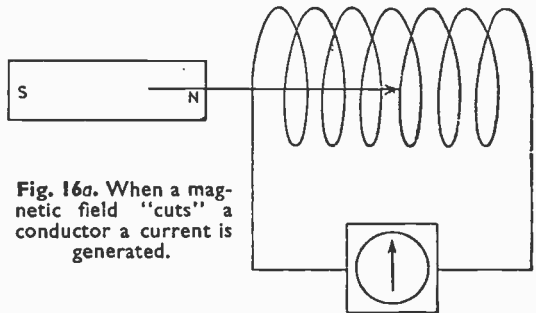
Fig. 16a. When a magnetic field "cuts" a conductor a current is generated.

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Fig. 16b. A simple means of recalling how the directions of field, motion and current are related.
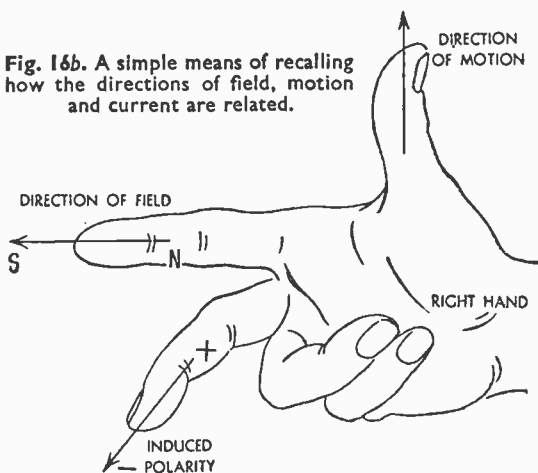
so that the current pulses overlap giving DC with a slight "ripple" (Fig. 22).

AC generators usually have three windings connected as in Fig. 23 *a* or *b*, and the result is a three-phase supply, as in Fig. 24. A single phase supply is available from any two of the three mains.

If we wish to find the power in an AC circuit we cannot multiply the "peak" voltage by the "peak" current, because these values exist only momentarily twice every cycle. On the other hand, *some* value of AC must correspond to a given value of DC (remember it is the *movement* of electrons which conveys the power and not their *direction*).

The value of AC comparable to DC is known as the "root mean square" (RMS) value. The peak value is $\sqrt{2}$ times greater. The peak voltage of 200 volt AC mains, for instance, is 200 × $\sqrt{2} = 283$ volts. Unless otherwise stated, AC voltages and currents are generally in RMS, not peak, values.

In an AC circuit containing resistance only, voltage and current are in phase and the power is given, as in a DC circuit, by taking EI (in RMS values). As we shall see, however, where an AC circuit contains inductance and/or capacity the voltage and current are generally out of phase and, therefore, although the rating is sometimes stated in volt-amperes, the calculation of the actual watts must take the difference of phase, or "phase angle", into account.

The ratio of watts to volt-amperes is known as the "power factor" of the circuit and is given by cos ϕ where ϕ is the phase difference of current and voltage. The power in a single-phase AC circuit is, therefore, EI cos ϕ.

The magnetic field round a
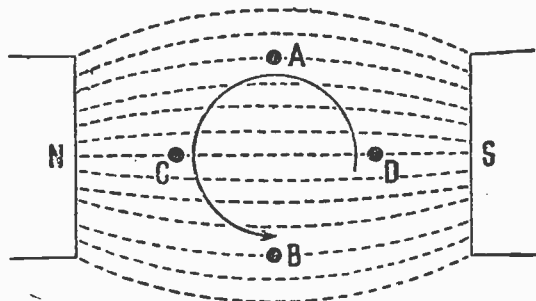
Fig. 17. A, B, C and D represent four positions of a conductor rotating in a magnetic field.
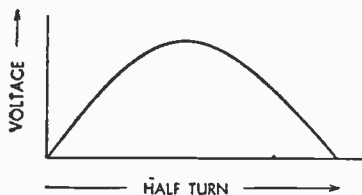
Fig. 18. During half a turn the voltage in the conductor varies as shown.

current can be concentrated by winding the conductor into a coil or "solenoid". As shown in Fig. 25, the field round a simple coil corresponds exactly to that of a bar magnet (Fig. 13(c)). By introducing a soft iron core we get an even stronger field (Fig. 26). This is called an "electro-magnet".

Inductance

The field from each turn in a coil cuts adjoining turns and induces an EMF in them whenever the current varies. A coil, therefore, has "self-induction".

The interesting thing is that when the current is increasing, the outward cutting of the field induces a "back EMF" which opposes and retards the growth of current. On the other hand, when the current decays, the field collapses inward and produces a "forward EMF" which tends to sustain the flow.

In overcoming the back EMF, the applied voltage does extra work. This work is returned to the circuit, however, when the field collapses. The field, then, is a form of energy.

The current-delaying property of a coil is termed "inductance". The unit is the "henry" which is possessed by a coil when one volt requires one second to build up one ampere. Inductance is the electrical equivalent of inertia.

Now what happens when we apply AC to a coil? As a preliminary, let us remind ourselves that when either AC or DC is applied to a *resistance* the current at any instant is determined by Ohm's Law. The two are always in step or in "phase", as we say (Fig. 27).

When we represent the current driven in an inductance by a DC voltage we get a diagram like Fig. 28. This diagram contains the clue to what happens when AC is applied to a coil. Clearly, if the frequency is sufficiently high the voltage will have begun to decrease before the top of the current curve has been reached. The value of current which would be permitted to flow by the resistance is not attained. The greater the frequency which is produced the less chance the current has to grow.
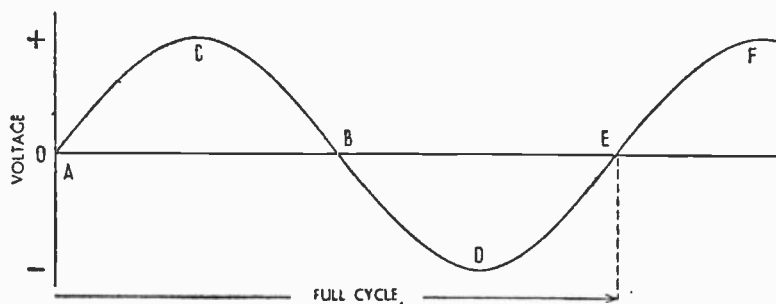
Fig. 19. By indicating the EMF in the reverse direction below the horizontal line we get the sine wave which is characteristic of alternating currents.
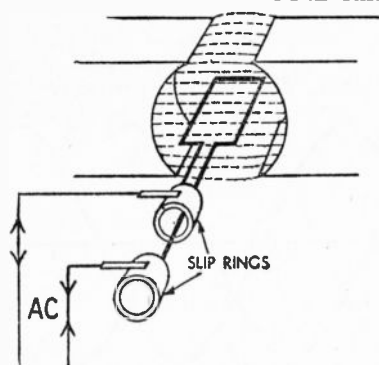
Fig. 20. Connecting to a rotating coil by means of slip-rings enables an alternating EMF to be applied to an external circuit.
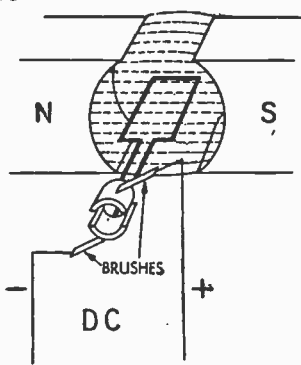
Fig. 21. A commutator connection gives EMF pulses in the same direction—that is, direct current.

A coil, then, limits the current an AC voltage can drive, the extent of limitation increasing with both inductance and frequency. This property corresponds to resistance in that it opposes current, but is not the same thing since no power is lost—the energy put into the field in one part of a cycle is returned in the next part.

For this reason, although the property is measured in ohms, it is called "reactance".

The reactance of a coil is $2\pi fL$ ohms, where π is $3\cdot1416$, f is the frequency in cycles per second and L the inductance in henries. Incidentally, the quantity $2\pi f$ occurs frequently in AC formulae, and is often replaced by the symbol ω, and is known as the "angular velocity".

As the current is delayed in building up, and also receives an extra boost when the field collapses, it does not remain in phase with the voltage, but lags behind,

as shown in Fig. 29. In an ideal resistance-less inductance the current is out of phase with the voltage by a quarter of a cycle, and is said to "lag by 90 degrees".
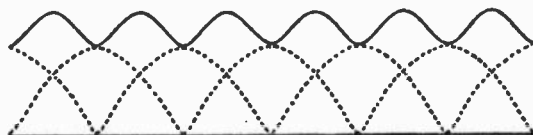
Fig. 22. DC generators give overlapping uni-directional pulses so that the output is a sustained flow plus a slight amount of "ripple".

If a second coil of wire is placed close to a coil carrying a varying current, it will have a current induced in it. The induced current
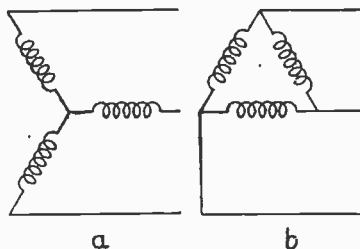
Fig. 23. Two ways of connecting the windings of an AC generator: a the star and b the delta.

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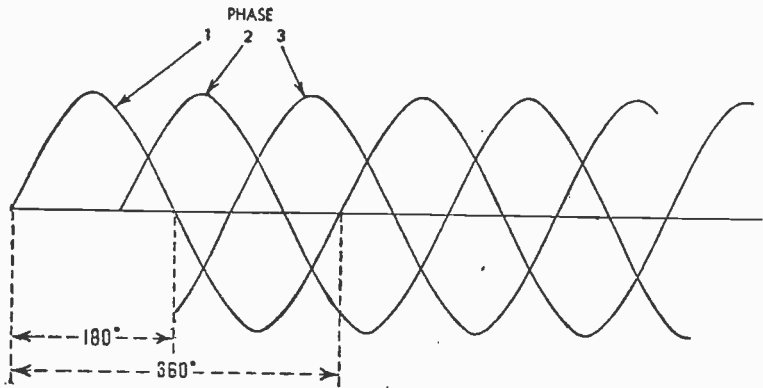
Fig. 24. In a three-phase AC system there is 120° between phases.

will vary in strength with the field fluctuations, and its EMF will be in proportion to the number of turns cut by the field.

By having more turns on the "secondary" winding than on the "primary" we can get an actual increase of voltage. The current available, however, will depend on the efficiency with which the power is transmitted through the magnetic field and on the losses in resistance, and will always, of course, be such that the power (EI cos ϕ) in the secondary is less than the power in the primary.

This arrangement (Fig. 30) is called a "transformer", and is used for both high- and low-fre-quency currents. The former type, to reduce losses in the shape of in-duced "eddy" currents in the core, usually have either no core at all or ones made of iron dust embed-ded in wax.

The transformation ratio, T, of a transformer is:

$$\frac{\text{Number of secondary turns}}{\text{Number of primary turns}}.$$

Any transformer is reversible, the "primary" being the input side. Output EMF is given by primary EMF $\times T$.

DC cannot be transformed, since a change of field is obtained only on starting and stopping the current. This is why AC is used
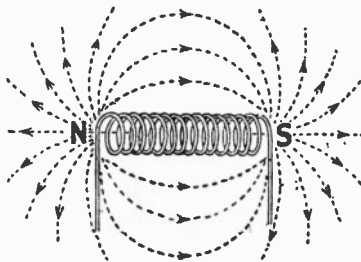
Fig. 25. A simple coil carrying a current sets up a magnetic field similar to that set up in a bar magnet.
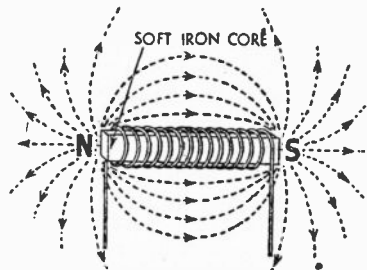
Fig. 26. The addition of a soft-iron core gives a solenoid a more localised and therefore more intense field.

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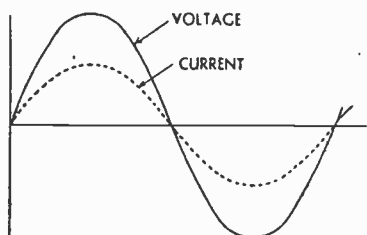
Fig. 27. Diagram representing "in phase" voltage and current.

Fig. 28. Curve illustrating the growth of current during time when a steady voltage is applied to an inductance.

almost universally now for electricity mains, as the voltage can be stepped up for efficiency in transmission (the higher the voltage the smaller the current and the less the loss in resistance) and stepped down for safety in use.

A uni-directional current which varies in strength is equivalent to an average DC with AC superimposed. When such a current is applied to a transformer (as in the anode circuit of a valve) only the AC component appears in the secondary (Fig. 31) and the only effect of the DC is to set up a steady field.

If the latter is strong, the AC may not be able to produce a proportional increase of field, and distortion may result. A steady primary current, therefore, reduces the inductance and is harm-ful if it approaches "saturation" strength.

At one time transformers were widely used for LF coupling as a step-up of voltage. In order that small, highly efficient magnetic cores could be used, the transformers were often resistance–capacity connected, so that the anode current did not flow through the transformer winding. Now that sets have ample sensitivity, transformers are seldom used for LF coupling and are mainly used for providing the necessary operating voltages in AC mains receivers.

A condenser consists of two conducting plates separated by an insulator termed the "dielectric".
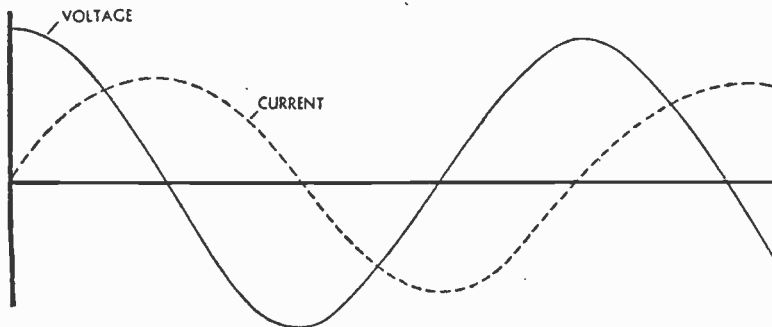
Fig. 29. In a pure inductance the current lags the voltage by 90 degrees.

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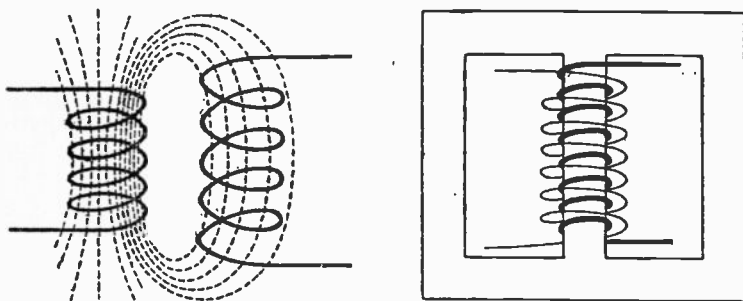
Fig. 30. How the magnetic field couples two windings and (*right*) diagram illustrating the practical basis of transformer design.

When a DC potential is applied, electrons flow on to the negative plate. Their electric field repels electrons in the dielectric, but, being of high-quality insulating material, this has sufficient internal force to prevent its electrons becoming "free". The flow of current is checked and the applied potential opposed by an equal and opposite "strain" in the dielectric. The action may be likened to the tension of a spring.

Charging the Condenser

During their initial movement the electrons in the dielectric dislodge electrons from the second plate of the condenser. These are attracted down to positive, leaving the second plate electron-deficient

—*i.e.*, positive. There are now two opposite charges on the plates, and the condenser is said to be charged (Fig. 32).

Capacity

The "capacity" of a condenser to hold a charge increases in proportion to the area of the plates. It is also fairly easy to see that it will be increased by reducing the thickness of the dielectric, as the electrons, opposed by a 'weaker "spring", can more easily dislodge electrons from the positive plate.

The unit of capacity is the "farad". In radio, capacities are generally stated in microfarads, *i.e.*, millionths of a farad.

It will have been noted that during the charging of a condenser
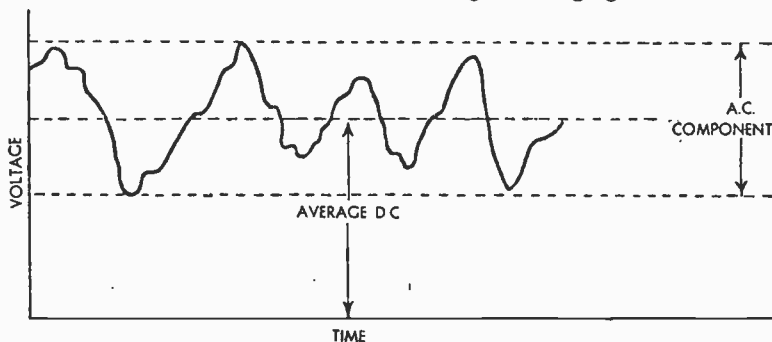
Fig. 31. Fluctuating DC corresponds to steady DC plus superimposed AC.
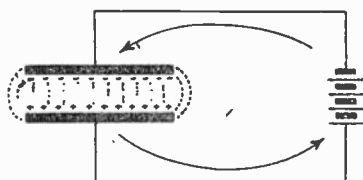
Fig. 32. While a condenser is charging electrons circulate in both arms of the circuit. Current stops when the "back EMF" of the condenser equals the EMF of the battery.

current flows round the whole circuit. It is only when charging is completed that the dielectric acts as a break in the circuit.

Evidently, from a DC point of view, we can think of a condenser as a store of electrical energy in the same way that a spring stores mechanical energy.

Capacitive Reactance

If AC is applied to a condenser it will be constantly charged in one direction, discharged, charged in the reverse direction, discharged and so on. Current will flow in the circuit continuously. The higher the frequency the larger will be the current (the bigger the movement of electrons in a given time).

The condenser will limit the current according to its capacity, but it will not absorb power, since energy stored in the electro-static field during charging will be given back during discharging. As with the coil, we measure the opposition of a condenser to AC in ohms, but term it "reactance".

The reactance of a condenser is

$$\frac{1}{2\pi fC} \text{ or } \frac{1}{\omega C}.$$

where C is the capacity in farads.

When a condenser is fully *charged* (and the voltage is at peak) there is no *current*. Maximum current occurs when the EMF is zero and the charging or discharging can occur unimpeded. Drawing the voltage and current curves, as in Fig. 33, we find that again they are 90° out of phase—but this time the current *leads* the voltage.

Inductances in series and parallel are calculated in the same way as resistances. With condensers, however, an increased value indicates lower opposition to current flow.

Capacities in parallel are added:

$$C = C_1 + C_2 + C_3, \text{ etc.}$$
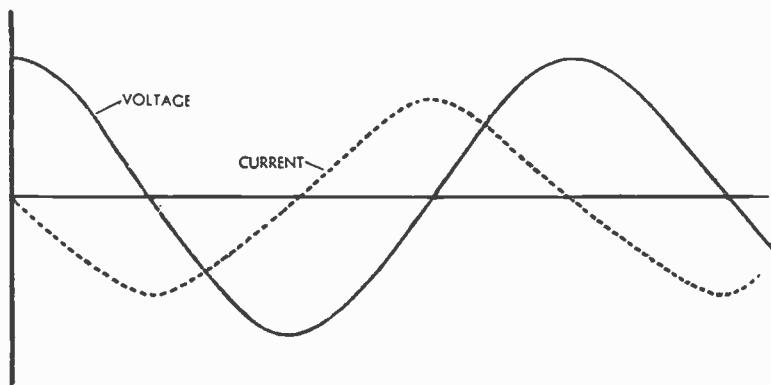
Fig. 33. In a pure capacity the current leads the voltage by a quarter of a cycle.
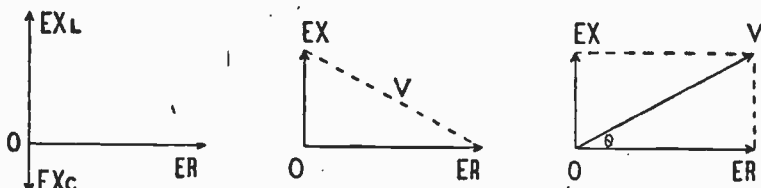
Vectors showing how voltages are added in a circuit containing impedance. **Fig. 34** (*left*). The inductive (EXL) and capacitive (EXC) voltages are 180° to each other and 90° to the resistive (ER). **Fig. 35** (*centre*). The sum of EX (the difference of EXL and EXC) and ER is V. **Fig. 36** (*right*). The phase angle (θ) between the applied voltage (V) and the current (which is in phase with ER) is obtained from the complete vector diagram.

The series arrangement increases the thickness of dielectric and so reduces the capacity:

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}, \text{ etc.}$$

The combined effect of resistance (R) and reactance (X) in a circuit is "impedance" (Z). Although both are measured in ohms, when in series they cannot be added arithmetically, because, due to the reactance, the applied voltage is out of phase with the current. They have to be added geometrically, and the method is indicated in Fig. 34, where the lines ("vectors") represent the strengths of and phase differences between the three voltages in a circuit containing resistance, inductive reactance and capacitive reactance.

The two latter are at 90° to the resistive component and 180° to each other. Subtracting the smaller reactive component from the larger, we get two sides of a right-angle triangle (Fig. 35). By geometry we know that the sum of the squares of these equals the square of the hypotenuse.

Remembering that each component of the voltage is equal to reactance (or resistance) times the current (Ohm's Law) we can write our formula as follows:

$$V^2 = R^2I^2 + \left(\omega L - \frac{1}{\omega C}\right)^2 I^2$$

$$V = I\sqrt{R^2 + \left(\omega L - \frac{L}{\omega C}\right)^2}.$$

But $Z = V/I$, where Z is the impedance.

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

Rearranging Fig. 35 as in Fig. 36, we can arrive at the actual phase angle θ between the total voltage and the current.

It can be shown that the impedance of R and X in parallel is:

$$Z = \frac{XR}{\sqrt{R^2 + X^2}}.$$

Resonant Frequency

The formulae above contain the secret of the "tuned circuit"— that simple device which makes it possible to transmit or to select any particular required transmission. As readers of earlier chapters will be aware, receivers are tuned to or brought into "resonance" with a transmission by means of a coil and condenser connected in parallel. Actually, as we shall see, if series connected, they resonate in the same way, but with different effect (Fig. 37).
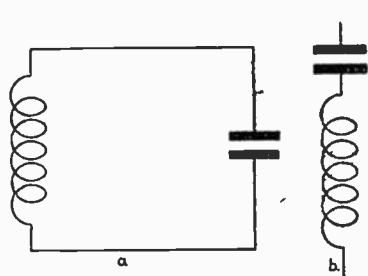
Fig. 37. Parallel, *a*, and series, *b*, tuned or "resonant" circuits.

Since the reactance of a coil increases with frequency and the reactance of a condenser decreases with frequency, it is obvious that at one frequency, and one only, the reactances of any coil and condenser will be equal. What does this imply?

The reactance of each is a measure of the electrical energy stored and returned by the magnetic field in one case and the electro-static in the other. We have only to remember that the current (or the voltage) between

the two are 180° out of phase (exactly half a cycle out) to realise that, at the one "natural frequency" at which the reactances are equal, the energy of the circuit can swing backwards and forwards, or "oscillate", between the two fields.

If a charged condenser discharges through a coil, the energy from the condenser will build up a field in the coil, which, in turn, will discharge into the condenser. An oscillatory current will flow at the natural frequency until the energy has all been dissipated in resistance and other losses.

On the other hand, if we apply a voltage of the right frequency, a circuit will respond or "resonate" by building up a large oscillatory current—very much as a child's swing, given small pushes at the right intervals, builds up a large oscillation.

We are helped to appreciate electrical resonance if we remember that inductive reactance corresponds to inertia (mass) and
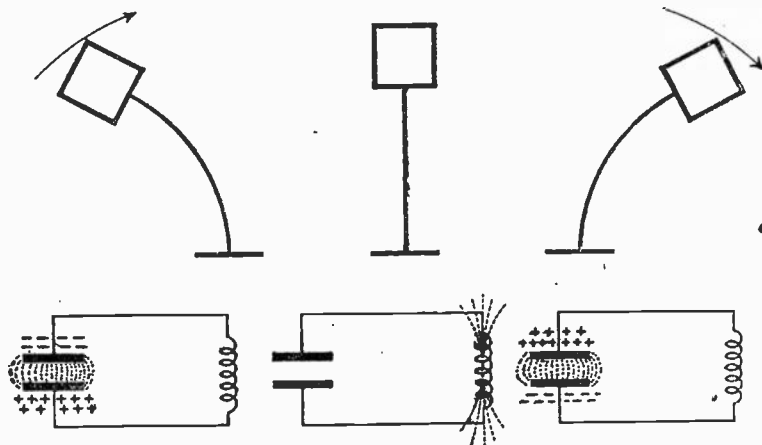
Fig. 38. Illustrating the analogy between a vibrating spring and an oscillating tuned circuit. Tension of the spring corresponds to charge in the condenser, and movement of the weight corresponds to the flow of current.

capacitive reactance to springiness. An oscillating circuit can be compared to a vibrating blade as follows (*see also* Fig. 38):

Blade	*Circuit*
(1) Pulled to one side.	(1) Condenser charged.
(2) Returning to centre.	(2) Condenser discharging.
(3) Maximum speed at centre and no strain.	(3) Maximum current and no voltage.
(4) Momentum carries onward against springiness.	(4) EMF of inductance drives current against back EMF of condenser.
(5) Strained in opposite direction.	(5) Condenser charged in opposite direction.

Just as the energy of the blade is gradually lost in friction and the creation of air-waves, so the energy of a resonant circuit is lost in resistance and the radiation of electro-magnetic waves in space. Whereas mechanical vibrators oscillate up to a few thousand times a second, electric currents may do so at a rate of many megacycles (millions of cycles) a second.

Looking at this characteristic of reactances in series and parallel from a more technical viewpoint, we easily appreciate that, at the natural frequency, the two reactances, being equal and opposite, cancel out, leaving only the (usually much smaller) resistance.

Acceptor Circuit

In the series arrangement, therefore, current will be maximum at resonance. This arrangement is called the "acceptor" circuit, because it presents an extremely low "dynamic resistance" to an applied voltage of the natural frequency. To other frequencies, the circuit presents either a predominately inductive or capacitive react-

ance plus the resistance, thus reducing the current.

In the case of the coil and condenser in parallel, the voltage across the two must be the same and the currents must be 180° out of phase. In other words, an applied EMF of natural frequency will produce maximum current *in* the circuit, but none *through* it— *i.e.*, the circuit will correspond to a very high resistance.

The Valve

We have found the electron very helpful in studying the condenser and coil; we shall find it doubly so in getting to·know the valve. When any substance is heated, what is really happening is that the atoms and free electrons, which are never motionless, are made to jostle about even more violently. In doing so, they create those particular electro-magnetic waves in space which react upon us as "heat".

A few materials, even at normal atmospheric temperatures, are so agitated and have so many free electrons that even the impact of light-waves is sufficient to dislodge some of the electrons. These are "photo-voltaic" substances. Most metals can be heated sufficiently to release a number of free electrons, and valve-makers have developed special materials which emit electrons at dull red heat or less.
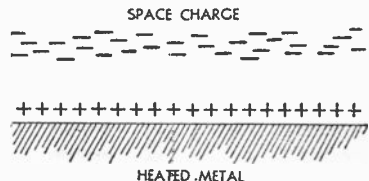
Fig. 39. Electrons freed from a heated filament remain above the surface as a space charge. Deprived of electrons the filament becomes positive.

Normally, when electrons fly off from a heated surface, the surface is thereby made positive, and so exerts an attractive force, which keeps the electrons hovering above it in a kind of cloud or "space-charge" (Fig. 39).

The valve (Fig. 40) uses a heated filament to produce such a space-charge, and also includes a metal plate, which is made positive with respect to the filament. Once the more distant "plate" or "anode" is sufficiently positive to overcome the force holding the space-charge to the filament, the electrons are attracted across to it. Within the limits set by the size and type of filament, the anode current increases in proportion to the voltage until, finally, the filament is emitting electrons as fast as it can and "saturation" point is reached. Change of anode current with anode voltage is shown in the "characteristic" curve of Fig. 41.

Fig. 41. Typical curve showing how the anode current increases proportionately as the anode voltage is raised.

There are two important things to notice. First, the anode voltage supply (usually a comparatively high voltage and therefore termed "high tension" or HT, as distinct from "low-tension", LT, for the filament) has to be connected to filament in order to provide a complete HT circuit. Secondly, the LT circuit serves only as a convenient method of heating the filament and does not itself contribute to the anode current.

The latter point is seen clearly in the mains valve. In mains sets it is convenient to obtain the filament current direct from the mains, either through a step-down transformer or by means of series resistances. In either case, however, variations of the supply would cause slight changes in the temperature of the filaments and, therefore, in the availability of electrons and, indirectly, the amount of anode current. The difficulty is got over by using the filament simply as a "heater" for a substantial "cathode", which may take half a minute to warm up and is, consequently, not affected by brief current fluctuations.

Fig. 40. By applying a voltage between anode and filament a flow of current through the valve can be maintained. The filament battery serves only to heat the wire and does not contribute in any way to the anode current.

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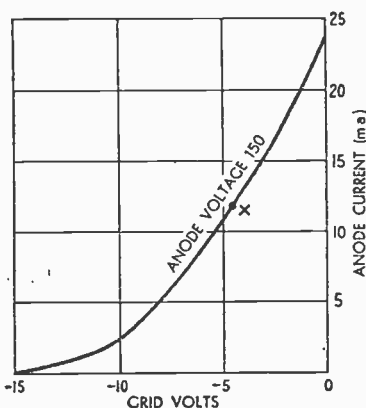
Fig. 46. Typical curve showing how the anode current of a triode valve at a fixed anode voltage decreases as the grid is made more negative.

current for a given change in grid voltage, and is, therefore, a valve with a low mutual conductance. In fact, a little reflection shows that

G_m (mutual conductance)

$$= \frac{\mu \text{ (amplification factor)}}{r_a \text{ (AC resistance)}}.$$

The signal voltage applied to the grid is AC, and, since any flow of electrons in the grid circuit would produce undesirable voltages in it, the grid is given a negative bias, so that on positive signals it does not actually become positive, but only less negative.

Selection of Valve

For the anode current to be always proportional to the grid voltage—which is necessary if distortion is to be avoided—the grid must operate within the straight portion of the characteristic. The negative bias, therefore, is usually arranged so that when idle, or "static", the valve is operating at the centre of the straight portion (for example, point X in Fig. 46). The valve itself has to be selected so that the straight part is long enough to cover the full range of grid voltage.

Valves in the amplification stages of a receiver are required to produce an amplified voltage in the anode circuit; the *power* is of minor importance. The higher the value of the anode impedance the higher the anode signal would be were it not for the fact that the HT voltage being limited, the increase of anode signal appears as a reduction of anode voltage.

Since anode voltage cannot be reduced too far without altering the operating conditions, a compromise or "optimum" value of anode load has to be employed.

and stated in milliamperes-per-volt.

A large change of anode current for a given bias change means, of course, that a curve of the type in Fig. 46 becomes steeper. Mutual conductance, therefore, is often called "slope".

For any particular anode voltage it is possible, of course, to measure the anode current and, by means of Ohm's Law, work out the DC resistance. This figure only applies to the one set of operating conditions, however, and is of little value, since in practice the valve is operated by AC on the grid.

A more useful figure is obtained by measuring the *change* in anode voltage for a certain *change* in anode current over the straight part of the characteristic. This ratio gives the "AC resistance" or impedance presented to a signal with the valve operating at the particular anode and grid voltages.

A valve with a high AC resistance, it will be appreciated, provides a small change in anode

Generally, this is two to three times the AC resistance of the valve.

The amplification given by a valve in association with an anode resistance load (R) is given by:

$$A = \frac{\mu R}{R + r_a}.$$

Valves in output stages are required to give *power* for operating the loudspeaker. A high anode current (low AC resistance) is desirable. Multiplying anode current and voltage gives the power expended in the valve or "anode dissipation". The power available in the loudspeaker without undue distortion is about a quarter of the anode dissipation.

To present the required optimum load to an output valve, the loudspeaker speech-coil must be "matched" to the valve—hence the output transformer. The re-quired transformer ratio is given by:

$$\sqrt{\frac{\text{Valve optimum load}}{\text{Speech coil impedance}}}$$

The impedance of a speech coil can be taken as approximately twice the DC resistance.

Capacities exist between the electrodes in a valve. In a triode the anode–grid capacity may be nearly 10 mmfds, and at radio frequencies this is sufficient to prevent useful operation, as the amplified anode voltage is "reflected back" to the grid.

To obviate this the screen-grid or "tetrode" valve was introduced (Fig. 47). This has an extra grid connected to HT, interposed between signal grid and anode. The valve gives the type of characteristic in Fig. 48. The strange kink is due to "secondary emission".

What happens is that at certain anode voltages, the electrons from the cathode achieve such a velocity that they crash into the anode with sufficient violence to dislodge other electrons from it. These "secondary" electrons and some of the others that have bounced back are drawn to the positive screen-grid. At certain voltages, the screen-grid current increases and the anode current is negative.

This disadvantage has been overcome in the "pentode" by the insertion of a further grid between screen-grid and anode

Fig. 47. A screen-grid valve with electrode assembly exposed, and the symbol by which it is represented in circuits.
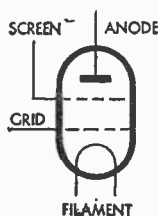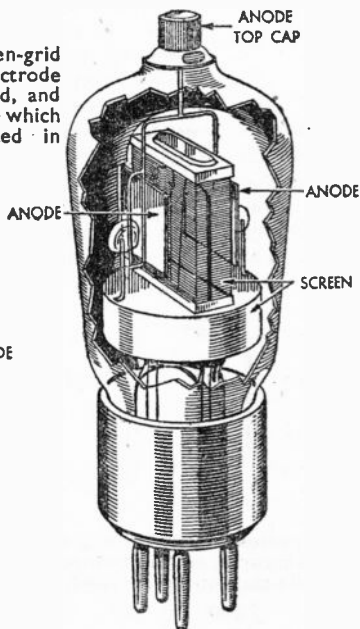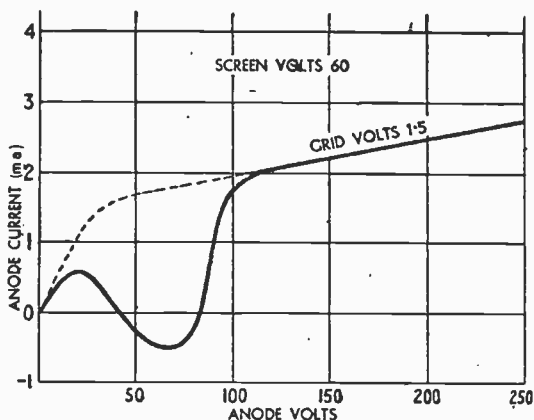
Fig. 48. A feature of the anode volts–anode current curve of the screen-grid valve is the "negative resistance" dip where an increase of voltage produces a decrease of current. Actually, the extra electrons drawn from the cathode flow to the screen.

secondary electrons do not rebound on to the screen-grid.

Pentodes and tetrodes are used for LF as well as RF purposes; they are more efficient than the triode but more liable to distortion.

Types for RF purposes are generally designed so that the amplification is reduced with an increase of bias. This "variable-mu" characteristic enables a valve both to handle powerful signals without "overloading" when operating with a large bias and to provide increased amplification when handling a weak signal and carrying a smaller bias.

Needless to say, variable-mu valves are always employed with automatic volume control.

(Fig. 49). This "suppressor" grid is connected to cathode, and shields the secondary electrons from the attraction of the screen-grid so that they return to the anode.

· Beam Tetrodes

Comparatively recently, "aligned grid" or "beam" tetrodes have been introduced which solve the problem, not by means of an extra grid, but by controlling the electrons into beams and setting the anode and screen at a certain critical distance so that

The numerous other types of valve in use all utilise the fundamental principles described, and practical variations of them are detailed in other chapters.

Explanations of how valves are used in domestic receivers are given in Chapter 2 and details of how they are made in Chapter 16.
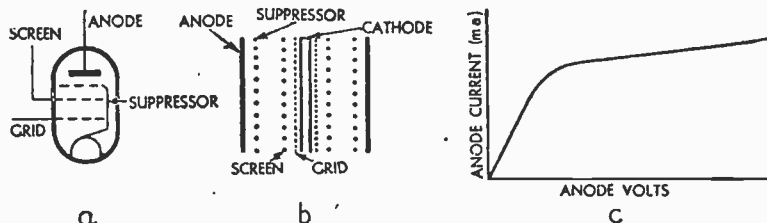
Fig. 49. Circuit symbol, *a*, of a pentode valve, and *b*, a section of the electrode assembly. In *c* is the characteristic curve, which corresponds to Fig. 48 with the negative anode current dip removed.

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REFERENCE

SYMBOLS OF UNITS. MULTIPLES AND SUB-UNITS. NOTATION. UNITS AND
EQUIVALENTS. COMMON ABBREVIATIONS. ELECTRICAL FORMULAE AND
DATA. WIRE TABLES. FLEXIBLE CORDS. COLOUR CODES.

Symbols of Units

A	= Ampere.		m.	= Metre.
Ah	= Ampere-hour.		O or Ω	= Ohm.
C	= Coulomb.		V	= Volt.
db	= Decibel.		VA	= Volt-ampere.
F	= Farad.		W	= Watt.
H	= Henry.		Wh	= Watt-hour.
J	= Joule.			

Symbols of Quantities and Constants

Symbol.				Quantity or Constant.	Unit.
B	.	.	.	Magnetic flux density.	Gauss.
C	.	.	.	Capacitance.	Farad.
D	.	.	.	Electrostatic flux density.	—
E	.	.	.	Electro-motive Force.	Volt.
f	.	.	.	Frequency.	Cycles per second.
F	.	.	.	Magnetic force.	—
H	.	.	.	Magnetic field strength.	—
I	.	.	.	Current.	Ampere.
k	.	.	.	Dielectric constant.	—
m	.	.	.	Mass.	—
M	.	.	.	Mutual inductance.	Henry.
P	.	.	.	Power.	Watt.
Q	.	.	.	Quantity of electricity.	Coulomb.
R	.	.	.	Resistance.	Ohm.
S	.	.	.	Reluctance.	Oersted.
T	.	.	.	Period.	Second.
v	.	.	.	Velocity.	—
V	.	.	.	Potential difference.	Volt.
W	.	.	.	Power.	Watt.
X	.	.	.	Reactance.	Ohm.
Z	.	.	.	Impedance.	Ohm.
θ (Theta)	.	.	.	Angular displacement.	Degree.
$\varkappa$ (Kappa)		.	.	Dielectric constant.	—
λ (Lambda)		.	.	Wavelength.	Metres.
π (Pi)		.	.	Circumference divided by diameter ($3\cdot1416$).	—
ϕ (Phi)	.		.	Phase displacement.	Degree.
ω (Omega)		.	.	Angular velocity ($2\pi f$).	—

Multiples and Sub-Units

Multiples and divisions of units are indicated by the following prefixes:—

M = meg or mega = 1,000,000
$$= 10^6.$$

k = kilo = 1,000 = 10^3.

m = milli =
$$\frac{1}{1,000} = 10^{-3} = 0{\cdot}001.$$

μ = micro =
$$\frac{1}{1,000,000} = 10^{-6} = 0{\cdot}000001.$$

μμ = micro-micro =
$$\frac{1}{1,000,000,000,000} = 10^{-12}.$$

Notation

In radio calculations the index to the base 10 is frequently used for brevity. Under this arrangement 100,000,000, for example, becomes 10^8, while $\frac{1}{10}$ becomes 10^{-1}.

Units and Equivalents

The following table shows the relation between electrical and mechanical units by which any conversion can be made.

1 ft.-lb.	= one pound raised through 1 ft.
1 H.P.	= 33,000 ft.-lbs. per minute.
	= 550 ft.-lbs. per sec.
	= 746 watts.
	= 0·746 kW.
	= 2,545 B.Th.U. per hour.
	= 42·4 B.Th.U. per minute.
	= 0·707 B.Th.U. per second.
1 H.P. Hour	= 0·746 kW. hour.
	= 1,980,000 ft.-lbs.
	= 2,545 B.Th.U.

1 kW.	= 1·34 H.P.
1 B.Th.U.	= 1 lb. of water raised 1° F.
	= 778·8 ft.-lbs.
	= 1,005 Joules.
	= 0·252 kilogram calories.
1 kWh.	= 1,000 watt hours.
	= 1 B.T.U. (Board of Trade Unit).
	= 1·34 H.P. hours.
	= 3,411 B.Th.U.
	= 2,654,200 ft.-lbs.
	= 3,600,000 Joules.
1 Therm	= 100,000 B.Th.U.

Common Abbreviations

A or AE	= Aerial.
AC	= Alternating current.
AC–DC	= All mains.
AF	= Audio frequency or low frequency.
AFC	= Automatic frequency control.
Amp.	= Ampere.
Amps.	= Amperes.
AVC	= Automatic volume control.
B/D or Brd	= Braided wire.
B and S	= Brown & Sharpe's Gauge.
BT	= Bellini–Tosi system of Direction Finding.
BWG	= Birmingham Wire Gauge.
C	= Condenser or capacity.
Cgf	= Grid-to-Cathode capacity.
cps or cs	= Cycles per second.
CR	= Cathode ray.
CW	= Continuous wave.
DC	= Direct current.
DCC	= Double cotton-covered wire.
DF	= Direction finding.

DIR	= Wire double lapped with pure rubber.	MC	= Moving coil.
		MCW	= Modulated continuous wave.
DPC	= Double paper-covered wire.	mfd.	= microfarad or microfarads.
DPR	= Double lapped pure rubber - covered wire.	mmfd.	= micro-microfarad.
		MW	= Medium wave.
		osc.	= oscillator.
DSC	= Double silk-covered wire.	P	= Padding condenser.
		PA	= Public address.
DWC	= ditto. white silk.	PB	= Push button.
		Pen.	= Pentode.
E	= Earth.	Pfd.	= Pico-farad.
EHT	= Extra high tension.	PM	= Permanent magnet.
Enam.	= Enamelled wire.	Pot	= Potentiometer.
EMF	= Electro-motive force.	PU	= Pick-up.
		QPP	= Quiescent push-pull.
ES	= Extension speaker.		
FC	= Frequency-changer valve.	R	= Resistance or resistor.
FM	= Frequency modulation.	RCC	= Resistance - capacity coupled.
FR	= Field resistance.	Rec.	= Rectifier.
GB	= Grid bias.	RF	= Radio frequency.
HC	= High-conductivity wire.	RT	= Radio-Telephony.
		S, Sw	= Switch.
HD	= Hard-drawn copper.	SCC	= Single cotton-covered wire.
HF	= High frequency.	SD	= Soft-drawn copper wire.
HT	= High tension.		
ICW	= Interrupted continuous wave.	SG	= Screen grid.
		SIR	= Wire with single rubber lapping.
IF	= Intermediate frequency.		
		Spk	= Loudspeaker.
IFT	= Intermediate - frequency transformer.	SR	= Starting relay.
		SSC	= Single silk-covered wire.
kc. or kcs	= kilocycles per second.	SW	= Short wave.
		SWC	= Single white silk-covered wire.
L	= Inductance.		
Lam.	= Laminated.	SWG	= Standard wire gauge.
LF	= Low (audio) frequency.	Sync.	= Synchronising.
		T	= Trimming condenser.
LS	= Loudspeaker.		
LT	= Low tension.	TCC	= Triple cotton-covered wire.
LW	= Long wave.		
m.	= metres.	TI	= Tuning indicator.
MA	= Mains aerial.	TPC	= Triple paper-covered wire.
M/a or ma.	= milliamperes.		
mc.	= megacycle.		

Trans.	= Transformer.	v.	= volt.	
TRF	= Tuned radio-frequency.	Vol	= Volume control.	
		W/C	= Wave-change switch.	
USW	= Ultra short wave.			
V	= Valve.	X's	= Atmospherics.	

ELECTRICAL FORMULAE AND DATA

For DC Circuits

Ohm's Law :

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

Power : Power (watts) = EMF (volts) × current (amps)
$$= EI = I^2R.$$

For AC Circuits

Ohm's Law :

$$I = \frac{E}{Z}. \quad E = IZ. \quad Z = \frac{E}{I}.$$

Power :

$$\text{Watts} = I^2R = EI \cos \phi$$

where ϕ is the phase angle between E and I.

Current (I), where there is Inductance (L) only:

$$I = \frac{E}{\omega L}. \quad \omega = 2\pi f.$$

Current, where there is Capacity (C) only:

$$I = \omega CE.$$

Current, where there are Resistance, Capacity and Inductance in series:

$$I = \frac{E}{\sqrt{R^2 + \left(\omega L - \frac{I}{\omega C}\right)^2}} = \frac{E}{Z}.$$

Impedance (Z):

$$Z = \sqrt{R^2 + \left(\omega L - \frac{I}{\omega C}\right)^2} = \sqrt{R^2 + X^2}.$$

Reactance (X):

$$X = \left(\omega L - \frac{I}{\omega C}\right).$$

Power Factor :

$$\text{Power Factor} = \frac{\text{True Power}}{\text{Apparent Power}}$$
$$= \frac{EI \cos \phi}{EI}$$
$$= \frac{R}{Z}$$

Average Value (for a sine wave)

$$= \frac{2}{\pi} \times \text{maximum value.}$$
$$= 0.637 \times \text{maximum value.}$$

RMS Value (for sine wave)

$$= \frac{I}{\sqrt{2}} \times \text{maximum value.}$$
$$= 0.707 \times \text{maximum value.}$$

Form Factor (for sine wave)

$$= RMS/AV = \frac{0.707}{0.637} = 1.11.$$

Resistances

Total value of resistances in series $= R = r_1 + r_2 + r_3 \ldots$

Total value of resistances in parallel $= R = \dfrac{I}{\dfrac{I}{r_1} + \dfrac{I}{r_2} + \dfrac{I}{r_3} \ldots}$

Condensers

Total value of condensers in series $= C = \dfrac{I}{\dfrac{I}{C_1} + \dfrac{I}{C_2} + \dfrac{I}{C_3} \ldots}$

Total value of condensers in parallel
$= C = C_1 + C_2 + C_3 \ldots$

Inductances

Total value of inductances in series $= L = L_1 + L_2 + L_3 \cdots$

Total value of inductances in parallel

$$= L = \cfrac{1}{\cfrac{1}{L_1} + \cfrac{1}{L_2} + \cfrac{1}{L_3} \cdots}.$$

Auto GB Resistance

The correct bias resistance (R) to use is given by:

$$R = \frac{E_B}{I_A},$$

where $E_B =$ bias volts and $I_A =$ anode current. Values are obtained from valve maker's data.

Anode Volt Drop Resistance

The value of a voltage drop resistance to use in anode circuits is given by:

$$R = \frac{V_1 - V_2}{I_a},$$

where $V_1 =$ the HT voltage, $V_2 =$ correct HT voltage for the valve, and I_a the steady anode current.

AC/DC Valve Ballast Resistance

The value of this resistance can be found from:

$$R = \frac{V_m - V_v}{I_v},$$

where $V_m =$ mains voltage, $V_v =$ total voltage of valve heaters in series, and $I_v =$ heater current.

Inductance of Coils

The inductance (L) of tuning coils with a single layer close wound on a cylindrical former is given by:

$L = 0 \cdot 001 \ \pi^2 d^2 n^2 l K$ microhenries

where $d =$ diameter of coil in cms., $l =$ length of coil in cms., $n =$ number of turns per cm., $K =$ a factor depending on the ratio of diameter of coil to length. K is given in the following table:

$\dfrac{d}{l}$	K	$\dfrac{d}{l}$	K
0·10	0·959	1·5	0·595
0·20	0·920	2·0	0·526
0·30	0·884	2·5	0·472
0·40	0·850	3·0	0·429
0·50	0·818	4·0	0·365
0·60	0·788	5·0	0·320
0·70	0·761	6·0	0·285
0·80	0·735	7·0	0·258
0·90	0·711	8·0	0·287
1·00	0·688	9·0	0·218
		10·0	0·203

Wavelength and Frequency

Radio waves travel at 300 million (3×10^8) metres a second. The relationship between wavelength (λ) and frequency is given:

$$\lambda = \frac{3 \times 10^8}{f}$$

$\lambda \times f = 3 \times 10^8 = 300,000,000$

where λ is in metres, and f in cps.

Oscillatory Circuits

Reactance of coil $= X_L = 2\pi f L$ (L in Henries.)

Reactance of condenser

$$= X_C = \frac{1}{2\pi f C}$$

(C in Farads.)

Net Reactance $= X = X_L - X_C$.

Wavelength in metres

$$= \lambda = 1884\sqrt{LC},$$

where L is in microhenries, and C is in microfarads.

Resonant Frequency

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

Dynamic Resistance, or the resistance at resonance of parallel circuit.

$$= R = \frac{L}{C \times r}$$

$r =$ equivalent series resistance.

$$Magnification = m = \frac{\omega L}{r}.$$

Sometimes this property is denoted by the letter Q.

Valve Anode Dissipation

The anode dissipation in watts of a valve is given by:

$$W = \frac{I_a E_a}{1,000},$$

where I_a = steady anode current in milliamps, and E_a the anode voltage.

LF Transformers

Iron Core Inductances. The inductance of an iron core is given:

$$L_{(H)} = \frac{4\pi T^2 \mu A 10^{-9}}{l},$$

where T = the number of turns, μ = permeability, A = cross sectional area in sq. cms., and l magnetic length in cms.

Magnetic Length. This is measured on a transformer stamping as shown by the dotted line in the diagram (Fig. 1).

The length line is taken centrally along the width of the outer frame and along a quarter of the width of the inner limb. The magnetic length from the drawing is $2x + 2y$.

Area is accurately determined by dividing the volume of iron in the core by the magnetic length. For general work, however, the cross section area of the frame (shown at $ABCD$ in the above drawing) may be taken. Measurements are in centimetres.

Power Transformers. The number of turns on the windings of a power transformer are in the same ratio as the primary to secondary voltages:

$$\frac{E_1}{E_2} = \frac{T_1}{T_2}.$$
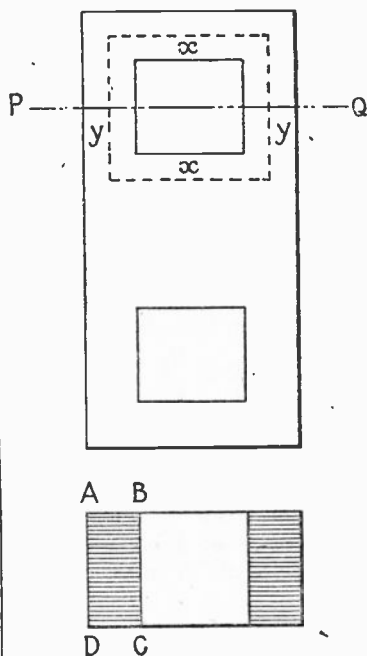
Fig. 1. Diagram showing transformer core measurements. *Above,* magnetic length; *below,* area.

Turns per Volt depend on the cross section area of the core, the frequency of the supply, and the flux density at which the iron is worked. This is given by:

$$\frac{1}{T} = 4\cdot44 \ 10^{-8} fAB,$$

where T = turns per volt, f = frequency, A cross section area in square inches, and B flux density in lines per sq. inch.

Small power radio transformers with a cross sectional area of 1·5 sq. in. have 6 turns per volt.

Output Transformers. The ratio of these depends upon valve load and speaker impedance:

$$\sqrt{\frac{\text{Valve Load}}{\text{Speaker Impedance}}}$$

with both values expressed in ohms.

Optimum Load. This is obtained from the valve maker's data. The optimum load is approximately 2 to 3 times the valve AC resistance.

For parallel output valves, the valve resistance is halved. In the case of push-pull circuits the valve resistance is doubled.

WIRE TABLES

BARE COPPER

SWG	Diam., ins.	Section Area, sq. ins.	Ohms per 1,000 yds.	Length per Ohm.	Weight per 1,000 yds.	Ohms per lb.	Approx. safe current in amps.
				ins.	ozs.		
50	0·001	0·00000079	30,570	1·18	0·145	3,365,000	0·003
49	0·0012	0·00000113	21,230	1·7	0·209	1,623,000	0·005
48	0·0016	0·00000201	11,941	3·02	0·372	513,500	0·008
47	0·002	0·00000314	7,642	4·71	0·581	210,300	0·012
46	0·0024	0·00000452	5,307	6·78	0·834	101,440	0·02
45	0·0028	0·00000616	3,899	9·24	1·14	54,750	0·025
44	0·0032	0·00000804	2,985	10·77	1·49	32,090	0·03
43	0·0036	0·0000102	2,359	15·26	1·88	20,040	0·04
42	0·004	0·0000126	1,910	18·87	2·32	13,146	0·05
41	0·0044	0·0000152	1,578	22·81	2·81	8,978	0·06
40	0·0048	0·0000181	1,326	27·15	3·35	6,340	0·07
				yards	lbs.		
38	0·006	0·0000283	·849	1·18	0·327	2,597	0·1
36	0·0076	0·0000454	529	1·89	0·525	1,008	0·15
34	0·0092	0·0000665	361	2·77	0·769	469·8	0·25
32	0·0108	0·0000916	262	3·82	1·06	247·4	0·4
30	0·0124	0·000121	199	5·03	1·40	142·85	0·5
28	0·0148	0·000172	139·5	7·18	1·99	70·14	0·7
26	0·018	0·000254	94·3	10·6	2·94	32·06	1·0
24	0·022	0·000380	63·2	15·8	4·4	14·366	1·5
22	0·028	0·000616	39	25·6	7·12	5·475	2·5
20	0·036	0·00102	23·6	42·4	11·8	2·004	4·0
18	0·048	0·00181	13·27	75·4	20·9	0·684	7·0
16	0·064	0·00322	7·46	134·6	37·2	0·2	18·0
14	0·08	0·00503	4·78	208	58·1	0·08216	19·0
12	0·104	0·0085	2·83	353	92·8	0·02877	28·0
10	0·128	0·013	1·87	535	148·8	0·012537	35·9

FLEXIBLE CORDS

Conductor		Current Rating	Resistance per 1,000 yds. at 60° F. for straight single cores, no allowance being made for twisting
Nominal Cross-sectional area	Number and Diameter (ins.) of wires		
sq. in.		amps.	ohms.
0·0006	14/0·0076	2	39·7
0·001	23/0·0076	3	24·2
0·0017	40/0·0076	5	13·9
0·003	70/0·0076	10	7·94
0·0048	110/0·0076	15	5·05
0·007	162/0·0076	20	3·43

WIRE TABLES—*Continued*.

SINGLE COTTON-COVERED					DOUBLE COTTON-COVERED				
SWG	Total thickness of covering in mils.	Turns per inch.	Turns per sq. inch.	Yards per lb.	SWG	Total thickness of covering in mils.	Turns per inch.	Turns per sq. inch.	Yards per lb.
40	4	112·5	26,600	3,910	40	7/9	78	6,080	3,456
38	4	100	10,000	2,550	38	7/9	71·5	5,110	2,287
36	4	86·2	7,430	1,610	36	7/9	64	4,010	1,477
34	5	70·5	4,970	1,280	34	8/10	55	3,020	1,024
32	5	63·3	4,010	835	32	8/10	50·5	2,550	755
30	5	57·5	3,300	634	30	8/10	47	2,210	587
28	5	50·5	2,550	452	28	8/10	42	1,790	422
26	5	43·5	1,892	311	26	8/10	37	1,400	294
24	5	37	1,369	219	24	8/10	32·3	1,043	203
22	5/6	29·8	888	134	22	9/11	26·3	692	129
20	5/6	24·1	581	81·7	20	9/11	21·7	473	79·4
18	6/7	18·3	335	46·3	18	9/11	17·3	299	45·4
16	7	14·1	198	26·1	16	10/12	13·3	177	25·6
14	7/8	11·4	130	16·9	14	12/14	10·75	115	16·6
12	7/8	9	81	10·3	12	12/14	8·5	72	9·09
10	7/8·	7·4	54	6·63	10	12/14	7·1	50·3	6·58

SINGLE SILK-COVERED					DOUBLE SILK-COVERED				
				yds. per oz.					yds. per oz.
47	1·2	312	97,300	1,375	47	2·2	238	56,600	1,190
46	1·2	278	77,300	1,000	46	2·2	217	47,100	871
45	1·2	250	62,500	752	45	2·2	200	40,000	675
44	1·2	227	51,530	599	44	2·2	185	34,200	536
42	1·2	192	36,860	387	42	2·2	161	25,900	358
40	1·3	164	26,900	276	40	2·5	137	18,800	258
				per lb.					per lb.
38	1·3	137	18,770	2,871	38	2·5	118	13,900	3,760
36	1·3	112	12,540	1,815	36	2·5	90·1	8,120	1,750
34	1·3	95·2	9,060	1,250	34	2·5	85·5	7,310	1,220
32	1·3	82·6	6,820	912	32	2·5	75·2	5,650	887
30	1·3	73	5,330	695	30	2·5	67·1	4,500	675
28	1·3	62·1	3,860	488	28	2·5	57·8	3,340	478
26	1·3	51·8	2,680	332	26	2·5	48·8	2,380	325
24	1·5	42·5	1,810	222	24	3	40	1,600	218
22	2	33·3	1,090	137	22	3	32·2	1,040	134
20	2	26·3	692	83·3	20	3	25·6	655	82·5
18	2	20	400	46·8	18	3	19·6	384	46·3
16	3	15	222	26·4	16	4	14·7	216	26·1

FUSE WIRE

If you run short of standard fuse wire, ordinary copper wire of suitable size can be used instead. Bare wire should be employed. The two most useful sizes are:

No. 35 SWG to protect a 5 amp. circuit ; and
No. 25 SWG to protect a 15 amp. circuit.

ENAMELLED

SWG	Total Thickness of covering in mils.	Turns per inch.	Turns per sq. inch.	Yards per oz.
50	0·2	833	694,000	6,480
49	0·2	714	510,000	4,510
48	0·3	526	277,000	2,540
47	0·3	435	189,000	1,630
46	0·4	357	127,500	1,128
45	0·5	303	91,800	835
44	0·5	270	72,900	642
42	0·6	217	47,100	411
40	0·7	182	33,100	286
				per lb.
38	1·0	143	20,450	2,810
36	1·0	116	13,450	1,840
34	1·0	98	9,600	1,202
32	1·2	83·3	6,940	915
30	1·2	73·5	5,400	694
28	1·6	60·1	3,610	488
26	1·8	50·5	2,550	330
24	2·3	41·1	1,690	221
22	2·5	32·8	1,080	137
20	2·7	25·8	666	83·3
18	2·7	19·7	388	46·9
16	3·5	14·8	219	26·4

EUREKA RESISTANCE WIRE

SWG	Diameter, ins.	Ohms per yard.	Yards per lb.	Current (amp.) for temperature rise of 100° C.
8	0·160	0·0335	4·2	29·0
9	0·144	0·0413	5·3	24·0
10	0·128	0·0523	6·7	20·1
11	0·116	0·0637	8·1	18·5
12	0·104	0·0793	10·0	14·8
13	0·092	0·1013	13·0	12·6
14	0·080	0·1339	17·1	10·5
15	0·072	0·1653	21·1	9·3
16	0·064	0·2094	26·7	8·1
17	0·056	0·2733	34·9	7·0
18	0·048	0·3718	47·6	5·75
19	0·040	0·5356	68·4	4·6
20	0·036	0·6613	84·6	4·1
21	0·032	0·8372	106·9	3·6
22	0·028	1·093	139·8	3·1
23	0·024	1·487	190·8	2·7
24	0·022	1·770	226·7	2·4
25	0·020	2·142	274·6	2·18
26	0·018	2·645	337·8	2·0
27	0·0164	3·186	406·5	1·82
28	0·0148	3·914	500·0	1·66
29	0·0136	4·634	592·3	1·54
30	0·0124	5·575	714·2	1·4
31	0·0116	6·370	313·0	1·3
32	0·0108	7·350	943·4	1·2
33	0·100	8·571	1093·2	1·08

COLOUR CODES

The values of most small components in receivers are indicated by standard arrangements of coloured bands or dots known as colour codes. Leading examples are resistors and fixed condensers.

The colour coding system has also been extended to indicate the value of fuses, while connections to such components as multiple condenser blocks and mains transformers made by flexible leads, are also coloured on definite systems.

Only ten colours are used to denote the values of resistors and tubular types fixed condensers. They should be memorised, thus:

o = Black.   5 = Green.
1 = Brown.   6 = Blue.
2 = Red.   7 = Violet.
3 = Orange.   8 = Grey.
4 = Yellow.   9 = White.

As an aid to memory, the colours used are in the same order as the colours of the solar spectrum, with black and brown at one end and grey and white at the other.

Resistors

Colour coded resistors have the body painted in one colour, one end tipped with another, while a third is applied in the form of a dot or band.

To read the code, the body colour gives the first figure of the value, the tip the second figure, and the spot the number of o's that follow.

Fig. 4 shows a typical resistor fully coded and with its value read off below.

When there is apparently no spot or tip, these then take the same colour as the body.

Sometimes a fourth colour is added to the end opposite to the tip to indicate the tolerance of the
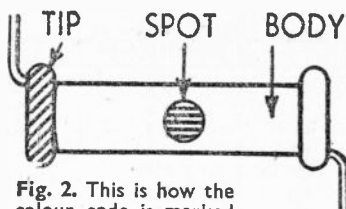
Fig. 2. This is how the colour code is marked on resistors.
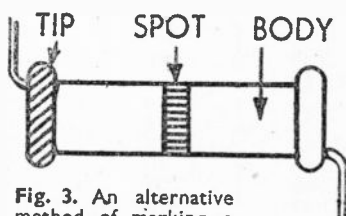
Fig. 3. An alternative method of marking, a band taking the place of the spot.
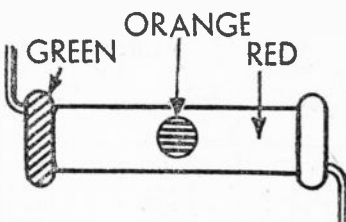
Fig. 4. The value of this colour coded resistor is read as follows: Body = red = 2; Tip = green = 5; Spot = orange = 000; therefore the total value is 25,000 ohms.

resistor. Only two extra colours are used for this purpose. These are metallic gold denoting a 5% tolerance, and metallic silver for a 20% tolerance.

Standard resistors which are not marked with these additional colours have a tolerance of 10%.

An alternative method of marking resistors is the use of bands of colours at one end as in Fig. 5.

The first band A is equivalent to the body colour, the second
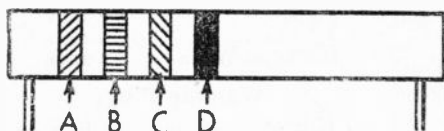
Fig. 5. Another method of coding resistors is by bands placed at one end. Band A represents the body colour; B the tip; C the spot; and D the tolerance value.

(B) to the tip, and the third (C) to the spot. To find the value of a resistor marked in this way, the colours are read from left to right.

The fourth band (D) is the gold or silver tolerance indication.

Condensers

Fully coded fixed condensers of the tubular and elongated rectangular type carry five dots or bands near one end. The first three indicate the value *in micro-microfarads* in the same manner as for resistors. The fourth colour indicates the tolerance, and the fifth the DC voltage rating.

Colours used to indicate tolerance and voltage rating are:

Colour	Tolerance	Voltage Rating
Brown .	1%	100
Red . .	2%	200
Orange .	3%	300
Yellow .	4%	400
Green .	5%	500
Blue .	6%	600
Violet .	7%	700
Grey .	8%	800
White .	10%	1,000

In these two applications of the code it will be noticed that the digit values of the code remain unchanged except for white, which instead of representing 9 becomes 10% and 1,000.

A fully colour coded condenser, marked as shown in Fig. 6, would have a value of 300 mmfd. which equals 0·0003 mfd.; a tolerance of 5%; and a DC voltage rating of 100.

If condensers are only marked with three colours, the capacity value only is indicated. In this instance the tolerance is 20% and the DC rating 500 v.

Some condensers are marked with only two colours giving an indication of tolerance and voltage rating. If, however, only one dot or band is used, the tolerance only is indicated.

However many colours are used, they are always grouped at one end, and are read from left to right from this end.

Here is a point to be born in mind about the grouping of the colours. Where the five colours are used and owing to the size of the condenser they cannot be readily arranged in one line, they may be split up and placed on different sides of the condenser.

In this case the group of three colours will indicate the capacity of the condenser, and the other two, which would appear on an-
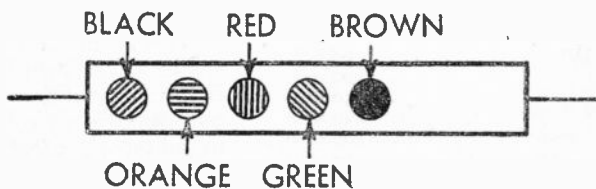
Fig. 6. A fully colour coded tubular condenser. The dots are always read from left to right.

BLACK   RED   BROWN

ORANGE   GREEN

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