THE
CATHODE-RAY TUBE HANDBOOK

S. K. LEWER, B.Sc.

PITMAN

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CATHODE-RAY TUBE HANDBOOK

BY

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LONDON
SIR ISAAC PITMAN & SONS, LTD.
1945

First Edition, 1945

SIR ISAAC PITMAN & SONS, Ltd.
PITMAN HOUSE, PARKER STREET, KINGSWAY, LONDON, W.C.2
THE PITMAN PRESS, BATH
PITMAN HOUSE, LITTLE COLLINS STREET, MELBOURNE
UNITEERS BUILDING, RIVER VALLEY ROAD, SINGAPORE
27 BECKETTS BUILDINGS, PRESIDENT STREET, JOHANNESBURG

ASSOCIATED COMPANIES

PITMAN PUBLISHING CORPORATION
2 WEST 45TH STREET, NEW YORK
205 WEST MONROE STREET, CHICAGO

SIR ISAAC PITMAN & SONS (CANADA), Ltd.
(INCORPORATING THE COMMERCIAL TEXT BOOK COMPANY)
PITMAN HOUSE, 381-383 CHURCH STREET, TORONTO

BOOK
PRODUCTION
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AUTHORIZED ECONOMY STANDARDS

Printed by Hazell, Watson & Viney, Ltd.,
52, *Long Acre, London, W.C.2.*
2709-44 (T.316)

PREFACE

THE cathode-ray oscillograph is finding an ever-widening application in numerous branches of science and technology. It has been my object in this book to facilitate the use of the cathode-ray tube in its various purposes by setting out the basic principles of its design, construction and operation. The foundations of successful employment of the instrument lie in the understanding of its technical qualities and characteristics.

The references indicated in the text are to papers of leading interest which will be found listed at the end of the book.

In the circuit diagrams, component values have been included where it was considered that they might be useful as a guide in experimental work. No attempt has been made to provide full constructional details.

I wish to record my thanks to *The General Electric Company, Ltd.,* for the illustrations used in Figs. 1, 22, 29, 30; to *Messrs. A. C. Cossor, Ltd.,* for Figs. 8 and 13; to *The Mullard Wireless Service Company, Ltd.,* for Fig. 2; and to *Standard Telephones and Cables, Ltd.,* for Fig. 15; and to these firms severally for information relating to the tube characteristics listed in Table II.

S. K. L.

NORTH WEMBLEY,
April, 1945.

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CHAPTER I

PICTURE DRAWING BY ELECTRONICS

ALTHOUGH the cathode-ray tube was invented nearly fifty years ago, it remained in the comparative obscurity of scientific research laboratories until the vast improvements in valve-making technique opened the way to the manufacture of more sensitive and less costly tubes. As a result, television became a practical possibility and the intense interest in this new art led in turn to further technical advancements in the design of cathode-ray tubes. Still more recently, the demand brought about by the war for the accelerated production of technical equipment and the development of new applications has placed the cathode-ray tube in a position of the utmost importance.

As a laboratory instrument, in the form of the cathode-ray oscillograph, it has opened up new methods of measurement and examination of all kinds of electrical and radio apparatus.[1] It has also aided the study of lightning discharges, the vibration of machinery, the efficiency of steam engines, the pressure developed in gunpowder explosions and the electric currents in the human brain.

Cathode-Ray Tube Construction

The cathode-ray tube is made of glass and contains a number of metal electrodes. It is either highly evacuated or filled with a small quantity of gas at low pressure. Its shape is elongated, tapering from a large diameter at one end to a tubular extension of relatively small diameter at the other end. In a few miniature types, the diameter is uniform over the whole length of the tube.

The largest tubes, which are used in television receivers, have a diameter of 12 to 24 inches and a length of 15 to 30 inches. The tubes designed for use in oscillographs are rarely more than 9 inches in diameter and about 18 inches long. A full range of sizes down to 1 inch diameter and a length of 5 inches is now available, the smaller sizes being preferred for portable instruments. (See Fig. 1.)

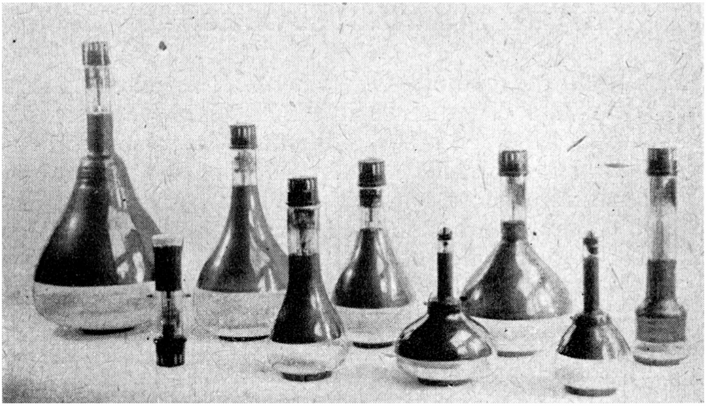

FIG. 1.

A variety of cathode-ray tubes for oscillographs and television receivers. The screen diameters range from 4 to 16 inches.

The front end of the tube, *i.e.* the end which is presented to the eye, is always made as nearly flat as possible, consistent with various constructional requirements. On the inside face of this end there is a thin coating of a special material, and upon this screen a spot of fluorescent light is produced by the impact of a beam of electrons generated in the tube. The pattern is therefore traced out on the inner surface of the circular glass wall, but it is clearly visible from the outside.

The movement of the luminant spot is caused by variations in the electrical conditions in the circuits connected to the tube.

At the opposite end there is an insulating cap carrying a number of electrical contacts. These are connected by short lengths of wire to the various metal electrodes which are mounted in a compact assembly close to the capped end.

Stationary and Moving Patterns

The cathode-ray tube provides a pictorial presentation of what is happening in an electrical circuit by actually tracing out on a screen the graphic information which a lecturer would present to his audience with a blackboard and a piece of chalk—with an important difference. Whereas the lecturer might be able to trace out a curve on the blackboard in a few seconds, or perhaps a few minutes if the figure is a difficult one, the cathode-ray tube can quite easily trace out even the most complex curves in a few millionths of a second if necessary.

This means that the cathode-ray tube can draw several hundred thousand pictures every second. If the tube is being used to represent a stationary, unchanging curve, each complete trace is a replica of the first. On the other hand, if the conditions in the circuit to which the tube is connected are undergoing some change or other, the change will immediately be apparent, for each successive trace will then be slightly different from its predecessor. This bears a close resemblance to the manner in which a succession of slightly different photographic " stills " can be made to reproduce a moving picture in the cinematograph.

The lecturer who uses white chalk on a blackboard and the draughtsman who draws with black ink on white paper rely on the same principles of optics as the cinema. The optical image received by the retina of the eye is produced there by the light which is reflected from the chalked blackboard, the inked paper and the silver screen. The cathode-ray tube does not rely on reflected light. It does all its work by the movement of the small spot of fluorescent light. Everything depends on this one spot.

The Spot and its Six Senses

In later chapters, the adjustment and the control of this spot and the methods by which it is made to present intelligible and useful patterns on the screen will be described in more detail, but for the present it will be sufficient to review briefly the characteristic features on which the whole action is based.

Focus

It is impossible to draw a thin, clean line with a blunt pencil. A sharp point is necessary. In the same way, a distinct picture can only be produced by the cathode-ray tube if the spot of light is small. For technical reasons it is undesirable, and in fact very difficult, to make the spot extremely small. But it should have well-defined edges. A hazy spot would produce a fuzzy picture. Usually a diameter of about one-fiftieth of an inch is considered satisfactory. The adjustment, which is provided in all cathode-ray oscillographs, for controlling the size and sharpness of the spot is called focusing.

Horizontal and Vertical Positions

When the spot is not actually tracing out a figure on the screen it remains at rest in its " home " or zero position at the centre. As in ordinary graphical representation of mathematical curves, the simplest way of defining a fixed position is by stating it in terms of two distances in two directions at right-angles to each other. Similarly, the position of any point on the map of the world is conveniently given by its latitude and longitude. To identify positions on either side of the equator the latitude is given as north or south, and likewise, positions on either side of the zero or standard longitude (Greenwich) are given as east or west. In a graph the corresponding terms are positive and negative.

On the screen of the cathode-ray tube, the conventional mathematical axes X and Y are used for reference. The point where the spot is normally at rest gives the zero position on each of these axes, like the point on the map having zero longitude and zero latitude. In practice, the figure which the spot has to trace out may lie in any sector. Space would in many cases be wasted if the zero position were always fixed at the centre of the screen, or for that matter at any other point. Obviously, there will be more space available on the screen if the " home " point can be moved to a suitable position having regard to the placing of the figure. In an oscillograph unit, therefore, two independent controls are provided for this purpose. One of them controls the X-shift (or longitude) position, and the other controls the Y-shift (or latitude).

Sensitivity

Just as an ordinary measuring instrument, like a voltmeter, becomes useless as an indicator when it is asked to measure something in excess of its normal range because the pointer goes off the scale, so also is the cathode-ray tube useless if it is connected to a circuit which sends the spot off the screen. The applied electrical signals must be reduced to a suitable magnitude. More commonly, however, the signals are not strong enough: in such cases they have to be amplified first. An excess of amplification is usually available, so that the right amount can readily be obtained by a sensitivity control.

Speed

The greatest usefulness of a cathode-ray tube lies in its response to those electrical changes where the variations are extremely rapid. It is indeed this quality that makes the cathode-ray tube superior to practically all other measuring and indicating devices. The time taken by the spot of light to travel on its various journeys must therefore be kept under close control. In some special arrangements, this can become a highly complex consideration, but in the majority of cases a simple time-scale is provided, including an adjustment for its speed.

Brightness

Finally, it is always a convenience to be able to adjust the intensity of the light spot. This is not the same thing as the focusing which has already been mentioned, although it happens in practice that any adjustment of one will most probably affect the other to some small degree. Broadly speaking, it is not sufficient to rely merely on focusing the spot. When it has been focused it may be found to be too dim or unnecessarily bright. If the spot is too intense, it will permanently mar the fluorescent quality of the screen. Consequently, an adjustment for the brightness control is usually included, and the thoughtful operator will always see that the brightness is reduced to the lowest satisfactory level.

Adjusting the Controls

These six controls are effected simply by the rotation of six small knobs generally mounted on the front panel of the oscillograph unit and are responsible for the apparent complexity of the apparatus. Like the switches, knobs and buttons that adorn the dashboards of various cars, all these controls are apt to give a somewhat bewildering impression, but a little experience with them soon brings confidence. Familiarity with the effects they produce comes directly from the knowledge of their purpose. No amount of blind, haphazard twisting of the control knobs will convert a jumping, swirling maze of intertwining curves and loops into a clean, intelligible, stationary pattern. Each control must be set at its right position, and this can only be achieved by a systematic and methodical approach and by clear reasoning.

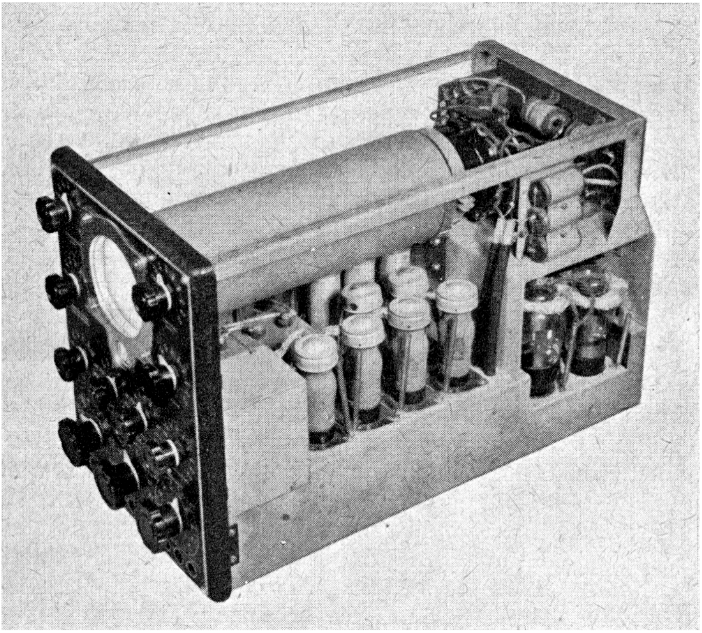

FIG. 2.

A portable cathode-ray oscillograph fitted with a 3½-inch diameter tube. The instrument includes a power supply unit, linear time-base and a two-stage push-pull Y-deflection amplifier having a gain of 7,000.

Fig. 2 is a photograph of a typical oscillograph complete with auxiliary equipment and power supply. The protecting case has been removed to show the compact arrangement of the components.

CHAPTER II

ELECTRONS AND ELECTRIC CURRENTS

MATTER consists of an enormous variety of molecules, some of them in very complex combinations, and others relatively simple. The molecules are themselves groups of atoms, of which there is a limited number of varieties. Actually, 92 different types of atom are known. Molecules and atoms are electrically neutral, although they consist of intricate self-contained systems of positive and negative electricity. These systems are normally in a state of electrical balance, and only when the balance is disturbed do the atoms and molecules exhibit electrical qualities.

Electrons and Protons

The atom is the smallest unit which can retain the chemical properties which characterise it as belonging to one of the 92 elements of matter. The intricate system which constitutes each atom is composed not of matter but of electric charges called *electrons* and *protons*. These are to be found in all the elements but in various modes of combination. An atom is believed to consist of a core, called the *nucleus*, and a number of electrons revolving in orbits round the nucleus. The core of an atom contains a number of protons and electrons bound very tightly together.

Electrons are charged negatively and protons are charged positively. Their electric values are equal and opposite, but the proton is 1,840 times as heavy as the electron. These units are indivisible. Half an electron is as unthinkable as half a soap-bubble. The nucleus has a resultant positive charge because it contains more protons than electrons, and the electrical balance of the normal atom is restored by the negatively-charged electrons which revolve round the nucleus.

Atomic Theory

All molecules are exceedingly small, and therefore exceedingly numerous. As Sir James Jeans has put it,* there are 1.89×10^{25} molecules in a pint of water, and if they were placed end to end they would form a chain capable of encircling the earth over 200 million times. The diameter of a molecule of water is 1.8 hundred-millionths of an inch.

Even so, the molecule is very large compared with an electron; it has a volume about a thousand million million times the volume of a single electron.

Besides the electron and the proton, other fundamental units have recently been discovered in scientific research. They have been named the *neutron,* the *positron,* the *photon* and the *mesotron.* All of them are far too small to be seen individually even by the most powerful of all microscopes—the electron microscope—but they can be weighed and measured with considerable accuracy by scientific methods.

In many respects, however, modern atomic theory is still of a hypothetical character. Electrons, protons, and so on, can only be described in terms of their behaviour, and their true nature remains unexplained. Mass can disappear and become converted into energy, and energy can re-appear as mass. But out of these depths of abstruse physics, certain simple conceptions have been drawn, and it is in the light of these simple conceptions that the principles of the cathode-ray tube can be described.

Insulators and Conductors

In some kinds of atom, the orbital electrons have very

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* *The Universe Around Us,* page 93.

little chance of escape from the influence of the nucleus. Such materials do not permit the conduction of electricity and are called *insulators.* Other atomic structures permit the movement of electrons with relatively little opposition, and an electron flow through the material can be readily effected. These materials are called *conductors.*

The Electric Current and Ionisation

When an electric charge moves from one place to another, there is said to be an electric current. A current of electricity through a solid conductor consists of a drift of loosely-bound electrons from one atom to another. In liquids and gases the current may be carried by atoms or molecules containing an excess or deficit of electrons. Such charged atoms and molecules are called *ions.*

A gas may be ionised by various means, of which perhaps the most important is the collision of high-velocity electrons with the atoms and molecules of the gas. Some of their orbital electrons become dislodged, leaving the atoms positively charged. These positive ions naturally attract the electrons which happen to be in the vicinity, and whenever recombination occurs and the atoms return to their normal state, there is an emission of light. This is the basis of the glow-discharge used in neon signs and mercury-vapour lamps.

Under the influence of an external electric field, the electrons and the positive ions travel in opposite directions, but the ions, being very much heavier, move much more slowly.

Current in a Vacuum

If the pressure of a gas is reduced sufficiently until the number of atoms and molecules becomes negligibly small, the effect of ionisation will disappear. A current may still pass, however, by the flow of electrons only. Most radio valves and cathode-ray tubes are highly evacuated so that no ionisation shall occur, for this would interfere with their normal operation, but in some types of valves and tubes a small quantity of residual gas is used to produce ionisation for specific purposes. These are sometimes described as " soft," while the high-vacuum types are frequently called " hard."

Currents in Circuits

In wire circuits, the current is carried entirely by electrons. If this consists of a continuous drift in one direction it is called *direct current* (D.C.). If the flow alternates in direction continuously so that the electrons drift to and fro periodically, it is called *alternating current* (A.C.).

In the electrical industry, A.C. is very widely used, largely on account of the ease with which it can be transformed to high or low voltages.

A standard frequency of alternation has been adopted for the British National Grid—50 cycles per second—and as this is maintained with an extremely high order of accuracy, it provides a convenient reference frequency for precision measurements. In the U.S.A. the frequency adopted as standard is 60 c.p.s.

In radio and oscillograph work, where A.C. is taken from the supply mains for providing a source of D.C. (through the usual rectifier-filter system), the alternating electric and magnetic fields which surround the connecting wires and various pieces of apparatus are sometimes responsible for induced hum or modulation effects. On a loudspeaker the low-pitched hum is recognisable immediately, but in an oscillograph the effects of A.C. induction are not always so easily detected.

Where D.C. is being used, it is frequently necessary to consider the direction of the current flow. In the early days of electricity, before electrons had been discovered, it was supposed—quite arbitrarily—that the current in a circuit flowed from the positive terminal of a battery towards the negative terminal. In accordance with the modern theory, however, the current is a flow of electrons, and because they are negatively charged the flow must be in the direction of the positive potential and away from the negative. This unfortunate conflict need not cause any confusion provided that it is made clear whether it is the electron flow or the so-called " current " which is being discussed.

Thermionic Emission

The most convenient source of electrons for use in small evacuated glass bulbs is that which relies on the phenomenon of thermionic emission. Various materials, especially the oxides of certain metals, liberate considerable quantities of electrons when they are heated to a high temperature. The problem of heating is easily solved by passing an electric current through a small resistance, usually in the form of a wire spiral. The thermionically active material can be applied either directly as a coating on the wire or on the outside of a metal tube surrounding the heating spiral, in which case the coating is said to be indirectly heated. The electrode assembly is known as a *thermionic cathode.*

The liberated electrons tend to cluster round the emissive surface unless there is an electric field to draw them away. This electron cloud is called a *space charge.*

Thermionic Cathodes

The active life of a cathode is affected by the presence of a gas or vapour. Contamination of a chemical character is highly injurious. In addition, there is the danger of *positive-ion bombardment.* This is the disruption of the cathode material caused by the impact of the positive ions which are present in the gas and which, by reason of the applied electric force, are impelled towards the cathode.

Provided that the positive ions are restricted in numbers and velocity, the cathode is not damaged although its active life is somewhat shorter than that of a similar cathode in a high-vacuum tube.

Fluorescence

The spot of light which traces out the picture on the screen of a cathode-ray tube is produced by *fluorescence*. This is the property which certain materials possess of emitting light when subjected to various influences such as ordinary daylight or ultra-violet light. In the case of the cathode-ray screen, the fluorescence is produced by the impact of the electron stream on the sensitive material. The electron stream is, in fact, the *cathode-ray*, and it is from this fundamental feature of its operation that the cathode-ray tube derives its name. The stream is focused down to a very narrow beam so that it strikes the screen in only one small spot.

The colour of the glow is usually green or blue, or bluish-green, and it depends on the nature of the fluorescent material. Red screens are used sometimes, and for television purposes it is generally considered preferable to use a screen with a white fluorescence, or as near to white as can be achieved.

The colour of the fluorescent powder is usually white or greyish, and gives no indication of the colour of the light spot. In manufacture, the powder is mixed with an adhesive binder and is sprayed thinly on to the inside wall of the tube under conditions of extreme purity.

If the electron stream is suddenly cut off, the spot of light does not immediately vanish. It continues for a short while, perhaps a fraction of a second, but dying away all the time. This *afterglow*, or *persistence*, depends on the type of material and on the intensity of the electron stream. A range of fluorescent materials exists from which a choice can be made so that the cathode-ray tube has either a long afterglow of about $\frac{1}{4}$ second or a short afterglow lasting only a few milliseconds. For special purposes, some tubes have extremely rapid screens in which the afterglow lasts for about 8 microseconds. The duration of the afterglow is obviously very important in television tubes in order that blurring should not occur when the image is in motion.

Some of the characteristics of fluorescent screens in common use are given in Table I.[2]

The cinema, which presents the eye with a rapid succession of still pictures, creates the impression of continuous, unbroken movement by relying on the persistence of vision. This property of the retina in the eye also assists in conveying to the brain the complete graphical information which is represented by the movement of the fluorescent spot of light in the cathode-ray tube.

TABLE I

APPLICATION	COLOUR OF FLUORESCENCE	AFTERGLOW
OSCILLOGRAPH (GENERAL)	GREEN	8 MILLISECS.
OSCILLOGRAPH (PHOTOGRAPHY)	BLUE-VIOLET	8 MICROSECS.
OSCILLOGRAPH (TRANSIENTS)	RED-ORANGE	$\frac{1}{4}$ SECOND
OSCILLOGRAPH	YELLOW	$\frac{1}{10}$ SECOND
TELEVISION	WHITE	$\frac{1}{25}$ SECOND

TYPICAL FLUORESCENT SCREENS
USED IN CATHODE-RAY TUBES

Electron Currents in Valves

Valves of various kinds are essential items of auxiliary equipment in every cathode-ray oscillograph. Moreover, valves and cathode-ray tubes have many features in common. A study of one therefore assists in the study of the other.

The valves used in radio apparatus, transmitters, receivers, amplifiers and so on, are high-vacuum devices. Ionisation does not play any part in their operation, and the current which passes through them is purely an electron current. As previously mentioned, the most convenient source of electrons is the thermionic cathode, and this may be of the indirectly-heated type or the directly-heated filament type. In addition to the cathode, a valve contains an anode for the collection of the electrons emitted by the cathode. In order that it may do this, it is given a positive charge and the electrons, which are negatively charged, are attracted to it. If there are sufficient electrons and if they strike the anode with sufficient velocity, they can in some cases raise the temperature of the anode to red-heat and may even melt it. But the anode is usually large enough to dissipate the heat and a dangerous rise in temperature is thus avoided.

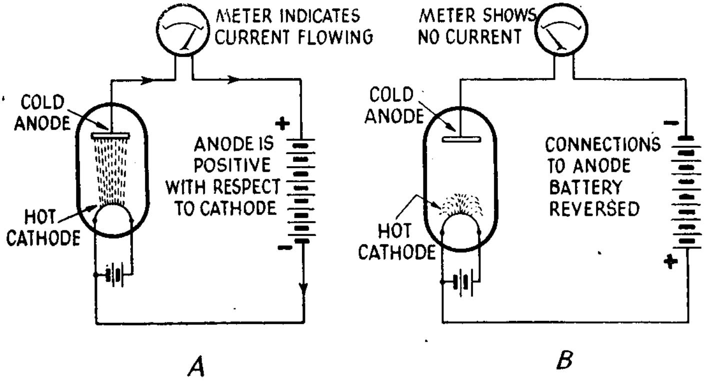

FIG. 3.

The flow of electrons through a diode. Current passes only when the anode is positive with respect to the cathode.

If the anode is made negative instead of positive with respect to the cathode, it will then no longer attract the electrons, and no current will flow between the cathode and the anode. The negatively-charged anode would actually repel the electrons back towards the cathode, but the important feature is that the valve will pass current when the anode is positive but not when it is negative. This is illustrated in Fig. 3.

Grid Control

By placing a perforated electrode in the electron path between the cathode and the anode, the amount of current flowing to the anode (assuming that the anode is positively charged) can be influenced merely by altering the electric charge applied to the perforated electrode. This action resembles that of a throttle. A negative charge on the perforated electrode will retard or repel the electrons which would otherwise flow freely through the openings towards the anode. Conversely, a positive charge will accelerate them and so increase the current to the anode.

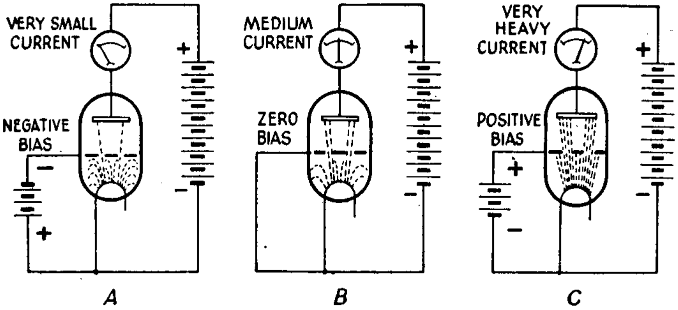

FIG. 4.

The electron current passing from cathode to anode increases as the grid bias becomes less negative and more positive. For simplicity, the battery for heating the cathode is not shown.

It is important, of course, that the perforations should be large enough to permit the flow without undue obstruction. In a valve, this electrode is made in the form of a wire mesh, or spiral, surrounding the cathode, and is called a grid. Its purpose is to control the current flowing to the anode, and it is therefore known as a *control grid.* Such a valve, having three electrodes, is called a *triode*.

In Fig. 4 the effect of altering the charge on the grid is shown in three stages: A—negative charge, B—zero charge, C—positive charge. The current to the anode is very small in A, moderate in B and large in C.

A grid having a fine, small mesh and placed close to the cathode has a highly sensitive control over the flow of electrons. The control is less sensitive if the mesh is coarse or if the grid is placed further away from the cathode.

Multi-Grid Valves

Some valves have several grids, so arranged that the electrons have to pass through all of them in turn before they finally reach the anode. These various grids serve different purposes, and are given such descriptive names as *screen grid* and *suppressor grid*. Their purpose is primarily to improve the efficiency of the valve as an amplifier.

Instead of being in the form of a mesh or spiral, the interposed electrode may be a cylinder or a disc with a single aperture in it through which the electrons can pass. These constructions are used in cathode-ray tubes as they are better suited to the special purpose of producing the narrow beam of electrons.

The Effect of Gas in Valves

So far, only high-vacuum valves have been discussed. If air were to leak into such valves their operation would be completely spoiled. But by suitable design of the electrodes and by proper circuit adjustment, it is possible to incorporate certain gases in valves with great advantage. The gases most commonly used are argon and mercury vapour. These are chosen on account of the readiness with which they can be ionised. The positive ions, which are gas atoms deprived of some of their electrons, have the effect of neutralising the negative space-charge which accumulates round the cathode.

The consequence of this is that very much larger numbers of electrons can leave the vicinity of the cathode, and because it is the electrons themselves which cause the ionisation of the gas atoms by their collisions with them, the process is rapidly cumulative. There is no longer any opposition or resistance to the flow of current. In fact, the current has to be limited to a safe value by a suitable circuit arrangement in order to prevent the destruction of the valve.

In valves fitted with control grids, the presence of an ionisable gas has a further very useful effect. When the negative charge on the control grid is reduced sufficiently to permit a certain small electron current to flow to the anode, the electrons collide with the gas atoms and ionise them. Besides leading to a rapid increase in the current passing through the valve, the existence of the positive ions also masks the controlling effect of the grid, and the current therefore continues to flow at its maximum value until the charge on the anode is removed. These gas-filled valves are called *thyratrons*. They have proved to be especially useful in the auxiliary apparatus incorporated in oscillograph units, as explained in Chapter VI.

Sine Waves and Graphical Representation

The cathode-ray oscillograph is primarily an instrument for depicting wave-forms, and a few observations may be made at this point regarding graphical representation which bear on the question of oscillograph patterns.

In Fig. 5, the wavy curve is the path traced out by a point which represents the relation between current and time in such a system, for example, as an electric fire connected to an A.C. supply main. The rise and fall of current, first in a positive direction and then in a negative direction as time progresses, is clearly shown. The trace shows four complete cycles of alternation and the beginning of the fifth. The duration of each cycle in this example is 1/50 second.

The *amplitude* of the curve is the height (or depth) to which it rises (or falls) from the zero value of current.

The shape of the curve corresponding to the usual A.C. supply is of the type known in mathematics as a *sine wave.* It is so called from its trigonometrical character. When an alternation is of this form it is said to be *sinusoidal.*

In radio and telephone engineering, the alternating voltages and currents are usually very complex, and the corresponding wave-forms are not of the simple sine form shown in Fig. 5. They are, in fact, combinations of many different sine waves of different frequencies added together so that the resultant curve looks extremely irregular. Nevertheless, even the most complex wave-forms can be repeated cyclically. The cathode-ray oscillograph handles them with ease.

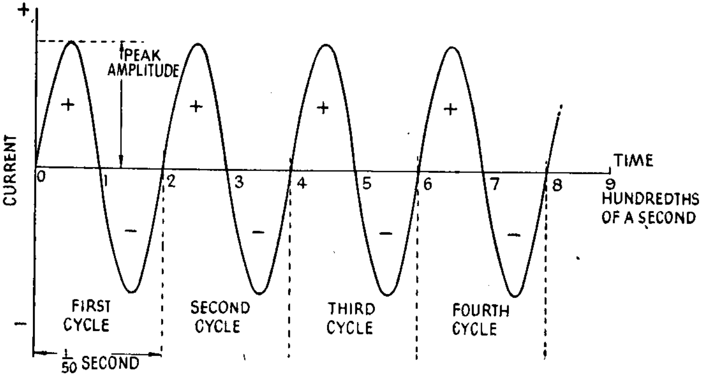

FIG. 5.

This sinusoidal curve represents the wave-form of the current flowing through a resistance connected to an A.C. supply. The frequency is 50 cycles per second.

Graphs are not confined to representing the change of some factor with time, or to showing cyclic variations. Any two factors which are inter-related may be plotted graphically, and the path traced by the point will show the relationship between them. For instance, if an increasing stretching force is applied to a spring, the spring extends. By plotting the extension of the spring against the force which produces it, making a mark on the graph for each pair of measurements, the result when the marks are joined up will be found to be a straight line. Provided the spring is not stretched beyond its elastic limit, the same spring will always behave in such a way as to give the same line. The extension is proportional to the force, or, using the alternative phraseology, the extension varies linearly with the force.

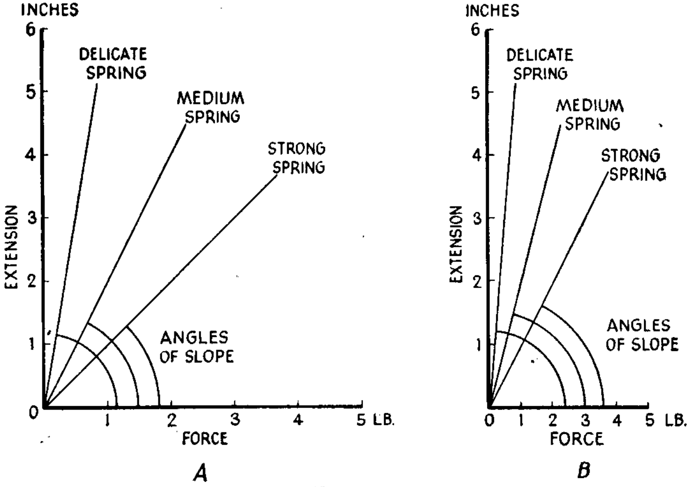

FIG. 6.

The extension of a spring is proportional to the stretching force. This is represented graphically by a straight line, the slope of which depends on the strength of the spring. In B, the relationships between extension and force are the same as in A, but the scale of force is reduced.

The *slope* of the line depends on the stiffness or sensitiveness of the spring. A strong spring yields little to the stretching force, and a delicate spring extends easily. These characteristics are represented in Fig. 6A.

Choice of Scale

Of course, the actual slope of the line as it appears on the graph in relation to the axes depends on the openness or closeness of the scales marked out along the axes. By re-drawing the graph with a more cramped scale along the " force " axis (but with the scale along the " extension " axis unchanged), the slope of each line would be made steeper: see Fig. 6B.

For general convenience, the best practice is to choose the scales before the graph is plotted so that the curve or the pattern will be spread out more openly over the space occupied by the graph. In oscillograph work, this adjustment is made by controlling the amplitudes of the applied voltages.

CHAPTER III

CONSTRUCTION OF THE CATHODE-RAY TUBE

THE fluorescent property of the sensitive screen used in the cathode-ray tube has already been described. It now remains to consider the methods by which the electron stream is formed into the sharply pointed ray and how it is caused to move up and down and across so that the spot of light can traverse the whole area of the screen.

The electrons which eventually strike the screen are liberated from a small thermionic cathode at the opposite end of the tube. If they are to produce fluorescence, they must have sufficient velocity. The electrons acquire this velocity, which is usually between 5,000 and 20,000 miles per second, by the accelerating effect of an anode maintained at a high positive potential.

In Fig. 7A, the drawing illustrates the simplest elements required to produce a beam of electrons. Such an arrangement by itself, however, could not be made to produce a narrow, sharply focused beam, and it would be impossible to alter the intensity of the beam without considerably altering its breadth.

Electrostatic Focusing

In practical high-vacuum cathode-ray tubes, another electrode, also positively charged, called the *second anode*, or anode No. 2, is used to assist the *first anode* in focusing the broad stream into a narrow pencil of rays so that it is less than ½-millimetre in diameter when it strikes the screen. The fluorescent spot of light is therefore correspondingly small. See Fig. 7B.

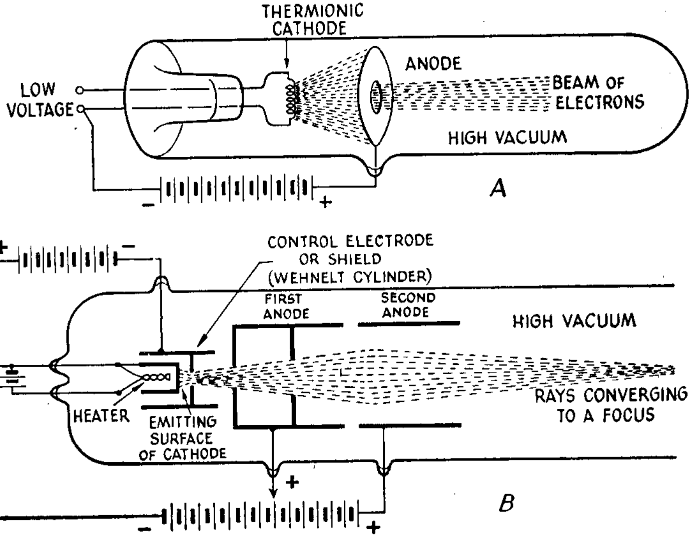

FIG. 7.

The simplest arrangement for producing a beam of electrons is shown in A. The more elaborate system represented in section in B exerts a focusing effect on the electron paths.

The pair of anodes act together in providing a lens action, the effective focal length of the system being adjusted by varying the ratio of the two anode voltages. It is sufficient to keep one voltage fixed within prescribed limits and to vary the other.

Surrounding the cathode is a further electrode in the form of a cylinder. It is maintained at a small negative potential with respect to the cathode, and by adjusting this potential the intensity of the beam and therefore the brightness of the spot can be controlled. This electrode, which acts in a manner similar to the control grid in a valve, is known as the *modulator,* or *shield,* or sometimes as a *Wehnelt cylinder.* If necessary, the spot can be extinguished by suitably increasing the negative potential.

The Electron Gun

The cathode, the shield and the two anodes form a compact assembly, and this assembly is known as the *electron gun.* Each electrode is essential to the proper working of the others, but each has a predominant function. Thus the potential applied to the shield controls the intensity of the beam, while the potential applied to the first anode controls the focus.

To some extent these controls affect one another. An adjustment of the brightness sometimes necessitates a resetting of the focus, and vice versa. Further, if the potential of the main accelerator anode is not within the optimum range of values, it may be impossible to focus the beam to a small spot however much the potential of the first anode be varied.

The makers of cathode-ray tubes always recommend a set of values for the various voltages to be applied to the electrodes. If these instructions are followed, and if certain other precautions (described in Chapter VII) are observed, there should be no difficulty in obtaining a small, sharply defined, round spot.

In most modern tubes a third anode is used. This has the advantage of virtually removing the interaction between the brightness and focus controls.

A typical form of anode assembly is shown in Fig. 8.

Gas-Focused Tubes

Instead of relying on the effect of the electric field created by the specially constructed anodes for focusing,

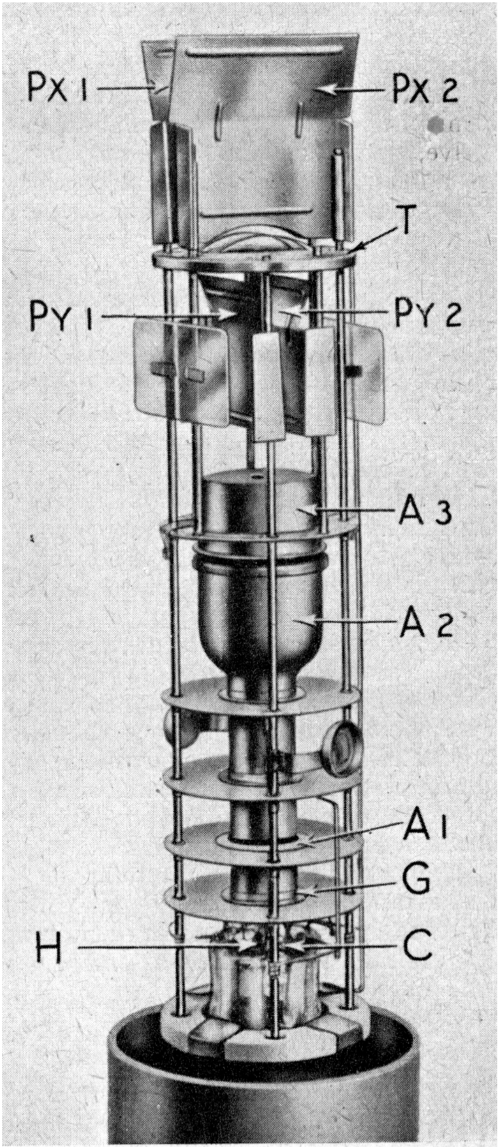

Fig. 8.

The electrode assembly of a three-anode cathode-ray tube, showing the positions of the anodes A1, A2, A3, the shield G, the cathode C, heater H, and the X and Y deflector plates.

a small quantity of gas is included in some types of tube for achieving the same effect. Strictly speaking, the gas does not have a focusing action but rather an automatic constricting action. It is necessary first to concentrate the electrons into a fairly narrow beam by causing them to pass through a small aperture in an accelerator plate, or anode. Then, as the electrons travel onwards through the gas, their collisions with the gas atoms cause these atoms to become ionised.

These gaseous ions are very much heavier than the electrons and are therefore comparatively sluggish in their movements. Consequently, there is little tendency for them to drift out of the path where they were originally formed. And because they are positively charged, they strongly attract the negative electrons and prevent them from straying sideways out of the beam. The positive ions in this way provide a self-stabilising core to the beam. The effectiveness of gas-focusing depends on the degree of ionisation, and the simplest method of controlling this is to adjust the intensity of the electron beam by varying the cathode-heating current. Gas-focused tubes are often constructed with filament type cathodes so that this adjustment may be made more easily.

Incidentally, a good many of the ions in the beam re-unite with some of the electrons, and in doing so emit a faint glow. The actual path of the ray can then be seen in a suitably darkened room.

Although gas-ionisation is a convenient method of focusing the beam, it has two disadvantages: the life of the cathode is shortened due to the bombardment by some of the positive ions, and on account of the sluggish movement of the ions the speed of operation as an oscillograph is limited to a maximum frequency of a few hundred kilocycles per second. If the rate of deflection becomes too rapid, the spot loses its sharp focus.

There is a third disadvantage, which can, however, be overcome by certain constructional modifications. The fault is known as *origin distortion* and appears as a kink in the wave-trace whenever it passes across the centre of the screen. It is due to the presence of the positive-ion space-charge between the deflector plates.

A drawing of the constructional elements required for producing the narrow beam in a gas-focused cathode-ray tube is shown in Fig. 9.

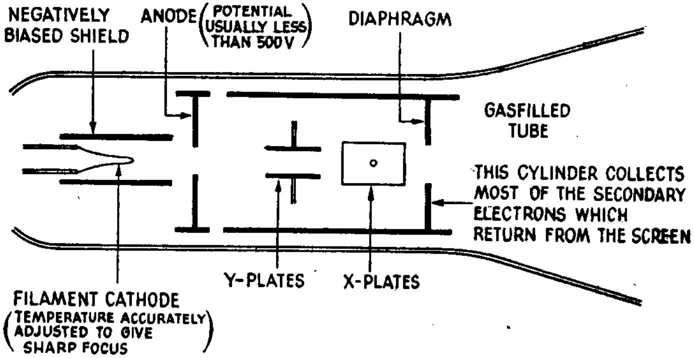

FIG. 9.

The elements required to produce a narrow beam of electrons in a gas-filled tube. The focusing is achieved by the concentrating effect of the positive ions formed in the path of the beam, and is adjusted by varying the cathode temperature.

Electromagnetic Focusing

Yet another method of focusing is sometimes used, although more often in television picture tubes than in oscillographs. A large coil of wire is slipped over the neck of the tube in the region otherwise occupied by the various electrodes of the gun, and a steady current of electricity is passed through the coil. This produces a steady magnetic field along the axis of the tube. When the electrons from the cathode travel towards the screen, their paths are made to curve in a slow spiral by the effect of the magnetic field so that they become bunched together at the end of their journey into a sharply pointed pencil of rays.

Fig. 10 shows the constructional elements required for electromagnetic focusing.

Deflection of the Beam

The spot of light will remain in the same place on the screen unless the beam is deflected. There are two simple methods by which the deflection can be accomplished. In both cases the direction of the beam is changed just after it has emerged from the gun.

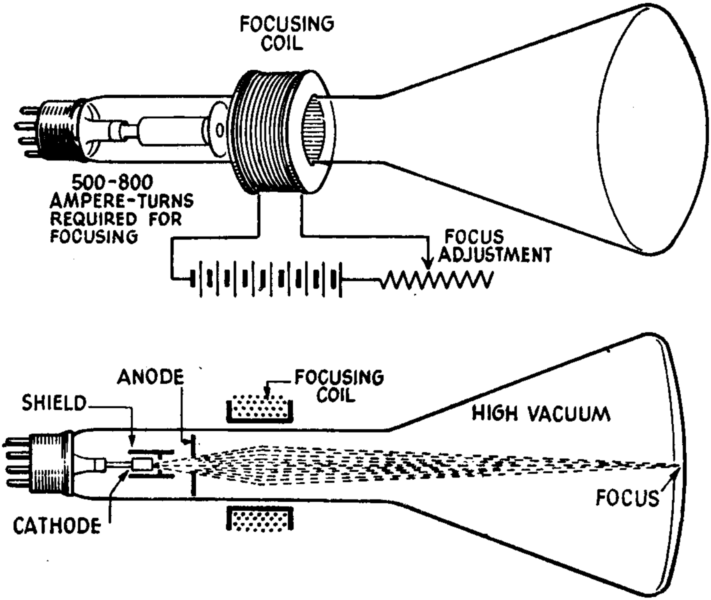

FIG. 10.

The constructional elements required for magnetic focusing. The adjustment is effected by varying the current flowing through the coil.

In one method the deflection is produced electrostatically (by applying a potential difference to a pair of electrodes) and in the other it is produced magnetically (using coils of wire carrying electric currents).

It is more usual to employ electrostatic deflection in oscillograph tubes, for this method has a negligible effect on the performance of the apparatus to which it is connected. Electromagnetic deflection, on the other hand, requires appreciable electric power for its operation, and in television receivers, where the deflection is produced by special auxiliary apparatus, this method is often pre-

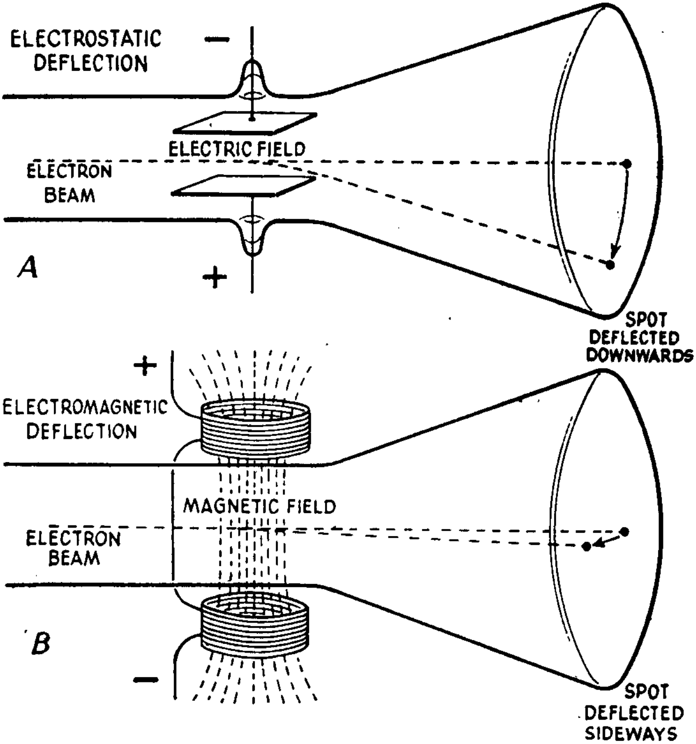

FIG. 11.

The position of the deflecting elements for electrostatic and electromagnetic deflection. The bending of the beam occurs only where it passes through the deflecting field.

ferred because it allows the beam to be deflected at wide angles without loss of focus.

The placing of the deflecting elements in relation to the path of the beam in the two methods is illustrated in Fig. 11.

Electrostatic Deflection

In the electrostatic case, two small metal plates are mounted in the tube parallel to each other and connected by wires to an external source of potential difference. An electric field then exists between the plates in a direction at right-angles to the beam.

When the electrons enter the space between the plates they are repelled by the negative plate and attracted by the positive plate. They are travelling so fast, however, that they move out of the electric field before they have had time to move sideways so far as to touch the positive plate. But at least they have been pulled sideways to an appreciable extent. Although the forward velocity which carries the electrons towards the screen remains unaffected, the sideways pull has altered the direction of the beam, and as long as the potential difference exists between the plates the beam will remain deflected. If the potential is removed, the beam will return to its straight, undeflected path.

By reversing the direction of the electric field, the beam can be deflected in the opposite direction. Moreover, the amount by which the path is altered depends directly on the strength of the electric field, *i.e.*, the deflection is proportional to the potential difference between the plates. It is also inversely proportional to the spacing between the plates.

Suppose now that an alternating potential is used instead of a steady potential. The effect of this will be to cause the spot to swing rapidly to and fro. The A.C. supply mains may well be used for this test. Since the frequency is 50 c.p.s., the movement of the spot will be too rapid for the eye to follow. Consequently, the appearance will be that of a straight line of light traced out as the spot oscillates to and fro.

It is worth noting at this stage that no current passes from one plate to the other. All that is required is a difference of potential. No power is consumed in the deflecting process.

Electromagnetic Deflection

Any current of electricity has associated with it a magnetic field. The stream of electrons travelling through the tube towards the fluorescent screen is an electric current. The fact that it exists in space without a metallic conductor makes no difference, and the electron beam is nevertheless surrounded by a magnetic field of its own.

By arranging another magnetic field to interact with it, a displacement of the beam can be produced. The action is similar to the disturbing effect which an ordinary magnet has on a compass needle. A pair of electromagnets placed on opposite sides of the beam provide a magnetic field which crosses the beam transversely. The effect of the interaction is to apply a mechanical force to all the electrons in the beam while they are passing through the applied magnetic field, and the direction of this force is at right-angles to the beam and at right-angles to the magnetic field. Fig. 11 B indicates these three directions and the manner in which the electromagnets are placed athwart the beam.

Just as the deflection produced electrostatically is proportional to the potential difference applied to the plates, the deflection in the electromagnetic case is proportional to the current flowing through the deflecting coils. It is also proportional to the number of turns of wire in the coils.

A comparison of the drawings A and B in Fig 11 shows that in order to deflect the spot in a vertical direction the electrostatic deflecting plates must be mounted vertically one above the other (the plates themselves being horizontal), whereas to produce a similar effect the electromagnets must be mounted so as to have their common axis horizontal.

For a horizontal deflection of the spot, *i.e.*, an x-deflection, the electrostatic plates must be vertical, their spacing being horizontal. The electromagnets would of course have to be mounted with their axes vertical.

Deflection in Two Directions

It has already been explained how the position of the spot at any point on the screen can be resolved into two quantities—the distances from two axes at right-angles. By providing two pairs of deflecting plates (or two pairs of electromagnets) and arranging one pair so that it is at right-angles to the other, it is possible to deflect the spot in either of two directions at right-angles, separately or simultaneously, and so shift it to any point on the screen by suitably controlling the potentials applied to the two pairs of plates (or the currents fed to the two pairs of coils).

The pair of plates which deflect the spot horizontally along the x-axis are called the *X-plates,* and the other pair which deflect the spot vertically, *i.e.*, along the y-axis, are called the *Y-plates.*

The Complete Cathode-Ray Tube

The essential elements of a high-vacuum cathode-ray tube are—

(*a*) the cathode
(*b*) the beam intensity control system
(*c*) The beam focusing system
    the so-called electron gun
(*d*) the deflecting system
(*e*) the fluorescent screen.

In the foregoing description, the alternative constructional systems have been outlined. Although with so many alternatives it would be possible to make several different types of tube, there are various technical reasons why some of the combinations would not prove satisfactory. In practice, only a few main types are encountered. Most of the tubes used in oscillographs intended for general application are of the high-vacuum, electrostatically-focused, electrostatic-deflection type, and it is this type with which this book is primarily concerned. A drawing representing the construction of such a tube is shown in Fig. 12.

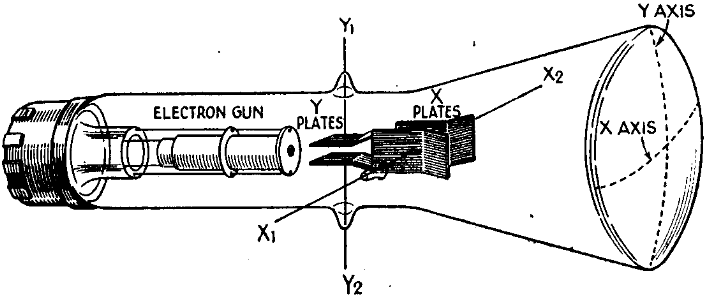

Fig. 12.

The position of the deflecting plates in relation to the electron gun. The pair of plates more remote from the screen are usually preferred for the Y-deflection, since the effective deflection-sensitivity increases with the length of the beam after deflection.

Deflection Sensitivity

If the electrons are travelling too fast when they pass through the deflecting zone, they will not respond sufficiently to the deflecting influence. The accelerating potential must therefore not be too high. The lower this potential, the greater the deflection. In other words, the tube becomes more sensitive as the accelerating voltage is reduced. There is a lower limit to this, however, for the spot may become too faint or it may become impossible to focus it sharply if the voltage is too low.

In the electrostatic-deflection type, which is always preferred where high sensitivity is required, the deflection sensitivity S is expressed as

$$S = \frac{K}{V} \text{ millimetres per volt,}$$

where K is a certain number depending on the tube construction and V is the accelerator-anode potential in volts (and not the deflecting voltage). The value of S gives the number of millimetres by which the spot is deflected for each volt of potential difference applied to the deflector plates.

The sensitivity in the case of electromagnetic deflection is

$$S = \frac{k\,L}{V} \text{ millimetres per gauss,}$$

where k is a fixed number depending on the tube, L is the distance for which the electrons travel through the deflecting field, and V is the accelerator-anode potential in volts.

Tubes which have the deflector system arranged close to the screen have less deflection-sensitivity than those in which this distance is great, for the actual displacement of the spot for any given angle of deflection obviously depends on the length of the beam from the point at which the deflection occurs.

Television Tubes

Television picture tubes are constructed especially to meet the somewhat different conditions under which they operate. For instance, the control over the brilliancy of the spot is extremely important. The light and shade of the picture depend upon the effectiveness of this control. Great sensitivity of the shield, or modulator, is therefore a feature of their design. No special attention is given in television tubes to providing high deflection sensitivity: deflection distortion is of greater significance. The sensitivity is often comparatively low. For such reasons as these, it is hardly practicable to use a television tube for general oscillograph purposes.

Double-Beam Tubes

It often happens in the examination of various kinds of apparatus that information is required simultaneously about two different quantities which are both varying with time or with some other third quantity. Instead of using two separate oscillographs, it is possible to observe the changes in the two quantities on the screen of one of the double-beam tubes designed for such purposes.

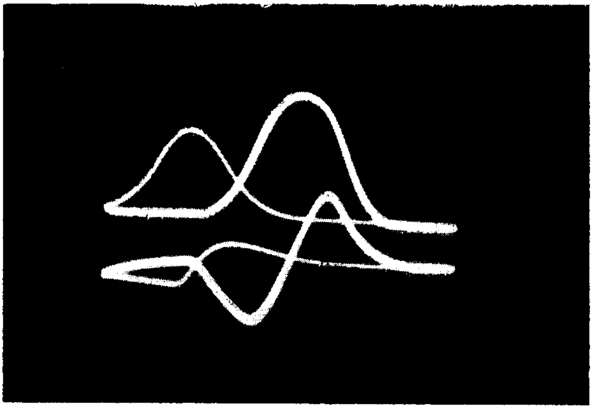

FIG. 13.

An example of the double trace obtained with a double-beam type of tube. The curves represent response characteristics in a radio receiver using frequency-modulation.

In construction they are similar to the ordinary tube, except that a metal plate is inserted in the path of the electron beam to split it into two beams. The two separate streams of electrons then pass between pairs of deflector plates in the ordinary way, connected separately to the different parts of the circuit.

The X-plates are common to both beams, but two pairs of Y-plates are provided. The two spots can thus be moved separately in the vertical direction, but whatever one spot is made to do in the horizontal direction the other spot does also.

Fig. 13 shows an example of a double trace obtained with one of these double-beam tubes.

Double Trace by Electronic Switching

Even with an ordinary single-beam tube it is possible to obtain two separate traces simultaneously on the screen. This is achieved by rapidly switching the deflector plates from one circuit to the other. If the switching is repeated at a frequency higher than about 25 alternations per second, the eye will not be troubled by excessive flicker.

Mechanical switching systems are hardly suitable for this purpose. Special valve circuits have been devised in which the switching is performed electronically. The effective voltages in the two circuits under observation are applied through the electronic cathode-anode paths in a pair of valves to the deflector plates of the oscillograph. The two valves are rendered alternately conducting and insulating by applying suitable control voltages to their grids.[3]

CHAPTER IV

THE CATHODE-RAY TUBE AND ITS CIRCUIT CONNECTIONS

It is an unavoidable complication that before the cathode-ray tube can be put to work it must be properly fed from supplies at several different voltages. The actual power required is trivial, because although the voltages are mostly quite high, the currents which flow are extremely small and often negligible. There is, of course, the supply to the cathode heater which consumes about

4 watts at a low voltage, usually between 2 and 6.3 volts. But the other electrodes must be maintained at higher voltages, of 400 at least and in some cases approaching 10,000 volts. The supply circuits for cathode-ray tubes must therefore be regarded as DANGEROUS.

High-Voltage Supplies

These high voltages are conveniently obtained from A.C. supply mains by first stepping up the mains voltage to several hundred or several thousand volts and then converting the high-voltage A.C. into high-voltage D.C. by means of rectifiers and smoothing circuits. Sometimes a double rectifier having two anodes is used, so that the current supply is maintained when the voltage periodically changes sign, but the current required is so small that it is sufficient to use a single anode rectifier (of the kind represented in Fig. 3). A reservoir condenser is included in the circuit to store the electric charge at the high potential, and the filter smooths out the succession of impulses of current from the rectifier into a steady flow.

A high resistance connected across this high-voltage D.C. supply can be tapped at various points to obtain various intermediate voltages. There is no need to use a separate transformer, rectifier and reservoir system for supplying the high voltage to each of the anodes in the cathode-ray tube.

The fluorescent screen receives a current in the form of the electron beam, but this is only of the order of a few microamperes. A graphite film on the inner wall of the tube, connected to the final anode and therefore to earth, enables the electric charge to leak away before it becomes large enough to interfere with the proper action of the beam.

Fig. 14 shows a typical circuit diagram of a power supply system and the way in which it is connected to the electrodes in the tube. The arrangement is very similar in principle to the power supply circuits which are used in radio receivers and transmitters and in amplifier equipment generally.

Safety Precautions

There is one difference, however, which is worth noting. It is a question of personal safety. Those who experiment with radio and amplifier circuits acquire by habit a disregard of danger where the *negative* side of the high-voltage supply is concerned, while they wisely avoid contact with the *positive* side of the supply. The reason for this practice is that in radio and amplifier apparatus it is preferable to earth the valve cathodes, and therefore

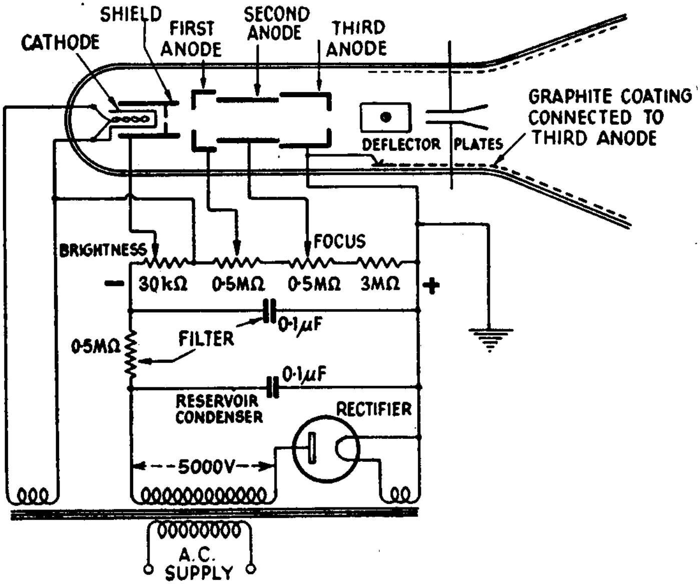

FIG. 14.

A typical power supply for a three-anode tube. The adjustable potentials for the brightness and focus are obtained from potentiometers. Note the connection to earth from the positive side of the high-voltage supply.

the negative side of the high-voltage supply is earthed. No shock would be experienced on touching it, whereas contact with the positive side presents a real danger. (This assumes that the operator is not touching any other part of the circuit.)

In cathode-ray tube practice, it is usually the *positive* side which is earthed, the reason for this being that if the fluorescent screen is not earthed, the pattern is likely to be distorted by the proximity of metal objects or the operator's fingers near the screen. Therefore the screen should be earthed, and because the screen is connected internally by the graphite coating to the final anode, this anode must also be earthed, and anything connected to the *negative* side of a cathode-ray tube supply is at a very high voltage to earth.

In any case, it is far better to switch off the supply completely whenever any of the connections have to be handled.

Connections to the Tube

The cathode-ray tube is always fitted with a multi-pin cap which fits into a corresponding socket connected to the various parts of the circuit. The deflector-plate connections are sometimes brought out through the sides of the tube (see Fig. 15) in order to reduce harmful electrostatic capacity effects and to avoid the greater length of wiring which is necessary when all the connections to the tube are bunched together in the cap.

In a large variety of applications it happens that several of the electrodes are connected to the same part of the circuit. Sometimes advantage is taken of this to economise in the number of pin connectors by connecting those electrodes together inside the tube and bringing out the common lead to one pin.

Operating Characteristics

Table II gives the ratings and characteristics of a

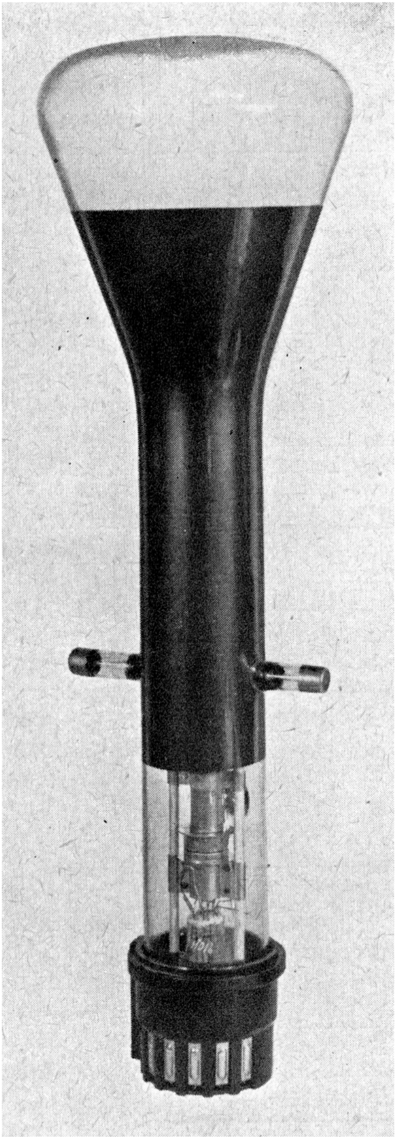

FIG. 15.

A high-vacuum cathode-ray tube in which the leads from the Y-deflection plates are brought out at the sides of the tube to avoid electrostatic coupling effects and to permit shorter connections.

TABLE II

MAKER	TYPE	SCREEN DIAM. (INCHES)	APPROX. LENGTH (INCHES)	HEATER		SHIELD VOLTAGE (CUT-OFF)	ANODE VOLTAGES			DEFLECTION SENSITIVITY (mm/VOLT)		COLOUR OF FLUORESCENCE	NOTES
				VOLTS	AMPS		V_1	V_2	V_3	X	Y		
COSSOR	09	4½	14¾	4·0	1·0	$-0·025\ V_3$	—	$0·25\ V_3$	1200-2000	$\frac{400}{V_3}$	$\frac{400}{V_3}$	GREEN	DOUBLE BEAM
G.E.C.	4102	2½	8	4·0	1·1	$-0·025\ V_3$	400-1500	$0·15\ V_3$	400-1500	$\frac{170}{V_3}$	$\frac{170}{V_3}$	GREEN	OSCILLOGRAPH
MULLARD	MW22-5	9	14½	6·3	0·6	—	—	5000	—	—		WHITE	MAGNETIC DEFLECTION
S.T.C.	4050 BB	7	18½	0·75	0·7-1·1	—	350-2000	—	—	$\frac{580}{V_1}$	$\frac{580}{V_1}$	BLUE	GAS FOCUS
S.T.C.	4063 YB	6¼	21	2·0	1·8-2·0	−30	150	$0·27\ V_3$	5000	$\frac{600}{V_3}$	$\frac{700}{V_3}$	BLUE	OSCILLOGRAPH
DU MONT	3 AP	3	11½	2·5	2·1	−50	425	1500	—	$\frac{340}{V_2}$	$\frac{350}{V_2}$	GREEN, WHITE OR BLUE	OSCILLOGRAPH
DU MONT	20 AP	20	28	2·5	2·1	−80	1800	4000	8000	$\frac{1150}{V_3}$	$\frac{1200}{V_3}$		TELEVISION

TYPICAL OPERATING CHARACTERISTICS
OF MODERN CATHODE-RAY TUBES

representative selection of oscillograph tubes. From the user's point of view, the important features are the screen diameter and the deflection sensitivity, consideration also being given to the duration of the afterglow. The voltage ratings are of interest to the designer of the oscillograph equipment as a whole.

Deflection Amplifiers

Most modern cathode-ray tubes have a reasonably high deflection sensitivity, and will therefore show a useful deflection of the spot for voltages of 50 or 100 volts, such as often come under examination in radio and allied apparatus. In general, it is a great convenience to be able to amplify the voltage which is to be investigated. This broadens the field of application by making it possible to study the behaviour of quite small voltages which, without amplification, would produce a barely perceptible deflection. Some oscillographs have a one-stage or a two-stage valve amplifier included as a part of the equipment. External amplifiers can, of course, be used whenever necessary.

A deflection amplifier must be as nearly perfect as possible. If an oscillograph is used for locating faults in a piece of apparatus, the observations will be difficult to interpret accurately if the deflection amplifier is faulty.

Hardly any current passes between the deflector plates —from one plate to the other—and for this reason the deflector plates can be connected to almost any circuit, even very high-resistance circuits, without disturbing the conditions which are to be examined. What little current there is arises from the leakage of electrons from the beam.

Where electromagnetic deflecting coils are used, the current which must flow in the coils represents an appreciable amount of electric power. Consequently, this method is unsuitable where an adequate reserve of power is not available. It would be impracticable, for instance, to connect the deflecting coils to a gramophone pickup or to the aerial circuit of a radio receiver.

Lissajous Figures

Imagine a person sitting on a swing, oscillating gently to and fro. Suppose the person is holding a string from which is suspended a pot of sand having a small hole in it, and that the pot is swinging from side to side. The sand trickles out in a fine stream and draws a wavy figure on the ground beneath the swing as the pot is carried from side to side and to and fro.

The figure will be different if the string is shortened so that the pot swings faster. Any change in the speed or timing will alter the figure, and there is a great variety of possible combinations. Such figures, produced by two oscillating motions at right angles, are called *Lissajous figures*.

If two alternating voltages are applied to the X-plates and the Y-plates respectively, the spot will describe a Lissajous figure. When the two voltages alternate at exactly the same frequency, the spot will describe a simple stationary figure—either a straight line or a circle or an ellipse. Which of these it happens to be depends upon the phase relationship between the alternations of the two supplies, that is to say, on the relative timing of the cycles of positive and negative voltage of the two supplies. See Fig. 16 A.

The figure will be stationary only if the frequencies are exactly the same. A slight difference between them will cause the figure to change gradually from a line to an ellipse, then to a circle, an ellipse, and a line again and so on. The bigger the difference, the faster will be the change, until when one frequency becomes twice the other frequency the pattern will be stable once more, but of a different character: see Fig. 16 B.

When the frequencies are in the ratio of three-to-one, the figure on the screen will be similar to one of those

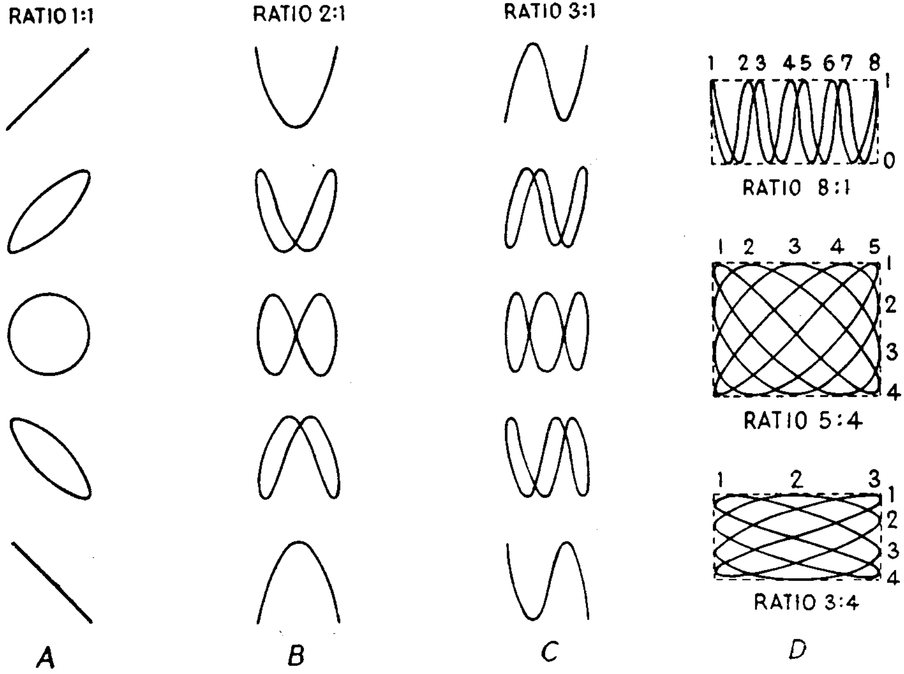

FIG. 16.

Lissajous figures. For any given ratio of frequencies, the figure varies with the phase difference as shown in A, B and C. In D, examples are given for other ratios but for only one phase relationship in each case.

shown in Fig. 16 C. The higher the ratio, the greater the number of loops in the figure. It should be noted that the form of the figure always depends on the phase relationship. And the figure may appear to be on its side if the X-frequency is some multiple of the Y-frequency instead of vice versa.

In Fig. 16 D, typical examples of patterns produced with other simple ratios are shown. In each case it will be seen that, by considering the pattern as lying within a rectangular frame and counting the number of reversals of the trace which occur along the horizontal and vertical edges of the figure, the ratio of the frequencies is obtainable directly.

One alternating voltage may therefore be analysed in terms of another, and, in fact, a sinusoidal reference voltage is used in some applications. Generally, however, it is more convenient to use a linear rate of variation for the reference voltage.

Linear Time-Base

There is no doubt that the linear time-base is the most important adjunct to the cathode-ray tube. It is a special form of electrical oscillator which provides a recurrent rise of voltage from zero to maximum at a steady rate, falling abruptly to zero after each maximum. This so-called " saw-tooth " voltage is applied to the X-plates. The spot is thereby moved steadily across the screen along the *x*-axis until it reaches the maximum deflection, after which it flies back to the beginning and starts off again at the same steady rate.

The duration of the steady sweep is vitally important. It fixes the time scale, or time " base," on which the pattern is traced out on the screen. It is called " linear " because the change which it produces is a steady one: the distance by which the spot is deflected sideways is proportional to the time which has elapsed since the beginning of the sweep. A graph showing its own displacement against time would be a straight line.

The various circuit arrangements which have been developed for generating the "saw-tooth" wave are of such importance that they call for detailed consideration in a separate section: see Chapter VI.

Spot-Shift

Normally, when no deflecting forces are applied, the spot appears at the centre of the screen. If all the changes in the voltages which are to be examined occur in one direction, such as, for instance, the rise and fall of the positive voltage on the anode of an amplifier valve, the spot will trace out a figure on only one side of its zero position. The advantage of a large-diameter screen is then largely wasted. By shifting the zero position to

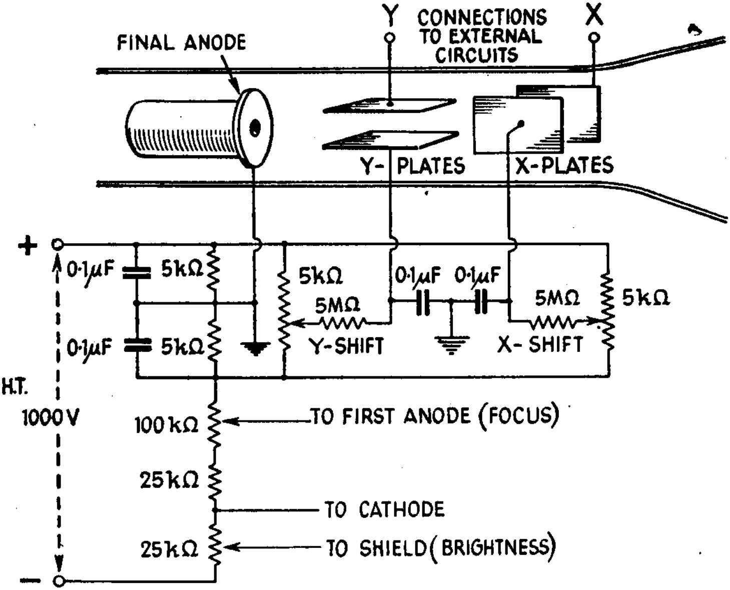

FIG. 17.

A typical circuit arrangement for the X and Y-shift controls. These are sometimes known as "push-about" controls.

the right or left, or up or down, as the case may be, more space will be available for tracing out a clear picture. A small congested pattern is always more difficult to interpret than a large open one.

To keep the spot continuously deflected it is necessary to maintain a suitable steady potential difference between the corresponding pair of plates. Any fluctuating voltage which it is required to examine can be superposed on this steady " shift " potential. All that is required is a potentiometer for providing the adjustable shift potential and a high resistance through which it is applied to one of the deflecting plates, the resistance being included to prevent the short-circuiting of the superposed voltage.

Fig. 17 shows the arrangement of potentiometers by which the spot can be shifted horizontally or vertically in the electrostatic type of tube. Where electromagnetic deflection is used, a steady current must be passed through the coils with chokes to prevent the dissipation of the applied fluctuating currents in the D.C. shift circuit.

CHAPTER V

VALVE AMPLIFIERS AND THYRATRONS

MANY of the uses to which the cathode-ray oscillograph is put are intimately related to the adjustment and operation of valve amplifiers of various kinds. A brief survey of the chief characteristics of amplifiers will therefore serve two purposes.

The control electrode of a triode valve, it will be remembered, is a grid. The voltage to be amplified is applied between this grid and the cathode of the valve. How much of the electron current passes through the grid to the anode depends on this voltage. As the grid voltage becomes less negative with respect to the cathode, the retarding effect diminishes and the anode current rises.

Its maximum value is limited by the electron-emission capability of the cathode and by the various conditions in the external circuit. In the opposite direction, a sufficiently high negative potential applied to the grid reduces the anode current practically to zero. This relationship is shown graphically in Fig. 18 A.

The anode voltage also influences the flow of electrons, for it is this voltage that gives them the necessary acceleration. Increasing the anode voltage will naturally increase the anode current at any value of grid voltage between the "cut-off" and "saturation" values. The characteristic curve for the higher voltage therefore appears further to the left. Reducing the anode voltage corresponds to a movement of the curve to the right.

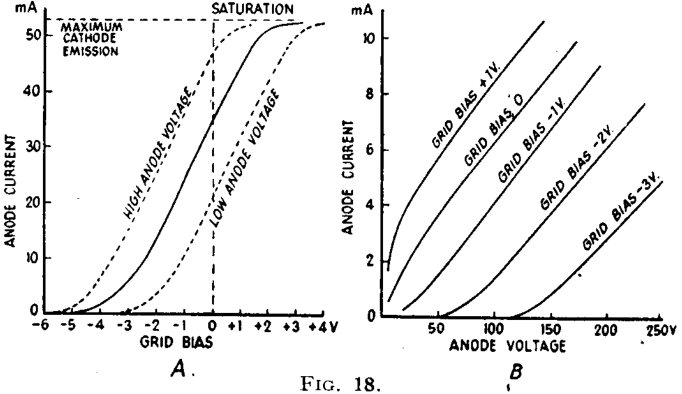

FIG. 18.

The characteristic curves of a triode valve, showing (A) the effect of grid voltage on the anode current and (B) the variation of anode current with anode voltage.

Another method of representing the relationship between grid voltage, anode current and anode voltage is shown in Fig. 18 B. For certain calculations in circuit analysis, it is often more convenient to have the curves in this form. Here each curve shows the dependence of anode current on anode voltage for a fixed value of grid voltage.

Voltage Amplification

The variations of current in the anode circuit which result from changes in the voltage applied to the control grid can be converted into variations of voltage by including a resistance in the anode circuit. In accordance with Ohm's law, the voltage across the resistance will be proportional to the current flowing through it. The change in this so-called " load " voltage is many times greater than the change in the grid voltage which produced it, and the valve is therefore acting as an amplifier.

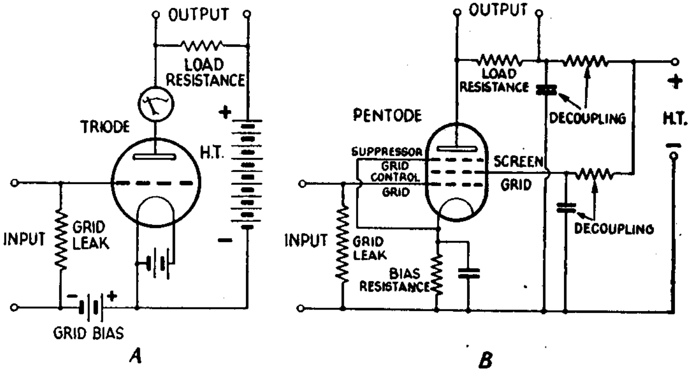

FIG. 19.

The basic circuit arrangements of triode and pentode valve amplifiers. The voltage-change appearing across the load-resistance is many times greater than the voltage-change applied to the input terminals. In B, automatic bias and decoupling are included whereby the amplifier may be operated from a mains supply unit instead of batteries.

Usually, the voltage to be amplified is alternating, and provided that the frequency lies within certain wide limits, the efficiency of the arrangement can be improved by substituting for the anode resistance a choke or a tuned circuit. These have the property of presenting a high resistance to alternating current of suitable frequency while the resistance to D.C. can be made very low.

An elementary amplifier circuit is shown in Fig. 19 A.

The principle employed here is the basis on which almost all radio receivers and transmitters are designed.

An amplifier may be required to operate at only one frequency or over a fairly narrow band of frequencies, or a very wide band, and the frequencies may be high (several megacycles per second) or comparatively low (a few hundred cycles per second). These considerations decide what types of coupling circuits are connected to the grid and anode of the valve.

Grid Bias

If the control is always at some negative potential—and never positive—it will not attract electrons. In other words, there will be no grid current. This is a very desirable feature in a valve amplifier, one of the reasons being that it will therefore not place a heavy load on any circuit to which it may be connected. A steady negative potential, called the *grid bias,* is commonly provided so that this condition is satisfied.

In mains-operated apparatus, it is customary to derive this bias voltage from the anode current by inserting a small resistance in the lead to the cathode. The current which passes through the valve also passes through this resistance, and the potential difference which appears across it is used to supply the negative bias voltage for the grid. The input voltage to the amplifier is connected in series with the bias.

Screen-Grid Valves and Pentodes

The efficiency of the valve as an amplifier can be increased by the inclusion of a *screen grid* between the control grid and the anode. The effect of this is twofold. First, it serves to prevent the loss of amplification by maintaining a strong flow of electrons to the anode when the anode potential falls to a low value once every cycle in the course of its operation. And second, it removes unwanted capacity coupling between the anode and the control grid, and thus prevents self-oscillation of the amplifier circuit.

A third grid is very frequently included—between the screen grid and the anode. This is called a *suppressor grid.* Its function is to repel the secondary electrons which are knocked out of the anode by the high-velocity electrons from the cathode, and the effect of this on the operational characteristics is to enlarge the permissible anode voltage swing. Such a valve is called a *pentode.*

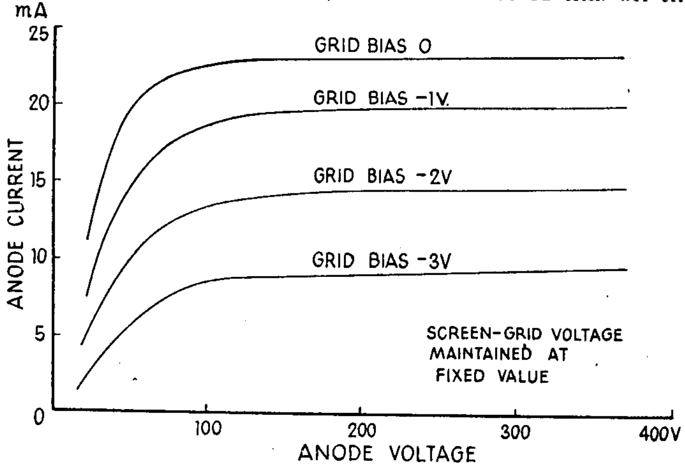

FIG. 20.

Typical characteristic curves of a pentode. These should be compared with Fig. 18 B, which relates to a triode. In the case of a pentode, the anode current is practically independent of the anode voltage over a wide range.

The screen grid is kept at a fixed high positive potential and the suppressor grid must be at a very low potential or at zero. Many valves of the suppressor grid type have the third grid connected internally to the cathode.

The curves shown in Fig. 20, which represent the anode-current/anode-voltage relationship for a typical pentode, should be compared with the curves of Fig. 18 B. The fact that a pentode acts as a " constant-current " device makes it especially useful in the linear time-base, as will be explained in Chapter VI.

Practical Amplifiers

The pentode is primarily an amplifier valve, and as such is used in almost every radio receiver and amplifier system. The basic connections of a pentode amplifier are shown in Fig. 19 B. Decoupling and automatic bias, commonly used where the apparatus is mains-driven, are also shown.

If the amplification produced by one valve is not sufficient, two or more valves can be used in succession with coupling circuits to suit the frequencies of the voltages to be amplified.

For general oscillograph work where an amplifier may be required to deal with signals within a wide range of frequencies, it is desirable that the amplifier should not need any adjustment for tuning to the signal frequency: *i.e.,* it should be aperiodic. This is achieved by using resistance-capacity coupling.

The Thyratron

At this stage the thyratron must be considered in greater detail. As explained in Chapter II, the effect of ionisation in a gas-filled valve, or thyratron, is to permit a comparatively heavy current to flow to the anode and to destroy the controlling action of the grid.

Provided that sufficient grid bias is applied to the thyratron in relation to its anode voltage, the current passing through it is negligible and ionisation is prevented. When the grid bias is reduced below a certain critical value, a very small electron current begins to flow to the anode. Ionisation will then occur suddenly and the current will immediately rise to its maximum value. Alternatively, this abrupt ionising effect can be brought about by keeping the grid bias steady and by raising the anode voltage above a certain critical value. The critical condition is determined by the ratio of the anode voltage to the grid voltage at the " trigger," or " striking " values. This ratio is known as the *grid control ratio*.

Fig. 21 A shows a typical control characteristic of a thyratron such as is commonly used in oscillograph time-bases. The critical values of anode voltage and grid bias voltage are indicated by the sloping line. In the example shown, for a bias of -9 volts, any increase of the anode voltage above 280 volts will cause ionisation. Similarly, a reduction of the bias below that value would also cause ionisation.

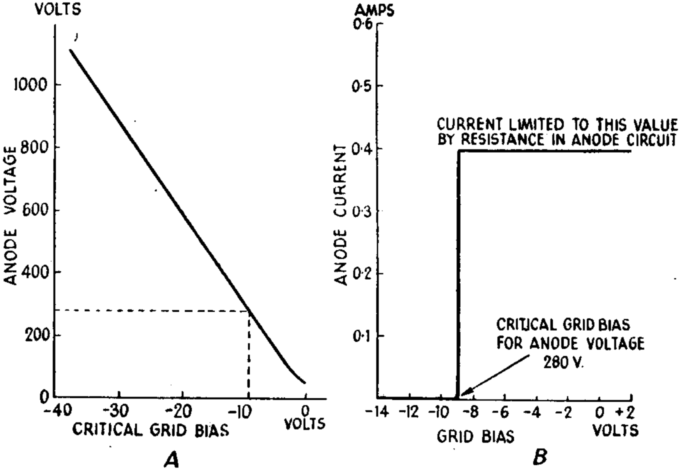

FIG. 21.

Thyratron characteristics. In A, the sloping line indicates the relation between anode voltage and grid voltage at the critical " striking " condition. In B, the anode current is seen to be unaffected by grid voltage after the grid voltage has been reduced below the critical value, thereby allowing the thyratron to " strike."

When this occurs, the resistance of the gaseous path in the thyratron practically disappears: the voltage between anode and cathode falls instantly to about 15 or 20 volts. The current is then limited only by the external circuit factors. This operation is represented graphically in Fig. 21 B.

To extinguish the ionisation, the anode voltage must be reduced below about 15 volts. It cannot be extinguished by making the grid strongly negative (except in special cases where the ionisation current is limited to a very small value).

FIG. 22.

A typical thyratron of the argon-filled type, specially designed for use in linear time-bases.

The thyratron therefore resembles a switch or relay device which is under the sensitive control of a small trigger signal and which requires re-setting after each operation. The industrial applications of thyratrons are very numerous, but in cathode-ray oscillograph technique and in television they serve only one purpose—a very important purpose—in the linear time-base circuit.

A typical thyratron, specially designed for use in time-bases, is illustrated in Fig. 22.

CHAPTER VI

THE LINEAR TIME-BASE

THE function of the linear time-base is to provide a constant time-rate of displacement of the spot along one of the axes, usually the x-axis. Several different circuit arrangements have been devised which give a suitable "saw-tooth" voltage wave-form. Some of them use one, two or even three high-vacuum valves, but probably the most popular is the thyratron time-base.

The steady voltage rise is obtained by feeding a continuous current into a condenser at a uniform rate. A condenser which is connected to a battery through a fixed resistance charges up eventually to the voltage of the battery, but the rate of rise of voltage across the condenser falls as the actual voltage increases. While this is happening, the current through the resistance is diminishing and eventually it becomes zero.

By replacing the fixed resistance with a resistance which diminishes in value as the voltage across it falls, the condenser-charging current can be kept constant.

The Constant-Current Pentode

The pentode can be used as a constant-current type of variable resistance. One part of the linear time-base circuit may therefore consist of a pentode in series with a condenser of suitable value, the two being connected to a fixed voltage supply. All the grids of the pentode can be given fixed potentials.

The next requirement is to discharge the condenser suddenly so that the voltage across it falls from its maximum value to zero or some negligibly small value. Immediately afterwards, the voltage across the condenser must begin to rise as before and continue steadily until the maximum is again reached after the same interval of time. Again the voltage must drop suddenly to zero and immediately begin a third steady rise, and so on.

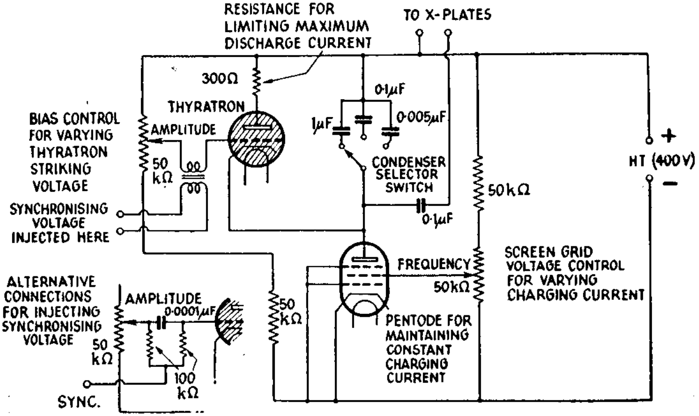

Fig. 23.

A linear time-base circuit using a thyratron. The frequency is controlled by the pentode screen potentiometer, while the range over which the control is effective is set by the condenser selector switch. The synchronising voltage may be injected inductively by a transformer connection, or (as shown in the inset) through a high resistance.

This regular discharge of the condenser could be achieved by an intermittent contact, operating for instance like a make-and-break in the ignition system of a petrol engine. The contact would have to be arranged to short-circuit the condenser. It is much more satisfactory, however, to avoid vibrating contacts and to use instead an electronic short-circuiting device. The thyratron fulfils the purpose very successfully.

The Thyratron Discharging Circuit

Fig. 23 shows a linear time-base circuit using a thyratron. The essential items in this arrangement are—

(1) the condenser which is to be repeatedly charged and discharged,

(2) the pentode which maintains the charging current constant,

(3) the thyratron which automatically discharges the condenser periodically.

The time-base assembly is connected to a D.C. supply the voltage of which is somewhat higher than the maximum deflection voltage required for sweeping the spot across the full width of the screen.

Two controls are needed where the time-base is to be used for general oscillograph test purposes, one for *frequency* and one for *amplitude*. It is practically impossible in the usual circuit arrangement to prevent a certain amount of inter-action between these controls, but provided that the controls are used intelligently it is easy enough to obtain a large or a small linear sweep voltage at any frequency within the range of operation. The reason for this interdependence will be apparent in the following explanation of the way in which the circuit functions.

Controlling the Frequency and Amplitude

The thyratron is provided with an adjustable bias voltage. If this is highly negative, the thyratron cannot "strike" until its anode voltage has reached a correspondingly high value. The anode voltage is the same as the voltage to which the condenser is charged, and a certain time must elapse while the charging current flows into the condenser in order to raise its voltage to this high value. The time required will be less if the striking voltage of the thyratron is lowered (by reducing its grid bias). But the time between the beginning of the charging to the moment when ionisation occurs is the duration, or period, of the time-base sweep. Therefore, lowering the grid bias from its originally high negative value will lower the peak voltage of the sweep and will also shorten the time of the sweep.

The sweep period is, of course, the reciprocal of the sweep frequency. For instance, if the period is one-tenth of a second, the time-base frequency is 10 c.p.s., neglecting the very small interval required for the "fly-back."

Fig. 24 A shows how the period depends on the voltage which is reached before ionisation occurs.

So far this operation has been described in terms of a given fixed charging current. If this current is increased to some other fixed value, the rate of charging will be faster and the striking voltage of the thyratron will be reached in a shorter time. The value of the steady charging current can be controlled simply by adjusting the potential of the screen-grid in the pentode: the higher the positive voltage on the screen-grid, the higher the current through the pentode and the higher the frequency of the time-base. The effect of varying the rate of charging on the frequency is shown in Fig. 24 B.

If the capacity of the condenser is large, it will take a comparatively long time for its potential to rise to the striking value set by the thyratron grid bias. Conversely, a small condenser will charge up quickly. A selection of different sized condensers therefore provides a variety of frequency ranges, each of which can be covered by variation of the pentode screen potential.

High-Speed Operation

For general use, a linear time-base is required to operate over a wide range of frequency. The slowest practicable rate is about 10 sweeps per second: below this the eye has difficulty in appreciating the figure on the screen as a pattern. Modern applications of the oscillograph demand increasingly higher time-base frequencies, and a sweep of about 250,000 c.p.s. is some-

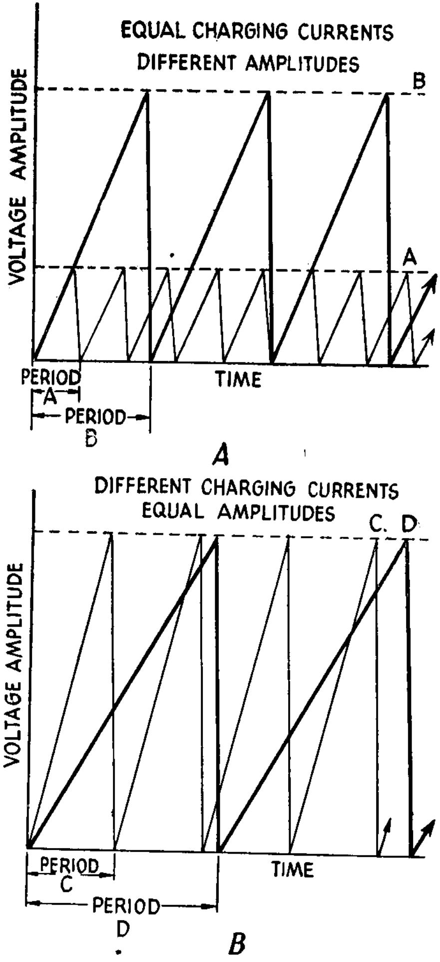

FIG. 24.

The effect of varying the value of the "striking" voltage (A) and the charging current (B) on the frequency of a "saw-tooth" oscillator as used in the linear time-base. The small voltage (about 15 volts) which remains across the condenser when the discharge is extinguished is negligible in comparison with the voltage sweep and is not shown in these graphs.

times necessary. The thyratron time-base, however, does not function reliably much above 40,000 c.p.s. For higher speeds, special circuit arrangements using high-vacuum valves, or so-called " hard " valves, have been devised.

The Hard-Valve Time-Base

A popular circuit arrangement, known as Puckle's

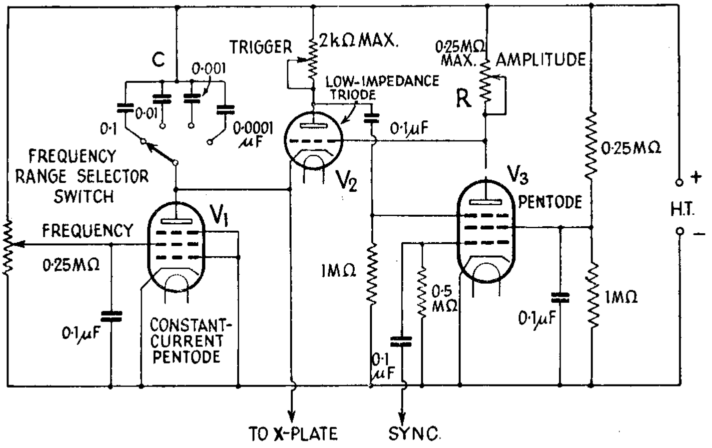

FIG. 25.

A linear time-base circuit using hard valves throughout. The valves V_2 and V_3 operate together as the equivalent of the thyratron shown in Fig. 23. This circuit is effective for all frequencies up to about 1 Mc/s.

time-base, using three high-vacuum valves, is shown in Fig. 25.[4] A pentode V_1 is used, as in the thyratron circuit, for maintaining a constant charging current for the condenser C. The thyratron is replaced by a pair of valves, V_2 and V_3, which operate together in such a way as to cause a very rapid discharge of the condenser C when the correct moment arrives.

While the condenser is being charged, the grid of the triode valve V_2 is biased negatively by the voltage across the resistance R (which is in series with the anode-cathode resistance of the pentode V_3), but eventually when the voltage across the condenser has reached a sufficiently high value, it lowers the effective bias on the grid of V_2 to the point where it allows current to flow through that valve. This rise of current causes the current in the valve V_3 to decrease, and this in turn drives the grid of V_2 more positive, thereby greatly accelerating the discharge of the condenser C through the valve V_2.

After the discharge, the valves return to their former condition and the voltage across the condenser C begins to rise again due to the steady current which passes through the pentode V_1.

The connection to the X-deflecting plate is taken from one side of the condenser, as in the thyratron circuit.

The trigger resistance (Fig. 25) which assists in promoting proper discharge action is usually made adjustable for, in general, it is found preferable to reduce its value as the time-base frequency is increased.

Whereas the thyratron time-base ceases to be satisfactory when an attempt is made to raise the frequency above about 40,000 c.p.s., the hard-valve time-base just described performs successfully at much higher frequencies, even as high as 1 Mc/s (1 million cycles per second).

Time-Base Amplifiers

If the cathode-ray tube requires a sweep voltage which is higher than the " saw-tooth " voltage developed by the time-base, it is necessary to provide suitable amplification. This can be achieved by conventional methods, but there is another aspect of deflection amplifiers which is sometimes very important, especially in television. In order to avoid a certain lack of balance in the pattern on the screen, known as *trapezium distortion* (and due to the variation in the Y-deflection sensitivity with the asymmetrical voltage applied to the X-plates), it is often preferable to use a push-pull system for producing the time-base voltage.[5] This means that instead of keeping one of the X-plates at a fixed potential while the potential of the other is allowed to follow the "saw-tooth" wave-form, the potentials of the two X-plates behave in the same way but in opposite directions. The difference between this system and the single-phase time-base may be likened to the use of a pair of scissors as compared with a knife.

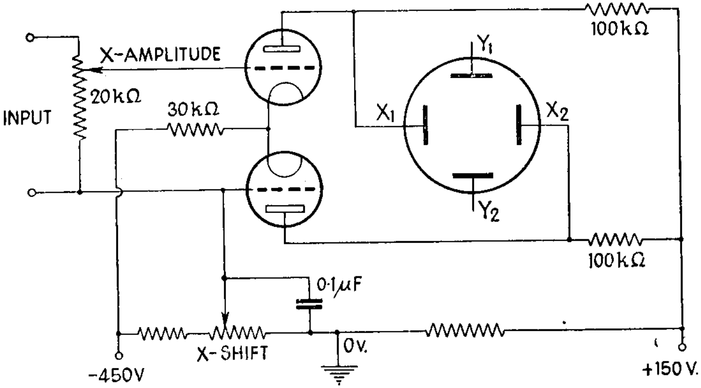

FIG. 26.

A cathode-coupled push-pull amplifier suitable for general use as a deflection amplifier or for enlarging the "saw-tooth" voltage-sweep produced by a linear time-base. The purpose of the push-pull arrangement is to overcome trapezium distortion.

A recently developed circuit for providing a push-pull voltage is the cathode-coupled amplifier.[6] Fig. 26 illustrates the basic circuit arrangement. It is worth noting that pentodes are not recommended for this particular purpose on account of the difficulty of avoiding amplitude distortion with the preferred high values of anode load resistance. The cathode-coupled push-pull system has become very popular, not only for use with a low-voltage time-base but as a general deflection-amplifier.

Many cathode-ray tubes of recent design are provided with improved constructional features which overcome the trapezium distortion, and with these tubes a single-phase deflection circuit is satisfactory.

Applications of the Linear Time-Base

The constant repetition of the pattern on the screen by

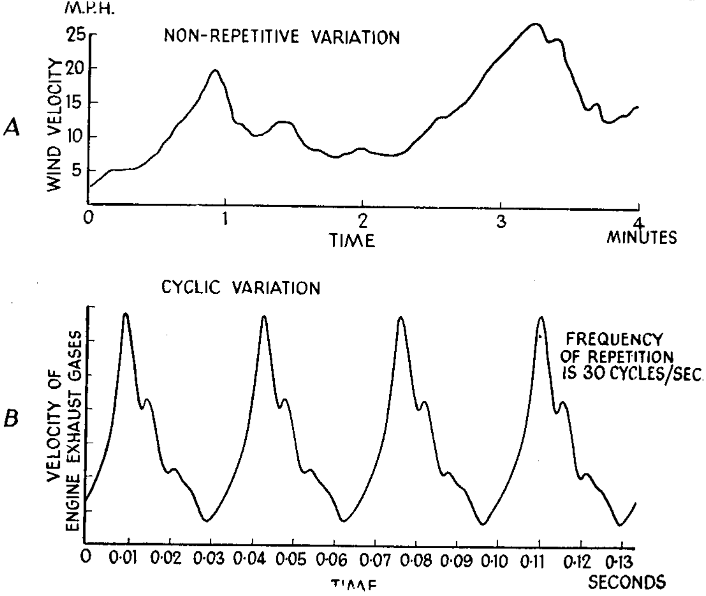

FIG. 27.

Examples of (A) non-repetitive variation and (B) repetitive, or cyclic, variation.

the recurrent sweep of the time-base voltage enables the eye to be presented with a stationary picture which can be examined at leisure. But it is essential that the changes in voltage which are being represented graphically shall themselves be repeated regularly and cyclically. It would be impossible to produce a stationary picture if the variations in the vertical deflection of the spot were different each time the spot is swept across the screen.

For instance, Fig. 27 A shows a curve representing the change with time of some factor such as wind velocity. This curve is completely irregular throughout the whole duration of the record. It is impossible to divide it up into sections of equal duration such that the shape of the curve is the same in each section.

On the other hand, the curve shown in Fig. 27 B is obviously repetitive. After a certain interval of time, the curve repeats itself. In this example, the period of the cyclic change is 1/30 second. If the effect were examined on an oscillograph with a time-base frequency of 30 c.p.s., the pattern would be a wave trace corresponding to one complete cycle of variation.

By reducing the speed of the time-base to 15 c.p.s., the spot would trace out two complete cycles in each horizontal sweep, and at a still lower speed, 10 c.p.s., there would be three complete cycles on the screen. Similarly, if the frequency of the cyclic variation of pressure, or whatever is being observed, is increased to some multiple of the time-base frequency, a corresponding number of cycles will appear. Thus, an alternating voltage of, say, 300 c.p.s. would show 10 complete cycles if the time-base frequency were adjusted to 30 sweeps per second.

Any cyclic change between the limits of 10 and several megacycles per second can therefore be examined on an oscillograph, provided, of course, that it can be translated into a corresponding fluctuating voltage. Numerous devices exist, such as microphones, photo-electric cells and radio receivers, for converting the various physical effects into voltage changes. It is beyond the purpose of this book, however, to discuss the ways and means by which this is achieved.

Synchronising the Time-Base

Any slight discrepancy between the frequency of the applied cyclic change and the frequency of the time-base causes the pattern to travel sideways along the time scale. In many cases this is very troublesome and it is necessary to " lock " the pattern. To do this, the time-base frequency is synchronised with the frequency of the applied signals.

Time-base circuits have a frequency control in the form of a grid voltage adjustment. By setting this control so that the time-base frequency is just too low to produce a stationary pattern, *i.e.*, so that the sweep period is too long, and by superposing on the grid bias a small alternating voltage derived from the applied signal voltage, the thyratron can be triggered off at the right moment to suit the timing of the applied cycle. In other words the signal voltage is used to prevent the time-base period from being too long.

In the hard-valve time-base shown in Fig. 25, the synchronising voltage is applied to the grid of the valve V_3, and the effect in initiating the discharge is just the same as in the thyratron circuit.

The " locking " action is very easily obtained, owing to the sensitivity of the grid control, but care should be taken to see that it is not overdone. An excessive locking voltage can result in serious distortion of the pattern, sometimes producing multiple traces.

In most oscillographs, the locking control, which is actually a small variable condenser or a potentiometer, is labelled " Sync " (and is commonly referred to as the " sink ") as an abbreviation of *synchronisation.*

Eliminating the Fly-Back

When the condenser in the time-base circuit is suddenly discharged at the end of each voltage rise, the spot flies back to its starting point. Sometimes this " fly-back " trace is quite visible and may tend to confuse the pattern. Whether or not it is bright enough to be inconvenient depends on the afterglow of the screen and on the adjustment of the circuit. In those cases where it is troublesome, a simple arrangement is included whereby the intensity of the cathode-ray is reduced during the short discharge period.

The fly-back is suppressed by using the voltage impulse which occurs during the condenser discharge to increase the negative voltage on the shield electrode. In this way, the number of electrons in the beam is momentarily reduced while it is swinging back to its starting position. A rectifying diode is often included in this arrangement so that the spot is not made brighter or de-focused by a voltage surge in the opposite direction when the deflecting sweep occurs.

CHAPTER VII

THE COMPLETE OSCILLOGRAPH

THE preceding chapters have covered (a) the construction of the cathode-ray tube, (b) the power supply equipment necessary for feeding it with various voltages, (c) the time-base used whenever measurements on a time scale are required and (d) the amplifier which magnifies small voltages until they are high enough to produce suitably large patterns on the screen.

The complete assembly with its associated circuits, when regarded as a single instrument, is called an *oscillograph*. It may be remarked that the name *oscilloscope* is frequently given to an oscillograph which has no time-base apparatus incorporated in it. The field of application of an oscilloscope is therefore somewhat restricted.

There is no " standard circuit " for cathode-ray oscillographs. Much depends on the values of the various voltages needed by the cathode-ray tube and the time-base and the deflection amplifier. In small oscillographs it is possible to derive all the necessary voltages from one common power supply unit. The larger tubes, which require higher voltages, are usually supplied from special separate rectifier-filter units.

Although there are many applications where gas-focused tubes are still used, there is a very strong tendency nowadays to use only the high-vacuum type.

A great deal of useful work can be done with a small tube having a screen diameter of 2½–3 inches. The maximum voltage recommended by the makers for a tube of this size is 800–1,000 volts, but excellent performance can be obtained if the voltage is reduced to the minimum rating of about 400 volts. This results in a higher deflection sensitivity and also tends to prolong the life of the fluorescent screen, but the chief advantage of restricting the voltage for this size of tube is that the supply can be used also for the time-base and for the deflection amplifier. Ordinary radio valves of the receiving type will then be suitable.

A Practical Oscillograph Circuit

A complete circuit diagram of a portable oscillograph embodying these features is shown in Fig. 28. The tube has a screen diameter of 2½ inches which is large enough for general purposes and permits quite accurate measurements to be made. Its small size and the small bulk of the associated apparatus make the whole oscillograph reasonably light to handle.[7]

This tube, shown in Fig. 29, has a deflection sensitivity of 170/V millimetres per volt, V being the accelerator voltage. In this instrument, this voltage is kept down to the minimum rated value of 400 volts, so that the sensitivity amounts to 170/400 or 0.425 millimetres per volt. To produce a deflection of 30 millimetres from a central position, a voltage between the plates of 30/0.425 or 70 volts is therefore necessary.

The deflection amplifier which is provided for improving the Y-sensitivity will magnify the applied voltage about 75 times, so that, with the amplifier in use, an

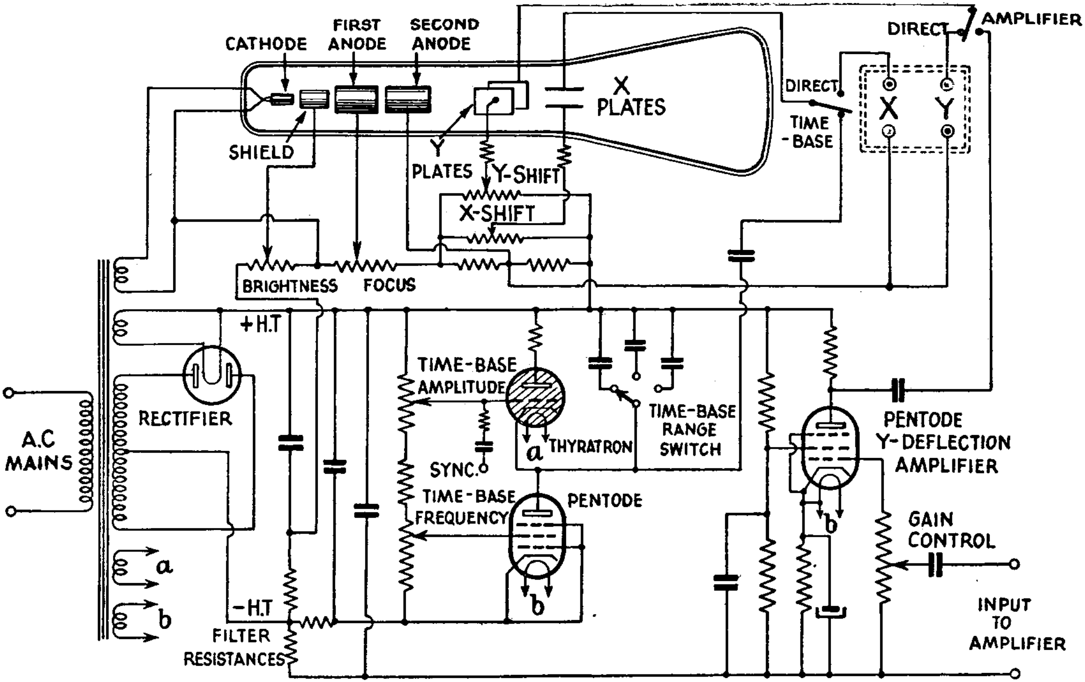

FIG. 28.

Circuit diagram of a typical cathode-ray oscillograph, complete with thyratron linear time-base, deflection amplifier and common power supply. Switches are provided so that, alternatively, connections may be made direct to the X and Y deflecting plates. To accommodate a three-anode tube, the circuit may be modified along the lines of Fig. 14

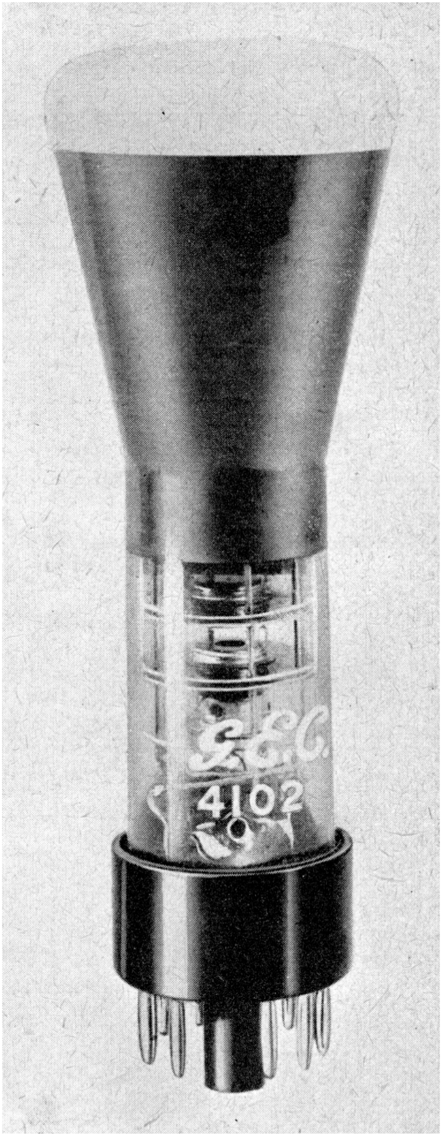

FIG. 29.

A small cathode-ray tube suitable for use in portable oscillographs and for monitoring purposes. The screen has a diameter of 2½ inches.

A.C. signal having a peak voltage of nearly 1 volt would swing the spot 30 millimetres, which is practically the maximum deflection accommodated by the screen.

The linear time-base is of the thyratron type with an ordinary R.F. amplifier valve used as the constant-current charging resistance. A switch is provided for selecting three different sizes of capacity, giving three speed ranges. Together with the potentiometer for controlling the time-base frequency, an over-all range of 10 to 15,000 c.p.s. is covered. Another potentiometer controls the bias on the grid of the thyratron and thus controls the amplitude of the time-base sweep.

Two more potentiometers connected in a resistance chain across the main high-voltage supply provide the adjustable voltages for the focus and brightness controls.

A fifth potentiometer is used as a gain control for the Y-deflection amplifier. Its primary function is to reduce any excessively high voltage so that it shall not overdrive the amplifier or the cathode-ray tube:

Yet two more potentiometers are required to adjust the reference voltages on the X and Y-deflector plates by which the respective spot-shifts are produced.

A single common power supply provides a maximum voltage of 400 volts D.C. through a double-anode rectifying valve and also provides low-voltage A.C. for the cathode heaters of the various valves and the tube.

It is worth noting that in this particular circuit arrangement where only one power supply is used, it is unavoidable that the deflection amplifier has its cathode connected to the negative side of the high-voltage supply to the tube. When the amplifier is in use, the negative H.T. line will therefore preferably be earthed and the accelerator anode and the fluorescent screen will be at a high potential to earth. The only disadvantage of this is that the pattern may move and become distorted if the glass is touched with the fingers.

If the amplifier is not required, the positive H.T. line should be earthed. The screen will then also be at earth potential and the pattern will not be disturbed by anything in contact with the glass.

A miniature oscillograph using this circuit is shown in Fig. 30.

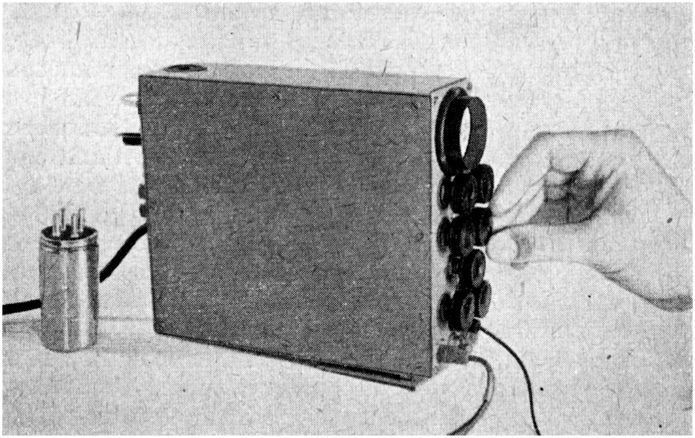

FIG. 30.

A miniature oscillograph employing a 1½-inch diameter tube, complete with internal power supply unit, linear time-base and signal amplifier. The instrument can be operated either from A.C. supply mains or from an accumulator. In the latter case, the vibrator unit which is seen at the extreme left is plugged into a socket provided on the rear panel. The weight of the complete oscillograph is only 6 lb., and the power consumption is **15 watts.**

Mounting the Tube

It is very desirable to allow some flexibility or resilience in the mounting of the tube in order to avoid the risk of displacing the electrodes by jolting or vibration. Further, there should be sufficient freedom for a small rotational adjustment about the axis of the tube to permit the orientation of the deflection axes in the horizontal and vertical directions.

When the screen has to be viewed in a well-lit room, it is advantageous to place a light-filter over it having the same colour as the fluorescent spot. This reduces the reflection of all light from the screen except that of the fluorescent colour and the contrast is thereby enhanced.

Precautions against Stray Fields

In the construction of a compact assembly, care is taken to prevent any disturbance of the electron beam by the magnetic field which is always present near a power-supply transformer. Sometimes the cathode-ray tube is enclosed in a shroud of a special alloy having high magnetic permeability and it is then immune from all interference arising in the external magnetic fields. In some cases where the tube is not shielded in this way, the earth's magnetic field will be found to have a small deflecting effect.

By reason of the high resistance of the circuits associated with the deflection systems, the cathode-ray oscillograph is susceptible to disturbing influences due to small induced electric currents. Wires which are connected to the A.C. supply mains or other source of A.C. are a common cause of blurring or wobbling of the pattern when they are not kept far enough away from the tube and the deflector circuit wiring.

The metal case in which an oscillograph is built constitutes adequate screening against these electrostatic disturbances, but if a metal case is not used, care should be taken to keep all A.C. circuit wiring well spaced from the tube.

Connections to the Deflector Plates

When the oscillatory voltages to be examined are of a very high frequency such as are used in short-wave radio communication, it is very desirable to make the connections from the test circuit to the deflector plates as short as possible. Unless this is done, serious inter-action may occur between various parts of the circuit or an erroneous pattern may be obtained on the screen. With most tubes it will be found that this necessitates making the connections to the back of the oscillograph cabinet. The fact that the instrument may have terminals located on the front panel labelled X and Y does not mean that the connection can successfully be made to those terminals in all cases.

A cathode-ray tube should never be operated with any of its deflecting electrodes completely isolated from the cathode. The necessary connection may be made through a high resistance, perhaps as high as 10 megohms, but generally speaking, it is better to use as low a resistance as the conditions in the circuit will allow.

Adjustment of the Controls

It is helpful towards easy and rapid use of an oscillograph if the operator is familiar with the controls. With so many knobs grouped together it can be rather tedious to have to search for the identifying label whenever an adjustment is required. When the positions of the knobs have been memorised, the operator's hand will automatically reach for the right knob without any tiresome reading of the labels. Practice with this end in view will repay the effort by leading directly to greater facility in obtaining the desired patterns.

The first adjustment to be made in setting up an oscillograph in a new circuit is to see that the spot is sharply focused and is neither too bright nor too dim. The sensitivity of the screen is permanently diminished by prolonged " burning " of the spot in one place, so it is advisable, when the pattern is not being examined, to reduce the brightness control until the spot is extinguished. Alternatively, the time-base can be switched on, thereby keeping the spot on the move: even this may tend to " wear " a line on the screen if the spot is very intense.

The amplitudes of the X and Y deflections obtained when test voltages are applied can be seen by the width and height of the outline of the pattern even if the figure is not stationary. It is very much easier to see what is happening when all of the pattern is contained within the boundary of the screen, and the amplitudes should be reduced accordingly if they are too large. Likewise, it is desirable that the amplitudes should not be too small.

Setting the Time-Base Frequency

If a linear time-base is being used, the next step should be the careful adjustment of the time-base frequency. Where possible, a rough calculation should be made to indicate an approximate value of a suitable frequency and then, following the maker's guide as to the ranges covered by the various switch settings, the frequency control should be turned quite slowly until the pattern becomes stationary. Sometimes the adjustment is extremely critical, and if the control is turned quickly the correct setting may be missed altogether.

The " sync " may be used in moderation to cause the time-base to synchronise with the applied voltage.

In those cases where the pattern is produced not with the linear time-base but by two external voltage sources, the detailed procedure will depend on the particular needs of the circuit. No general advice can be given—except perhaps the reminder that a clear conception must be formed as to what the oscillograph is being asked to do.

CHAPTER VIII

THE OSCILLOGRAPH AT WORK

It is impossible in this book to cover more than a few of the applications of the cathode-ray oscillograph. The examples which have been selected represent a wide range of uses in the field of radio engineering, where the oscillograph is pre-eminent. In the other sciences its applications are of a more highly specialised character, but the electrical principles employed are the same.

D.C. Measurements

The most elementary use of the cathode-ray tube is the measurement of a steady potential difference, as, for example, the voltage across the terminals of a battery. For this purpose, however, an ordinary moving-iron or moving-coil voltmeter is generally more convenient.

The advantage to be gained by using a cathode-ray tube for D.C. measurements lies in the negligible load which it places on the circuit. If a voltmeter were connected across the anode and cathode pins of a valve in a conventional amplifier circuit in an attempt to measure the anode voltage, the reading obtained would be incorrect, for the resistance of the voltmeter would then be in parallel with the resistance of the cathode-anode path in the valve, with the result that the anode voltage would fall as soon as the meter was connected.

In such a case as this, the cathode-ray tube may be used very satisfactorily. The steady potential applied to the deflector plates will produce a steady shift of the spot, and all that is necessary is to measure this displacement. A sheet of transparent squared paper may be placed over the end of the tube for this purpose. The scale should be calibrated, or at least the sensitivity should be known from which the voltage corresponding to the measured deflection can be calculated.

Only one pair of plates need be used in this case, but it would be preferable to apply an oscillatory voltage, such as the time-base sweep, to the other pair merely to avoid the burning of the screen by a stationary spot.

A steady direct current can be measured in the same way, provided that it can be made to produce a sufficiently large potential difference across a resistance. The cathode-ray tube will give a measure of the voltage, and the current producing this voltage-drop in the known resistance can be calculated from Ohm's law.

Alternatively, magnetic deflection could be used to measure the current. A pair of coils, each consisting of about 2,000 turns of wire, placed just in front of the electron gun would be suitable for indicating currents of the order of 50-100 milliamperes.

A.C. Measurements

Voltages and currents derived from an alternating supply can similarly be measured by connecting the test circuit to one pair of plates. Since the voltage is alternating, the spot will trace out a straight line, and the length of this line will represent the extreme displacement of the spot from the negative peak to the positive peak.

The R.M.S. value of an alternating voltage or current (assuming it is sinusoidal in form) is commonly used in preference to the peak value, and is measured from zero. The peak value (positive or negative) measured from zero is $\sqrt{2}$ times the R.M.S. value. Thus, a line trace on the screen having a length equivalent to 24.2 volts would correspond to 14.1 volts positive or negative from zero, and the R.M.S. value of this is 10.0 volts.

The frequency of the alternating voltage or current has no effect on the sensitivity of the cathode-ray tube. A calibration made with the steady direct voltages will hold good for A.C. of practically any frequency, even up to several megacycles per second. At high radio frequencies, the electrostatic capacity of the deflecting plates may have a serious effect on the circuit under test, and at such extremely high frequencies other disturbing factors, such as the distortion of the pattern due to capacity coupling between the X and Y plates, may have to be taken into account.

Alternating voltages can be used for obtaining oscillographic traces of characteristic curves of various types of valves automatically,[8] but as this method is of interest only to valve manufacturers concerned with large-scale testing, no detailed account is given here.

Audio-Frequency Applications

The use of a cathode-ray oscillograph greatly facilitates the adjustment of audio-frequency amplifiers. The two outstanding qualities of such amplifiers are the ability to deal faithfully with all the signal voltages fed into them without becoming overloaded, and the relationship between the amplification and the frequency of the signal that is being amplified.

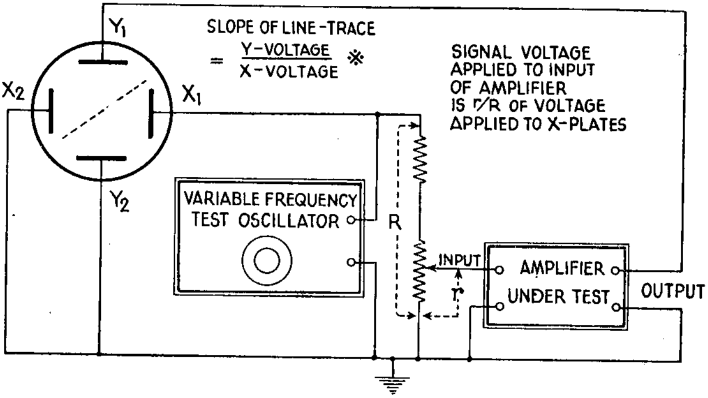

FIG. 31.

A circuit arrangement for examining the characteristics of an audio-frequency amplifier. If necessary, an auxiliary amplifier may be used to follow the test oscillator in order that the A.F. voltage available may provide an adequate X-deflection.

* If the X and Y-deflection sensitivities are not equal, their ratio must be taken into account in calculating the actual voltage amplification.

A " flat " characteristic is not always desirable. In gramophone amplifiers, for instance, greater magnification is required at very low frequencies owing to the inevitable limitation in the bass during the original cutting of the record. To examine these characteristics, a circuit arrangement of the kind shown in Fig. 31 should be used.

In this method, the oscillograph compares the amplitudes of the input and output voltages at various frequencies. A fairly high test voltage at the selected frequency is applied to the X-plates, and a small fraction of this, obtained from the potential divider, is fed into the amplifier. The output is applied directly to the Y-plates.

The simultaneous deflection in two directions at right-angles results in a sloping straight line, provided that no phase distortion is present. If there is phase distortion, it will be apparent as a broadening of the line into an ellipse.

There are two observations which can be made on this line—its slope and its length. The slope, or the ratio of the vertical deflection to the horizontal deflection at any point on the line, gives the ratio of the output to the input voltage in the amplifier, due regard being paid to the amount of reduction afforded by the potentiometer. If the tube has different deflection sensitivities for the X and Y-plates, this must also be taken into account.

When the line is straight over the whole of its length, the amplifier is free from amplitude distortion. But if the line curves over near the top, the amplification is evidently not as high as it ought to be when the input voltage reaches a high value: amplitude distortion is then present.

By varying the frequency, it is easy to watch the effect on the degree of amplification. If the amplifier has a " flat " characteristic, the slope will remain the same over the full frequency range.

Comparison of Frequencies

Where an alternating supply of known frequency is available, such as the 50-cycle supply mains, it is a simple matter to measure the frequency of an audio tone by direct comparison with it.

In the simplest arrangement, the two sources of voltage are connected to the X and Y-plates respectively. Stationary Lissajous figures will be obtained whenever the frequencies are related by some simple numerical ratio. The interpretation of these patterns is easy enough when the ratio is small (see Fig. 16), but if it is large, other forms of circuit connection are more convenient.

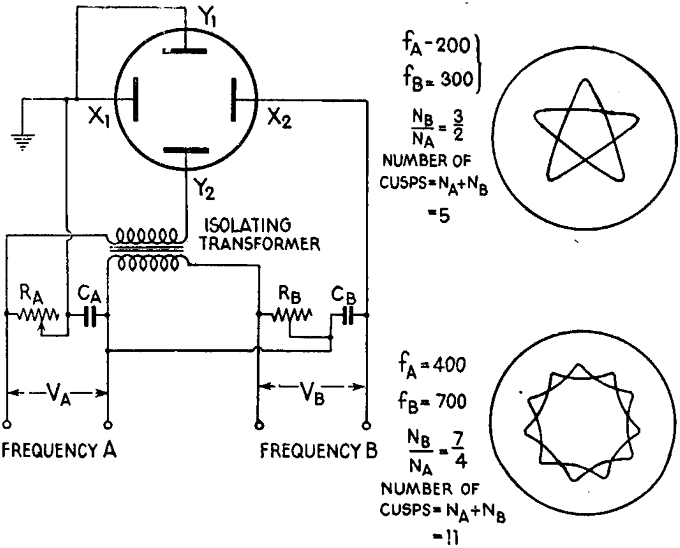

FIG. 32.

An improved circuit arrangement for the comparison of two frequencies. The circuit is especially suitable where the ratio of the frequencies is high. The values of R_A C_A and R_B C_B are first adjusted separately to produce two circles of different diameters. When both voltages are applied together, the composite figure is obtained, and this becomes star-shaped when the frequencies bear a simple ratio to each other.

The circuit shown in Fig. 32 yields a ring figure like a star when the two frequencies bear a simple numerical ratio to each other, and is suitable when the ratio is quite high.[9] By reversing the connections to the transformer, the star can be turned inside-out so that the cusps are on the inside, but the analysis of the pattern is then not so easy.

The general relationship which holds for this type of circuit may be described by the following example. If the two frequencies are 1,400 and 400 c.p.s., the ratio is 7 : 2. When the points are on the outside, star-like, the number of cusps will be $7+2=9$. On the other hand, if the circuit is rearranged so that the cusps are on the inside, the number of cusps will be $7-2=5$.

Alignment of Tuned Circuits

The modern radio receiver contains several tuned circuits which must be accurately adjusted in relation to each other if the sensitivity and selectivity are not to suffer. It is possible to carry out the necessary adjustments with the aid of meters connected in the circuit, but this is very tedious, and the whole operation is rendered much more simple and much quicker if a cathode-ray oscillograph is used.[10]

In this application, the Y-plates serve to indicate a radio-frequency voltage amplitude, but the X-plates provide a *frequency-base*. The frequency of the test signal which is fed into the receiver is made to vary cyclically over a small range by a mechanical tuning device or the equivalent electronic frequency-modulator, and the voltage output from the tuned circuits is examined on the oscillograph as a function of the frequency.

Several different circuit arrangements have been used for this tuning alignment, but they are all modifications of the same principle. One typical circuit is shown in Fig. 33. The output voltage from the last of the tuned circuits under test is rectified by means of the diode rectifier, and the resultant uni-directional voltage is applied to one of the Y-plates: the other Y-plate is earthed. The linear time-base incorporated in the oscillograph is used for providing a voltage sweep across the X-plates and is set at a low speed, about 15 sweeps per second, to coincide with the speed at which the frequency of the test voltage is made to vary.

In the mechanical system, the frequency is varied by rotating a variable tuning condenser connected to the signal generator, the condenser being so designed that it causes the frequency to vary at a steady time-rate up to a limiting value and then to return to its starting value. If the condenser shaft rotates at a constant speed, the frequency of the signal will vary in linear form exactly like the voltage developed by the time-base.

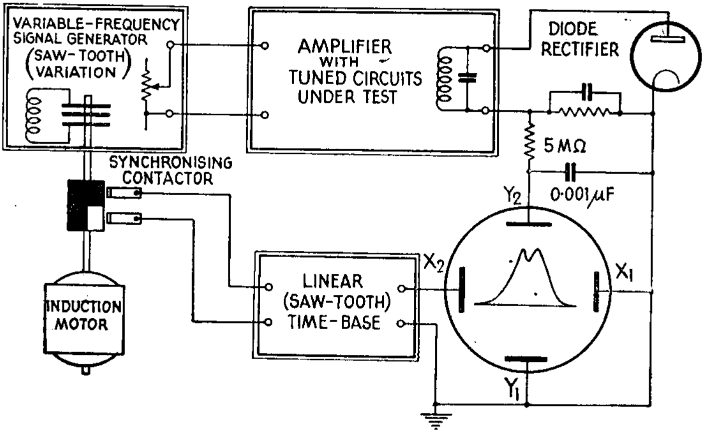

FIG. 33.

The use of a cathode-ray tube for examining the response curves of tuned amplifiers by means of a frequency-modulated oscillator. The horizontal deflection is proportional to the frequency, the linear voltage time-base being synchronised with the variation of frequency.

The horizontal axis of the pattern is therefore not a time-base but a frequency-base. Within certain practical limits, the pattern would have the same shape whatever the speed of the sweep happened to be, provided that the condenser shaft and the voltage time-base operated at the same speed. A small voltage surge injected into the time-base circuit from an intermittent contact driven by the condenser shaft provides the usual synchronising impulse.

The alternative electronic method of cyclically varying the test-frequency uses a " saw-tooth " oscillator circuit which causes a periodic variation in the reactance of a valve connected to the signal generator tuning circuit.

While the system is running, various adjustments can be made to the tuning circuits under test, and their effect on the amplitude of the signal and the shape of the selectivity curve can be watched directly.

Panoramic Radio Reception

When a radio receiver is adjusted and tuned in the normal way, only one station can be heard at a time. If more than one station is heard, the effect is confusing and unpleasant to the ear. In certain circumstances it is important to know what other stations are operating in the same band of frequencies while continuing to receive the wanted station. This is impossible by ordinary oral reception, but by using a cathode-ray tube a visual examination of the frequency-band can be effected, and any one or several of a number of signals can be watched, the selection being made by eye.[11]

The principle employed is similar to that used in the alignment of tuned circuits as just described. The receiver is tuned periodically over a band of frequencies and the signals received are applied to the Y-plates of a cathode-ray tube. The X-plates are supplied with a " saw-tooth " voltage which varies in step with the cyclic tuning of the receiver.

The spot is therefore carried across the screen as the receiver tuning varies automatically from one end of the frequency-band to the other. Whenever a signal from a station operating in this frequency-band is received, the spot is deflected vertically by an amount proportional to the strength of the signal. If no signals are audible, the trace is a horizontal straight line, but when a station begins to operate it will appear as a narrow peaked hump at the point in the trace corresponding to its carrier frequency.

In the case of telegraphic signals, the hump exists only for the duration of the dot and dash characters, and a trained operator can read the message by watching the signal on the screen. Speech-modulated transmissions appear as humps with blurred fringes at the sides, these fringes varying with the amplitude and frequency of the modulation.

The tuning-band is thus set out graphically as a frequency spectrum, and the existence of signals within the selected portion of the spectrum can be examined at leisure. The operator has a " panoramic " view of the tuning-band from which he is able to detect the sudden appearance of a new station anywhere in the band, or watch for its cessation, without interfering with his observations of other stations.

Transmitter Modulation Adjustment

The radio-frequency voltage produced by a transmitter using the conventional amplitude-modulation method varies in accordance with the applied modulation voltage. The amplitude is, in fact, in strict proportion to the amplitude of the sound waves which are received by the microphone. In order that the transmitter may operate most effectively, the degree of modulation (*i.e.*, the extent to which the R.F. amplitude varies) must not be too great nor too small.

The oscillograph enables a constant check to be made on the depth of modulation. The most convenient arrangement out of several alternative methods is the one which produces a trapezoidal figure. A glance at this pattern indicates instantly the amount by which the R.F. carrier voltage is being varied by the modulation signals.

Here the Y-plates are connected to a part of the output circuit of the transmitter, so that the Y-deflection is a measure of the amplitude of the R.F. voltage. See Fig. 34. The fact that the spot is being deflected up and down at the carrier frequency (which may be several megacycles per second) is of no importance.

The X-plates are supplied with voltage obtained from the modulation circuit. The amplitude of the X-deflection depends therefore on the amplitude of the modulation signal. The frequency of the deflection in the X-direction will be within the audio range in the case of speech or music transmission, but here again the frequency is of no importance.

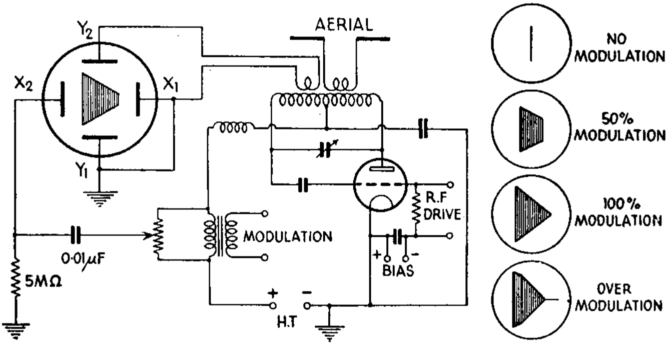

FIG. 34.

A circuit arrangement for checking the modulation of a radio transmitter by examination of the trapezoid figure. Examples are shown of the patterns obtained with various degrees of modulation

When there is no modulation, the screen shows a straight vertical line. As soon as modulation occurs, however, the amplitude of the R.F. carrier voltage will increase and decrease with the positive and negative alternations of the modulating voltage. Provided that the transmitter is correctly adjusted the straight line will immediately spread out into a trapezoid, showing that the R.F. voltage amplitude is proportional to the amplitude of the applied modulation voltage.

The maximum permissible depth of modulation, if overload distortion is to be prevented, is reached when the trapezoid has extended its width so far that it becomes a triangle. The trapezoid fluctuates in width in the course of a speech transmission, and any overloading is shown by the appearance of a horizontal line at the point of the triangle or flattening of the sloping sides where the R.F. amplitude fails to increase proportionally.

Such an arrangement is extremely useful in setting up a transmitter and keeping a check on correct operation. Many hours may be spent fruitlessly in fault-finding without its aid.

Reflection of Radio Waves

In just the same way as the echo of a sound impulse can be heard by reflection from suitably large surfaces, so radio waves are reflected from different objects, provided that the objects are large enough. If they are small compared with the wavelength, there is no appreciable reflection. By the use of short-wave radio, it has been possible to obtain strong reflections from aircraft in flight at considerable distances. This is the principle on which radiolocation depends. Gas-holders and barrage balloons are also effective reflectors.

Medium-wave broadcasting is not affected by such objects. The wavelength is so great that only when the conducting body is more than about a quarter-mile in length does it reflect a useful fraction of the wave energy. The ionosphere, which is the region in the upper atmosphere where natural ionisation exists as a result of solar radiation, is, of course, sufficiently extensive to have an effect on quite long waves.

The wave energy travels at the rate of 186,000 miles per second, and consequently the echoes are very rapid. A reflecting surface 93 miles away would return a signal pulse back to the transmitter after an interval of one thousandth of a second. At one mile the delay would be a little over ten millionths of a second.

Since the velocity of the wave is known, the distance can be calculated from the time interval. Here the linear time-base of the cathode-ray oscillograph provides a satisfactory means of measuring the time interval. As in other applications of the oscillograph, it is preferable to have a continuous succession of pulses for observation so that, by synchronising the time-base, a stationary picture is obtained. A very short pulse is obviously necessary in order to avoid any overlapping in the pattern traced out on the time scale.

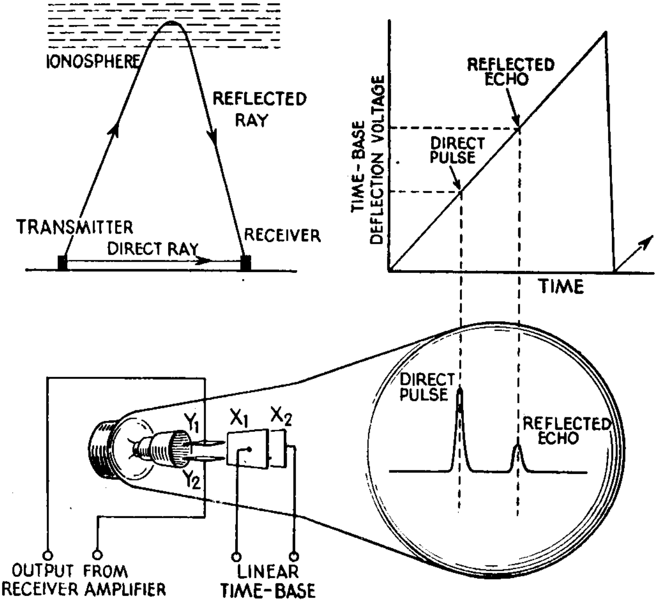

FIG. 35.

Radio echoes from distant reflecting surfaces appear on the cathode-ray screen as small peaks displaced from the direct signals on the linear time-base. The extra distance travelled by the echo can be read off directly from the horizontal scale.

Fig. 35 represents the paths by which radio waves from a transmitter may reach a receiver. The direct ray travels a shorter distance than the reflected ray and therefore takes a shorter time. The two corresponding pulses appear as two separate Y-deflections on the time-base, one a little later than the other, as shown in the figure. If the X-sweep frequency is 1,000 c.p.s., the full length of the sweep corresponds to one thousandth of a second, so that if the separation between the pulses is a tenth of the sweep length, the corresponding time interval is one ten-thousandth of a second. The reflected ray therefore travels 18.6 miles further than the direct ray.

In television reception, the picture can be marred by the superposition of the " echo " picture which is received just a little later than the direct picture radiation. Fortunately, this trouble is present only in a few cases where, for instance, some large area of metal such as a gas-holder lies at an inconvenient distance from the transmitter and receiver. In these circumstances, it is usually possible to exclude the reflected ray by using sharper focusing of the receiving aerial system.

Cathode-Ray Direction Finding

Several elaborate methods have been developed in which cathode-ray tubes are used for radio direction-finding in marine and aerial navigation.[12] Radio has been used for this purpose for many years, but in the earlier systems the indications were in the form of oral modulation signals. The visual observation of a fluorescent screen has been found preferable to aural reception, however, largely for the reason that it is far less disturbed by atmospherics and other interference.

In general, these systems require the radiation of special signals from a co-operating transmitter. The signals are received by directional aerials and are passed through amplifiers to the deflecting-plates of the cathode-ray tube. The pattern on the screen, which depends on the phase and voltage relationships of the signal currents induced in the aerials, automatically indicates the direction of the incoming signals.

Photography of Cathode-Ray Tube Patterns

In some circumstances it is desirable to make a permanent record of the trace obtained on the screen. A drawing can, of course, be made on transparent paper if the pattern remains stationary and is not too complicated, but in many cases it is more convenient to obtain the record photographically. Although the standard Willemite screen can be made to yield satisfactory pictures under most conditions, it is often preferable to use a tube fitted with one of the specially actinic screens. The optical system and the length of the exposure require careful consideration.[13]

Literature

The diverse applications of the cathode-ray tube have been described in detail in a wide range of technical periodicals during the last twenty years, and more articles and papers are constantly being added to the already long list.[14]

For advanced work in any particular direction, the reader will benefit by consulting the original papers as published in the various technical journals, to which it is hoped the references given on pages 96 and 97 will provide a useful guide.

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