THE PRINCIPLES OF THE CATHODE RAY TUBE

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THE PRINCIPLES OF THE CATHODE RAY TUBE

We are all becoming more and more familiar with the use of the Cathode Ray Tube, both for the reproduction of the picture in television equipment, and for the measurement and examination of voltages, waveforms, etc., by means of the oscilloscope. There is a risk, however, that familiarity with its applications may lead us to take the cathode ray tube very much for granted, so that we fail to appreciate the principles upon which its operation is based. A short series of articles, of which this is the first, explains how and why the cathode ray tube does its work.

An electron (elemental negative charge) in an electrostatic field experiences a force which accelerates it towards the positive region of the field. In a simple diode, therefore, electrons emitted by the cathode move with increasing speed towards the anode (Fig. 1), and their final velocity when they strike the anode depends upon the difference of potential between the anode and cathode.

THE ELECTRON GUN

Suppose there is a small hole in the centre of the anode. A certain number of electrons, instead of striking the anode, will pass through the hole. *Unless acted upon by some other force* they will continue along a straight path at their final velocity. Such an arrangement, shown in Fig. 1A, is a simple form of *electron gun*. An electron gun is one of the main components of a cathode ray tube.

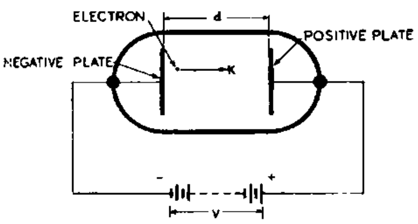

FIG. 1

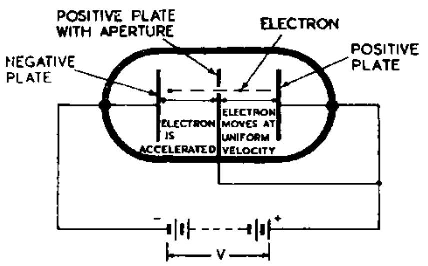

FIG. 1A

LUMINESCENCE

Over a century ago, during investigations of electric discharges in tubes from which most of the air had been exhausted, it was observed that, once a certain degree of evacuation had been achieved, luminous effects appeared on the walls of the tube, which phosphoresced with a colour depending upon the composition of the glass.

In the late 1870's it was discovered that certain substances were particularly active in this way. Fig. 2 shows an apparatus exhibited by Sir William Crookes in 1879. A diamond, mounted in the centre of an exhausted tube, showed a bright green phosphorescence under electronic bombardment, and is stated to have given as much light as a candle.

Later, materials of far greater sensitivity and far less expensive were developed, and to-day a wide range of different chemical substances are available for use as screen "phosphors".

So far, then, we have seen that a cathode ray tube is essentially a device in which electrons, emitted by a cathode, are made to travel at high speed under the influence of an electron gun, and to strike a surface coated with a phosphor, the energy of the electrons then being converted into light.

FOCUSING THE BEAM

The "cathode ray", being composed of electrons, tends to spread out into a wide beam because the electrons are negative charges, and similar charges repel each other. For all normal applications of the cathode ray tube the beam must come to a fine focus at the screen so that the light is produced as a very small spot.

In the course of the first somewhat haphazard experiments which ultimately led to the development of the modern cathode ray tube, it was found that if the tube was surrounded by a coil carrying a direct current, a considerable measure of focusing could be achieved. Final focusing of the beam in modern picture tubes is still obtained magnetically, but part of the focusing in picture tubes and complete focusing in oscilloscope tubes is performed electrostatically by means of a device termed an *electron lens*. The various ways in which focusing is achieved will be dealt with in a future article.

DEFLECTING THE BEAM

It is interesting to note that practically every basic principle employed in modern cathode ray tubes was discovered—often by pure chance—during early experiment. In one of these experiments it was observed that when a permanent magnet was arranged close to the tube, the beam was deflected at right angles to the magnetic field, as illustrated in Fig. 3.

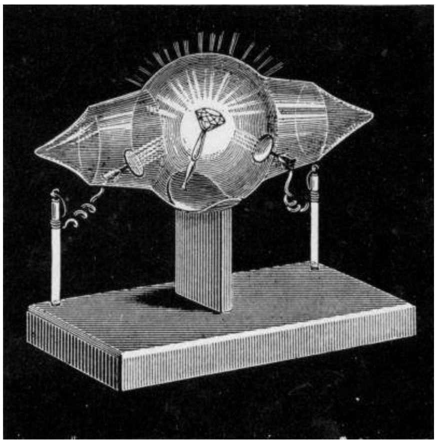

FIG. 2

Another method of deflecting the beam is by an electrostatic field. It will be readily understood that since the electrons forming the beam are negative charges, they will be attracted by a positively charged plate, and repelled by a negatively charged plate.

One of the first applications of this principle was due to Sir J. J. Thomson, who used a modified cathode ray tube for measuring the charge-to-mass ratio of an electron and also its velocity. In this tube he employed a magnetic field to deflect the beam, and a pair of flat plates between which was established an electrostatic field to return the beam to its original direction.

Both magnetic and electrostatic deflection of the beam are employed in modern tubes—deflection due to a current flowing in a coil for picture tubes, and deflection due to varying the potential difference between plates located in the tube for oscilloscope tubes. Fuller details of deflecting systems must also be left for a future instalment, but it should be mentioned here that arrangements are made for deflecting the beam in two directions—horizontally and vertically—so that the beam can be directed to any point on the screen.

To recapitulate : we have, in the cathode ray tube, a device in which a finely focused beam of swiftly moving electrons can be made to move over a screen, its path on the screen being traced as a line of light. The illumination is, of course, of very short duration, and the "trace" must be repeated at very rapid intervals to enable it to be examined by the human eye.

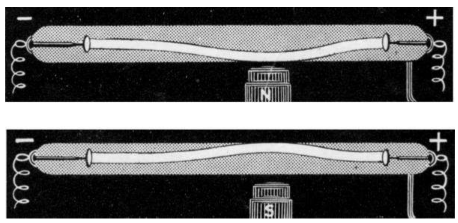

FIG. 3

Beam deflected under influence of magnets in early experimental discharge tubes. These tubes were not completely exhausted and the discharge was therefore luminous.

(Part 2 of this series will indicate the main applications of the cathode ray tube, and will deal more fully with the electron gun.)

THE PRINCIPLES OF THE CATHODE RAY TUBE

PART 2

The first instalment of this series gave a brief explanation of the principles on which a cathode ray tube operates. This month the wide range of applications of the cathode ray tube are indicated, and the construction of the electron gun is described in greater detail.

THE C.R. TUBE AS A MEASURING INSTRUMENT

The earliest application of the cathode ray tube was as a measuring device. Because the deflection of the beam is directly proportional to the deflecting force, the tube operates as a very sensitive galvanometer, its deflection being a measure of the voltage applied to the deflecting device, be it a coil or a pair of plates. A familiar present-day example is the Mullard High-Speed Valve Tester, in which the vertical deflection of the light spot is used to indicate the results of the various tests.

Because the electrons forming the beam have infinitesimally small weight, and therefore little inertia even at the very high speeds at which they travel along the tube, the beam, which represents the "pointer" of the instrument, will respond practically instantaneously to the deflecting force. This renders the tube suitable for use as an *oscilloscope* to measure and to examine very rapid variations of voltage. By arranging that the vertical deflection of the beam is proportional to the voltage to be examined, and that the horizontal movement is uniform over a fixed period of time, the cathode ray tube can be made to show how the voltage varies from instant to instant—for example, to trace wave-forms. In Fig. 1 is reproduced a photograph of a typical wave-form as traced on the screen of a cathode ray tube.

THE C.R. TUBE FOR TELEVISION

The other major application of the cathode ray tube is, of course, for picture reproduction in television. For this purpose the beam must be made to trace a series of horizontal lines across the screen, each line being just below the previous line. Thus, a rectangular area, known as the "raster", is swept out or "scanned", line by line. (In practice, the sequence of line scanning is a little different: the first, third, fifth, etc., lines ("odd" lines) are scanned first, and the second, fourth, sixth, etc., lines ("even" lines) are filled in afterwards.)

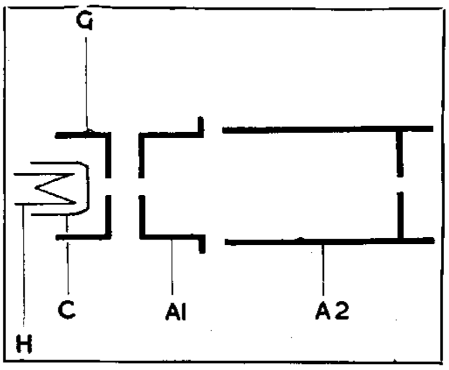

Fig. 2.—Simplified Sectional Diagram of an Electron Gun.

It is also necessary to vary the intensity of the beam continuously so that the illumination of the raster will vary from point to point. It is the essence of television reception that the modulation and the movement of the beam are so controlled and timed that the illumination at any point on the raster is proportional to that of the corresponding point in the scene which is being televised.

THE ELECTRON GUN

The electron gun is the component of a cathode ray tube in which electrons, emitted by a cathode, are made to travel at high speed as a concentrated beam which come to a fine focus at the screen. Because the electron gun structure for both oscilloscope tubes and picture tubes are similar in all essential details, it will suffice to describe that used in current Mullard picture tubes.

Fig. 2 shows the gun in diagrammatic section. C is the cathode, consisting of a nickel tube closed at one end by a small disc coated with the emissive material—a mixture of the oxides of barium and strontium. It is heated to the emitting temperature by a tungsten heater (H) inserted in the cathode tube.

A1 and A2 are cylindrical anodes, each closed at one end by a disc pierced by a small central hole. A1 is maintained at a positive potential of a few hundred volts, and A2 at a positive potential of some thousands of volts.

The positive voltages on these two electrodes attract the electrons emitted from the cathode, and cause them to travel along the tube in the direction of the screen at high speed. The shape and spacing of the two anodes, and the values of the potentials applied to them, produce a complex electrostatic field which has a focusing action on the electrons so that the great majority of them pass through the small apertures and proceed towards the screen as a focused beam.

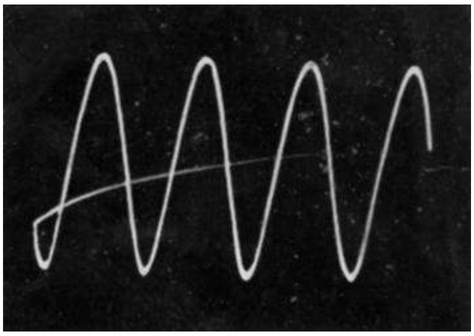

Fig. 1.—Typical Oscillograph of a Sine Wave-form.

G is the grid—a short nickel cylinder, closed at the end by a nickel disc pierced by a small hole. To G is applied a negative grid bias potential of such value that, under no-signal conditions, the electron stream (beam current) leaving the neighbourhood of the cathode and grid will, on striking the luminescent screen, produce a light value corresponding to the darkest tone of the picture.

Between grid and cathode is also applied the picture signal, which modulates the electron stream so that for lighter portions of the picture the density of the electron stream increases. The amount of light produced on each point on the screen thus corresponds to the light tone of the same point in the scene being televised.

The negative potential of the grid also assists in the focusing action.

THE PRINCIPLES OF THE CATHODE RAY TUBE

PART 3

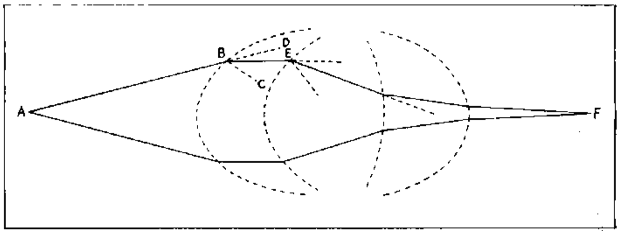

Fig. 1.—Focusing effect of an electric field.

So far, in this series, it has been explained in general terms how a narrow beam of swiftly moving electrons—the "cathode ray"—is produced by the electron gun, and is made to move over the luminescent screen on which the movement of the beam is displayed as a spot of light. It has also been explained that in an oscilloscope tube the beam is made to trace such figures as wave-forms and frequency response curves; and that in a picture tube the beam sweeps out a rectangular picture area or "raster", the intensity of the beam, and hence the amount of light emitted, being at any instant proportional to the brightness of the particular part of the picture being transmitted.

In the present article, the method of focusing the beam accurately on the screen is described.

FOCUSING

The diameter of the light spot on a picture tube should be equal to the thickness of a single line of picture, and this, for a 12-inch tube is in the order of one-fiftieth of an inch.

Now the beam is a stream of electrons, and electrons are elemental negative charges. Because like charges repel each other, the beam will tend to spread. Unless, therefore, some method of bringing the beam to a focus on the screen is employed, the light spot produced by the beam will be far too large.

The chief means of focusing employed in picture tubes—and the sole means adopted in oscilloscope tubes—is electrostatic in principle. A full explanation of electrostatic focusing involves fairly complex mathematics, and even a physical explanation is far from simple. It must therefore suffice to state that, in a non-uniform electrostatic field, electrons tend to follow the path along which the potential gradient is greatest.

THE ELECTRON LENS

This is explained by Fig. 1 which represents an electric field, the broken lines indicating lines of equal potential. An electron originally travelling in the direction A-B, will, on arrival at point B tend to travel in the direction B-C, which is the path of maximum potential gradient (measured, say, in change of volts per centimetre). As, however, the electron already has a velocity in direction A.B.D., it will, in fact, take an intermediate path, in some such direction as B-E. The electrical field has a similar influence on all other electrons except those travelling along the axis in the direction A-F.

In a cathode ray tube, by suitable geometrical design of the various electrodes, and by selecting appropriate values for the H.T. and E.H.T. voltages, the potential distribution in the region of the electrodes can be made to counteract the tendency of the electron beam to spread, and the beam becomes convergent instead of divergent.

This arrangement of electrodes and potentials is known as an electron lens, because its action on the electronic beam is very similar to that of an optical lens on a beam of light.

Fig. 2 shows the effect of the electron lens on a divergent beam, the divergence being deliberately exaggerated for ease of representation. The illustration is of the electron lens of an oscilloscope tube. By adjusting the voltage to the first anode, the beam can be brought to focus accurately on the screen.

It is not convenient to adjust the focus of television picture tubes in this way by varying the H.T. voltage. The electron lens is therefore so designed that its effect is somewhat less than that required for perfect focusing. The focal point of the electron lens is then on the far side of the screen as illustrated in Fig. 3. Final focusing is then achieved by magnetic means.

MAGNETIC FOCUSING

The focusing magnet of a picture tube is usually a pot-type electromagnet with a small air-gap, surrounding the neck of the tube. The focusing effect of a magnet depends upon the fact that an electron entering a magnetic field tends to move in a circular path at right angles to the field. In the case of the electrons forming the beam of a cathode ray tube, their path in a magnetic field will not be a circle but a spiral, the radius of the spiral being determined by the strength of the magnetic field, and the pitch of the spiral by the beam velocity which is, of course, governed mainly by the E.H.T. voltage. As the electrons move out of the magnetic field the diameter of the spiral decreases.

Fig. 4 shows the effect of the focusing magnet. In the television receiver, final adjustment of the focus is obtained by varying the current passing through the winding of the focus coil by means of a variable resistor.

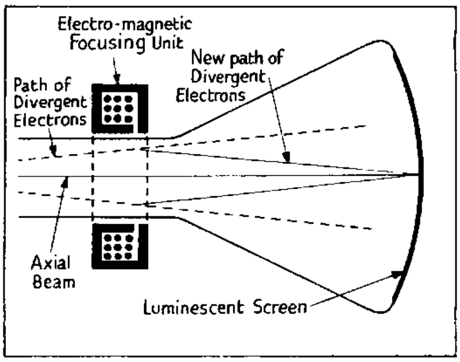

Fig. 4.—The principle of magnetic focusing.

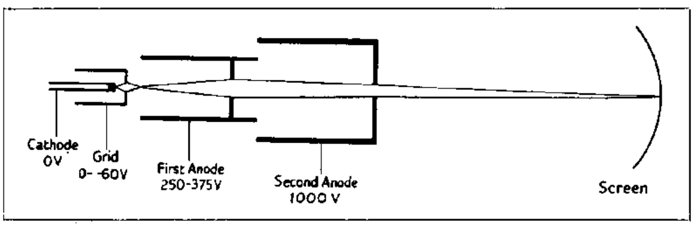

Fig. 2.—Complete focusing by electron lens of an oscilloscope tube.

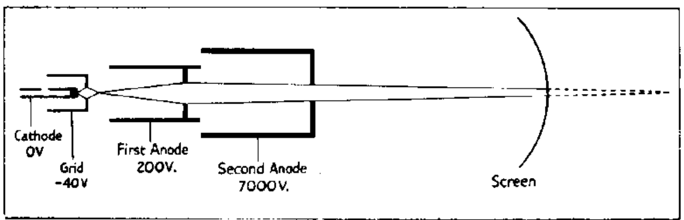

Fig. 3.—Partial focusing by electron lens of a television picture tube.