THE CATHODE-RAY TUBE

AND

TYPICAL APPLICATIONS

A NON-TECHNICAL DISCUSSION
OF THE CATHODE-RAY TUBE

PRICE: FIFTY CENTS

ALLEN B. DU MONT LABORATORIES, Inc.
INSTRUMENT DIVISION
1000 Main Avenue Clifton, N. J.

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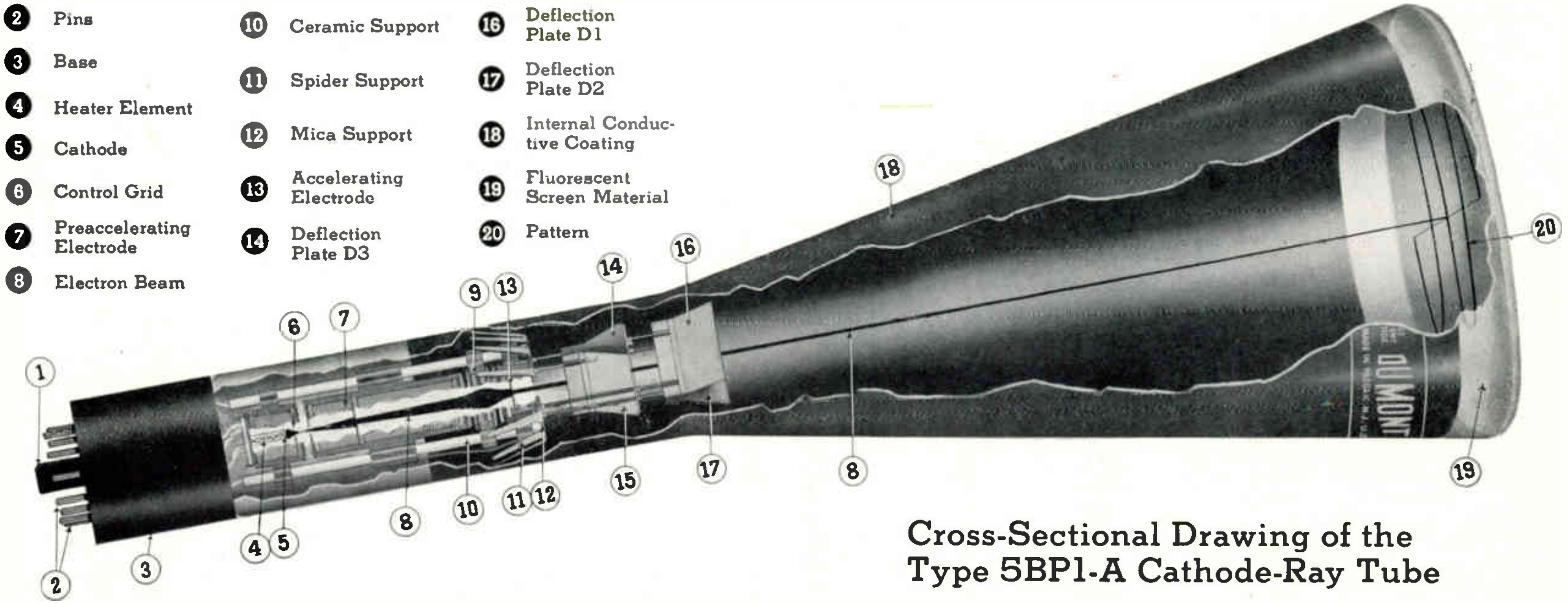
A NON-TECHNICAL DISCUSSION OF THE CATHODE-RAY TUBE

① Key
② Pins
③ Base
④ Heater Element
⑤ Cathode
⑥ Control Grid
⑦ Preaccelerating Electrode
⑧ Electron Beam
⑨ Focusing Electrode
⑩ Ceramic Support
⑪ Spider Support
⑫ Mica Support
⑬ Accelerating Electrode
⑭ Deflection Plate D3
⑮ Deflection Plate D4
⑯ Deflection Plate D1
⑰ Deflection Plate D2
⑱ Internal Conductive Coating
⑲ Fluorescent Screen Material
⑳ Pattern



Cross-Sectional Drawing of the Type 5BP1-A Cathode-Ray Tube

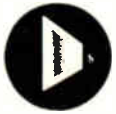
EXAMPLES OF TYPICAL CATHODE-RAY TUBE APPLICATIONS


Sinusoidal voltage wave plotted as a linear function of time.


Pattern for determination of phase difference. Two sinusoidal voltages. Frequency ratio 1:1.


Typical oscillogram of a damped oscillation showing decrease in amplitude with increasing time.


Pattern for determination of frequency ratio of two sinusoids. Vertical to horizontal frequency ratio of 5:2.

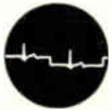

Trapezoidal pattern used for measuring percentage modulation of radio transmitters.


Envelope pattern of high-frequency carrier modulated by low-frequency sinusoid.


Characteristic curve of the output of a typical discriminator circuit of an F-M radio receiver plotted against time.


Frequency response curve showing wide band-pass of the intermediate-frequency amplifiers of an F-M radio receiver.


A typical oscillogram obtained when testing camera shutter speeds.


Electrocardiogram which shows action of the heart plotted as a function of time.


Curve showing detonation in an automobile engine.


Two cycles of G-392 cycles per second as produced by a single reed of an accordion and showing rich harmonic content of this tone.

Frontispiece: The modern cathode-ray tube and some of its applications

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PRINTED
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TABLE OF CONTENTS

TABLE OF CONTENTS—*(Continued)*

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS—*(Continued)*

INTRODUCTION

The modern Cathode-ray Tube, from its inception as a laboratory curiosity, has been developed by scientific research into one of the most versatile indicating and measuring devices ever conceived. The superiority of the cathode-ray tube over other indicating and measuring devices lies in the fact that the indicating element is an electron beam which is practically inertia-free. Because of this freedom from inertia, the cathode-ray tube is capable of responding to voltage variations over frequency ranges of millions of cycles per second. By directing this electron beam against a fluorescent screen, voltage variations may be observed in the form of a moving spot of light.

In view of the fact that it is possible to convert light, heat, sound, and mechanical motion into voltage impulses, it is quite apparent that the cathode-ray tube is not limited strictly to electrical applications. In fact, the cathode-ray tube can be used to provide visual data on variations of any natural phenomenon which can be converted into equivalent voltages.

As used in the oscillograph, the cathode-ray tube provides scientists, engineers, laboratory workers, and maintenance personnel working in all fields with a convenient and practical method for obtaining precise information in visual form. The need for hand-plotted graphs, made from point-to-point investigations, is eliminated. Considerable time is saved. With certain types of cathode-ray tubes, special screens are used to facilitate the making of photographic recordings so that desired information may be preserved for reference purposes.

A few of the many industrial applications of the cathode-ray tube include the study and testing of radio and television receivers, radio and television transmitters, welding circuits, transmission lines, electronic control devices, circuit breakers, relays and other electrical equipment. The cathode-ray tube is equally valuable for the study of vibrations, acoustics, properties of metals, detonation in internal-combustion machines, the analysis of colors, and the precision adjustment of watches and camera shutters.

As a medium for television-picture reproduction, the cathode-ray tube is the most satisfactory method which has been devised — mainly because the inertia-free beam of the cathode-ray tube provides a scanning device which operates satisfactorily at the frequencies required to produce a high-definition picture of several hundred lines per inch. Then too, the scanning action of the beam can be readily synchronized because it is electronically controlled.

The knowledge and experience gained in developing cathode-ray tubes for television proved invaluable in the development of radar during World War II. Radar, like television, presents its information in the form of tiny spots of light on the face of a cathode-ray tube. Each spot of light represents the "echo" or reflection of a transmitted radio wave which has struck an object within the range of the radar system. By receiving, amplifying, and converting these "echoes" into light, each "echo" on the screen of the tube furnishes the operator with certain desired information.

Two cathode-ray tubes are often employed in a radar system. One is known as the A scope, the other as the PPI. The A scope presents the "echoes' in the form of "pips" which are vertical displacements of a horizontal trace. The position of each "pip" along the horizontal axis and the amplitude of the "pip" tell both the range of the object and its approximate size. The PPI, or plan-position indicator, in addition to furnishing range and size, also indicates the azimuth or bearing of the object from the position of the radar transmitter. This information is presented in the form of a polar map with light and dark shadows to indicate cities, coast lines, and rivers as well as ships and airplanes. The center of this "polar map" is the location of the radar station.

The most valuable feature of radar is its ability to penetrate darkness, smoke, overcast, and fog — to "see" objects which are not visible to the human eye.

It can readily be seen from the foregoing that the cathode-ray tube is not a laboratory curiosity but a precision device that is directly applied in all fields of engineering, as well as in the home and in the research laboratory.

Chapter 1

HISTORY AND DEVELOPMENT OF THE CATHODE-RAY TUBE

BASIC THEORY

The operation of the modern cathode-ray tube is based upon the natural properties of an incredibly small, negatively-charged particle called the electron. Electrons are present in all matter, which is composed of atoms made up of a positively-charged nucleus and one or more planetary electrons surrounding the nucleus. In the stable atom, the positive charge of the nucleus is equal to the combined charges of the planetary electrons; electrically therefore, the atom is neutral. However, the structure of some atoms is such that one or more of the outer planetary electrons may readily be removed. The electrical structure of that atom is then unbalanced and the atom exhibits electrical properties. Likewise, when an atom acquires more than its usual number of planetary electrons, it then also shows electrical activity. Thus, it may be considered that electrical phenomena are due to a deficiency or a surplus of electrons in an unbalanced atomic structure. Nature attempts to restore the unbalanced state to a stable condition, and in doing so creates those effects which we know as electrical phenomena.

There are two properties of the electron that are of particular interest to the student of electron behavior within the cathode-ray tube: (1) when an atom releases an electron, the free electron travels at very high speeds, (2) the electron has an exceedingly small mass and it is therefore almost inertia-free and not appreciably affected by the force of gravity.

DISCOVERY OF "CATHODE-RAYS"

The events leading to the discovery of "cathode-rays" date back to numerous experiments conducted by early scientists, including Coulomb and Faraday, who were investigating the behavior of gases under strong electric fields. Using a partially evacuated tube such as that shown in Figure 1, and applying a potential difference of several hundred volts between the cathode K and the anode A, many new and interesting phenomena were observed.

It was discovered that when the gas within the tube was at atmospheric pressure, very little current passed through the tube; but when the gas pressure was reduced, the current flow increased and the inner appearance of the tube passed through a series of characteristic changes.

As the pressure was reduced to about 1 centimeter of mercury, a faint glow appeared about the cathode and the anode. This glow formed threads of light which united into a single streamer extending between the cathode and the anode.

When the pressure was further decreased, this glowing streamer became detached from the cathode by a dark space which was called the "Faraday dark

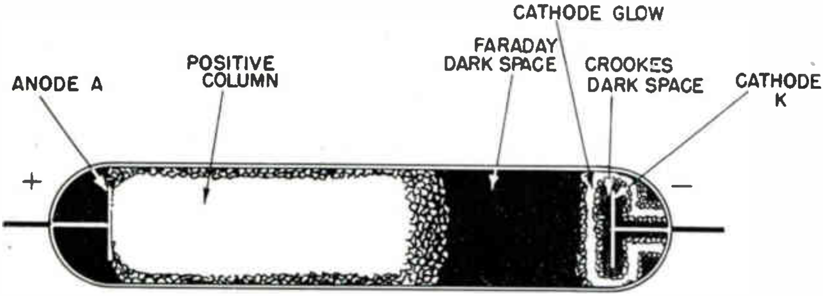


Fig. 1—Experimental gas-discharge tube

space" in honor of its discoverer. The glowing streamer was called the positive column.

When the gas pressure was decreased to about 0.1 mm. of mercury, the positive column receded toward the anode and broke into alternate light and dark striations perpendicular to the axis of the tube, and a distinct glow appeared around the cathode. This glow was separated by a dark space named the "Crookes space" after Sir William Crookes.

As vacuum techniques improved, thus making possible better evacuation of the tube, it was noted that as the pressure decreased more and more the "Crookes space" and the cathode glow expanded. This expansion resulted in the positive column striations becoming more and more crowded onto the anode until finally only the "Crookes space" remained in the tube. When this point was reached, it was observed that the glass in the region of the cathode fluoresced with a greenish color. Jules Plucker, a German physicist and mathematician, attributed this effect to an invisible ray which bombarded the glass with sufficient energy to cause fluorescence and heat. These invisible rays he called "cathode rays", a coined name which is still in common usage despite subsequent discoveries which have revealed the true nature of these so-called "cathode rays".

CROOKES' EXPERIMENTS

Sir William Crookes, an English physicist and chemist, spent many years studying the phenomena of "cathode rays". One of the earliest experimental tubes, similar to that used by Crookes, is shown in Figure 2.

This tube consists of a a glass envelope evacuated to the desired pressure. At one end of the tube is the cathode K (an aluminum electrode), at the other end is a glass plate C and the positive anode A. Parallel to both the cathode and the glass plate, and approximately 2½ centimeters in front of the cathode is a mica disc B which has a small aperture in its center. As rays are projected from the cathode, those rays which succeed in passing through the aperture in the mica disc strike against the glass plate and cause it to fluoresce at the point of impact.

A modern version of the famous Crookes tube is shown in Figure 3. In this tube, the cathode K is in the form of a flat disc and the anode A is sealed in a side leg of the tube. At the opposite end of the tube from the cathode is placed a tiny Maltese cross of metal which is so hinged that it can be raised to a vertical plane or lowered to lie flat, parallel to the bottom of the tube. When the Maltese cross is in the lowered position and cathode rays are projected from the cathode, the opposite end of the tube fluoresces with a brilliant greenish color under the bombardment of the cathode rays. However, when the Maltese cross is raised so that it lies in the path of the rays, a well defined shadow of the cross appears on the face of the tube. Crookes used this experiment to prove that cathode rays leave the cathode in a direction normal to its surface (that is, at right angles) instead of dispersing in the manner of light rays. Since the cross is faithfully reproduced, he proved also that cathode rays travel in straight lines.

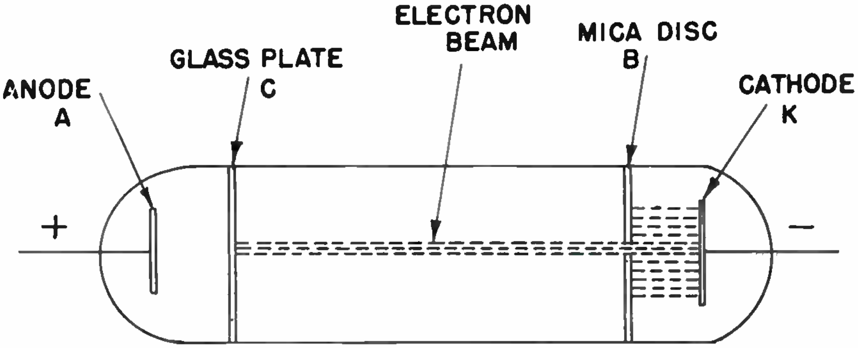


Fig. 2—Early experimental Crookes' tube

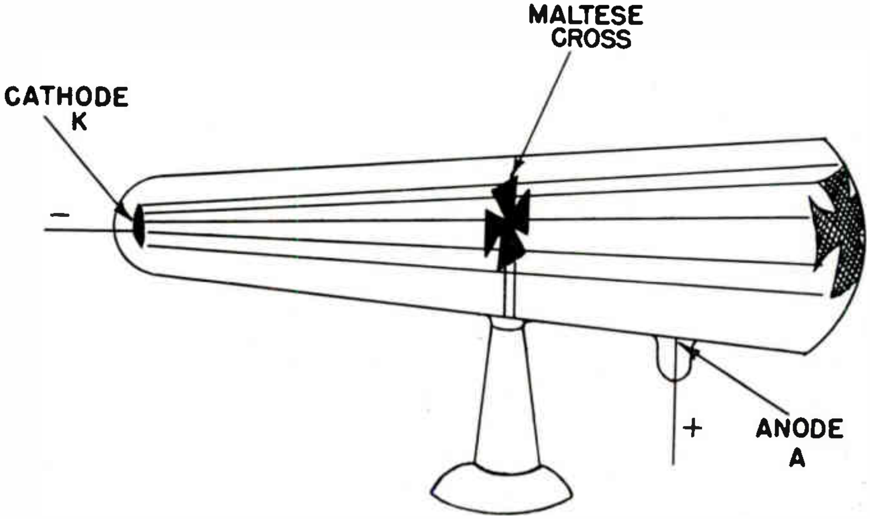


Fig. 3—Modern version of the famous Crookes' tube

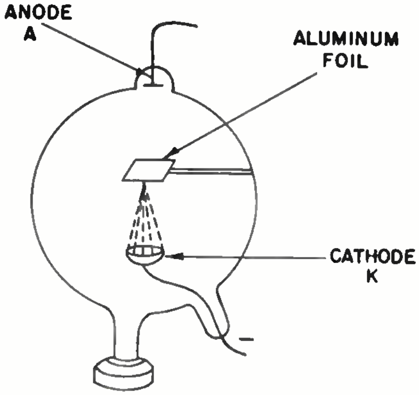


Fig. 4—Focusing cathode-rays with Crookes' tube

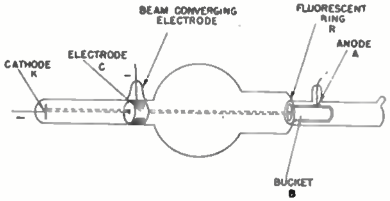


Fig. 5—Perrin's tube

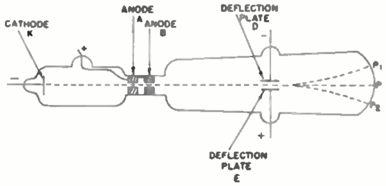


Fig. 6—Thomson's apparatus for producing and deflecting an electron beam

By inserting a concave shaped cathode K in a tube similar to that shown in Figure 4, and suspending a piece of aluminum foil above the cathode, Crookes proved further that it is possible to focus cathode rays; and that when cathode rays are focused upon the foil, the rays lose momentum and release sufficient energy to heat the foil to incandescence.

In 1879, Sir William Crookes after a further series of experiments concluded that cathode rays were not "rays" in the same sense given to light rays but instead were a beam of moving "particles".

PERRIN COLLECTS THESE "PARTICLES"

In 1895, Jean Perrin discovered that each of the so-called "particles" constituting cathode rays carried a negative charge. By means of a tube similar to that shown in Figure 5, Perrin succeeded in catching these "particles" in a "bucket" B located at one end of the tube. In Figure 5, the cathode K is located at the extreme left, the anode A at the extreme right. Located between the cathode and the anode is a cup-shaped electrode C with a small aperture in its center which acts to concentrate the "particles" into a narrow pencil-like beam. The ring R around the end of the opening to the bucket is a coating of fluorescent material which provides a visual indication as to whether or not all the "particles" enter the "bucket". This tube foreshadowed focusing action, although focusing devices were not employed as such until a much later date.

FIRST USE OF CATHODE-RAY TUBES FOR PRECISION MEASUREMENTS

The cathode-ray tube was first used as a precision measuring device by Sir J. J. Thomson who, in 1897, measured the velocity of these negative "particles" and discovered that the ratio of their charge to their mass is one of the fundamental constants of nature.

Thomson's tube is shown in Figure 6. This tube consists of a highly evacuated glass envelope which is divided into two main sections by two thick metal discs A and B which fill the cross section of the tube. As the negative "particles" are emitted from the cathode K they are accelerated toward the positively charged anode A. Some of the "particles" pass through the aperture in anode A and also succeed in passing through the smaller aperture in anode B which is electrically connected to anode A.

Thus, the "particles" which emerge from anode B form a concentrated stream which is fairly well defined. Without any charge applied to deflection plates D and E, this stream of "particles" passes midway between the two deflection plates and strikes the glass face of the tube to produce a fluorescent spot of light at point P. By applying suitable voltages to the deflection plates, Thomson was able to move the stream of particles up or down to strike the tube face at point PI or point P2. By using a magnetic field in addition to an electric field, Thomson was able to select "particles" of a constant velocity and accurately determine their velocity. Thomson did not employ the use of a fluorescent material on the tube face. Deflection of the stream was calibrated by means of a rough scale marked on the outside face of the tube.

DISCOVERY OF ELECTRONS

The term electron did not come into use until after 1890 when it was applied to these negatively charged "particles" by Dr. Johnstone Stoney. However, it was not until 1910 that the scientific world accepted the electron theory as presented by R. A. Millikan, American physicist, who, aided by his students, had performed innumerable experiments in calculating the precise charge of the electron. The results of these experiments proved conclusively that all charges are perfect integral multiples of the small unit charge borne by the electron and that there are never any intermediate fractional charges.

Confirmation of these same conclusions by other prominent scientists in related fields has firmly established the accuracy of Millikan's calculations. However, use of the term "cathode-ray" still persists, despite its inaccuracy. A much more accurate designation would be, "stream of electrons".

BRAUN'S EXPERIMENT

The first application of the cathode-ray tube for purposes of measurement is credited to Professor Ferdinand Braun in 1897. Braun's apparatus, shown in

Figure 7, is larger than Thomson's and simpler in design. A stream of electrons is produced at the cathode K, a flat disc perpendicular to the axis of the tube as in Thomson's apparatus. The anode A is removed to a side leg so that it is entirely clear of the path of the electron stream. The metal diaphragm B is insulated and has a circular aperture (approximately 2 millimeters in diameter) in its center. Thus the electron stream projected from the cathode passes through the aperture and emerges as a cylindrically shaped beam. At the opposite end of the tube is a fluorescent screen D, which consists of a mica plate coated with a mineral substance which exhibits the property of intense fluorescence under bombardment by the electron beam. With this apparatus it is possible to measure the deflection of the electron beam as produced by a magnetic field, an electric field, or a combination of both, in any direction upon the screen.

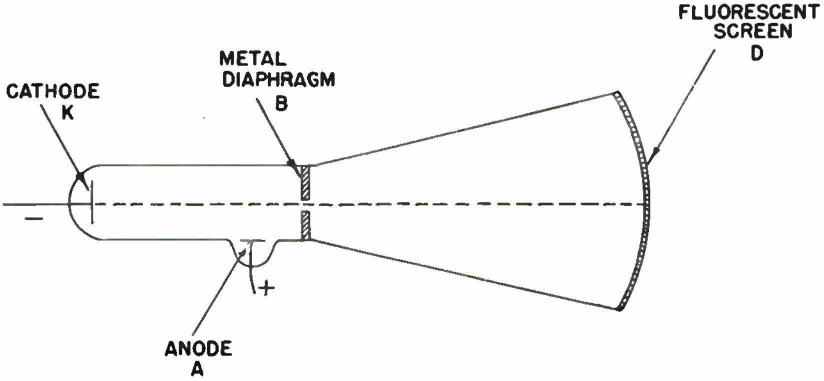


Fig. 7—Braun's apparatus as a measuring device

Braun is also credited with using a periodic time-base voltage to produce horizontal deflection of the beam and thus obtain a temporal plot of the observed signal. The Braun oscillograph was like the modern oscillograph in all its essential details. However, the images of these early tubes were only partially satisfactory and many improvements and refinements have been developed to achieve present-day quality and performance.

WEHNELT'S CONTRIBUTION

One of the major problems of cathode-ray tube design was the need for a high and constant voltage to develop the electron stream. To attract a sufficiently great number of electrons from the cold cathode to produce a beam of usable intensity, all cathode-ray tubes had so far required the use of an extremely high, positive anode-voltage.

In 1905, Wehnelt, who also gave his name to the cylinder (grid) surrounding the cathode of the modern cathode-ray tube, introduced the hot cathode as an electron-emitting electrode. Although Wehnelt's hot cathode was crude compared to later forms of emitters, it provided a much more intense electron beam than did the cold cathode, and it also permitted the use of much lower operating voltages.

Wehnelt's hot cathode consisted essentially of a flat platinum ribbon which had a spot of lime deposited at its center. When current was passed through it, the cathode heated to a glowing red color and electrons were emitted from the lime spot. These electrons were attracted to a center-holed flat disc to which a positive potential was applied. One of the shortcomings of Wehnelt's hot cathode was its short life.

The short cathode life was found to be due to imperfect evacuation of the tube which resulted in ionization of the gas molecules by the electron stream. These ions in turn bombarded the cathode and eventually damaged it to the point where the tube became inoperative.

PROBLEM OF FOCUSING THE BEAM

It was obvious that if the cathode-ray tube was to be of any practical value as an indicating device, some means must be provided for forming the stream of electrons into a narrow beam which could be uniformly deflected and which would produce a small, well-defined spot of light on the fluorescent screen.

The problem to be overcome was basically as follows: Electrons are negatively charged particles and, since like charges repel, the mutual repulsion of the electrons normally tends to cause the electron stream to diverge as it leaves the cathode. The divergence of the beam is further increased by the process of generation of electrons, for they accumulate about the cathode region and form a "space charge" which acts to repel newly emitted electrons. The total result is a diverging beam which produces a large spot of inadequate brightness.

This problem remained unsolved until 1921 when Van der Bijl and Johnson discovered that by inserting a small amount of gas within the tube a marked improvement in focusing action could be obtained.

GAS-FOCUSED CATHODE-RAY TUBES

As a result of the work of Van der Bijl and Johnson, the focusing action of the early types of cathode-ray tubes was obtained by utilizing a small quantity of inert gas such as argon, helium, or neon, introduced into the tube at a low pressure. The purpose of the gas was to counteract the natural dispersing action of the electrons in order to obtain a concentrated beam. The theory of operation is as follows:

When a gas is inserted into a tube at a low pressure, the gas atoms are at comparatively great distances apart. An electron leaving the cathode travels a comparatively great distance and acquires considerable kinetic energy before it meets a gas atom. When a high-velocity electron collides with a gas atom, one or more electrons are dislodged from the gas atom and leave the atom with a positive charge. The electron-deficient atom is then called an ion and the process that caused it to become an ion is known as ionization. Since there is a continuous emission of electrons from the cathode, there is a continuous formation of positive ions, the number being dependent on the gas pressure (nearness of the gas atoms to one another) and the velocity of the electrons (determined by the accelerating potential). Because of their greater mass, the positive ions remain within the path of the electron beam and form what might be considered a "positive core". If the "positive core" of ions is sufficiently strong, it acts to attract any electron diverging from the beam and to draw it in toward the axis of the beam, thus producing a converging action.

CONSTRUCTION OF A GAS-FOCUSED CATHODE-RAY TUBE

The general construction of a gas-focused cathode-ray tube is shown in Figure 8. A small quantity of gas has been inserted into the tube, at the desired pressure, to effect proper focus of the electron stream. The source of electrons is the directly heated cathode K which obtains its power from an external source. For more efficient operation, the cathode is made of either tungsten or platinum wire which has been coated with a small quantity of an electron-emitting substance such as barium or strontium. The anode A is a circular disc with a small aperture in its center. Usually the potential applied to this anode is of the order of 1000 volts positive with respect to the cathode. A focusing electrode B has been introduced in the form of a cylinder enclosing the cathode; its purpose is to concentrate the electron stream which leaves the cathode and thereby increase the efficiency of the electron gun. Deflection-plate pair H1 and H2 are used to deflect the beam along the horizontal axis; V1 and V2 are used similarly to deflect the beam along the vertical axis.

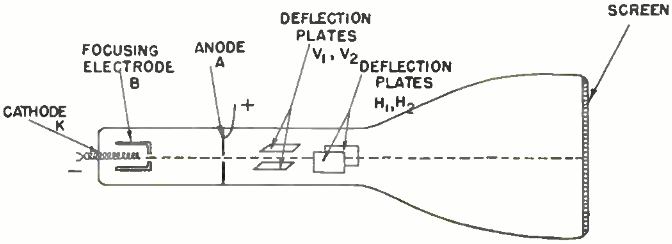


Fig. 8—Gas-focused cathode-ray tube

DISADVANTAGES OF GAS-FOCUSING

Although the gas-focused cathode-ray tube possesses valuable advantages in that it is capable of producing a sharply focused spot of adequate brilliance, there are many disadvantages which limit its use. One of the main disadvantages is the rapid deterioration of the cathode or electron emitter, greatly shortening the life of the tube, which is caused by the attraction of the negative cathode for the positive ions. The heavy ions strike the cathode and within short time they completely disintegrate the emitting surface, making the tube unusable.

A second disadvantage of gas-focused cathode-ray tubes is the origin distortion or "threshold effect" which occurs at the electrical center of the tube. Ionic focusing of the beam takes place along the path of the beam between the anode and the fluorescent screen. Ionization of the gas in the path of the electron beam is the essential part of gas focusing since it results in the formation of the positive ions which focus the beam. In electrostatically-deflected cathode-ray tubes, the presence of these ions causes a decrease in deflection sensitivity for small deflection potentials since the focusing ions neutralize the deflecting field. The effect of a small potential drop is to separate positive gas ions from electrons by attracting the positive ions to the negative deflecting plate and the electrons to the positive deflecting plate.

The movement of the electrons and the ions observes Newton's Second Law (Force = Mass × Acceleration), therefore the ions, because of their greater mass, will move more slowly than do the electrons and therefore, there will always be more ions than electrons present in the deflecting field. This accumulation of ions forms a positive space charge which tends to weaken the deflecting field and cause a loss in deflection sensitivity. At deflecting potentials above this critical point, the positive space charge is removed and the deflection again becomes normal. This threshold effect results in distortion of the waveform under examination. This factor was the chief reason for discarding gas-focusing in favor of electronic focusing in the present day high-vacuum cathode-ray tube, discussed in the following chapter.

A typical example of waveform distortion as caused by the threshold effect is shown in Figure 9. It will be noted that this distortion is noticeable only at the point marked A, which is in that portion of the sine wave pattern at which the beam deflection voltage nears and crosses the zero axis of the tube. In television applications, the threshold effect manifests itself in the form of a "gas cross" which is illustrated in Figure 10.

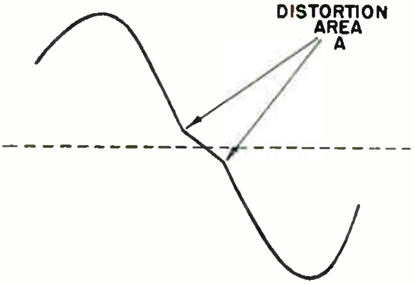


Fig. 9—Origin distortion in gas-focused cathode-ray tube

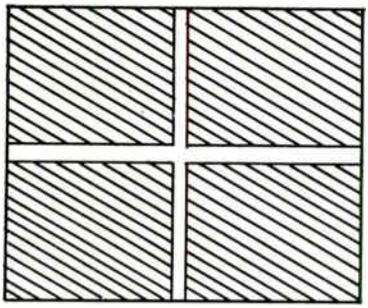
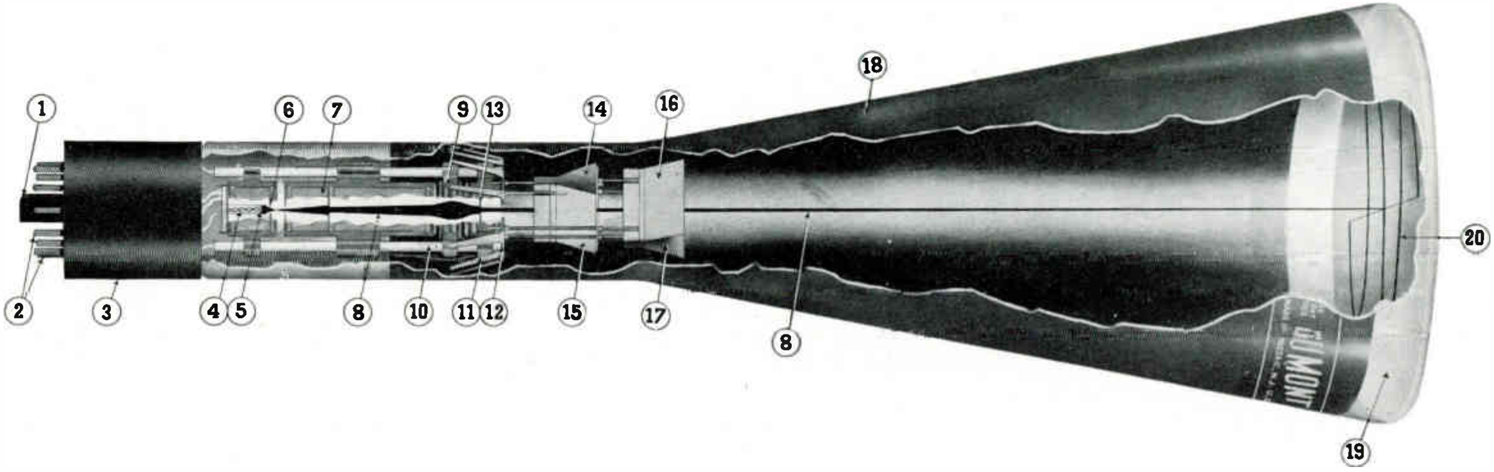


Fig. 10—Origin distortion causing "gas cross" in gas-focused cathode-ray tube

An additional disadvantage of gas-focused cathode-ray tubes is the defocusing effect which is experienced when deflecting signals of high frequency are applied. The correct focus of a given gas-focused electron beam depends at all times upon the ionizing properties of the beam. However, when a high frequency signal is applied to the deflecting plates, the movement of the electron beam is faster than is the rate at which ions are formed. Therefore, there is a loss of focusing action due to the fact that at a given instant there is an insufficient number of ions within the beam to properly converge the electrons. Furthermore, those positive ions outside of the beam act to attract electrons within the beam and thus tend to disperse the beam.

Since gas focusing is dependent upon the number of ions produced, which in turn is dependent upon the beam current and the gas pressure, any change in gas pressure, whether it be due to adsorption or absorption of gas within the tube or to changes in ambient temperature, will cause instability of operation resulting in a change in the focus and intensity.



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2. Pins
3. Base
4. Heater Element
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15. Deflection Plate D4
16. Deflection Plate D1
17. Deflection Plate D2
18. Internal Conductive Coating
19. Fluorescent Screen Material
20. Pattern

Fig. 11—Complete modern cathode-ray tube

Chapter 2

THE MODERN CATHODE-RAY TUBE: CONSTRUCTION AND THEORY OF OPERATION

CONSTRUCTION

The modern cathode-ray tube consists essentially of five major components: the glass envelope which is sometimes called the bulb, the tube base, the electron-gun assembly, the deflection-plate assembly, and the fluorescent screen. (See Figure 11).

For the purposes explained in this booklet, the glass envelope and the tube base are strictly mechanical features and they do not perform any part in the electrical functioning of the tube. The glass envelope serves as a housing for the electron gun, the deflection plates, and the fluorescent screen and also maintains the vacuum and provides a support for the Dixonac, which is an electrode, and in addition it supports the screen material. The tube base provides a means for making connections from external circuits to the various electrodes of the tube.

The electron gun provides a source of electrons, directs them toward the face of the tube, focuses them into a narrow beam, and accelerates this beam so that it strikes the screen of the cathode-ray tube with sufficient energy to cause fluorescence.

The deflection-plate assembly consists of two pairs of plates which are mutually perpendicular. By applying suitable voltages between the plates of each pair it is possible to move the electron beam up and down or right and left over the entire face of the cathode-ray tube.

The fluorescent screen provides a means for visibly observing the movement of the electron beam. The fluorescent screen is formed by coating the inner face of the cathode-ray tube with a chemical substance which emits light at whatever point it is struck by the electron beam.

THE ELECTRON-GUN ASSEMBLY

The electron-gun assembly is comprised mechanically of four major components: the cathode-grid assembly; the preaccelerator anode assembly; the focusing electrode, or first anode assembly; and the accelerating electrode, or second anode assembly. These assemblies are mounted by means of ceramic supports which run the entire length of the electron gun structure.

The CATHODE-GRID ASSEMBLY consists of the heater, the cathode,

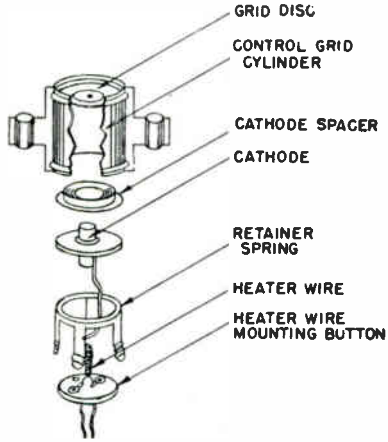


Fig. 12—The cathode-grid assembly

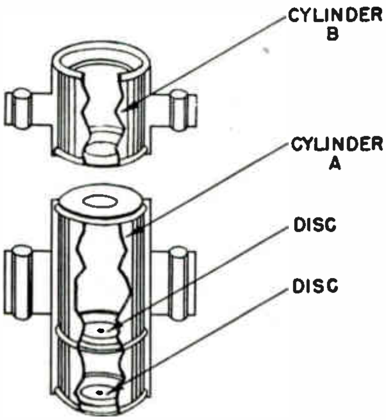


Fig. 13—Preaccelerator electrode assembly

the control grid and various structural elements, as shown in Figure 12.

The HEATER is a spiral coil of high-resistance wire, usually tungsten or tungsten alloy, which is coated with an insulating material to form a protective covering, or shell, for the wire. Useful emission does *NOT* take place from the heater coil; its sole function is to heat the cathode coating to an electron-emitting temperature. This feature distinguishes the heater from a directly-heated, or filamentary, cathode in which the heated wire is also the emitting body. It will be noted that the heater is securely locked in place by a retainer spring.

The CATHODE is a thin metal sleeve made of nickel or nickel alloy which encloses the heater coil. This sleeve is coated on the outside with an oxide of one of the alkaline-earth metals which, when heated to a temperature of about 700 degrees centigrade, emits electrons in great quantities. This type of construction, known as an indirectly-heated cathode, is considered more satisfactory for a-c operation than is the directly-heated cathode because the separation of the heating and emitting functions minimizes a-c "hum" and prevents electrical disturbances and undesirable a-c modulation from entering the tube circuit through the heater-supply line.

The CONTROL GRID, or modulating electrode as it is sometimes called, is a cylindrically shaped electrode which completely encloses the heater and the cathode. The control grid is the Wehnelt cylinder previously mentioned in Chapter One.

The control grid is open at the end adjacent to the retainer spring, shown in Figure 12, and capped at the other end by a disc with a small aperture in its center. A cathode spacer is located between the cathode and the grid disc to maintain proper spacing between these components. The diameter of the grid aperture (with no voltage applied to the grid) determines the number of electrons which can pass through it. The grid also provides a very effective means for controlling the current in the beam, since a negative grid voltage acts effectively to reduce the opening of the grid aperture.

The construction of this assembly is used in the most modern type of gun and is known as the "locked-in cathode". It is found in nearly all electrostatic-type tubes. Known as the Zero I_{b1}-Type, this electron gun also employs a preaccelerating electrode similar to that described in the following paragraph. The main features of tubes employing this type of gun are the locked-in cathode, and the fact that the focusing electrode draws no current due to elimination of apertures in the focusing electrode.

THE PREACCELERATOR-ELECTRODE ASSEMBLY

The preaccelerator electrode is a single cylinder, as shown in Figure 13, designed to confine the electron beam to a definite cross-sectional area and to provide a field-free region as the beam passes through this electrode. The purpose of the length of this metal cylinder is to provide the necessary preaccelerator length to satisfy the electron lens design of the tube. In some cathode-ray tubes this cylinder may be divided into two parts.

THE FOCUSING ELECTRODE

The focusing electrode, Figure 14, consists of a completely hollow, metal cylinder of comparatively short length. When the proper voltage is applied to this cylinder, the beam is focused on the fluorescent screen of the cathode-ray tube. This electrode was formerly called the first anode since early cathode-ray tubes did not contain a preaccelerator.

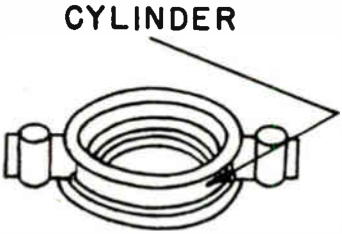


Fig. 14—The focusing electrode assembly

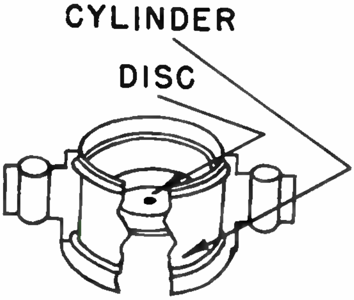


Fig. 15—The accelerating electrode assembly

THE ACCELERATING ELECTRODE

The accelerating-electrode assembly, Figure 15, is a metal cylinder containing a disc with an aperture in its center. This anode is used to provide the final accelerating force on the electron beam before it passes between the deflecting plates. Previous to the introduction of the preaccelerator electrode in cathode-ray tube design, the accelerating electrode was called the second anode.

THE DEFLECTION-PLATE ASSEMBLY

Located within the neck of the cathode-ray tube, between the second anode and the fluorescent screen, is the deflection-plate assembly. This assembly consists of two pairs of deflection plates, the plane of one pair being at right angles to the plane of the other pair. The complete deflection-plate assembly is shown

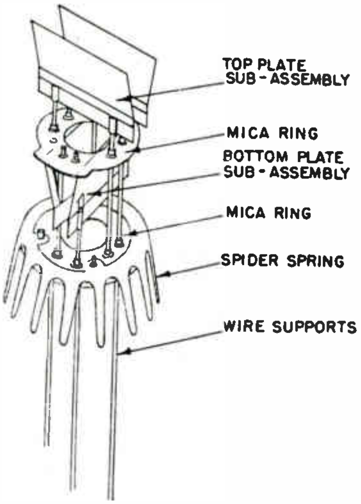


Fig. 16—The complete deflection plate assembly

in Figure 16. Mechanically, the deflection-plate assembly is divided into a top deflection plate sub-assembly and a bottom deflection plate sub-assembly.

Frequently the deflection-plate pairs are referred to as the horizontal-deflection plates and the vertical-deflection plates, the designation indicating the direction that each pair moves the electron beam and not the physical plane in which the pair lies within the tube. Either pair of deflection plates can be used for vertical deflection with the remaining pair serving for horizontal deflection. The design of the instrument in which the tube is to be used will determine the selection of deflection-plate pairs for each axis of deflection.

The deflection plates are made of a non-magnetic metal and are mounted on mica platforms by means of wire supports. The deflection plates are assembled with the electron gun and inserted as a unit within the tube. The spider spring below the lower deflection-plate sub-assembly, therefore, serves to center the complete unit within the neck of the tube.

THE GLASS ENVELOPE

The glass envelope or bulb of the cathode-ray tube, Figure 17, is usually made of blown glass and must be mechanically strong to withstand the stresses of ordinary handling and temperature changes; this is particularly important in the case of large tubes, because they are subjected to considerable stress under atmospheric pressure due to the high degree of evacuation.

The inner face of the tube serves as a base on which the fluorescent screen material is applied. The inner walls of the tube between the screen and the neck are usually coated with a conductive material (graphite), known commercially as "aquadag" or "dixonac" which is electrically connected to the accelerating electrode so that electrons striking the walls of the tube are returned to the circuit. By such an arrangement, the walls of the tube are maintained at uniform potential so that the electron beam will not be disturbed by charges which might otherwise accumulate on the walls.

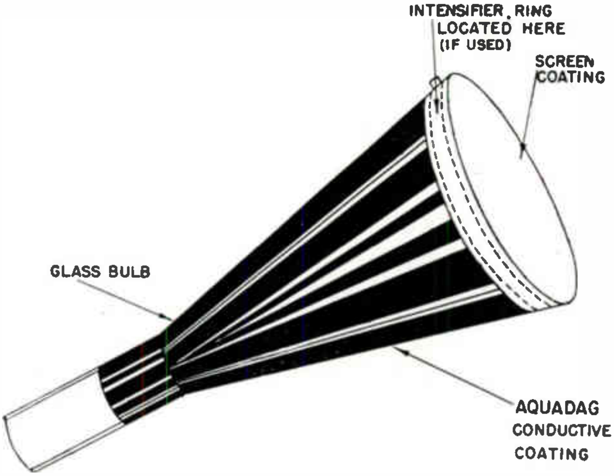


Fig. 17—Glass envelope or bulb

In some cases, an additional ring of conductive material is located between the screen and the internal conductive coating. This ring, known as the intensifier band, is usually connected to a potential of about twice the magnitude of that applied to the accelerating electrode. This is considered, of course, as a relative voltage taken with respect to the cathode. For example, if the cathode is operated at —1500 volts with respect to ground, and if the accelerating electrode is operated at ground, the intensifier is usually operated at + 1500 volts. Thus, relative to the cathode, the accelerating electrode is operated at +1500 volts while the intensifier is operated at 3000 volts, twice the relative potential applied to the accelerating electrode. The use of such an intensifier electrode makes possible many economies in the design of circuits which are to be used with cathode-ray tubes.

THE TUBE BASE

The tube base is formed of an insulating material, usually phenolic, to provide a convenient method for making external electrical connections to the various electrodes of the cathode-ray tube. The leads from the electrodes of the cathode-ray tube are soldered to the ends of the pins of the tube base so that they may be connected into a suitable socket.

THE FLUORESCENT SCREEN

There are three general types of materials used for fluorescent screens in cathode-ray tubes: silicates, sulphides, and tungstates. In applying a screen material to the face of the glass envelope, the thickness of the material must be carefully controlled since screen brilliance depends on this factor. Screen materials are usually applied by settling the material from a water suspension or by spraying the screen material onto a thin binder which has previously been applied to the inner face of the tube.

THEORY OF OPERATION

THE HEATER COIL

The sole function of the heater coil is to heat the cathode to the proper operating temperature. No useful emission takes place from the heater coil.

When the heater coil is connected to a suitable power source, the applied voltage creates an electric field within the wire and causes electrons to drift slowly along the wire in the direction from the negative to the positive terminal of the voltage source. However, the movement of these electrons is opposed by the atoms which compose the wire. This opposition to current flow, known as resistance, results in loss of electrical energy and thus generation of heat within the wire. This heat is then transferred by radiation to the cathode which is in close proximity to the heater coil.

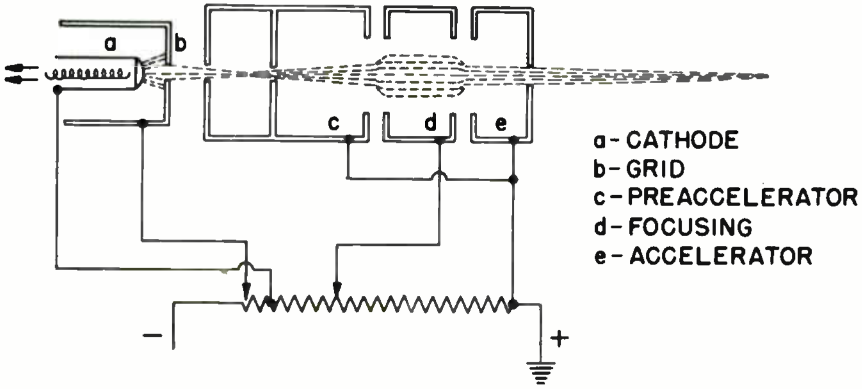


Fig. 18—Passage of electron beam through gun of cathode-ray tube

THE CATHODE AND ELECTRON EMISSION (See Figure 18)

As the cathode is heated, heat is transferred by conduction to the oxide coating on the outside of the cathode sleeve. It is from this oxide coating that the useful electron emission takes place. This coating, when heated to a temperature of about 700 degrees centigrade, readily permits a great number of electrons to acquire sufficient velocity to overcome the surface forces of the coating and fly into space. This is known as electron emission and, because it is due to heat, is called thermionic emission.

Although it is possible to obtain a certain amount of emission by heating almost any metal, it has been found that oxides of certain alkaline-earth metals when used as a coating on metal or alloy bases are much more efficient as electron emitters and can be operated at comparatively low temperatures. The quantity of electrons which are emitted is dependent upon two factors: the nature of the substance and the temperature at which it is operated. At a fixed temperature, a given substance will emit electrons at a constant rate.

NORMAL OPERATION

In the case of the tube illustrated in Figure 18, a Du Mont Type 5BP1-A, operating conditions call for the cathode to be operated at approximately —1500 volts with respect to the second anode. Under such conditions, the grid will be operated between — 1500 and — 1530 volts, depending upon the setting of the intensity control. The focusing electrode is operated at approximately —1070 volts with respect to the second anode, and both the accelerating electrode and the preaccelerating electrode are operated at zero volts (ground potential). The electrons possessing enough energy to escape from the cathode are repelled by the walls and the end of the grid cylinder which is more negative than the cathode. The electrons which do not possess sufficient energy to overcome this repelling action of the grid are forced back into the cathode while those which have sufficient energy escape through the tiny aperture in the end of the grid cylinder. Those that escape from the grid cylinder are accelerated by the electrostatic field between the grid and the preaccelerator electrode, a very strong field because of the large difference in potential between the two electrodes.

In that region between the grid and preaccelerating electrode, the electrons are accelerated to very high speed. Once inside the preaccelerating electrode, the initial velocity of the electrons is such that they are not appreciably attracted toward the walls of the preaccelerator. Those electrons which are most divergent strike the disk which is situated about ⅓ of the way along the preaccelerating electrode and are removed from the beam. Those electrons which are traveling along the axis of the tube pass through the aperture in this disk and continue on their way with only a slight divergence, until they approach the area between the preaccelerator and the focusing electrode. At this point, the electrostatic field which exists between the focusing electrode and the preaccelerating electrode is such that it tends to reduce the speed of the electrons and to cause them to diverge. However, this diverging action takes place for only a very short time, (the time necessary for the electrons to travel to the mid-point of the focusing electrode), because the focusing electrode is of relatively short length. As the electrons pass through the electrostatic field between the focusing electrode and the accelerating electrode, the lines of force of this field are in the direction of electron-travel and the electron beam is constricted, as well as positively accelerated in the direction of the fluorescent screen. Any electrons which diverge too much to be properly focused on the screen of the cathode-ray tube are eliminated from the beam by failure to pass through the aperture in the disc located in the accelerating electrode.

INTENSIFIER BANDS

In certain commercial uses of the cathode-ray oscillograph, circuits are encountered whose characteristics demand performance with respect to luminosity which is beyond the practical limits of the Type 5BPI-A Cathode-ray Tube, herein discussed. With transient phenomena, for example, the traces produced on the cathode-ray screen may be too dim for satisfactory observation or recording; or again, with recurrent phenomena, easily discerned by direct viewing or photography, the light output may not be sufficient for enlargement by means of a projection-lens system.

An increased light output, from fluorescent screen material, usually can be obtained by increasing the beam current or by increasing the accelerating voltage. However, beam current is limited by the maximum permissible spot size since the spot size increases with the beam current. On the other hand, the accelerating voltage is limited by deflection sensitivity which varies inversely with the accelerating voltage.

A new type of cathode-ray tube containing an additional electrode, the intensifier, was designed by Allen B. Du Mont Laboratories, Inc. The intensifier electrode resolved the problem of obtaining increased light output without losing deflection sensitivity or increasing spot size.

The intensier electrode is located near the screen end of the cathode-ray tube. Operated at a higher voltage than the accelerating electrode, the intensifier serves to accelerate the beam subsequent to deflection; thereby, the beam may be deflected at a low accelerating potential and then further accelerated after deflection by a higher potential applied to the intensifier electrode.

The extension of cathode-ray technique to include an ever growing field of applications necessitated the development of a means by which faster writing rates might be observed, with an even greater increase in light output.

To resolve the problem of obtaining an even greater light output, the Allen B. Du Mont Laboratories, Inc., developed the high-voltage cathode-ray tube. The solution, whereby spot size was not increased nor deflection sensitivity appreciably decreased, lay in the use of several intensifier bands. By this means the accelerating voltage is divided into stages and is applied to the electron beam both before and after deflection.

The intensifier bands consist of three electrodes located near the screen-end of the cathode-ray tube, as shown in Figure 19.

Fig. 19—Du Mont Type 5RP-A showing intensifier bands of a high-voltage cathode-ray tube

The potentials for the intensifier bands are obtained from a high-voltage power supply. Connections to the power supply are made by three contacts on the body of the tube, as shown. These bands apply increased accelerating voltage to the electron beam in three equal steps.

Modification in the shape of the glass bulb and proper location of the intensifier bands keeps distortion to a minimum. An additional band, located between the second anode and the three intensifier bands, shields the deflection plates from the intensifier field and from external electrostatic fields. This band is connected to ground by an external contact on the body of the tube. It is possible to operate this tube satisfactorily at ratios of intensifier to second anode voltages up to ten to one.

It should be borne in mind that these features are not embodied in cathode-ray tube Type 5BP1-A, herein discussed, but are mentioned so that the reader may have an understanding of complete cathode-ray technique; in many cases, however, the high-voltage cathode-ray tube may be operated in standard equipment with standard deflection amplifiers.

GRID ACTION OR CONTROLLING THE BEAM INTENSITY

The control grid provides the means for controlling the intensity of the electron beam. Since the brilliance of the spot produced by the electron beam is dependent at all times on the number of electrons in the beam, the grid, because of its nearness to the cathode-emitting surface, offers a convenient method for effecting such control. It has been pointed out that with a given accelerating voltage and with 0 volts applied to the grid, the size of the grid aperture is the determining factor as to how many electrons can pass through the grid. However, when a negative voltage is applied to the grid (with respect to the cathode), this negative grid assists the space charge in repelling electrons which are emitted from the cathode and thus acts to limit the effective aperture of the grid.

Normally, the grid of the cathode-ray tube is operated at a negative potential which is specified by the manufacturer of the tube. At this specified value, a certain number of electrons will pass through the grid and produce a spot of a certain intensity on the screen of the tube. When the grid is made more negative than this value, fewer electrons pass through the grid and therefore the spot intensity is diminished. Conversely, when the grid is made less negative, a greater number of electrons pass and the spot intensity is increased. Thus the electrical operation of the grid of the cathode-ray tube is analogous to that of the grid in a conventional vacuum tube, as both act to control electron flow through the tube. It will be noticed, in Figure 18, that the electrons leaving the cathode are converged toward the axis of the tube and cross over along this axis. This is due to the negative charge on the grid which repels the negatively charged electrons.

FOCUSING THE BEAM

Since electrons are negative and thus bear mutual repulsion for one another, the electron beam which passes through the grid aperture is a divergent one. Such a beam would render the cathode-ray tube useless as an accurate indicating device for the following reasons: (1) the spot size produced at the screen would be much too large to trace useful patterns, and (2) it would be impossible to deflect a divergent beam with any degree of uniformity. Therefore, it is imperative that the beam be made to converge into a narrow one; one that will produce a small-size spot and also one which can be uniformly deflected.

There are several ways by which this may be accomplished: (1) by inserting an inert gas into the tube, (2) by passing the beam through an electrostatic field, and (3) by passing the beam through a magnetic field. The gas method of focusing as discussed in Chapter I has been long since discarded; the two other methods are discussed in the following paragraphs.

ELECTROSTATIC FOCUSING

This method for focusing an electron beam makes use of what is known as electron lenses, which are the result of two electrostatic fields created by, first, the difference of potential between the preaccelerating electrode and the focusing electrode and, secondly, the difference in potential between the focusing electrode and the accelerating electrode. Both the accelerating and preaccelerating electrodes are usually operated at a fixed positive potential with respect to the cathode, which in many cases is as high as several thousand volts. The focusing-electrode potential, on the other hand, is usually taken from a variable source and ranges between 15 and 25% of the value of the accelerating potential.

The lines of force in the electrostatic field created by the difference of potential between the two electrodes may be considered as being the equivalent of a thick concave lens, as shown in Figure 20. As the electron beam enters this electrostatic field, the lines of force of the field will produce a diverging action on the beam in very much the same manner as an optical lens bends a beam of light.

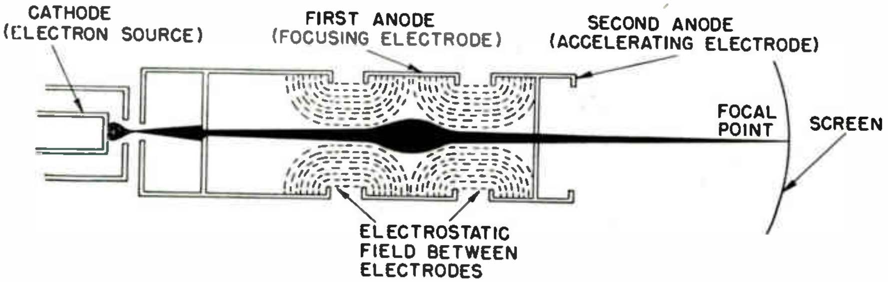


Fig. 20—Focusing the electron beam by means of an electrostatic field

The electrostatic field set up by the focusing and accelerating electrodes takes this diverging beam and reconverges it into a narrow, clearly defined beam. The action of this latter field may be considered equivalent to the effect of a convex lens on a beam of light.

To illustrate the similarity of optical focusing as compared with electrostatic focusing, a similar optical system is shown in Figure 21. In the electrostatic system of focusing, the focal length of the electron lens is changed by varying the voltage ratio between the focusing electrode and the accelerating electrode. In this way, the focal point (or point at which the beam converges to form the spot on the screen) can be moved forward or backward within practical limits.

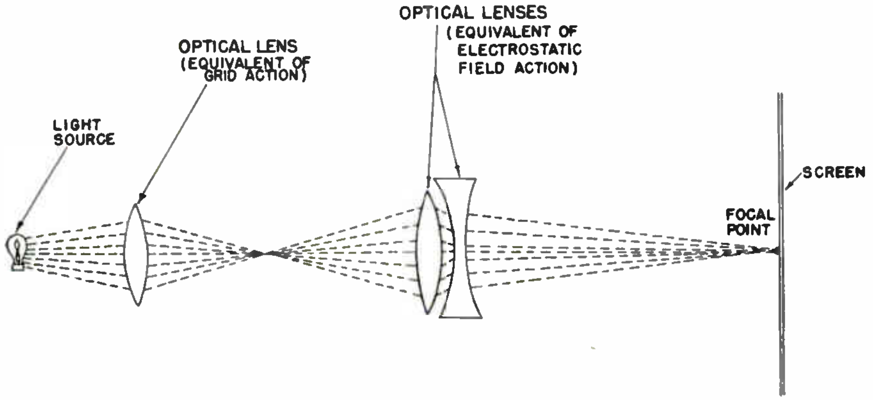


Fig. 21—Optical analogy of electrostatic focusing

ELECTROMAGNETIC FOCUSING

An alternative method for focusing the beam employs the principle of electromagnetic control. With this method, a solenoid is placed around the neck of the cathode-ray tube (Figure 22) and current is passed through the coil. This establishes an electromagnetic field within the tube. As shown in Figure 22, the field within the coil is almost uniform and parallel to the axis of the coil. Outside the coil, the field is weaker and there is, also, a radial component due to the curving of the lines of force away from the axis.

An electron moving along the axis of the field will experience no deflecting force because it travels through that portion of the field whose lines of force coincide with the line of travel of the electron. However, an electron traveling at an angle to the axis will, because of its radial velocity, be acted upon by the field, thus causing the electron to move in a spiral. The electron continues its spiral motion while under the influence of the electromagnetic field. When it emerges from the field, the resultant force, as determined by the axial component and the radial component, directs the electron toward the screen in such a direction that it strikes at the focal point.

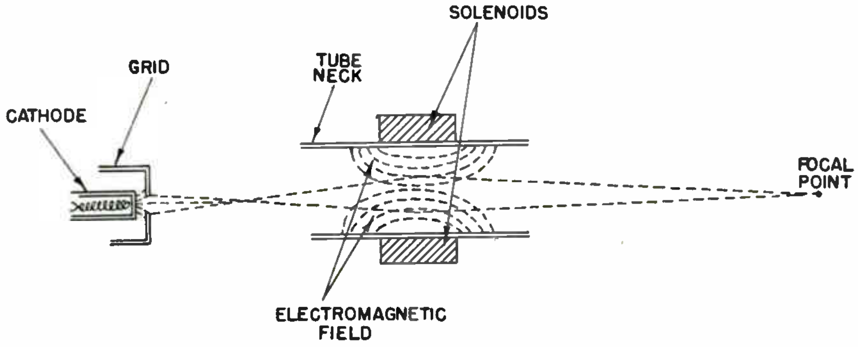


Fig. 22—Focusing the electron beam by means of an electromagnetic field

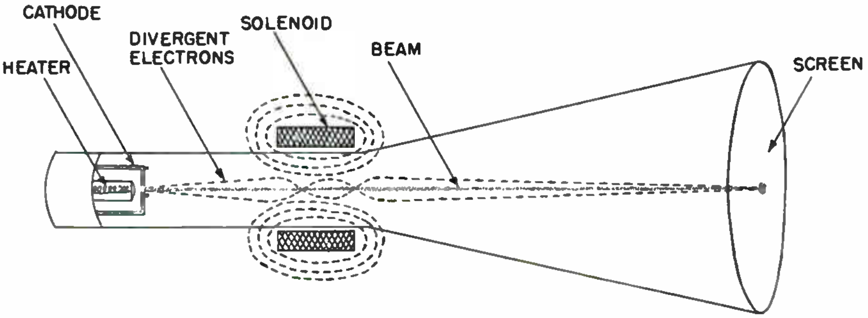


Fig. 23—Illustrating the spiral path taken by an electron in an electromagnetic field

By properly positioning the solenoid and by adjusting the current through the coil, only the electrons with radial velocities [with respect to the axis of the focus coil] may be made to follow spiral paths, some of larger diameters and some smaller, but all taking the same time and all emerging from the field so that they converge at a common focal point. This spiral path of the electrons is illustrated in Figure 23. In practical operation, the solenoid is set at a predetermined point to provide a rough focus adjustment; fine adjustment is then obtained by varying the current through the coil.

COMPARISON OF ELECTROMAGNETIC AND ELECTROSTATIC FOCUSING

The electromagnetic system of focusing possesses three distinct advantages: (1) The relative simplicity of the electrode system of the electromagnetically focused tube makes for low production costs. (2) With an electromagnetically focused tube, astigmatism of the focus system may be readily corrected by a simple adjustment of the solenoid coil. With an electrostatically-focused tube, astigmatism is a permanent fault, since the focusing electrodes cannot be adjusted. (3) Defocusing action, resulting from a change in beam current, is not as apparent with electromagnetically focused tubes as it is with electrostatic types.

Electrostatically-focused tubes, on the other hand, require considerably less current for focusing of the electron beam. Furthermore, since focusing voltage is the result of a ratio of voltages (these voltages are obtained from a bleeder). variations in the output voltage of the power supply do not affect focus.

DEFLECTING THE BEAM

Since the cathode-ray tube is essentially an indicating device, it is necessary to provide some means for deflecting the beam so that a pattern may be traced on the fluorescent screen of the tube and thus provide the desired information in visual form. There are two fundamental methods for deflecting the electron beam: (1) electrostatic, and (2) electromagnetic. Electrostatic deflection is used almost exclusively in oscillographic work, whereas electromagnetic deflection is most generally used in television applications. The advantages and disadvantages of these two systems are discussed in the following paragraphs.

ELECTROSTATIC DEFLECTION

Electrostatic deflection is accomplished by means of two pairs of deflection plates which are placed at right angles to each other within the cathode-ray tube between the electron gun and the fluorescent screen. The pair of plates which deflects the beam along the horizontal axis is called the horizontal deflection-plate pair; the pair which deflects the beam along the vertical axis is called the vertical deflection-plate pair. It is important to remember that the designation of the plate pair applies to the direction in which the plate pair moves the beam and NOT to the physical position taken by the pair within the tube. The choice of whether the front or the rear pair be used for a specified direction of deflection is dependent upon the design of the equipment.

A typical plate-pair arrangement is shown in Figure 24. Although deflection plates are sometimes perfectly flat, it will be noticed that each of the deflection plates shown in Figure 24 has the trailing edge bent outward at an angle. The reason for that is that higher sensitivity can be obtained by lengthening the plates, so that the electrons remain under the influence of the applied electrostatic field set up by the deflecting voltage for a longer period of time. This increased sensitivity or greater deflection of the beam would cause the beam to strike the trailing edges of the plates if the edges were not diverged.

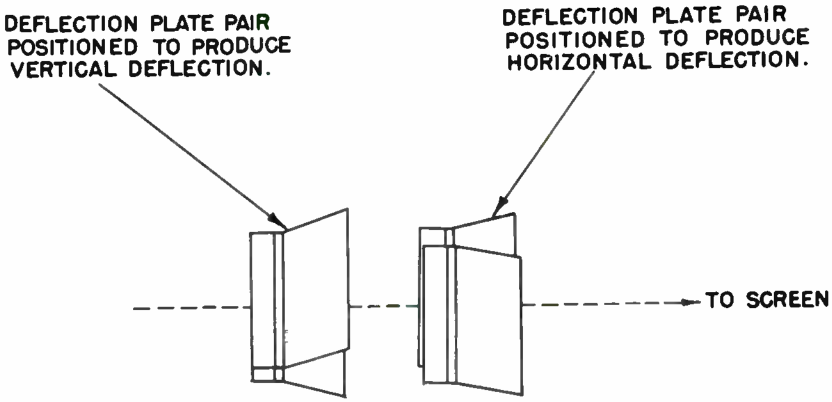


Fig. 24—Typical arrangement of deflection plates in the cathode-ray tube

To simplify the explanation of electrostatic deflection, it is advisable to consider the action of each pair of plates separately, then the combined action of both pairs of plates.

That *like* electrostatic charges repel and *unlike* charges attract is one of the basic laws of physics. Accordingly, an electron, being a negatively charged particle, will be attracted to a positively charged body and repelled by a negatively charged body.

Shown in Figure 25 is a pair of deflection plates which, in this case, has been positioned to produce horizontal deflection of the beam. With no voltage applied to the deflection plates, the electron beam would be undeflected and would therefore pass through the electrical center of the plates and strike the fluorescent screen at point 0.

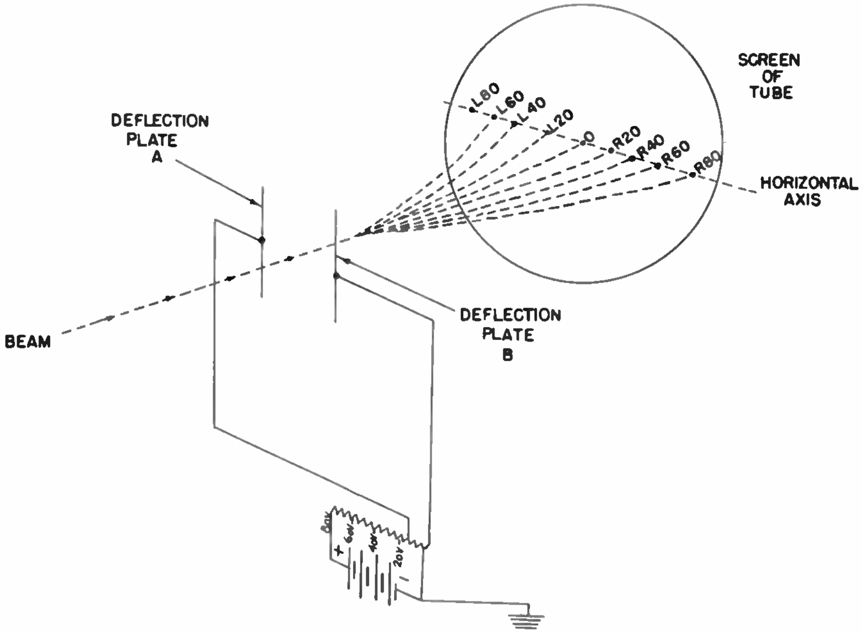


Fig. 25—How the beam is electrostatically deflected along the horizontal axis

If the rotor of the potentiometer is moved left to the 20-volt position, deflection plate A is charged positive with respect to plate B. This 20-volt difference in potential causes the beam to be deflected to the left toward plate A and away from plate B. The beam then strikes the screen at point L20. If the potentiometer is moved to the 40-, the 60-, and the 80-volt positions in progressive steps, the deflecting voltage is proportionately increased and the beam is deflected further to the left so that the spot moves to point L40, L60, and L80 respectively. With this arrangement, it is possible to move the spot to any position along the horizontal axis between points 0 and L80.

By reversing either the battery connections or the leads to the deflection plates, the polarity of the voltage applied to the plates is reversed; that is, plate A is charged negative and plate B positive. Then, by following the same procedure explained above, the spot may be moved from point 0 to the right along the horizontal axis to point R20, R40, R60, R80, or any intermediate position.

Thus it can be seen that by application of suitable deflecting voltages of proper polarity, the spot may be moved either to right or to left along the horizontal axis of the tube.

Figure 26 shows a pair of deflection plates which has been positioned to produce vertical deflection of the beam. Vertical deflection is accomplished in exactly the same manner as was described previously for horizontal deflection. The only difference is the physical position which the plates occupy within the tube. For example, when plate A is positive and plate B negative, the beam

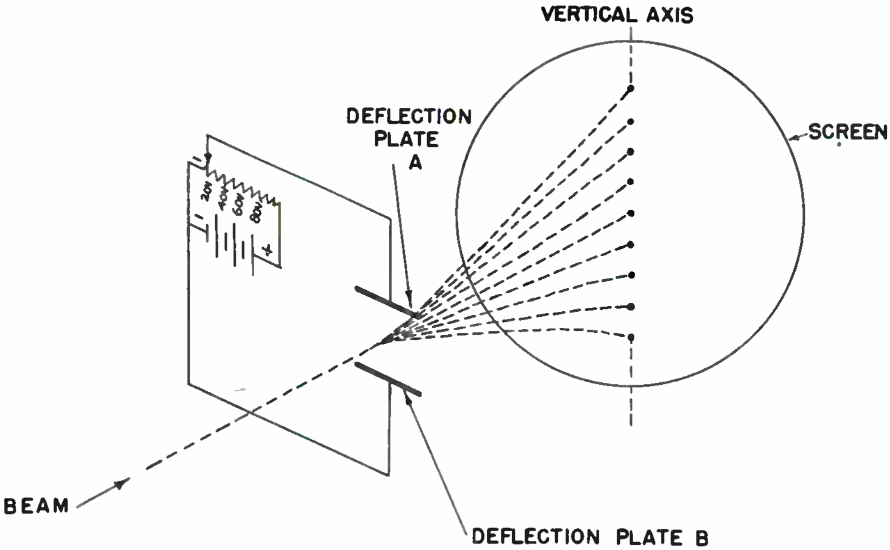


Fig. 26—Showing how the beam is electrostatically deflected along the vertical axis

may be moved upward along the vertical axis to any position between axis point 0 and point U80. By reversing polarity of the deflecting potential, (as previously explained), the spot may also be moved downward to any point between point 0 and point D80. In both cases, the distance by which the beam is deflected will be determined by the voltage applied.

Thus it can be seen that by application of correct polarities and suitable voltages, the spot may be moved anywhere, up or down, along the vertical axis of the tube.

Figure 27 shows both the vertical and the horizontal deflection plates within a cathode-ray tube. Each pair of plates has its own separate voltage source as before. With this arrangement it is possible to position the spot anywhere on the screen of the cathode-ray tube by applying the proper deflecting voltages in proper polarity.

For example, if plates A and C are charged positive 20 volts with respect to plates B and D, the horizontal deflecting force tends to move the beam toward point H20 and the vertical deflecting force tends to move it toward point V20. These two forces, acting at right angles to each other, can be represented by a single force, or resultant which deflects the beam diagonally to point R20. Similarly, if the voltage difference between plates A and C and plates B and D is increased progressively to 80 volts, the spot will move diagonally through points R40, R60, and R80. In this manner, the spot may be moved anywhere within quadrant A of the tube screen. The spot may be likewise positioned in quadrants B, C, and D by using correct polarities and suitable deflecting voltages.

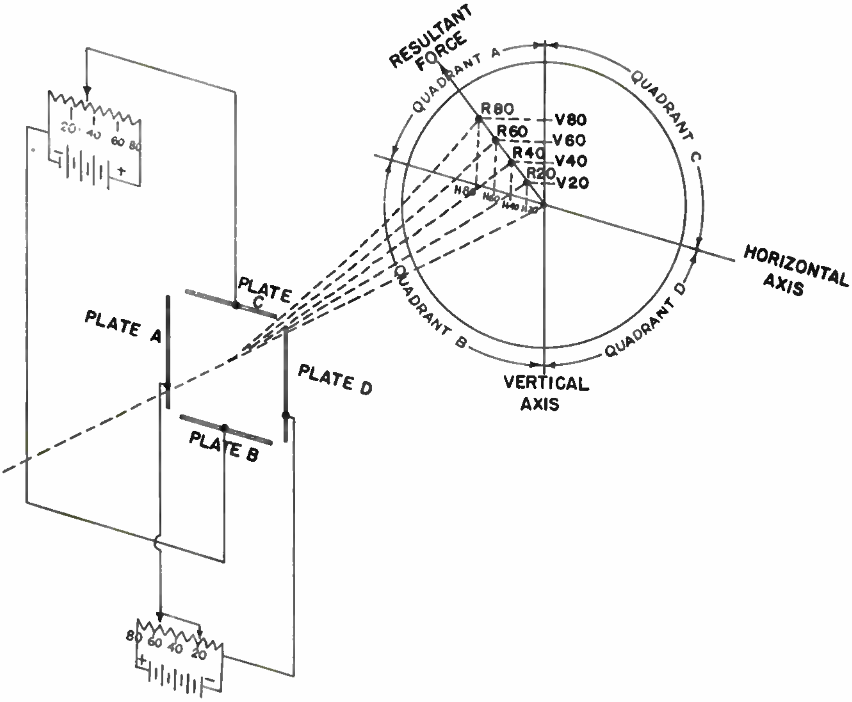


Fig. 27—Showing action of both horizontal and vertical deflection plates

A-C VOLTAGES APPLIED TO DEFLECTION PLATES

In previous paragraphs it has been shown how the electron beam reacts to the application of d-c deflecting voltages. It is equally important to understand what happens when an a-c voltage is applied to the deflection plates. A typical waveform of an a-c voltage is shown in Figure 28. It is known as a sine wave because the curve follows the sine law [Y=A sin PX]. Notice that the sine wave starts at zero value, rises to a maximum value in one direction, descends to zero, changes polarity and rises to a maximum value in the opposite direction, and then returns to zero again. One complete course of voltage change is called one cycle.

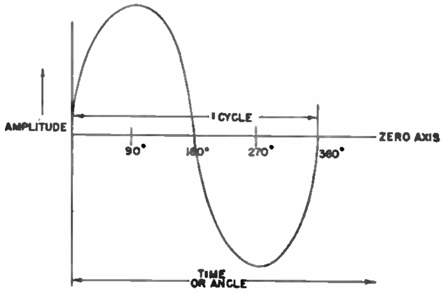


Fig. 28—Typical sine wave of a-c voltage

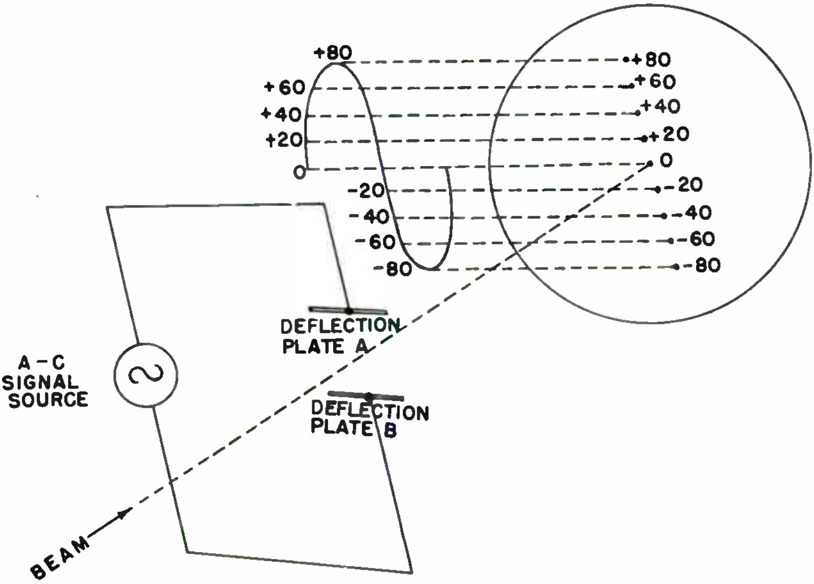


Fig. 29—Two deflection plates placed to produce vertical deflection of the beam with an a-c voltage applied

Figure 29 shows two deflection plates positioned to produce vertical deflection of the beam and connected to a suitable a-c voltage source. When the sine wave voltage is at zero, no potential difference exists between the deflection plates. Therefore the beam is undeflected and strikes the screen at its electrical center, point 0. As the sinusoidal voltage rises toward maximum in a positive direction, the combined action of positively charged plate A and negatively charged plate B deflects the beam progressively upward through points +20, +40, +60, and +80. After reaching maximum point +80, the amplitude of the deflecting voltage decreases but the polarity remains unchanged. Therefore, the beam returns through points +60, +40, +20, to 0. As soon as the sine wave crosses the zero axis, the polarity changes and plate A becomes negatively charged and plate B positively charged. Then, as the sine-wave voltage rises to maximum in the negative direction, the beam is deflected downward through points —20, —40, —60, to —80. At maximum value —80 the amplitude of the voltage starts to decrease but the polarity is still the same, therefore the beam returns through points —60, —40, —20, to 0. This action is repeated over and over again with each cycle of applied voltage; the number of times this happens per second (cycles per second) is called the frequency. With this setup, every instantaneous value of the a-c deflecting voltage is applied to the deflection plates as the voltage passes through each complete cycle. The apparently solid vertical trace which appears on the fluorescent screen is actually a continuous series of individual spots formed by the displacement of the beam by each of these instantaneous values occuring in succession. The length of the trace represents the peak-to-peak amplitude of the applied deflecting voltage. However, above about 16 cycles per second, due to the persistence of the human eye and the extremely rapid movement of the beam up and down the screen, the trace appears as a continuous unbroken line.

To reproduce the well-known sine curve on the screen of a cathode-ray tube, it is necessary to apply horizontal as well as vertical deflection to the beam in order that a two-coordinate system be provided. Furthermore, to obtain a stationary pattern of the curve, horizontal deflection of the beam must be accomplished at a time rate or frequency which is exactly the same, or exactly a submultiple frequency of the sinusoid used for vertical deflection.

In Figure 30 is shown the pattern of a sawtooth voltage which is linear with time. When such a voltage is applied to the horizontal deflection plates, the beam moves across the horizontal axis at a uniform rate of speed during the rising portion of the curve. The beam then returns rapidly to its original starting position when the sawtooth voltage drops to zero value. The time consumed for this return is known as the "flyback period".

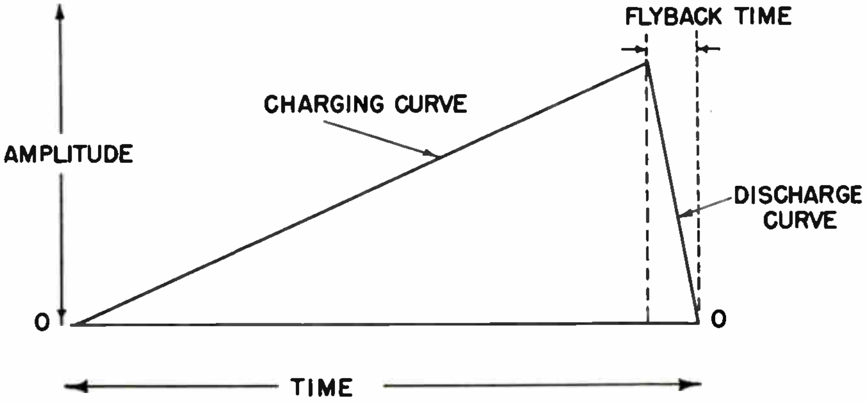


Fig. 30—Typical sawtooth voltage

Figure 31 shows a simple method for reproducing a sine wave on the face

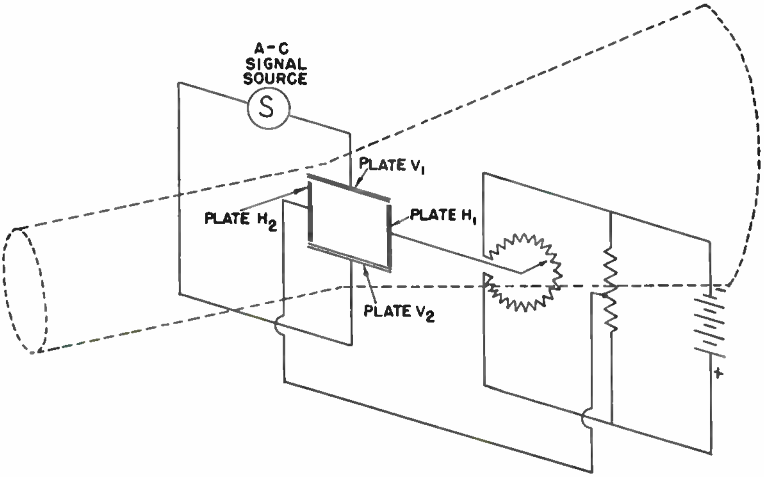


Fig. 31—Simple method of reproducing sine wave on screen of cathode-ray tube

of the cathode-ray tube. At the left, an a-c voltage source is connected to plates V1 and V2 for vertical deflection of the signal. At the right is a simple sweep circuit which is connected to deflection plates H1 and H2 to provide a uniform horizontal sweep of the electron beam across the screen. Assume that the rotor of the potentiometer is rotated at such a rate of speed that the beam will complete one horizontal sweep across the screen in exactly the same time that it requires for the a-c voltage to complete one cycle. Under such conditions, Figure 32 shows how the simultaneous horizontal and vertical deflections of the electron beam combine to produce a stationary trace of one cycle of the sine-wave signal voltage applied to the vertical deflection plates. It will be noticed that, at any given instant, the amplitude of the sine-wave voltage determines the vertical position of the beam, and the instantaneous value of the sawtooth wave determines the spot displacement along the horizontal axis.

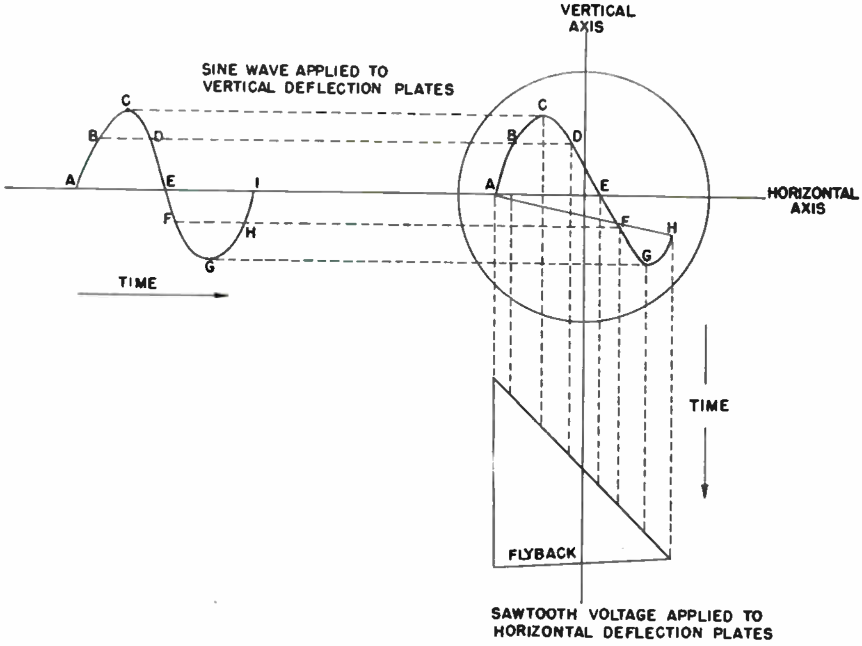


Fig. 32—Projections showing how sine wave pattern is reproduced

As previously stated, when one cycle of the sine wave has been completed, the charging curve of the sawtooth voltage must drop to zero value to return the beam to the starting point. This action is repeated again and again. Because the "flyback time" is very short compared with the time for the linear sweep, there is no apparent interruption and the trace appears complete on the screen of the cathode-ray tube.

ELECTROMAGNETIC DEFLECTION

Since an electron beam is a flow of electrical current and can be compared to a conductor carrying a current, it is also possible to deflect the beam by means of a magnetic field. Instead of using a magnet, the usual procedure is to mount suitably designed solenoids within close proximity to the neck of the tube and to position them between the electron gun or focus coil and the fluorescent screen. By passing current through the solenoids, the electron beam can be deflected at right angles to the electromagnetic field created within the tube.

For example, Figure 33 is a cross-sectional view which shows a pair of solenoids positioned to effect horizontal deflection of the beam. The direction of the electron beam may be considered as being directed away from the reader and into the page, or as it would appear as viewed from the cathode-end of the tube looking toward the screen. Assume that current is flowing through the solenoids, thus creating an electromagnetic field whose lines of force are in the direction shown in Figure 33. The concentrated lines of force will deflect the beam at right angles; the amount or distance of deflection being determined by the relative strength of the electromagnetic field. By controlling the current passed through the solenoids, the electromagnetic field may be adjusted to move the beam to any point between O and R along the horizontal axis. Similarly, by reversing the polarity of the solenoids the direction of the lines of force of the electromagnetic field is reversed and the beam may be deflected from point 0 leftward to point L along the horizontal axis. By observing proper polarity and selecting correct current values through the solenoids, it is apparent that the beam can be moved to any position along the horizontal axis. Likewise, if the same procedure outlined above is followed, and if the solenoids are properly oriented, the electron beam can be made to move anywhere along the vertical axis of the tube.

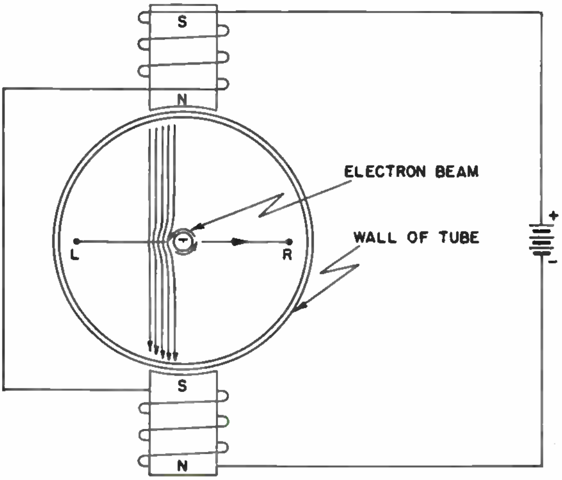


Fig. 33—Showing how an electron beam may be deflected by an electromagnetic field

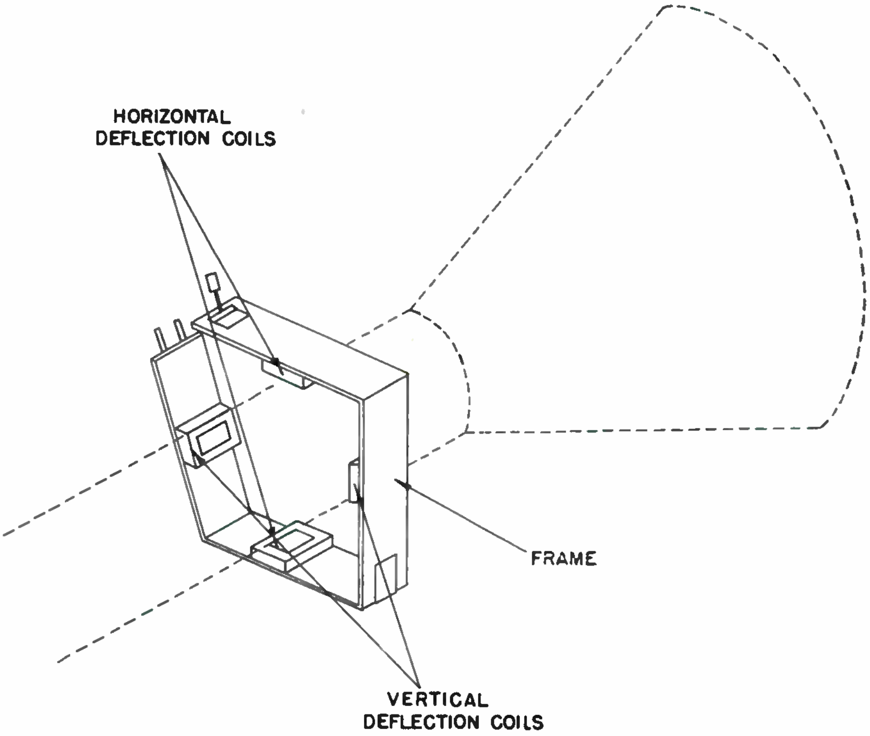


Fig. 34—Typical yoke and solenoid assembly for electromagnetic deflection

Figure 34 shows a yoke and solenoid assembly which is used to produce both horizontal and vertical deflection of the beam. There are two pairs of solenoids; pair H1 and H2 are used to produce horizontal deflection; pair V1 and V2, vertical deflection. The simultaneous application of the two electromagnetic forces acting at right angles to each other produces a single resultant force which, if proper polarities and current strength are observed, will deflect the beam to any desired position on the face of the tube.

DISADVANTAGE OF ELECTROMAGNETIC DEFLECTION SYSTEMS

An inherent disadvantage of the electromagnetic method of deflection makes it unsuitable for oscillographic applications, viz.: In using an oscillograph to determine the shape of an unknown waveform, the frequency components of the signal are also unknown. It was pointed out in the preceding paragraph how deflection of the electron beam with an electromagnetic system is dependent on the strength of the electromagnetic field set up by the solenoids and that the electromagnetic field strength was determined, in turn, by the current flow through the solenoids. When an unknown signal is applied to the solenoids, both the current flow through the solenoids and the field strength within the tube will vary in accordance with the varying amplitude of the impressed signal. If this were the only action that took place, then the signal waveform could be faithfully reproduced on the screen.

However, there is another effect which must be considered. With any inductive system the electrical reactance increases as frequency increases, and decreases as frequency decreases. Since the unknown signal applied to the solenoids also has unknown frequency components, these frequency components act either to reduce or increase the current flow through the solenoids. These changes in current flow caused by frequency variations are superimposed on the changes due to amplitude variations of the signal and are imparted to the electromagnetic field where they cause serious distortion and provide a trace which cannot be regarded as an accurate reproduction of the input signal, because it is not independent of frequency. For this reason, magnetic deflection is limited to applications where the deflection frequency is constant, as in radar and television.

FLUORESCENT SCREENS

The function of the screen in a cathode-ray tube is to convert the kinetic energy of the moving electrons into luminous energy at that point at which the electron beam strikes against the screen. Although an electron beam in itself is not visible to the naked eye, the bombardment of the beam on even the face of an untreated glass bulb will produce a faint glow. However, the usual practice is to coat the inner face of the tube with certain chemicals, such as willemite (zinc orthosilicate), calcium tungstate, or zinc sulphide, which possess the property of emitting a fluorescent light when bombarded by electrons traveling at high velocities.

The characteristics of the light emitted by a fluorescent screen under bombardment depend mainly on the following factors: (1) the chemical composition of the screen coating, (2) the thickness of the coating, (3) the position from which the light is viewed, (4) the treatment of the screen during manufacture, (5) the velocity of the electrons striking the screen, (6) the quantity of electrons which strikes a given screen area per unit of time, known as beam current, and (7) the length of time that a beam activates a given screen area, known as the excitation time.

In describing the light characteristics of a given screen, the terms fluorescence, phosphorescence, and luminescence are generally used. Luminescence is the exhibition of light not directly caused as a result of the generation of heat but produced by cathode-ray bombardment, among other possible causes. This type of light is commonly called "cold light." Fluorescence is that property which produces a glow which lasts only while the screen material is excited by bombardment of the electron beam. Phosphorescence is that property which causes the screen to glow after excitation has been removed.

The duration of phosphorescence varies with the material used, the intensity of the electron beam, and the excitation time. In some cases, phosphorescence may be extended to several minutes. The phosphorescence or persistence characteristics of a screen material may be classified generally as short, medium, or long.

The commonly used luminescent colors are green, blue, yellow and white. Standard cathode-ray tubes are usually classified with a phosphor-code designation such as P1, P2, P4, etc., which describes not only the persistence characteristics of the screen but also the color of the emitted light. A brief description of the various screen types and their applications is given in the following paragraphs. Complete characteristics of each type of phosphor are published by manufacturers of cathode-ray tubes.

TYPES OF SCREENS

The Type P1 screen produces a green trace of medium persistence and is well suited for general-purpose oscillographic work. It is quite efficient, and bright traces can be obtained with comparatively low accelerating voltages. The spectral distribution of the light produced is in the region of high sensitivity of the human eye, resulting in good contrast when the tube is illuminated by external daylight or incandescent lighting. Although the P1 screen is only moderately efficient for photographic purposes, satisfactory results may be expected for the recording of recurrent phenomena and slow transients. By increasing the accelerating potential on the tube, both visual and photographic efficiency may be increased many times.

The Type P2 screen produces a bluish-green trace with a long-persistent yellow phosphorescence. It is useful for visual observations of transient signals and low-frequency recurrent signals. With this type of screen, a pattern can be observed for a period ranging from a fraction of a second to several minutes after excitation has been removed, depending upon the writing rate of the spot, the accelerating potential, and the level of the ambient light.

The Type P4 screen is generally used for television applications. Its color composition, which appears white to the eye, is chosen in such a way that a minimum of eye fatigue is caused even when the screen is observed for long periods of time. Its persistence is well balanced so as to minimize flicker effects, yet give clear pictures of fast-moving objects.

The Types P5 and P11 screens are similar in that both produce a blue trace and both are used commercially for photographic work. Because of this, both screens were formerly classified under the designation P5. However, as a result of the rapidly increasing importance of cathode-ray photography during the past years, the requirements for photographic work have become more exacting. It has therefore become necessary to provide more precise definitions of the characteristics of such screens.

Inasmuch as the two screen materials, each of which has advantages in certain photographic applications, are sufficiently different to warrant different type designations, it was agreed by the Radio Manufacturers Association to designate the screens having the characteristics of the calcium tungstate as P5 and those having the characteristics of the sulphides as P11. The general characteristics of P5 and P11 screens may be compared as follows: Both screens are of the short persistence, blue-fluorescent type and of high photographic actinity. The main difference is the considerably higher photographic and visual efficiency of the Type P11 screen and the shorter persistence of the Type P5 screen. The P11 screen is advantageous for all still photographic applications, particularly of high-speed phenomena, and for continuously moving film recording up to the limit (approximately 200 kc/sec) where persistence produces blurring of the screen. The use of the P5 screen is recommended only for high-speed, continuous-motion picture recording at speeds above 200 kc/sec, which is the blurring limit of the P11 screen.

The Type P7 screen produces a blue-fluorescent trace with a long-persistent yellow phosphorescence. It is useful for visual observation of transient signals and very-low-frequency recurrent signals. The P7, like the P2, will permit a pattern to be viewed for a period ranging from a fraction of a second to several minutes after excitation has been removed, depending upon the writing rate of the spot, the accelerating potential, and the level of the ambient light. The P7 screen has a higher persistent light output than the P2 screen for the lower writing rates and has the further advantage that the large difference in color between the initial fluorescent light and the persistent light makes it possible to filter out the bright "flash" by means of a yellow filter. For observation of high-frequency transients, the persistence-time of the Type P2 screen is considerably greater than that of the Type P7.

WRITING RATES

The writing rate of an electron beam is the distance of spot travel, either horizontally, vertically or both per unit of time. However, since the waveform being displayed governs the speed at which the electron beam writes, the term maximum writing speed is usually more descriptive. For example, as the electron beam is deflected to display a sine wave on the screen, the writing rate varies from very slow as the beam reaches either peak of the wave, to very fast where the beam crosses the X-axis. Therefore, specifications as to writing speed are usually given as maximum writing speeds. These values are expressed in inches per microsecond.

It has been pointed out that, in addition to screen thickness, beam velocity, and beam current, the brilliance of the fluorescent trace is dependent also upon the excitation time or the time period during which the beam actually activates a given area of the fluorescent screen. It therefore follows that the faster the writing rate of the beam, the less energy a given screen area receives per unit of time, and thus the less brilliant will be the spot. There will also be a definite maximum writing rate above which it will be impossible either to record or to observe the trace.

When recurrent signals are under investigation, there is no limitation since the pattern can be made to remain stationary. In this case the beam moves over the same screen area a sufficient number of times to produce a trace of satisfactory brilliance. In the study of non-recurrent signals, such is not the case because the pattern is traced but once. Because the signal and its writing rate are unknown, it is impossible except by empirical means to determine whether the spot will be bright enough to be useful. This same limitation exists for both visual observations with long-persistence screens and for photographic recordings, although the absolute values of the limits may be different in the two cases. In all cases, however, it will be found that the contrast between the luminescent trace and the screen will be greatly increased by operating the equipment in a completely darkened room. It is not at all uncommon to obtain satisfactory photographic recordings of writing rates of 400 inches per millionth of a second (microsecond) when using Types P5 or P11 screens in a high-voltage tube, such as the Type 5RP-A. Satisfactory visual observations at writing rates exceeding 400 inches per microsecond when using long-persistence screens are a matter of routine with present-day commercial cathode-ray instruments.

Chapter 3

THE CATHODE-RAY OSCILLOGRAPH

Fundamentally, the cathode-ray oscillograph provides a means for plotting a visual curve on a fluorescent indicating screen. The coordinates of the curve are usually of the orthogonal or Cartesian type, and, in the conventional instrument, the horizontal axis represents time. Instantaneous values of any quantity which can be converted into an electrical potential, the amplitude of which will vary according to the variation of that quantity, are plotted along the vertical axis of the screen. Essentially, thus, a cathode-ray oscillograph is an instrument with which the value of an unknown variable voltage may be plotted against a time reference.

Cathode-ray oscillography is primarily the analysis of oscillations in any physical medium by a study of the electrical waveforms produced by these oscillations. The only limitation of an oscillograph in the study of oscillations is the convertability of the oscillations into an equivalent electrical voltage. But in almost all problems, a conversion into electrical potentials can be effected either by some type of transducer such as a vibration pickup unit for vibration, pressure pickup unit for pressure, photo cell for light, microphone for sound, or in general by a variable impedance which may be a variable resistance such as a carbon pile, a variable inductance or a variable capacitance.

In a specific problem the unknown variable is plotted along the vertical axis of the oscillograph as a function of some known quantity such as time, which is plotted along the horizontal axis. The circuits of the oscillograph generate a voltage that varies directly with time. This voltage is used as the time base. This internal time base is in the form of a sawtooth wave and is applied to the X-axis so that the unknown quantity on the Y-axis may be plotted as a linear function of time.

The practical applications of such a device are manifold. A little thought discloses any number of ideas for special applications. A few of the more general are the study and testing of the operation of radio receivers, radio transmitters, welding circuits, transmission lines, electronic control devices, circuit breakers, ignition coils, relays, and many other electrical devices. An oscillograph may also be used to advantage in the study of vibrations, properties of metals, and dynamic-mechanical unbalance. Production-testing applications include fast and accurate adjustment of watches and musical instruments. Not to be overlooked are uses in the field of internal-combustion engines where detonation studies and pressure-volume curves can be plotted.

In considering the scope of the cathode-ray oscillograph, it should be remembered that, as a measuring device, it employs a pointer that has negligible inertia. Hence the only limitation imposed on the oscillograph occurs where the electrons available in the beam are insufficient in number to excite the screen of the cathode-ray tube, and at deflection frequencies so high that the transit time of the electrons across the face of the deflection plates is long enough to cause to appear a deflection potential which reverses in polarity during transit time. This effect is not apparent at frequencies below 200 megacycles per second. The effect decreases or the limiting frequency becomes higher when high accelerating potentials are used.

It should be emphasized that the cathode-ray oscillograph does not offer the solution to a problem but only supplies information or data regarding the nature of the problem, in the manner of a voltmeter. Such information serves as a guide in the analysis of the phenomenon which is being studied. Nor is the oscillograph a corrective instrument that in itself performs a specific operation on an electrical signal or on its source. Rather, the oscillograph is an indicator that displays visually the essential characteristics of a signal, no matter how complex the signal may be. Thus, the oscillograph's operator is enabled to check quickly the functioning of machinery or electrical equipment and to isolate the causes of any malfunctioning of the equipment.

Since an interpretation of the pattern that appears on the screen of the cathode-ray tube is essential to the understanding of any analysis, and that interpretation must be correct if the results are to be of any value, it should be borne in mind that the unknown signal is *always* plotted as a function of a signal of which the characteristics are known. If the characteristics of the signal on one axis are not known, it is virtually impossible to analyze the signal under investigation on the other axis.

The information which is obtained by analyzing patterns is of the greatest importance in determining the characteristics of the device that is under study. For example, the path of a known signal through an amplifier can be followed and the gain and distortion characteristics of the amplifier can be quickly and easily determined, as well as the point at which the circuit may be faulty. By using the linear time base as the known variable, an unknown waveform can be

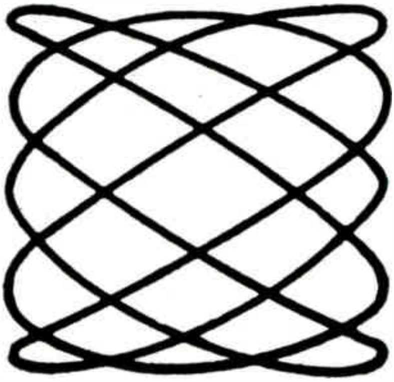


Fig. 35—Lissajous patterns showing frequency ratio of 5 to 3

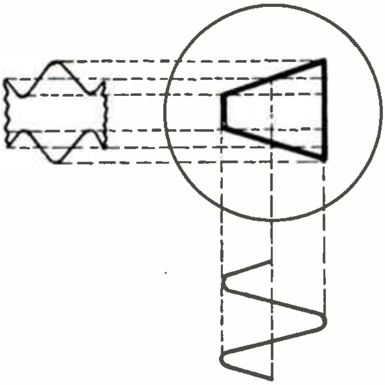


Fig. 36—The modulation-trapezoid pattern

plotted and analyzed or the dynamic characteristics of the unknown circuit can be studied. The waveform of a signal plotted as a function of the linear sawtooth sweep can indicate the presence of undesirable harmonics, parasitic oscillation, or the degree of faithfulness with which a device follows a desired cycle of operation.

A familiar case of operation employing a standard sinusoidal signal for horizontal deflection is the application of the cathode-ray tube to the comparison of frequency of two signals. The unknown signal is fed into the vertical input and the known signal of standard frequency is fed into the horizontal input; in this application the frequency of the unknown signal is measured by interpreting the resulting Lissajous pattern. This pattern is shown in Figure 35.

Another common use is to connect a modulated-carrier signal upon the vertical input and the modulating voltage on the horizontal input. The resulting pattern, shown in Figure 36, is known as the trapezoidal pattern of modulation, and it is used to study percentage modulation.

Provision is made in many oscillographs to modulate the intensity of the trace on the fluorescent screen by an external signal. The front panel of such an oscillograph has a terminal, coupled capacitively to the control grid of the cathode-ray tube, for the introduction of the external, intensity modulating signal. Positive pulses through this terminal intensify the trace at intervals corresponding with the time between pulses. Negative pulses dim the trace and, if strong enough, blank the beam.

THE COMPONENTS OF THE OSCILLOGRAPH

POWER SUPPLY

A cathode-ray tube in itself is not a complete indicating device. Figure 37 is a block diagram of a typical oscillograph. In order to produce a spot on

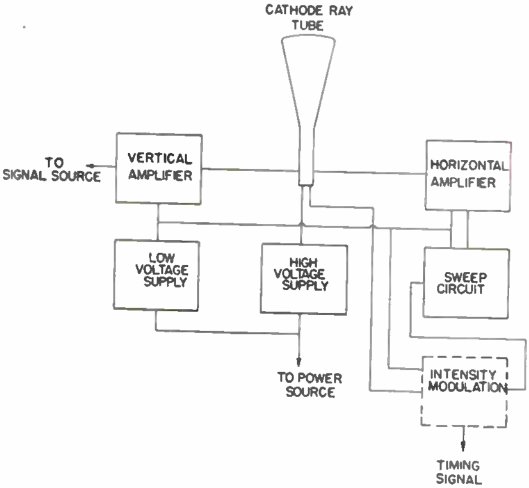


Fig. 37—Block diagram of the cathode-ray oscillograph

the fluorescent screen, the proper voltages must be applied to the various electrodes of the tube. Fortunately, the power requirements are not severe, although potentials of at least 1000 volts are necessary. The purposes of the different voltages applied to the electrodes of the tube are to focus, to accelerate and to position the electron beam so that a small, intense, yet visible spot is produced to trace the curve on the fluorescent screen. In addition, a source of heater power is made available to operate the indirectly heated cathode of the cathode-ray tube.

AMPLIFICATION

The combination of the cathode-ray tube and power supply then is enough to form the indicator element. Unfortunately, the tube itself is a relatively insensitive device and potentials in the order of several hundred volts are necessary for full-scale deflection. Most applications involve input potentials of lesser magnitudes and, therefore, an amplifier is necessary to supply the deflection voltages to the tube.

While the amplifier permits the study of small voltages, it also imposes limitations on the character of signals that can be transmitted by the amplifier. With the unknown signal applied directly to the deflection plates, the maximum amplitude observable is limited only by the full-scale deflection of the beam; the maximum frequency which can be applied is limited by the transit time of the electrons of the beam between the deflection plates, and also by the shunt capacitance between deflection-plate terminals. Generally, transit-time effects restrict usefulness to below 200 megacycles in tubes operated at accelerating potentials of about 1500 volts. Low capacitive reactance at higher frequencies also loads down the signal source.

A direct-current voltage applied to the plates deflects the beam proportionally to the magnitude of that voltage, and the beam remains fixed in its deflected position until that d-c deflection voltage is removed or changed. Therefore, there is no low-frequency limitation when direct connection is used. In fact, it is the application of a direct-current voltage, controllable in magnitude, that is used to position the beam in both horizontal and vertical directions in the oscillograph unit.

When an amplifier is interposed between signal source and deflection plates, the signal is faithfully reproduced when the limitations of the amplifier are not exceeded. These limitations include frequency discrimination both in the amplifier and input-attenuator circuits, phase distortion and the maximum allowable direct- and peak-input voltages.

The minimum signal-voltage is determined by the least amount of beam deflection that can be tolerated for effective study, and therefore by the gain of the deflection amplifier. The maximum voltage that can be applied is limited by the voltage range of the input-amplifier stage. Of course, a radio-frequency signal will not be passed by an audio-frequency amplifier, nor will a direct-current signal be amplified by an alternating-current amplifier.

This discussion of the amplifier has thus far been restricted largely to the vertical axis. Similarly, these considerations apply to the horizontal amplifier. For most applications, the signal applied to the horizontal deflection-plates provides for the movement of the spot at a uniform rate with respect to time. Such a signal provides the time-axis along which is plotted the unknown variable voltage. After the spot has traveled the width of the screen, it snaps back to its starting position and the process is repeated. Without going into a detailed discussion of the generator which supplies the horizontal voltage, it will suffice to say that since the waveform of this time-axis deflecting voltage may often be of a sawtooth shape, it is, therefore, rich in harmonic content. Since this sawtooth-voltage is amplified by the horizontal amplifier, the frequency and phase characteristics of that amplifier must permit undistorted amplification of sinusoidal signals of frequencies extending both far above and below the sawtooth frequency. Frequently the sawtooth frequency range is from a few cycles per second to over 50,000 cycles per second.

It is also desirable in the oscillograph that the horizontal and vertical amplifiers have similar phase characteristics in order to facilitate accurate comparisons of frequency and phase relationship between two different a-c signals by applying the voltages to both sets of deflection-plates. The result of this comparison is a pattern also called a Lissajous Figure.

THE SWEEP GENERATOR

The linear time-base generator, or sweep generator, is the integral part of the oscillograph unit that generates the sawtooth voltage for the linear time-base. The sawtooth wave is generally developed by a relaxation oscillator in which a gas-discharge tube is utilized. The sweep oscillator is characterized by its ability to synchronize its own frequency of oscillation with the frequency of the unknown signal so that, in cases of recurrent phenomena, the spot begins its excursion each period at the same point on the wave of the unknown. The luminescent pattern that results therefrom is a stabilized wave. With the pattern "locked in", the rapid retrace of the wave many times a second appears to the human eye as a still photograph, so to speak, because of the persistence of the fluorescent-phosphorescent screen of the cathode-ray tube and the persistence of vision of the human eye.

In some applications, it is necessary to record a phenomenon that does not recur but which exists for a short time interval, and then disappears. Such a phenomenon is called a transient. If the ordinary sweep oscillator were used, the horizontal travel of the spot would be entirely independent of the transient, and the observer would have no assurance that the beginning of the unknown wave occurred at the beginning of the spot's excursion across the screen. This possibility is nicely provided for by a single-sweep circuit that generates a time-base only when a transient initiates it. Initiation of the single sweep may be effected either by the transient itself, in case that transient cannot be controlled at will by the observer, or by an independent voltage applied to the synchronizing terminal; this latter voltage should also control the initiation of the transient to effect proper synchronization of time base and transient.

Single-sweep circuits have been improved considerably in later years. Instead of employing gas-triodes, or thyratrons, for these circuits, the present day circuits usually employ high-vacuum or "hard" tubes. Single sweep circuits are commonly called "driven-sweep", "start-stop", "slave-sweep", or "triggered-sweep" circuits.

Some oscillographs employing driven-sweep circuits are designed with special beam-blanking circuits which automatically reduce the intensity to zero when no signal is being viewed. Upon the initiation of the sweep, however, the intensity is immediately restored to its original value for the duration of the sweep.

Automatic beam control is of particular aid in photographing transients. In a darkened room or with a camera like the Du Mont Type 271-A Oscillograph-record Camera, the shutter can be opened prior to the occurrence of the transient, left open for the duration of the transient, and closed after the cycle is completed without fogging the film.

This feature is highly desirable in driven-sweep circuits but many difficulties are experienced in the design of automatic beam-blanking circuits. As a result, such features add to the cost and are not incorporated in every oscillograph.

For applications that involve rotating machinery, it is often desirable to use a sinusoidal sweep. A sinusoidal sweep can be obtained from an external sinusoidal oscillator or from a small generator mounted on a rotating shaft of the equipment under study. The frequency then corresponds to the speed of the shaft.

Where photographic recording of transients is involved, the travel of a continuously exposed and continuously moving film very often provides the linear time-base; and the horizontal deflection-circuits are not used at all. In such an arrangement the shutter of the camera is removed.

Reference was made in the foregoing to the time required for the beam to return to its original starting position. In some studies, the appearance of the return trace caused by the return passage of the beam is objectionable and means are provided to blank it out. This blanking-out process is accomplished by applying a negative pulse to the grid of the cathode-ray tube during the return-trace interval. The negative pulse may be derived from the sawtooth wave generated by the sweep oscillator.

TIMING MARKERS

The subject of blanking or intensifying the beam naturally brings to mind the application of beam-intensity modulation for other purposes. In the case of television, the grid of the cathode-ray tube is modulated by a voltage which causes the spot or trace to become lighter or darker in accordance with the voltage variations. This same principle is used in oscillographs to provide timing demarcations, or reference points on the trace or pattern. These timing marks are provided by an external oscillator or a pulse generator whose frequency is known. At times, the signal available for beam modulation is less than that needed for extinguishing the beam, and therefore, an amplifier is needed. This amplifier is commonly known as the Z-axis amplifier. A further use for this amplifier is to intensify the beam over portions of the trace where the writing rate of the spot is so great that the fluorescent screen is not sufficiently excited. Thus, the intensity is more uniform throughout the entire trace and photographic exposure is facilitated. Furthermore, the portion of the trace which is most interesting is often the least visible. Intensity modulation of the beam, thus, may prevent burning and damage to the fluorescent-phosphorescent screen caused by operation of the intensity control at maximum (i. e., zero bias) in an attempt to improve the total visibility.

DESIGN CONSIDERATIONS

In general, the requirements of the power supply for the amplifiers, the sweep circuit, and the positioning circuits are more exacting than those for the high-voltage supply for operation of the cathode-ray tube. Not only is the filtered output exceptionally free from a-c ripple, in order to prevent hum from appearing on the trace due to voltage variations on the amplifiers, but also small irregularities in the power source must be eliminated to prevent momentary disturbances of the position of the beam and of the size of the pattern. The cathode-ray tube is shielded from the magnetic fields of the transformer and filter chokes, since beam-position is influenced by magnetic as well as by electrostatic fields. It is interesting to observe that the magnetic field of the earth itself is sufficient to cause at least a half-inch of deflection in the larger tubes.

Usually the power supply of the oscillograph is contained in the instrument.

SOME TYPICAL OSCILLOGRAPHS

Figures 38, 39, and 40 illustrate three typical oscillographs. That shown in Figure 38 is the Du Mont Type 274-A Cathode-ray Oscillograph which was developed as an inexpensive, general purpose instrument for laboratory, radio service, and educational applications. The Type 274-A serves as an excellent null-indicator on inductance-capacitance bridges, as a means for viewing voltage waveforms, as an output meter, as a means for measuring time and amplitude of pulses, as an indicator in studies of sound, light, electricity, and many general applications.

Fig. 38—Du Mont Type 274-A Cathode-ray Oscillograph

Fig. 39—Du Mont Type 275-A Cathode-ray Polar-coordinate Indicator

Fig. 40—Du Mont Type 280 Cathode-ray Oscillograph

Shown in Figure 39 is the Du Mont Type 275-A Polar-Coordinate Indicator, which employs a circular time-base. This instrument represents an application of cathode-ray oscillography to the field of mechanical engineering in that all types of rotating machinery can be examined, most particularly the functioning of internal combustion engines.

Figure 40 shows the Du Mont Type 280 Cathode-ray Oscillograph, a highly complex instrument used mainly for television studies and in the research laboratory. With this instrument it is possible to select a single scanning line, or fraction of a line, from the composite television signal for critical study or recording. This instrument is one of the most advanced of all present-day cathode-ray oscillographs.

DISPLAY OF WAVEFORMS

An understanding of how patterns are traced on the screen of a cathode-ray oscillograph must be obtained as an approach to a knowledge of oscillography. With this in mind an analysis of two fundamental patterns is discussed under the following headings:

a. Patterns plotted against time (using the sweep generator for horizontal deflection)

b. Lissajous Figures (using a sine wave for horizontal deflection).

PATTERNS PLOTTED AGAINST TIME

A sine wave is typical of and convenient for this study. This wave is amplified by the vertical amplifier and impressed on the vertical-axis deflection plates. Simultaneously a sawtooth wave from the time-base generator is amplified and impressed on the horizontal-axis deflection plates.

The electron beam moves in accordance with the resultant of the sine and sawtooth signals. The effect is shown in Figure 41 where the sine and sawtooth waves are graphically represented on time and voltage axes. Points on the two waves that occur simultaneously are numbered similarly. For example, 2 on the sine and 2 on the sawtooth wave occurs at the same instant. Therefore, the position of the beam at instant 2 is the resultant of the voltages on the horizontal and vertical deflection plates at instant 2. Referring to Figure 41, by projecting lines from point 2, the position of the electron beam at instant 2 can be located. If projections were drawn from every other instantaneous position of each wave to intersect on the circle representing the tube screen, the intersections of similarly timed projections would trace out a sine wave.

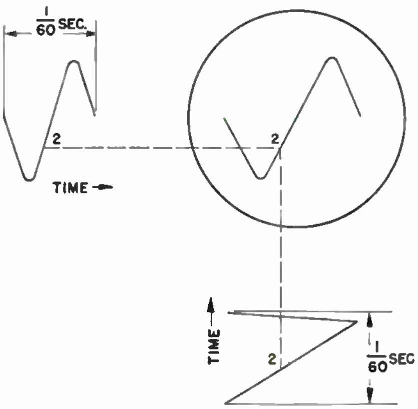


Fig. 41—Presentation of sine and sawtooth waves

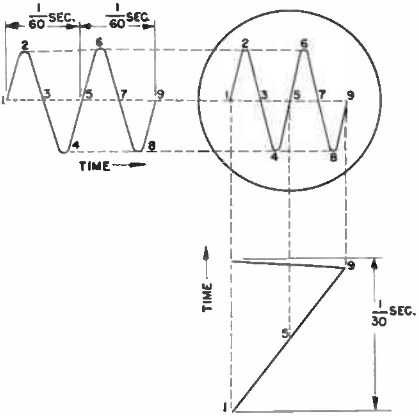


Fig. 42—Frequency of the sawtooth reduced to ½ of that in Fig. 41

Figure 41 illustrates the principles involved in producing a sine-wave trace on the screen of a cathode-ray tube. Each intersection of similarly timed projections represents the position of the electron beam acting under the influence of the varying voltage waveforms on each pair of deflection plates. Figure 42 shows the effect on the pattern of decreasing the frequency of the sawtooth wave. Any recurrent waveform plotted against time can be displayed and analyzed by the same procedure as used in these two examples.

The sine-wave example just illustrated is typical of the method by which any waveform can be displayed on the screen of the cathode-ray tube. Such waveforms as square-wave, sawtooth-wave, and many other irregular recurrent waveforms can be observed by the same method explained in the preceding paragraphs.

LISSAJOUS FIGURES

Another fundamental pattern is the Lissajous figure, named after the 19th century French scientist, Lissajous. This type of a pattern is of particular use in determining the frequency ratio between two sine-wave signals. If one of these signals is known, the other can be quickly calculated from the Lissajous pattern obtained. Common practice is to connect the known signal to the horizontal channel and the unknown to the vertical channel. The amplifiers may or may not be used depending upon the voltage and frequency of the signals.

The presentation of Lissajous figures can be analyzed by the same method as previously used for sine-wave presentation. A simple example is illustrated in Figure 43. The frequency ratio of the signal on the horizontal axis to that on the vertical axis is 3 to 1. If the known signal on the horizontal axis is 60 cycles per second, the signal on the vertical axis is then 20 cycles.

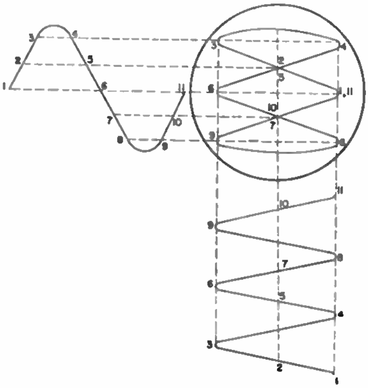


Fig. 43—Presentation of Lissajous figures

DETERMINATION OF FREQUENCY RELATIONSHIP

The Lissajous pattern is traced by joining intersections of projections from like numbered points on the signals. The frequency relationship, determined by the ratio of the number of loops touching two mutually perpendicular sides, is calculated most readily when the two signals are out of phase. For example, Figure 44 shows a complex Lissajous figure. The vertical line, AB, is touched

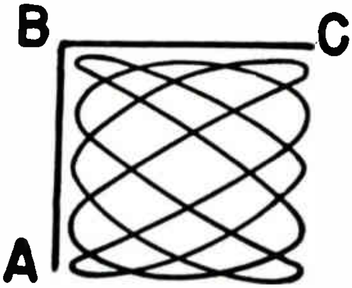


Fig. 44—Method of calculating frequency ratios

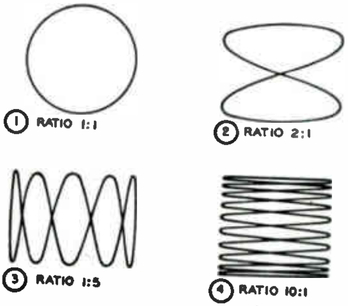


Fig. 45—Other Lissajous patterns

by 5 loops and the horizontal line, BC, is touched by 3 loops. The ratio of the frequency on the horizontal axis is to the frequency on the vertical axis as the number of loops which touch line AB is to the number of loops which touch line BC. Algebraically:

$$\frac{\text{Frequency on horizontal Axis}}{\text{Frequency on vertical Axis}} = \frac{\text{Number of loops touching BC}}{\text{Number of loops touching AB}}$$

PHASE-DIFFERENCE PATTERNS

Coming under the heading of Lissajous figures is the method used to determine the phase difference between signals of the same frequency. The patterns involved take the form of ellipses with different degrees of eccentricity.

The two frequencies under investigation will produce an accurate picture on the oscillograph screen of the exact phase difference between the two waves. If these two waves are exactly the same frequency but different in phase and if they maintain that difference, the pattern on the screen will remain stationary. However, if one of these frequencies is drifting slightly, the pattern will drift slowly through 360°. The phase angles of 0°, 45°, 90°, 135°, 180°, 225°, 270°, 315° are shown in Figure 46. Each of the eight patterns in Figure 46 can be analyzed separately by the previously described projection method. Figure 47 shows two sine waves which differ in phase being projected onto the screen of the cathode-ray tube. These signals represent a phase difference of 45°.

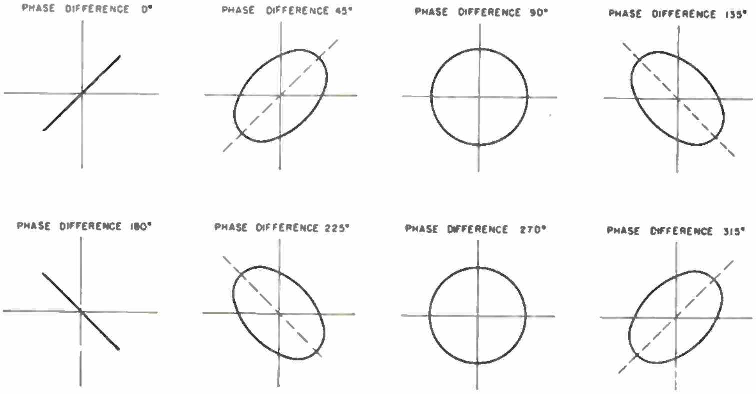


Fig. 46—Lissajous patterns obtained from major phase-difference angles

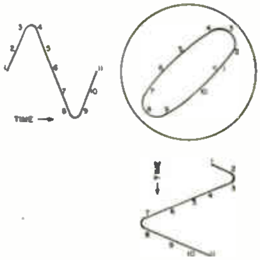


Fig. 47—Two sine waves 45 degrees out-of-phase

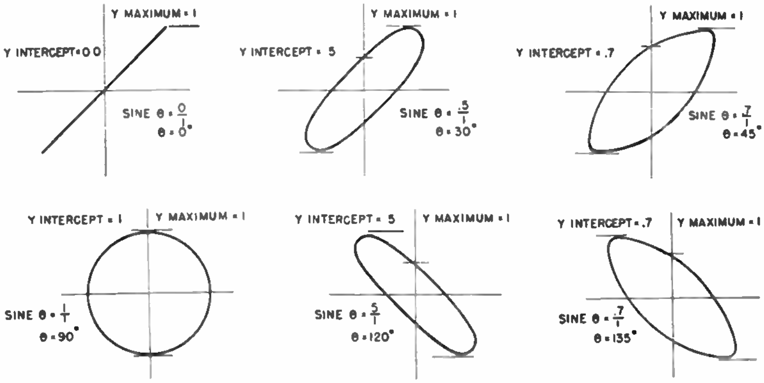
DETERMINATION OF THE PHASE ANGLE

The relation commonly used for determining the phase angle between signals is:

$$\text{Sine } \Theta = \frac{\text{Y intercept}}{\text{Y maximum}}$$

where Θ = phase angle between signals,
Y intercept = point where ellipse crosses vertical axis measured in tenths of inches (calibrations on the calibrated screen),
Y maximum = highest vertical point on ellipse in tenths of inches.

Examples of the use of the formula are given in Figures 48 through 53.



Figs. 48 to 53—Examples of the formula for phase difference

In each case the points Y-intercept and Y-maximum are indicated together with the sine of the angle and the angle itself.

These various patterns may be observed from a single signal source, such as the test signal found on many oscillographs, by means of a phase shifter of which there are many types. The procedure is to connect the original signal to the horizontal channel of the oscillograph and the signal which has passed through the phase shifter to the vertical channel of the oscillograph. The various phase-shift patterns may then be observed.

OTHER TIME BASES

Numerous new applications of the cathode-ray oscillograph are being developed daily. Many of these applications require time bases which are different from the conventional sawtooth and sine-wave time bases. These applications are two numerous and too specialized to be considered to any great extent in this book. However, some special types of time bases are listed as follows (1) circular sweep; (2) spiral sweep; (3) radial sweep; (4) delayed sweep; (5) expanded sweeps.

OSCILLOGRAPH ACCESSORIES

Several factors have contributed to the development in cathode-ray oscillography of some basic accessory devices. The widespread penetration of the oscillograph into numerous and varying fields of application has been accomplished without a multitude of oscillographic instrument designs, but rather by the extension and improvement of the fundamental, general type to include an ever-widening class of possible applications. Notably, the development of a high-voltage cathode-ray tube and suitable voltage supplies to operate this type of tube has extended the possibilities of the hot-cathode oscillograph, a packaged unit, to a point where it rivals, and perhaps excels, the performance of the cold-cathode, continuously evacuated oscillograph. The addition of the high-voltage tube (the Type 5RP-A) makes it possible to observe writing rates in the neighborhood of 400 inches in a millionth of a second! A notable example of an oscillograph's achieving this astounding writing rate is the Du Mont Type 281-A, with its associated high-voltage supply, the Type 286-A. The extremely high writing rates achieved by the hot-cathode type of tube have necessitated the development of some means for recording such high writing-rates. A camera, especially designed for oscillographs, was developed and is known as the Du Mont Type 314 Oscillograph-Record Camera. With this camera, all types of traces may be photographed — high or low frequency, periodic or aperiodic. The camera may be used for continuous-motion or single-image recordings, and for periods up to 200 hours. A film-speed range of 1 to 3600 — one inch a minute to 5 feet a second — is electronically controlled and instantaneously changeable from low to high speed.

Fig. 54—Type 281-A Cathode-ray Indicator (top) and Type 286-A High-voltage Power Supply

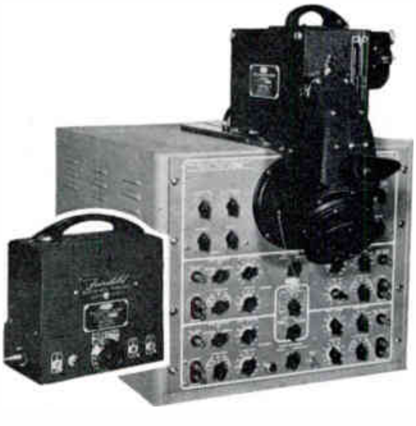


Fig. 55—Type 314 Oscillograph-record Camera mounted on the Du Mont Type 279 Dual-beam Cathode-ray Oscillograph

Fig. 56—Type 271-A Oscillograph-record Camera

Fig. 57—Type 264-A Voltage Calibrator

Another camera, known as the Du Mont Type 271-A, is also available for single-exposure recordings and is used where only single-frame recordings are required. The Type 271-A has the advantages inherent in simplicity of design—inexpensiveness, durability, compactness, and general utility.

Another instrument, used in conjunction with cathode-ray oscillographs, is a device for making peak-to-peak voltage measurements from the waveform that appears on the screen of the cathode-ray tube. Known as the Du Mont Type 264-A Voltage Calibrator, the significance of this accessory lies in the fact that, by its use, the cathode-ray oscillograph becomes a quantitative measuring device. The Type 264-A, a very simple device, provides a calibrating voltage whose amplitude, though continuously variable, is always known. The known amplitude of the calibrating voltage is matched to that of the unknown signal appearing on the screen of the cathode-ray tube. In contrast to a voltmeter, quantitative measurements may be made of any part of a complex, composite waveform with the Type 264-A.

These are only a few of the accessory instruments, and others are yet to be developed. The point to bear in mind is that cathode-ray oscillography is an ever developing, dynamic science, and the cathode-ray oscillograph is undoubtedly destined to hold an ever increasing importance wherever measurements are made, in science and in industry.

SPECIALIZED OSCILLOGRAPHS

Actually, television receivers and radar indicators and other such devices employing cathode-ray tubes are nothing more than highly specialized cathode-ray oscillographs. Since the oscillograph was one of the earliest devices which employed a cathode-ray tube, it was only natural that experimenters contemplating the use of the cathode-ray tube in television and radar should draw upon the already proven circuits of the cathode-ray oscillograph.

Chapter 4

THE CATHODE-RAY TUBE IN TELEVISION

TELEVISION DEFINED

Television is the general term which is applied to the electrical transmission of scenes or images over a distance, with or without the aid of wires, and the simultaneous reproduction of those scenes or images instantaneously at a remote receiving point. Television is analagous to sound transmission with the difference that the listener is also an observer; the observer at the television receiver not only hears what is going on but he also sees what is taking place. Thus, television is attended by many new and additional technical problems which do not exist in sound transmission. The solution of these problems, however, can be more readily understood if a parallel is drawn between the method of sound transmission and the method of picture transmission.

COMPARISON OF SOUND AND TELEVISION

In the familiar sound broadcast, sound is converted into electrical voltage through the medium of the microphone. This conversion must be made, since it is impossible to broadcast sound in the form of sound over any great distance. Likewise, in television, light cannot be broadcast as light but must also be converted into electrical potentials. The iconoscope camera of television, in performing the conversion, corresponds to the microphone of the sound broadcast.

When a sound wave is converted by a microphone into equivalent electrical voltage, there is a continuous variation in the voltage from one instant to the next because the sound impulses arrive at the microphone at different times. Sound contains meaning by being continuous and varying, and the electrical voltage varies continuously with the sound.

However, in the case of light, the meaning of a picture (which is merely reflected light) is determined by the *arrangement* of the contents of the picture; this is a geometrical arrangement, whereas, the meaning of sound is determined by the arrangement of the sound with respect to time. When a picture is presented for conversion into electrical voltage, the entire picture is presented at once, not individual parts in succession as in the case of sound.

Since a picture must be transformed into a similar varying voltage, some means must be used to convert the picture areas into successive time intervals. The method for doing this is called scanning.

THE ICONOSCOPE

The device used to scan the picture and to convert it into successive electrical impulses is called an iconoscope. Actually, the iconoscope is only one of several devices that may be employed for this purpose — others are the image orthicon and signal orthicon. However, the iconoscope is the most familiar tube and is a representative example.

The iconoscope is a specialized type of cathode-ray tube. It contains an electron gun which generates and directs an electron beam at a photosensitive plate called a "mosaic". The tube is constructed, as shown in Figure 58, so that the electron beam and the picture for transmission may both be applied simultaneously to the mosaic. The picture for transmission is focused on the mosaic by an optical lens, identical with a camera lens, which is mounted on the box which contains the iconoscope tube. In effect, the mosaic and lens act as a camera, with the mosaic corresponding to the film.

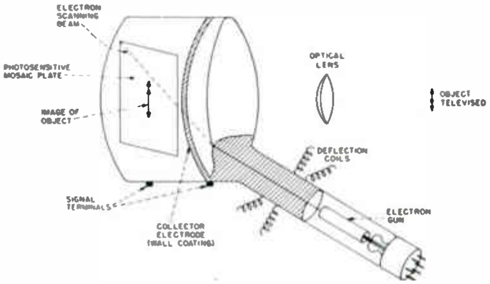


Fig. 58—Structure of the Iconoscope

The lens focuses the image being televised onto the mosaic. The nature of the mosaic is such that it will record the amount of light striking it and store up that information in the form of minute, discrete electrical charges distributed over its surface. In this manner the picture information is collected where it can later be removed by an electron beam and passed on to the following circuits of the television equipment.

The structure of the mosaic located within the iconoscope includes a photosensitive material deposited on a mica plate, in the form of thousands of cells insulated from one another. A signal plate is mounted on the opposite side of the mica and is thus capacitively coupled to each of these cells. When light is admitted through the lens, each cell loses electrons which are attracted to a positively charged metallic coating on the inside wall of the cathode-ray iconoscope, called the "collector ring". As a result, each cell is charged positively with respect to its equilibrium potential.

At this point complete picture information is contained in the charges of the mosaic, just like complete picture information is contained on each grain of the chemical coating of a film when the camera lens is opened. In the case of television, however, the information exists in the form of electrical charges. A process analogous to developing a film is performed on the mosaic by the electron beam of the iconoscope. This is known as scanning.

SCANNING

In scanning, the electron beam of the iconoscope is moved in a fixed, repeated path over the area of the mosaic. As the electron beam strikes each of the charged cells of the mosaic, the electrical balance of each cell is returned to neutral. That is, the beam replaces the deficiency of electrons in each cell and the capacitance between each cell and the signal plate discharges. Consequently, the scanning operation produces a series of voltage variations on the signal plate, corresponding in magnitude to the light intensity applied to each cell. The light intensity applied to each cell obviously varies from cell to cell because of the way in which a natural object, with its variety of surfaces and planes, reflects light. Thus, from cell to cell there will be a variation in the magnitude of charge, just as there is a variation in the light and shade qualities of an object from one area to another.

The voltage variations which are produced by the scanning process thus become the electrical equivalent of the picture. This picture can be reproduced on any ordinary cathode-ray tube. If this cathode-ray tube is connected so that its electron beam is caused to sweep across the screen in precisely the same way and in synchronism with the beam of the iconoscope, a rectangle of light will be observed on the screen. This rectangle of light is called a "raster". The raster serves as a frame or surface on which the picture is to be reproduced. If a positive voltage is applied to the grid of the cathode-ray tube, the raster becomes brighter. If a negative voltage is applied, the raster becomes less intense.

Thus, since the picture signal is made up of positive and negative impulses, it will cause the raster to become brighter for the time a positive impulse is applied to the grid, and darker for the time during which negative impulses are applied. Since the sweep of the cathode-ray tube is synchronized to that of the iconoscope, the light and dark of the image on the mosaic will be reproduced on the cathode-ray tube.

The technique of scanning employs two separate sweep circuits to deflect the electron beam along a horizontal and vertical path. While any regular path could be followed which traversed the whole image area, a straight-line scanning path is usually employed. Thus, as shown in Figure 59, the electron beam is swept from point 1 across the image area to point 2, and then from point 3 to point 4, etc., the scanning path being the resultant of the horizontal and vertical deflections. The RMA standard scanning pattern consists of 525 horizontal sweeps of the electron beam while moving from top to bottom of the image area in 1/30th of a second.

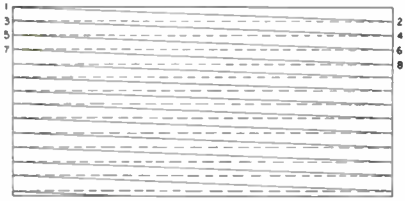


Fig. 59—Simple straight-line scanning

In actual practice, so-called "interlaced scanning" generally is employed. In interlaced scanning, as shown in Figure 60, the beam is swept from point 1 to point 2, as above, but the second sweep is from point 5 to point 6, the line 3-4 being skipped. On reaching the bottom line of the raster, the beam returns not to the 1-2 line but rather to the 3-4 line, and it then sweeps the 7-8 line. In the interlaced method half the lines are swept from top to bottom of the raster, and then the other half are swept.

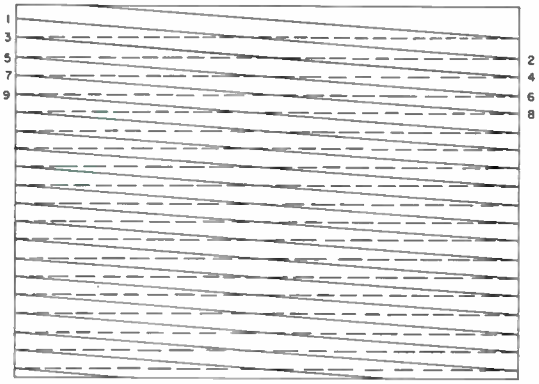


Fig. 60—Interlaced scanning

In the cathode-ray tube in the receiver, the same pattern of scanning is followed. Separate sweep circuits, in synchronization with the iconoscope sweep circuits, drive the beam of the cathode-ray tube. As the electron beam scans the fluorescent screen of the cathode-ray tube, with no signal on the grid, a uniform rectangle of light is produced. If straight-line scanning without interlace is used, there is a certain amount of flicker present in the raster. The time interval between the scanning of any one line and the return of the electron beam to that line, while being only 1/30th of a second, is long enough to introduce a noticeable flicker. It has been determined that interlacing the scanning process, however, as described in the foregoing, practically eliminates flicker since, to the eye, the beam appears to scan the picture completely in only 1/60th of a second. The persistence of vision of the human eye and the duration of phosphorescence of the screen of the cathode-ray tube are also contributing factors. The fluorescence of the screen cannot last too long however, or there will be an overlapping of successive images as sometimes happens in a moving picture. Conversely, if the duration is too short, the eye will not retain the image long enough to reduce flicker. With the interlaced method of scanning, the ideal mean is virtually achieved.

SYNCHRONIZATION OF ICONOSCOPE AND RECEIVER

Synchronization of the sweep circuits in the iconoscope with the sweep circuits in the receiver is accomplished by the use of blanking and synchronizing pulses. A blanking pulse is a pulse which blocks the electron beam from reaching the mosaic. Hence, for the duration of the blanking pulse no signal comes from the signal plate. Blanking is accomplished by applying a strong negative signal to the control grid.

When the beam is blanked, a synchronizing pulse is applied to the deflection circuits. A series of these pulses is transmitted with the picture signal to assure correct correlation between the position of the electron beam in the iconoscope and the position of the electron beam in the cathode-ray tube of the receiver. The synchronizing pulses control the frequencies of the sweep generators for horizontal- and vertical-path timing. By this means, the position of the electron beam in the iconoscope is made to correspond at all times with the position of the beam in the cathode-ray tube of the receiver.

Synchronizing pulses are applied at the end of each scanning line and at the end of a field.* During this time, the beam is moved to the beginning of a new line or to the start of a new field. Since the blanking pulse also occurs at this time, no image appears on the screen during these retrace periods.

TELEVISION BROADCASTING

Television transmission is considerably more complicated than sound transmission. It must be remembered that both the sound and the picture are transmitted simultaneously. The sound of television is transmitted as in standard frequency-modulated sound transmission. The sound is picked up by a microphone, amplified, and used to modulate the carrier wave of the transmitter. The waveforms from the signal plate of the iconoscope are amplified and used to amplitude-modulate the picture-signal carrier. A synchronizing generator creates two series of pulses—one for horizontal-path timing and one for vertical-path timing, which are added to the picture signal so that the sweep generators in the television receiver can be synchronized to the pattern in the iconoscope. The two signals, the picture and synchronizing pulses, are transmitted together and compose the complete video signal.

In the amplifying system the synchronizing pulse is added to the picture element by blanking the amplifier; that is, the voltage is made a value equivalent to no picture information and the synchronizing pulse is then inserted to form the complete video signal. A modulation amplifier takes the complete video signal for modulation of the radio transmitter.

In order to modulate a picture-signal carrier for transmission, the signal output from the mosaic signal-plate must be amplified. In many respects the amplifier system in television is similar to that used in sound broadcasting. The requirements for successful picture amplification are more rigorous however, and are necessitated by the great sensitivity of the human eye to subtle distortions of phase and amplitude and the necessity for handling signals over a wide band of frequencies.

BAND WIDTH

In order to transmit pictures with fine detail, it is necessary that the picture signal contain modulating frequencies as high as four megacycles. This is the chief reason why the channels for television transmission are located at the higher frequencies. The sound carrier, and the necessary clearance between sound and picture carriers, and between the carriers and the edges of the bands

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*"Field," in straight line scanning, is a single vertical passage of the scanning element over the picture area; in interlaced scanning, a field is half of the picture-area.

requires another two megacycles. Therefore, a six-megacycle band is allocated to each television-transmitting channel so that both sound and picture signals may be broadcast simultaneously.

At first glance it would appear that 6 mc is not sufficient space for a television channel since the 4 mc video-modulation frequency would normally cause side bands 4 mc above and below the carrier frequency, which would necessitate an 8 mc channel for the video alone.

This would be true except for the fact that a side band filter is employed to eliminate practically the entire lower side band. This type of transmission is called "quasi-single side band" or "vestigial-single side band" transmission. The standard television channel, as established by the Federal Communications Commission, requires that the picture-signal carrier be located 1.25 mc above the lower-frequency limit of the channel and the sound-signal carrier 4.5 mc above the picture-signal carrier. This arrangement allows 4 mc of the channel on which the upper side bands of the picture-carrier may be transmitted without interference from the sound-carrier, because the useful side-band components of the frequency-modulated sound carrier do not extend more than 150 kc above and below the sound-carrier frequency. Thus, the sound signal occupies comparatively little space in the channel.

Figure 61 is a graph showing how a typical television channel is divided in order to meet these standards. The example used in this figure is television channel #5, 76-82 mc, which is the frequency of WABD, Du Mont's television station in New York City.

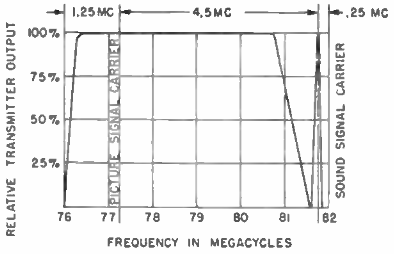

Fig. 61—Division of a typical television channel

THE TELEVISION RECEIVER

A simplified block diagram of a television receiver is given in Figure 62. This diagram shows the television receiver divided into seven major sections, as follows: the R-F section, the Sound Channel, the Picture Channel, the Vertical-Sweep Generator, the Horizontal-Sweep Generator, the Cathode-ray Tube, and the Power Supply.

Functionally, the television receiver operates in the following manner. The R-F section tunes to the desired frequency and picks up the two modulated carriers from the antenna. This R-F section contains a heterodyne oscillator which is tuned to a frequency which, when mixed with the incoming signals, produces two intermediate frequencies, one from the picture carrier and one

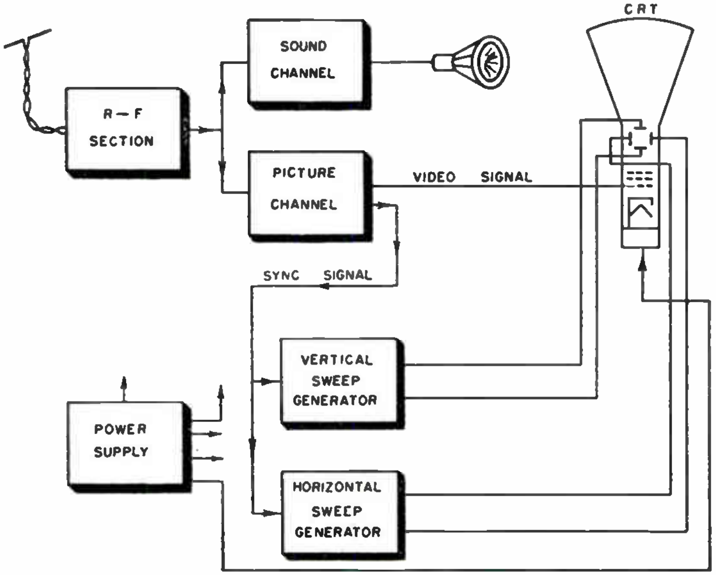

Fig. 62—Block diagram of a television receiver

from the sound carrier. These two intermediate frequencies appear simultaneously in the plate circuit of the converter tube. Tuned circuits at this point pass the picture signal through the picture I-F channel and the sound signal through the sound I-F channel, with each of these channels tuned to reject the other signal.

The sound section amplifies the frequency-modulated sound I-F signal, passes it through one or more limiters and then to a discriminator where the audio signal is "detected". The "detected" signal is amplified by the audio amplifier which operates the loudspeaker.

The picture section amplifies the picture I-F signal, which is amplitude-modulated, detects it, and feeds the resulting video signal to the video amplifier. The video signal is further amplified and applied to the grid of the cathode-ray tube to control the instantaneous intensity of the beam in accordance with the original picture pattern on the mosaic of the iconoscope at the transmitter.

At some point in the video amplifier, generally at the plate of the first video amplifier tube, the synchronizing pulses are separated from the video signal and fed to both the vertical- and horizontal-sweep generator sections. The synchronizing pulses serve to synchronize these two circuits which sweep the beam across the screen of the cathode-ray tube, regardless whether magnetic or electrostatic deflection and focus tubes are used.

Once again, therefore, the amazing versatility of the cathode-ray tube is demonstrated, since television is largely an adaptation of the cathode-ray tube to a particular application. The next application of the cathode-ray tube to be examined is Radar. Developed under a war-time impetus to a high degree of complexity, Radar also, to a great extent, is based on previous achievements of the cathode-ray tube.

Chapter 5

USE OF THE CATHODE-RAY TUBE IN RADAR

Radar—or Radio Detection and Ranging—is an application of radio principles for the purpose of detecting and recognizing objects before they can be seen, or otherwise discovered. Radar also establishes the exact position of an object in terms of its distance, azimuth and elevation with respect to the situation of the radar station. One of the important components of a radar set is the cathode-ray tube by means of which the radar operator can "see" objects beyond the range of vision or obscured by darkness, fog, or smoke.

RADAR THEORY

As long ago as 1922 it was observed that a ship, when passing between a transmitter and receiver reflected some of the radio energy back to the transmitter. This is the basis of the essential differences between radio and radar, namely, that a radar transmitter receives some of the energy it sends out. When a beam of radio-frequency energy strikes a reflecting object, energy is re-radiated. A small part of the re-radiated energy returns to the radar system. The receiver part of the radar system detects the reflected signal and indicates on a cathode-ray tube the presence of the reflecting object. The range and direction of the detected object are calculated from the fact that radio-frequency energy has a constant velocity and the receiver antenna can be made directional.

RADAR METHODS

There are three general types of radar, viz., continuous wave (c-w), frequency modulation, and pulse modulation. Of these, pulse modulation is most widely used because of certain definite advantages it possesses over the other two. Continuous wave makes use of the Doppler effect; namely, radio-frequency energy changes in frequency when reflected by an object moving toward or away from the energy source. Continuous-wave radar transmits energy continuously and the system measures the difference in frequency between the transmitted and reflected energy. By this method the speed of a detected object is determined by the rate of change of frequency. But for slow moving or stationary objects this method of detection is not adequate.

Frequency-modulation radar varies the frequency of the transmitted energy over a specific band, continuously and periodically. The frequency of the energy radiated differs from that of the energy received. The frequency difference is a function of the time lapse between transmission and return of the energy. The amount of time required for the energy to return is determined by the distance over which the energy must travel. The frequency difference can therefore be used as a measure of range. A moving target, however, causes a further frequency change because of the Doppler effect, and the accuracy of this radar method is thus limited.

Pulse-modulation radar transmits energy in brief, powerful pulses of 1 to 50 millionths of a second's duration (1 to 50 microseconds). The transmitter and receiver are alternately connected to the antenna. While the transmitter is sending out its pulses, the receiver is disconnected and turned off. After the pulses have been sent out the transmitter is turned off and disconnected from the antenna. Before any reflected pulses return to the antenna, the receiver is connected and turned on. When all reflected pulses have returned, the process is repeated; in this manner a distinction is made between the transmitted and the reflected pulse. A cathode-ray tube is used with the receiver to indicate the time interval between transmission of the pulse and its return. The time interval is the measure of the distance traveled — since the energy travels at a constant velocity. Pulse-modulation radar does not depend on relative frequencies or the motion of the detected object and therefore has had a much wider use than continuous-wave or frequency-modulation radar.

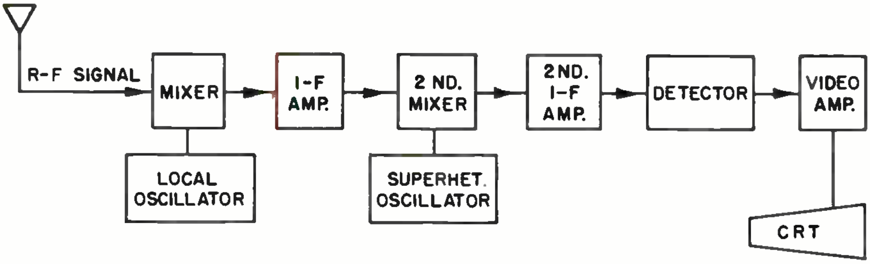

Fig. 63—Fundamental radar receiver

LOCATING AN OBJECT BY RADAR

The location of any object can be accurately determined if its position in space is known in three coordinates, as shown in Figure 64. Sometimes only two coordinates are necessary, as in fixing the position of a ship where only the range and angular bearing are required. For an airplane, however, altitude must also be known in addition to range and angular bearing, or azimuth. The three coordinate measurements are made in a pulse-modulated radar system by means of a time-distance relationship. Since radio-frequency energy travels at a constant velocity, the time lapse between transmission and return of the energy, when multiplied by the velocity, is equal to the distance traveled. The velocity of radio-frequency energy is that of light, 186,000 miles per second or 328 yards per microsecond.

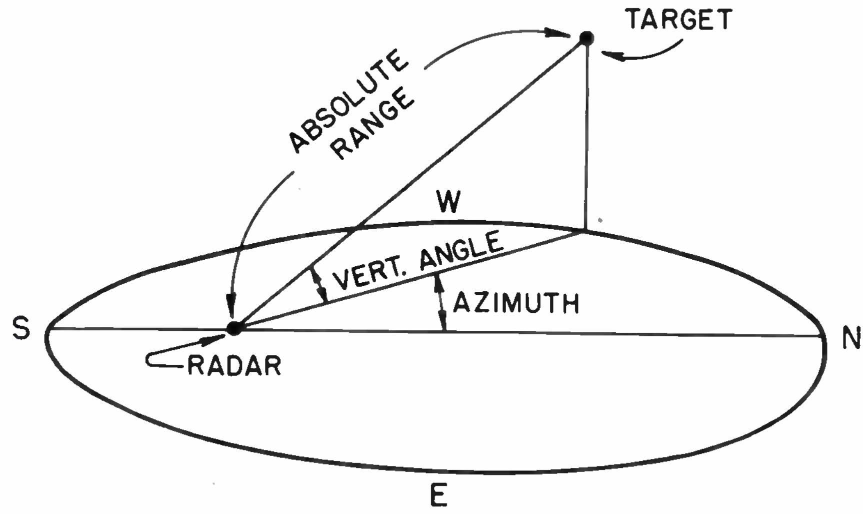

Fig. 64—Fixing an object in space

For example, if a 1-microsecond pulse is directed at an object 32,800 yards away, 100 microseconds are required for the pulse to reach the object and another 100 microseconds are required for the pulse to return. The total time lapse of 200 microseconds is the travel time to and from the object, or twice the range. If range equals time x rate of travel (328 yards per microsecond), then, in this example, the range equals $\frac{200}{2} \times 328 = 32,800$ yards, since 200 is the total travel or elapsed time. Obviously, the accuracy of such a measurement depends on the method of measuring time. Frequently, it is necessary to measure the ranges of more than one object simultaneously; for these cases also, the cathode-ray tube is ideally suited, since it separates the pulses on its screen and provides a known rate of motion by its electron-beam sweep.

MEASUREMENTS ON THE CATHODE-RAY TUBE SCREEN

On the screen of the cathode-ray tube, the beam-trace is deflected horizontally at a constant rate of say, 1 inch per 100 microseconds. If the electron beam starts its sweep, beginning at the left at the instant a pulse leaves the antenna, then at the end of 100 microseconds the pulse will have traveled 32,800 yards and the beam trace will have moved 1 inch to the right. An object 32,800 yards distant will return the pulse to the antenna at the end of another 100 microseconds and the beam trace will have moved a total of 2 inches to the right.

If the reflected pulse is applied to the vertical deflection plates of the cathode-ray tube, the electron beam will be deflected vertically at the 2-inch mark on the screen of the cathode-ray tube. Since a deflection at the 2-inch mark equals a lapse of 200 microseconds and since the distance may be calculated in terms of the total elapsed time and the rate of travel (distance = ½ x 200 x 328 yds/sec = 32,800 yds.), then the deflection on the screen may be read directly in yards, as illustrated in Figure 65.

If the pulse and sweep are started together, the procedure may be repeated periodically in order to continuously excite the fluorescent screen and thereby secure sufficient persistence of the trace. With the same pulse-sweep timing, the repeated traces will overlap and produce a clear, easily read pattern.

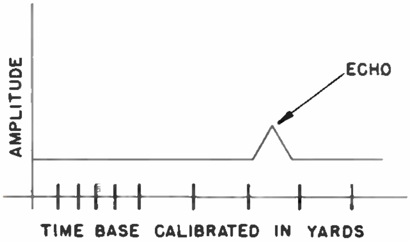

Fig. 65—Time base calibrated in terms of distance

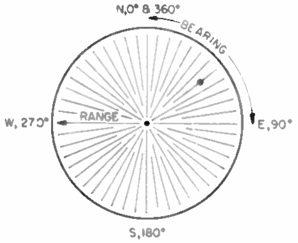

Fig. 66—The bearing indicator

AZIMUTH OR BEARING MEASUREMENT

The directional characteristics of a radar antenna, in conjunction with the cathode-ray tube, are used to determine the compass angle at which the echoed signal is received. The common point from which this angle is measured is true north.

The structural dimensions of the radiator of radio-frequency energy, the antenna, determine the direction in which the radiated energy is concentrated: and greater concentration is obtained when several radiators are used. The complete radar antenna uses radiators, reflectors, and directors to produce a narrow beam in a single direction. If the beam pattern is made to concentrate maximum energy in one direction when transmitting, the receiving pattern for the reflected signal likewise will show greater strength in one direction than another. Since the same antenna is used for receiving and transmitting, and the receiving pattern of an antenna is the same as the transmitting pattern, correct azimuth bearing is obtained when the radar antenna is directed toward the spot from which the maximum reflected signal is received. See Figure 66.

THE SINGLE-LOBE ANTENNA PATTERN

In measuring azimuth or bearing the antenna array is mounted on a rotatable pedestal. The radar beam is swept horizontally through the area under investigation. When the reflected signal is received and indicated on the cathode-ray tube, the position of the antenna is adjusted for the maximum amplitude of the deflection of the trace as viewed on the screen of the cathode-ray tube. Maximum signal is received only when the axis of the antenna coincides with a line drawn from the antenna through the target.

The single-lobe receiving pattern of a typical radar antenna is illustrated in Figure 67 in which signal strength is plotted against the angle of the antenna and the target.

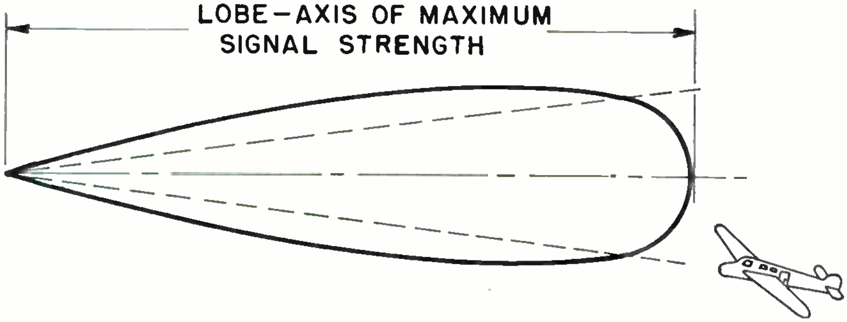

Fig. 67—Single-lobe antenna pattern

THE DOUBLE-LOBE ANTENNA PATTERN

For greater accuracy, a double-lobe system is used for determining azimuth. The axes of the lobe patterns of two antennas are displaced by an angular distance so that the patterns intersect at one point only, called the crossover point. Thus, there is only one azimuth bearing at which equal signals are produced for a particular target, as shown in Figure 68. At all other positions of the antenna array, the signals will be unequal.

PURPOSE OF THE DOUBLE-LOBE ANTENNA PATTERN

Since relative signal strength is plotted against angular position of the antenna with respect to the target, the rate of change of signal strength is not constant; the signal strength varies more rapidly on the side of the lobe than near the axis. The accuracy with which the azimuth bearing of a target can be determined is greatest when the signal strength changes most rapidly. By using a double-lobe pattern a further increase in the rate of change of signal strength with angular position is achieved. This multiplies the accuracy of an antenna system by 4 or 5 times. It also provides a directional guide in the fact that a signal received on the side of one lobe will be greater than that for the second lobe, if the antenna is off the target, and therefore will indicate the direction wherein adjustment is needed. The double-lobe antenna pattern is used where extremely accurate bearing measurments must be made.

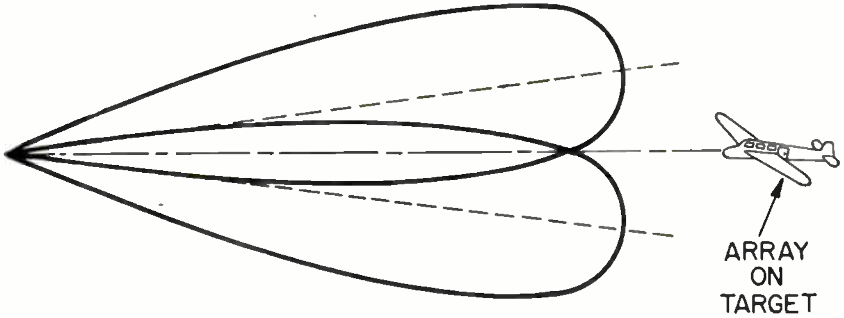

Fig. 68—Double-lobe antenna pattern, showing array on target for maximum directional accuracy

ANGLE OF ELEVATION MEASUREMENT

The third, dimensional measurement required in order to locate an object such as an airplane, is the altitude; this can be determined from the angle of elevation and the absolute range. The tilted antenna method is commonly used to measure the angle of elevation. In the same manner that azimuth is measured, a single- or double-lobe antenna pattern is used to form the vertical free-space pattern. The antenna array is tilted through the angle to be explored. The antenna must also be elevated sufficiently so that the radiated energy will not strike the earth's surface. Otherwise, a direct radiation and a reflected radiation will both reach the object or target with a difference in arrival time because of the unequal lengths of the paths traveled. When the double-lobe pattern is adjusted for maximum signal strength, the altitude may be calculated readily from the range and angle of elevation.

PART PLAYED BY THE CATHODE-RAY TUBE

In all uses of radar, and in many other military applications of electronics, the cathode-ray tube has played a prominent part because of its ability to translate into visual information the facts obtained through the radar principal. Besides its use as a visual indicator, the cathode-ray tube incorporated in an oscillograph is the most important piece of test equipment in servicing radar and maintaining its accuracy.

DUMONT