SECTION 2

ADVANCED
PRACTICAL
RADIO ENGINEERING

TECHNICAL ASSIGNMENT

THE CATHODE-RAY TUBE
AND
ITS APPLICATIONS TO RADIO

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INTRODUCTION.—The study of tubes would not be complete without a discussion of the cathode-ray tube and its many applications in the field of radio. For a number of years the cathode-ray tube has proved its usefulness in up-to-date laboratories as an oscilloscope; in broadcasting stations it provides a means of quickly checking amplifier fidelity and degree of modulation; in experimental television the cathode-ray tube offers the only practically inertialess method of scanning, and hence is the most practical method of obtaining the high scanning velocities necessary for an image of good definition; in all types of industries the cathode-ray tube has proved its usefulness along with other electronic devices.

Up to several years ago cathode ray tubes were expensive and had short operating life. Research by large manufacturers and others toward tubes that would prove both economical and practical for television, has led to the development and production on a commercial scale of highly satisfactory tubes for everyday use in many branches of the radio and electronic fields. Fig. 1 shows two modern cathode-ray tubes manufactured by Western Electric Company.

(In this discussion the terms "oscilloscope" and "oscillograph" will be used interchangeably as will the terms cathode "ray" and "beam". In either case the term used is a matter of personal preference.)

Just as with radio vacuum tubes, increased usage of cathode-ray tubes led to larger manufacturing volume which in turn led to decreased prices and improved tubes. Today cathode-ray oscilloscopes are used in practically every type of radio test work. In broadcasting stations the cathode-ray oscilloscope is used as a monitor for continuous observation of the modulation characteristics of the transmitter output; in

Fig. 1.—Two cathode-ray tubes made by Western Electric Company.

some modern broadcast transmitters provision is made for plugging in an oscilloscope at a number of points along the r-f circuit and the more important adjustments are made with the use of this instrument. In receiver factories it allows the visual alignment of intermediate-amplifier circuits and observation of the tuning characteristics of circuits. In the radio service field inexpensive oscilloscopes are available for performing the above functions, for measuring voltages and currents, for checking vacuum tube characteristics, for inspecting the wave form of the outputs of radio receivers and public address systems, for determining the overload point of amplifiers, etc. The cathode-ray oscilloscope offers the only practical means for adjusting the phase, amplitude and wave-form of the many complex voltages used in a television system.

It must not be thought that the use of a cathode-ray oscilloscope renders all other test equipment obsolete. There are many functions which meters will perform much more quickly and more satisfactorily. However, there are tests and measurements which, by the use of meters alone, would require many individual measurements and laborious plotting of curves, that can be greatly simplified with the curves plotted instantly in a visual form by means of the oscilloscope. Not only can such curves be made immediately available, but changes in circuit and voltage adjustments will visually react on the curves instantly, so that a circuit can be quickly adjusted to predetermined characteristics with the operator continuously viewing all the effects of his adjustments. If a permanent record is required of any conditions during adjustment, it is a simple matter to photograph the pattern on the fluorescent screen.

For radio work it is essential that an oscilloscope mechanism be capable of operation at very high frequencies. It is highly desirable that it is not easily damaged by the application of voltages somewhat in excess of rated values. For general use it must be comparable in price with other available test equipment. Parts must be standardized and replacements easily obtainable.

The cathode-ray tube meets all of these requirements. It has no mechanical moving parts, the entire operation being electrical. The moving element has very little inertia, being simply a stream of high velocity electrons. It is capable of operation at frequencies in the high radio-frequency range, far beyond the scope of mechanical types of oscillographs. It requires auxiliary equipment no more bulky or complex than the power supply and audio amplifier of an ordinary broadcast receiver. It can be produced on a quantity basis and sold at a price not beyond the means of the smallest broadcasting station, or the average up-to-date radio service shop. Tubes can be standardized and closely duplicated in production. In voltage measurements, the application of moderately excess voltage simply throws the electron beam off the fluorescent screen but does not damage a moving mechanism as would be the case if the measuring device were an ordinary meter. Thus it would seem that the cathode-ray tube has extensive applications in the field of radio test work.

FUNDAMENTAL THEORY.—A cathode ray consists simply of a beam of very rapidly moving electrons. In high-vacuum high-voltage cathode-ray tubes designed for television the electrons actually travel at velocities as high as 1/10th the velocity of light, or approaching 20,000 miles per second. The negative electrical terminal of a battery or of a vacuum tube is called the "cathode." The electron is a negative charge of electricity and the ray consists of many electrons, therefore, the ray is termed a "cathode ray" and the tube designed to utilize such a ray is called a "cathode-ray" tube.

The cathode-ray tube dates back much further than the conventional radio vacuum tube. The direct ancestor of both the cathode-ray tube and the X-ray tube is the Crookes tube invented by Sir William Crookes. In that tube a stream of electrons was sent across a vacuum by means of a high difference of potential. If the electrons strike certain mineral substances, those substances will become fluorescent and glow. If the electrons are caused to strike a metal plate within the tube at high velocity, X-rays will be emitted. X-rays were discovered in 1895 by Professor Roentgen while experimenting with a Crookes tube.

In 1897 Dr. F. Braun designed the cathode-ray tube as a development of the Crookes tube. In the Crookes tube the electrons go from one electrode to the other through all portions of the tube. Braun introduced a metal plate with a very small hole in it, between the cathode and the anode. This metal plate is made positive with respect to the cathode and the electrons emitted from the cathode attain very high velocities, normally as high as 10,000 miles per second. Most of the electrons strike the plate; some, however, pass straight through the small hole and form a pencil or ray of high-velocity electrons which strike the extreme end of the tube. The arrangement of such a tube is shown in Fig. 2.

If the extreme end of the tube, marked x, is coated inside with certain fluorescent mineral substances, such as zinc silicate in the form of powered mineral willemite, the spot where the electron beam hits will glow. The brightness of the glow at the spot struck by the electron stream is largely a function of the velocity of the electrons, so there is shown in Fig. 2 a second positive potential applied at the fluorescent screen on the extreme and almost flat end of the tube. This second positive potential is usually several times greater than that applied to the first anode so that the electrons passing through the small hole

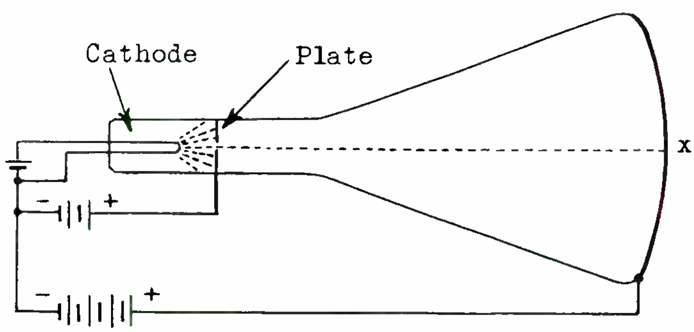


Fig. 2.—Action of the electron gun.

in the first anode plate are greatly accelerated. The luminous glow at the fluorescent screen, caused by the impact of the cathode ray, may be anywhere from a greenish-blue to white, the exact color being determined by the type of fluorescent material used.

In some of the older cathode ray tubes the fluorescent surface, not being a particularly good conductor, tended to gradually assume a negative charge which detracted from the positive charge of applied voltage and decreased the velocity of the electrons. To eliminate that condition the surface of the glass before the fluorescent coating was applied, was first coated with a metal film, so thin as to be quite transparent. Over the film was placed the fluorescent material. This allowed the electrons to leak off as fast as they arrived but did cause a considerable loss of light through the outer surface of the flat end of the tube through which the light is viewed. Modern practice has developed a fluorescent coating which will emit the proper ratio of secondary electrons to primary electrons to prevent the accumulation of a negative charge, the secondary electrons going to a highly positive metallized inner surface of the tube. This will be discussed in greater detail later when the actual construction of the modern tube is taken up. With such means for preventing the accumulation of negative charge the metal film beneath the fluorescent surface is unnecessary and its elimination permits a brighter light through the viewing end of the tube.

A consideration of the cathode ray, which consists simply of a stream of high-velocity electrons, will show that it is very little different from an ordinary flow of current through a wire. A certain current flow through a straight conductor is simply a slow drift of free electrons through the conductor; the actual direction of the drift is a straight line because the conductor is straight and the electrons are restricted to the physical limits of the conductor even though their individual movements are not continuously in a straight line. The electron drift for a given small value of current is very slow because of the extremely large number of electrons which are free to move under the influence of the difference of potential.

The condition within the cathode ray tube is somewhat different; here the extremely large number of free electrons is not available, the current consisting simply of the few electrons which happen to pass straight through the small hole in the anode plate after being emitted by a heated cathode. On the other hand, those few electrons are not restricted by continual collisions with large copper molecules and are thus free to accelerate to very high velocity in the length of the tube. The cathode ray, unlike the current in the piece of wire, is therefore made up of a beam of a few very high velocity electrons, the beam being held to a straight line, not by the limits of the conductor, but by the high velocity of the electrons themselves and by a method of focusing which will be explained. In other respects, however, the cathode ray and the current through the conductor are similar and both may be considered simply as a flow of current.

Every flow of current creates, at right angles to itself, a magnetic field. In an electric motor the field caused by a current flow in the armature conductors when opposed to a fixed magnetic field will cause the armature conductor to be repelled and the armature to rotate. If a magnetic field is impressed across a cathode ray, the magnetic field caused by the beam itself will cause the cathode ray to be deflected in one direction depending upon the polarity of the fields, and *the amount of the deflection will be a function of the strength of the fields*. This is shown schematically in Fig. 3. (As in a motor, the direction of motion is actually at right angles to the plane of the magnetic lines of force. Thus a *vertical* magnetic field will cause a *horizontal* movement of the beam.)

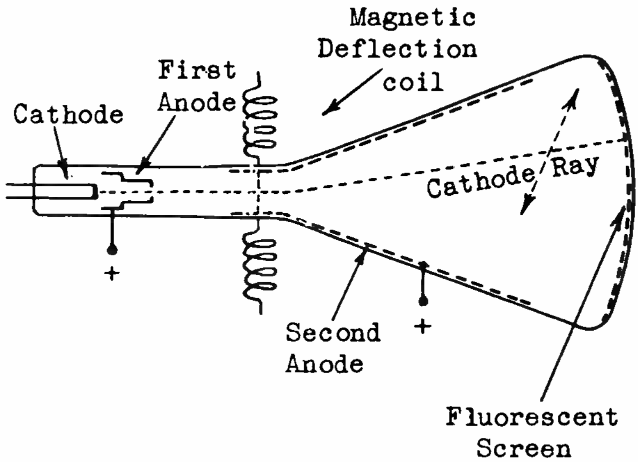


Fig. 3.—**Magnetic deflection of the electron stream is used here. (Deflection should be assumed at right angles to the magnetic field).**

In Fig. 3 the cathode with its terminals is shown. This may be either a tungsten or oxide-coated filament or, in line with modern receiving tube practice, an indirectly heated cathode. Part of the emitted electrons pass through the hole in the first anode and form the cathode ray to the fluorescent screen. After the cathode ray leaves the first anode it passes through the field of the two magnetic poles as shown and is deflected at right angles to the magnetic lines of force. If an alternating current is passed through the field windings the cathode ray will move back and forth over the fluorescent screen in accordance with the polarity and amplitude of the field current. The second anode is the metallized inner coating of the bulb.

Similar results may be accomplished by the application of an electrostatic field. A negative charge will repel electrons and a positive charge will attract them. Thus if two opposing plates, similar to capacitor plates, are arranged as shown in Fig. 4, and opposite electrostatic charges are placed on the plates making the upper plate positive and the lower plate negative, the cathode ray will be deflected as shown. If a source of alternating voltage is connected across the two deflector plates the voltage on the plates will rise, fall, and change in polarity in accordance with the amplitude and polarity of the voltage source and the electron beam will be deflected up and down across the fluorescent screen in accordance with the amplitude and polarity of the voltage applied to the deflection plates. Thus a varying electric field can be made to accomplish exactly the same results as the varying magnetic field.

If two sets of deflection plates, or two sets of magnetic field coils, are arranged at right angles to each other, one pair will cause the cathode ray to sweep horizontally across the fluorescent screen while at the same time the other pair will cause a vertical movement of the ray. By properly timing the voltages applied to the pairs of plates the entire surface of a rectangle on the end of the tube can be "scanned", the only moving mass being that of the cathode ray. The arrangement of the plates is shown in Fig. 5. The horizontal plates cause a vertical deflection of the cathode ray and the vertical plates cause a corresponding horizontal deflection of the ray. Fig. 6 clearly shows one set of plates in a modern RCA cathode ray tube.

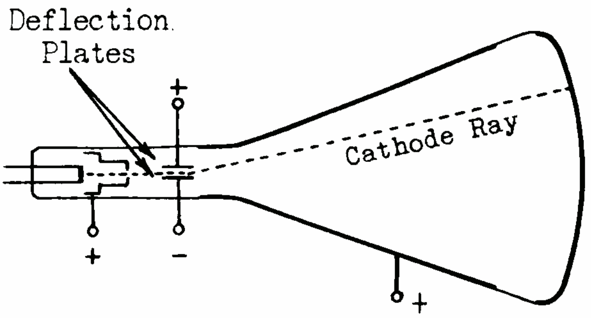


Fig. 4.—Cross section of C.R.T. showing vertical deflection plates.

If a voltage is applied to the vertical deflection plates only, and the voltage caused to vary over a certain range, reversing in polarity as it passes through zero, the luminous spot will move in a straight line up and down the end of the tube. If the voltage is an a-c voltage that varies so rapidly that the eye cannot follow the movement of the spot, a vertical luminous line will be seen on the fluorescent screen. This is shown in Fig. 7(A).

If the a-c voltage is applied only to the horizontal deflection plates, the luminous line will appear in a horizontal position across the end of the tube, as shown in Fig. 7(B). The length of the line in either case is a function of the voltage amplitude. Thus the distance above and below center can be calibrated and, by applying the voltage across the vertical deflection plates as in 7(A), the peak amplitude of the alternating voltage can be measured. The calibration can be made with known d-c voltages and marked on the surface of the bulb. A similar calibration could be made along a horizontal line for the use of the horizontal deflection plates.

If the same values of alternating voltage, in phase and equal in amplitude, are applied across both pairs of plates, the luminous line will be traced at an inclination

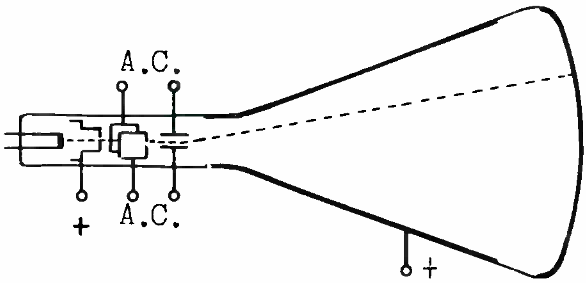


Fig. 5.—Cross section of C.R.T. showing both sets of deflection plates.

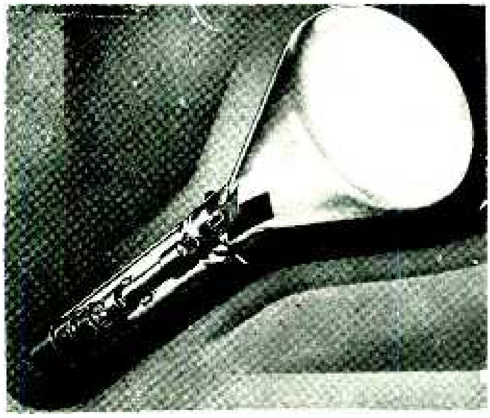


Fig. 6.—An R.C.A. cathode-ray tube.

as shown in 7(C). If the polarity of the voltage across one pair of plates is then reversed, placing the voltages 180° out of phase, the inclination will be changed as in 7(D). If in 7(C) or 7(D) the phase relation of the voltages is unchanged but the amplitude of one or the other is changed, the inclination of the line will be changed. If the horizontal deflection voltage amplitude exceeds that of the vertical deflection voltage, the inclination of the line will more nearly approach the horizontal, and vice versa.

If the amplitudes of the voltages are equal but the phase relation between the voltages is varied, the luminous tracing ceases to be a straight line. If the voltages are displaced by 90°, the tracing takes the form of a circle, 7(G). At intermediate angles between 0° and 90°, the tracing will be in the form of various shaped ovals. Figs. 7(E) and 7(F) represent the pattern equivalent to 7(C) and 7 D) respectively if the phase angle of one of the deflection voltages in each of the latter is shifted a few degrees. If the amplitude ratio and phase relation are both varied, the tracing may assume quite complex shapes.

Figs. 7(H) and 7(I) represent the elliptical patterns which will be obtained if the horizontal and vertical deflection voltages are displaced by 90° but are of unequal amplitude. In 7(I) the vertical voltage exceeds the horizontal voltage; in 7(H) the reverse is true. The phase displacement in both is 90° and if the voltage amplitudes were made equal, circular patterns would result. This is a particularly important pattern because it is used as an indication of correct adjustment of the phase inverting network of the Doherty high-efficiency amplifier and in other circuits where a true 90° phase shift is required such as in the phase inverting networks used in the modulation circuits of frequency-modulated transmitters employing the Armstrong circuit, and elsewhere.

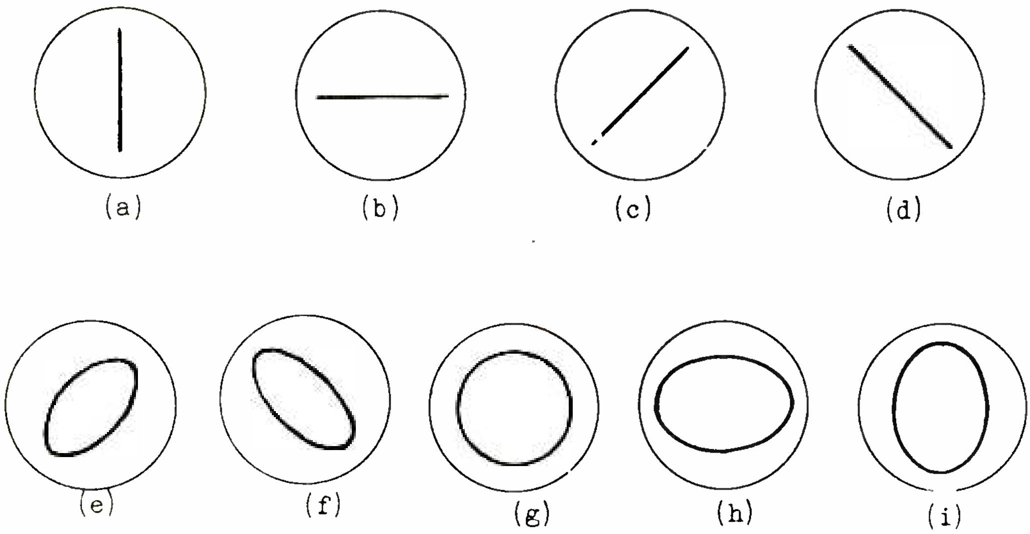


Fig. 7.—Variation in pattern on a C.R.T. for several voltage combinations.

Thus, by applying available voltages to the deflection plates, a good idea of the relative amplitudes and phase relation of the two voltages can be had by inspection of the pattern traced by the cathode ray.

In the study of a wave form, the alternating voltage to be studied is applied across the vertical deflection plates. Across the horizontal deflection plates is placed a "saw tooth sweep" voltage. Such a voltage is shown in Fig. 8.

The method of producing such a voltage will be discussed later. Essentially, during the "Sweep" period a capacitor charges at a steady rate through a fixed value of resistance, discharges almost instantly through a discharge tube, charges again, etc. Thus during the "sweep" period the spot moves horizontally across the fluorescent screen at a steady rate, returns on the discharge at too rapid a rate to make an impression on the eye, "sweeps" across the screen again, etc. If an alternating voltage is placed on the vertical deflection plates only, with no horizontal deflection voltage, the luminous spot will trace a straight vertical line as in Fig. 7(A). Leave this alternating voltage on the vertical deflection plates and apply the saw-tooth voltage of Fig. 8 to the horizontal deflection plates, and adjust the two voltages to exactly the same frequency. Then the spot, in moving up and down in accordance with the voltage of the vertical deflection plates will also be moved horizontally across the screen at a steady rate. The position of the spot will be a function of both voltages. The "sweep" period of the horizontal deflection voltage occupies practically the entire cycle, the return time being negligible.

With both voltages having the same frequency, the spot will be moved from one side of the screen to the other while one cycle of the vertical voltage is taking place. If the vertical voltage is sinusoidal, a sinusoidal cycle will be traced on the fluorescent screen. This is shown in Fig. 9. The "sweep" voltage simply "spreads out" the cycle of voltage applied to the vertical deflection plates so that the shape of the cycle as well as its amplitude may be determined.

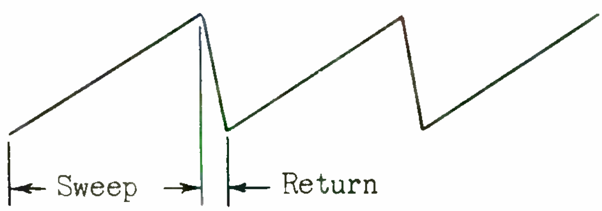


Fig. 8.—A "saw-tooth" wave used as the horizontal sweep.

If the sweep frequency is made just one-half of that of the vertical deflection voltage, two vertical cycles will take place during one sweep across the screen. The luminous trace will then be as in Fig. 10.

If the voltage to be investigated contains harmonic components so that it is distorted from a sinusoidal form, this will be shown. An example of such a voltage is in Fig. 11.

If it is desired to find the form of the plate current in an amplifying tube, and the tube is being operated into the saturation plate current region with positive peak grid voltages, the vertical deflection should be effected by means of deflection *coils* since this will make the oscillograph a current operated device. Similar results may be obtained with electrostatic deflection by connecting a resistance of nominal value in series with the plate circuit and connecting the deflection plates across the resistor. The voltage form across the resistance will be a reproduction of the form of the current through the resistance. By either method the tracing on the fluorescent screen may be somewhat as shown in Fig. 12, indicating saturation plate current with a large grid current on the positive alternation, and plate current cut-off on the negative alternation, each condition causing harmonic distortion in the output. This condition, of course, indicates excessive grid excitation.

CONSTRUCTION AND OPERATION OF THE CATHODE-RAY TUBE.—A typical cathode-ray tube for oscilloscope operation is the RCA Type 7JP1. This tube is a high-vacuum tube with a viewing screen 5 inches in diameter. Other types of fluorescent screens vary from 3 to 12 inches in diameter, and one manufacturer has placed on the market a television type tube having a diameter of 30 inches. The 3-inch type, such as the 908 is commonly used where compactness and minimum cost are important factors. As a rule, the larger the tube, the higher the anode voltages required, the greater the electron velocity, and hence the lower the deflection sensitivity. This will be explained later.

Fig. 13 shows a Sylvania

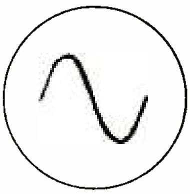


Fig. 9.

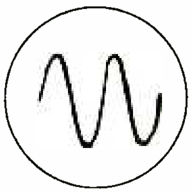


Fig. 10.

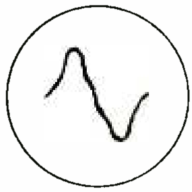


Fig. 11.

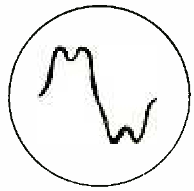


Fig. 12.

Fig. 9.—A sine wave distortion. Fig. 10.—Two sine waves appear when the sweep frequency is made equal to one-half the frequency of the vertical deflection voltage. Fig. 11.—A wave similar to Fig. 9 but containing harmonics. Fig. 12.—Another distorted wave form.

rectangular face picture tube of the type which was designed specifically for use in television receivers.

The cathode-ray tube may be divided, for study into three major parts: First, the fluorescent screen; second, the electron gun; third, the deflection mechanism.

the other hand, the yellow-green of zinc silicate is near the color of maximum visual sensitivity, so that for equal light intensity the spot will appear to the eye several times brighter than the blue of calcium tungstate. In some tubes, where photographic recording is to be used along with visual observations, the

Fig. 13.—Sylvania Rectangular picture tube.

THE FLUORESCENT SCREEN.—The principal factors in the design of the fluorescent screen are: Brightness of the luminous spot for given applied voltages; color of the spot, both as it affects the eye and as it affects a photographic film; duration of the spot.

The brightness of the spot, as it affects either the eye or a photographic film, is to a considerable extent a function of the color of the spot. For example, the fluorescent color of calcium tungstate is a deep blue which is about thirty times as active photographically as the yellow-green fluorescence of pure sinc silicate. On

fluorescent screen is made up of a combination of zinc silicate and calcium tungstate, thus combining the desirable properties of both substances with good visual and good photographic sensitivity. Such a combination is used in the W.E. 224-C low voltage cathode ray tube.

The duration of the spot is very important. For a given luminous intensity, the longer the duration of the spot the greater the total amount of light radiated. However, where a series of transient phenomena are to be photographed, where each transient voltage or current will probably be different from the preceding one, or where adjustments are being made while visually observing the luminous trace, too long persistance of the spot will cause a blur from one condition to the next. For most work a short spot duration is desirable. In the case of the RCA Type 908, the brightness becomes negligible in less than 25 microseconds. This is a much shorter duration than is ordinarily used for television work. In the kinescope, the RCA cathode-ray tube developed for television reception, (See Fig. 13), the fluorescent material is a synthetic zinc orthosilicate phosphor, very much like natural willemite. This material, at the end of less than 1/40th second loses 80 per cent of its luminescence, and by approximately .06 second practically all the visible luminescence has disappeared. The light is yellow-green, peaked to 5,230 Angstroms, very close to the maximum sensitivity of the eye which is at 5,560 Angstroms. (The Angstrom is the unit used to express the λ of light. One Angstrom is equal to one-hundred millionth of a centimeter.) With such material the luminous efficiency is high because the eye reacts very well to light of this particular color.

THE ELECTRON GUN.—The electron gun is that group of tube elements which produces the cathode ray, or moving beam of electrons. While in theory the production of the cathode ray is very simple, in practice a number of factors must be taken into consideration. Among those factors are, the intensity of the spot, which is a function of the number of electrons and the velocity with which the electrons strike the screen; the size of the spot, which is controlled by the focusing of the beam, the sharpness of focus being a function of the shapes and dimensions of the first and second anodes, and the ratio of the two anode voltages; the deflection sensitivity, which is a function of the electron velocity, the greater the velocity, the lower the deflection sensitivity.

A typical electron gun and deflection plate assembly is shown in Fig. 14. The electrons are pro-

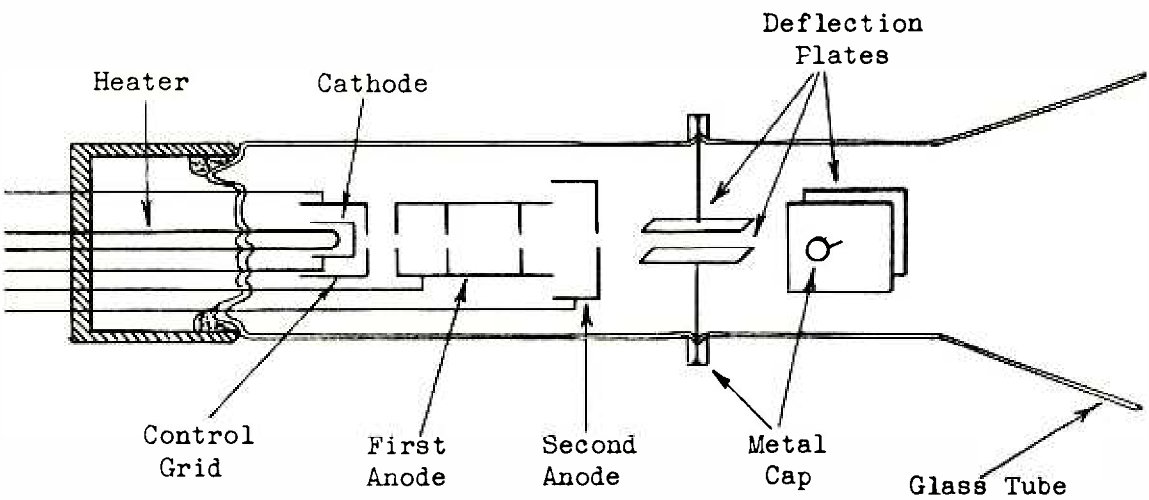


Fig. 14.—Detailed view of the C.R.T. plate assembly.

duced by means of an indirectly heated cathode just as in an ordinary receiving tube, the only difference being that the emitting surface is on the extreme end of the cathode. The control grid is made in the form of a sleeve over the cathode with a small aperture immediately in front of the emitting surface. The control grid is normally held negative, the amplitude of the negative bias determining the number of electrons which pass through the aperture and hence, for a given anode potential, the intensity of the spot. The first anode consists of a metal sleeve immediately following the control grid. The electrons passing through the grid aperture are accelerated by the positive potential of the first anode and the width of the electron beam is restricted by the width of the apertures in the first anode through which it must pass.

After leaving the first anode the electrons come under the influence of the higher positive potential of the second anode and are both further accelerated and focused to produce a spot of the desired diameter on the screen. This focusing is very important. The electrons in the cathode ray, all being negative, tend to repel each other with the consequent tendency toward dispersion of the ray. Thus in the highly evacuated tube, if the second anode were not present, the electrons leaving the first anode would repel each other and the fluorescent spot on the screen would be indistinct and have a large area. By proper focusing, the spot may be made small and very intense. Fig. 15 shows the electron gun on a larger scale. (The second anode in

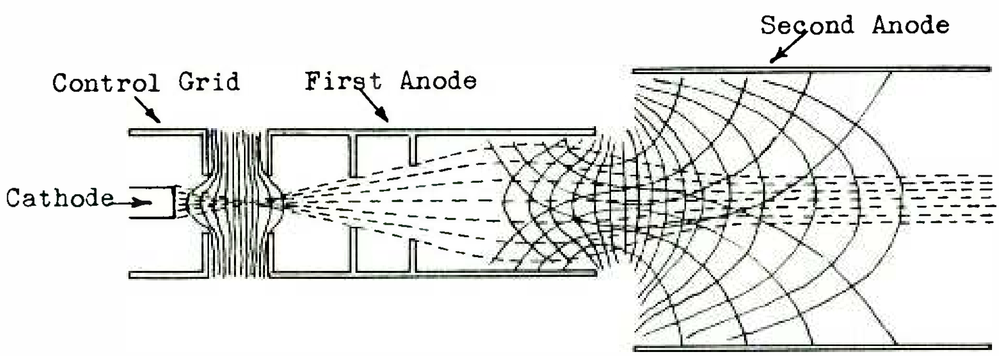


Fig. 15.—Electric field pattern in a C.R.T.

many tubes consists of a metallic [aquadag] coating on the inner surface of the bulb rather than a tube element as shown in Fig. 14.) The combination of the electrostatic fields of the first and second anodes affects the electron beam just as an arrangement of lenses controls a light beam. The combination as shown in Fig. 15 is the equivalent of four lenses.

The actual focusing of the beam is accomplished by varying the ratio between the first and second anode voltages. The second anode voltage is usually fixed at the desired value—1,500 volts in the case of the RCA Type 5UP1—and focusing is accomplished by varying the first anode potential. For this reason the first anode is often called the focusing anode. In general, the voltage ratio between anode 2 and anode 1 should be about 5 to 1 although there is considerable deviation from this ratio in various types of tubes because proper focus is also a function of the shape and dimensions of the first and second anodes. Thus if the voltage of anode 2 is 2,000 volts, that of anode 1 is usually in the order of 400 volts for best focus. The focusing voltage is taken from a potentiometer in the power supply voltage divider circuits.

Fig. 16 shows a typical cathode ray oscilloscope circuit. It will

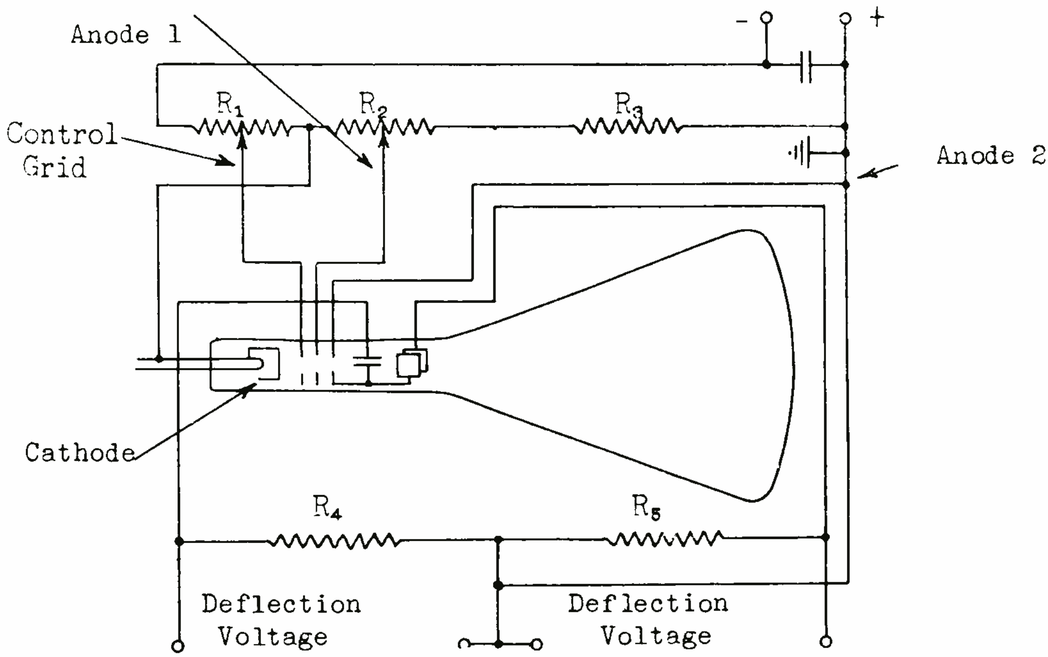


Fig. 16.—Typical control circuit for a C.R.T.

be observed that the control-grid voltage, which is varied by means of potentiometer R_1, is negative at all adjustments. The first anode or focusing voltage is controlled by potentiometer R_2.

The connection of the deflection plates and the second anode should particularly be noted. One of each pair of deflection plates is connected to the second anode and the second anode is grounded. The free deflection plates also connect back to Anode 2 through R_4 and R_5, those resistors forming a leakage path to prevent electron accumulation on the plates. All deflection plates are thus maintained at the same d-c potential as the second anode, and *the positive high-potential point is grounded,* with the negative side of the circuit being at high potential above ground. This is done as a safety precaution; connections for measurement must be made to the deflection plate terminals and it is thus easier and safer to insulate the negative side of the circuit above ground. With the positive side of the high-voltage circuit grounded, *it is essential that the heater transformer secondary be insulated for the full anode d-c voltage.*

The focusing of the beam and the intensity of the spot, if the second-anode voltage is fixed, are controlled by variation of the first anode and control-grid voltage. The sharp focus of the beam is accomplished by varying the ratio between the first and second-anode voltages. The size and intensity of the spot may then be varied by variation of the control-grid voltage. Making the control-grid voltage less negative increases the second-anode current, increases the size of the spot, and increases the brightness. Thus when the brightness is increased by decreasing the negative grid bias, the first-anode voltage should also be readjusted to focus and bring the spot back to the desired diameter. In the case of the RCA 5UP1 the negative grid bias for complete cut-off is approximately -180 volts with first-anode potential of 2400 volts. If the first-anode voltage is increased, the negative grid bias must also be increased for complete cut-off.

THE DEFLECTION MECHANISM AND DEFLECTION SENSITIVITY —The deflection of the cathode ray may be accomplished either by an electrostatic or an electromagnetic field. The force necessary to deflect the cathode ray is a function of the velocity of the electrons making up the beam, this in turn being a function of the second-anode potential. The velocity of the beam is given by the equation,

$$v = 5.95 \times 10^7 \sqrt{E_a}$$

where v is the velocity in centimeters per second and E_a is the second-anode voltage. For E_a = 4,500 volts, the electron velocity is somewhat greater than one-tenth the velocity of light.

The displacement of an electron from the straight line as it travels through a magnetic field is equal to,

$$d' = \frac{evBL^2}{2m\ v^2} \qquad (2)$$

where d' = displacement from the initial straight line, e = the charge on the electrons, m = the mass of the electron, B = the intensity of the magnetic field, L = the length of the path in the magnetic field, v = the velocity of the electron.

As the beam leaves the area immediately under the deflection coils it must travel the distance to the fluorescent screen. Thus the additional amount of the deflection from the deflection coils to the screen is a function of the distance traveled, and is equal to,

$$d'' = \frac{evB\ell L}{mv^2} \qquad (3)$$

where L is the distance from the deflecting magnetic field to the fluorescent screen. Combining equations 2 and 3 to obtain the total deflection d of the cathode ray at the fluorescent screen,

$$d = d' + d'' = \frac{e}{m} \cdot \frac{B\ell}{v} \left(\frac{\ell}{2} + L\right) \qquad (4)$$

centimeters

e and m, the charge and mass of the electron are constants. Thus the total deflection of the beam, for a given tube in which ℓ and L are fixed in construction, is a function of B, the intensity of the magnetic field, and an inverse function of v, the velocity of the electrons in the cathode ray.

When deflection plates are used instead of coils—the more common condition in ordinary oscilloscope work—the deflection sensitivity is usually expressed in millimeters per volt d.c., (mm/volt d.c.). That is, if the deflection sensitivity is expressed as .2 mm/volt d.c., a difference of potential of one volt between a pair of deflection plates will cause the spot on the fluorescent screen to be deflected .2 millimeter. If 100 volts is applied across the same plates, the spot will be deflected 20 mm.

Where deflection plates are used, the deflection of the spot is equal to,

$$d = .5E\ell L/E_a y \qquad (5)$$

where E = the voltage across the pair of deflection plates, E_a = the second-anode voltage, ℓ = the distance the electron travels between the deflection plates, L = the distance from the center of the deflection plates to the fluorescent screen, and Y = the distance between the deflection plates. For a given tube ℓ, L and y will be fixed in construction. Thus the amount of deflection for a given deflection voltage E will be inversely proportional to the second-anode voltage E_a because the higher the second anode voltage, the greater the electron velocity. Since the deflection sensitivity is defined as the amount of deflection of the spot per volt across the deflection plates, the deflection sensitivity must be inversely proportional to the second anode voltage.

This is shown in the manufacturer's tube ratings. For the RCA Type 905A, the deflection sensitivity is given as follows:

	E_a = 1500V	E_a = 2000V
Deflection Sensitivity (Plates D_1 and D_2) mm/v d.c.	.295	.221
Deflection Sensitivity (Plates D_3 and D_4) mm/v d.c.	.348	.262

Two points should be observed in this rating. First, the deflection sensitivity.

Deflection sensitivity is an inverse function of second-anode potential; therefore, deflection sensitivity plotted as a function of second-anode potential will not appear as a straight line but rather as a (hyperbolic) curve having a negative slope, as explained in Graphical Analysis.

In view of the non-linearity of the curve and the considerable percentage difference between two known reference points, the use of "proportional parts" or simple interpolation to find the sensitivity is inaccurate. The use of inverse proportion is indicated; for example, if the deflection sensitivity at E_a = 2,000 volts is .221 mm/v d.c., the deflection sensitivity at E_a = 1,500 volts will be:

$$X = .221 \times \frac{2000}{1500}$$

$$= .295 \text{ mm/v d.c.}$$

Second, the deflection sensitivity is greater for one pair of plates than for the other pair. This is because the deflection plates D_3—D_4 are further from the screen than are the plates D_1—D_2, the value of L thus being greater. (See Equation 5.) Some tubes are so constructed that the deflection sensitivity is the same for both pairs of plates.

It will be seen that if the cathode-ray oscilloscope is to be calibrated and used to measure voltages, as in radio service and test work, the anode voltage must be maintained at a constant value because variations in E_a are reflected as variations in the deflection sensitivity, and hence in the calibration.

It may be thought that with the high anode voltages required for operation of the high-vacuum type cathode-ray tubes, a large power supply will be required. That is not the case. In the case of one type of tube which operates with second-anode potential of 5,000 volts, the anode current with normal grid bias is only 70 microamperes, a total power consumption of only .35 watt. At full brilliance with zero grid bias the power in the anode circuit is only .7 watt. Thus while the anode rectifier must deliver a high voltage, the actual power consumption from the filter is almost negligible, and filtering is extremely easy. A single 2 µF capacitor across the rectifier circuit is ordinarily sufficient where only the cathode-ray tube forms the load circuit.

The spot should never be left stationary on the screen for even a short interval. The beam producing a spot of high intensity may quickly burn the fluorescent screen if allowed to remain stationary. Such operation may also cause excessive heating of the glass with resulting puncture. An alternating voltage should be applied across at least one and preferably both sets of deflection plates before the spot is produced.

Pyrex glass is ordinarily used for large cathode-ray tubes to ensure strength. The atmospheric pressure on the face of a highly evacuated 9-inch diameter tube is about 960 pounds and good construction to withstand this pressure is essential. The total pressure increases directly with area which in turn varies as the radius squared. Thus in large cathode-ray tubes as used in television the pressure on the tube will be in the order of thousands of pounds.

THE SWEEP-CIRCUIT.—Where the cathode-ray oscilloscope is to be used in the study of wave forms, modulation percentage, distortion, etc., a linear sweep voltage is necessary to cause the spot to move horizontally across the screen while at the same time the voltage under investigation is applied across the vertical deflection plates. This voltage must have a saw-tooth form with the return time negligible with respect to the sweep time. This is shown in Fig. 8, and the effect of such a sweep voltage is shown in Figs. 9 to 12 inclusive and in Figs. 22 and 24.

The most simple method of producing such a voltage is by means of a relaxation oscillator employing a gaseous triode such as the Type 885.

The 885 is a grid-controlled gaseous rectifier. The operation of such a tube is simple. With fixed plate voltage and large negative bias, no current flows. If the negative grid voltage is slowly reduced, a point will be reached at which plate current flows and ionization of the gas takes place. After ionization takes place, further variation of the grid voltage in either direction has no effect on plate current and plate current can be stopped only by the removal or very great reduction of the plate potential.

Another method of operation is as follows: starting with a fixed negative bias and zero plate voltage, the plate is made positive and the plate voltage is slowly increased. At a certain critical value of plate potential, ionization will occur and a large plate current will flow. As explained above, plate current can be stopped only by a large reduction of plate voltage. The critical plate voltage at which ionization starts is a function of the negative grid bias. With a bias of 20 volts, ionization will start when the plate potential is increased to approximately 200 volts. It is this method of operation which is used in the relaxation oscillator to produce the sweep voltage.

Fig. 17 shows the most simple form of sweep-circuit oscillator. With the bias adjusted to some predetermined negative value by means of R_1, voltage E is applied across C through resistor R. As explained, the 885 tube is blocked at this instant. Current flows through R charging capacitor C, the plate potential of the 885 rising with the voltage across C as the capacitor charges. When the capacitor is charged to the point where the plate potential (voltage across C) is approximately 10 times the negative bias voltage E_c, ionization takes place and C discharges suddenly through the low resistance of the ionized tube. The discharge of the capacitor effectively *removes* the plate potential from the tube, plate current ceases, and the entire operation repeats itself.

The time required for the voltage across C to reach the tube breakdown point is determined primarily by the capacity of C and the resistance of R. Increasing either C or R will increase the charging time and thus decrease the oscillation frequency, and vice versa.

By the adjustment of C and R, the frequency of the relaxation oscillator can be made any desired value. However, the simple circuit as shown has a very serious fault for sweep purposes; the capacitor charge is not linear with respect to time and hence the sweep voltage is not linear. This is due to the fact that the current through R is not constant during the charging period. When the voltage is first applied across CR, there is no c.e.m.f. and the current is large. As the capacitor charges the c.e.m.f. builds up charge to the gas breakdown voltage is a function of the pentode I_p which in turn is determined by pentode E_c. If the pentode $-E_c$ is increased, I_p is decreased, more time is required for the capacitor to charge, and the relaxation oscilla-

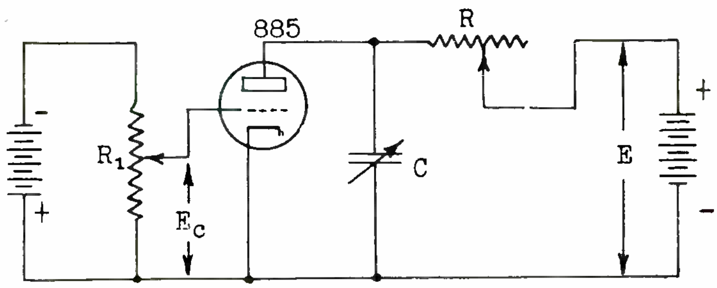


Fig. 17.—A simple sweep-circuit oscillator.

and the charging current tapers off. Thus the capacitor charge is in the form of an exponential curve instead of the desired straight line.

This can be corrected only by replacing R with some device which will limit the initial charging current and which will allow essentially constant current flow during the entire charging period. Such a device is a pentode vacuum tube. An examination of a family of $E_p I_p$ characteristic curves for a pentode will show, for any given grid voltage, almost constant plate current over almost the entire range of plate voltage. Thus by adjustment of the grid bias of the pentode, the charging rate can be made any desired value within the limits of the tube and this adjustment is equivalent to varying R in Fig. 17. With a given value of C, the time of tor frequency is decreased. Making the pentode E_c less negative has the opposite effect. A complete linear sweep-circuit, employing a Type 885 tube as a relaxation oscillator and a remote cut-off pentode to control the changing rate of C, is shown in Fig. 18.

The operation of this circuit is quite simple. The 885 is the relaxation oscillator. Its frequency is controlled by capacitor C, of which any one of four capacities may be selected, 400 µµF, .001 µF, .01 µF or .1 µF, and the capacitor charging rate which is controlled by the plate current of the pentode. It will be observed that the plate-filament resistance of the pentode is in series with the 885 plate voltage which is supplied by a Type 80 full-wave rectifier. When voltage is applied the 885 is blocked, as explained for the simple circuit. Plate voltage is applied to the pentode and plate current flows, the amplitude of the plate current being determined by the pentode control grid voltage which, by means of the potentiometer can be adjusted to any value between zero and -22.5 volts. As pentode plate current flows capacitor C charges; when the voltage across C reaches the critical breakdown point of the 885, ionization occurs and C discharges almost instantly through the 885, the discharge removes the plate potential from the 885, ionization ceases, and the 885 again blocks; C again starts to charge due to the pentode plate current, and the entire operation is repeated. The 700 ohm resistor in the 885 plate circuit is not a factor in the charging time; it is simply a current limiting resistance to limit the discharge current through the 885 to a safe value. (All the voltages shown as supplied by batteries will normally be obtained from the rectifier through a voltage-divider circuit.)

The sweep frequency can be controlled by selection of the proper capacity at C and by adjustment of the pentode grid bias. Either the selection of a smaller capacitor at C, or a decrease of the negative pentode grid bias will increase the

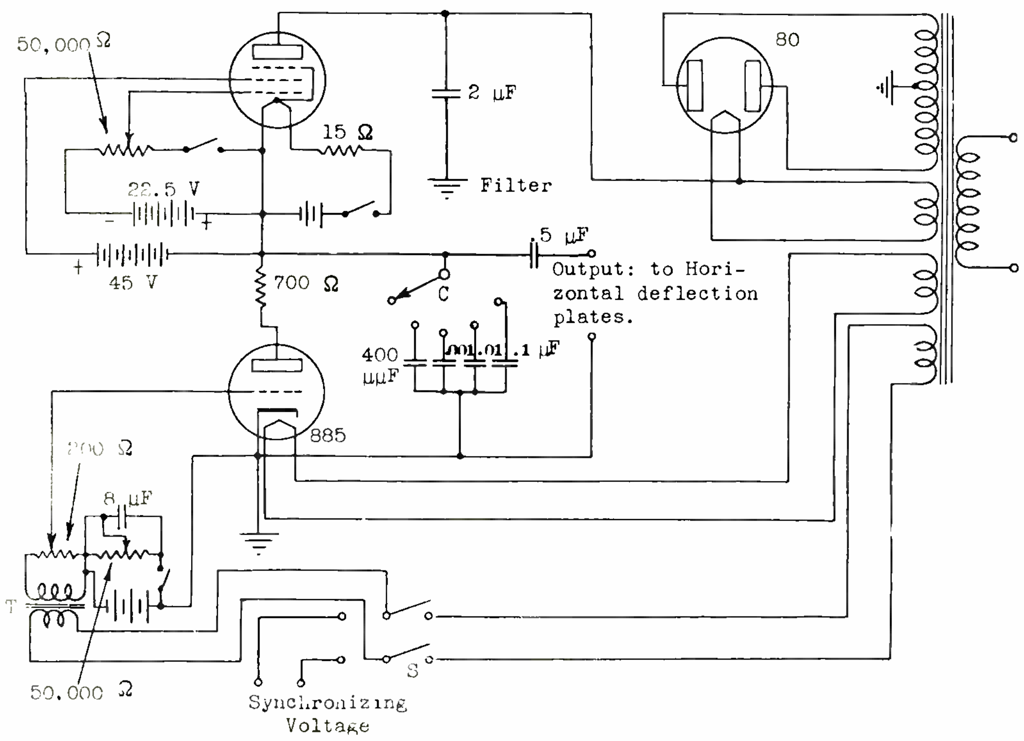


Fig. 18.—A complete sweep-circuit.

oscillator frequency, and vice versa. In the selection of capacitors for C it is always desirable to use as small capacitors as practical with the corresponding reduction in pentode plate current, as this will reduce the actual capacitor charge per cycle and hence the discharge current though the 885. However, if C is made too small, the operation will be unstable.

Unlike most vacuum-tube circuits, the relaxation oscillator employing a gaseous triode has a very definite and quite low high-frequency limit. As the frequency is increased C or R or both must be decreased. To obtain sufficiently high saw-tooth output voltage, C must be kept small compared with R. As the frequency is gradually increased and C is decreased in proportion, a point is approached where the charging current of C decreases to a magnitude comparable to that of the leakage currents in the tube and across C and as this point is approached the operation becomes unstable.

A second high-frequency limiting factor is the time required for deionization of the tube once the plate voltage has been reduced. Due to these factors the upper frequency limit for really satisfactory operation is in the order of 10,000 cycles although it is possible to operate at somewhat higher frequencies. For higher sweep frequencies a type of blocking oscillator employing a vacuum tube should be used.

SYNCHRONIZATION.—It is obvious that the oscillator frequency adjustments as explained above are far from precise. The capacities of the capacitors at C will vary somewhat with use; the pentode plate current will change with tube life, and even during periods of operation. Therefore, when investigating an alternating voltage for wave form, etc., it is necessary to exactly synchronize the sweep frequency with the voltage under test in order to hold the image stationary on the screen as shown in Figs. 9 to 12 inclusive. Even a slight difference in frequency will cause the image to drift across the screen, the velocity of drift depending upon the frequency difference.

Fig. 18 shows a method by which synchronization is accomplished. Suppose the voltage under test is at 60 cycles, obtained from the same power source that supplies the sweep-circuit plate voltage rectifier. Throw switch S to the right. This connects a 60-cycle voltage of 2.5 volts across the primary of the audio frequency transformer T. (Assume the relaxation oscillator has previously been adjusted to approximately 60 cycles so that a cycle of the voltage under test is drifting across the screen.) This 60-cycle signal is impressed across the 200 ohm potentiometer and hence in series with the 885 bias. As the charge on C approaches the critical value a positive alternation is applied in series with the 885 negative bias, decreasing the bias and causing ionization and capacitor discharge before the critical voltage of C is quite reached. C again starts to charge, approaches the critical value, and is again discharged at the instant the combined decrease in grid bias and increase in 885 plate potential are sufficient to start ionization. Thus, although the adjustment of the natural period of oscillation of the relaxation oscillator is only approximate, it is pulled into positive and exact synchronism by the action of the synchronizing voltage applied to the 885 grid.

If the voltage under test is not 60 cycles, taken from the power line, switch S is thrown to the left and a small portion of the voltage under test is applied to the terminals shown. Only a volt or so is necessary for this purpose. To obtain positive synchronism, the 885 grid bias and grid excitation are adjusted by means of the 50,000 ohm and 200 ohm potentiometers respectively.

Where it is desired to show two cycles on the screen, as in Fig. 10, the oscillator is adjusted, by means of C and the pentode grid bias, to a frequency of approximately one-half that of the voltage under test. The synchronizing circuit is then corrected by closing S and adjusted until positive synchronism is obtained. Due to the lower oscillator frequency the charge of C at the first synchronising positive cycle is not sufficient to break down the gaseous tube. By the time of the second positive synchronizing alternation, however, the charge in C has increased to the point where ionization can be started. Thus the oscillator will be locked into synchronism at one-half the synchronizing frequency and two cycles will remain stationary on the screen. Three or more cycles could be shown in a similar manner.

A complete cathode-ray tube circuit with its associated sweep circuit can be built up by combining the circuits of Fig. 16 and Fig. 18. The only additional apparatus necessary is a high-voltage rectifier for the cathode-ray tube. Since the load current from such a rectifier is so small, and the problem of filtering correspondingly simple, a half-wave rectifier is ordinarily used to supply the necessary d-c high voltage. In order that observation of voltages over a quite wide range of amplitude is possible, the oscilloscope unit usually includes amplifiers and controls for increasing and controlling the voltages applied to the horizontal and vertical deflection plates.

Two amplifiers ordinarily are used, one to amplify the horizontal sweep voltage for increasing the horizontal deflection range as shown in Fig. 22, and one to allow variable amplification of the voltage applied across the vertical deflection plates. The design of the vertical deflection amplifier may be quite simple or somewhat complex, depending upon the purpose for which the oscilloscope is to be used. In the ordinary commercial oscilloscope designed for general purpose use the vertical deflection amplifier is usually a simple resistance-coupled amplifier with a variable gain control. Ordinarily the input voltage to be inspected can be applied directly to the deflection plates or through either one or two stages of amplification. For inspection of sinusoidal voltages in the ordinary audio-frequency range or with *any* low-frequency voltages, the simple amplifier may be used satisfactorily.

However the simple resistance coupled amplifier, if designed to have good low and intermediate (audio) frequency gain characteristics, has very poor high-frequency characteristics, the gain falling off rapidly above about 20,000 cycles per second. This is not particularly important where a sinusoidal (single frequency) voltage is to be investigated. However, in some work and particularly in television, very peculiar voltage wave-forms must be investigated—square-topped, saw-tooth, sharply peaked, etc.—and some of those voltages are at fairly high fundamental frequencies. The principal difficulty here is that such waves are made up of a sinusoidal fundamental plus a great number of harmonic frequencies. For example, a circuit which will pass without distortion a 13,000-cycle saw-tooth voltage must also pass without noticeable attenuation all frequencies up to and beyond 200,000 cycles per second. For a narrow vertical sided flat-top voltage of the same frequency the necessary frequency band is even greater. The simple resistance-coupled amplifier is not capable of such wide range amplification.

Thus when using one standard commercial oscilloscope to examine the horizontal pedestal voltage of 15,750 cycles per second in a television circuit the wave-form as shown on the screen when applied directly to the vertical plates without amplification is as in Fig. 19.

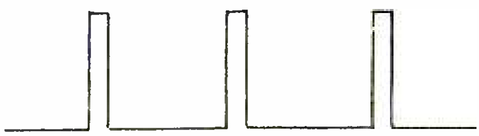


Fig. 19.—A square-top voltage.

After passing through the vertical deflection amplifier the wave-form is as shown in Fig. 20. It is obvious that the loss of high-frequency harmonic components in the amplifier tends to make the wave-form approach that of its sinusoidal fundamental.

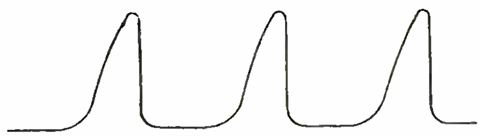


Fig. 20.—Result of passing a square-top voltage through a low-fidelity amplifier.

To view the video voltages in a television circuit even higher frequencies are necessary—in the order of several megacycles. Thus to be of any value in the investigation of television control voltages the vertical deflection amplifier in the oscilloscope must be properly compensated just as is a good video amplifier, or else the voltage to be investigated must be applied directly to the vertical deflection plates without amplification.

For television work the vertical deflection amplifier should by all means be of the high-fidelity wide-range compensated type because many voltages to be examined are of insufficient amplitude for satisfactory direct application to the deflection plates.

In order to properly interpret

the patterns obtained on an oscilloscope, the engineer must become thoroughly familiar with the peculiarities and weaknesses of his instrument as well as with its advantages.

USING THE OSCILLOSCOPE.—Fig. 21 shows a commercial type of oscilloscope (Allen B. Dumont Labs., Inc.) and Fig. 22 the manner in which the sweep voltage amplitude may be varied to permit examination of the wave-form of an applied voltage. In 22 (A) four cycles of the applied voltage are shown on the fluorescent screen. In this case the sweep frequency is one-fourth the frequency of the applied voltage. The amplitude of the sweep voltage is reduced so that the four cycles are condensed into about one-third the width of the screen. In 22 (B) nothing is changed except the amplitude of the sweep voltage (see horizontal gain control, second knob from the bottom on the right). With horizontal gain increased the sweep amplitude is greater and the four cycles now occupy the full width of the screen and the wave-form can be seen more clearly. In 22 (C) the horizontal gain is still further increased until the beam is thrown completely off the screen at each end and the applied voltage wave is expanded for critical examination of its shape.

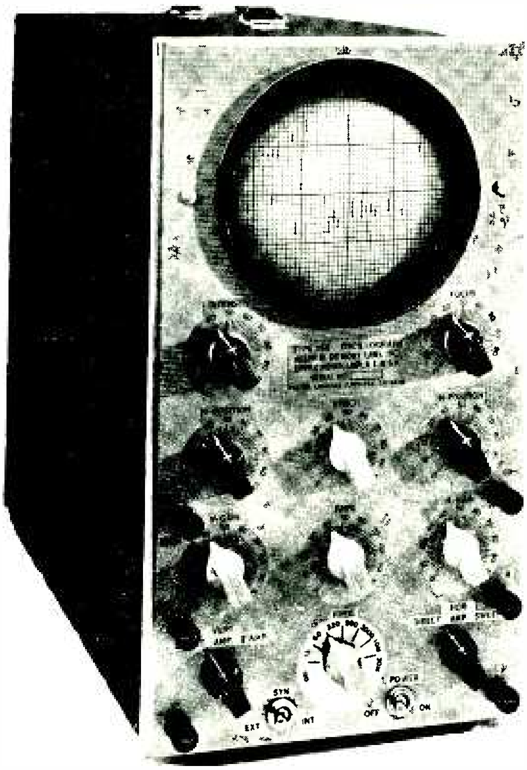


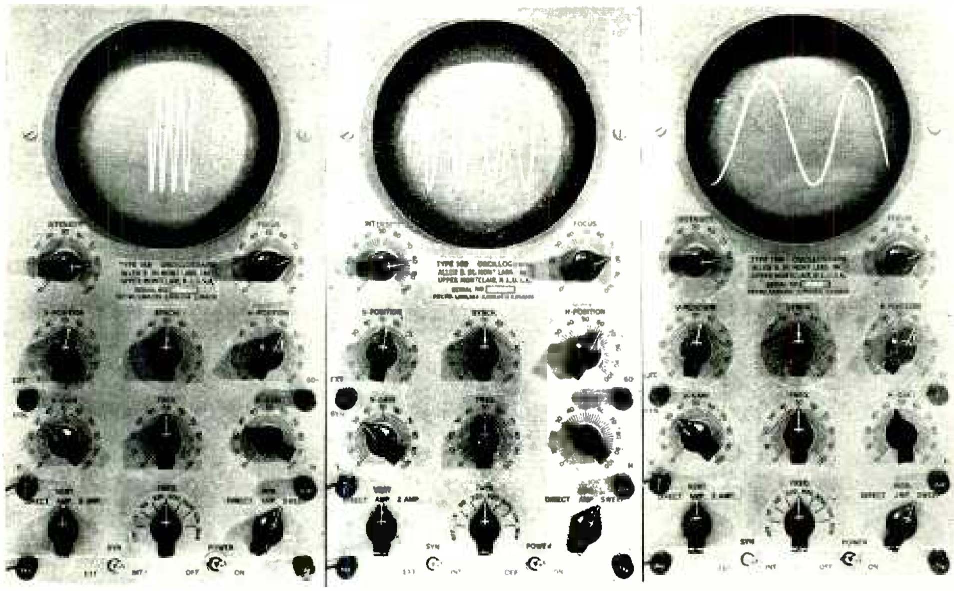
Fig. 21.—A Dumont type 208-B oscillograph.

It should be noted in the illustrations that after the sweep frequency was locked into step with the applied voltage by means of a synchronizing circuit so that the trace was stationary, and the amplitude of the applied voltage was adjusted so that optimum use was made of the horizontal screen dimension, the horizontal gain control of the sweep voltage amplitude allowed the wave to be compressed and expanded horizontally at will.

Fig. 22 clearly shows the various controls by means of which voltages over a large range of frequency and amplitude may be examined visually. The controls allow adjustment of the focus and intensity of the beam, horizontal and vertical centering of the image, the step and fine adjustment of the sweep frequency so that the latter may be locked into synchronism with the applied voltage, and controllable amplification of both vertical and horizontal voltages. The necessary apparatus, including the sweep frequency generator and amplifiers, is contained within the oscilloscope unit. The tube shown in Fig. 22 has a screen diameter of five inches. Fig. 23 shows the mounting of a cathode-ray tube in an R.C.A. oscillograph with the cover removed.

The vertical oscilloscope deflection voltage may be the modulated output of a radio transmitter, in which case the percentage of modulation and the form of the modulation envelope will be indicated. This is shown in Fig. 24.

The outline of the luminous tracing is the form of the audio frequency modulation envelope. The fine vertical lines are the tracings of the radio frequency. At high



(A) (B) (C)
Fig. 22.—Front view of a Dumont scope showing panel controls.

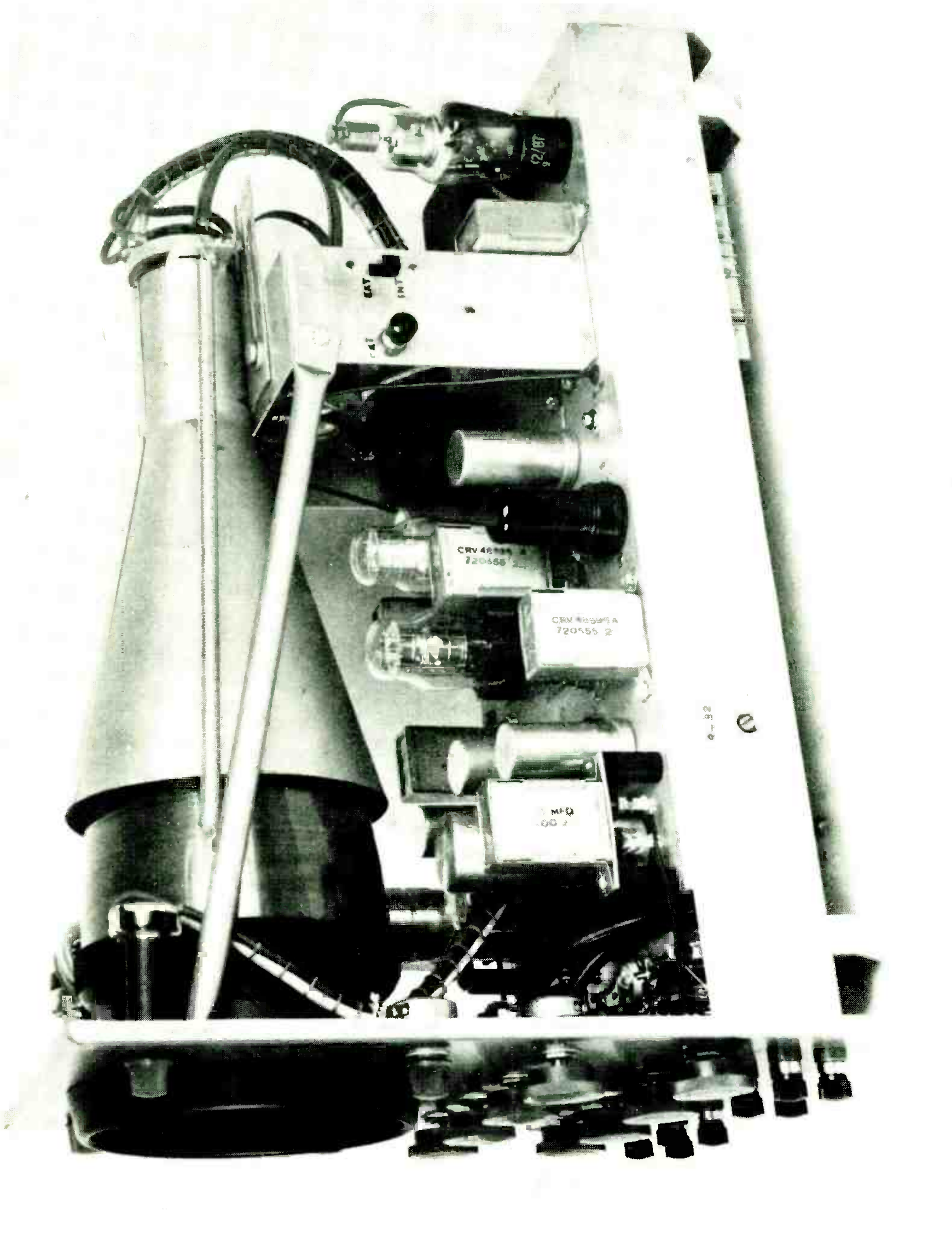


Fig. 23.—A modern R.C.A. Oscilloscope type WO-60C with cover removed.

radio frequencies the space within the envelope is simply a luminous glow. At lower frequencies the actual line structure may be seen. In all the illustrations of Fig. 24, two audio modulation cycles are shown, thus the frequency of the horizontal sweep voltage must be one-half that of the modulation frequency.

Fig. 24 (A) indicates a condition of under-modulation, the actual modulation percentage being about 30 per cent. No audio distortion is indicated. Fig. 24 (B) represents an ideal condition of practically 100 per cent modulation with no noticeable audio distortion. Fig. 24 (C) indicates a condition of over-modulation—that is, modulation in excess of 100 per cent—with consequent serious audio distortion.

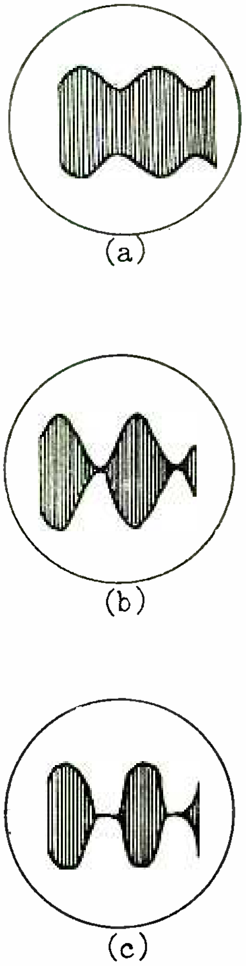


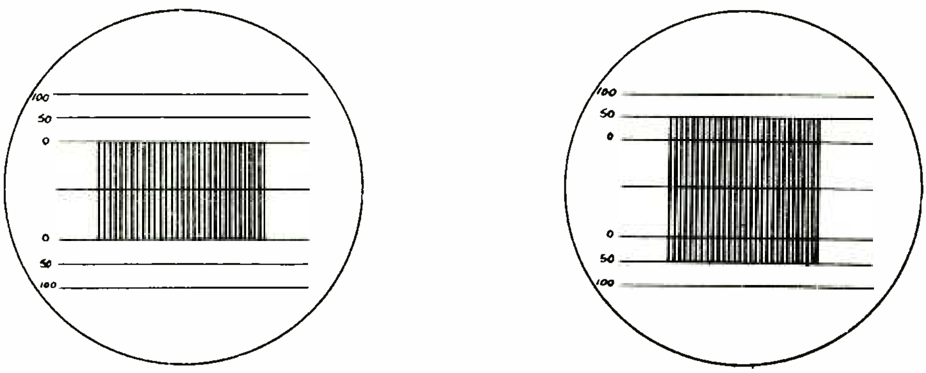
Fig. 24.—(A) Under-modulation. (B) 100% modulation. (C) Over-modulation

To obtain a pattern similar to those of Fig. 24 it is necessary that a single modulation frequency be used and that the sweep frequency be somewhere in the order of (but below) the modulation frequency. For example, to show two complete modulation cycles at 400 cycles/second, the sweep frequency would be 200 cycles/second. Ordinary speech and music is made up of a complex arrangement of frequencies, many of which are quite high. Thus, if the sweep frequency were made very low—say in the order of 30 or 40 cycles/second, the individual modulation cycles, except for an occasional low-frequency passage, would not be apparent. What would be shown however if the r-f carrier was modulated, would be the increased width of the vertical deflection with modulation.

Thus, if a portion of the unmodulated carrier voltage is applied across the vertical input terminals and the sweep voltage set at a low frequency, the r-f cycles will not be apparent and the image on the screen will consist simply of a rectangular fluorescent pattern which may be adjusted to convenient width and height. If modulation is then applied to the carrier, the vertical amplitude will increase above and below the central horizontal axis. At 100 per cent modulation the peak carrier voltage will be twice as great as that of the unmodulated carrier and the vertical dimension of the rectangular pattern on the fluorescent screen will be twice as great as for the unmodulated carrier.

Lines may be drawn in ink on the face of the tube to represent the unmodulated carrier voltage and the various degrees of modulation. it will then only be necessary for the operator to adjust the unmodulated carrier input so that the vertical dimension of the pattern exactly coincides with the upper and lower zero modulation lines. This automatically verifies the calibration and any degree of modulation can be read directly from the plotted calibration. This is shown in Fig. 25. (A) shows the width of the pattern for the unmodulated carrier. (B) shows the pattern for 50 per cent modulation. While this type of pattern does not indicate distortion it allows quick visual indication of the degree of modulation.

In some modern broadcasting transmitters a cathode-ray oscilloscope is built in as an integral part of the equipment, just as are voltmeters and ammeters, and so connected that the modulation characteristics of the output may be continuously observed. Since the indicators on meters have considerable inertia, and thus do not respond instantly and fully to peak signal levels, the almost inertialess cathode-ray oscilloscope offers the only accurate means of maintaining transmitter modulation very near the maximum allowable value without exceeding the permissible limits on the peaks. Under-modulation prevents full utilization of the transmitter radio-frequency carrier power; over-modulation broadens the tuning characteristic of the received signal, introduces serious audio distortion, and does not increase the volume of the received signal. Thus a cathode-ray oscilloscope is a very valuable piece of apparatus at a broadcast transmitting station.



(A) (B)

Fig. 25.—Another method of checking modulation.

TUNED CIRCUIT ADJUSTMENTS.—The

cathode-ray oscilloscope is particularly useful to the factory or radio service shop for adjusting the characteristics of intermediate-frequency coupling circuits, band-pass filters, etc. For this purpose some auxiliary apparatus is necessary. Suppose it is desired to adjust the tuning of a stage of i-f amplification in a superheterodyne receiver in which the intermediate frequency is 456 kc/s. If cathode-ray equipment is not available, this job will ordinarily be done by the use of a 456 kc signal output from a modulated oscillator, and an output meter, adjusting the i-f circuit tuning and coupling for maximum output. However, with modern high fidelity audio amplifiers, this simple procedure will usually result in excessive selectivity instead of the desired flat top bandwidth. By the use of a cathode-ray oscilloscope and auxiliary apparatus, the actual tuning characteristics may be visually observed.

A typical circuit of cathode ray equipment for such work is shown in Fig. 26. This circuit is the Triumph Model 77 Oscillograph-Wobbulator. The operation of this circuit, with the exception of the "Wobbulator" is similar to those previously described. A Type 913 cathode-ray tube (one-inch screen) is shown in the upper right corner. In the upper left corner is a twin triode 6A6 which provides amplification for both horizontal and vertical applied voltages if required. The 885 operates in a relaxation circuit as explained above.

The 6A7 tube operates in an r-f oscillator circuit the frequency of which is fixed at 840 kilocycles. This oscillator, in conjunction with the 6J5 immediately below, forms the "Wobbulator" or frequency modulator. The term "wobbulator" is used to describe a circuit in which the frequency is "wobbuled" from side to side. In this case the 840 kc frequency is wobbled or modulated over a total range of 30 kilocycles, that is, plus and minus 15 kilocycles, from 825 kc to 855 kc. This is done in a simple manner as follows: the grid and cathode of the 6J5 are connected directly across the oscillator tuned circuit, thus placing the 6J5 input capacity in parallel with the circuit tuning capacity. The 6J5 is then excited by an adjustable voltage from the sweep circuit oscillator. As the sweep voltage is applied to the grid of the 6J5 it varies the effective input capacity and thus the effective capacity of the tuned circuit so that the oscillator frequency is modulated as explained above.

The 6A7 is a mixer tube. The cathode and grids 1 and 2 form a triode oscillator. If 456 kc/s output is desired, the oscillator oscillating at 840 kc/s + and -15 kc/s and the output of an external signal generator at 840 + 456 or 840 - 456 kc/s are applied to grid 4. (This is shown on the right of the diagram as "R.F. In".) Thus in this case the external signal generator will be tuned to either 1,296 kc/s or 384 kc/s—probably the former. At the plate of the 6A7, and hence at the terminals "R.F. Out", will be the resulting 456 kc/s varied + and - 15 kc/s or from 441 kc/s to 471 kc/s.

This variable frequency, which ordinarily will also be amplitude modulated at an audio frequency in the external signal generator, is applied to the grid of the first detector or to the input of the i-f

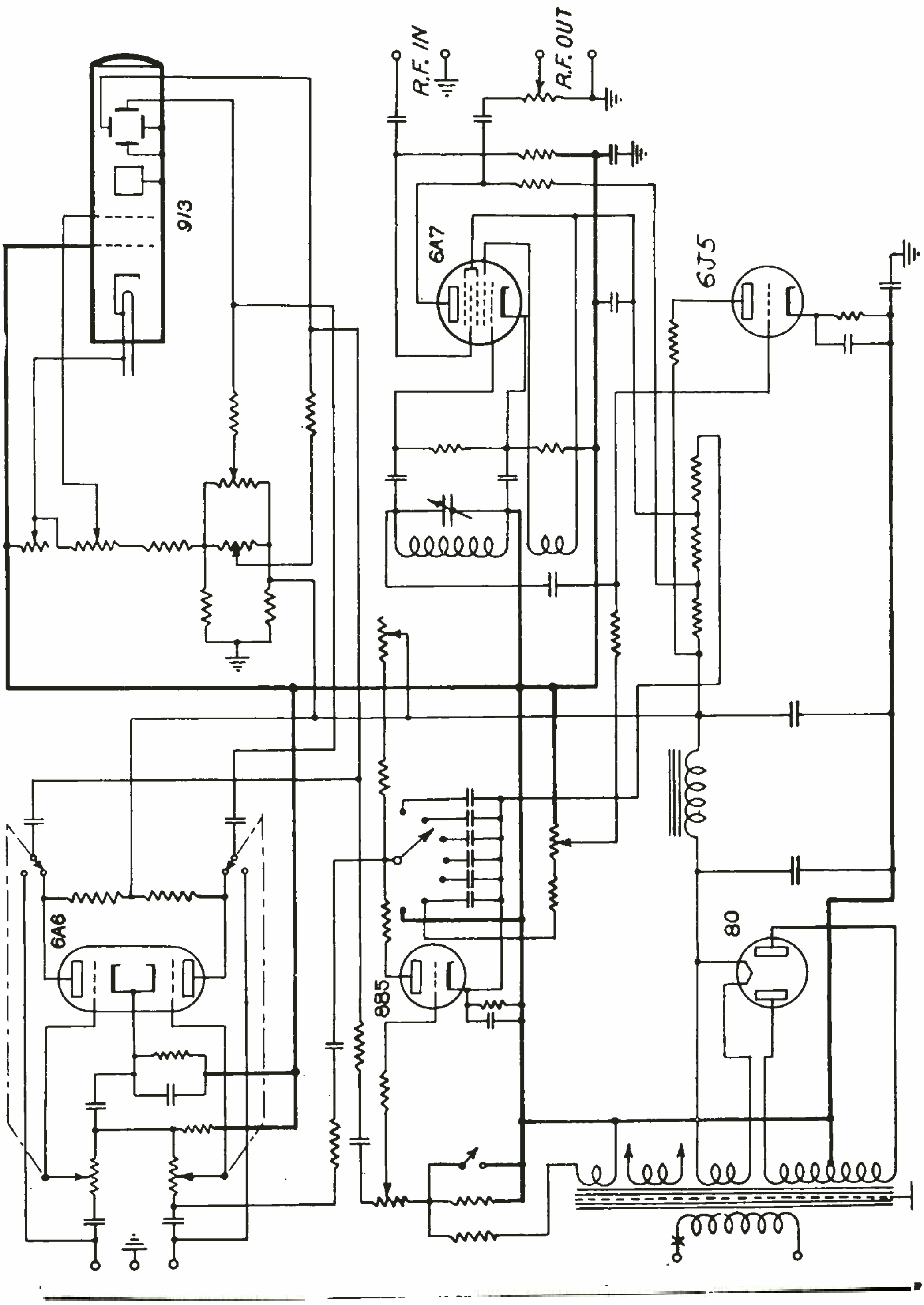


Fig. 26.—Circuit of a Triumph Model 77. Oscillograph-Wobbulator.

stage it is desired to tune. The audio output of the second detector will be connected across the vertical deflection input terminals. (See upper left corner of Fig. 26), amplified if necessary, and then impressed across the vertical deflection plates of the cathode-ray tube. The horizontal sweep (saw-tooth) voltage is being impressed across the horizontal plates of the cathode ray tube. (Sixty cycles will ordinarily be used for the sweep frequency in this case.)

As the beam moves horizontally across the fluorescent screen under the influence of the sweep voltage, *the frequency applied to the i-f amplifier is varying at the same rate.* As the variable frequency signal is applied to the i-f amplifier, the rectified audio output of the second detector reaches maximum as the frequency sweeps through circuit resonance (the frequency at which the i-f amplifier is peaked) the signal output decreasing on both sides of that point. The rectified output voltage of the second detector is applied across the vertical deflection plates and the polarity is made such that the beam deflects upward with increase of signal. This traces a line on the fluorescent screen as shown in Figs. 27, 28, 29, and 30. Fig. 27 represents a case where the i-f circuits are peaked at the proper frequency but with too loose coupling so that the higher frequency side-bands are lost.

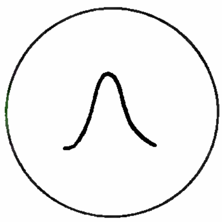


Fig. 27.—Loose i-f coupling.

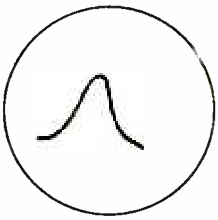


Fig. 28.—Loose i-f coupling and improper alignment.

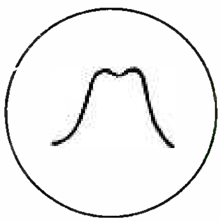


Fig. 29.—Correct i-f alignment.

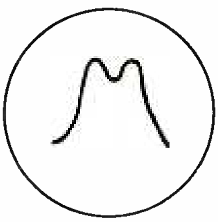


Fig. 30.—I-f overcoupled.

Fig. 28 illustrates similar loose coupling but the circuits tuned to other than the correct frequency as indicated by the trace being off center. Fig. 29 illustrates an excellent square-top bandpass adjustment. Fig. 30 illustrates much too tight circuit coupling which produces large peaks on each side of resonance and a decided dip at resonance.

With properly set up equipment in the laboratory or shop, alignment of i-f and r-f stages may be done accurately, with the effect of every receiver adjustment instantly made visual.

An outstanding advantage of electronic frequency modulation over mechanical systems which, by means of a motor driven capacitor, vary the frequency of the applied signal, is that in the electronic modulation of a fixed frequency, the desired frequency being produced by beating with an external frequency, the *frequency modulation in kilocycles is the same for all beat frequencies produced.* In the unit shown in Fig. 26, the adjustment is made for a total variation of 30 kilocycles and the output, whether at quite high r-f or low i-f, is modulated over a range of 30 kilocycles.

When a cathode-ray oscillograph and supplementary equipment is so set up in a laboratory or shop that it is convenient to use, and when the engineer has had sufficient practice so that he can quickly connect up and adjust the necessary circuits and interpret the traces on the fluorescent screen, many uses will be found for this apparatus.

THE CATHODE-RAY TUBE
and
ITS APPLICATION TO RADIO

EXAMINATION

1. Explain briefly the theory of the cathode-ray tube. State some of its practical applications.

2. Describe the construction of a typical cathode-ray tube designed for electrostatic deflection.

3. (A) How does a variation in control-grid voltage affect the spot?

(B) How does a variation in anode voltages affect the spot?

4. Explain how electrostatic deflection is accomplished. In what plane are the vertical deflection plates mounted? Why?

5. How is electromagnetic deflection accomplished? What is the plane of movement of the ray under the influence of coils mounted in the horizontal plane? Why?

6. Explain the use of a cathode-ray tube designed for electrostatic deflection as a voltmeter. What voltage does the total length of the luminous line indicate?

7. What is meant by the "deflection sensitivity" of a cathode ray tube? How does this sensitivity vary with second-anode potential? Why?

8. You are using an RCA type 905A tube with second-anode potential of 1,750 volts. What RMS voltage must be applied to plates $D_1 - D_2$ to deflect the spot a total distance of 2 inches on the screen?

9. What is a sweep circuit as applied to the cathode-ray tube? What is the form of the sweep voltage? Explain briefly how such a voltage is developed. Why is a sweep voltage necessary?

10. Explain how the cathode-ray tube is used to align the i-f amplifier of a superheterodyne receiver. What auxiliary apparatus is required in addition to the oscilloscope power and sweep circuits?