THE CATHODE-RAY OSCILLOSCOPE AND ITS USE IN COMMUNICATIONS

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STUDY SCHEDULE NO. 39

For each study step, read the assigned pages first at your usual speed. Reread slowly one or more times. Finish with one quick reading to fix the important facts firmly in your mind. Study each other step in this same way.

☐ 1. The Cathode-Ray Tube .... Pages 1-7

The cathode-ray tube, which provides a visual indication that is useful in adjusting, operating, and maintaining radio communication equipment, is studied.

☐ 2. The Complete C.R.O. .... Pages 7-15

How sweep circuits, amplifiers, and power supplies are used with a c.r.t. to form the very useful and versatile cathode-ray oscilloscope.

☐ 3. Typical Commercial C.R.O.'s .... Pages 16-24

Here we study in detail the operation and construction of the RCA 155 and the Du Mont 208B c.r.o.'s because they are typical commercial 'scopes.

☐ 4. Using a C.R.O. in Communications .... Pages 24-36

How a c.r.o. is used to determine frequencies, phase shifts, defects, and maladjustments in transmitters, modulation characteristics, neutralization, antenna phasing, distortion, and frequency response of radio transmitters.

☐ 5. Answer Lesson Questions.

☐ 6. Start Studying the Next Lesson.

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THE CATHODE-RAY OSCILLOSCOPE AND ITS USE IN COMMUNICATIONS

Cathode-Ray Tubes

OFTEN, in previous Lessons, we have found it very helpful to use graphs that show how the current or voltage in a circuit varies with time. The graphical form is frequently the best way of presenting such information, and sometimes it is the only way that makes the information readily usable. Yet, for all their usefulness, graphs have one serious drawback: they must be produced by the slow and tedious process of plotting individual points that are found by making measurements or by making mathematical calculations.

Obviously, it would be desirable to have some means of producing a graph that would not require so much work—say a meter that would produce a continuous trace of its readings on a moving sheet of paper. Assuming that the paper moved at a regular, known rate, such a trace would give us a graph of current or voltage against time. Instruments of this sort have, in fact, been invented, and are very useful for the work they can handle. However, because of mechanical limitations, they can follow variations up to only about 100 c.p.s. This limited frequency response makes them unsatisfactory for communications work.

A kind of electronic meter that has no moving parts, and is therefore not subject to mechanical limitations, can be used at frequencies up to several megacycles per second. This device is called a cathode-ray oscilloscope*, or simply 'scope (commonly abbreviated c.r.o.). In this instrument, an electron beam draws the graph on the screen of a cathode-ray tube. Associated "sweep" circuits cause the graph to be repeated over and over at a high rate of speed, so that, although the graph is actually an instantaneous, non-permanent record of the variations in current or voltage, it appears to be a stationary picture.

The use of the cathode-ray oscilloscope is not limited to speech communications. The principles laid down in this Lesson are used in television, radar, loran, and in laboratory and industrial applications of cathode-ray tubes. In this Lesson, however, we are going to restrict our discussion to the use of the cathode-ray oscilloscope in transmitting equipment, including the investigation of the performance of the components in the transmitter from the studio to the antenna.

Since the cathode-ray tube is the most important item in the c.r.o., let us start with a description of this tube.

BASIC OPERATION OF A C.R.T.

Long before cathode-ray tubes were used, it was discovered that certain chemicals give off light when bombarded with electrons. This is known as

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*A recording meter is called an *oscillograph* and its permanent record an *oscillogram*. A cathode-ray tube device that pictures variations but does not make a permanent record is generally (but not always) called an *oscilloscope*. "Oscillo" in electrical work pertains to oscillations, "scope" is from the Greek "to see," and "graph" is from the Greek "to write." Thus, an oscilloscope is a device "to see oscillations," and an oscillograph is a device used "to write (draw) oscillations."

fluorescence. Some chemicals continue to glow for a short time after the electron bombardment ceases, a phenomenon that is called *persistence.* A material that gives off light for a long time after it has been excited is called a long-persistence material; one that glows for a short time has a short persistence.

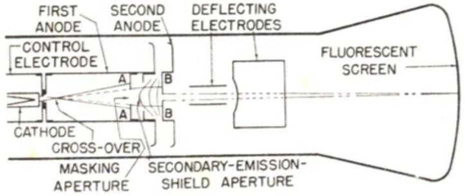


FIG. 1. A conventional cathode-ray tube electron gun, in which the first anode operates at a positive potential, and contains a masking aperture that is shown at AA.

Suppose, now, that we coat a transparent screen with one of these chemicals and allow a thin beam of electrons to strike it. A dot of light about the size of the beam will be produced on the screen at the point of impact. Now, suppose we are able to direct the beam of electrons in such a manner that it moves vertically in response to an applied voltage and horizontally at a regular rate. If we start the dot of light on the left side of our screen, it will then produce a trace on the screen whose height at any instant represents the amplitude of the applied voltage at that instant—in other words, a graph of voltage against time. If the dot moves across the screen quickly and the screen has sufficient persistence, the screen material will glow from the bombardment long enough for the complete trace to be visible.

It is necessary to have three main parts in a cathode-ray tube for it to perform these actions. These are: (1) a beam-producing device, called the electron gun; (2) a system that can deflect the beam; and (3) a fluorescent screen.

THE ELECTRON GUN

The functions of the electron gun are to provide a source of electrons, accelerate the electrons to a high speed, focus the electrons into a very fine jet, and control the number of electrons in the beam. (This last determines the intensity of light given off by the screen material.) Fig. 1 shows a cross-sectional view of a complete c.r.t. with the parts labeled. The following description refers to this figure.

The indirectly heated cathode provides the electrons. The emitting surface, which is made of material very much like the cathode material of an ordinary tube, is made very small in order to concentrate the source of the electrons.

Around the cathode is a can-like control electrode with a small hole in the bottom. This element is called "grid 1" or "the control grid" and is usually designated g_1. Its function is to control the quantity of electrons from the cathode and thereby control the intensity of the light spot produced on the screen. Its action is exactly like that of the control grid in any vacuum tube. Because of its construction, the control grid also provides a primary focus on the electrons from the cathode. As in other vacuum tubes, the potential of the control grid is negative with respect to the cathode.

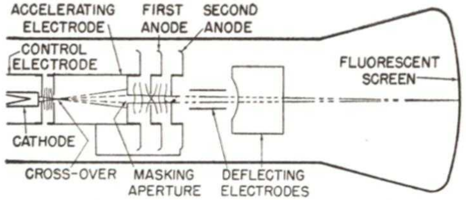


FIG. 2. Gun design based on zero first-anode current, in which the accelerating electrode has been lengthened to carry a masking aperture and the first anode shortened to a disc that is used for focusing.

Next is the first anode (commonly designated A_1), which consists of a cylinder with two baffles in it. There is a small hole in the center of each baffle. The potential of the first anode is made highly positive with respect to the cathode to attract the electrons and get them moving at a very high rate of speed. The baffles or masking apertures restrict the path of electrons into a narrow, nearly parallel path. This anode is called the focusing anode for reasons we shall learn in a moment.

The beam of electrons streaming out from anode 1 is fairly broad and would cause a very large spot on the screen. It is, therefore, necessary to introduce a focusing system to make the spot at the screen as small as possible. This is done by inserting a second anode that is more positive in potential than the first anode. The electrostatic field set up between the first and second anodes produces curved electric lines of force that focus the electron beam in much the same way that a glass lens focuses light rays. The curvature of the lines of force can be varied at will to provide a control on the focus by changing the potential difference between the two anodes. This is analogous to moving a glass lens back and forth to focus a light beam. Theoretically anode 2 is the focusing anode, but, because anode 2 is kept at a fixed potential in the usual c.r.t. power supply, focusing is accomplished in practice by varying the potential on anode 1. Hence, anode 1 is called the focusing electrode.

Variations of the arrangement described above exist in tubes made by other manufacturers. One variation shown in Fig. 2 has a second grid, between the control grid and the first anode, that is connected to anode 2. This version is called the "zero-current 1st anode" type. Notice that in the tube shown in Fig. 1 electrons strike the masking plate A attached to anode 1; therefore, current flows to this anode. However, in the tube in Fig. 2 the electrons do not strike the first anode, so no current flows to it. As we will see later, this simplifies the design of the power supply for the tube.

Focusing. The method of electron beam focusing that we have just studied is known as *electrostatic* focusing. Another type is *magnetic* focusing; this is used in radar and television tubes, where images with considerable detail are necessary, because it is capable of focusing the electron beam to a very fine point. The electron beam is produced by an electron gun consisting simply of a cathode, control electrode, and accelerating anode. As shown in Fig. 3, a solenoid is placed around the neck of the tube parallel to the electron beam at a point beyond the electron gun. Because of the interaction of the magnetic field of this solenoid with that of the electron beam, electrons that leave the gun in any direction other than straight ahead are spiraled into the center line and hence into focus.

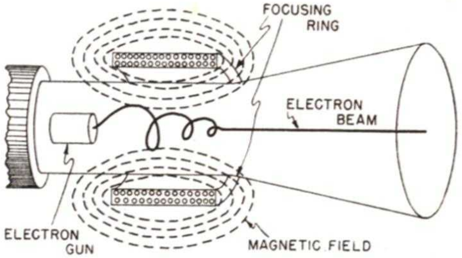


FIG. 3. Magnetically focused cr tube.

DEFLECTION SYSTEMS

Now that we have produced a thin beam of electrons, we need some way of deflecting it so that it will travel over the face of the screen. There are two main systems used to produce deflections — electrostatic and electromagnetic.

Electrostatic Deflection. Since electrons are attracted by positive charges and repelled by negative charges, we can deflect the beam of electrons by passing it between a pair of plates, as shown in Fig. 4, and applying a voltage to the plates, making one positive and the other negative. The beam will deflect toward the positive plate. This is called *electrostatic* deflection.

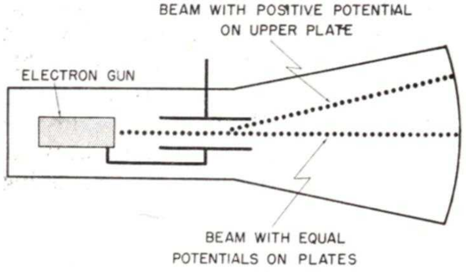


FIG. 4. How deflection plates deflect the beam.

If two sets of plates are used, one set at right angles to the other, the spot can be moved both up and down and right and left on the screen.

It is common practice to operate the deflection plates at or near the d.c. potential of the second anode. Note in Figs. 1 and 2 that one set of deflecting electrodes is close to the second anode. If there were a large potential difference between these deflecting electrodes and the second anode (A_2), the electrostatic field between them would *defocus* the electron beam in much the same manner that the electrostatic field between the first and second anode focuses the beam. For this reason, one plate of each pair of deflecting plates is frequently connected directly to the second anode. Because the deflecting voltage is usually referred to ground, it is convenient to ground the second anode and the two plates connected to it. This means the cathode must be at a high negative potential for the proper potential difference to exist between the cathode and the second anode.

In some tubes, leads are brought out from all four deflection plates, and the common connection between two of these plates, when used, is made externally. In other tubes this connection is in the tube itself.

When two sets of plates are used, one for vertical deflection and the other for horizontal deflection, the pair closer to the second anode (farther from the screen) produces a greater deflection of the electron beam than does the other pair for the same amount of applied voltage. A given voltage applied to either set of plates produces the same angular deflection of the beam from the center line: however, an angular deflection produced at the first pair causes a greater movement of the spot on the screen than does the same angular deflection produced at the second pair, because the distance between the first pair and the screen is greater. As a result, a greater voltage must be applied to the second pair of plates to produce the same deflection. For this reason, the deflecting plates nearer the screen are used for horizontal deflection, since the horizontal sweep voltage is usually generated in the oscilloscope and can readily be made as large as desired.

TYPE	DEFLECTION	FOCUS	FILAMENT VOLTS	FILAMENT AMPS	ANODE #2	ANODE #1	BOOSTER ANODE #3	DEFLECTION SENSITIVITY VERT.	DEFLECTION SENSITIVITY HOR.
2BP1	ES	ES	6.3	0.6	2000	450	—	175	270
3BP1-A	ES	ES	6.3	0.6	2000	575	—	148	200
3KP1	ES	ES	6.3	0.6	2000	450	—	90	120
5BP1-A	ES	ES	6.3	0.6	2000	450	—	76	84
5CP1-A	ES	ES	6.3	0.6	2000	575	4000	79	92
5FP4-A	EM	EM	6.3	0.6	6000	250	—	—	—
7CP1	EM	ES	6.3	0.6	2400	300	8000	—	—
7CP4	EM	ES	6.3	0.6	2400	300	8000	—	—
7DP4	EM	ES	6.3	0.6	1430	250	6000	—	—
7GP4	ES	ES	6.3	0.6	2000	600	—	120	140
9AP4	EM	ES	2.5	2.1	1425	250	7000	—	—
10BP4	EM	EM	6.3	0.6	9000	250	—	—	—
12AP4	EM	ES	2.5	2.1	1460	250	7000	—	—

FIG. 5. Important characteristics of typical cathode-ray tubes. All electrostatic deflection tubes shown here are zero-current first anode types. The electrostatic (ES) deflection sensitivity is given in volts per inch; the deflection sensitivity of electromagnetic (EM) deflection types depends on the structure of the deflecting coils and is, therefore, not given.

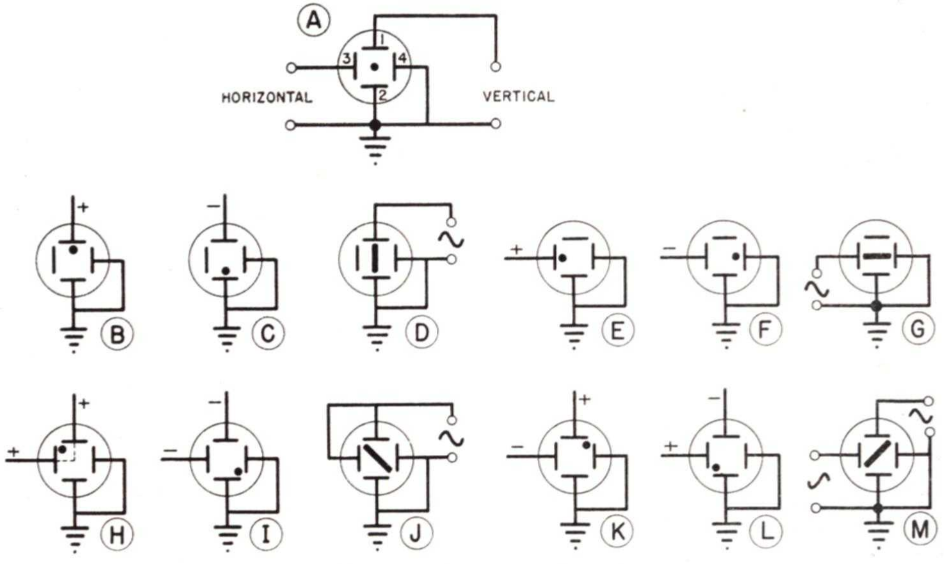


FIG. 6. How the spot is deflected.

As shown in Fig. 5, which is a table of characteristics of typical cathode-ray tubes, deflection sensitivities for both vertical and horizontal plates are generally given in terms of the number of volts necessary to produce a one-inch deflection on the c.r.t. screen.

Fig. 6 illustrates the effect on the spot of light of different voltages on the deflecting plates. Because of the opaqueness of the screen, you can't actually see the deflecting plates when you look at the screen of a cathode-ray tube; they are shown here merely to illustrate their action. Notice that the plates are named for the deflection that they cause, not their physical position.

In Fig. 6A, there is no voltage on the plates; the spot is centered on the screen. Now let's see what happens when we apply various voltages to the free deflecting plates, 1 and 3. (Plates 2 and 4 are grounded; in what follows, when we say a positive or negative voltage is applied to plate 1 or plate 3, we mean with respect to ground.)

In B, a positive voltage is applied to 1. The spot moves upward. (The electron beam, being negative, is attracted towards the positive plate.) In C, plate 1 is made negative; this sends the spot downward. The amount of deflection in either case is directly proportional to the applied voltage on the plate.

If we apply an *alternating* voltage to 1, the spot will move up and down (6D). If the spot moves faster than about 16 times each second, we see a solid vertical line on the screen instead of a moving spot.

Similarly, E, F, and G show what happens to the spot when a positive, negative, or alternating voltage is applied to plate 3.

The results of applying voltages of the same polarity simultaneously to the vertical and horizontal plates are shown in H and I. If equal a.c. in-phase voltages are applied to the plates (assuming equal deflection sensitivity for the two sets of plates) a solid line tilted at 45° (J) is formed. The direction of the tilt can be changed by applying *out of phase* voltages to the two sets of plates. This is illustrated in K, L, and M: K and L show what happens when voltages of opposite polarity are applied, and M shows the result of applying a.c. voltages that are 180° out of phase. Any degree of tilt can be obtained by varying the relative phases of the voltages on the plates.

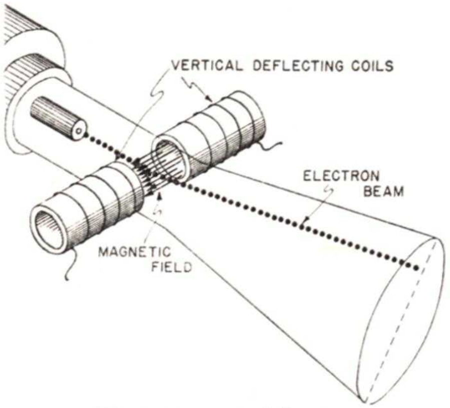


FIG. 7. Magnetic deflection.

Electromagnetic Deflection. Another type of deflection system widely used in television is the electromagnetic system, generally called simply *magnetic*. One pair of coils placed, as shown in Fig. 7, alongside the neck of the tube between the electron gun and screen will cause vertical deflection of the electron beam. For horizontal deflection, another set of two coils at right angles to the set shown is required.

The deflection sensitivity of these cathode-ray tubes is generally not given in tables of characteristics. The deflection depends on the strength of the deflecting magnetic field, which depends not only on the current through the deflecting coils but also on the structure and placement of these coils. Since these factors are variable, deflecting coils should be designed for a specific tube and application.

Some tubes are made with one set of electrostatic deflection plates and one set of magnetic deflection coils, in order to eliminate the interaction that is bound to exist in dual sets of electromagnetic coils.

Booster Anodes. The deflection sensitivity of a tube depends on the velocity of the electron stream passing through the deflecting system; the greater the velocity, the greater the voltages or magnetic field intensities that are required to deflect the beam a given amount. To offset this, the velocity of the electron beam in some cathode-ray tubes is kept low in the deflection zone by applying relatively low voltages to the second grid and the first and second anodes. Additional acceleration of the electron beam to produce a bright spot is produced by a *booster anode* connected between the deflecting system and the screen.

The booster anode (commonly designated A_3) consists of a single conducting ring or series of conducting rings deposited on the inside of the glass near the edge of the screen. Suitable high positive potentials are applied to these anodes to increase the velocity of the deflected beam.

C.R.T. SCREENS

About seventeen different materials, called phosphors, have been used for screens of c.r. tubes. Each material, or in some instances combinations of material, produces a certain desired effect. Of these seventeen, however, only two are commonly used in communications. A P1 screen gives off a greenish trace and has a medium persistence, that is, the brilliance drops to practically zero in 1/100 second. This type of screen is widely used for direct visual observation of wave forms where a green image can be used. A P4 screen gives a blue-white trace of medium persistence, and is used extensively in television and in work where long periods of observation are required. Other phosphors have been developed for special purposes; for example, P5 and P11 screens produce a short-persistence blue image suitable for use when the c.r.t. image is to be photographed. These screens are generally not used for direct visual observation.

Many cathode-ray tubes are available in several different screens.

C.R.T. Classification. Some c.r.t.'s are classified by numbers, such as 906, 913, etc. However, a new system in which the first number in a c.r.t. type designation indicates the screen diameter in inches and the last part indicates the type of screen used is now generally employed. Thus a 5CP4 is a 5-inch cathode-ray tube with a P4 screen; likewise, a 2BP1 is a 2-inch tube with a P1 screen.

The Complete C.R.O.

Now that we have studied the cathode-ray tube, let us consider the equipment used with it to form a complete cathode-ray oscilloscope.

A simplified block diagram of a c.r.o. is given in Fig. 8. Notice that it includes the c.r.o., a high-voltage supply, a horizontal sweep generator, horizontal and vertical amplifiers, and a low-voltage power supply.

The input signal is applied through the vertical amplifier to the vertical deflecting plates. The horizontal sweep voltage can be taken either from an external source or from the horizontal sweep generator through switch S_1. It is then amplified and applied to the horizontal deflecting plates. Both the horizontal and vertical amplifiers are generally wide-band amplifiers.

The horizontal sweep generator is used to provide a stationary pattern on the c.r.t. screen and to provide a linear time base.

Voltage for the horizontal sweep generator and for the horizontal and vertical amplifiers is supplied by a conventional power supply. The power supply for the c.r.t., however, is a high-voltage low-current source that differs from the usual power supply.

C.R.T. POWER SUPPLIES

All c.r. tubes require considerable d.c. voltage for proper operation. Very

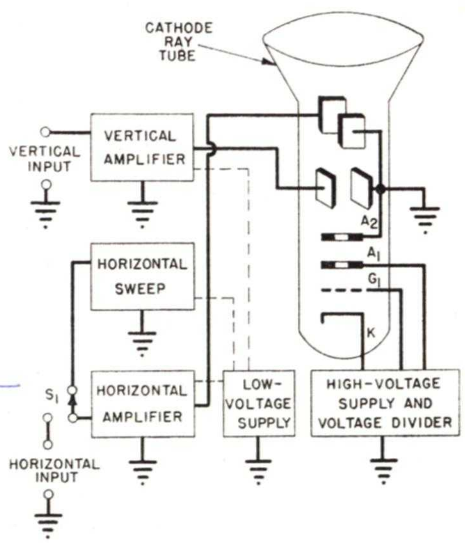


FIG. 8. Block diagram of a complete cathode-ray oscilloscope.

little d.c. current is necessary, however, a fact that simplifies the power supply design.

The power supply and voltage divider for a 908-A cathode-ray tube are shown in Fig. 9. Let's see how they work.

Since the current flow in the cathode-ray tube is small, generally less than one milliampere, the filtering action of C_1 alone is sufficient in this power supply.

R_1, R_2, R_3, R_4, R_5, and R_6 serve both as a power supply bleeder and as a voltage divider for the electrodes of the c.r.t. The common point between R_1 and R_2 is grounded; the voltage across R_1 is positive with respect to ground, that across R_2 (and also those across R_3, R_4, R_5, and R_6) is negative with respect to ground.

Potentiometers R_7 and R_8 connected across R_1 and R_2 are used for positioning the electron beam. For example, the d.c. voltage on D_3 can be made either positive or negative with respect to D_4 (the other vertical deflecting plate) by moving the contact arm on R_7; this controls the vertical position of the spot. Any a.c. voltage applied to the **VERTICAL INPUT** terminals will be superimposed on the d.c. positioning voltage through C_4 and R_9 and will move the spot vertically. Similarly, R_8, C_3, and R_{10} are used to apply a positioning voltage and an a.c. signal to D_1 and D_2, the horizontal deflecting plates.

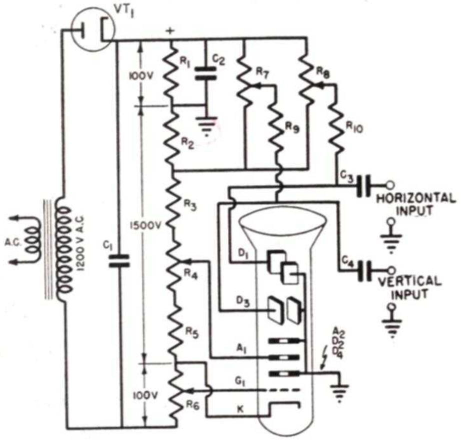


FIG. 9. The power supply and voltage divider for a 908A cathode-ray tube. One plate of each of the two pairs of deflecting plates is connected to the second anode in this c.r.t.

Potentiometer R_4 is the **FOCUS** control; it is used to control the voltage on anode 1 (A_1). Potentiometer R_6 is the **INTENSITY** control; it is used to provide a negative voltage on the first grid (G_1) with respect to cathode.

Interaction between the focus and the intensity controls is minimized by designing the voltage divider so that the current through it is much larger than the variation in the tube current. This means that the high-voltage source for a conventional oscilloscope must supply more current to the voltage divider than is necessary for the cathode-ray tube itself.

Fig. 10 shows a power supply circuit for a 5BP1-A c.r.t. Notice that all four of the deflecting plates are free and that dual ganged potentiometers (R_7, R_8 and R_9, R_{10}) are used for centering (positioning). To see how they work, suppose the contact arms on R_7 and R_8 are moved up. The voltage on D_4 will go positive with respect to ground and that on D_3 will go negative the same amount. Thus the potential difference between the two deflecting plates (which causes beam deflection) will be twice the voltage from either deflecting plate to ground. Since the latter voltage is the one that may cause defocusing, this method provides a maximum amount of beam deflection for a minimum amount of defocusing of the beam.

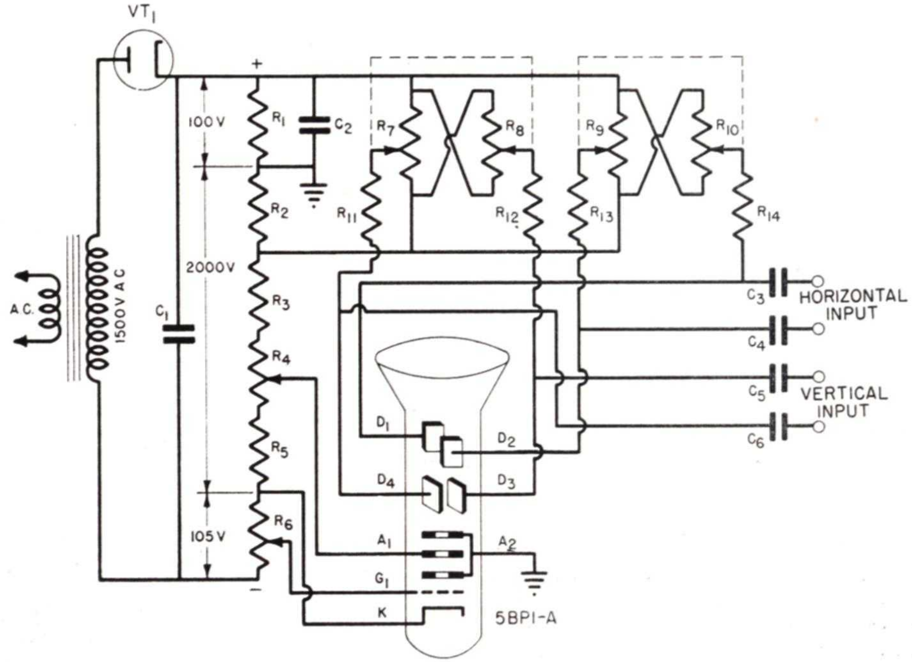


FIG. 10. A typical power supply and voltage divider for a 5BP1-A c.r.t. In this tube all four deflecting plates are free. This permits a balanced deflecting system. Note how dual potentiometers are used for positioning the spot without defocusing the beam.

The booster anode of a c.r.t. is generally operated at a positive voltage with respect to ground. In some c.r.o.'s this voltage is the low voltage d.c. used for the amplifiers and sweep circuits. In other cases, as illustrated in Fig. 11, a separate rectifier, VT_1, is used to obtain this positive voltage.

Although power transformers for c.r.t.'s need to supply only a few milliamperes, they are generally physically large because of the high-voltage insulation required.

LINEAR SWEEP GENERATORS

Now let's see what we must do to produce the image of an a.c. wave on the screen of the c.r.t.

Suppose we want to visualize a pure sine-wave signal like that generated by an audio oscillator. You know from what we said earlier that such signals, when applied to the vertical deflecting plates of the c.r.t., produce a vertical line. The spot in this case is actually moving in a sine wave fashion, but, because it is able to move up and down only, we can see nothing but the line that represents the distance between

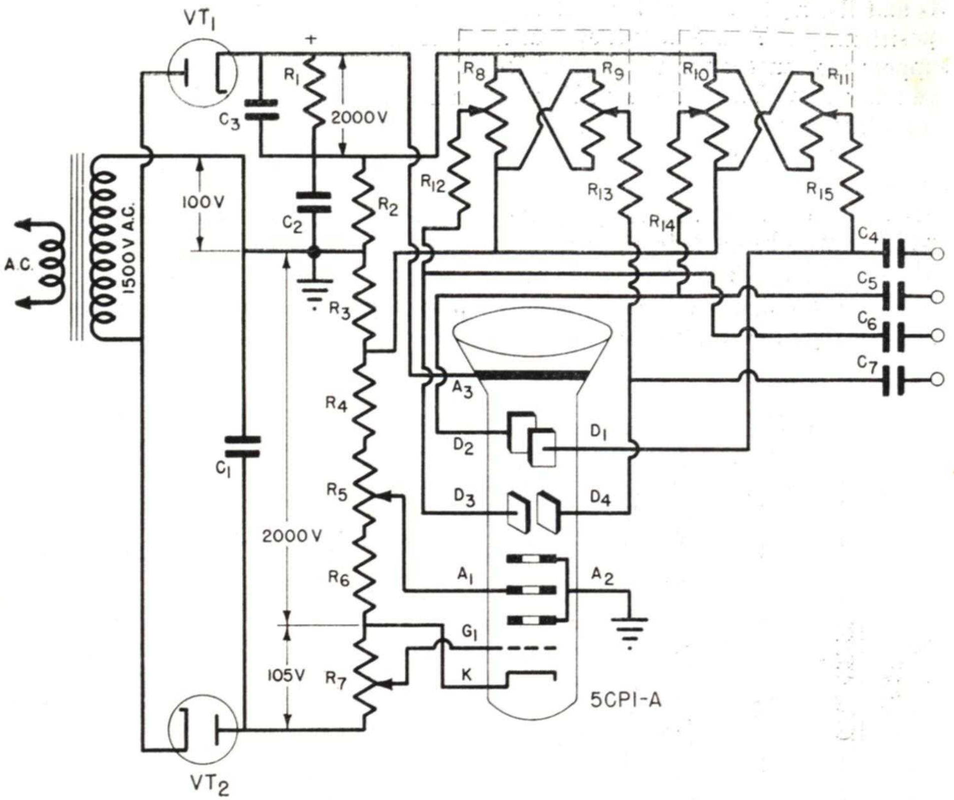


FIG. 11. A power supply and voltage divider for a 5CP1-A c.r.t. This has a booster anode (A_3) which operates from a separate positive power supply, VT_1 and C_3.

the positive and negative peaks of the voltage. To produce the familiar sine wave, we must find some way to move the spot at a regular rate from left to right at the same time that it is moving up and down.

We could do so by applying a steadily increasing voltage to the horizontal deflecting plates while the sine-wave voltage is applied to the vertical plates. However, if we were to do so, the image would quickly pass across the screen—whereas what we want is an image that will stay fixed in position as long as we want it to.

Since we want to examine a pure sine wave, each cycle of which is the same as the one before it and the one after it, all we need to reproduce on the c.r.t. screen is one cycle of the wave. We can do so by applying a voltage of the proper characteristics to the horizontal plates. This voltage must start at some initial value that will place the spot at the desired position at the left of the screen, increase steadily in value until one cycle of the sine wave has been traced out, then return at once to the initial value and repeat the process over and over. The effect of this will be to make the trace of the sine-wave signals appear to stand still, for it will be retraced over and over again.

Such a voltage is shown in Fig. 12A. As you can see, it increases linearly from point 1 to point 7, then decreases at once to its original value, then starts another cycle.

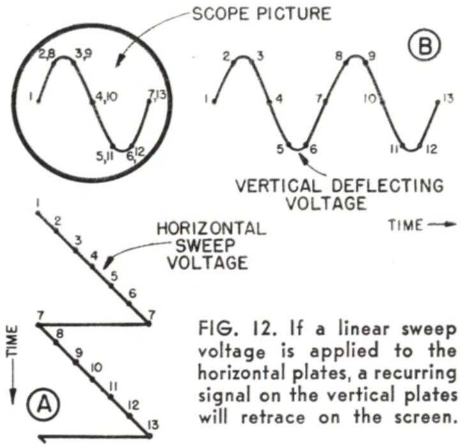


FIG. 12. If a linear sweep voltage is applied to the horizontal plates, a recurring signal on the vertical plates will retrace on the screen.

Fig. 12B shows what happens when this voltage (often called a "saw-tooth" wave because of its shape) is applied to the horizontal plates of the c.r.t. at the same time the sine-wave voltage is applied to the vertical plates. The curve in the circle marked "SCOPE PICTURE" is numbered to correspond to equal time intervals of both the horizontal and the vertical voltage. As you can see, the spot is moved horizontally across the screen from left to right until one cycle of the sine wave has been traced; then it returns at once to the left side of the screen and repeats the process. If the cycle is repeated oftener than 16 times per second, screen persistence and the phenomenon known as persistence of vision will make the trace appear to be a solid, stationary line.

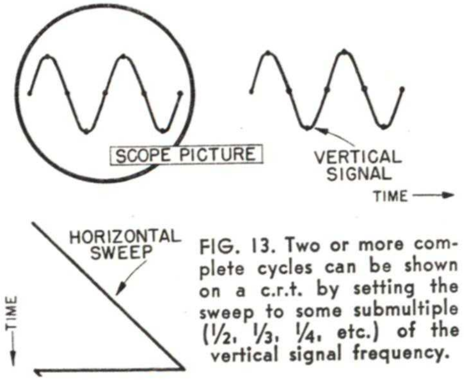


FIG. 13. Two or more complete cycles can be shown on a c.r.t. by setting the sweep to some submultiple (½, ⅓, ¼, etc.) of the vertical signal frequency.

We have made one cycle appear on the c.r.t. screen by using a saw-tooth sweep voltage of the same frequency as our vertical voltage. If, instead, we made the sweep voltage one-half the frequency of the vertical voltage, two cycles would be shown. An example is shown in Fig. 13. Similarly, three cycles would be shown if the horizontal voltage were one-third the frequency of the vertical voltage, and so forth.

What happens when the sweep frequency is greater than the signal frequency is illustrated in Fig. 14. Notice that the sine wave is broken into 3 parts when the sweep frequency is tripled. Similarly, a sweep 4, 5, 6, etc. times the incoming signal will break the image into 4, 5, 6, lines etc.

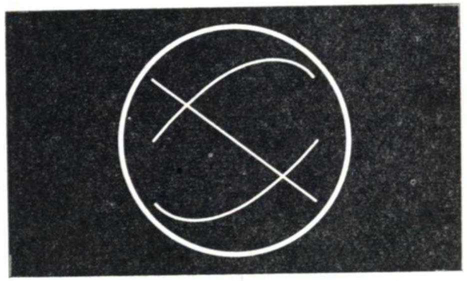


FIG. 14. When the horizontal saw-tooth sweep frequency is a multiple of the vertical signal frequency, the pattern will be broken into several lines. In this example, a sine wave is applied to the vertical plates, and the horizontal sweep frequency is three times the vertical frequency, and the picture is broken into three lines.

PRACTICAL SWEEP CIRCUITS

The horizontal sweep voltages of Figs. 12 and 13 are ideal sweep voltages: the left-to-right deflection voltage is absolutely linear, and the "fly-back" time—the time required for the sweep voltage to return from its maximum to its minimum value—is zero. Let us study the practical circuits used to produce, as nearly as possible, this wave form.

To understand the operation of practical sweep circuits, we must first understand how the circuit in Fig. 15A works. Let's assume that the condenser has no charge and the switch is open. When switch S_1 is closed, current will flow to charge condenser C_1. The condenser cannot charge up instantaneously, because the amount of current flowing into it is limited by resistor R_1; instead, the voltage across the condenser builds up gradually, as shown in Fig. 15B.

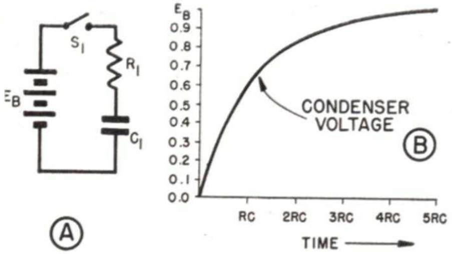


FIG. 15. When a d.c. voltage is suddenly applied to a series RC circuit, it takes a certain amount of time for the voltage across the condenser to build up to the applied voltage. As shown in B, the time for this voltage increase can be expressed in "time constants" where a time constant is equal to R × C. Note that the charging is completed in about 5 time constants.

The time that it takes for the condenser to charge up to full voltage depends on the value of both the condenser and the resistor. If a large value of resistance is used, the current flow is less and the charge-up time more. If the condenser capacitance is increased, but the rate of current flow is the same, a longer time is required for the condenser voltage to build up.

The time for the condenser voltage to increase to .63 of the supply voltage is called one "time constant." The time constant is equal to the resistance in megohms times the capacitance in microfarads, or

$$t = R \times C$$

If, in our example, C_1 is .01 mfd. and R_1 is 1 megohm, the time constant is .01 second. Thus the condenser voltage will increase to .63 of the supply voltage .01 second after the switch S_1 is closed.

► Incidentally, in *two* time constants the voltage will increase to 63% of the difference between the supply voltage and the voltage at the end of the *first* time constant. At the end of .02 seconds in this example, then, the condenser voltage is 86% of the supply voltage E_B. Likewise, at the end of three time constants (3RC) the voltage is .95, after 4RC it is .98, and at the end of 5RC (.05 seconds) the condenser is, for all practical purposes, fully charged.

Let us see how this principle is used to generate a saw-tooth sweep voltage. In the circuit of Fig. 16A, a second switch, S_2, has been added, and the condenser voltage is applied across the horizontal deflecting plates of the c.r.t. When S_1 is closed at time 1 (assuming that S_2 is open) the condenser voltage will start to build up as shown in Fig. 16B (this is like the start of the curve in Fig. 15B). In 0.1 time constant the voltage will increase practically linearly to 0.1 of the supply voltage. Now if at the end of this time (point 2, which, in the example given above, is .001 second) S_2 is closed, condenser C_1 will discharge and its voltage will drop to zero. If S_2 is immediately opened again, the cycle will repeat. If we momentarily close S_2 whenever the condenser voltage reaches 0.1 of the supply voltage (points 3, 4, 5, etc.), we will get the desired saw-tooth wave form of Fig. 16B. In this particular case the frequency of oscillation will be 1000 c.p.s.

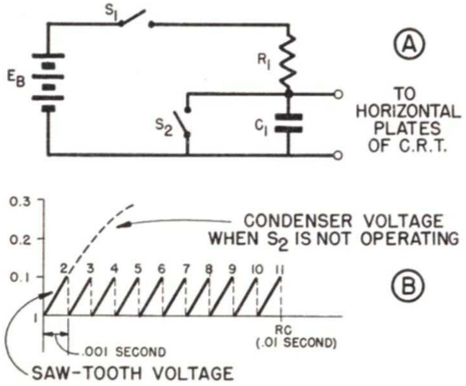


FIG. 16. A basic saw-tooth voltage generator circuit. Switch S_2 is momentarily closed (at 2, 3, 4, 5, 6, etc.) whenever the sweep voltage reaches a fixed value, in this case, 0.1 of the supply voltage.

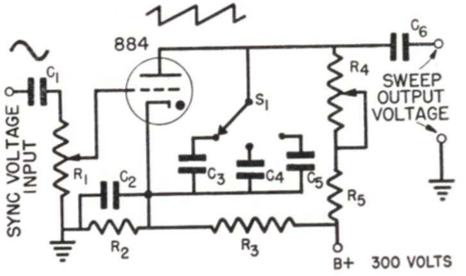


FIG. 17. A practical sweep generator circuit using an 884 gas triode tube as a relaxation oscillator.

The circuit of Fig. 16A is not a practical one. We can, however, use it by replacing S_2 with a gas triode tube as shown in the circuit of Fig. 17. No plate current flows in this tube until a certain critical value of plate voltage is reached. When this voltage is reached, however, the tube ionizes and quickly discharges the condenser. Thus, the tube acts as an automatic switch.

Since the value of the time constant can be changed by varying either R or C, the frequency of the oscillations can be changed by varying R or C. In the circuit of Fig. 17, R_4 is used as a fine frequency control, and, by means of the switch S_1, various values of capacitance (C_3, C_4, or C_5) are used for coarse frequency control.

To keep it linear, the output sweep voltage is limited to only about 0.1 of the supply voltage. Thus, when E_B is 300 volts, the maximum linear sweep voltage is only about 30 volts. This is certainly not enough for full screen deflection of a c.r. tube. For example, a 5BP tube with 2000 volts on A_2 has a sensitivity of 84 volts per inch, so about 420 volts are needed to swing the beam across the full 5" of the screen. Therefore, as we showed in Fig. 8, a wide-band amplifier (the horizontal amplifier) is used to amplify the sweep voltage.

As you saw in Fig. 12, the c.r.t. gives an exact reproduction of the voltage wave if the sweep voltage is linear and returns immediately from its peak to its smallest value. However, the sweep voltage we can get from a practical generator is never perfect in either of these respects. Let's see what happens if the sweep is non-linear or does not return immediately.

Fig. 18 shows an extreme example of a non-linear sweep. Notice that the wave form being observed is crowded to one side of the screen.

A non-linear sweep can be caused by either (1) operation of the sweep generator over the non-linear region of a condenser charge curve, or (2) a poor low-frequency response of the horizontal amplifier. The latter frequently occurs when the sweep rate is low.

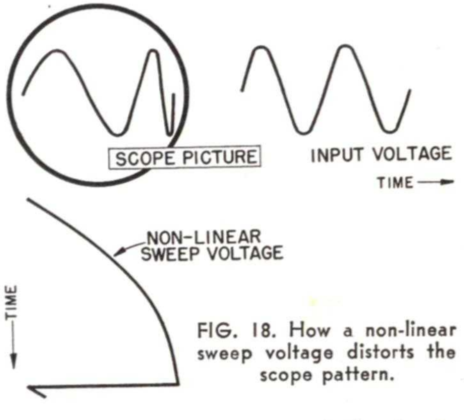


FIG. 18. How a non-linear sweep voltage distorts the scope pattern.

Furthermore, in a practical sweep circuit, like that in Fig. 17 for example, the sweep condenser cannot discharge immediately when the gas tube fires. How this affects the sweep voltage and c.r.t. picture is shown in Fig. 19. The return trace is shown as a dotted line because it is generally very rapid and therefore may not be visible.

Blanking. In many c.r.o.'s, a special circuit is used to blank out this return trace of the c.r.t. beam. The basic circuit is illustrated in Fig. 20A. A series RC circuit is connected across the sweep voltage and the voltage across the resistor is applied to the grid of the c.r.t. A short time constant is used—that is, R times C is less than the time for one cycle of the sweep voltage. Thus, as the sweep voltage (shown in Fig. 20B) increases from r to s, the voltage across C_1 will likewise increase and the grid of the c.r.t. will remain practically at ground potential. During the sweep fly-back time (from s to t) the voltage applied across R_1 and C_1 will suddenly drop. Since the condenser C_1 is charged up and cannot change voltage instantly, the entire voltage drop across the condenser (s to p in C) will appear across R_1, thus producing a negative voltage pulse on the grid of the c.r.t. that blanks out the electron beam during this fly-back time. Condenser C_1, however, discharges quickly through R_1, so the blanking voltage will be gone.

Other Sweep Circuits. The basic sweep circuit we have just shown is the most common type. There are, however, several variations that are designed to produce a more nearly linear sweep.

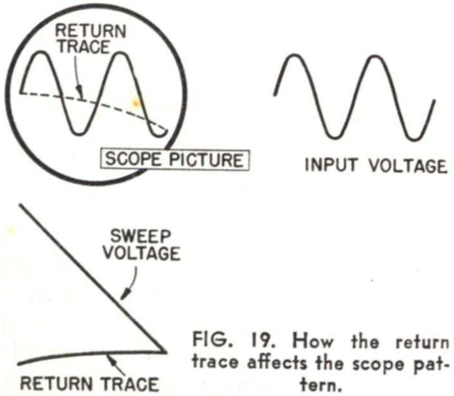


FIG. 19. How the return trace affects the scope pattern.

Fig. 21 shows one of these circuits which uses a pentode instead of a resistor to limit current flow into the sweep-voltage condenser. Remember that the plate current of a pentode is substantially constant over a wide range of plate voltages (assuming the grid bias and screen voltage are constant), and that the voltage across a condenser will increase linearly when a constant current is applied to it.

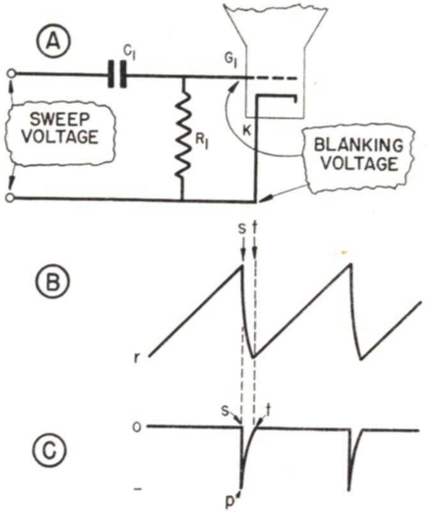


FIG. 20. When a short time constant RC circuit is connected across the horizontal sweep voltage (B), the negative voltage pulse (C) produced across the resistor will blank out the return trace on the screen.

In this circuit the sweep condensers (C_2 through C_6) are charged up through the 6SK7 pentode. The 884 is used to discharge the condensers at the end of each cycle. The sweep voltage deviates from a straight line only when the pentode current is no longer constant. Since this occurs when the pentode plate voltage falls to about 25% of the supply voltage, the maximum sweep voltage output can be approximately 75% of the supply voltage. Compare this with the maximum of about 10% of the supply voltage if only a resistor is used to limit current flow. The coarse frequency control in the circuit in Fig. 21 is obtained by switching in various fixed condensers. The fine frequency control is obtained by using R_2 to vary the bias of the pentode tube.

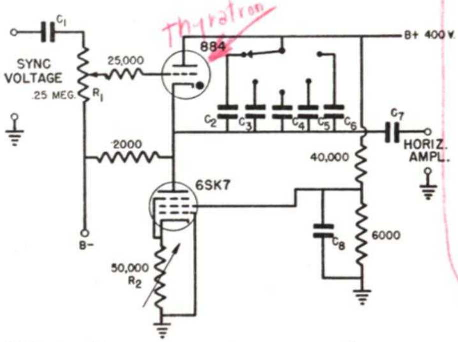


FIG. 21. Linear sweep circuit using the constant current property of a pentode.

When this circuit is used with small tubes (up to 3"), it is sometimes not necessary to use an amplifier to produce a full horizontal sweep across the screen.

SYNCHRONIZATION

If the sweep frequency is not exactly the same as that of the applied wave (or a sub-multiple thereof) the image will continually drift across the screen. Generally, if the sweep rate is too slow, the pattern will drift to the right; if it is too fast, the pattern will drift to the left. To prevent this drift, the signal and sweep frequencies must be "locked" together.

Synchronization is produced by adjusting the sweep control so the frequency of the sweep voltage is slightly less than that of the applied signal. At the same time, part of the signal voltage is fed back into the grid circuit of the thyratron used in the sweep generator. Applying an a.c. signal to the grid of the thyratron makes its breakdown voltage vary: it will break down at a lower voltage when the signal applied to the grid is positive, and requires a greater voltage when the signal makes the grid more negative. Once each cycle, at exactly the same part of the cycle, the combined effect of the grid signal voltage and the sweep condenser voltage makes the tube break down. Thus the sweep generator voltage is tied in to the signal voltage so that a stationary trace is produced on the screen of the c.r. tube. The sweep voltage can be synchronized to multiples or sub-multiples of the incoming signal in a similar manner.

In Fig. 21, C_1 and R_1 are used to supply part of the signal voltage to the grid of the thyratron. The synchronizing voltage is usually taken from some part of the amplifier that drives the vertical plates, although, in most oscilloscopes, an alternate connection to an external source is also provided.

It is possible to over-synchronize by applying too much synchronizing voltage to the grid of the sweep generator tube. Over-synchronization distorts the image. An example of the distortion caused by extreme over-synchronization is shown in Fig. 22.

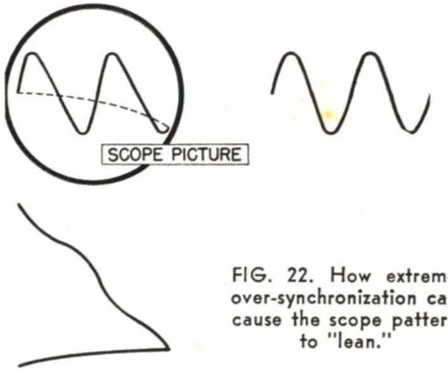


FIG. 22. How extreme over-synchronization can cause the scope pattern to "lean."

Typical Commercial C.R.O.'s

Let us now study the construction and operation of two typical commercial oscilloscopes, the 3″ RCA 155 (a representative low-cost oscilloscope) and the more expensive Du Mont 208.

RCA 155 C.R.O.

Fig. 23 shows the general appearance of the RCA 155 oscilloscope. Fig. 24 shows a complete schematic wiring diagram of the instrument. (Notice that the schematic diagram of the c.r.t. differs somewhat from those we have shown earlier. There is at present no general agreement on a diagram for c.r.t.'s.)

Power Supplies. Notice that the high and low-voltage power supplies use the same transformer T_1. The low-voltage supply is a conventional full-wave rectifier (using VT_2) with a single-section pi filter L_1, C_{19}, C_{20}, C_{21}, C_{22} in the output; it delivers 400 volts for operation of the amplifier and sweep circuits. The high-voltage supply uses VT_1 as a half-wave rectifier feeding into an RC filter C_{12}, R_{13}, C_{13}. This supply furnishes only 600 volts, but it is in series with the low-voltage supply; the combination furnishes 1000 volts, which is the voltage required for proper operation of the 906 c.r. tube (VT_6). This arrangement eliminates the expensive power transformer that would be needed if a separate 1000-volt supply were used. The positive terminal of the high-voltage supply is grounded to permit its output to be added to that of the low-voltage supply.

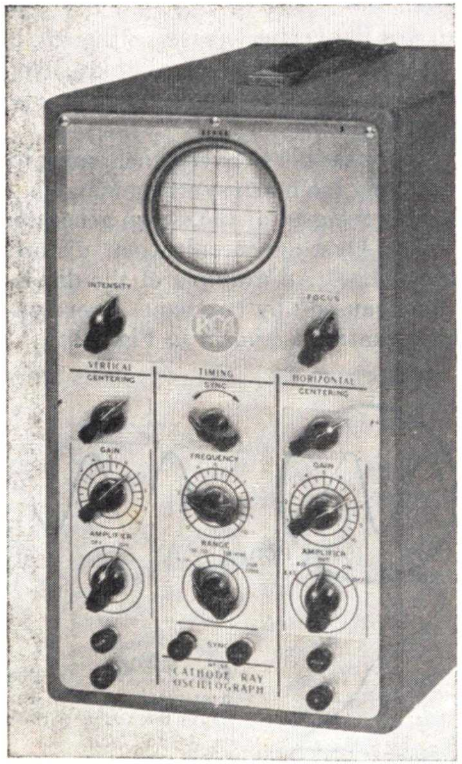


FIG. 23. The controls on the RCA 155 oscilloscope.

The .025 mfd. filter condensers C_{12} and C_{13} of the high-voltage supply are oil-impregnated paper condensers capable of withstanding 1000 volts. Such small capacities are permissible in the filter circuit because the c.r.t. has a very low current drain. It is for this reason, too, that R_{13} can be used instead of an inductance in the filter circuit without much reduction of the output voltage.

The Voltage Divider. The d.c. potentials for the elements of the 906 c.r.t. are obtained by tapping at different points on the voltage divider across the output of the two power supplies in series. Two variable resistors are used in the divider—R_{14}, which is used to control the bias on the control grid (G_1), and R_{16}, the focusing control, which controls the voltage on anode 1 (A_1). Notice that one of each pair of the deflecting plates is connected to anode 2 (A_2); this prevents defocusing of the beam. Controls R_{22} and R_{23} are

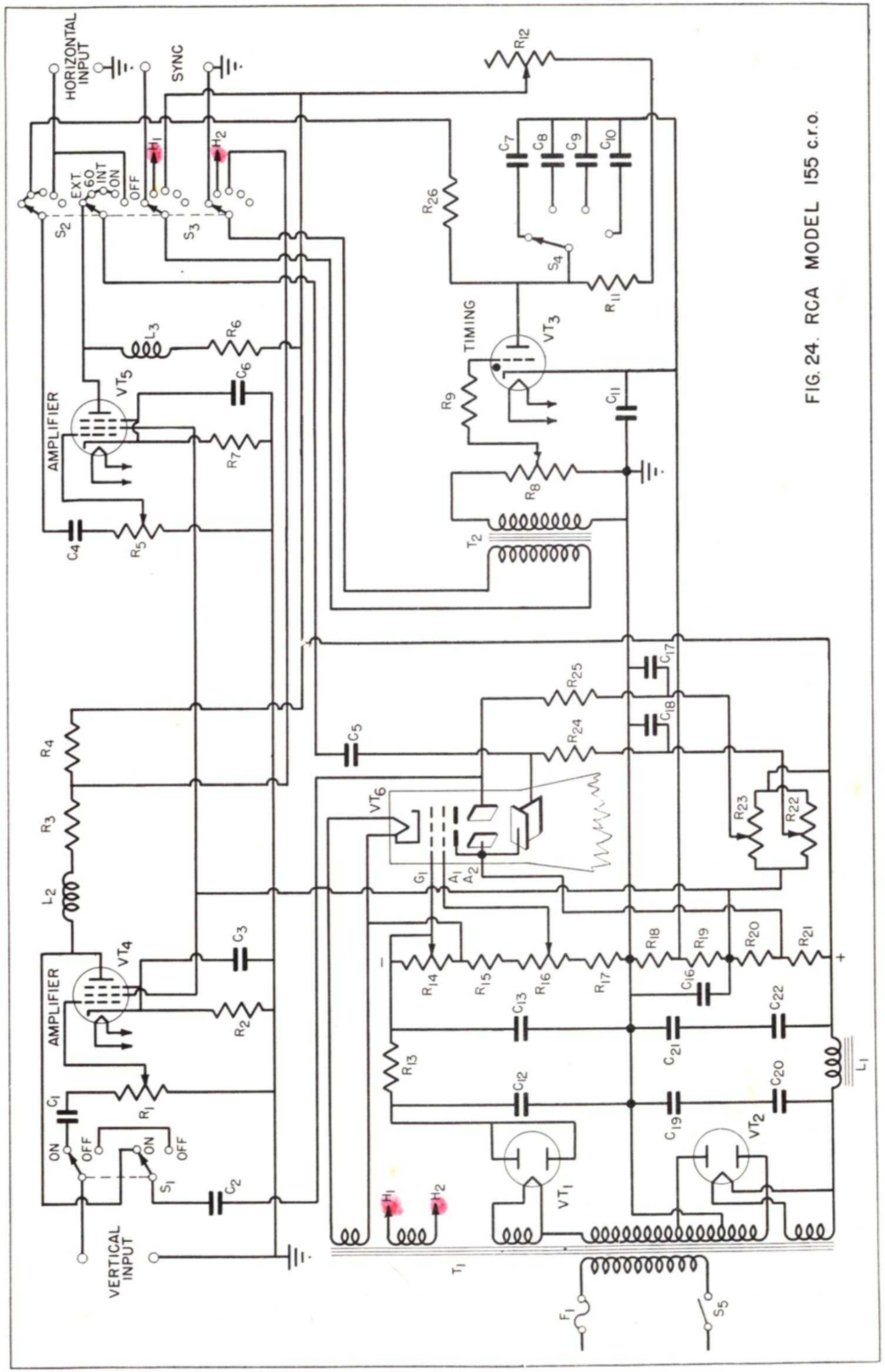


FIG. 24. RCA MODEL 155 c.r.o.

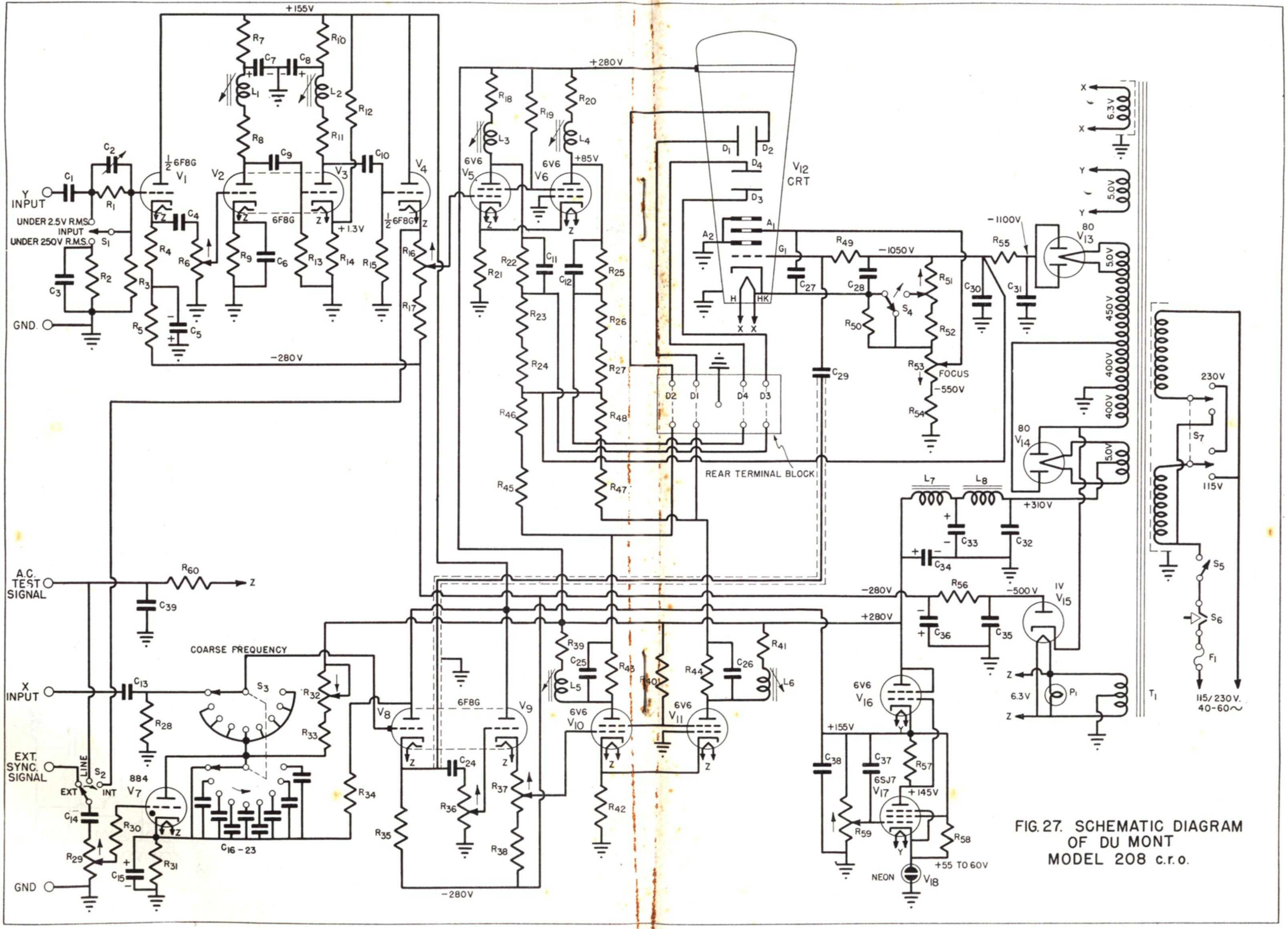


FIG. 27. SCHEMATIC DIAGRAM OF DU MONT MODEL 208 c.r.o.

used to move the spot to any desired initial position, usually in the center of the screen.

The a.c. voltages for the deflecting plates are fed from the amplifiers through C_2 and C_5 and developed across R_{24} and R_{25}, which are 2.2-meg. isolating resistors.

The Sweep Circuit. The sweep generator, marked "timing," uses an 884 gas discharge tube. A selector switch S_4 connects the proper condenser (C_7, C_8, C_9, or C_{10}) into the circuit for the sweep frequency range desired (from 15 to 22,000 cycles per second in four overlapping ranges). The sweep generator condenser is charged through R_{11}, a 150,000-ohm fixed resistor, and a 2-meg. variable resistor R_{12}. The latter is the "fine" frequency control.

The synchronizing transformer T_2 feeds the control signal into the timing tube grid through the sync control potentiometer R_8.

The Vertical Amplifier. When switch S_1 is in the ON position in this c.r.o., the input signal is connected to the grid of the 6SJ7 (VT_4) vertical amplifier tube through the 0.25-mfd. condenser C_1. The amplifier is flat from 20 to 35,000 cycles per second and is usable to 100,000 c.p.s. This flat response is produced by the plate load combination of L_2, R_3, and R_4. L_2 compensates for the normal drop in high-frequency output of a resistance-coupled amplifier by acting as an increasing load as the frequency increases, thus raising the stage gain. The output of the amplifier is fed through the 0.25-mfd. condenser C_2 to the vertical deflecting plates.

The Horizontal Amplifier. This stage is similar to the vertical amplifier. Twin ganged switches S_2 and S_3 permit either the internal sweep generator or an external one to be used, and also allow internal, 60-cycle, or external synchronization of the internal sweep generator. When the switch is in the "EXT" position, an external synchronizing voltage applied to the SYNC terminals goes to the grid of the sweep tube through the synchronizing transformer T_2. The output of the sweep generator is then fed through coupling condenser C_5 to the horizontal deflecting plates.

When S_2-S_3 is set to the position "60," 60-cycle a.c. is fed from the filament supply of the voltage amplifier tubes to the sync transformer so that the sweep can be locked to this frequency or some multiple of it. In the next position, "INT," part of the output voltage of the vertical amplifier is fed to the sweep input and "locks" the sweep with it. This is the most used position. In the next position, "ON," the sweep is not in the circuit. This position is used when an external signal is fed into the "HORIZONTAL INPUT" terminals; in this case, the signal is amplified by the horizontal amplifier and applied to the horizontal plates. When the switch is turned to "OFF," the signal on the horizontal input terminals is connected to the deflecting plates through C_5. The amplifier and the sweep generator are not in the circuit.

SETTING THE CONTROLS

Now, let's learn how to use the RCA 155 'scope to examine a wave form. We'll use a voltage from a 60-cycle power line for our example. Refer to Fig. 23 to see where the controls mentioned in the following discussion are located. To put the instrument into operation, set the 'scope controls as follows:

Step. 1. The ON-OFF switch is a part of the INTENSITY control. Turn the INTENSITY control until the switch clicks ON, and wait for about a minute to permit the circuits to warm up. Then advance the INTENSITY control until a spot of light is seen on the screen. Turn the INTENSITY control only enough to make the spot of light barely visible. THIS IS IMPORTANT—IF A BRIGHT SPOT OF LIGHT IS PERMITTED TO REMAIN AT ONE POINT ON THE SCREEN FOR AN APPRECIABLE PERIOD OF TIME, THE SCREEN CHEMICALS CAN BE BURNED AWAY. THIS DESTROYS THE ABILITY OF THAT POINT ON THE SCREEN TO REPRODUCE LIGHT. This is known as "spot burning."

Step 2. Next, adjust the focus of the spot. Turn both GAIN controls to zero to keep voltage off the deflecting plates.

Rotating the FOCUS control will make the spot of light increase in size and spread into an irregular shape. Adjust the control so that the spot is round and as small as possible. If the spot is now too bright, turn back the INTENSITY control until the spot is just easily visible. Be sure to eliminate any halo of light around the spot.

Step 3. Next, center the spot, still with no voltages on the deflecting plates. The VERTICAL centering control (underneath the INTENSITY control) will move the spot up or down, and the HORIZONTAL centering control (underneath the FOCUS control) will move it to left or right. Use these controls to move the spot to the exact center of the screen.

Step 4. Since we will use the internal sweep, set the HORIZONTAL AMPLIFIER switch (S_2-S_3 on the schematic and at the lower right of the front panel in Fig. 23) to INT, the position for control of the sweep by the voltage under study. This connects the input of the timing circuit to the vertical amplifier and its output to the horizontal amplifier.

Turn up the HORIZONTAL GAIN control (R_5 in Fig. 24). The spot will turn into a faint horizontal line. Increase the intensity setting; the horizontal line will become brighter. When the spot begins to move, fewer electrons strike any given point on the screen in a given time, so the beam intensity can be increased without danger of burning the screen. Adjust the HORIZONTAL GAIN control so that the line extends about two-thirds the distance across the face of the tube.

Step 5. To analyze a 60-cycle wave from the power line, the RANGE switch in the TIMING group must be set to the first range, which covers frequencies between 15 and 120 cycles. Remember, we want the sweep voltage frequency to be the same as our 60-cycle frequency.

Step 6. Now connect the voltage to be analyzed to the VERTICAL terminals, at the bottom left of the panel. You can get a voltage from the power line by using a step-down transformer, connecting the low-voltage winding to the c.r.o. terminals.

Step 7. Next, turn the VERTICAL AMPLIFIER switch on the ON position. Then advance the VERTICAL GAIN control (R_1) until the line of light on the screen changes into some kind of pattern, most likely a series of rapidly moving lines or figures.

Step 8. Now rotate the TIMING SYNC control (R_8 in Fig. 24) to about mid-position. Adjust the FREQUENCY control (R_{12}) in the TIMING group until the pattern on the screen stands still. You will find several "stationary" points within the range of the control; choose the one that gives a single complete cycle of the sine wave on the screen. The sweep circuit is now set to 60 cycles, and "locked" with the incoming wave.

The VERTICAL GAIN control will now vary the amplitude (height) of the sine wave, while the HORIZONTAL GAIN control will vary the width of the image. Adjust these two controls so that the image is well within the dimensions of the screen of the cathode-ray tube.

It now may be necessary to readjust the SYNC control until the image stands still. (It may still get out of step momentarily, causing the image to jump occasionally.) Use the least amount of SYNC voltage (knob turned farthest toward the left) that will give a stationary image; too high a setting can distort the image by causing a non-linear sweep.

Distortion Produced by the Controls. Image distortion may occur if the signal amplitude is increased so much that the image extends out near the edge of the screen. Since only a portion of the screen can be used without distorting the image, a large size screen is desirable. Commercial oscilloscopes usually have screens 3 to 5 inches in diameter. The 3-inch tube limits the useful image to about 2 inches in each direction.

Fig. 25 shows how the relative amplitudes of the horizontal sweep and the vertical voltage affect the usefulness of the image. In 25A the sweep is turned too low; the horizontal gain control should be advanced to pull out the image lengthwise, to avoid the too-sharp peaks. In 25C, the image has been stretched too far; in 25D it has been increased in height too much, producing a square shape at the bottom. Proper adjustment of horizontal and vertical gain controls produces the well-proportioned image of 25B.

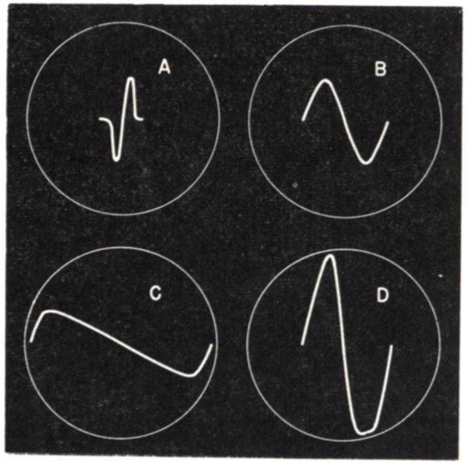


FIG. 25. Improper adjustment of the controls can distort the produced image as shown here.

Stray Voltages. Stray voltages, in addition to those being studied, may be picked up by the c.r.o. and appear on the screen. Strays are most apt to be picked up in the neighborhood of power or audio transformers, especially when test leads are connected to the vertical input terminals but are not connected to any source of voltage.

If the test leads are touched together or connected to a source of voltage, the stray voltage will usually be minimized. If, however, the stray is very strong, it may come through even with the leads connected to a voltage source, and will appear as a series of humps that "crawl" around the stationary pattern. The only cure for this is to shield the test leads or move the instrument to another location.

DU MONT 208B C.R.O.

A picture of the Du Mont 208B oscilloscope is shown in Fig. 26. The circuit diagram of the instrument is shown in Fig. 27, which, because of its size, is located on pages 18 and 19. (Notice that still another diagram of the c.r.t. is used by this company.) We shall describe some of the features of the circuit, but we shall not take up in detail the operation of the controls, because they are similar to those of the RCA 155.

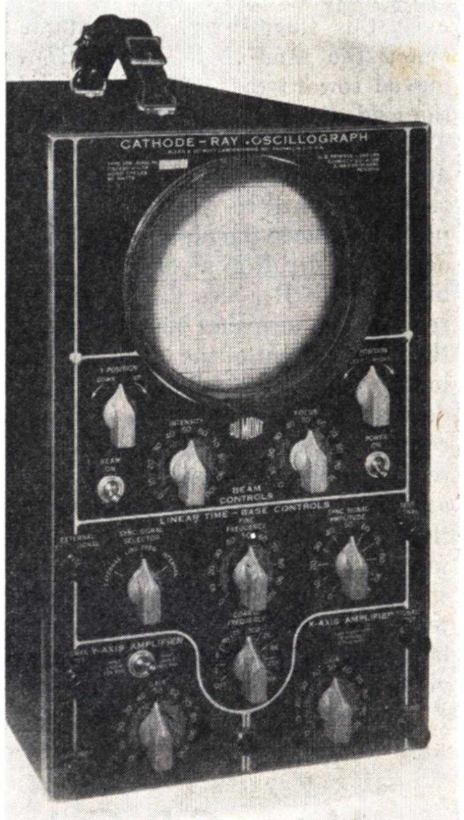
Power Supplies and Voltage Divider. The high and low-voltage power supplies of this 'scope are wound on the same core. The high-voltage supply consists of a half-wave rectifier (V_{13}) and resistance-capacity filter (C_{31}, R_{55}, and C_{30}). The output is —1100 volts. The potentials for the electron gun are obtained from a voltage divider (R_{51}, R_{52}, R_{53}, and R_{54}). Notice that the control grid is kept at a fixed negative potential and the intensity is varied by adjusting the voltage on the cathode with R_{51}. Provision is made (S_4) to turn the beam off when it is not being viewed; this is done by applying a greater positive voltage on the cathode and so, in effect, cutting off the tube.

The low-voltage power supply consists of a conventional full-wave rectifier (V_{14}) with a two-section inductance-capacity filter (L_7, L_8, C_{32}, C_{33}, and C_{34}) to supply +280 volts. A —280 volt source for biasing is provided by tapping off of one side of the low voltage winding through a 6X5 rectifier (V_{15}). A resistance-capacity filter (R_{56}, C_{35}, C_{36}) smooths out the ripple in this supply.

A well-regulated voltage of +155 volts for the amplifier plate supplies is provided by a 6SJ7 (V_{17}), 6V6 (V_{16}), and a 991 neon tube voltage regulator (V_{18}). Very stable operation results even if there are quite severe line voltage fluctuations.

A 5CP1 is used as the cathode-ray tube. This tube requires, in addition to the —1000 volts for the electron gun, about +300 volts on the accelerating (booster) anode A_3. This voltage is obtained from the +280 volt power supply.

Vertical Amplifier. In an ordinary resistance-coupled amplifier, the interelectrode and stray capacities are lumped as a shunting capacity across the output to reduce the response at higher frequencies. This decrease in response was compensated for in the RCA 155 by the use of inductances (L_2 and L_3) in the plate circuits of the amplifiers. The 208B also uses this method (L_1, L_2, L_3, L_4, L_5, and L_6) and, in addition, it also uses cathode followers (V_1 and V_4) to obtain a good high frequency response. (Cathode followers were discussed in an earlier Lesson.) The input capacitance of the cathode follower is very small and does not load the circuit under measurement at higher frequencies. The gain control for the vertical amplifier is connected at the output of the cathode follower input stage (V_1).



Courtesy Allen B. Du Mont Laboratories, Inc.

FIG. 26. A cathode-ray oscillograph.

A switch (S_1) and compensating network (C_2, R_1, C_3, and R_2) are used as a coarse gain control in the input circuit. The output of the first cathode follower (V_1) is fed into a conventional twin-triode amplifier (V_2 and V_3) with compensating inductive plate loads (L_1 and L_2). The output of this amplifier is fed into a second cathode follower stage (V_4), which also contains the Y (vertical) positioning control.

The positioning control used in the RCA 155 is sluggish, because the coupling condensers have to be charged each time the position of the spot is changed. This is at times very annoying. In the Du Mont scope, however, this sluggishness is eliminated. When the arm of R_{16} (Fig. 27) is moved toward the —280 volt supply, the grid of V_5 is made more negative. This causes an increase in the voltage applied to the plate of V_5, which is directly coupled to vertical deflecting plate D_3. Since the plate current of V_5 decreases, the drop across the cathode bias resistor R_{21} also decreases. This resistor also furnishes bias for tube V_6; the plate current of the latter therefore increases, and the voltage at its plate decreases. The plate of V_6 is directly coupled to deflecting plate D_4. The net result of these actions is that the voltage on D_3 increases at the same time the voltage on D_4 decreases, so a minimum of defocusing occurs. Further, since V_5 and V_6 are directly coupled to the deflection plates, there is no time lag between adjustment of R_{16} and vertical movement of the spot.

Signals passing through the vertical amplifier (V_1 through V_4) are developed across R_{16}. They are therefore superimposed on the d.c. positioning voltage and move the spot to produce the vertical deflection.

Horizontal Amplifier and Sweep Generator. A conventional saw-tooth oscillator using a 6Q5G tube (V_7) is used for the linear time base. A gain control (R_{36}) and positioning circuit (using R_{37}) similar to that in the vertical amplifier couples the sweep circuit to the horizontal plates. Notice that there are no intermediate triode stages in this amplifier. A synchronizing selector switch S_2 and sync control (R_{29}) are provided to permit synchronization of the sweep to external signals, to power line voltage, or to signals applied to the vertical amplifier. When the sweep frequency range switch (S_3) is in the OFF position, external signals can be applied to the horizontal amplifier. The fly-back of the sweep voltage is applied to the control grid of the cathode-ray tube through a circuit having a short time constant (C_{29} and R_{49}) to blank out the return trace. The sweep is designed to be linear from 2 to 50,000 cycles per second.

Using C.R.O.'s in Communications

Now that we have studied complete c.r.o.'s, let us see how they can be used in communication work.

LISSAJOUS PATTERNS

If we apply a.c. voltages to both sets of plates, instead of a.c. to the vertical and a saw-tooth to the horizontal, a pattern known as a Lissajous figure is obtained that can be used for determining frequencies and phase shifts.

If exactly the same a.c. voltage is applied to both pairs of deflecting plates in phase, a straight slanting line is obtained (Fig. 6). Should the voltages be of the same frequency, but out of phase, a loop or circle will form. For example, if the voltages are equal, but are 90° out of phase, we will get a perfect circle (Fig. 28).

The patterns produced by several different phase relationships are shown in Fig. 29. Since the exact shapes of these patterns depend upon the relative amplitudes of the voltages, it is best to adjust the amplitudes to approximately the same value when the c.r.o. is being used to measure phase differences. To do this, turn off the vertical gain and adjust the horizontal gain to produce a line of some reasonable length. Measure this line and make a note of the horizontal gain control setting. Next, turn off the horizontal gain and adjust the vertical gain to produce a vertical line of the same length. Finally, reset the horizontal gain control to the position that gave the first line.

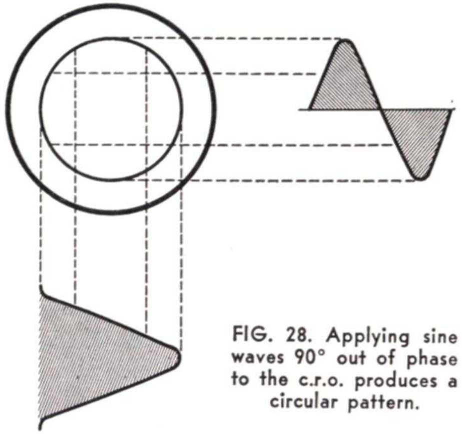


FIG. 28. Applying sine waves 90° out of phase to the c.r.o. produces a circular pattern.

When the figure is formed, its angle, as Fig. 29 shows, indicates the phase difference. Since we are usually interested only in finding whether a phase shift has occurred and are satisfied with a very rough approximation of the amount, a glance at the pattern generally tells us what we want to know.

If we want to find the exact value of the phase difference, we can do so, even when the amplitudes are not exactly equal, by measuring the distances A and B shown in Fig. 30. (The vertical lines shown in this figure cross at the point where the spot was originally centered.) Dividing B by A gives a number that is the sine of the angle the ellipse makes with the horizontal; this angle indicates the phase difference between the two voltages. We can find the angle by looking up the sine value in a trigonometric sine table.

For example, suppose we find that B

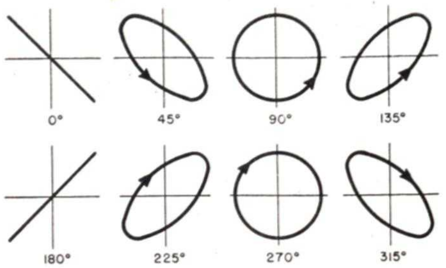


FIG. 29. The pattern changes from a slanting line to an oval, then to a circle, as the phase difference is changed.

is ½ inch and A is 1 inch. Then, dividing ½ by 1, we get .5. A sine table shows this to be the sine of 30°, 150°, 210°, and 330°. We can narrow these to a pair of possibilities by noticing the direction of the tilt; 30° and 330° ellipses will tilt one way, 150° and 210° ellipses will tilt the other (compare the tilts of the 45° and 315° ellipses with those of the 135° and 225° ellipses in Fig. 29). Say we find that the pattern tilts to the left; by comparison with Fig. 29, we can say that the phase angle is either 30° or 330°, since its tilt is like those of the 45° and 315° patterns. We cannot determine whether it is 30° or

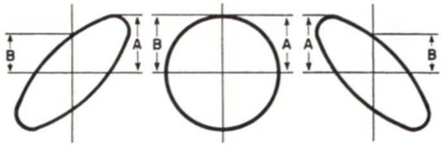


FIG. 30. Measure A and B to determine the phase shift.

330°, however, unless we can find out the direction of rotation of the spot (notice the arrows in Fig. 29) or can increase the phase shift by using a special circuit. If we do the latter, and the pattern becomes circular, we have a 30° phase difference; if it changes to a line, we have a 330° difference.

The phase shift patterns shown in Fig. 29 are correct for one orientation of the c.r. tube and for one arrangement of the connections to its plates. If the tube is rotated 90° or the plates are connected differently, the patterns will interchange — the 0° pattern will become the 180° pattern, the 45° will become the 225°, the 135° will become the 315°, and vice versa. To determine the true zero for your particular oscilloscope, you must connect the same voltage, from the same source, to both the vertical and horizontal plates and notice which way the line slants.

Any pattern that is a single line, oval, or circle shows that the two a.c. voltages have the same frequency. A series of closed loops means that the two frequencies differ, and the position and number of the loops give the ratio of the two applied frequencies. If we know the frequency of either the signal on the vertical plates or that on the horizontal plates, this ratio will let us find the frequency of the other signal at once.

For example, suppose we find that we get the pattern shown in Fig. 31A. To determine the frequency ratio, imagine that lines A and B are drawn on the tube. The number of times the pattern touches line A indicates the frequency of the vertical signal, the number of times it touches line B indicates the frequency of the horizontal signal. In our example, line A is touched four times and line B once. Therefore, the frequency ratio is 4 to 1, which means the frequency of the signal applied to the vertical plates is 4 times that of the signal applied to the horizontal plates. Thus, if a 60-cycle voltage is applied to the horizontal plates, the vertical plate voltage has a frequency of 240 cycles.

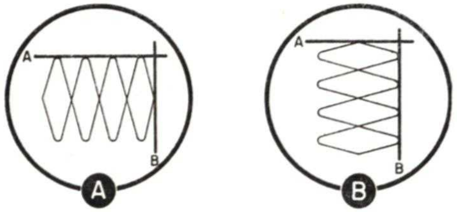


FIG. 31. Using imaginary lines A and B to determine frequency in a Lissajous figure.

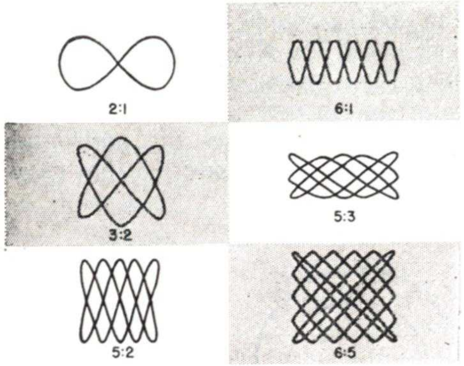


FIG. 32. Several typical Lissajous figures showing frequency ratios.

It is possible for the image to turn around, as shown in Fig. 31B. Now the figure touches the line A once and the line B four times, so the ratio is now 1 to 4 and the horizontal signal frequency is 4 times the vertical signal frequency. Thus, if the horizontal voltage is still 60 cycles, the vertical voltage must be 15 cycles.

A number of typical patterns are shown in Fig. 32. (These are somewhat idealized for clarity; actual oscilloscope patterns are not as regular as these.) In all cases, counting the number of times the loops touch the imaginary lines A and B will give the frequency ratios. The frequency of the vertical signal is always given first in these ratios.

TRAPEZOID PATTERNS

A very important use of the c.r.t. is in the determination of the operating characteristics of a radio transmitter. The percentage of modulation, amount of phase shift in various stages of the audio- and radio-frequency amplifiers, frequency modulation in amplitude-modulated transmitters, hum level, parasitics, overload, and distortion can all be found by studying the modulation envelope as shown on a c.r.t.

The popularity of the c.r.t. in modulation checking is partly due to the relative simplicity and economy of the whole test set-up. A test set-up of a c.r.t. and power supply costs very little more than a good r.f. ammeter and is much more informative.

A commercial oscilloscope may be used to check modulation. However, since the majority of voltages to be measured are on the order of several hundred volts, it is usually not necessary to burden the tube with amplifiers; in fact, the voltages under study are fed to the deflection plates through attenuating circuits so that the signals can be brought within the range of the screen. A separate power supply with positioning controls of the types illustrated in Figs. 9, 10, and 11 is generally used, although it is possible to obtain the necessary power from the transmitter as in some built-in scope.

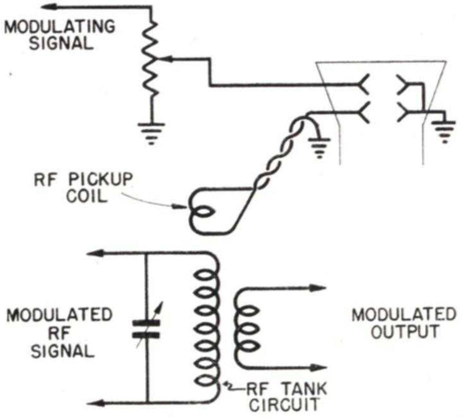


FIG. 33. How the modulating signal and the modulated signal can be applied to a c.r.t. to form a trapezoid pattern.

Fig. 33 shows the most common method of applying the modulated signal to the c.r.o. deflection plates. Notice that the modulated carrier is applied to the vertical deflecting plates and the modulating voltage is applied to the horizontal plates. The c.r.t. picture obtained, illustrated in Fig. 34, is called a "trapezoid" pattern because of the geometric shape it has when the carrier is modulated less than 100%. (A trapezoid is a four-sided figure of which only two sides are parallel.) Figs. 34A and 34B show the patterns for 50% modulation and 100% modulation.

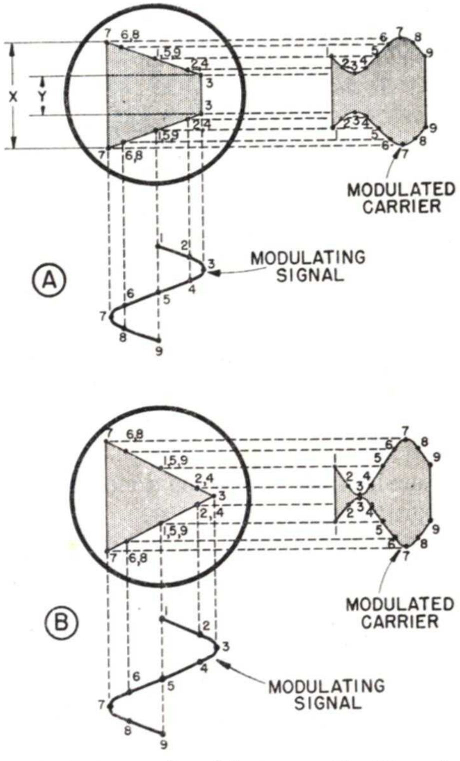


FIG. 34. In A is shown the trapezoid pattern obtained for 50 per cent amplitude modulated carrier, and B, the trapezoid pattern for 100 per cent modulation.

The principal advantage of using a c.r.t. in this manner is that so doing permits the modulation to be checked while a program is being transmitted. Another method, which we will take up in a moment, requires that a steady tone be transmitted during the check; naturally, this cannot be done while a program is being broadcast.

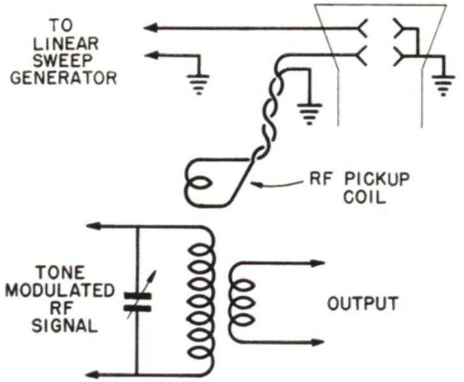


FIG. 35. A time-amplitude c.r.t. pattern is obtained by applying the tone-modulated r.f. voltage to the vertical deflecting plates and a linear sweep to the horizontal deflecting scope plates.

How to Compute Modulation Percentage. To calculate modulation percentage from a trapezoid pattern, the bases of the trapezoid (X and Y in Fig. 34A, for example) must be measured. Any units can be used for the measurement, provided the same are used for both. The following formula converts these measured values into modulation percentage:

$$\text{Modulation } \% = \frac{(X-Y)}{(X+Y)} \times 100.$$

If X = 3 and Y = 1, we obtain,

$$\text{Modulation } \% = \frac{3-1}{3+1} \times 100$$

$$= \frac{2}{4} \times 100 = 50\%.$$

In the special case in which the pattern is a triangle (Fig. 34B), there is no distance Y. Our formula then becomes:

$$\text{Modulation } \% = \frac{X}{X} \times 100 = 100\%.$$

So we know at once that we have 100% modulation when the pattern is a triangle and not a trapezoid.

TIME-AMPLITUDE PATTERN

At various points in earlier Lessons of your Course, you have seen diagrams of modulated waves. Such a wave can be reproduced on the screen of a c.r.t. in what is called a time-amplitude pattern. This pattern is obtained by modulating the carrier with a single audio tone. As shown in Fig. 35, the modulated carrier is applied to the vertical deflecting plates of the c.r.t. while a linear time base is applied to the horizontal deflection plates. A typical pattern is shown in Fig. 36; this one is produced when the sweep rate is one-half the modulating frequency and the modulation is 75%.

The percentage of modulation can be calculated from a time-amplitude pattern in the same manner as from a trapezoid pattern, using the minimum amplitude as Y and the maximum amplitude as X in the equation given earlier. These amplitudes are marked in Fig. 36.

Under some circumstances, a time-amplitude pattern is more informative than a trapezoid pattern. Its main disadvantage is that the pattern cannot be made while a program is being transmitted.

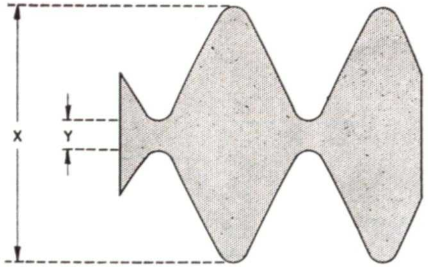


FIG. 36. This is the time-amplitude (modulated-wave) pattern for a sine-wave modulated carrier. The amount of modulation is 75%, and the linear sweep on the scope is one-half the frequency of the modulating signal.

The diagram in Fig. 35 shows a pick-up coil placed close to the antenna coupling coil for obtaining r.f. for the vertical plates of the c.r.t. In some cases, it is possible to pick up enough r.f. merely by placing a short piece of high-tension ignition cable near a high-frequency bar, connecting the cable to one of the deflection plates, and connecting the other deflection plate to ground. When this is done, the plates should be shunted by an r.f. choke or by a very high resistance to provide a d.c. path from one plate to the other.

If the scope amplifier is not capable of amplifying the r.f. voltage, and the transmitter power is too low for you to obtain sufficient r.f. pick-up from a single wire or coil, you can connect the plates through a low-capacity condenser directly to the high side of the final tank coil. The condenser chosen should be of such a value that it will not upset the tuning of the circuit.

The audio-frequency potential required for the trapezoidal diagram is obtained from the plates of the modulator stage through a small condenser. It may well be that this connection does not give an audio potential that is in phase with the modulated output. If so, the pattern produced is like that shown in Fig. 37. Such a pattern is difficult to interpret. When this effect occurs, it is best to shift the phase of the modulating signal applied to the horizontal plates to bring the narrowest part of the pattern to the extreme edge of the diagram. This phase shift can be produced by connecting the audio-frequency voltage to the deflection plates (or to the horizontal amplifier) through a high resistance, then shunting the deflecting plates with a condenser. The value of the condenser must be determined from experiment.

Whenever an amplifier is used to amplify the signal to the deflecting plates, be careful not to overload the amplifier; if you do, you cannot tell whether variations from the expected wave form on the scope are caused by a defect in the transmitter or by the fact that the amplifier is overloaded.

ANALYSIS OF TYPICAL PATTERNS

Let us now see how various troubles and maladjustments in an amplitude-modulated radio transmitter are indicated by trapezoid and time-amplitude (modulated wave) patterns. It is necessary to know how to interpret both of these types of pattern because, in many cases, one method alone does not give conclusive evidence of the condition of the transmitter, and because a trouble may be better indicated by one method than another.

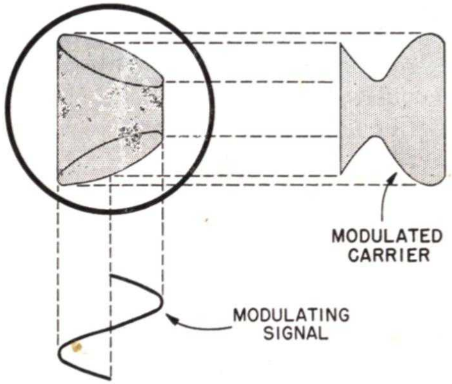


FIG. 37. When there is a phase shift between the modulating signal and the modulated carrier, this type of trapezoid pattern will be obtained.

The interpretations we make of these diagrams are not to be taken as an absolute guide to transmitter troubles, because different causes in different transmitters will produce identical appearances on the screen. The important thing to remember is that there is something wrong in the transmitter if a departure from the ideal pattern occurs.

After you operate a station for a short time, you will become familiar with various faulty patterns and proficient in correcting the trouble. Thousands of dollars can sometimes be saved by a quick analysis of the trouble and prompt correction of the fault.

Overmodulation. A basic improper operating condition is overmodulation. The modulated wave is shown in Fig. 38A and the corresponding trapezoid in Fig. 38B. The modulated-wave pattern is more useful in this case because it is easier to recognize.

Distorted Audio. If the modulated wave is distorted by some non-linear action in the speech amplifier or modulator stage, the patterns of Fig. 39 will appear. In the trapezoid, the distortion appears as bright bands. The modulated wave pattern shows the distortion more obviously.

This condition may arise if an audio stage is overdriven in an attempt to raise the modulation level when the modulator does not have sufficient capacity to modulate the carrier 100%. The lack of capacity in the modulator may be caused by loss of emission in the modulator tubes, by a reduction of plate voltage in a stage in the speech amplifier or modulator driver, or by an increase in r.f. excitation.

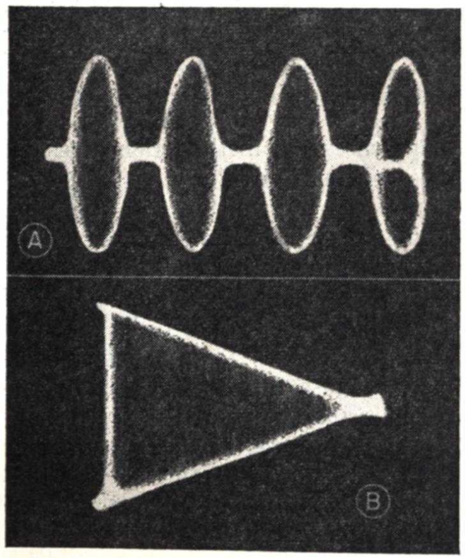


FIG. 38. Overmodulation is indicated by a modulated wave and a trapezoid pattern as shown in A and B respectively. Here, the modulated wave gives a better indication.

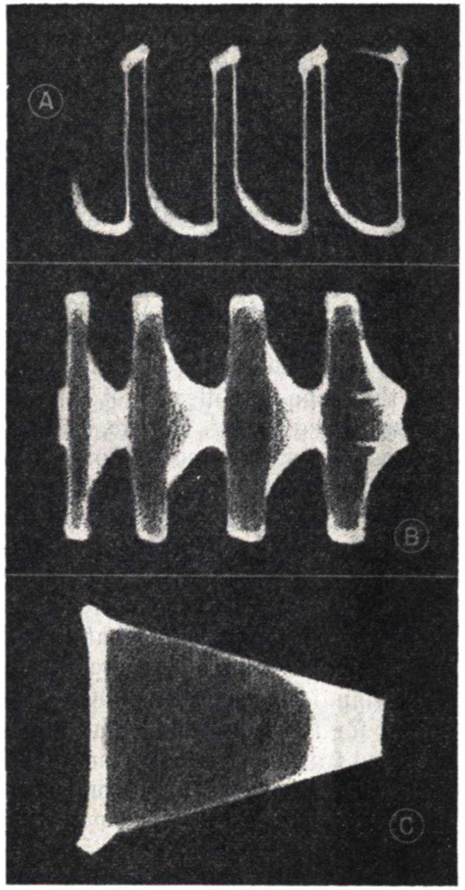


FIG. 39. A severely distorted audio signal A when used to modulate an r.f. carrier will produce the modulated wave of B, and the trapezoid of C.

The patterns resulting from overmodulation combined with distorted audio are shown in Fig. 40. Here again the modulated-wave pattern shows the conditions better than the trapezoid.

Insufficient R.F. Excitation. If the r.f. excitation of the modulated stage falls off because of reduced emission of a buffer or driver stage or because of a decrease in the anode potential in one of these stages, the patterns of Fig. 41 are produced. Notice the sloping sides of the trapezoid pattern and the flat top of the modulated-wave pattern. The modulation is said to be "downward" under these conditions, because the average power output of the transmitter does not increase as much as usual during modulation; in fact, it may even decrease.

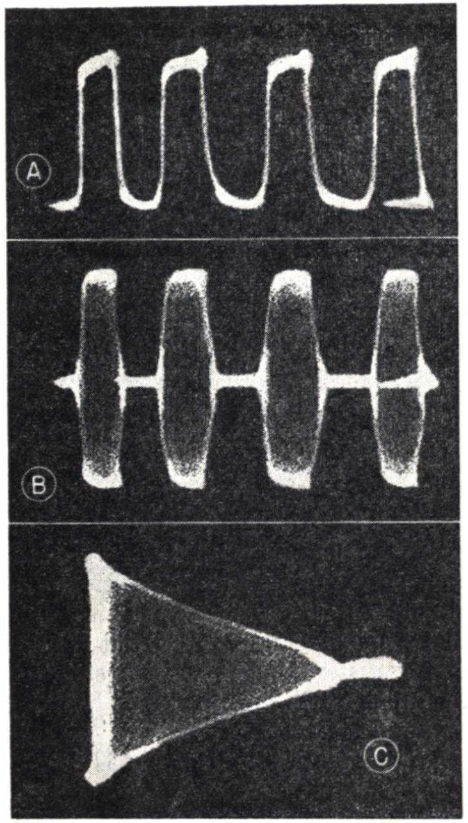


FIG. 40. Overmodulation and a distorted audio signal (shown at A) cause the modulated wave and trapezoid patterns of B and C.

Non-linear R.F. Output. Failure of the r.f. output of a modulated stage to vary linearly with the modulating voltage is shown more clearly by the trapezoid pattern than by the modulated-wave pattern. An example is shown in Fig. 42. Here the r.f. output voltage increases more on positive audio peaks than it decreases on corresponding negative peaks. This is called "upward" modulation, because the average output power of the trans-

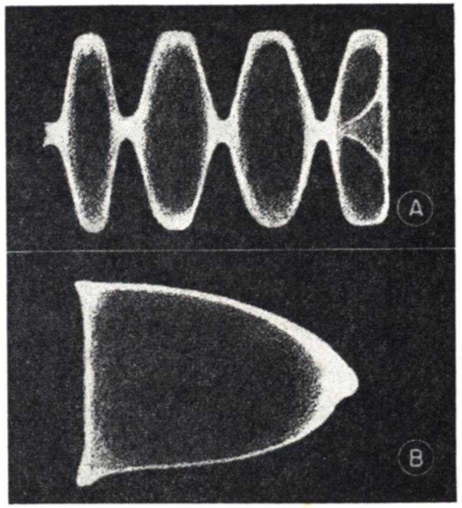


FIG. 41. Insufficient r.f. excitation of a modulated r.f. stage is shown here. Note in A the inability of the carrier to increase power on the positive peaks. This is an example of "downward" modulation.

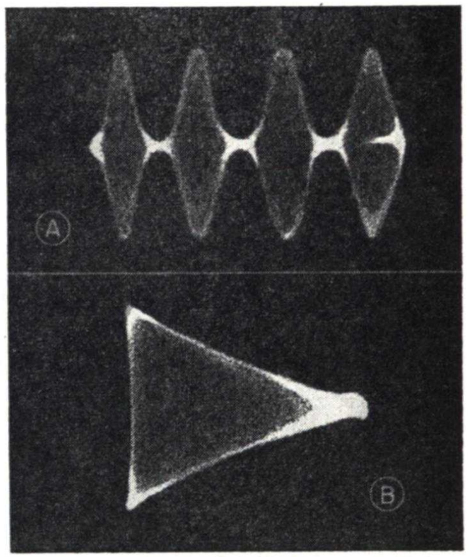


FIG. 42. Non-linear modulation causes the modulated-wave and trapezoid patterns of A and B. In this case the modulation is "up." During modulation, due to this distortion, the output will increase more than it should for a certain amount of modulation. Note that in this case the trapezoid is the more useful pattern.

mitter increases abnormally during modulation.

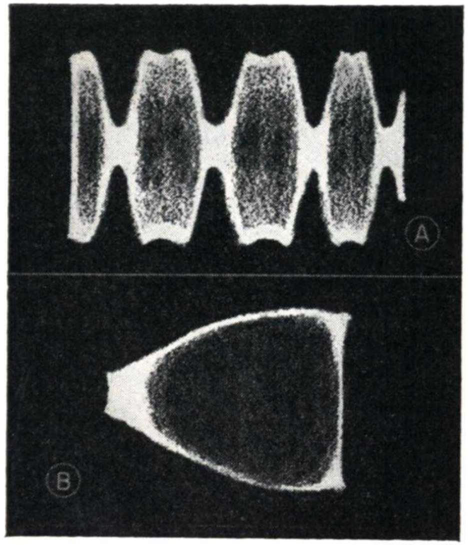


FIG. 43. When the plate tank circuit of an a.m. transmitter is tuned off resonance, these c.r.t. patterns are produced. Note the significant dip shown in the modulated wave pattern A. In B, the modulation is "down." During modulation the average power output may even decrease below the unmodulated value.

Improper R.F. Tank Tuning. When the plate tank circuit of an a.m. transmitter is tuned off resonance, the patterns in Fig. 43 are produced. Notice that the dip in the modulated-wave pattern indicates this condition clearly. This is another example of "downward" modulation.

Incorrect Impedance Matching From Modulation Transformer. An improper impedance match between the modulating and the modulated stage may occur when the transmitter is initially adjusted or may occur as a result of a change in some circuit component at a later date. Fig. 44 shows the patterns that result from each of the two possible mismatches.

If the output impedance of the modulation transformer is greater than the actual r.f. load impedance, the audio signal (Fig. 44A) is not appreciably distorted, but the r.f. stage is overmodulated. The patterns in Figs. 44B and 44C result.

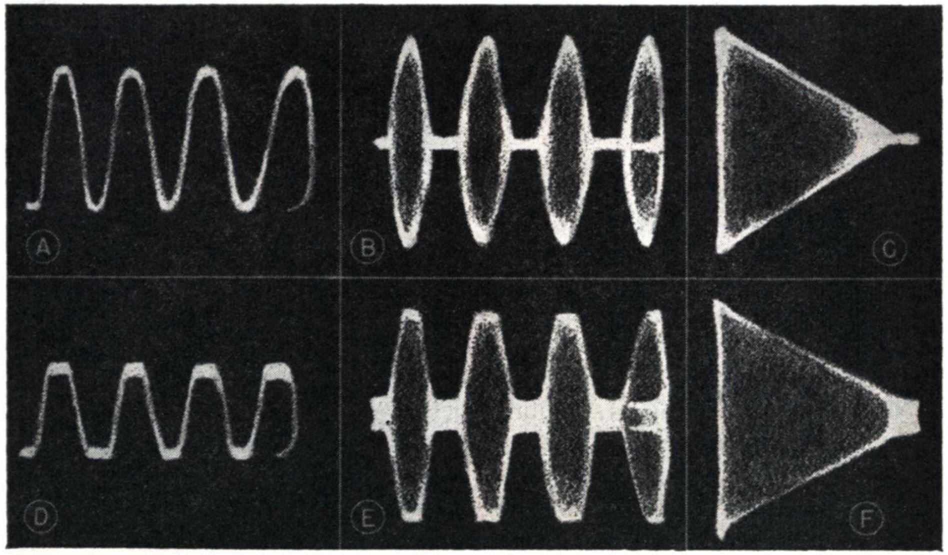


FIG. 44. If the modulation transformer is not properly matched to the modulated r.f. stage the distortions shown here will be present. In A, B, and C where C is the audio output of the modulator the transformer output impedance is higher than that of the load. This overdrives the r.f. stage. In D, E, and F the audio stage output impedance is lower than the load impedance and distortion occurs in the audio stage.

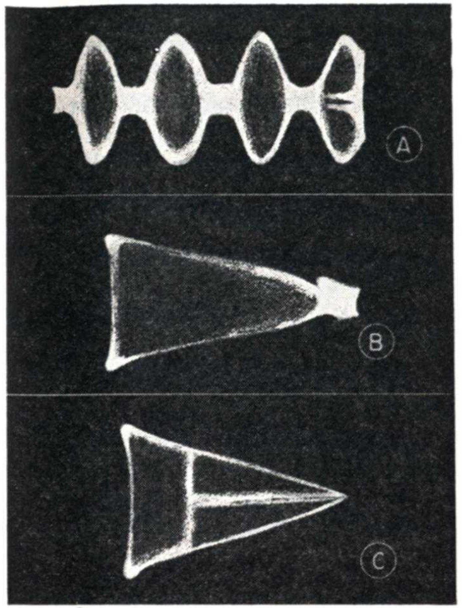


FIG. 45. If a modulated r.f. stage is improperly neutralized, regeneration will occur during the modulation cycle. This condition is more obvious in the two examples of B and C than in A.

If the output impedance is lower than the load impedance, the carrier is not fully modulated and the impedance mismatch causes distortion of the modulating signal (Fig. 44D). Figs. 44E and 44F show the patterns that result.

In each case, the modulated-wave pattern indicates the distortion more clearly than does the trapezoid.

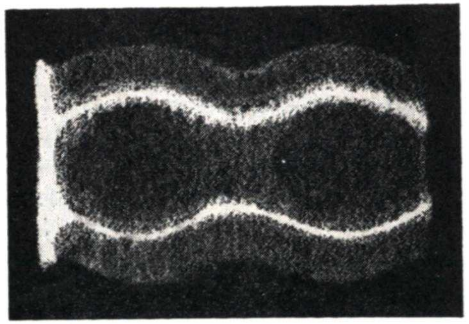


FIG. 46. This shows the modulated wave pattern of a transmitter with excessive 60-cycle hum modulation of a carrier modulated by a 1000 c.p.s. sine wave. In this case the linear sweep of the scope is set to 30 c.p.s.

Improper Neutralization. If a modulated r.f. stage is not properly neutralized, regeneration and possibly oscillation will occur during the modulating cycle. This can cause a variety of patterns; those shown in Fig. 45 are typical. The trapezoid patterns in B and C give somewhat better indications of this condition than does the modulated-wave pattern in A, but both types of patterns are useful.

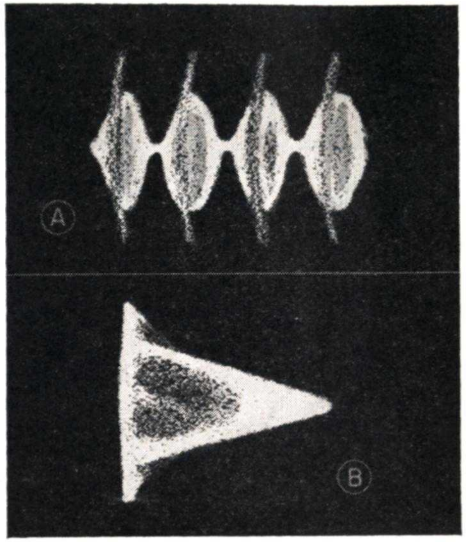


FIG. 47. Parasitics in a modulated r.f. stage will be indicated as shown in the modulated wave of B and the trapezoid of C. Note that the modulated wave pattern shows the trouble much more clearly. The modulating audio signal is shown in A.

Excessive Hum. Hum on the carrier of a radio transmitter is best observed by creating a modulated-wave pattern with the linear sweep set to a sub-multiple of the hum frequency. In Fig. 46 the effect of 60-cycle hum on a carrier modulated at 1000 c.p.s. is shown.

Parasitics. Parasitic oscillations can occur in several ways and a variety of c.r.t. patterns are possible. In Fig. 47 are patterns formed by parasitics in a modulated stage that appear only on positive modulation peaks.

Incidentally, the presence of parasitics does not indicate improper neutralization. The stage may be properly neutralized and still produce parasitics.

OTHER C.R.T. MODULATION CHECKING METHODS

There are two other types of c.r.t. presentations in which no sweep circuit is required.

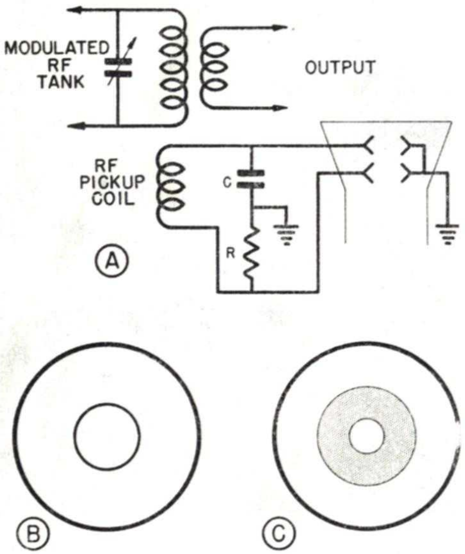


FIG. 48. In A is shown a method of obtaining a circle pattern on a c.r.t. (B) which under modulation produces the doughnut-shaped pattern of C. In C the degree of modulation is 50%.

Variable Circle Pattern. The first of these produces a circular pattern like that shown in Fig. 48. The modulated r.f. is picked up by a coil that is loosely coupled to the tank circuit and applied to a phase-shifting circuit so that two r.f. voltages 90° out of phase are obtained. An RC circuit like that shown in Fig. 48 can be used. The voltages across R and C are always 90° out of phase, and, since values are chosen that make R = X_c, the two voltages are equal. When these voltages are applied to the two sets of plates, a circle (Fig. 48B) is formed. Whenever the transmitter carrier is modulated, the circle fills in, producing a doughnut-shaped pattern (Fig. 48C).

100% modulation causes the circle to fill in completely. Over-modulation is indicated by a completely filled-in circle that has a bright dot in its center.

Double Triangle Pattern. The other method compares the unmodulated r.f. with the modulated r.f. frequency. Fig. 49A shows the circuit. The horizontal plates are connected to the crystal oscillator stage through a small capacity. When no modulation is present, a straight line appears on the screen at an angle depending on the voltage on the plates. This angle can be adjusted to 45° by making the voltages equal. In some cases an ellipse may be formed because of a phase shift between the oscillator and the final stage. This does not indicate faulty operation and can be corrected by shifting the phase at the cathode-ray tube to produce a straight line.

When the transmitter is modulated, the line pivots about its center and produces a double solid triangle. In Fig. 49, B indicates no modulation; C, 50% modulation; and D, 100% modulation.

This method is particularly useful because it can be used to detect phase (or frequency) modulation in an a.m. transmitter. When this occurs, the pattern of Fig. 49E is produced.

In each of the two above methods, any type of modulating frequency can be used. It can be fixed or variable.

THE C.R.T. AS A NEUTRALIZATION INDICATOR

Because the cathode-ray tube does not draw any current from the circuit to which it is connected, it makes an excellent neutralization indicator. To neutralize an r.f. stage, turn the filament of the stage on and apply excitation to the grid, but do not apply voltage to the plate. Connect the vertical deflection plate of the c.r.t. to the plate tank coil. Turn the tuning condenser through resonance. At resonance no r.f. should appear on the screen if the stage is properly neutralized. If r.f. is present, adjust the neutralizing condenser or condensers until the r.f. disappears from the screen. In a push-pull stage, adjust the neutralizing condensers in sequence step by step until no r.f. is present.

ANTENNA PHASING

We have shown how phase angle can be measured to within a few degrees with the oscilloscope. Such a measurement is very useful in adjusting a transmitter antenna, especially if two or more radiators are used to give a predetermined field pattern. In such a case, the signal to one antenna is fed to one pair of plates and the signal to the other antenna is fed to the other pair of plates. The phase of the antenna currents is then adjusted by a network in the "dog house" in the base of the antenna tower — usually by varying a variable condenser — until the desired angle is reached.

This adjustment, in some cases, must be made fairly often. One broadcast station, for example, has 4 vertical radiators placed at the corners of a rectangle ½-wavelength long and 1/3-wavelength wide. The shape of the radiation pattern depends on the phase relationship between the antennas, and the pattern, in this case, must be changed for night-time operation. To make it easy to check on this daily change, the transmission lines carrying the r.f. to the four towers are brought to a panel in the operating house. A switching arrangement allows any two towers to be checked for phase relationship. Marks on the c.r.t. screen show the correct pattern for each set of towers.

DISTORTION

The oscilloscope is useful in detecting distortion in any part of the station equipment. By feeding a sine-wave voltage into a microphone, a line, or an amplifier, you can soon detect distortion on the screen of the oscilloscope when the input voltage is varied. Three of the basic distortion patterns that you will encounter are shown in Fig. 50. Fig. 50A is the sine-

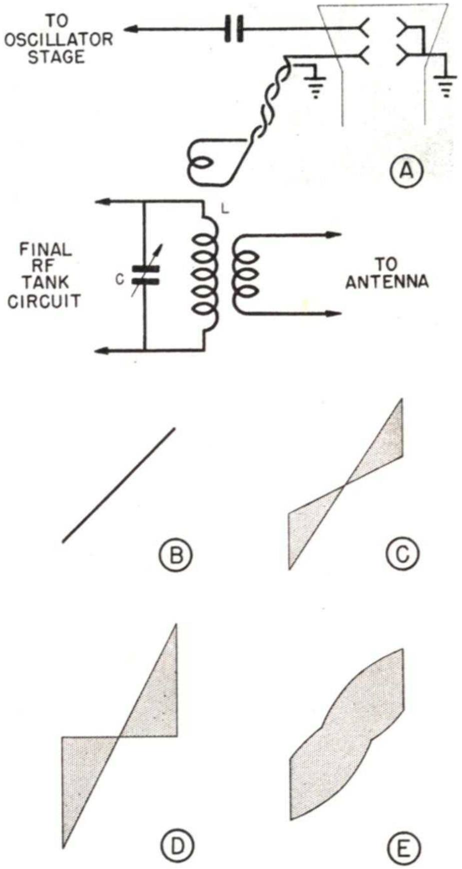


FIG. 49. How a cathode-ray oscilloscope can be used to detect phase shift in an amplitude-modulated transmitter.

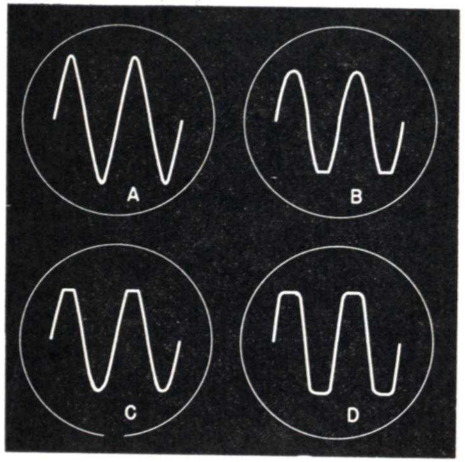


FIG. 50. Basic distortion patterns.

wave input, which should be reproduced at each stage. Figs. 50B and 50C show the distortion that occurs if a stage is operating non-linearly: in 50B the stage is overdriven on negative peaks, in 50C it is overdriven on positive peaks. Fig. 50D shows that the stage is operating linearly but is overloaded.

FREQUENCY RESPONSE

There is available a recording which can be used in place of an audio oscillator for periodic checks on "off periods." This recording has a frequency sweep from 20 to 10,000 c.p.s. and repeats itself every 1/10 second. The horizontal sweep on the oscilloscope is set at 1/10 second (10 c.p.s.), and the output of the stage to be checked is applied to the vertical deflecting plates. This allows a pattern of the complete frequency response to be viewed on the screen at one time. This method is convenient, saves time, and can be used to check the frequency response of all the station from amplifiers through the antenna.

Lesson Questions

Be sure to number your Answer Sheet 39RC.

Place your Student Number on *every* Answer Sheet.

Most students want to know their grade as soon as possible, so they mail their set of answers immediately. Others, knowing they will finish the next Lesson within a few days, send in two sets of answers at a time. Either practice is acceptable to us. However, don't hold your answers too long; you may lose them. Don't hold answers to send in more than two sets at a time or you may run out of Lessons before new ones can reach you.

1. What is the purpose of varying the first anode voltage of a c.r.t.?
2. Which set of deflecting plates is more sensitive, *the set nearest the screen, or the set farthest from the screen?*
3. Why are the deflecting plates of a c.r.t. at approximately the same d.c. potential as the second anode?
4. What is the purpose of the saw-tooth voltage in a c.r.o.?
5. If you want fewer cycles of the signal showing on a c.r.t. screen, would you *increase* or *decrease* the horizontal sweep frequency?
6. Why should the synchronizing voltage (SYNC control) be adjusted so that the least amount giving a stationary image is used?
7. When synchronizing the sweep of a c.r.o. to make the pattern "lock in," is the sweep frequency adjusted *above, below*, or the *same* as the synchronizing signal frequency?
8. Why should the INTENSITY control of a c.r.t. be reduced when the image is only a spot on the screen?
9. Draw a sketch of the trapezoid pattern indicating 50 per cent modulation.
10. What type of c.r.t. pattern can be used to detect frequency modulation in an a.m. transmitter?

Be sure to fill out a Lesson Label and send it along with your answers.

STICK — AND YOU'LL WIN!

"How can I be a success?" The simplest answer to that question is "finish whatever you start."

Until success is attained, the individual tasks confronting you are relatively unimportant in themselves. The really important thing is their effect upon you, what you *learn* from them, the *practice in succeeding* that you acquire in accomplishing these tasks.

We can always find plenty of reasons for quitting, but what do we accomplish, what do we learn by quitting? We only learn how to quit—how to fail.

If success in any undertaking is dependent upon effort (and we all agree that it is), then the more effort we make, the greater our success. You may not be able to trace the success present in every effort, but it is there just the same. You don't attain success in one jump. You succeed by degrees, and the degree of success is in exact proportion to the degree of effort.

"*Nothing succeeds like success.*" What does this mean? Simply that each success paves the way for further successes. Failure is merely a ceasing of effort —quitting—giving up. You can't fail unless you quit trying, so stick with each job until you win, and add it to your list of successes. It is not the jobs themselves that bring success; it's what you do with them.

J. E. SMITH