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CATHODE-RAY TUBES AND THEIR ASSOCIATED CIRCUITS

DEPARTMENTS OF THE ARMY AND THE AIR FORCE

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CATHODE-RAY TUBES AND THEIR ASSOCIATED CIRCUITS

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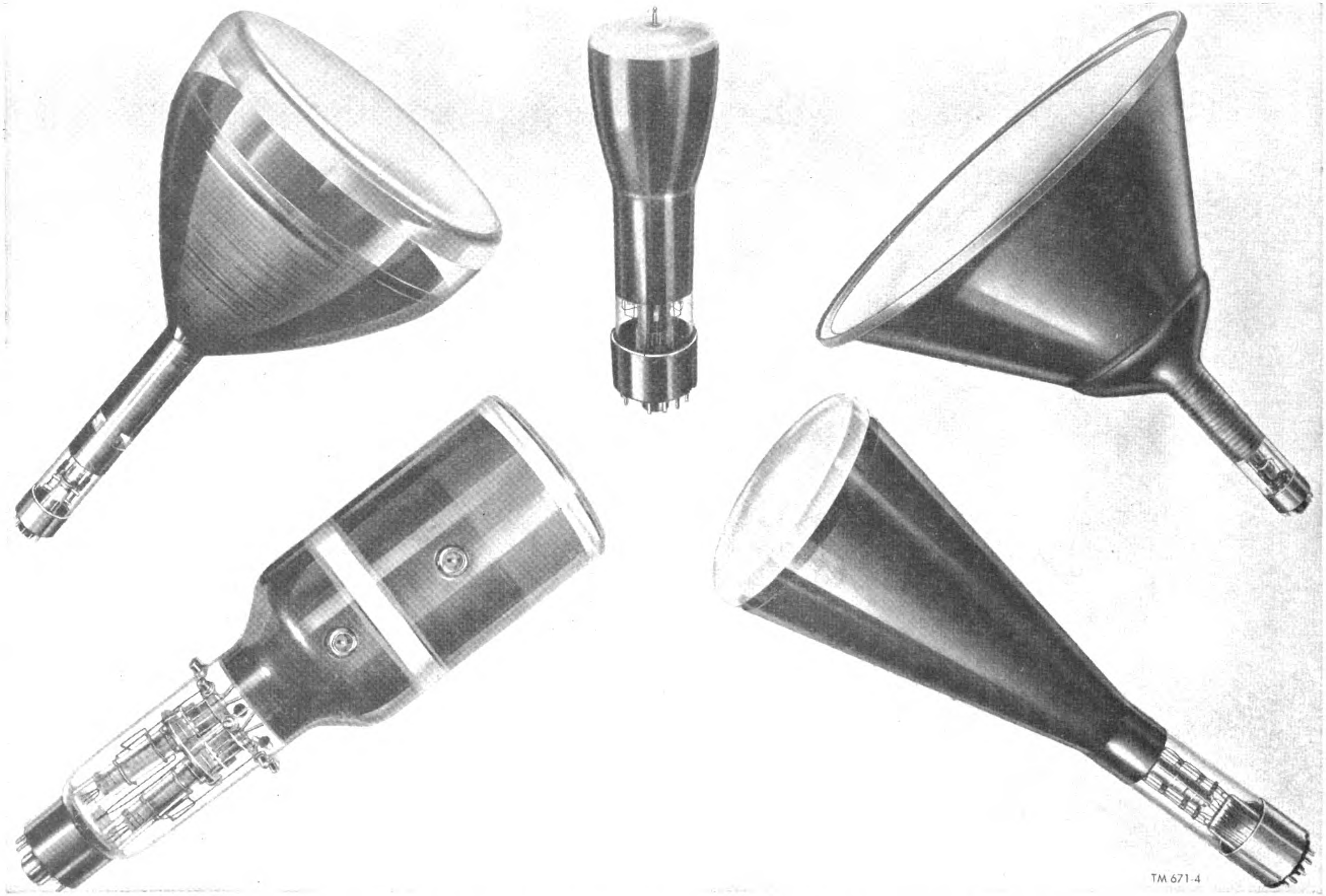

Figure 1. Present-day cathode-ray tubes, showing the characteristic thin neck and flared end.

CHAPTER 1

FUNDAMENTALS OF CATHODE-RAY TUBES

Section I. INTRODUCTION

1. Historical Background

a. Development of Cathode-Ray Tubes.

(1) In 1898 a research worker, Karl F. Braun, created a new type of vacuum tube. Present-day vacuum tubes were then unknown (although the diode had made its appearance), but experiments with various kinds of tubes from which air had been withdrawn had been conducted for some time. The Braun tube was the result of numerous developments over the years, and it is discussed here because it can well be called the forerunner of modern cathode-ray tubes.

(2) Construction of the device was relatively simple, as illustrated in figure 2. The envelope was glass. A metal plate, K, was located inside the housing, at one end, with a connection extending through the glass. A thin metal electrode, A, which served as the anode, was located at a distance along the axis of the tube. This electrode extended upward into the envelope, but an essential part protruded through the glass housing in order to permit an electrical connection. A baffle, B, with a tiny hole at its center, was located approximately halfway along the length of the tube, near the end of the narrow neck. This baffle just fitted the inside diameter of the neck. An insulated plate, on which was a thin deposit of special chemicals, was located at the other end of the tube, near the inside surface of the flat portion. This plate was the screen, SC.

(3) Operation of the device was simple. It was a high-vacuum tube and a high voltage, as much as 50,000 volts, was applied between the cathode, K, and the anode, A, so that the anode was positive relative to the cathode. The high difference of potential between these two electrodes resulted in the forcible extraction of *negative charges* from the cathode and their acceleration toward the screen. At the time the Braun tube was developed, the association between charges drawn from the cathode and the electrons was still in doubt. The fact had been established, however, that the cathode particles carried a negative charge and could be attracted by a positively charged plate. It was not until several years later that the negative charges became known as *electrons*. Consequently, it is not strange that the particles pulled out of the cathode gave the tube the name *cathode-ray* tube.

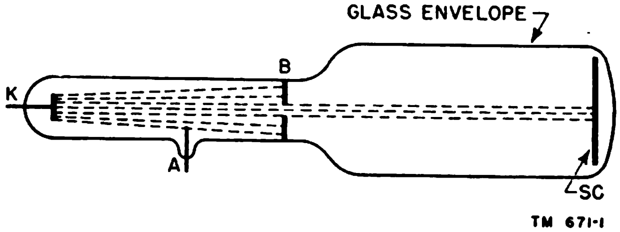

Figure 2. Cross-section view of Braun tube.

(4) The charges left the cathode at random (in a forward direction) as shown by the dotted lines in figure 2, but because of the baffle many of them were blocked from the screen. A sufficient number of these charges, however, penetrated the opening to form a thin stream and continue to the screen. Their presence in the tube and their arrival at the screen were indicated by a glow on the screen at the point where the beam of charges struck. This action is called *fluorescence.*

(5) The ability of the cathode rays to make certain substances fluoresce under their impact had been known for some time, even though the exact process involved was only surmised. Also, it was known that a stream of such charges could be *deflected*, or moved, from its normal path by certain fields. This action is understandable because surrounding the moving charges are fields which react with either an externally applied electromagnetic field or an externally applied electrostatic field.

(6) The early cathode-ray tube was intended as an *indicator* of the behavior of a cathode-ray stream when acted upon by such external fields. The means for observing the action of the stream of charges was the glow on the screen. As long as the beam charges remained in one position, the location of the glow on the screen would remain fixed. When some action caused the beam of charges to deviate from its normal path, the change would be indicated by a new position of the point of glow. Consequently, the movement of the cathode-ray stream could be followed by observing the screen. Changes in the electrostatic and electromagnetic fields could be noted by the effect they had on the charges and this in turn would be displayed by the screen. Therefore, association of one change with another was made very simple.

(7) The purpose of the cathode-ray tube has never changed. The function of the modern tube is the same as that of the original Braun tube—that is, it is an indicator. The modern tube uses a beam of electrons, the deflection of which is accomplished by electrostatic or electromagnetic fields, or both. The indication that appears on the screen is the result of fluorescence of the screen material by the bombarding electrons. The present-day tube also indicates the movement of the electron beam while the latter is under the influence of varying electrostatic and electromagnetic fields, except that now it is the voltage or the current responsible for these fields which is the subject of investigation or which is associated with the trace developed on the screen by a moving dot of light.

(8) The requirement of a high voltage on the anode of the Braun tube, to pull electrons out of the cold cathode, imposed numerous and serious limitations on the utility of the device. Because vacuum-tube amplifiers were unknown in 1898 and because the high anode voltage imparted a high velocity to the charges in the stream, the device was usable only when high voltages and high currents were available for the creation of strong electrostatic and electromagnetic deflecting fields. Among the means for introducing the electrostatic fields was the application of a high voltage across a pair of parallel plates. These plates were located one on each side of the tube envelope along the path of the charges between the baffle and the screen. The electromagnetic deflecting field was created by two flat current-carrying windings in series, one on each side of the tube and so located that their fields aided each other.

(9) The control grid was added to the vacuum tube by DeForest. Vacuum-tube amplifiers made possible the expansion of the field of electronics, particularly long-distance telephony and radio communication. Electronics experimenters became extremely interested in all means which would facilitate the investigation of electric and magnetic effects at the frequencies which were in use. As the knowledge concerning circuit behavior increased, more new, useful circuits were conceived. Work of this kind went on in all laboratories, including the military, but, because of the limitations of the research equipment available at that time, the activity was continually beset with difficulties.

(10) A new type of cathode-ray tube was developed by J. B. Johnson, for whom it was named, and announced in 1921. Although it resembled the old Braun tube, it contained many new features of great value to the scientific world. Figure 3 is an outline drawing of this tube showing its various elements.

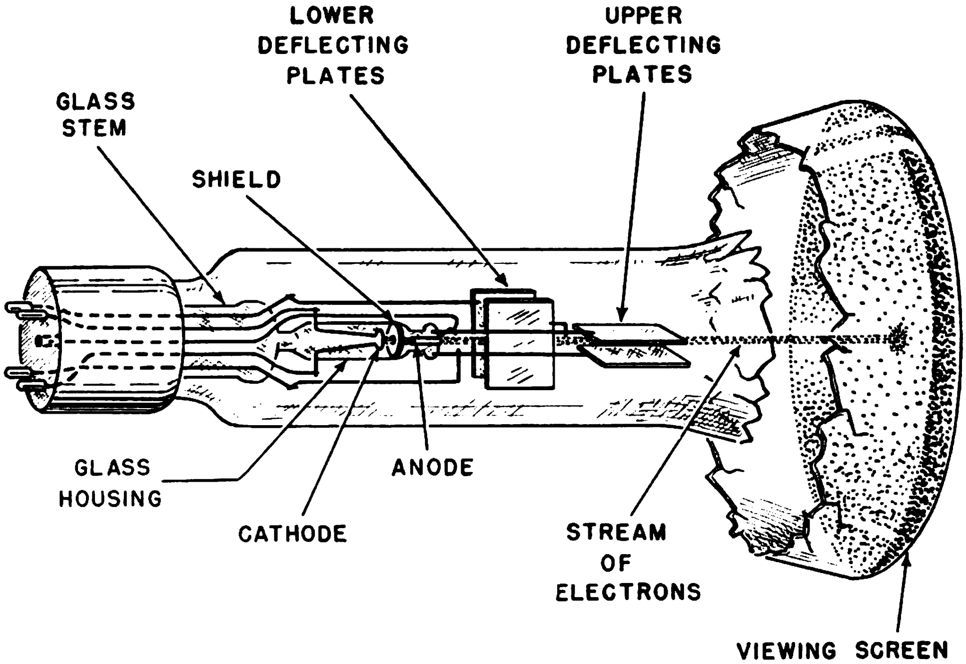

Figure 3. Johnson cathode-ray tube.

(11) The Johnson tube was made of glass and had a narrow neck which flared out and ended in a flat surface. Within the narrow part of the tube was a filament which could be heated by an external battery to a temperature high enough to emit electrons. Directly above the emitting part of the filament was an assembly consisting of a shield, with a tiny hole at its center, and a tubular anode. The filament, the shield, and a part of the anode were sealed within a glass stem. The anode received a voltage from a battery which made it about 300 volts positive relative to the filament. The emitted electrons were, therefore, attracted toward the anode. Those which penetrated the tiny opening in the shield passed through the hollow core of the anode out into the main portion of the envelope and advanced toward the screen of the tube. This screen consisted of a thin deposit of special substances on the inside surface of the flat end of the tube. Fluorescence of the screen could be observed through the glass face of the tube.

(12) Two pairs of parallel plates placed at right angles to each other one above the other were located above the tubular anode. These were the deflection plates. They were so positioned that the undeflected electron beam passed through the center of the space between each facing pair.

(13) Adoption of electrostatic deflection was a forward step in the design of cathode-ray tubes. The Johnson tube was the first to use two electrostatic fields for beam-deflecting purposes and the first to establish this arrangement as a definite feature of such indicator tubes. The reason *two* pairs of deflection plates were used may not be evident at this time and will not be treated here because it is explained later in this chapter. Let it suffice now to say that two voltages, usually alternating, were applied to these plates in order to control the beam; one was the voltage being investigated and the other was a *timing* voltage.

(14) Another significant improvement in cathode-ray tube construction was the addition of a small amount of argon gas to the envelope. It performed an important function. The presence of argon gas ions in the space between the anode

and the screen caused the electrons to form into a narrow beam which, through variation of the filament-to-anode voltage, could be made to develop a sharply defined, tiny dot of bright light wherever it struck the screen. This adjustment was called *focusing*.

(15) The Johnson tube was a great step forward for several reasons. First, the hot filament electron emitter permitted the use of a low anode voltage, 300 volts in comparison with 50,000 volts used in the early Braun tube. This meant that the velocity of the charges in the beam was relatively low, and the intensity of the electrostatic field required for deflection was much reduced. This represented a substantial increase in the sensitivity of the tube. Second, the improved characteristics of the screen material used produced a more satisfactory image. Third, the general structural organization of the elements was better, especially the closeness of the plates in each pair.

(16) Although the hot-cathode Johnson tube contributed tremendously to the development of electronics, it still was not all that was desired. The presence of gas ions in the beam which struck the screen made the beam, as a whole, relatively heavy and so imposed a limit upon the frequency of the voltage which could be used to deflect the beam. The heavy gas ions could not move as rapidly as the lighter electrons—that is, they could not follow the changes in the voltage applied to the deflection plates. The result was that the upper frequency limit relative to application was about 100,000 cps (cycles per second). This was entirely too low to meet the needs of the electronic art, which already was dealing with radio frequencies, although 100,000 cps was much higher than the 25 to perhaps 100 cps which was the limit of the early Braun tube.

(17) The modern cathode-ray tube (fig. 4) is directly comparable with the Johnson tube because it is of the electrostatic deflection type. As can be seen in the illustration, the modern version is somewhat more complicated internally but it is a greatly improved device. It is a high-vacuum tube from which the oxygen has been removed, and it uses a hot cathode. The focusing of the electron beam so that it produces a bright sharp spot on the screen is accomplished more easily than before. Above all, the tube is stable in performance. In direct comparison with the Johnson tube, the modern version is somewhat less sensitive. This is unimportant, because vacuum-tube amplifiers used with present-day tubes give the system, as a whole, as much sensitivity as is desired for most uses.

(18) The source of the electrons is an indirectly heated cathode. An assembly of

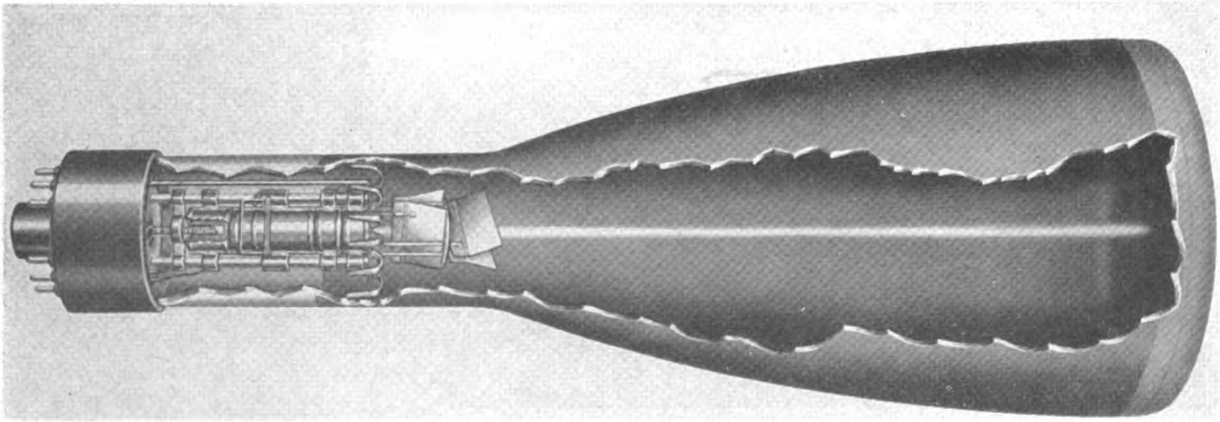
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Figure 4. Modern cathode-ray tube of electrostatic-deflection type.

cylinders to which various control d-c (direct-current) voltages are applied is responsible for the control of the electrons and their formation into a very tightly packed beam, and is also responsible for the acceleration of the beam toward the screen. The screen is a deposit on the inside surface of the flat end just as in the Johnson tube. The electrostatic deflection plates are traversed by the electrons after they have been formed into a beam.

(19) The tube shown in figure 4 is just one example of a group. There are others of different lengths and screen diameters, as well as kinds which utilize electromagnetic fields for the accomplishment of many actions. Figure 1 shows a group of typical tubes. Each of these is explained later in this chapter. All tubes, whether electrostatic or electromagnetic, have the same distinctive physical outlines shown in figure 1.

b. IMPORTANCE OF CATHODE-RAY TUBE.

(1) The importance of the cathode-ray tube in military applications stems from a number of its capabilities. Several have been mentioned, but it is well to emphasize them again and to state the others. These are—

(*a*) The ability to portray visually the manner in which an electrostatic field changes in intensity, and in that way afford a display of the instantaneous changes in the voltage which is responsible for the field—namely, voltage wave shape.

(*b*) The ability to portray visually the manner in which an electromagnetic field changes in intensity, and in that way afford a display of the instantaneous changes in the current which is responsible for the field—namely, current wave shape.

(*c*) The ability of the electron beam to follow field intensity changes at all frequencies from 0 up to 10,000 mc (megacycles) or higher, which means the visual display of voltages, transient or recurrent, within this frequency range.

(*d*) The ability to control the intensity of the screen fluorescence or the brightness of the spot on the screen from zero to maximum.

(*e*) The ability deliberately to position the luminous dot of light with any degree of brightness at any particular point on the screen by arranging deflecting fields which have predetermined characteristics. In this way, the point on the screen struck by the electron beam can be preset automatically and any desired type of pattern can be developed.

(2) The aggregate of all these facilities is an *indicator* which, when used with different kinds of apparatus, can present a wide variety of information for visual examination. The kind of information is determined by the design of the associated apparatus and its purpose. The electrostatic and the electromagnetic fields that are called to act on the beam are only a means to an end. Every characteristic of a periodic quantity, such as frequency, phase, amplitude, harmonic content, duration, and others, can be determined by making this quantity responsible for the production of the field which deflects the electron beam.

(3) Many military needs require the timing of actions of very short duration. The cathode-ray tube is an ideal indicator because of the frequency response characteristics of the electron beam. The shorter the time interval involved, such as several microseconds or even fractions of a microsecond, the greater is the value of the cathode-ray tube as the display element. In fact, this special kind of vacuum tube made radar practical because it afforded a convenient visual display of the time interval between the departure of the searching signal and the instant of return of the echo. Examples of the many kinds of patterns developed on radar screens are illustrated in chapter 6 of this manual.

(4) The ability to position the beam at any point on the screen and the automatic control of the brightness of the spot by suitable deflecting fields are the founda-

tion of the display which appears on a television receiver picture tube. Such a picture is formed by a traveling dot of light of varying brightness as determined by the individual elements of the scene being televised.

c. Uses of Cathode-Ray Tube.

(1) The cathode-ray tube cannot be used alone. Associated circuits and equipment have to be used with it; these will be described later in this manual. The content of the display on the screen is a function of the related circuits or equipment. The interpretation of the display is determined by the purpose of the entire system.This means that like-dimensioned cathode-ray tubes may be found in a wide variety of armed forces equipments, each of which may be designed specifically to develop certain definite kinds of data. On the other hand, unlike-dimensioned cathode-ray tubes may be found in different equipments which are performing like functions, but because of the individual requirements of the system cathode-ray tubes of different lengths and different screen diameters are used.

(2) From the viewpoint of application, cathode-ray tubes may be grouped into two categories—indicators in test and measuring equipment and indicators in receiving equipment. The test and measuring equipment group is completely covered by the general title of oscilloscopes. In these devices, an example of which is shown in figure 5, the cathode-ray tube is the display element on which is portrayed the electrical quantity being investigated. This may be of varied nature, as determined by the design of the electronic equipment used with the cathode-ray tube, and also as determined by the electrical conditions in the circuit being examined. Voltages and currents of all kinds in receivers, transmitters, oscillators, amplifiers, in fact, virtually all kinds of electronic equipment used by the armed forces, may be examined visually and all characteristics may be determined.

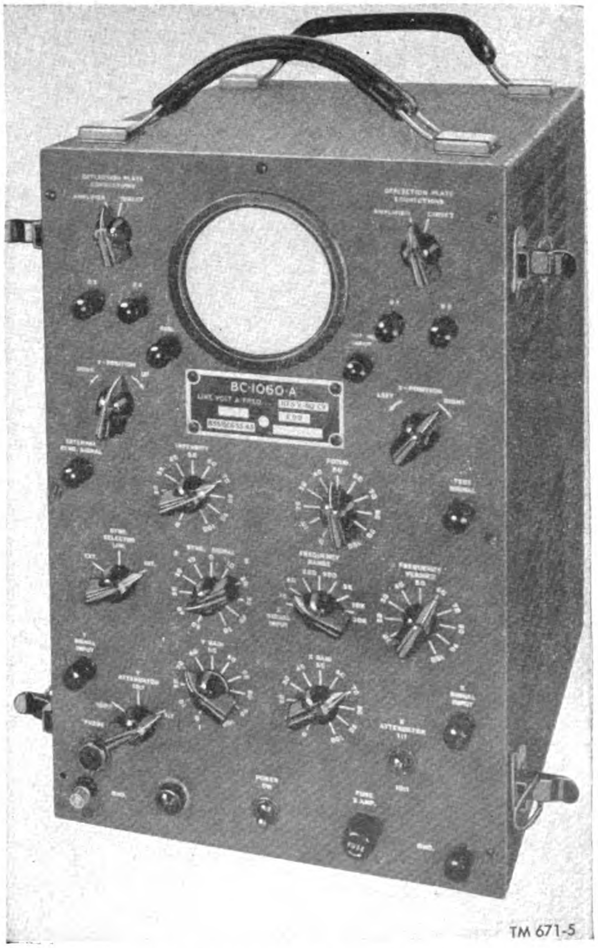

Figure 5. Typical oscilloscope.

(3) The nature of these voltages and currents and their origin in a system are seldom limiting factors. Means usually are provided for probing into almost all parts of the circuits used in these equipments. Since the electrical quantities are determinable, circuit performance, as well as the need for circuit adjustments, is clearly shown on the screen of the tube.

(4) The second category of cathode-ray tubes includes radar systems, other applications of the electromagnetic wave echo principle, and television receivers. Although many different functional names, such as range, azimuth, elevation scopes, or PPI scopes (plan-position-indicator oscilloscopes) may be assigned to the indicators in accordance with the uses of the device, their general principles of operation are similar. The names do

not denote changes in operating theory, but rather state the purpose of the indicator in the entire system and the nature of the information displayed on its screen. An example of a radar indicator unit is shown in figure 6.

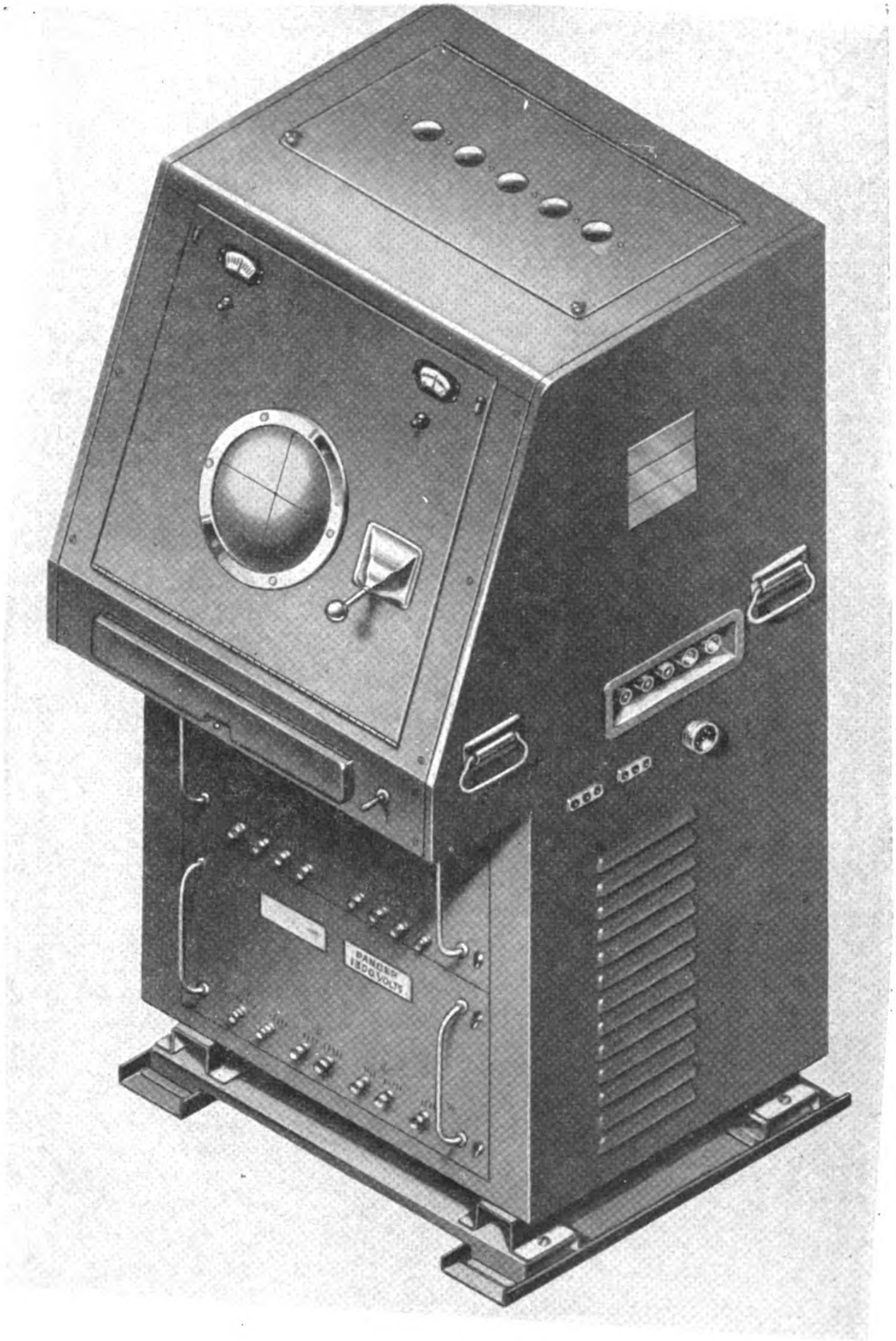

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Figure 6. Military radar indicator unit.

2. Motion of Electrons in Electrostatic Field

a. Nature of Charged Bodies. The atoms which constitute all matter are composed of elementary particles of electricity known as electrons and protons. The amounts of electricity represented by these two basic particles are equal, but the magnitude of the elemental charges is far too small to be of much practical use. A *charged* body contains an excess or a deficiency of a large number of electrons. Charge in solid bodies usually is described by referring to either addition or removal of electrons rather than of protons. Electrons are more mobile because of their much smaller mass (1/1850 that of the proton) and are forced more readily to move from place to place. Any body which has been forced to accept more electrons than it normally holds is said to be charged *negatively.* A body which has been forced to lose some of its electrons is said to be charged *positively.*

b. Electric Fields and Lines of Force.

(1) Bodies bearing charges react in a certain manner upon each other. For example, a hard-rubber comb assumes a negative charge if it is run through the hair a few times. If the comb is brought near some small bits of paper, the latter are given an opposite charge. The result is that the comb attracts the paper. A glass rod as-assumes a positive charge if it is rubbed with a silk cloth. If the rod is brought near some small bits of paper, they are given an opposite charge, and the rod then attracts them. Evidently some force exists between the bodies. The *field* concept was introduced to explain these occurrences. An *electrostatic field*, sometimes called an *electric field*, is a region in which electric forces are acting. This field represents energy, or the ability to do work. The work is done in the form of a force that is exerted on other charges within the field. Hence, the electrostatic field, or electric field, may be referred to as a *field of force.* Consider two neutral bodies, such as a pair of small pith balls freely suspended by fine threads. One of these is given a positive charge when touched by the positively charged glass rod mentioned above. The other is given a negative charge when touched by the negatively charged rubber comb. Electrostatic fields now exist around these two oppositely charged bodies. The electric field around the positively charged ball exerts a force on the negatively charged body. The electric field surrounding the negatively charged body exerts a force on the positively charged ball.

(2) These fields are invisible and can be detected only by the effects they produce. In order to assist in visualizing them, the artifice of *lines of force* is used. These lines have no reality and are merely a convenient way to represent the patterns formed by the electric fields. They are the paths along which the force is exerted. This force not only has definite magnitude but also acts in a definite direction. Hence, the lines of electrostatic force usually are represented as arrows, to indicate direction.

(3) Two conventions exist as to the direction of a line of electric force. One practice is to consider the effect of the field on a unit positive test charge. This charge would be repelled by a body having a positive charge and would be attracted to a body having a negative charge. Therefore, a line of electric force would have a direction from the body or region of positive charge to the body or region of negative charge, or from positive to negative. If the unit test charge is considered to be negative, the direction indicated above would be reversed (fig. 7). In the cathode-ray tube we are interested only in the effect of the field on the elec-

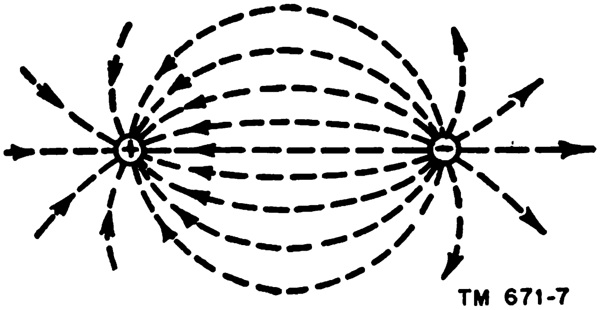

Figure 7. Electrostatic field between two bodies with unlike charges in which the direction of the lines of force is indicated by the effect of the field on a unit negative test charge, such as an electron.

tron, which is the basic negative charge. For that reason, the direction along which the electrostatic line of force acts is shown from *negative to positive*, as this is the direction of electron motion.

(4) The lines of electrostatic force have two important properties. First is the property of lengthwise contraction. A stretched rubber band tends to contract along its length and in so doing accomplishes work by converting potential energy into energy of motion, called kinetic energy, and also heat. The potential energy present along a line of electric force may be converted to kinetic energy and heat when that line of force contracts. This means that a stationary charge, such as an electron, may be moved.

(5) Second, lines of force acting in the same direction have the property of lateral repulsion. Therefore, the lines of force which join two charges are curved at points other than on the straight-line axis between the charges (fig. 7). Because of the equal repulsion on both sides of the axial line of force, this line is straight. At distances from the axis, the lines of force curve outward because of the greater repulsive force from the direction of the axis and the smaller repulsive force from the outer side of the force line.

c. **Fields Between Unlike Charges.**

(1) It is a basic law of physics that unlike charges attract each other and like charges repel each other. This law is based on observation, experiment, and analysis. The lengthwise contraction of the electrostatic lines of force was assumed as an aid in the explanation of this phenomenon.

(2) Consider two small bodies which are charged oppositely (fig. 7). These two bodies tend to attract each other. Lines of electrostatic force are shown connecting them. Every line of force between two charges should be shown joining these two charges. However, because of limitations in illustrating, some of these lines are shown incomplete. The unlike charges may be far apart without in any way altering the condition that lines of force from a negative charge will terminate on a positive charge. Although the magnitude of the force exerted will be quite small with widely separated charges, this does not change the over-all picture.

(3) There should be no space between the lines of force. This would imply that between the lines no force is felt. Actually, all the area should be understood to be filled with the lines of force, but because of the limitation of illustration only certain lines are shown. These lines represent force per unit area perpendicular to the lines. The spacing of the lines has a quantitative aspect; where the lines are concentrated, the field is intense.

(4) In the event that the two unlike charges are distributed uniformly over the surface of large or irregularly shaped bodies, the pattern of the lines of force is quite different. However, the general principles which have been given still apply.

d. **Fields Between Like Charges.**

(1) Consider the configuration of the electric field between two like charges (fig. 8). The lines of force shown seem to have no termination. This appears to be true be-

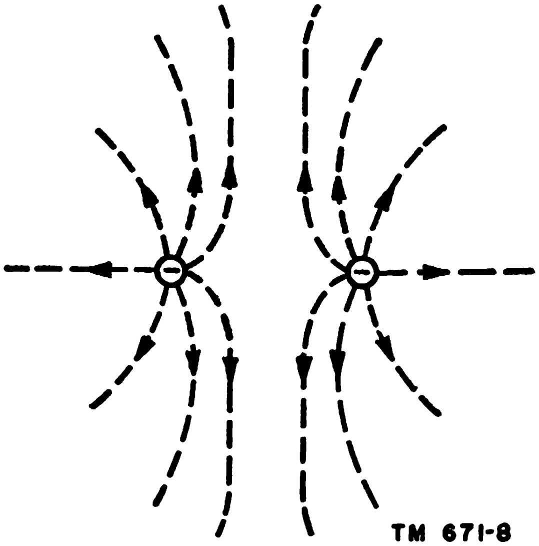

Figure 8. Electrostatic field between two like charge (negative) showing the lateral repulsion effect and th flattening of adjacent lines of force having the sam direction.

cause only part of the fields can be shown in the illustration. What actually is shown is that section of two separate fields extending between two unlike charges (one being shown and the other existing at some remote location in space), which is in the vicinity of the two like charges.

(2) The repulsion which exists between two like charges is due to the lateral repulsion between lines of force having a similar direction. The charges, being attached to the lines, likewise feel the same forces and move apart. The motion of the charges is caused by these repulsive forces between similarly directed lines of force. Since lines of force cannot cross, the distortion indicated in figure 8 results. If the charges are prevented from moving because of the nature of the system, the repulsive forces are still present. The facing lines of force are flattened along their length as a result of the repulsion between them.

e. Forces in Field Between Charged Plates.

(1) Two parallel metal plates are arranged a short distance apart and then are connected to a source of d-c voltage. Plate C (fig. 9), which is connected to the negative terminal of the voltage source, has an excess of electrons and is charged negatively. Plate A, which is connected to the positive terminal of the voltage source, is positively charged. An electrostatic field is created between the plates, and the space is filled with lines of electrostatic force. Most of the lines of force that are shown joining the oppositely charged plates are straight because of the balanced repulsive forces around the lines. With forces of equal magnitude tending to repel each line from all directions, the balancing of these forces leaves the line straight. This is not true of the lines at the borders of the plates, or fringing area. These lines curve outwardly because of the unbalanced forces. Disregarding the nonuniform fringe field, the rest of the field can be seen to be a *uniform field.*

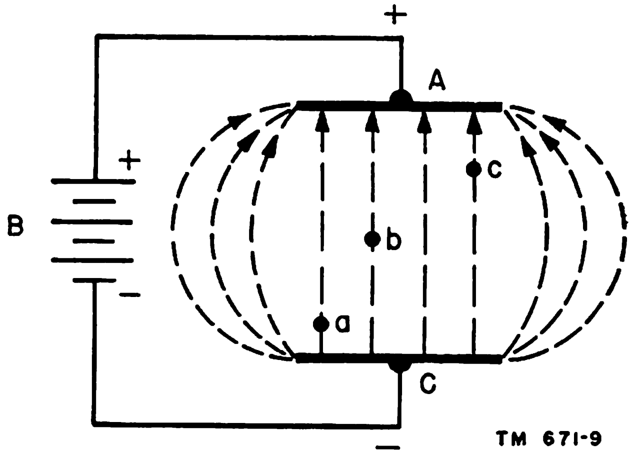

Figure 9. Electrostatic field between two charged plates showing the uniform field consisting of parallel lines of force and the fringe field consisting of curved lines. Three individual electrons, a, b, and c, are shown in field.

(2) Before a charge was placed on the metal plates, a balanced condition existed, and an equal number of electrons were present on both plates. During the course of charging the plates, it was necessary for work to be done on the electrons. The force needed to accomplish this work was applied by the voltage source. This voltage source thus introduces the initial difference of potential or electromotive force that is needed to make the electrons move around the circuit. As the electrons are transferred from one plate to another, they convey energy and gradually establish a corresponding difference of potential between the plates themselves. When the electrons finally come to rest and the plates have been charged to the voltage of the power source, the energy which was imparted by the voltage source has been transferred to the electrostatic field. The charge in the plates establishes a corresponding difference of potential between the plates themselves. The difference of potential between the two parallel facing plates represents the capabilities of the electrostatic field to make electrons move, just as the original difference of potential from the voltage source enabled the electrons to move through the system initially.

(3) If three individual electrons are located within the uniform electrostatic field (fig. 9), these electrons are acted upon by that field. The positively charged plate A attracts the electrons a, b, and c; the negatively charged plate C repels these electrons. Both of these forces are acting in the same direction. The electrons are made to move away from the negatively charged plate and toward the positively charged plate. Electron b, which is located midway between the charged plates, experiences equal force of attraction and repulsion, both tending to move b in the same direction. Electron a, which is nearer the negatively charged plate, experiences a greater force of repulsion because of its nearness to the negatively charged plate. It feels a smaller force of attraction to the positively charged plate because of its greater distance from that plate. The total force exerted on electron a therefore is maintained in the same manner as that exerted on electron b. Electron c, located nearer the positive plate, experiences a reduced repulsion force from plate C but an increased attractive force from plate A. The total force exerted on electron c is the same as that exerted on electron b. Regardless of the location of an electron within the uniform electric field, the force exerted is the same. Also, the electron tends to move in a direction which is parallel to the electrostatic lines of force.

(4) The field does work on the electrons, which acquire kinetic energy from the potential energy contained in the field. To specify the magnitude of energy gained by the electron, the term *electron volt* is used. If the difference of potential between the pair of parallel plates is 1,000 volts and if the electric field accelerates the electron from one plate to another, or through 1,000 volts, the electron has gained 1,000 electron volts of kinetic energy. It can be said that the electron has a velocity of 1,000 volts. The velocity of an electron also can be expressed in terms of a percentage of the velocity of light. The following table gives the approximate electron velocities for various accelerating voltages:

Accelerating voltage (volts)	Percent of light velocity (percent)
1,000	7
5,000	14
10,000	19
25,000	33
50,000	44

f. Equipotential Points and Lines.

(1) By definition, the potential of a point is the work which must be done on a unit charge to transport it from a ground reference point to the point in question. As work is the product of force by distance, the potential of a point in space is proportional to either force or distance when the other quantity is fixed. In a uniform electric field the force is constant at all points, therefore, the potential at any point is proportional to the distance from the reference point.

(2) If two surfaces are 1 centimeter apart and have a difference of potential of 300 volts between them, the potential along any line of force between the plates increases progressively from zero at the reference point (the negative plate) to a maximum of 300 volts at the positive plate. To move a charge to a point midway between the plates an amount of work must be done on the charge which is half the amount needed to move the charge all the way to the positive plate. Thus, this midway point would have a potential of 150 volts (fig. 10). A point in space that is located at one-fifth the total distance away from the negative plate would have a potential of 60 volts. In a uniform field, the points of different potential, as established on one line of force, are exactly the same as similar points on the other lines of force. Therefore, points of equal potential (equipotential points) exist on each line of force.

(3) If the equipotential points are connected, a pattern of equipotential lines is produced (fig. 10). Each equipotential line actually represents an equipotential plane, and thus each line shown in the

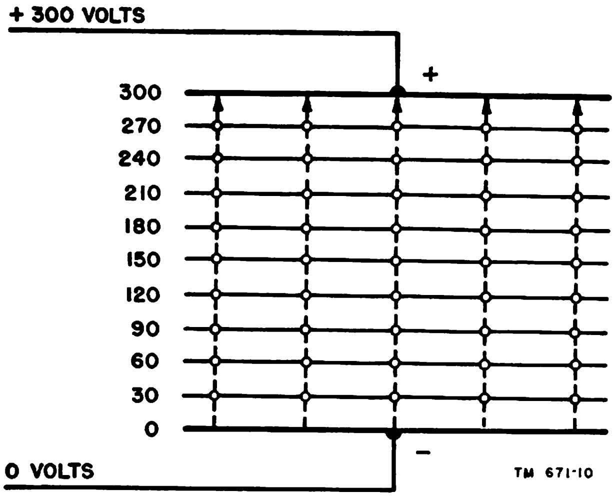

Figure 10. Potential of points located within uniform electrostatic field between two charged plates. Point midway between plates will have a potential of 150 volts, as shown. Points of equal potential along lines of force (dashed lines) between charged plates are connected to form equipotential lines (solid lines).

illustration should be thought of as a cross section of a plane. The potential of any point located on an equipotential line is the same as that of any other point. At any point along the 150-volt equipotential line which is located midway between the charged surfaces the potential is the same, 150 volts. At any point along the 270-volt equipotential line the potential is the same, 270 volts. These equipotential lines are *not* lines of electrostatic force but are lines along which the potential is uniform. Equipotential lines cross the lines of electrostatic force at right angles. Hence, the electrons, which tend to move parallel to the electric lines of force, move across an equipotential line at right angles.

(4) Thus far only the uniform field, consisting of straight and parallel lines of electric force, has been considered. If the field is examined at the borders or fringes of the charged plates, it will be seen that the lines of electrostatic force are curved outwardly. The equipotential lines must be at right angles to the lines of electric force; hence, these too are curved. When an electron is on the fringe field, it does not move directly to the positive plate but follows a curved path, always at right angles to the curved equipotential lines.

g. MOVING ELECTRON IN FIELD BETWEEN CHARGED PLATES.

(1) In most cases, the fields that are used within the cathode-ray tube are not uniform. A simple nonuniform field may be produced by two surfaces, one plane and the other curved (fig. 11). In the vicinity of the curved surface the lines are curved, gradually straightening out as the plane surface is approached. At this surface the lines run parallel to each other and to the surface. Electron b moves directly to the positive plate B, following a straight-line path. This path is, at every point, perpendicular to each equipotential line that is crossed by the electron. Electrons a and c, on the other hand, must follow curved paths, as shown, in order to cross the equipotential lines at right angles. Thus, the three electrons tend to converge upon plate B in a much smaller area than that from which they originated.

(2) To make the electrons *diverge*, a different field configuration is needed. This may be produced by changing the direction of curvature of the curved electrode (fig. 12). Here the electrons obey the same laws and diverge in moving toward the positively charged plate B. Note that when the field curves in one direction, the electrons within that field are made to converge. When the field curves in the

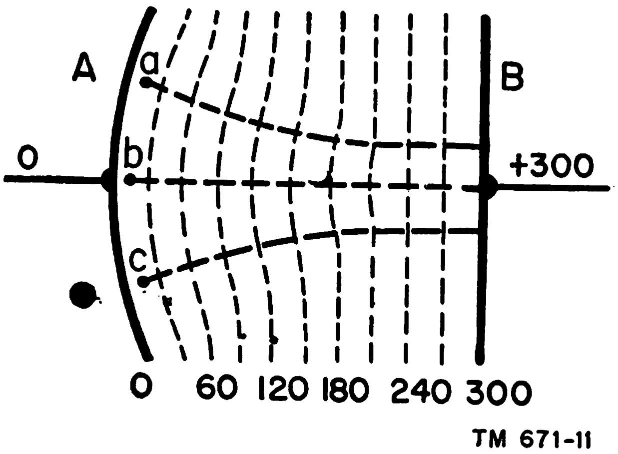

Figure 11. Equipotential lines shown between plane and curved charged plates. Electrons move perpendicular to lines and, in moving toward plate B, the three electrons shown tend to converge.

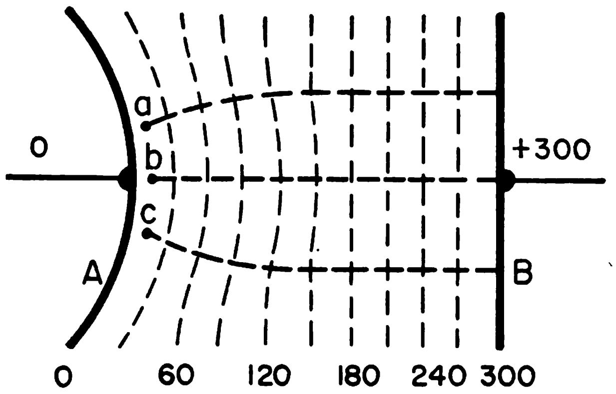

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Figure 12. Equipotential lines shown between plane and curved charged plates. The three electrons reach plate B much farther apart than they were originally when near plate A.

opposite direction, the electrons within that field are made to diverge. The curvature of the electrostatic field has been produced by curving one of the charged surfaces.

(3) A simpler method of producing this curvature is to use two plane surfaces or disks with aperatures at their centers. The equipotential lines (fig. 13) bulge through the holes because of the field which extends through the openings. Electron movement is influenced not only in the space between the disks but also outside this space in the vicinity of the openings. Assume that three electrons, a, b and c, are moving toward the aperture in plate A from the left. They first are made to converge as they cross the lines which bulge through the opening in plate A. They then tend to cross each other within the field between the two holes. Finally, they continue along a diverging path as they cross the lines which bulge through the opening in plate B. Electron b moves along a straight-line path, as it is on the axis of symmetry, and advances across each of the equipotential lines at right angles.

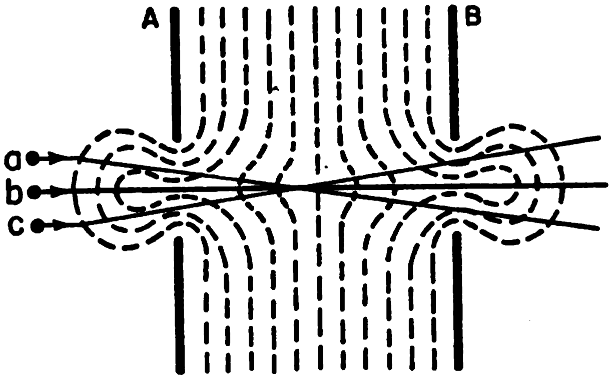

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Figure 13. Equipotential lines between two disks, each having an aperture at its center. The lines in the vicinity of the aperture in disk A curve in the opposite direction to those in the vicinity of the aperture in disk B.

(4) The effect on the three electrons above is roughly similar to the effect on three light rays which pass through a simple optical lens. Just as a glass lens refracts the rays of light in such a way as to bring them to a focus, so the electric field bends the electron paths.

(5) Two hollow cylinders arranged along a single axis may be used (fig. 14). If the smaller cylinder A is made positive with respect to a fixed reference point, while cylinder B is made more positive than A, an electrostatic field is set up between the cylinders. All the lines of force are acting in the same direction, and, because of their lateral repulsion, they tend to be flattened near the axis. In this vicinity the lines tend to run along almost parallel paths. The resulting equipotential lines assume three general forms (fig. 15)—convex within cylinder A, plane in the region where the edges of the two cylinders are near each other, and concave in cylinder B.

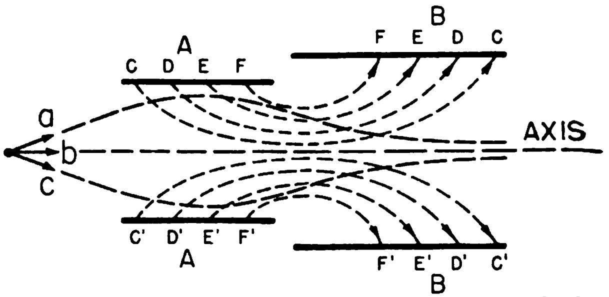

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Figure 14. Electrostatic field between two charged cylinders. The pairs of letters indicate the start and end of each line of force, and the arrows indicate the direction of the force as being from the cylinder of lower potential toward the cylinder of higher potential.

(6) Consider a source of electrons (fig. 15) from which three electrons, a, b and c, are emitted at a comparatively low velocity. These electrons move toward the cylinders because of the positive charge that exists there. When the electrons enter cylinder A, they begin to feel another force caused by the electrostatic field which exists between the cylinders. This field has a tendency to carry the electrons away from the inner surface of cylinder A and toward the inner surface of cylinder B. Both of these forces act upon the electron, and its actual movement is the combined result of the two. When the electrons first enter cylinder A, they are moving at a comparatively low velocity. The influence of the field between the two cylinders is great. This field causes the diverging electrons, a and c, to change their direction of motion and begin to move toward the axis. As the electrons approach the axis, they are being accelerated through the field by the higher positive charge on cylinder B. By the time the now converging electrons reach cylinder B, they are traveling at a higher velocity. The force tending to urge them to the inner surface of cylinder B has less effect. The electrons speed on through cylinder B and eventually converge at some remote point beyond cylinder B.

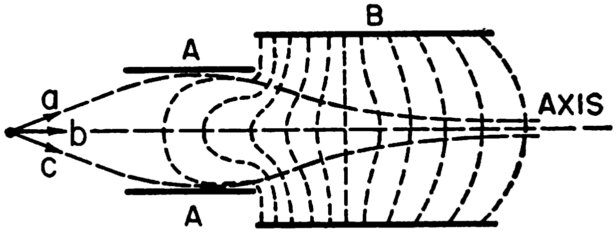


Figure 15. Equipotential lines resulting from electrostatic field that exist between two charged hollow cylinders.

(7) The direction in which electron b moves is not changed by the electrostatic field. This electron moves in such a way that it crosses each equipotential line at right angles. Thus, electron b is accelerated through the field but its original direction of motion is unchanged.

3. Motion of Electrons in Electromagnetic Field

a. Magnetic Field and Lines of Force.

(1) When a charge is made to move, there is set up about that charge a field of force. This is known as an *electromagnetic*, or simply a *magnetic*, field, which is a direct result of the *motion* of the charge. If this motion stops, the magnetic field disappears. If the motion is constant, the strength of the field is unvarying. If the motion varies, the strength of the field changes. This field originally was detected by its influence on a magnetic compass needle. Although the exact nature of the space in which the field existed was not known, it was recognized as a special condition akin to magnetism. Therefore, the term *electromagnetic* or *magnetic* field was originated.

(2) This field represents potential energy which can be converted to kinetic energy when causing another object which has its own magnetic field to move. It is customary to show a pattern of this field of force and to indicate by arrows the direction along which the magnetic force acts. This direction was decided arbitrarily to be the direction along which a unit north magnetic pole moves under the influence of the magnetic field in question.

(3) It has been shown that an electrostatic line of force joins unlike charges and starts from and terminates upon charges. Magnetic lines of force are not attached to the charge but form complete loops around the moving charge in planes which are at right angles to the direction of the motion of the charge. These loops of magnetic force, which constitute the magnetic field, extend outward infinitely. Because of limitations in illustration and because the intensity of the force diminishes as the distance from moving charge is increased, usually only a few lines are shown. The direction of force due to the magnetic field at any point on a magnetic loop is tangential to the loop at that point and at right angles to the direction of the moving charge or electron flow (fig. 16).

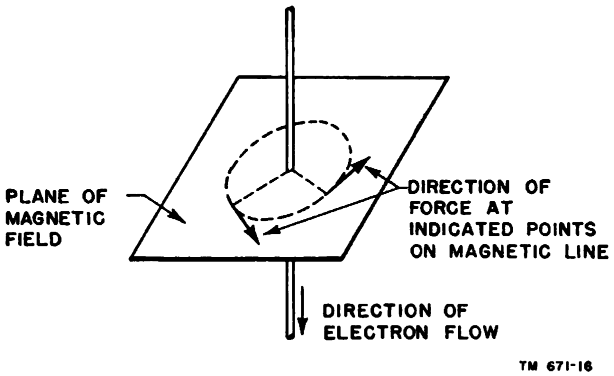


Figure 16. Relationship of direction of current flow, plane of magnetic field, and direction of force caused by magnetic field.

b. Magnetic Field Around Conductor.

(1) A moving charge in a conductor constitutes current flow. Surrounding every current-carrying conductor are closed loops of magnetic force which may be detected by test compass needles. The strength of the magnetic field at any point in space is directly proportional to the amount of current flow and inversely proportional to the distance from the conductor to the point of measurement.

(2) Consider two equal test areas surrounding the conductor. Unless the areas are spaced equally from the conductor, the field strength is not uniform (fig. 17). If some object susceptible to magnetic forces were placed at different points in the field, it would feel forces of varying magnitudes. In most cathode-ray tube applications a uniform magnetic flux is required. Figure 18 shows a portion of the magnetic field that exists between the poles of a horseshoe magnet. The portion indicated by the broken lines may be considered uniform, and the two test areas depicted are areas containing uniform magnetic flux. The remainder of the path for the magnetic lines of force is within the horseshoe magnet itself. Thus, the straight flux lines shown are merely a section of the larger flux loops.

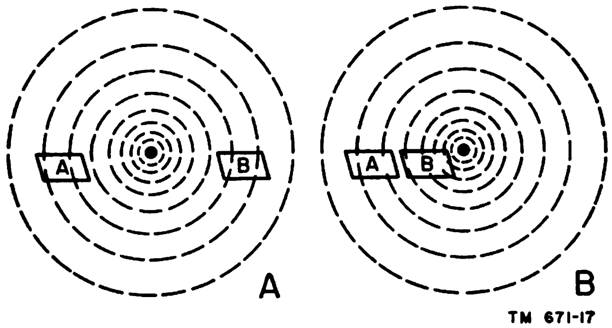


Figure 17. Nonuniform magnetic field around current-carrying conductor. Number of lines of force cutting identical test areas are equal in A but are unequal in B.

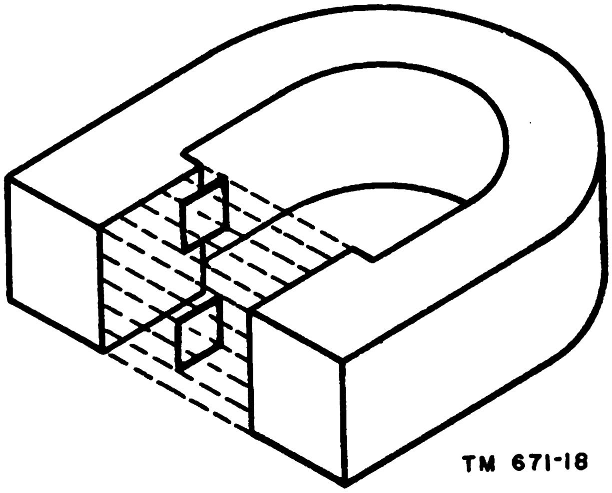


Figure 18. Uniform magnetic field between poles of horseshoe magnet. Both test areas are cut by the same number of lines of magnetic force.

c. Magnetic Field Around Coil.

(1) As a step toward the development of a uniform magnetic field, the simple current-carrying conductor is formed into a single loop. The concentric circles of force now become eccentric circular loops with considerable crowding of the lines of force within the single wire loop. A greater number of magnetic lines exist per unit area within the wire loop than exist outside the loop. This field intensity can be increased further by increasing the amount of current flow. Also, reducing the radius of the loop or producing a cumulative effect by using more than one turn increases the field intensity.

(2) When a solenoid is used, the fields produced by the individual turns combine and develop a resultant field through and around the solenoid. The pattern produced by the lines of magnetic force begins to exhibit some degree of uniformity within the center windings of the

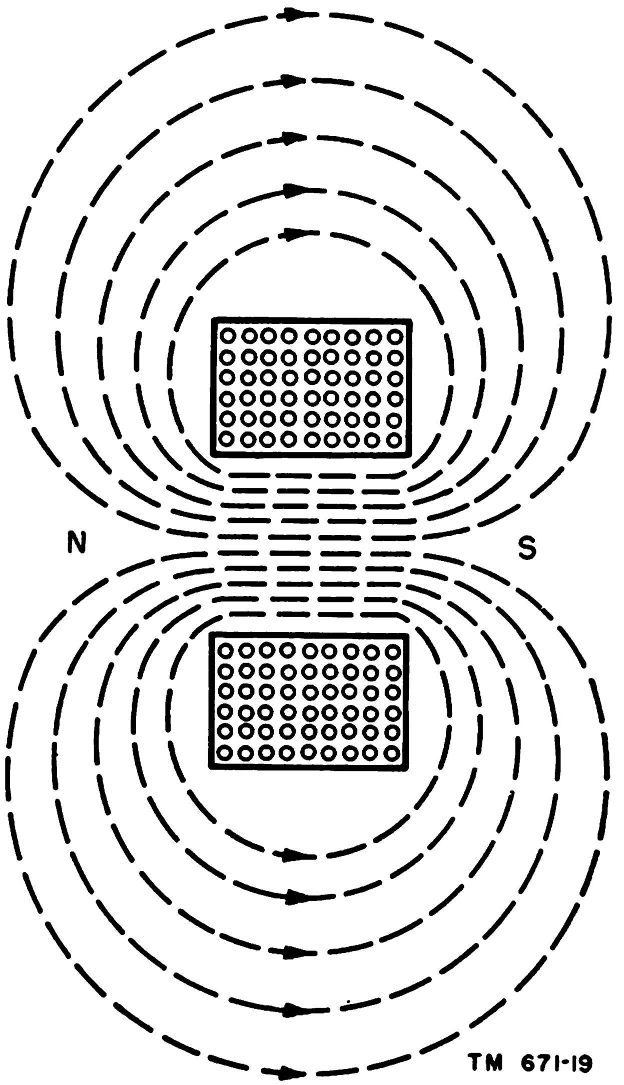


Figure 19. Approximate uniform field within multilayer coil. Drawing shows coil in cross section. Electron current flow is toward the reader in the upper section of the solenoid and away from the reader in the lower section of the solenoid.

solenoid. A multilayer solenoid, whose length is short, may produce a strong magnetic field which is quite uniform within the solenoid (fig. 19).

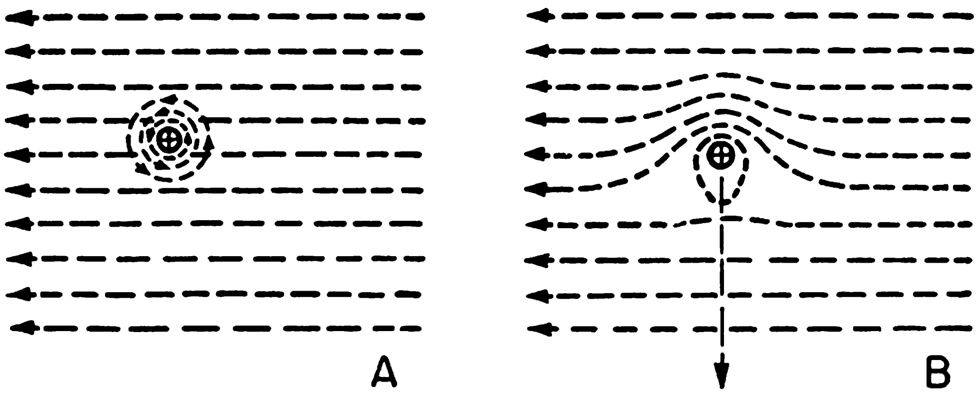
d. INTERACTION BETWEEN MAGNETIC FIELDS.

(1) Assume that a conductor is placed within a uniform magnetic field such as was produced above by a multilayer short solenoid. The conductor is surrounded by its own magnetic field because of the moving charges in the wire. If the individual fields are examined (fig. 20), it will be seen that both fields are acting in the same direction *above* the conductor. The fields are acting in opposite directions *below* the conductor. The result is that a much more intense magnetic field is produced above the conductor because of the addition of two forces acting in the same direction. Below the conductor, the resultant magnetic field is reduced in intensity. This is because of the addition of two forces acting in opposite directions. Magnetic lines of force tend to shorten themselves along their length and to repel each other laterally. Therefore, a force is exerted on the conductor in such a way as to move it *downward* (fig. 20). It may be seen that the action is from the stronger field toward the weaker.

(2) If the current through the conductor is reversed, the direction of the magnetic field surrounding the wire is reversed. The relative positions of strengthened and weakened parts of the combined field then are changed. The wire now feels a force which tends to push it in the opposite direction upward. The direction of the force, and therefore the motion, are perpendicular to both the motion of the charges and the direction of the field.

(3) Instead of the moving charges within a conductor, assume that they are located in space or in a vacuum in the form of moving electrons. The force that would be exerted on the moving electrons would be the same as the force which has been described as acting on the conductor.

e. ELECTRON MOTION IN UNIFORM MAGNETIC FIELD. When an electron is propelled into a uniform magnetic field, a force is exerted on it. This causes the electron to move at right angles to the direction of the lines of force and at right angles to its original direction of motion. If the electrons move into the field shown at right angles (fig. 21), the force exerted tends to move the electrons downward. As the electron already has kinetic energy, tending to move it toward the screen, the resultant force is the combination of the two perpendicular forces, and a downward deflection will result. The amount of the deflection is increased if the velocity of the electron is reduced, the field strength is increased, or if the length of the field is increased. It should be noted that the magnetic field does no



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A. Individual fields surrounding a current-carrying conductor which is located within a uniform magnetic field Electron current is flowing into the page. B. Resultant field tends to force the conductor downward.

Figure 20. Magnetic fields.

work on the electron because force is perpendicular to the motion of the electron at all times.

f. Circular and Helical Motion of Electron.

(1) If an electron is projected in a *long* field at right angles to the lines of force, it experiences a constant force which acts at right angles to the direction of motion. Since the electron remains within the field and feels this constant force at every point, the path of the electron becomes a circle (fig. 22). In this particular case, the path is initially upward. If the direction of the field were reversed or if the electron entered the field from the opposite direction, the initial movement would have been downward when tracing the circular path. The radius of the circle is determined by the same factors as those which determined the amount of deflection given above.

(2) An electron which enters a magnetic field, moving parallel to the lines of force, is not affected by the lines of magnetic force but continues to move in its original direction. In this case the magnetic field produced by the moving charge produces exactly the same effect all around the electron; consequently, no change in direction occurs. If the electron enters the field at some intermediate angle between 0° and 90°, a composite motion results, partly circular and partly linear. This combination produces a corkscrew-shaped or *helical* path. The direction of rotation of the helix is determined by the direction of the lines of magnetic force relative to the advancing electron. If the forward motion of the electron is in the direction of the magnetic field, the path is an ordinary right-hand corkscrew (fig. 23). The radius of the turns depends on the velocity of the electron. With a given velocity the greater the angle (approach-

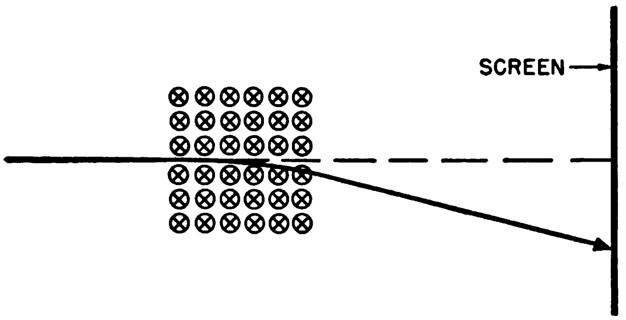

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Figure 21. Deflection of electron projected into short, uniform magnetic field. Field is directed into page.

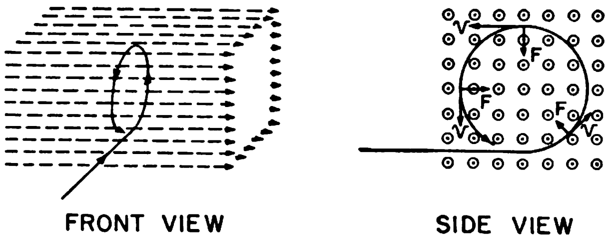

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Figure 22. Circular motion of electron projected perpendicularly into uniform magnetic field. F is the direction of the force exerted by the magnetic field, while V is the direction of the instantaneous velocity of the electron.

ing 90°) at which the electron approaches with respect to the lines of magnetic force, the greater is the loop size.

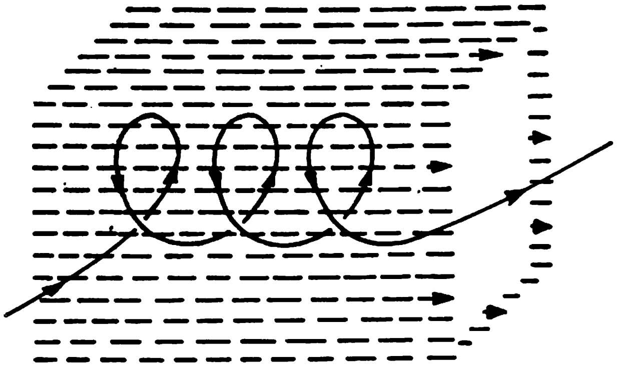


Figure 23. Helical motion of electron having both vertical and horizontal velocity components, in a uniform magnetic field.

4. Electron Gun

a. Basic Electron Gun. In order to produce the beam of electrons which will be focused and deflected by either electrostatic or magnetic fields, an electron gun is required. The electron gun is that portion of the cathode-ray tube which produces a narrow beam of electrons that is to pass through the deflection system and finally strike the fluorescent screen. Although there are many variations in electron guns, their basic functions are the same. All electron guns provide a means of generating a supply of electrons; a method of accelerating these electrons at high velocity toward the fluorescent screen; a method of controlling the number of electrons that make up the beam; and a means of focusing the divergent electrons to produce a small point of light on the screen.

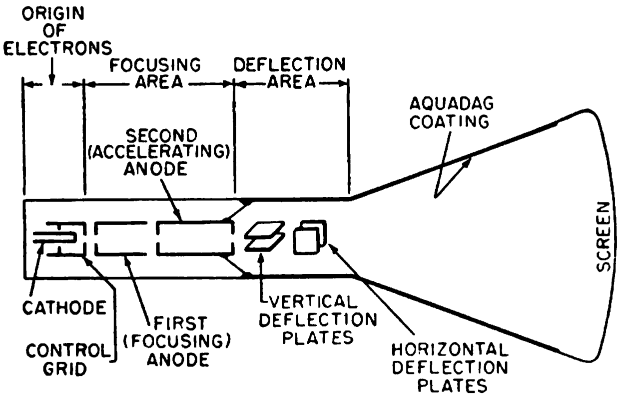


Figure 24. Basic electrostatic cathode-ray tube. The electron gun consists of the heater-cathode, control grid, and first and second anodes.

b. Electrostatic and Electromagnetic Tubes. In the electrostatic cathode-ray tube (fig. 24), the electron beam is focused and deflected by means of electrostatic fields. These fields are produced by applying voltages to suitably shaped electrodes within the tube. In the electromagnetic, or magnetic, type (fig. 25) focus and deflection are accomplished by means of magnetic fields. These fields are produced by means of current-carrying solenoids. The solenoids are mounted externally around the neck of the tube.

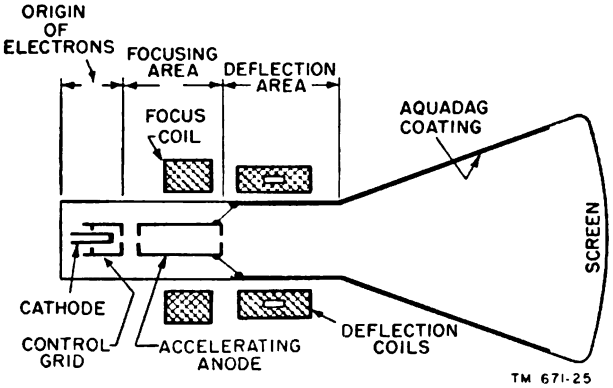


Figure 25. Basic electromagnetic cathode-ray tube. The electron gun consists of the heater-cathode, control grid, and accelerating anode. Although the focusing element is considered a portion of the electron gun in the electrostatic type, usually it is not considered a part of the gun because in the magnetic type this element is an externally mounted coil.

5. Formation of Beam

a. Cathode Emission. Most cathode-ray tubes utilize an indirectly heated cathode. Passage of current through the twisted heater wire causes it to become red hot. Some of this heat is transferred to the cathode cylinder which surrounds the heater. Thermal agitation of the earth oxides which form the coating on the cathode results in the emission of a large quantity of electrons from the cathode surface. A cloud of electrons, known as the *space charge*, is formed around the cathode. As the cathode loses electrons, it assumes a positive charge which attracts the electrons in the space charge back to the cathode. A condition of equilibrium is reached in which just as many electrons leave the space charge to return to the cathode as leave the cathode to enter the space charge.

b. GRID CONTROL. The control grid in most cathode-ray tubes consists of a hollow metal cylinder which fits over the cathode. The cylinder has a small aperture at one end. The grid always is operated at a voltage which is negative with respect to the cathode. Because of the nearness of the control grid to the cathode, only a small difference of potential is needed to produce an electrostatic field of large magnitude. Therefore, small changes in control grid voltage produce considerable effects. High accelerating potentials applied to other electrodes in the gun cause many electrons to move from the space charge, through the control grid aperture, and toward the fluorescent screen. The number of electrons which make up this electron beam (or cathode ray) can be controlled closely by the negative charge on the control grid. The more negative this element becomes, the fewer will be the number of electrons that enter the electron beam. As in an ordinary vacuum tube, it is possible to make the charge on the grid so negative as to cut off beam current completely. The brightness of the image which finally will be seen on the fluorescent screen of the cathode-ray tube is determined partly by the number of electrons which strike the screen and the velocity at which they arrive. A control of pattern intensity or brightness may be obtained by varying the negative charge on the control grid.

c. FOCUSING IN ELECTROSTATIC TUBES. The electrostatic field that is set up between two hollow cylindrical electrodes is used to focus the electron beam. This field acts on the diverging electrons in the beam in such a way as to cause them to converge. The required point of convergence is at the fluorescent screen. To compensate for slightly different electron path lengths in various tubes and for different electron velocities and beam density, it is desirable to have control over the focus action. Therefore, a means always is available to vary the intensity of the electrostatic focus field. By varying the voltage on the first electrode with respect to the second, the strength of the field may be changed to permit optimum location of the focal point. In this way a small point of light, sharply focused, will appear on the screen.

d. FOCUSING IN ELECTROMAGNETIC TUBES. A multilayer coil of short length is located around the neck of the cathode-ray tube. When current is passed through this coil, known as the *focus* coil, an intense, uniform magnetic field is set up within the neck and along the axis of the tube. This field acts on the diverging electrons in the beam in such a way as to cause them to describe a single-turn helical path within the field. The electrons converge at or near the fluorescent screen. The control of the proper focus is accomplished by varying the amount of current through the focus coil. This changes the intensity of the magnetic field which in turn properly locates the focal point. It is also possible to move the focus coil along the neck of the tube so that the focus control has the correct operating range.

6. Fluorescent Screen

a. PRODUCTION OF LIGHT OUTPUT.

(1) Certain materials called phosphors have the ability to glow visibly whenever a beam of electrons strikes them. By absorbing some of the kinetic energy from the electrons in the beam, some of the electrons in the phosphor crystal structure are raised to higher energy states or excitation levels then their normal states. These higher energy states are unstable, and certain probability functions exist that the excited electrons will give up the additional energy in the form of radiation, and in so doing fall back to their normal energy states in the crystal. This radiant energy generally falls within the visible light portion of the electromagnetic spectrum, and hence light is produced.

(2) When the electron beam strikes the screen material, other electrons are knocked completely out of the phosphor. These free electrons are known as secondary electrons and the process is referred to as secondary emission. This secondary emission results in some ionization of the phosphor because of the removal of electrons. Any free secondary electron in the vicinity of the positive charges will be attracted to this region of the phosphor and may produce light by the same process as do the primary beam electrons if the energy is great enough.

(3) To provide intermediate energy level trapping states in the phosphor crystal and help initiate the energy transfer process, very small amounts of certain

impurities are added to the basic phosphor material. The impurity, known as an *activator*, largely determines the color of light produced when the phosphor is struck by the electron beam. For example, a common phosphor is zinc sulfide. When this material is activated with silver, it produces a blue light; when activated with copper, the color is blue-green; and when activated with manganese, the color is orange. A variation in the amount of activator changes the color of light produced or may actually quench the light completely.

b. CASCADE SCREEN. This type of screen is made up of two separate phosphors, one coated on top of the other. The purpose of such a combination is to make available the best characteristics of separate phosphors and to combine them on the face of a single tube. For example, assume that a screen material is required which has high efficiency and a particularly long afterglow; that is, considerable visible light remains after the electron beam has left the screen. A phosphor is known which has the required long afterglow but it is very inefficient. If a highly efficient phosphor is coated on top of the phosphor which has the required long afterglow, the following action occurs: The electron beam hits the highly efficient phosphor, which glows brightly upon impact; the bright light which is produced is used to excite the second layer; under the influence of the light from the first phosphor, the second phosphor produces visible light for a considerable period of time.

c. LUMINESCENCE.

(1) Visible radiation or the production of visible light by any means is known as *luminescence*. When light is produced by living organisms (such as the firefly) the term bioluminescence is used. Light produced by a chemical reaction is referred to as chemiluminescence. Cathodoluminescence is the term applied to luminescence that is caused by the impact of electrons, produced by cathode rays, against some surface. This last-named term is the one we deal with in cathode-ray tubes, where the surface is the screen of the tube.

(2) Materials can luminesce during and after their period of excitation. *Fluorescence* is the term used to refer to luminescence produced while the material actually is being excited or during the time that the electron beam actually is striking the screen. The period of fluorescence continues as long as the electron beam is active and may exhibit any color; this depends on the material used. *Phosphorescence* refers to light emission which persists after the excitation has been removed. Thus, after the bombardment by the electron beam, the screen continues to give off light for a period of time which depends on the type of material that is used. The color of light produced during the period of phosphorescence may be the same as that produced during fluorescence, or it may be a different color.

d. PERSISTENCE. The duration of the period of phosphorescence or afterglow is the *persistence* of the screen material. If the persistence is from a few microseconds to about 1 millisecond, it is referred to as *short*. A *medium-persistence* screen may have an afterglow which lasts from a few milliseconds to 1 or 2 seconds. Any screen that has persistence which exceeds this amount is referred to as a *long-persistence* screen. The persistence which is required depends on the specific application. For example, when observing a screen pattern which is constantly changing at a fast rate, a medium or short-persistence screen is needed. On the other hand, if a transient is to be observed and studies, a long-persistence screen may be desired.

e. SPECTRAL ENERGY DISTRIBUTION. The human eye responds to only a narrow portion of the electromagnetic spectrum. Even within that narrow portion, the relative sensitivity of the average eye varies considerably. If a curve is drawn showing relative sensitivity versus wavelength, it will be seen that maximum sensitivity occurs at a wavelength of about 5560 Å. (One angstrom unit, Å., corresponds to a wavelength of 10^{-8} centimeters.) This corresponds to a greenish-yellow light. Curves which show the relative intensity versus wavelength of a particular phosphor are known as spectral-energy distribution curves. The exact shape of the curve varies widely; this depends on the particular phosphor involved. When two different phosphors are used, two well-defined peaks may be seen in the curve (fig. 26).

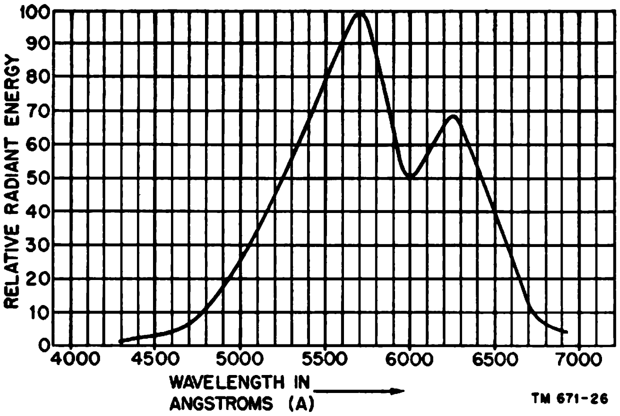


Figure 26. Typical spectral-energy distribution curve of a screen material made up of two different phosphors, showing two radiant energy peaks at two different wavelengths.

f. Writing Speed Characteristic. Writing speed refers to the linear velocity of the trace over the screen, usually stated in inches or centimeters per second. This is an important characteristic in the observation of transient phenomena and certain radar displays. The writing speed is determined largely by the frequency and peak-to-peak amplitude of the deflection signal that is applied to the cathode-ray tube. For example, a 1 megacycle sine wave having a peak-to-peak amplitude of 2 inches requires a writing speed of 6.28 inches per microsecond.

g. Phosphors. Phosphors for excitation by cathode rays today are classified into 15 general groupings, designated from P1 to P15. A trend toward standardization exists, but it has not progressed sufficiently to include the exact chemical composition and persistence of the common phosphors referred to in the following table.

Table I.—Phosphor Ratings

Phosphor No.	Fluorescence	Phosphorescence	Persistence	Applications
P1	Green	Green	Medium	General oscilloscope use, such as for periodic waveform observation.
P4	White	White	Medium	Principally used for television picture tubes.
P5	Blue	Blue	Very short	Principally used in oscillography where high-speed photographic recording is required.
P7	Blue-white	Greenish-yellow or yellow.	Very long	Used for observation of slow and medium transient phenomena. First used in radar (cascade screen).
P11	Blue	Blue	Short	Principally used for photography, but for lower speeds and higher efficiency recordings than the P5 phosphor.

h. Spot Burn. When the beam of electrons strikes the fluorescent screen, some of the kinetic energy is converted into heat. This reduces the efficiency of most phosphors. If the beam is concentrated on a small part of the screen, the generated heat is confined, and the temperature of that area rises. The amount of heat produced is increased if an extremely bright spot resulting from a dense electron beam is used. As a result, permanent loss of screen efficiency may occur in that area. There may be sufficient heat produced to burn away the phosphor. In that case there will be no luminescence in the affected area. In order to prevent a burning of the screen, excessive intensity should not be used and the beam should not be allowed to remain for long periods of time.

Section II. ELECTROSTATIC CATHODE-RAY TUBE

7. Elementary Electrostatic Cathode-Ray Tube

a. Organization and Function of Elements. The basic type of electron gun used in electrostatic cathode-ray tubes is known as the *triode* gun (fig. 27). It consists of an indirectly heated cathode which is in the form of a cylinder closed off at one end by a small plate. This plate is coated with barium and strontium oxides which emit a large number of electrons. The cathode is brought to operating temperature by a twisted heater element which is contained within the cathode cylinder and separated from it by a heat-conducting ceramic sleeve. Surrounding the cathode is a cyl-

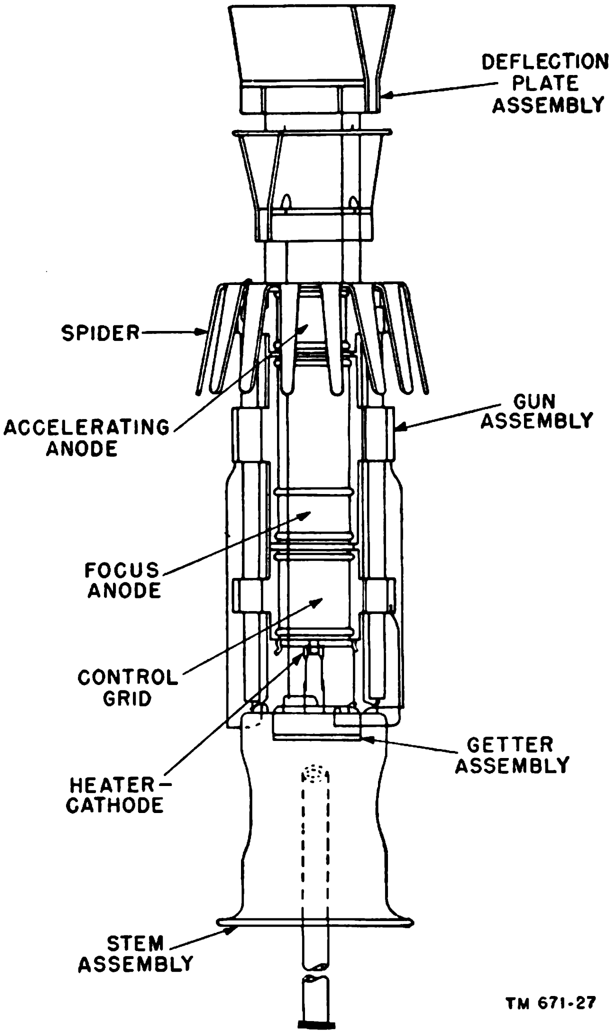


Figure 27. Complete triode electrostatic electron gun assembly with deflection plates.

inder which has a baffle with a tiny aperture at its center. The cylinder is known as the control grid. The grid aperture is smaller than the emitting surface, and the spacing between the aperture and the cathode emitting surface is very small. Facing the control grid is the first anode cylinder (often called the *focus* anode). This is coaxially symmetrical with the control-grid cylinder and contains several baffles, each with an aperture at its center. Next to the first anode is the second anode, usually called the accelerating anode. This structure is coaxially symmetrical with the first anode and has two baffles. An extension of the second anode exists in the form of a conducting coating on the inside of the envelope, extending from the limit of the anode cylinder almost to the screen of the tube. Connection to this coating is accomplished by a *spider* arrangement of electrically conducting spring contacts which are mounted on the gun.

b. Schematic Representation. Consider the schematic representation of the basic triode electrostatic cathode-ray tube (fig. 28). The second, or accelerating anode, A2, is connected to a fixed positive potential of several thousand volts. The first or focus anode, A1, is operated at a positive potential which is approximately one-third of the potential applied to the second anode. The focus anode potential is made variable in order to change the magnitude of the electrostatic field that acts as lens No. 2. In this manner, a control of focus is obtained. The control-grid potential always is negative with respect to the fixed cathode potential. The negative voltage is approximately 10 to 100 volts. It is made variable to afford control of the density of the beam, which determines the intensity of the pattern on the screen. The control grid functions with the first anode to form lens No. 1 which assists in the focusing action.

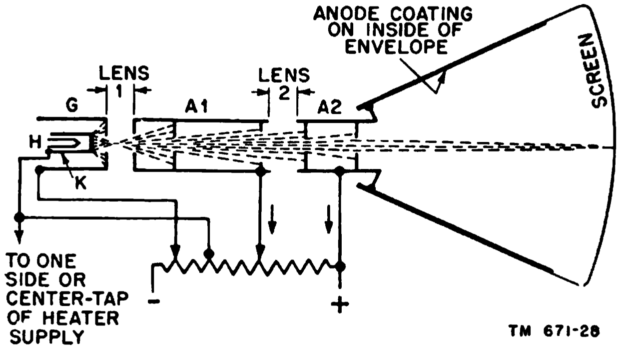


Figure 28. Schematic representation of triode electrostatic electron gun showing location of the two lenses.

c. Physical Shapes.

(1) The glass envelope of the electrostatic cathode-ray tube is conical in shape, with a long tubular neck in which the electron gun is mounted. The fluorescent screen is coated on the large inside face of the cone. Because of the high voltages that are used, a high degree of vacuum is required for the tube. This high degree of vacuum, coupled with the large surface area of the screen face, makes the tube dangerous to handle. Any weakening of the envelope which might be caused by a mechanical shock or a scratch on the glass may cause a severe implosion. The result may be widespread scattering of

fragments of glass and screen material. The usual precautions are to wear heavy gloves and shatterproof goggles and to handle the tube with extreme care. The powdered graphite coating (aquadag) that is applied to the inner surface of the tube serves several purposes: In addition to acting as an extension of the second anode and collecting the secondary electrons that are knocked off the screen, it serves as an electrical and optical shield. The electrical shielding effect around the electron beam reduces the influence of stray external electrostatic fields. This prevents undesired deflection or defocusing. Because the coating is black and opaque, it prevents stray light from entering the sides of the envelope and shining in on the image produced on the fluorescent screen. This prevents a reduction in contrast.

(2) The screen diameter of electrostatic cathode-ray tubes ranges from 1 inch up to and over 20 inches, although the most commonly used screen sizes are 3, 5, and 7 inches in diameter. Much information concerning the screen can be obtained from the standard type number which is used by most manufacturers—2AP1, 5BP4, etc. The first digit identifies the nominal screen diameter in inches. The first letter identifies the order in which tubes of the same diameter were registered. The last letter-number combination identifies the type of phosphor used. The designation 5BP1 indicates that the tube has a screen diameter of 5 inches, it was the second 5-inch tube registered, and the screen phosphor is type P1 which glows with a green color and has a medium persistence.

(3) Electrode connections are made with multiple-contact sockets, while high-voltage connections are frequently made with connections in the glass envelope itself.

d. Modifications and Multigun Tubes.

(1) Several improvements over the basic triode gun have come into common usage. These include the use of a tetrode gun and a zero-first-anode-current electron gun. In the tetrode electrostatic gun, also called the preaccelerator or screen-grid type, an additional electrode is inserted between the control grid and the first anode. This second grid, operated at the same potential as the second anode, produces a number of advantages in tube operation. Some of these are: greater electron acceleration, a denser electron beam having a smaller diameter and thus producing a smaller and brighter spot on the fluorescent screen, and the elimination of interaction between the control grid and the first anode. The major disadvantage of the tetrode gun is excessive current drawn by the first anode. This is overcome by the zero-first-anode-current gun. Here a complete redesign of the length and spacing of the electrodes is used and many masking baffles are eliminated. This produces a gun which has all the advantages of the tetrode plus negligible current drawn by the first anode.

(2) Where it is desired to present information from different sources or to show simultaneous observation of two or more phenomena, a multigun tube is used. Here, anywhere from 2 to 10 similar electron guns, placed side by side, are mounted within the neck of a single cathode-ray tube. Each gun produces its own separate pattern on the screen.

8. Electrostatic Focusing

a. Complete System. A typical electrostatic focusing system is of the dual-lens variety (fig. 29). The electrostatic field set up between the control grid and the first anode can be referred to as lens No. 1. The function of this lens is to focus the bundle of electrons which pass from the cathode through the grid opening into a cross-over point of minimum diameter. It is desirable that this cross-over point be as small as possible because it is finally imaged on the screen. The second lens consists of the electrostatic field which is set up between the focus anode and the accelerating anode. This field acts on the diverging electrons in such a way as to cause them to change their direction of motion and converge at the screen. In addition, several baffles are used in the control grid and focus anode in order to mask off undesired fringe electrons so that a dense beam

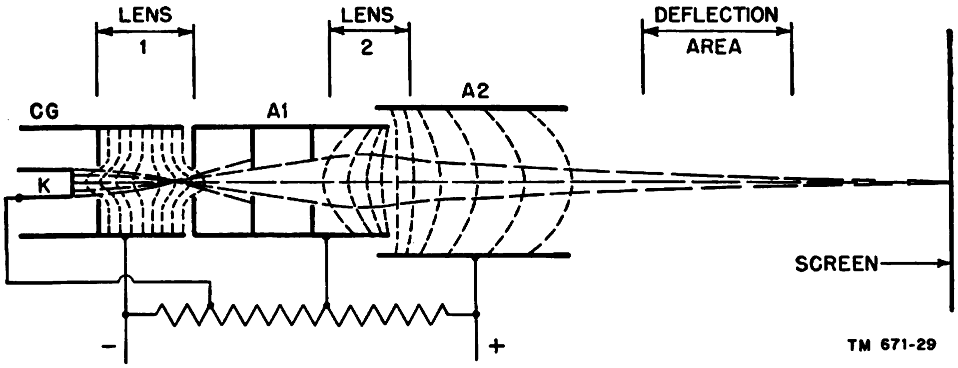


Figure 29. Practical electrostatic focusing system showing the two sets of equipotential lines that form the lenses of triode electron gun.

of small cross-sectional area is produced. If the voltage on the control grid is changed, the effect is to change the location of the first cross-over point as well as its dimension. A variation in the voltage applied to the first anode has somewhat the same effect and, in addition, changes the location of the second cross-over point.

b. Optical Analogy. The situation described above is somewhat similar to a two-lens optical system for producing a bright point of light upon a screen (fig. 30). Here two glass lenses and several opaque masking baffles are used to produce the required spot.

c. Grid and Anode Control.

(1) The control grid of the cathode-ray tube is operated at a potential which is negative with respect to the cathode. Consider the equipotential lines that exist between the control grid and the first anode for two conditions of operation; for example, a grid bias of 0 volts and −30 volts (fig. 31). With zero voltage on the control grid, the area between the cathode and the grid aperture has a positive potential. Under these conditions, the area of the cathode that is emitting corresponds to a projection of the area of the grid aperture. The maximum number of electrons is passing through the grid opening, producing a high-density beam current. With −30 volts on the grid, only the small area at the center of the cathode acts as an emitter. The remaining surface is prevented from emitting because the negative lines of equipotential increase the effect of the space charge in that vicinity. Under these conditions a reduction in beam density occurs. If the control grid is made sufficiently negative, the beam current may be completely cut off and no pattern will be produced. In addition to this effect, the shape of the field affects the paths of the electrons so that the position of the cross-over point, as well as its dimensions, is altered.

(2) Although the control-grid voltage affects the focus of the beam, its most important use is to control the intensity of the pat-

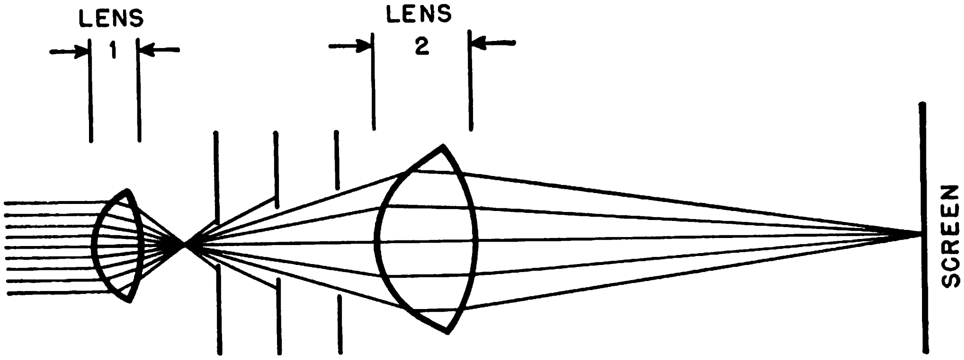


Figure 30. Optical equivalent of electrostatic focusing system.

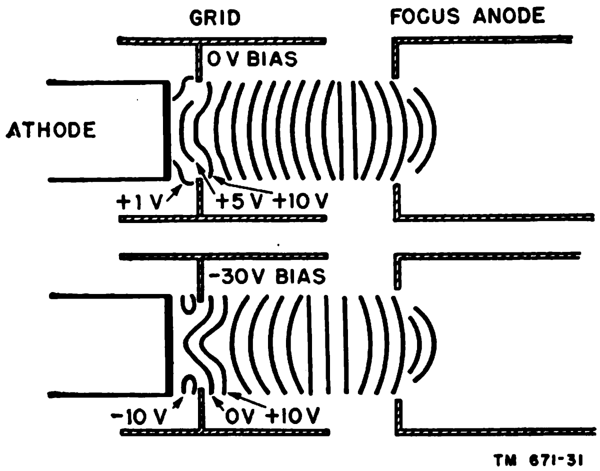


Figure 31. Equipotential lines with grid bias equal to 0 volts and —30 volts with respect to the cathode.

tern produced on the screen by changing the electron beam density. The *intensity control* or *brightness control* found in most cathode-ray tube instruments allows an operator to vary the intensity of the pattern produced on the screen from complete extinction to the limit of the tube. This control is a potentiometer that supplies a continuously variable negative potential to the control grid with respect to the cathode. Frequently, a signal voltage is applied to the cathode grid. The result is a variation of the intensity in accordance with the amplitude and the polarity of the applied signal. This process is known as *intensity modulation* and has many practical applications in television and radar displays.

(3) The voltage on the first anode also is made variable by use of a potentiometer, known as the *focus control*, which varies the field intensity between the first and second anodes. This electrostatic field is the principal focusing lens. It determines the location of the final cross-over point in conjunction with the location of the first cross-over point. Although this field may be varied by changing the second anode voltage, this also will affect the acceleration of the electrons and will require the controls to be located in higher voltage circuits. Note that any variation in focus anode voltage affects the field between it and the control grid. Therefore, a variation in the focus control may require a readjustment in the intensity control and vice versa.

d. INTENSIFIER ANODE. Some electrostatic cathode-ray tubes use one or more intensifier anodes in the form of conducting coatings on the inside of the glass envelope (fig. 32). The purpose of the intensifier anode is to increase the brightness of the trace. An extremely bright trace is required for daylight viewing or projection purposes. A simple method of producing an intense trace is to increase the magnitude of the accelerating voltage. This increases the electron velocity and permits a greater amount of energy to be converted into light at the screen. If a higher accelerating voltage is applied to the second anode, the increase in velocity occurs before deflection. The accelerated electrons thus spend much less time in the deflection field with a result that the normal deflection voltages have less effect. A more satisfactory method involves the use of high accelerating potentials with the resultant increase in electron velocity *after* the deflection has occurred. The intensifier anode is the element to which this high accelerating potential is applied.

e. SPOT SIZE. In order to produce thin, well-defined traces on the screen of a cathode-ray tube, it is necessary that a small spot be used. Although a fairly small spot often is produced near the center of the tube, there is a tendency for the spot size to increase as the spot moves toward the periphery. This is due to the greater radius of curvature of the beam focal point compared to the radius of screen curvature. Thus, the beam strikes the screen not at the point of minimum beam diameter, but after its second cross-over. Also, the deflection system tends to defocus the spot near the tube periphery. In general, the

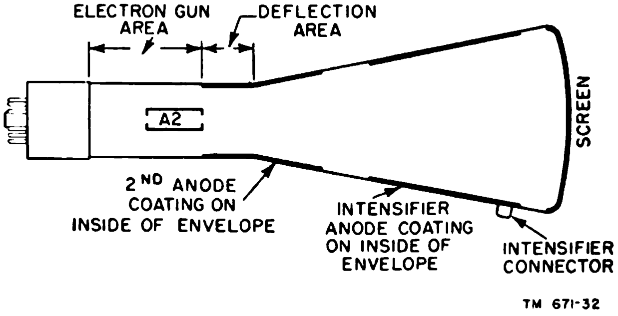


Figure 32. Cross section of envelope of 5LP1A cathode-ray tube showing the second and intensifier anode coatings.

spot size is increased with a higher density electron beam and with a reduced accelerating potential. The spot dimension also depends on the gun design which in turn is related to the specific purpose for which the tube was designed. Usually, the tubes having large screen sizes have somewhat greater spot dimensions. A typical 3-inch electrostatic cathode-ray tube may have a spot diameter of about .035 inch. A spot diameter of about .027 inch might be typical for a 12-inch tube.

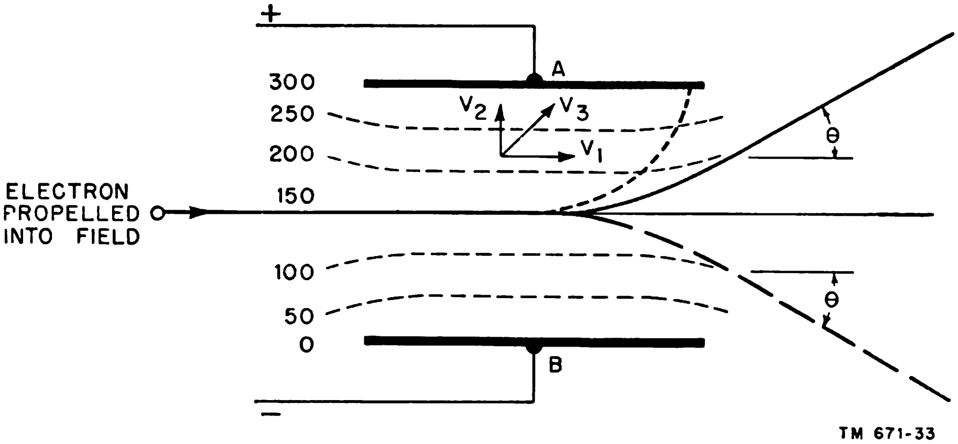


Figure 33. Deflection of electrons between two parallel plates. If excessive deflection potentials are used, the electrons will strike the edge of the plates (dotted line).

9. Electrostatic Deflection

a. Deflection Between Charged Parallel Plates. Assume that an electron or a stream of electrons is propelled into the electrostatic field that exists between two parallel charged plates. There it will come under the influence of a force perpendicular to its original direction. The vector v_1 represents the initial velocity of the electron. The electrostatic field acting on the electron results in an acceleration in the direction of the field, causing the electron to travel in a parabolic path curved toward the positive plate. The vestor v_2 represents the velocity toward this plate acquired by the electron at any instant. The resultant velocity is seen to be the vector sum v_3 of the velocities v_1 and v_2. If the direction of the electrostatic field is reversed, the deflection will be toward the lower plate.

b. Position of Deflection Plates. Note that the plates which are horizontally mounted produce a vertical deflection of the electron beam. These are known as *vertical deflection* plates. If a second pair of parallel plates is mounted at right angles to the first, horizontal deflection can be produced. These are known as *horizontal deflection* plates (fig. 34). Both sets of plates are mounted in the tube neck just beyond the accelerating anode. They usually are constructed as part of the electron gun to simplify manufacturing. Frequently, they are flared to permit wide angles of deflection without having the electron beam strike the edges of the plates. Standard practice is to designate the pair of plates nearest the screen as D1 and D2 and use these as the horizontal deflection plates. The plates nearest the second anodes are referred to as D3 and D4 and usually are used as the vertical deflection plates.

c. Electron Path After Leaving Field. The path of the electron after leaving the deflecting field is a straight line, tangent to the path at the point where the electron leaves the field. Moving bodies tend to follow straight paths unless some applied force causes a deviation. Once the elec-

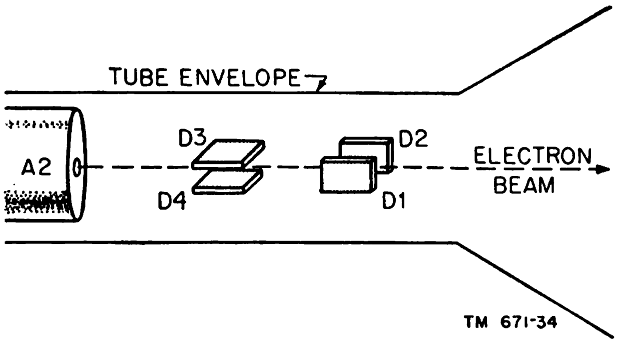


Figure 34. Arrangement of deflection plates within electrostatic cathode-ray tube. Plates D1 and D2 are the horizontal deflection plates while D3 and D4 are the vertical deflection plates.

tron has left the deflection field, the transverse or crosswise component disappears, and the electron advances unimpeded until it strikes a surface.

d. ANGLE OF DEFLECTION. The angle of deflection is that angle between the path of the electron as it leaves the field and a line parallel to the axis of the tube. For a given intensity of field this angle is directly proportional to the length of the deflection field which is determined by the length of the deflection plates. With a longer field there is more time for the field to act on the electron beam and cause deflection. Also, the closer the spacing between the deflection plates, the more intense the field for a given voltage between plates. This increases the angle of deflection. The angle also may be increased by increasing the difference of potential between the charged plates. Under these conditions, the transverse force is increased, with a resulting increase in deflection. Finally, the angle of deflection may be increased by *reducing* the accelerating voltage. This reduces the velocity of the electrons and allows them to spend more time within the deflection field, which can therefore produce a greater effect.

e. DEFLECTION SENSITIVITY AND FACTOR.

(1) Deflection sensitivity of a cathode-ray tube is a constant which indicates how much the spot on the screen is deflected (in inches, centimeters, or millimeters) for each volt difference of potential that is applied to the deflection plates. For example, tube specifications may describe a certain tube as having a deflection sensitivity of .2 millimeter per volt d-c. This means that when the tube is operated according to the stipulated conditions, every volt of d-c applied to the deflection plates causes the spot to move .2 millimeter from its undeflected position. Deflection sensitivity is directly proportional to the length of the deflection plates and the distance between the deflection plates and the screen. It is inversely proportional to the separation between the deflection plate and the accelerating voltage.

(2) Deflection factor indicates the voltage required on the deflection plates to produce a unit deflection on the screen, and it is the reciprocal of deflection sensitivity. It is expressed in terms of a certain number of d-c volts per centimeter (or per inch) of spot movement. For example, in the tube mentioned above as having a deflection sensitivity of .2 millimeter per volt d-c, the deflection factor is 50 volts per centimeter. It is also common to express the deflection factor in terms of the second anode voltage. That is, the deflection factor is given as a certain amount for each kilovolt of second anode voltage that is used—for example, 60 volts d-c per inch/kilovolt of second anode voltage. With 1 kilovolt applied to the second anode, the factor is 60 volts per inch. With 2 kilovolts applied to the second anode, the factor is 120 volts per inch.

f. RADIAL DEFLECTION. An unusual type of electrostatic deflection is used when radial deflection is required. Radial deflection causes the electron beam to trace a spot that moves toward or away from the center of the screen. This is accomplished by mounting a thin metal rod at the center of the screen. This rod coincides with the tube axis and extends several inches into the envelope. When this rod is made negative, the radial field which it produces in conjunction with the second anode coating causes a radial deflection away from the center. When the opposite polarity is applied to this special electrode, radial deflection toward the center results.

10. Development of Linear Trace

a. One of the most important types of deflection involves the production of a linear trace. A linear trace is the pattern produced by a spot which moves at a uniform velocity. This spot travels equal distances in equal periods of time. A spot which moves across a 5-inch fluorescent screen in such a way that it covers a constant distance of 1 inch for every second of elapsed time is said to be moving at a uniform velocity. The trace produced by the spot is a linear trace. The linear trace is important because it affords a simple method of making time measurements on the screen of a cathode-ray tube. If it is known that the spot is located at the extreme left of a 5-inch screen at a certain time, and that it moves horizontally across the screen at a uniform velocity of 1 inch per second, it is evident that when the spot is at the exact center of the screen a time interval of 2½ seconds has elapsed. When the spot has moved four-fifths of the entire distance across the screen, a time interval of 4 seconds has elapsed. A *timebase* has been produced. This timebase may be traced in any direction, but the common practice is to trace it horizontally. The linear trace also is useful when using a cathode-ray tube to produce a graph of some variable quantity plotted against time.

b. To cause the spot to move in the manner described above an arrangement involving a voltage source and a potentiometer can be used (fig. 35).

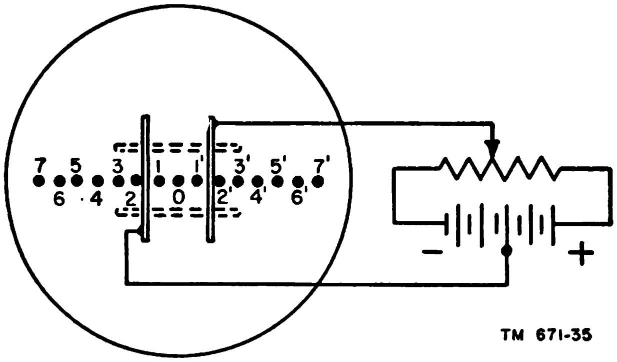


Figure 35. Horizontal spot movement to left and right from center position.

When the arm on the potentiometer is set at its midposition, both horizontal deflection plates are at the same potential. With no difference of potential between the plates, no deflection is produced and the spot is at the 0 position. As the arm is moved quickly toward the left, the right-hand deflection plate becomes more negative and the spot is deflected toward the left through positions 0 to 7. If the potentiometer arm then is moved slowly and uniformly from the extreme left-hand to the extreme right-hand position, the voltage on the right-hand horizontal deflection plate varies gradually from most negative, through zero, to most positive with respect to the fixed potential on the opposite deflection plate. This causes the spot to move slowly and uniformly across the screen through positions 7 to 7′. If the arm finally is moved quickly back to the midpoint, the spot begins to retrace its path and move through positions 7′ to 0. By repeating this procedure periodically, the spot is made to move slowly across the screen from left to right, then rapidly retrace its path.

c. If the spot is made to move rapidly enough, the persistence of the screen and the persistence of the human eye combine to give the illusion of a continuous horizontal line of light. This line of light may exhibit some flicker if the rate of motion is only 15 to 25 times per second, but at higher speeds little flicker is observed.

d. It is usual to require rapid spot movements. Therefore, the mechanical system described above is not satisfactory. A practical substitute is a specially designed circuit that generates a slow linear rise of voltage accompanied by a rapid fall. Such a circuit is known as a sawtooth generator because of the shape of the waveform produced (fig. 36).

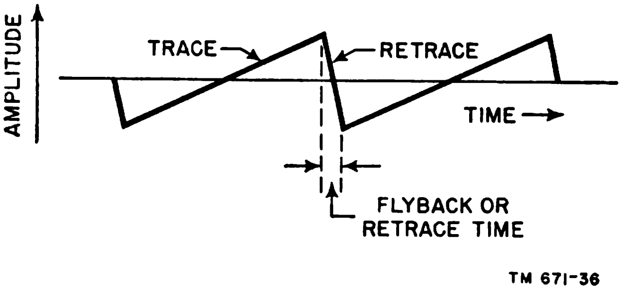


Figure 36. A practical sawtooth signal which is used to produce a linear trace.

Section III. ELECTROMAGNETIC CATHODE-RAY TUBES

11. Elementary Electromagnetic Cathode-Ray Tube

a. Organization and Function of Elements. The basic electron gun used in the electromagnetic cathode-ray tube is the triode gun (fig. 37). The cathode and control-grid arrangement for the electron gun is the same as it is in the electrostatic tube. Beyond the control grid is a hollow cylinder which has several baffles and which is coaxially symmetrical with the control-grid cylinder. This is the accelerating anode. A *spider* arrangement

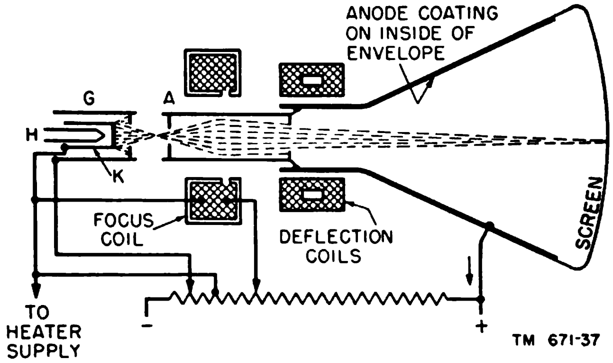


Figure 37. Basic triode electromagnetic electron gun.

connects this anode to the conducting coating within the tube. This coating acts as an extension of the accelerating anode and as a shield. An externally mounted coil is used to produce the magnetic field, which is the principal focusing means.

b. Schematic Representation. The accelerating anode is connected to a fixed positive potential of several thousand volts. The control grid is maintained negative with respect to the cathode, as it is in the electrostatic tube. A variable control is provided so that the intensity can be changed. A source of several hundred volts is used to supply current for the focus coil.

c. Physical Shapes.

(1) The glass envelope of the electromagnetic cathode-ray tube is usually more bowl-shaped than that of an electrostatic tube (fig. 38). The neck is almost always of smaller diameter than that of an electrostatic tube of similar screen size. The considerations involving care in handling and functions of the powdered graphite coating are the same as those discussed in paragraph 7*c*. A recent development is the metal type of electromagnetic cathode-ray tube. In this type, a glass neck and face are used in conjunction with a metal truncated cone. Three reasons are advanced for its development: lightness of weight, greater manufacturing flexibility (resulting in a less expensive tube with larger screen sizes), and better optical quality.

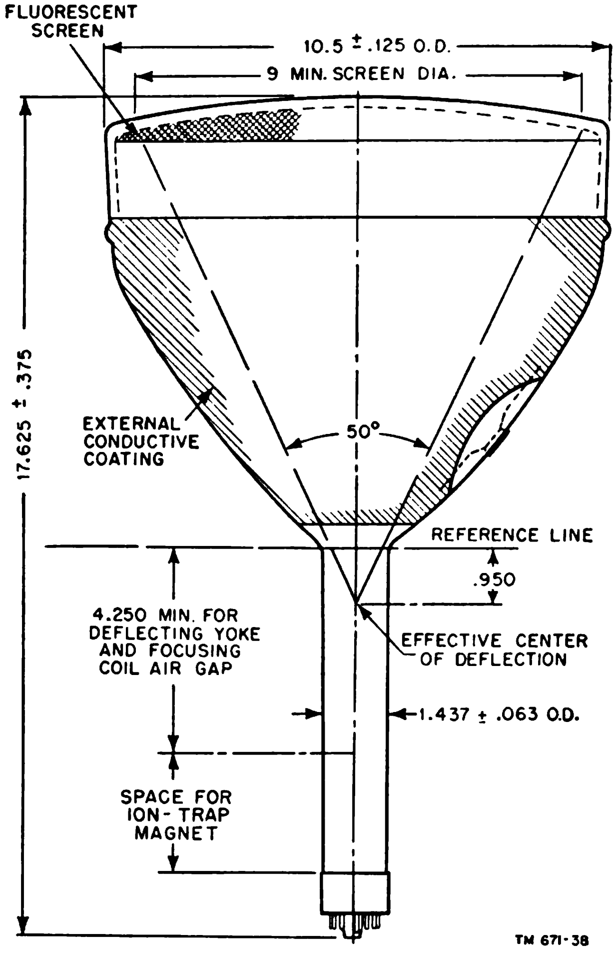


Figure 38. Outline of 10BP4 electromagnetic cathode-ray tube. Dimensions are in inches.

(2) The screen diameter of electromagnetic cathode-ray tubes ranges from 2 inches to over 30 inches, although the most commonly used screen sizes are 5, 7, 10, 12, 16, and 19 inches in diameter. The same standard tube designations and means of making electrode connections are used as those in the electrostatic tube.

d. Modifications of Electron Gun. Several improvements over the basic triode electromagnetic gun have been used. One of these involves the insertion of an additional electrode between the control grid and the accelerating anode. This electrode is in the form of a short metal cylinder known as the screen grid. Usually, it is operated at several hundred volts positive with respect to the cathode. The purpose is to prevent interaction between the control grid and the accelerating anode. Another modification involves a change in the position of the masking baffles. This results in producing a smaller spot on the screen and minimizes defocusing caused by deflection fields. It also is possible to produce intensity modulation by applying signals to the screen grid.

e. Ion Traps.

(1) The presence of negative ions which have been liberated from tube electrodes or residual gas poses a problem in the electromagnetic cathode-ray tube. In electrostatic focus and deflection, the mass of the particles involved plays no part and electrons and ions are focused and deflected simultaneously. However, in an electromagnetic cathode-ray tube the greater mass of the ion prevents it from being acted upon properly by the focusing and deflection fields. The ions

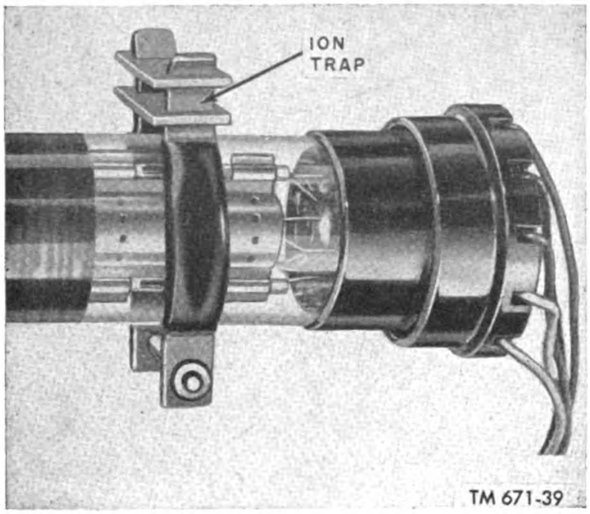


Figure 39. One type of ion-trap magnet.

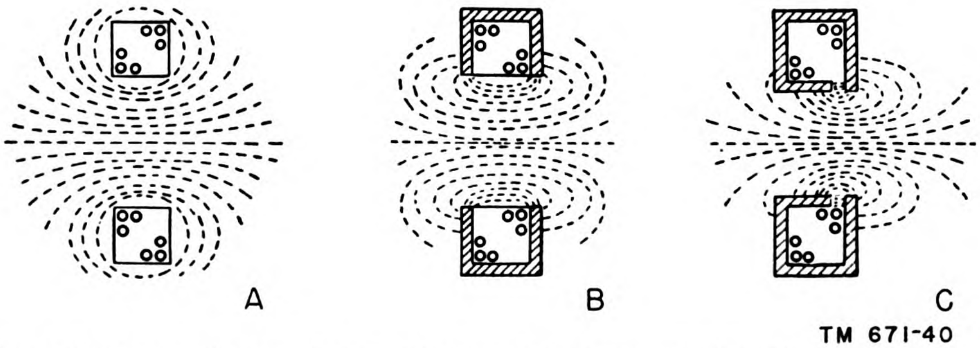
hit the center of the screen in the form of a large unfocused beam. Although the amount of fluorescence produced is small, the continuous bombardment eventually may produce a large burned area, called an *ion spot*. This reduces the sensitivity of the center of the fluorescent screen to desired patterns.

(2) Two methods are used to prevent the harmful effect produced by the ions. One of the these involves the use of a metal-backed fluorescent screen. When a thin coating of aluminum is deposited on top of the fluorescent coating it usually is found that no ion spot is produced. A more common method is to use an *ion-trap* magnet which is slipped around the neck of the cathode-ray tube adjacent to the socket (fig. 39). The magnet works in conjunction with a modified electron gun. This gun is made to produce a bent electrostatic field that carries both ions and electrons toward the accelerating anode. The ion-trap magnet operates on the electrons in this combined beam in such a way that they change their direction of motion and return toward the main axis of the tube. In this manner only the electrons strike the fluorescent screen, while the ions strike the anode and are removed. The placement of the ion-strap magnet is critical. If it is incorrectly placed or alined, the intensity of the pattern is reduced considerably or the pattern may not appear at all.

12. Electromagnetic Focusing

a. Complete System. The system used to focus the electron beam in an electromagnetic cathode-ray tube involves two lenses. The first lens is produced by the electrostatic field between the control grid and the following electrode. This produces the first cross-over point in the same manner described in paragraph 8*a* for the electrostatic tube. The diverging electrons then enter the second lens which is produced by the magnetic field of the focus coil. This uniform magnetic field acts on the diverging electrons in such a way that they describe a single-turn helical path, such as the one described in paragraph 3*f*. With the proper magnetic field strength, the resulting second cross-over point is at the screen.

b. Focus Coil Current Requirements. The focus coil itself consists of a multilayer solenoid which has a great many turns. These are wound on a form which has a short length. The solenoid



A, unshielded focus coil; B, focus coil surrounded, except for inner surface, by magnetic shield; C, focus coil surrounded by magnetic shield except for small air gap on inner surface.

Figure 40. Magnetic fields within.

is magnetically shielded to confine its field to its own immediate vicinity. The intensity of the magnetic field is not increased thereby because of the large reluctance of the air gap. A small air gap in the inner surface of the shield permits a rather concentrated field to extend outward into the neck of the tube (fig. 40). In order to produce the proper magnetic field for correct focusing, the proper coil must be chosen. The coil selected depends on the number of turns and the current flowing in it, which gives the specification called *ampere turns*. Although there is considerable variation from tube to tube, a typical value might be 400 to 600 ampere turns. A focus coil having 4,000 turns and carrying .15 ampere carries 600 ampere turns.

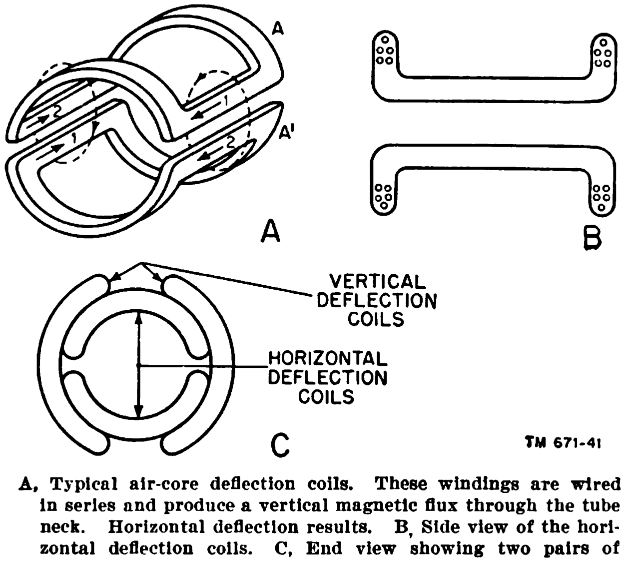
c. MAGNETIC FOCUSING. To produce the proper focusing action it is necessary to produce a magnetic field whose strength is correct. If the magnetic field is too intense, the cross-over point will be located behind the screen. If the field is too weak, the cross-over point will be located in front of the screen. A rheostat usually is used to control the amount of current flowing through the focus coil. This control, known as the *focus control*, permits the field strength to be varied to produce the correct focus. The rotational forces which act on the diverging electrons in the magnetic field of the focus coil are proportional to the angle of divergence from the axis of the tube. Consequently, all the diverging electrons which enter the field from the first cross-over point are returned to the axis of the tube at the screen.

d. POSITION OF FOCUS COIL. The mechanical arrangement of the focus coil allows it to be moved and tilted. Changing the position of the focus control changes the operating range of the focus control. In addition, the position of the coil somewhat determines the size of the spot. Finally, the undeflected location of the spot is partially determined by the tilt of the focus coil. For example, if the electron gun of the tube is slightly out of alinement, so that the undeflected spot is above the center of the screen, it is possible to produce proper centering by tilting the top edge of the focus coil downward toward the screen. This method of centering introduces undesirable changes in the spot shape.

13. Electromagnetic Deflection

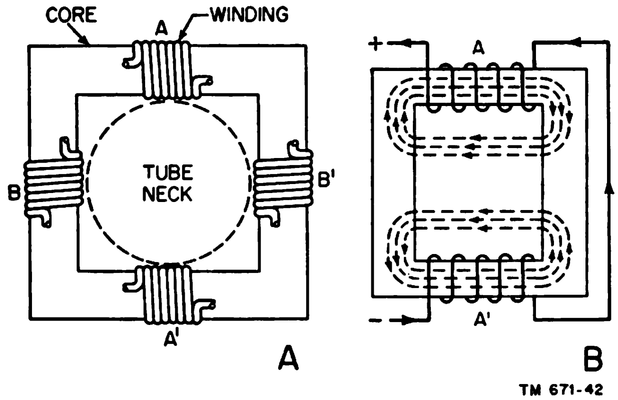
a. DEFLECTION COILS. In an electromagnetic cathode-ray tube, magnetic fields are used to cause deflection of the electron beam. The force exerted on the electron beam will always be at right angles to the motion of the electrons and at right angles to the direction of the magnetic lines of force. The magnetic fields which deflect the beam are produced by causing currents to flow through deflection coils mounted externally around the neck of the tube. Usually four deflection coils are used. Two of these are wired in series and are mounted in order to produce a magnetic field whose lines of force run vertically through the neck of the tube. This vertical magnetic field causes a horizontal deflection of the spot. The other pair of coils is wired in series and mounted in order to produce a magnetic field whose lines of force run horizontally through the neck of the tube. This horizontal magnetic field causes a vertical deflection of the spot.

b. POSITION OF DEFLECTION YOKE. All deflection coils are housed together in an assembly that slips over the neck of the cathode-ray tube. This assembly, known as the deflection *yoke*, is located beyond the focus coil and next to the flared portion of the tube envelope. Several physical arrangements are common. The usual air-core deflection yoke is made up of four coils wound in the form of rectangles. The rectangular winding then is bent to fit around the neck of the tube (fig. 41). An alternate deflection yoke which uses an iron dust core may be used to produce greater flux uniformity (fig. 42).



A, Typical air-core deflection coils. These windings are wired in series and produce a vertical magnetic flux through the tube neck. Horizontal deflection results. B, Side view of the horizontal deflection coils. C, End view showing two pairs of deflection coils.

Figure 41.



A, Square-shaped iron-core deflection yoke; B, Connections and field produced by the vertical deflection coils.

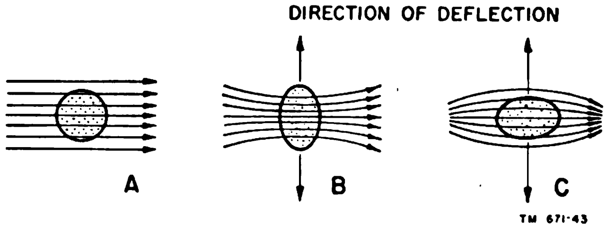
Figure 42.

c. Electron Path After Leaving Field. When the electron enters the magnetic deflection field it experiences a deflecting force as it does in the electrostatic deflection system. This force is at any instant perpendicular to the direction of motion of the electron at that instant, and it does not change the kinetic energy of the moving electron. While in a uniform deflecting field, the electron describes a path which is a circular arc. However, after the electron has left the field, the path is straight because no other forces are acting.

d. Angle of Deflection. The angle between the path taken by the electron as it leaves the deflection field and the axis of the tube is known as the angle of deflection. This angle depends on the current through the deflection coil, the number of turns, the length of the deflection field, and the accelerating potential used. In an electromagnetic tube the angle of deflection varies inversely as the square root of the accelerating voltage rather than inversely as the accelerating voltage as in the electrostatic tube. Therefore, increasing the accelerating voltage on a magnetic cathode-ray tube has less effect in reducing the deflection angle than it does in the case of an electrostatic tube. Commercial practice has somewhat changed the concept of the *deflection angle.* This angle is now frequently taken to mean the entire angle bounded by the maximum allowable swing of the beam. Therefore, if the electron beam can be deflected 25° above and 25° below the axis of the tube, the tube is said to have a deflection angle of 50°.

e. Deflection Sensitivity and Deflection Factor. The deflection sensitivity may be expressed in terms of deflection on the screen per unit field strength, for example in millimeter per gauss, centimeter per gauss, or ampere turn. This sensitivity is determined by the angle of deflection and the distance from the center of the deflection field and the screen. The deflection factor in an electromagnetic cathode-ray tube, according to common usage, defines the amount of current required in a standard coil to produce a certain deflection angle.

f. Effect of Deflection on Focusing. So far, only deflection by means of uniform magnetic and electrostatic fields has been considered. If nonuniform fields are made to act upon an electron beam, all parts of the beam are not deflected by the same amount. This causes the shape of the spot produced by the beam to be changed during the deflection process (fig. 43). In addition, the entire pattern shape may be altered because of nonuniform deflection fields. The lines of force from the horizontal and vertical deflection fields should be exactly perpendicular to each other throughout the entire deflection region. If this is true, the resultant deflection is proportional to the amplitude of the vertical and horizontal components. However, if the lines of force are not perpendicular, components of deflection which should be exactly horizontal and vertical are no longer in those directions. Considerable pattern distortion will result. Nonuniform fields may result from incorrectly designed or incorrectly located deflection coils or from interaction caused by external fields.



A. Shows a uniform field acting on the beam with no distortion resulting; B, Defocusing produced by a nonuniform pincushion field; C, The distortion resulting from a nonuniform barrel field.

Figure 43. Various types of deflection defocusing.

14. Development of Trace

a. Deflection Coil Current Requirements. In order to produce a linear trace which can be used as a timebase, such as was discussed in connection with the electrostatic tube, certain requirements must be met. In the case of the electrostatic cathode-ray tube it was seen that a gradually rising and rapidly falling sawtooth voltage was required. The amount of deflection was directly proportional to the difference of potential between the deflection plates. In an electromagnetic tube the amount of deflection is directly proportional to the current through the deflection coil. Therefore, a gradually rising and rapidly falling sawtooth *current* is needed. Because of the inductance of the deflection coils, it is not possible to produce a sawtooth of current by applying a similarly shaped voltage to the deflection coils. Instead, a specially shaped voltage, which will be discussed later, is required.

b. SPOT MOVEMENT. If the properly shaped voltage is applied to the horizontal deflection coils so that a sawtooth current is produced, the spot moves at a uniform velocity across the screen. This movement of the spot is the same as that which already has been discussed in connection with the electrostatic tube. If the spot is made to move back and forth rapidly enough a horizontal line of light will be produced. This line may be used as a timebase. If the frequency of the sawtooth current is above approximately 25 cps, little flicker will be present.

15. Comparison of Electromagnetic and Electrostatic Cathode-Ray Tubes

a. CHARACTERISTICS AND USES OF ELECTROMAGNETIC TUBES.

(1) The electromagnetic cathode-ray tube has the following advantages over the electrostatic tube: A well-focused electron beam of higher current density can be produced. Greater accelerating voltages can be used to obtain brighter screen patterns without as great a reduction in the deflection sensitivity of the tube. The structure of the electron gun is simpler and more rugged. The over-all length of the envelope is shorter.

(2) The disadvantages of the electromagnetic cathode-ray tube are as follows: Large, bulky focus coils and deflection yokes are used. More power is required to operate the focus and deflection systems. The circuits which supply deflection signals are somewhat more complex and there is a definite limit to the type and frequency of deflection signals that can be used.

(3) The electromagnetic tube is used widely in intensity-modulated displays especially when a large screen diameter is required. Most PPI scan radars and television displays use this type of cathode-ray tube.

b. CHARACTERISTICS AND USES OF ELECTROSTATIC TUBES.

(1) The electrostatic cathode-ray tube has the following advantages over the electromagnetic tube: No bulky external coils are used; the entire focusing and deflection systems are contained within the envelope. Somewhat simpler external circuits can be used to deliver the deflection signals required for proper operation. Higher deflection frequencies and more complex waveforms can be applied without these signals being seriously affected by the deflection system of the tube. Low deflection powers are required as the tube is essentially a voltage operated device. The weight of the tube and its associated components is less.

(2) The disadvantages of the electrostatic cathode-ray tube are as follows: High current density patterns are not produced easily without defocusing. Patterns with considerable brightness over a large screen area usually cannot be formed without a loss in deflection sensitivity. The over-all length of the tube is greater and its electron gun structure is more complex.

(3) The electrostatic tube is widely used in test instrument applications. Also it is employed in certain radar displays such as the A scan and J scan where an intensity modulated display is not used. The tube is also found in other systems where weight is important, such as in aircraft installations. Some early television displays having cathode-ray tube screens with diameters of less than 7 inches used electrostatic tubes.

Section IV. BIDIRECTIONAL DEFLECTION

16. Resultant of Two Forces

a. Addition of Forces. Any force which acts within a system has a definite magnitude and acts in a definite direction. Therefore, force is said to be a *vector* quantity. This is drawn as an arrow whose length represents the magnitude of the force and whose direction indicates the direction along which the force is acting. The addition of forces then merely becomes a matter of graphical construction (fig. 44). If two forces are acting in the same direction, the total force is merely the sum of their individual magnitudes. If the two forces are acting in opposite directions, the total force is the difference between their magnitudes. The direction of the resultant force is the same as that of the greater of the two. For example, if a 3-pound and a 4-pound force are both acting in the same direction on an object, the object will feel a total force of 7 pounds in that direction. If the forces are acting in opposite directions, the total force felt will be 1 pound in the direction that the 4-pound force operated.

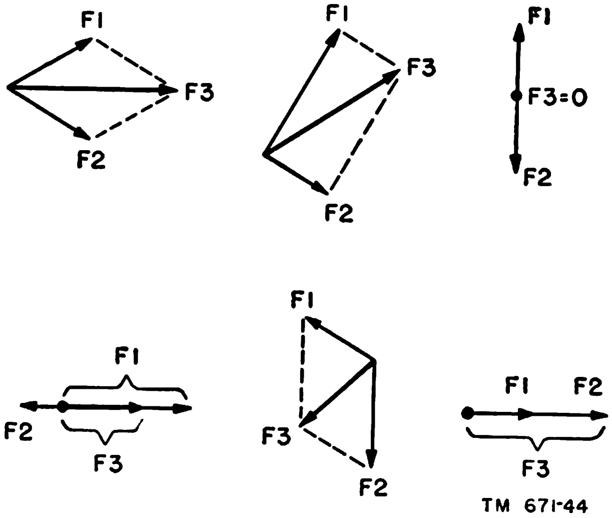


Figure 44. Vector representation of two forces, F1 and F2, having various magnitudes and operating in various directions. The resultant force is always F3.

b. Forces at Right Angles. When forces are acting at right angles to each other, the resultant force is determined by the relative magnitudes of the forces. This resultant can act in any direction from the direction of one force, through 90°, to the direction of the second force. Also, the size of the resultant may have any value from the magnitude of the larger force to 1.414 times this magnitude (fig. 45).

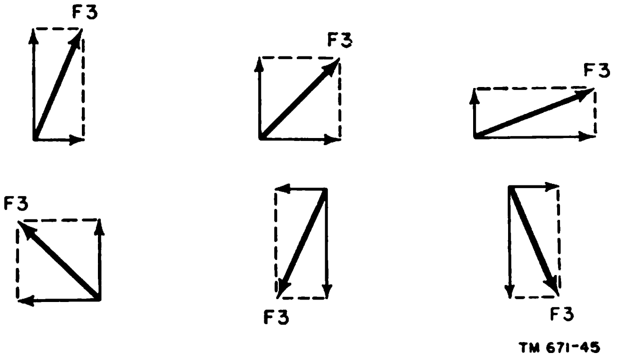


Figure 45. Vector representation of two forces at right angles. The resultant is designated as F3.

17. Bidirectional Electrostatic Deflection

a. Spot Deflection in Horizontal Direction. When a voltage is applied to the horizontal deflection plates, an electrostatic field is produced. This field exerts a horizontal force on the electron beam. Whether the beam moves toward the left or the right is determined by the direction of the field. With the left-hand plate positive with respect to the right-hand plate, the deflection is toward the left. When the polarity is reversed, the direction of deflection is toward the right. The amount of deflection is determined by the strength of the deflection field. This is determined by the magnitude of the difference of potential between the deflection plates.

b. Spot Deflection in Vertical Direction. When a voltage is applied to the vertical deflection plates, an electrostatic field is produced. The force exerted by this field causes the beam to be deflected in a vertical direction. Whether an upward or a downward deflection is produced depends on the direction of the field. This is determined by the polarity of the charge as described in *a* above. The amount of vertical deflection is determined by the magnitude of the charge.

c. Resultant Spot Deflection. The two forces which act on the electron beam are seen to be at right angles. The resultant spot position depends on the resultant force. If forces producing equal deflections are applied, the beam is deflected at an angle which is midway between horizontal and vertical, or 45°. If the two forces producing equal deflection are acting upward and toward the right, the resultant diagonal deflection is at a 45° angle toward the upper right-hand portion of the screen. Two forces producing equal deflection acting upward and toward the left produce a diagonal deflection at a 45° angle toward the upper left-hand portion of the screen. Similarly, if the forces are acting downward and toward the left, the resultant is a diagonal deflection at a 45° angle toward the lower left-hand portion of the screen. Forces acting downward and toward the right result in diagonal deflection at a 45° angle toward the lower right-hand portion of the screen. If the deflections produced are *not* equal, the resultant deflection is in the same general directions as that above but not at 45°. The exact angle of deflection will be determined by the magnitude of the deflection forces involved. Therefore, it is possible to deflect the electron beam in any direction. The spot on the screen can be positioned at *any* location on the screen. This may be done by arranging two sources of variable voltage which are applied to the two pairs of deflection plates (fig. 46).

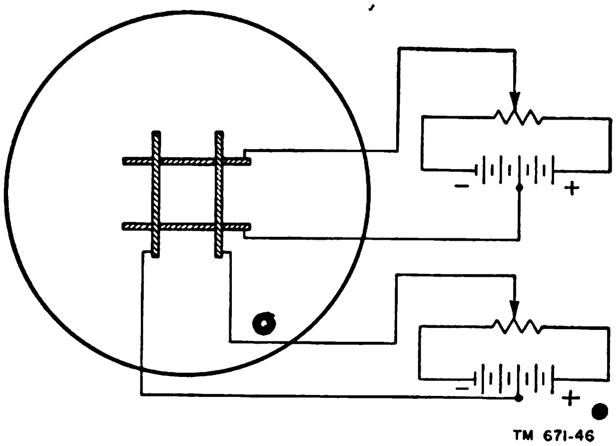


Figure 46. Basic method of causing spot deflection to any point on the screen.

18. Bidirectional Electromagnetic Deflection

The same principles of bidirectional deflection apply to electromagnetic tubes as those which have been discussed under electrostatic tubes. The two perpendicular forces are the result of magnetic fields rather than of electrostatic fields. These magnetic fields are produced when current is made to flow through the deflection coils. A reversal in the direction of current flow reverses the direction of the magnetic field. This permits either an upward or a downward deflection in the case of the vertical deflection coils. The horizontal deflection coils produce the required deflection to the right or left. The magnitude of the deflection depends directly on the amount of current flow through the deflection coils. It is also possible with this system to cause the spot to move to any position on the screen of the cathode-ray tube by the application of suitable currents to the deflection coils.

19. Formation of Screen Pattern

a. IMAGE FORMATION. The image on the screen of the cathode-ray tube is produced by a moving electron beam. This beam causes a small spot of light to appear on the fluorescent screen. If the spot moves rapidly enough, a line of light is produced. The line of light is made to form various patterns on the screen which may convey useful information. No matter how complex the pattern appears on the screen, it is produced by the progressive motion of a single spot of light. Many patterns that convey useful information appear to be stationary on the screen. Actually, this is the result of a rapidly moving spot that continually retraces its path.

b. USING LINEAR HORIZONTAL DEFLECTION. Assume that a pattern which represents a single cycle of sinusoidal voltage is desired on the screen. The most common representation of a sine wave is actually a graph. The vertical axis of this graph represents the amplitude of the voltage, while the horizontal axis represents time. This plot of voltage amplitude versus time results in the common sine wave pattern that is used. If the electron beam is deflected vertically in direct proportion to the amplitude of the signal to be traced, moving upward for the positive alternation and downward for the negative, a vertical line of light would be produced. If, however, the beam is made to move horizontally at a uniform velocity at the same time, the desired pattern will result. The pattern is produced by a vertical deflection force which depends on the signal amplitude acting in conjunction with a horizontal deflection force, which produces the linear timebase. Consequently, the required graph is traced on the screen. This process will be discussed in greater detail later in this manual.

c. USING NONLINEAR HORIZONTAL DEFLECTION. When it is not desired to show a linear timebase or when the horizontal axis of the graph to be traced on the screen is to be nonlinear, a nonlinear horizontal deflection must be used.

Section V. SUMMARY AND REVIEW QUESTIONS

20. Summary

a. A charged body contains an excess or a deficiency of electrons.

b. An electrostatic field is a special condition of space surrounding every elemental charge of either polarity. This field represents potential energy.

c. An electron tends to move parallel to the lines of electrostatic force and at right angles to the equipotential lines.

d. The force exerted on an electron located anywhere within a uniform electrostatic field is the same.

e. Beams of electrons may be made to converge or diverge by proper curvature of equipotential lines.

f. A magnetic field is produced when charges are made to move.

g. An electron moving within a magnetic field feels a force which is at right angles to the direction of the magnetic lines of force and at right angles to its motion.

h. The electrostatic cathode-ray tube uses electrostatic fields for focus and deflection of the electron beam. The electromagnetic cathode-ray tube uses magnetic fields for these purposes.

i. The intensity of the pattern produced on the screen may be controlled by varying the amount of negative voltage on the control grid.

j. The focus control in the electrostatic tube varies the voltage on the focus anode with respect to the accelerating anode. In electromagnetic tubes, a variation in current through the focus coil is used.

k. Certain materials, called phosphors, have the ability to glow visibly when a beam of electrons strikes them.

l. Persistence of a phosphor refers to its afterglow.

m. Spot burn is produced by a sharply focused, extremely bright, motionless spot on the screen.

n. The basic triode electrostatic electron gun consists of heater-cathode, control grid, and focus and accelerating anodes.

o. Complete electrostatic focusing uses two lenses made up of electrostatic fields.

p. The pairs of parallel plates, mounted at right angles within the cathode-ray tube, accomplish electrostatic deflection.

q. The angle of deflection in an electrostatic tube depends on the length and spacing of the deflection plates, the amount of deflection potential, and the accelerating voltage.

r. A linear trace permits a cathode-ray tube to be used for time measurement and for graphs showing some variable versus time.

s. If the spot moves rapidly enough, a solid line of light is produced.

t. The ion trap prevents the formation of an ion spot on the screen of an electromagnetic cathode-ray tube.

u. Complete electromagnetic focusing uses two lenses; one is made up of an electrostatic field and the other of an electromagnetic field.

v. Two pairs of coils mounted at right angles around the neck of the cathode-ray tube accomplish electromagnetic deflection. This assembly is called the deflection yoke.

w. The angle of deflection in an electromagnetic tube depends on the current through the deflection coil, number of turns, length of the field, and the accelerating voltage.

x. Nonuniform fields cause defocusing of the beam and distortion of the pattern.

y. Two deflection forces, operating at right angles, may move the electron beam to any point on the screen.

21. Review Questions

a. What constitutes a charged body?

b. What is an electrostatic field? An electric field?

c. What is the direction of the electrostatic lines of force? Why?

d. Give two important properties of electrostatic lines of force.

e. What is meant by the fringe field?

f. The velocity of an electron in an electrostatic field is determined by what factor?

g. What is an equipotential line?

h. In what direction will an electron move under the influence of an electrostatic field? An electromagnetic field?

i. Give several methods of causing electron beams to converge or diverge.

j. Give two important properties of magnetic lines of force.

k. What is the advantage of using a multilayer solenoid over a simple current-carrying conductor in producing a magnetic field?

l. Under what conditions will an electron describe a helical path?

m. What is the difference between an electrostatic and electromagnetic cathode-ray tube?

n. Give the purpose of the following electrodes in an electrostatic cathode-ray tube: heater, cathode, control grid, focus anode, accelerating anode, deflection plates, powdered graphite coating, and fluorescent screen.

o. Give the purpose of the following elements in an electromagnetic cathode-ray tube: focus coil and deflection yoke.

p. How is pattern brightness varied?

q. How is pattern focus varied in an electrostatic cathode-ray tube? In an electromagnetic tube?

r. What is the purpose of the air gap in the shield of the focus coil?

s. Distinguish between the terms fluorescence and phosphorescence as applied to cathode-ray tube screens.

t. What is a phosphor?

u. Distinguish between spot burn and ion spot.

v. Why are cathode-ray tubes dangerous to handle?

w. What is the purpose of the intensifier anode that is used on some electrostatic cathode-ray tubes?

x. Give some factors which determine the size of the spot which is produced on the screen of the cathode-ray tube.

y. What forces act on the electron as it passes through two parallel charged plates?

z. Describe the path of the electron after it leaves the deflection field.

aa. What is meant by the angle of deflection and what determines the size of this angle?

ab. Distinguish between deflection factor and deflection sensitivity.

ac. What is meant by radial deflection and how can it be accomplished?

ad. What is the importance of a linear trace?

ae. Give two reasons why a rapidly moving light spot will trace a line of light on the screen of a cathode-ray tube.

af. For what purpose is an ion-trap magnet used? Why is it unnecessary in electrostatic tubes?

ag. Why is the focus coil mounted so that it may be moved and tilted?

ah. Explain why nonuniform fields cause defocusing and pattern distortion.

ai. Explain how it is possible to move the spot on the screen to any location by application of only two forces operating at right angles.

CHAPTER 2

BASIC DISPLAY SYSTEMS

Section I. FUNDAMENTAL DISPLAY SYSTEM

22. General

Cathode ray tubes are used with associated circuits for the study of voltage waveforms and of the general characteristics of various electrical impulses. The signal to be studied is fed to the cathode ray tube in such a manner as to produce a waveform on the screen. The vertical axis of the picture measures instantaneous voltage values of the input signal; the horizontal axis measures time. The circuits used to produce such presentations are called *display systems*. The oscilloscope is a basic display system.

23. Basic Oscilloscope

The basic oscilloscope consists of six sections. These are shown as blocks in figure 47.

a. To present the voltage waveform of an input signal on a cathode-ray oscilloscope it usually is necessary first to increase the amplitude of the signal. As explained in paragraph 15*b* small voltages fed to the deflection system of the cathode-ray tube do not result in a measurable deflection of the electron beam. Therefore, the first circuit to which the input signal is fed is the *vertical-deflection amplifier*. This section amplifies the signal so that its trace covers a good portion of the face of the cathode-ray tube. The vertical amplifier can consist of one or more stages of amplification, depending on the voltage requirements of the deflection system of the cathode-ray tube. If the input signal is observed on the face of the cathode-ray tube without a signal on the horizontal deflection plates, all that can be

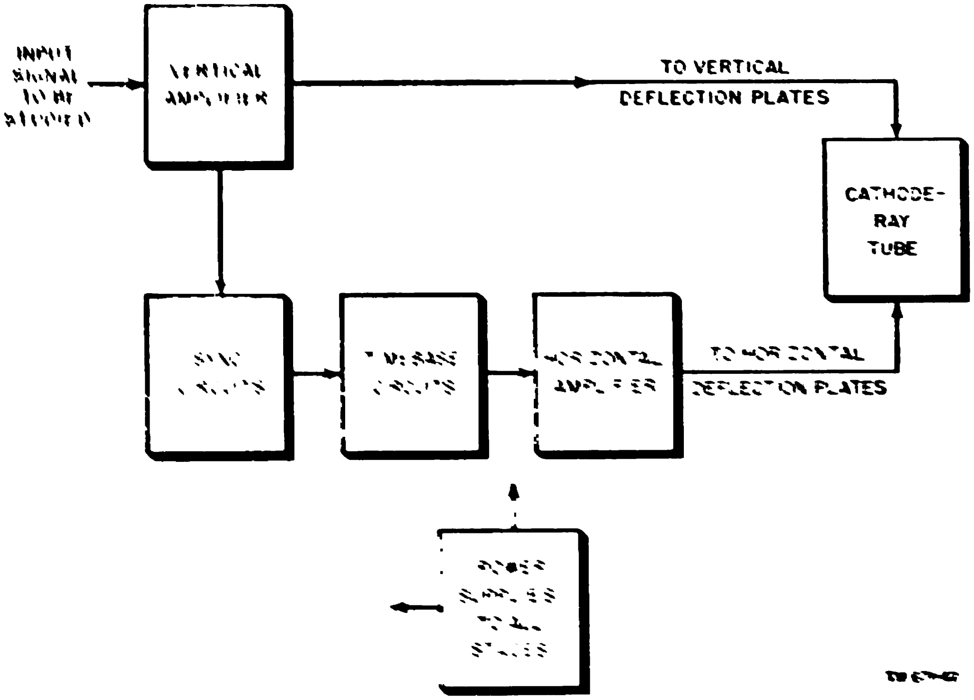


Figure 47. Simplified block diagram of the basic oscilloscope.

seen is a spot moving up and down, tracing a vertical line. To follow the form of the signal with respect to time, it is necessary to have a time base against which the signal can be plotted.

b. The *timebase circuit* generates a voltage which increases linearly with respect to time. It is applied to the horizontal-deflection plates of the cathode-ray tube. This voltage causes the electron beam to sweep across the face of the tube horizontally, and then return rapidly to its initial position. Since the timebase voltage is a linear function of time, the input signal is shown as a graph of voltage plotted against time. The frequency of timebase voltage can be set at one-third the frequency of the input signal. This results in the presentation of 3 cycles of the input signal to one sweep; i. e., 3 complete cycles of the input signal are seen on the face of the cathode-ray tube. This proportion is necessary for good analysis. In order to adjust the horizontal trace to fill any portion of the screen desired, the timebase signal is fed to an amplifier.

c. The *horizontal-deflection amplifier* amplifies the timebase signal before it is fed to the horizontal-deflection plates. This timebase signal need not come from a special timebase generator. In some cases, the 60 cps a-c (alternating current) supply of the oscilloscope, or some other type of external signal, is used instead of the timebase. The horizontal amplifier generally is very similar in construction to the vertical amplifier. To make certain that the voltage from the horizontal amplifier, in combination with the voltage from the vertical amplifier, produces a steady trace on the face of the cathode-ray tube, synchronizing circuits must be used.

d. The *synchronization system* locks the sweep voltage from the timebase circuits in step with the input signal from the vertical amplifier. To accomplish this, part of the input signal fed to the vertical amplifier is sent through the synchronizing circuits to the timebase generator.

e. The *cathode-ray tube* is the display element of the oscilloscope. The deflection voltages from the vertical and horizontal amplifiers are fed to its plates, and a trace is produced in the manner explained in chapter 1. Included in the cathode-ray tube section are various circuits for positioning, focusing, and intensifying the electron beam. The elements of the electron gun as well as the circuits just mentioned receive their operating voltages from the power supply.

f. The *power supply* is the source of operating voltages for all the sections of the oscilloscope. In general, two ranges of voltage are required: a high voltage (1,000 to 1,500 volts) for the cathode-ray tube, and a low voltage (300 to 450 volts) for the other tubes and circuits. In some cases the power supply is a separate unit from the rest of the oscilloscope. For use on domestic commercial power lines and on military power sources, the transformer of the power supply usually is designed to work on 115- to 125-volt, 50- to 60-c. p. s. a-c.

24. Variations of Basic Oscilloscope

The basic oscilloscope whose block diagram is shown in figure 47 can be used to analyze only the simplest waveforms (fig. 48). For more advanced analysis, other circuits must be added. If, for example, it is desired to observe pulses with an irregular recurrence rate, the sweep circuits of the oscilloscope must be changed to give a sweep voltage at irregular intervals corresponding to the recurrence rate of the pulse signal, otherwise the trace will not be a steady one. To accomplish this, triggered sweep circuits are added.

a. Triggered Sweep System.

(1) This system is a sweep generator that furnishes either a periodic or a nonperiodic time base voltage. The generator does not operate until an external signal, called the trigger signal, is fed to it. In many cases, the signal to be observed serves as the trigger signal by upsetting the operating balance existing in the generator circuit and causing it to generate a sweep voltage. If this trigger signal is fed to the generator periodically, the resulting sweep is periodic; if it is not fed periodically (if it is, for example, an irregularly recurring pulse) the resulting sweep appears at irregular time intervals.

(2) Triggered sweeps are used in oscilloscopes designed for the observation of nonperiodic pulses and transients. In these oscilloscopes, it is desired to have a sweep voltage only when the signal to be observed appears. In pulse applications, for example, where the pulse is usually of interest rather than the interval between pulses, the pulse signal triggers the sweep system so that only the

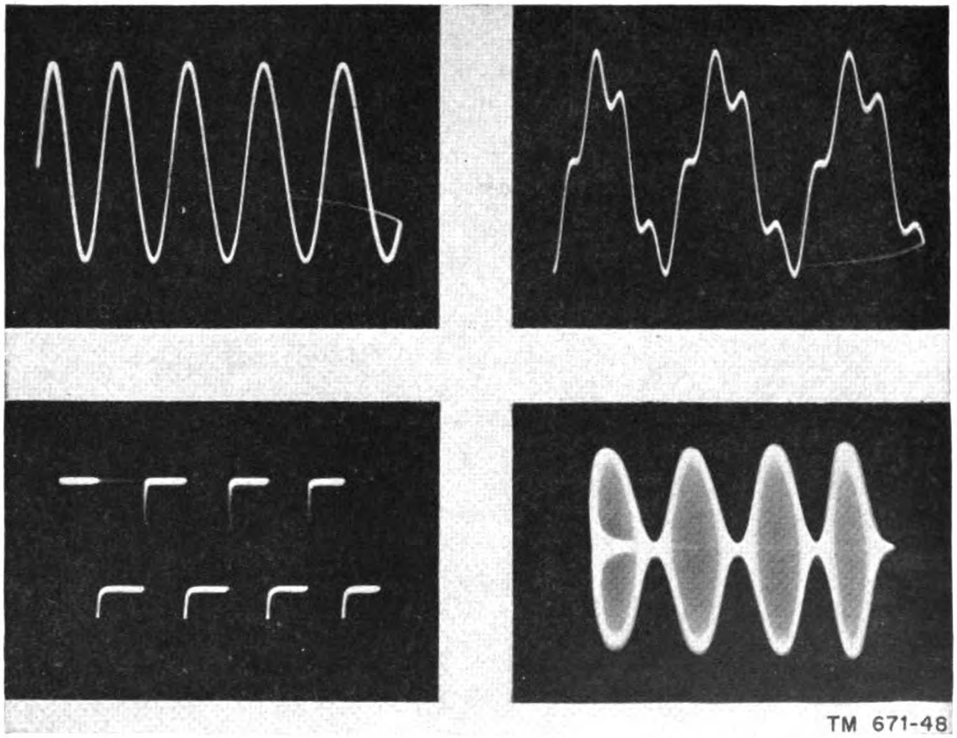


Figure 48. Typical waveform patterns observable with the basic oscilloscope.

pulse is shown on the face of the cathode-ray tube.

(3) To make the pulse even more outstanding, the electron beam of the cathode-ray tube can be kept at a low intensity until the pulse arrives at the oscilloscope. When the pulse arrives, the intensity of the beam is increased so that it sweeps across the screen and leaves a bright trace. The circuit which accomplishes this action is called a Z-axis circuit.

b. Z-Axis Circuit (Intensity Modulation).

(1) In operation, a signal is fed either to the control grid or the cathode of the cathode-ray tube. This signal changes the control-grid bias in the tube, resulting in a change in the density of the electron beam.

(2) One of the most common uses of the Z-axis circuit is that of *blanking* (eliminating) the timebase retrace. This is accomplished in the following manner: Initially, the electron beam of the cathode-ray tube sweeps across the screen in one direction, either at normal or increased intensity. After the beam reaches the end of its trace, it returns quickly to the starting position. During this return, or retrace, the Z-axis circuit increases the negative bias in the tube, resulting in a decrease of the electron density of the beam. This causes the retrace to be unobservable (at normal *brightness* setting).

c. Delay Networks. These are circuits which delay the input signal before it reaches the vertical-deflection plates. This permits the timebase voltage to be fed to the horizontal-deflection plates and so to start the sweep before the input signal is superimposed upon it. This action is important in the observation of pulses and transients where it is necessary to follow the complete amplitude variation of the input signal. By having the sweep start before the input signal is shown, none of the input signal waveform is lost.

25. The Synchroscope

A synchroscope is an oscilloscope designed especially for the observation of nonrepetitive waveforms such as nonperiodic pulses and transients. The synchroscope has triggered sweeps which are calibrated to observe waveforms of very short duration. The sweep may be as short as a fraction of 1 microsecond.

a. Block Diagram.

(1) A block diagram of a simple synchroscope is shown in figure 49. It should be noted that the major difference between this diagram and figure 47 (the basic oscilloscope) is the addition of the trigger and delay circuits. The switching arrangement makes available a variety of sweep voltages.

(2) The circuit can be operated as a simple oscilloscope. To do this, the switches are set as shown, and the input signal is fed into the vertical amplifier, with the sawtooth generator supplying the sweep voltage. The trigger circuits are not used.

(3) For pulse and nonperiodic waveform observation, the triggered sweep generator and the delay network are switched into the circuit. The trigger signal can come from the trigger generator or from an external signal source through the sync amplifier. The initial position of the electron beam is at one end of the cathode-ray tube screen. At this point, there is no visible spot on the screen. After a trigger pulse is sent to the triggered sweep generator, the latter generates a sweep voltage which goes to the horizontal-deflection plates of the cathode-ray tube. At the same time, the electron beam is intensified by a voltage from the Z-axis circuit. The electron beam then traces the waveform of the input signal across the cathode-ray tube screen. After this is done, the beam is shut off and returns to its initial position. This cycle is repeated with the next trigger signal.

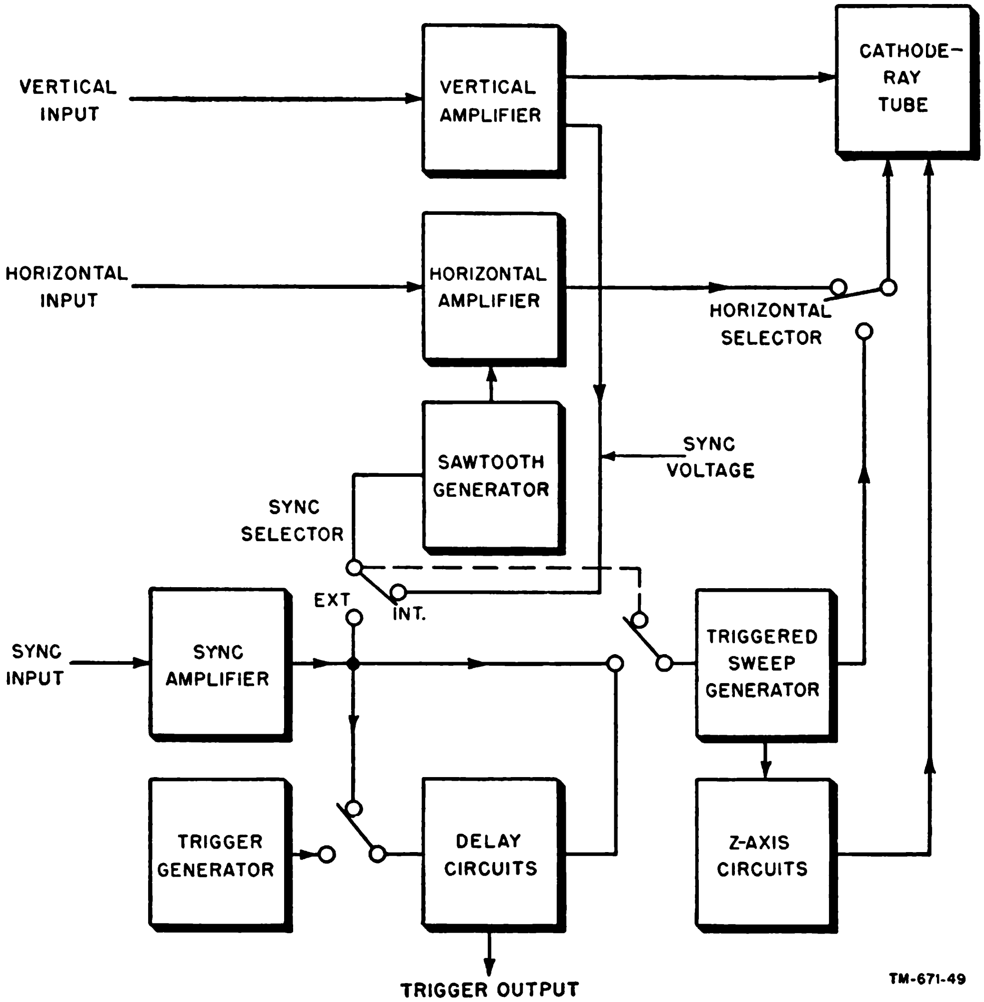


Figure 49. Simplified block diagram of the synchroscope. The switches are shown in position for oscilloscope-type measurements.

b. COMPARISON BETWEEN SYNCHROSCOPE AND OSCILLOSCOPE. The synchroscope is used to observe pulses and nonperiodic waveforms beyond the range of a standard oscilloscope. In addition, a trigger generator in the synchroscope circuit allows this instrument to record, across the width of the screen, only that portion of the input waveform of interest. However, the additional circuits used in the synchroscope are costly and are seldom used for general-purpose waveform observation. For the latter, the oscilloscope is quite satisfactory.

26. Uses of Oscilloscope and Synchroscope

The oscilloscope and its variations are designed primarily for the observation of rapidly changing voltages. When used to measure these voltages, their accuracy is limited by the deflection sensitivity per inch of the cathode-ray tube, and the sharpness with which the beam can be focused. The smaller the dot on the screen, the more accurately can the trace be measured.

a. TEST APPLICATIONS. Some typical applications of oscilloscopes are: the testing of electrical and mechanical vibrators; the measurement of voltage, current, impedance, and power; the visual alinement of a-m (amplitude-modulated), f-m (frequency-modulated), and television receivers; the testing of power supplies to determine ripple voltage; ignition characteristic tests on internal-combustion engines; and speed measurement. Synchroscopes are used especially to test the characteristics of beacon transmitters and magnetron oscillators.

b. ANALYSIS. The primary advantage of the oscilloscope over other measuring equipments is its presentation of the pictorial aspect of a voltage waveform. Thus, the waveform of any voltage can be compared to standard waveforms of voltages whose characteristics are completely known. In this way, any waveform can be analyzed and the voltages described. Analysis of this sort is used for phase and frequency measurements, for determining the cut-off characteristics of pulses, and for finding the characteristics of interference signals, among other applications.

Section II. DEFLECTION-MODULATED RADAR DISPLAYS

27. General

a. One of the most important uses to which cathode-ray tubes and their associated circuits are applied is the location of specific objects, or *targets*, in space. This is the function of radar equipment, for which the cathode-ray tube serves as the display unit. There are two types of radar systems. One is called *pulsed radar* because it uses pulse signals for the detection of targets. The other type is called *c-w radar*, for it uses a continuous-wave signal. The latter system is seldom used. The typical pulsed radar unit shown in the block diagram of figure 50 consists of—

(1) A transmitter of high-frequency, high-power pulses.

(2) An antenna system which directs these pulses in a systematic way to cover a specific area, and also receives the pulse as it returns after hitting an object. These antenna systems are extremely directional. They transmit pulses along a narrow path toward the one particular spot at which they are aimed. Likewise, when used for receiving the echo, they receive pulses from only the spot at which they are aimed.

(3) A superheterodyne receiver whose input is tuned to the same frequency as the transmitter.

(4) A switching arrangement which cuts out the receiver when the transmitter sends a pulse to the antenna and cuts out the transmitter when the receiver is operating to respond to the echo.

(5) An indicating system which translates into observable and measurable form the information brought back by the echo pulses. The cathode-ray tube display circuits are part of this indicating system.

(6) A timing system for synchronizing all of the components of the radar system. It also fixes the rate at which pulses are generated and transmitted.

(7) A computing and tracking system for automatically aiming a gun battery, etc., on a target detected by the radar system. This section is optional and is included only with those radar sets designed specifically for tracking.

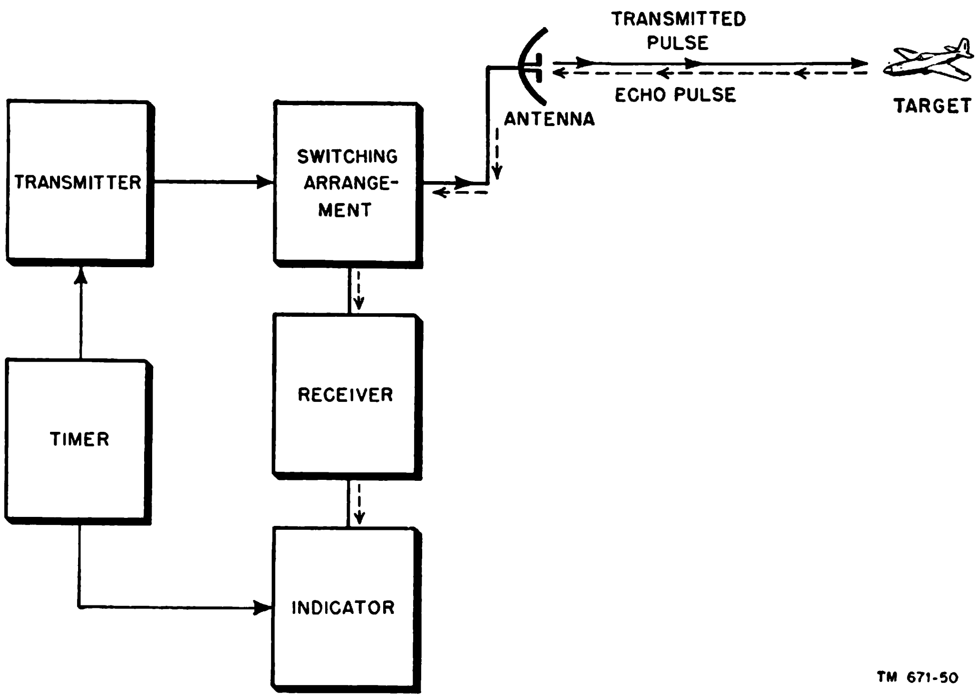


Figure 50. Basic sections of a typical pulsed radar system. The solid arrows indicate the path of the transmitted pulse; the dotted arrows represent the echo.

b. The display units used in pulsed radar are either *deflection modulated* or *intensity modulated.* These terms describe the method by which the echo signal affects the trace on the face of the cathode-ray tube in the indicator. In deflection-modulated displays, the input signal (the echo), after detection and amplification, is applied to the deflection system of the cathode-ray tube, and shows up as a pulse or *pip* on a single horizontal or circular sweep. Typical radar displays of this type are the A-scope and the J-scope. In intensity-modulated systems, the echo is fed to an intensifying circuit which changes the control-grid bias of the cathode-ray tube. Normally, the grid is biased at cut-off. When an echo is received, the echo voltage decreases the negative bias on the control grid, resulting in an increase in the electron-beam density. This action produces a bright spot on the normally dark screen.

28. Deflection-Modulated Radar Displays

In these systems, the position of an echo pulse on the trace (either linear or circular) indicates the *range* of a target—that is, its distance from the radar antenna. Since both the sweep and the distance traveled by the transmitted pulse and its echo are linear functions of the time, the two can be correlated. In figure 51 are shown the two most common types of deflection-modulated displays, the A-scope and the J-scope. The length of the A-scope trace is divided into a number of intervals. Each interval is equal to a fixed distance (100 yards, 1,000 yards, etc.). The circular trace of the J-scope is divided similarly. In some indicators the range is calibrated either directly onto the tube face or onto a piece of glass or plastic which is placed over the cathode-ray tube face. In most units, however, marker signals from an indicator timing circuit are used. These may be steps, notches, or hairlines which divide the sweep into equal intervals, each interval representing a constant distance—2,000 yards for example. Some display units use movable markers which are made to travel along the trace until they line up with the echo pulse. The range is read directly off the control which causes the marker to move. The fundamental deflection-modulated radar system is the A-scope.

a. A-Scope (or A-Scan) System.

(1) This system (fig. 52) is nothing more than a synchroscope without the horizontal input and Z-axis circuits. The echo signal passes from the receiver to the vertical (video) amplifier. At the

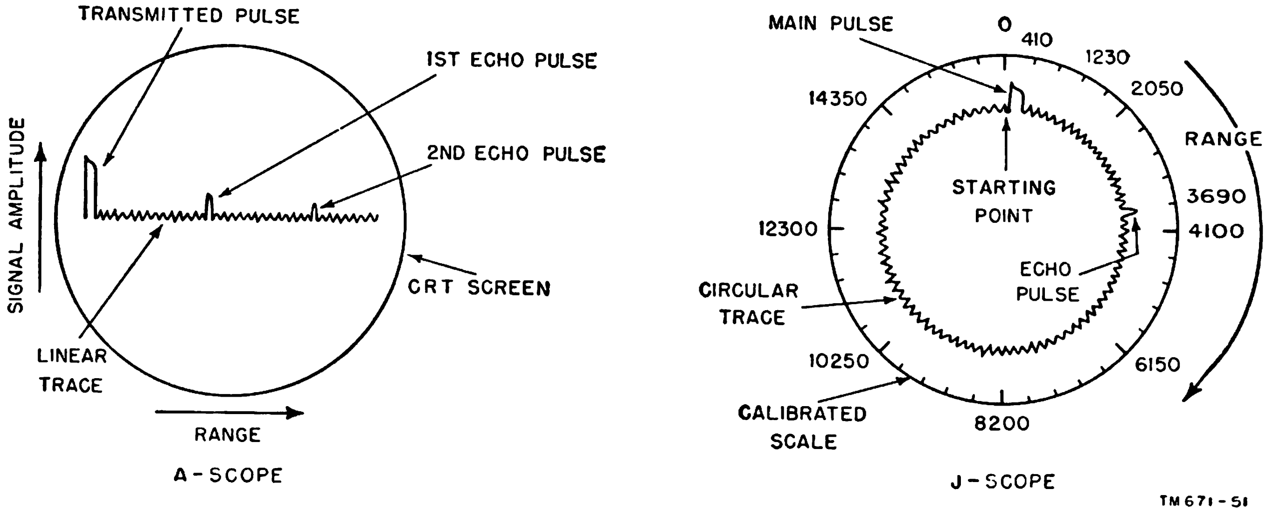


Figure 51. A-scope and J-scope displays. The trace between pulses shows the effects of the noise generated by the various resistors and vacuum tubes in the receiver circuits.

same time a trigger signal is fed to the triggered sweep generator. The trigger for starting the sweep can come from the central timing section of the radar system, or from the transmitter. The sweep generator furnishes a horizontal time-base voltage to the cathode-ray tube, while at the same time the received signal is amplified and sent to the vertical-deflection plates. For the period during which the transmitted signal is on the way to the target and on the way back, there is no received signal; the trace on the screen therefore is a straight hori-

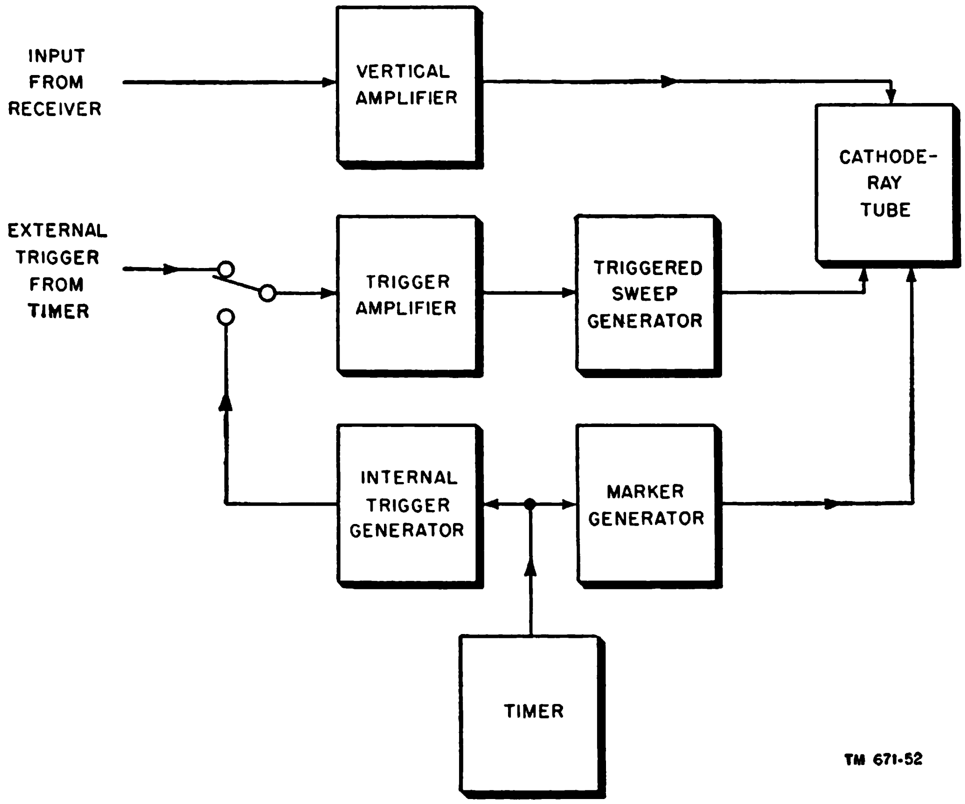


Figure 52. Simplified block diagram of A-scope indicator.

zontal line. When the echo is received, however, it is amplified and produces an increase in the vertical deflection of the beam giving a pip on the screen. The distance between the radar antenna and the target is indicated by the position of this pip on the trace. Some of the pulse voltage of the transmitter is impressed directly upon the receiver, resulting in an initial pulse on the cathode-ray tube trace. This is used as the zero distance reference position on the trace. All distances are measured from it. To facilitate the measurement of the distance of the echo pip from the zero reference, markers generated by the marker generator are used.

(2) The A-scope seldom is used by itself as the only indicator in radar receivers because the A-scope display gives only the range of a particular target. The angular position of a target left or right of the heading (the azimuth) and the angle of height above or below the horizontal plane of the radar antenna (the elevation) can be obtained by observing the cathode-ray tube screen for the strongest echo signal as the antenna is directed toward various positions in the neighborhood of the target. When this strongest signal appears as a large pip on the screen, the position of the antenna axis gives the azimuth and the elevation of the target. This, however, is not a convenient method for obtaining the information in continuous search systems where it is desired to cover a large area in a short time. Intensity-modulated display systems furnish either the elevation or the azimuth, or both, directly on the face of the display tube. The A-scope usually is found in radar systems using two or more types of indicators. The A-scan furnishes an accurate reading of the range of the target, while the other indicator furnishes the azimuth and the elevation. When it is desired to follow a single target continuously (as in *searchlighting*), as in artillery fire control, for example, this is done with the A-scope because of the accuracy of its range determination. The A-scope also is used as a test instrument to observe video input signals during the testing and alinement of radar receivers.

b. J-SCOPE SYSTEM.

(1) Except that it uses a circular sweep instead of a linear sweep, this type of display is practically the same as the A-scope display. Time and range measurements on the J-scope tube are more accurate than those on the A-scope tube because the same single trace that appears across the A-scope is stretched in a circle whose circumference is about three times the length of the A-scope trace. For example, if the face of the A-scope tube is 3 inches in diameter, the linear trace across it has a maximum length of 3 inches. A tube with a 3-inch diameter, however, has a face circumference of 9.4 inches, and the circular trace used in the J-scope can have this maximum length of about 9 inches. The return signal is indicated as a radial *pip* or pulse pointing away from the center of the tube on the circular trace (fig. 51). To accomplish radial deflection, a thin metallic rod is inserted through the face of the tube almost up to the deflection plates. The signal input from the receiver is fed to this central electrode. The manner in which radial deflection occurs and the circular sweep is produced for such tubes is explained elsewhere.

(2) A simplified block diagram of a J-scope is shown in figure 53. A crystal oscillator and a phase-shifting network furnish two sine-wave voltages, 90° out of phase, to the deflection plates to produce the circular trace. The trigger and sweep circuits blank out the tube, intensifying the electron beam only during the active sweep time. This blanking action can be utilized if, for example, the trace is expanded to sweep two circles for one transmitter pulse, with the echo pip appearing on the second sweep. The first sweep is then blanked out.

(3) The J-scope is used in radar for extremely accurate range determination of a particular target. In the laboratory, the J-scope is applied to the measurement of very short time intervals.

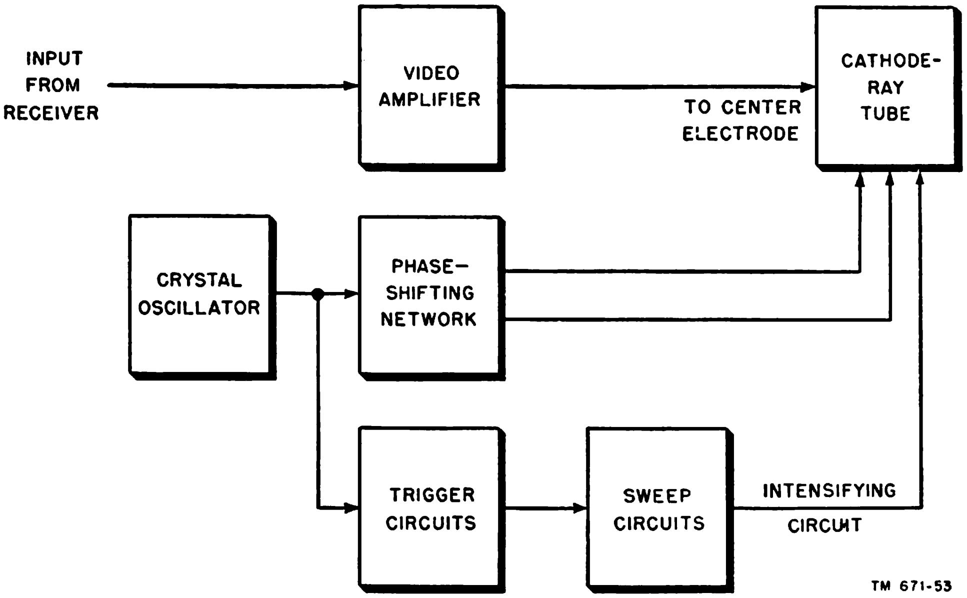


Figure 53. J-scope indicator block diagram. The echo pulse in this system goes to a central electrode in the cathode-ray tube. The electron beam is intensified by means of the intensifying circuits only during the time when the beam is sweeping a trace on the tube face.

29. Intensity-Modulated Radar Displays

Deflection-modulated displays are limited in their application in radar because they provide a measurement of only one dimension, range. To locate a target, it is necessary to know its position with respect to three directions or coordinates—elevation, azimuth, and range. Intensity-modulated displays furnish two of these three coordinate values. Two such displays used together, or one used with a deflection-modulated display, completely locate an object in space. In intensity-modulated displays, echo signals appear as bright patches against a dark background. This is the result of feeding the returning signal to either the control grid or the cathode of the cathode-ray tube to increase the intensity of the trace on the face of the normally dark tube. The three most common types of intensity-modulated displays are the B-scope, the C-scope, and the PPI.

a. B-Scope and C-Scope.

(1) In both the B-scope and the C-scope, the sweep scans a rectangular area on the screen of the cathode-ray tube (fig. 54). In both, the horizontal axis represents the azimuth or bearing. The vertical axis in the B-scope represents the range. The vertical axis in the C-scope represents the elevation angle.

(2) Figure 55 is a block diagram of the basic components of a B-scope indicator. The difference between the B-scope and the C-scope is in the vertical-deflection circuits of the indicators. The vertical-deflection circuits of the B-scope are driven by a linear timebase signal from a sweep generator. This sweep is initiated by a sync signal from the central timing circuits of the radar system. Thus, the vertical sweep is proportional to the time, which is proportional to the distance covered by the pulse. The vertical-deflection system of the C-scope is driven by a sweep voltage from a variable potentiometer hooked up to the radar antenna. The uniform change in elevation of the antenna as it scans the space in front of it results in a uniform change in the setting of the potentiometer. Therefore, the resulting sweep voltage and its trace on the cathode-ray tube correspond to the change in elevation of the antenna. This type of sweep-generating circuit is described in detail in chapter 6. The horizontal-deflection circuits of the B-scope and the C-scope are the same type of circuits as those used for the vertical-deflection system of the C-scope.

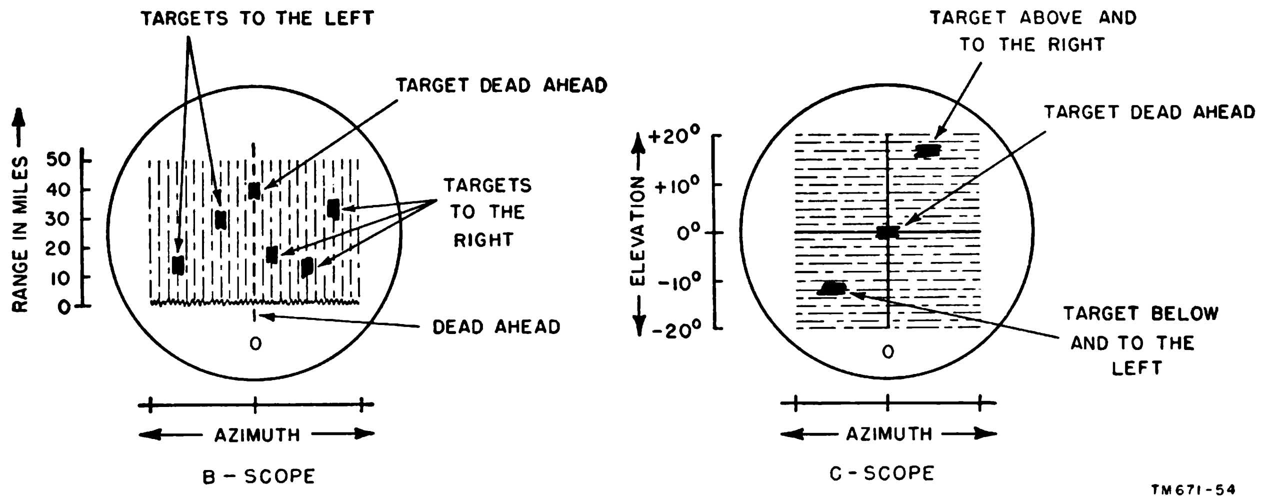


Figure 54. B-scan and C-scan displays. The range and angle calibrations shown are merely examples and vary according to the use of the system.

In this case, the *horizontal* motion of the antenna is translated into a regularly varying voltage which causes the horizontal sweep in the cathode-ray tube. The echo signal is fed from the antenna through the receiver to a video amplifier circuit. From here it goes to either the cathode or the control grid of the tube, where it intensifies the trace. There is no sweep voltage which is proportional to time. Consequently, the range of the target is not observable.

(3) The B- and C-scopes are used in radar systems for the continuous scan of an assigned area. The B-scope is used chiefly for ground (or sea) targets in a limited sector; the C-scope is more commonly used for aircraft interception and beam landing.

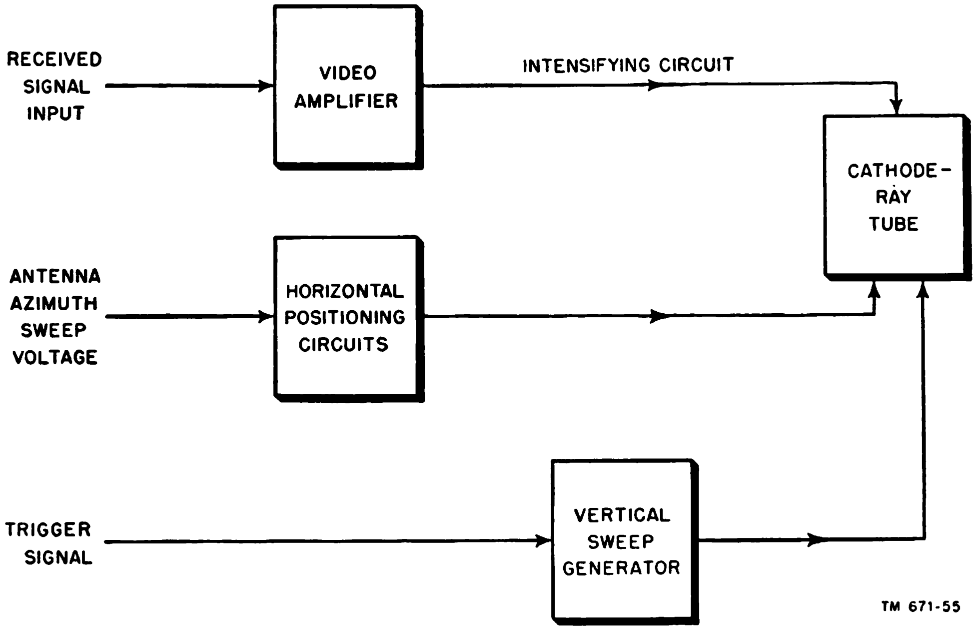


Figure 55. Simplified block diagram of B-scope indicator. The C-scope indicator consists of the same major sections except that the vertical-deflection plates are controlled by a voltage from the antenna rather than from a sweep generator as is shown here.

b. PPI System.

(1) This display presents a map of the area scanned by the radar antenna (fig. 56). Like the B-scope, the PPI presents the range and the azimuth of appearing on the screen; its display, however, is circular, rather than rectangular, with the radar site at the center. Magnetic deflection generally is used. Because the PPI is intensity-modulated, the reflecting objects appear as bright patches on a dark background. The distance from the center of the display to a bright spot is the range. The azimuth of the spot is angular distance, clockwise around the display, from a heading. The off-centered PPI is a variation of this display in which one sector of the scanned area is expanded to fill the face of the tube. Many other variations are used, depending on the amount of detail required in the display.

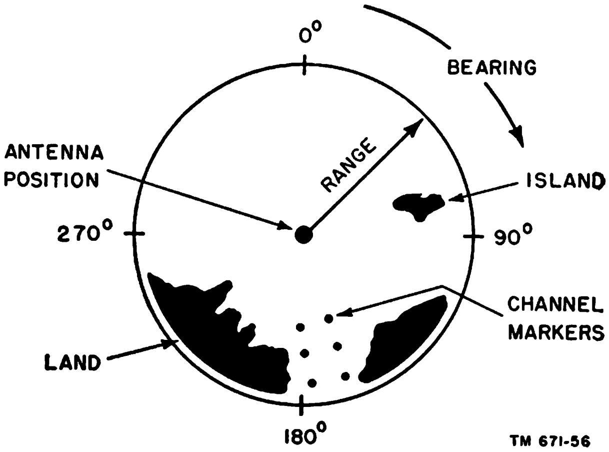


Figure 56. A PPI display. This is a typical presentation of land and sea masses.

(2) The block diagram of a simple PPI is shown in figure 57. The trigger input signal from the central timing system synchronizes the start of the sweep with the other operations of the complete radar system. A linear timebase voltage is produced by the sweep circuits. This voltage goes to the electromagnetic deflecting assembly or yoke of the cathode-ray tube. In some PPI's, this yoke rotates around the neck of the tube in synchronization with the rotating antenna of the radar set. In effect, therefore, one end of a linear sweep, from the center of the tube to the edge, is rotated through 360° with the other end fixed at the center of the tube face. In this way, the angular position (azimuth) of the timebase is coordinated with the direction of the antenna. In some cases, the yoke is fixed in position, but its magnetic field rotates, producing the radial sweep. The production of the radial sweep is explained in greater detail in chapter 6.

(3) The PPI is used in horizontal search radar where it can cover a complete area 360° around the radar site. Since the PPI presents a map-like display, the information gathered from this radar indicator can be correlated easily with standard maps of the area covered.

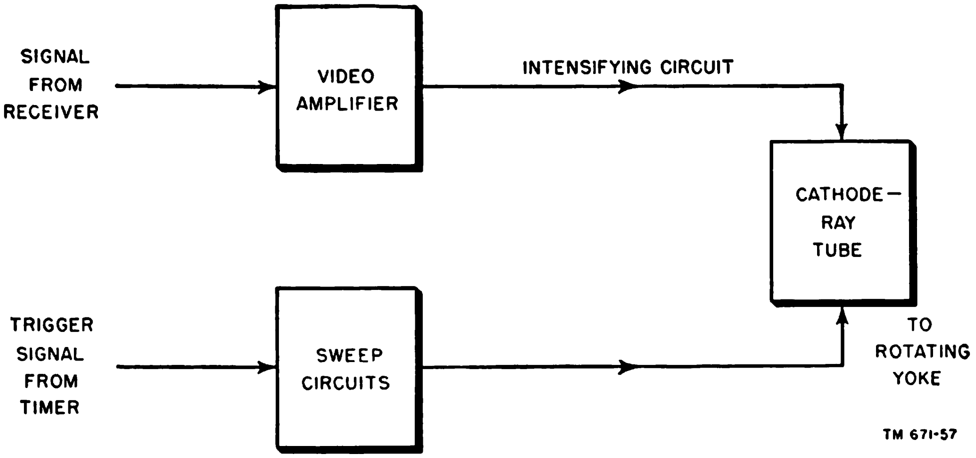


Figure 57. Simplified block diagram of PPI showing major sections of rotating yoke system.

Section III. SPECIALIZED DISPLAY SYSTEMS

30. Radio Direction Finder

a. Radio direction finders are used to locate radio transmitting stations. One direction finder gives only the bearing of a transmitter. Two direction finders are necessary to obtain the precise location of the transmitter. When thus used, this type of indicator serves as a source of signal intelligence concerning the location of enemy installations and units. The radio direction finder also is useful in air and sea navigation. A ship uses its direction finder to obtain its bearing with respect to two fixed transmitters whose positions are known. The radio direction finder often is used with a radar set of the range-indicating variety. Consequently, both the bearing and the range of a transmitter can be determined.

b. The radio direction finder consists of a receiving antenna, a radio receiver, and an indicator. The antenna is extremely directional. Consequently, the direction of the received radio wave, as given by the antenna position, is the bearing of the transmitter.

c. The basic components of the radio direction finder are shown in block form in figure 58. The receiver takes the signal from the antenna, amplifies it, and sends it on to the modulation circuits of the indicating system. Here, the input signal is combined with a voltage from the modulating voltage generator to form a propeller-like bearing pattern on the face of the cathode-ray tube (A of fig. 59). Only one of the points of the propeller indicates the bearing of the transmitting station. To select the correct point, the *sense* pattern circuits are switched in. This adds the received signal from a nondirectional part of the antenna to the indicator. Consequently, the display is changed into an arrow-like pattern (B of fig. 59), which points to the true bearing of the transmitter.

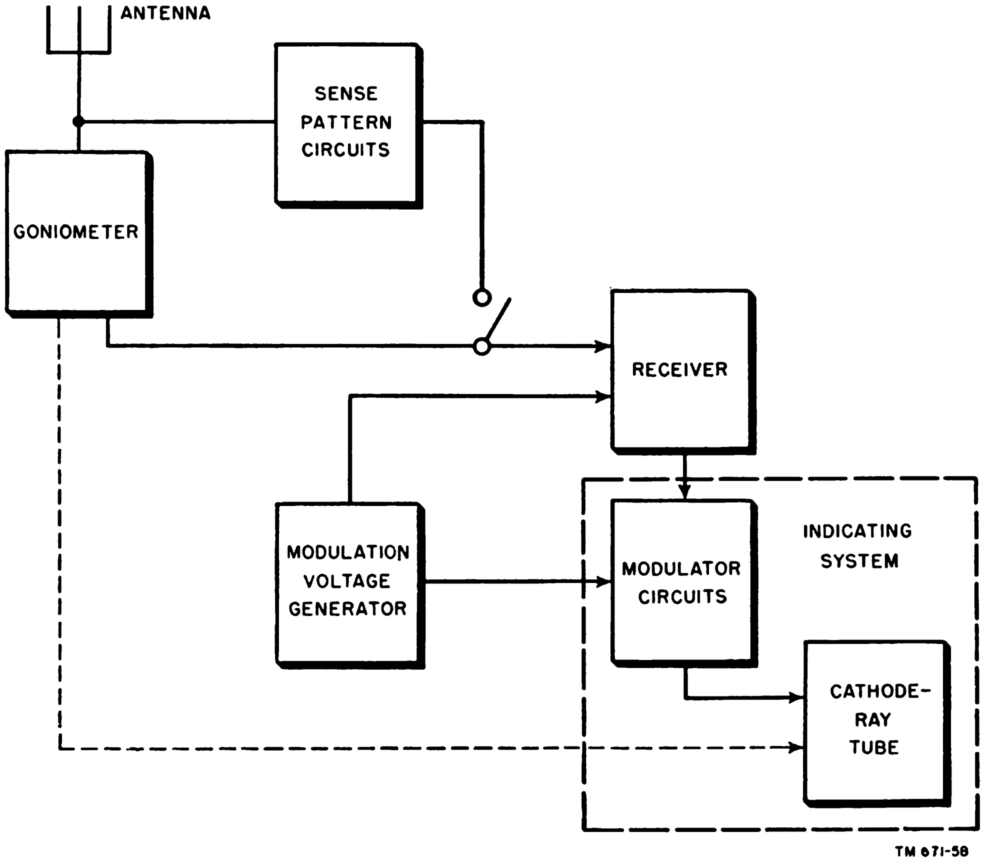
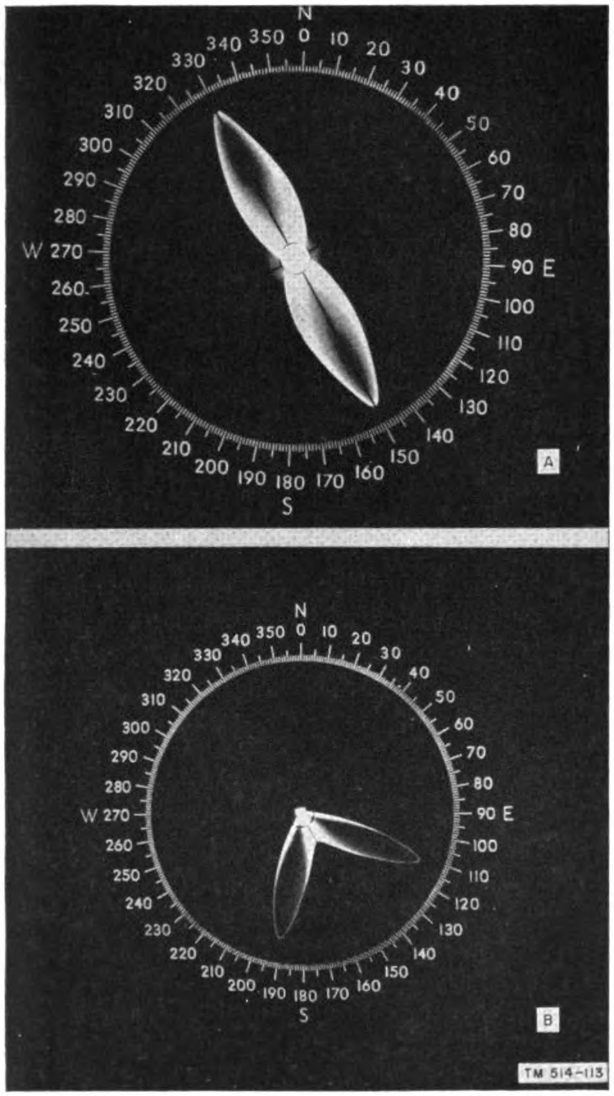


Figure 58. Block diagram of radio direction finder receiver and indicator. The goniometer mechanically rotates the electromagnetic deflection yoke of the cathode-ray tube.



A, propeller-like bearing pattern; B, presentation of the sense pattern.

Figure 59. Typical radio direction finder displays.

d. Large radio direction finding installations generally use two sets of fixed antennas. One set is oriented to receive signals from the north-south direction; the other set is oriented to receive signals from the east-west direction. The signals received by each of these antennas are fed into a rotating r-f (radio-frequency) transformer. This device, called a *goniometer*, is an instrument for measuring angles. It combines the antenna signals in such a way that the signal fed to the receiver appears to come from a rotating directional antenna. The goniometer also rotates the electromagnetic deflection system of the cathode-ray tube to coordinate the bearing indication on the tube with the direction of the signal fed into the receiver. Some units use all-electronic goniometers with electrostatic cathode-ray tubes. Smaller radio direction finding units use rotatable loop antennas. Examples of such units are found in aircraft and on small sea vessels.

e. Most direction finders have aural-null bearing indicators in addition to the cathode-ray tube display unit. Such units consist of earphones or speakers fed by audio amplifiers in the receiver circuit. When the antenna points in the direction of a transmitted signal, the continuous sound issuing from the speaker or earphones ceases, giving a null. This aids in adjusting the antenna for a true bearing presentation on the cathode-ray tube.

31. Loran

a. Loran is a navigational aid used for both ships and aircraft. By measuring time intervals between the arrival of pulses, and using two pairs of fixed transmitters, a ship or an airplane can determine its position. Both transmitters of one pair emit pulses, one transmitter at a fixed time interval before the other. A ship receiving both pulses is on a line equidisant from both transmitters if the pulses arrive with the fixed time interval. However, if the ship is closer to one station than to the other, the time interval between pulses depends on which station the ship is closer to. For example, if the time interval between pulses is set at 20,000 usec (microsecond), the pulses at a point equidistant from the pair of transmitters will arrive with a time difference of 20,000 usec. At a point close to the station sending out the first pulse (the *master* station), the time difference would be greater, say 38,000 usec. At a point close to the station emitting the second pulse (the *slave* station), the time difference would be small, approximately 1,000 usec, for example. To determine its position, a ship or an airplane must obtain bearings from two pairs of loran stations. One time difference determines a curve upon which the ship lies; a second time difference determines another curve which intersects the first, giving the position.

b. The antenna and the receiver used in loran are wideband units. The received pulse is fed to the vertical-deflection plates of the electrostatic cathode-ray tube (fig. 60). Two traces are developed by the electron beam of this tube, one for the master pulse and one for the slave pulse. Both traces are presented, the master above the slave,

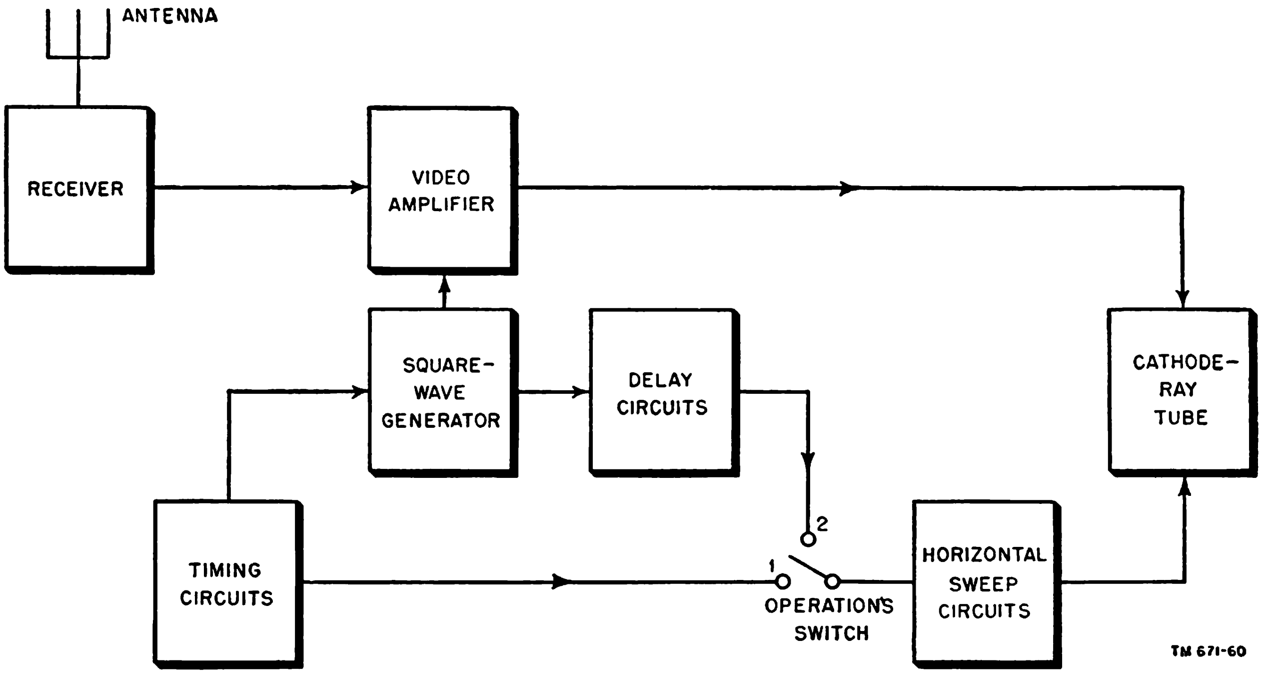


Figure 60. Simplified block diagram of a loran receiver and indicator.

at equal amplitudes. The time difference between the pulses on both traces is found either by using adjustable markers or by an automatic time-difference indicator which measures directly in microseconds the time difference between the leading edge of the master pulse and the leading edge of the slave pulse (fig. 61). The timing circuits are responsible for fixing the sweep time of the cathode-ray tube and for calibrating the markers used in the display. The timing signals trigger the square-wave generator which produces two voltages, one for the upper trace, and one for the lower trace. The operations switch, when in position 2, magnifies horizontally the pulses presented as part of the trace in position 1, so that more exact measurements can be made. The sweep circuit furnishes the horizontal sweep voltage.

32. Television Receiving System

a. Purpose. Television receivers are not only used commercially, but are used also in radar equipments for checking the light output and other screen characteristics of the cathode-ray tube. These receivers use intensity-modulated, rectangular displays.

b. Block Diagram.

(1) A simplified block diagram of a typical television receiver is shown in figure 62. The received signals containing both the picture (video) and sound (audio) information pass from the antenna to the r-f amplifiers where a particular signal is selected and amplified. The signal is then combined in the mixer circuit with a local oscillator signal. The combining action produces two i-f (intermediate-frequency) signals, one for the sound, and one for the picture. The sound signal is sent through sound i-f amplifiers and eventually is fed to the loudspeaker. The picture or video signal goes to the indicator section.

(2) The indicator section of the television receiver is somewhat similar to the one used in the B-scope. In this case, however, both sweeps, the horizontal as well as the vertical, are produced by electronic sweep circuits. The frequency of the horizontal sweep is much higher than that of the vertical sweep since 262½ horizontal sweeps occur during one vertical sweep. The video signal carries its own trigger signal, called the sync signal. This is separated from the video signal in the sync separator. The sync

signal controls both the horizontal and the vertical sweep generators. The resulting deflection voltages are fed to the cathode-ray tube to produce, with the video signal, the final two-dimensional display.

33. Miscellaneous Display Systems

Many of the display systems mentioned in this chapter are described in detail in chapter 6. There are other types of display systems, most of them designed for specialized applications.

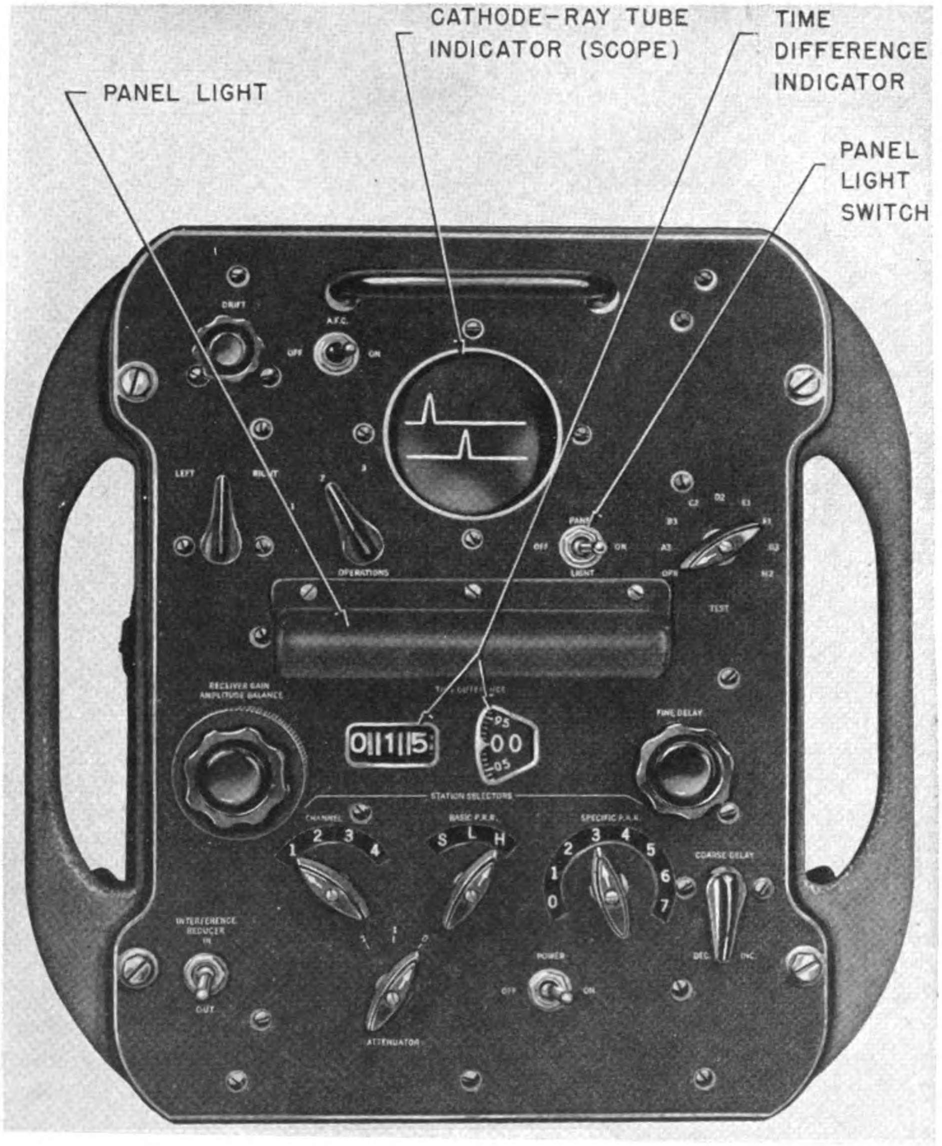


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Figure 61. Typical front panel of a loran indicator. The display on the cathode-ray tube shows both the master signal and the slave signal on the upper and lower traces, respectively.

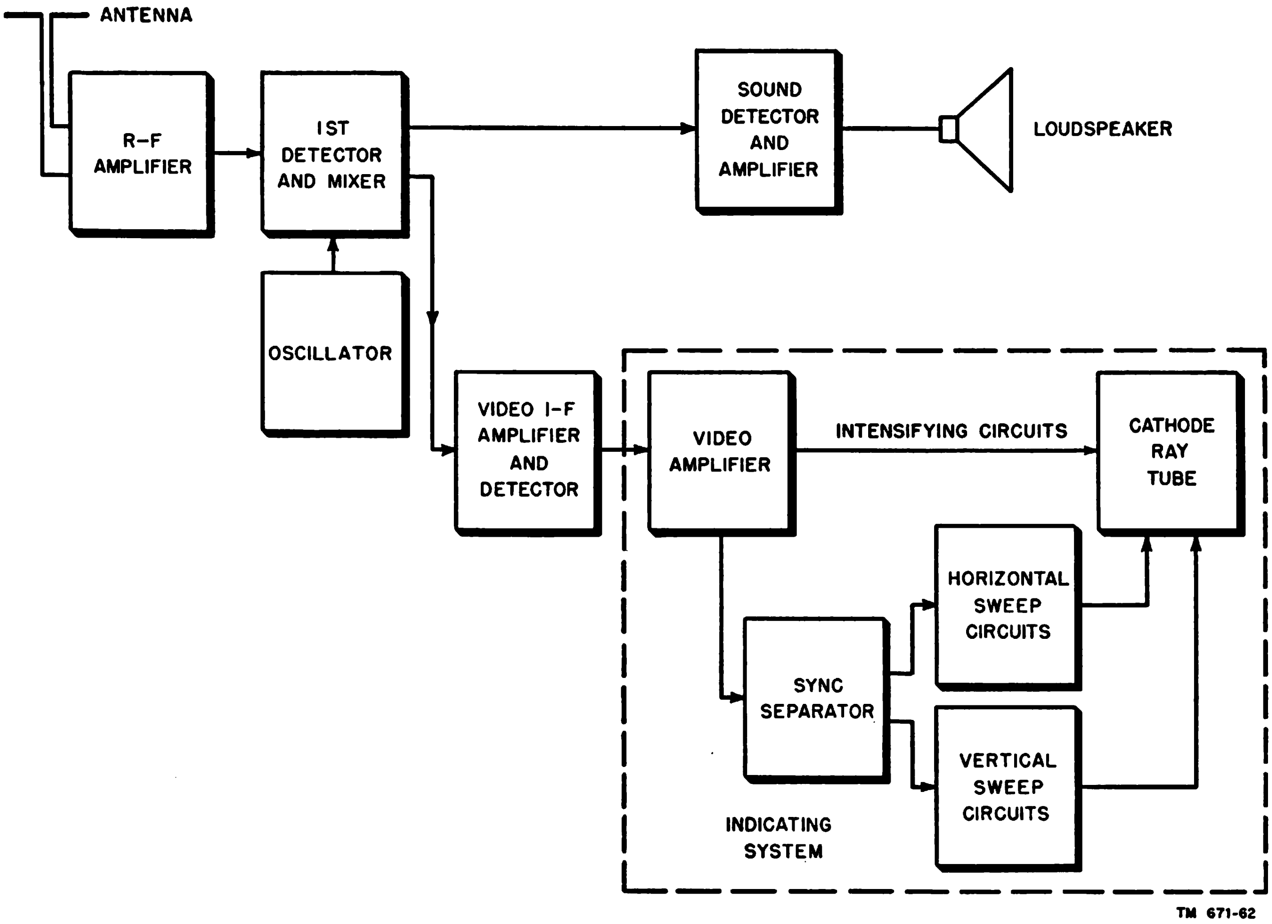

Figure 62. Typical television receiver.

Section IV. SUMMARY AND QUESTIONS

34. Summary

a. Display systems are electronic equipments using cathode-ray tubes for the measurement and analysis of electrical signals.

b. The basic oscilloscope consists of a vertical-deflection amplifier, a timebase system, a horizontal-deflection amplifier, a synchronization system, a power supply, and a cathode-ray tube.

c. For more advanced waveform analysis than is possible with the basic oscilloscope, trigger circuits, delay circuits, and intensity-modulation circuits are added.

d. The synchroscope is an oscilloscope with the addition of trigger circuits for the observation of nonrepetitive waveforms.

e. Deflection-modulated pulsed radar displays present the echo signal as a vertical or radial *pip* on the trace of the cathode-ray tube.

f. Intensity-modulated pulsed radar displays present the echo signal as a bright patch on the normally dark tube face.

g. The A-scope is a deflection-modulated radar display presenting the range of a target on a horizontal trace.

h. The J-scope is a deflection-modulated radar display presenting the range of a target on a circular trace. Its range determination is more accurate than that of the A-scope.

i. B- and C-scopes are intensity-modulated radar displays presenting two coordinate values for any target detected. The B-scope gives range and azimuth; the C-scope presents elevation and azimuth.

j. The PPI system is an intensity-modulated radar display giving the azimuth and range of a target on a map-like presentation.

k. The circular presentation of the PPI is formed by a rotating electromagnetic field derived either from a yoke assembly which rotates about the neck of the cathode-ray tube, or a fixed assembly whose electromagnetic field is made to rotate.

l. The radio direction finder modulates the radio signal from a transmitter to produce a propeller-like pattern on the screen of the cathode-ray tube which indicates the bearing of the transmitter. A sense pattern indicates which tip of the propeller pattern gives the correct bearing.

m. Loran display systems present the pulse signals from a pair of transmitters (master and slave) as two horizontal traces. The time difference between the arrival of the pulses at the loran receiver is read directly from the display. In conjunction with a similar pair of transmitters, it helps to determine the location of the receiver.

n. Television receivers are intensity-modulated, rectangular-display systems reproducing the video portion of the transmitted signal. Two timebase sweeps are used in this display to give a two-dimensional picture.

35. Questions

a. Explain the function of each of the major components of the basic oscilloscope.

b. What type of circuit often is added to the basic oscilloscope for the observation of non-periodic pulses and transients?

c. How is intensity modulation effected in a cathode-ray tube?

d. How is the horizontal sweep in the synchroscope initiated?

e. The range of a target is determined on the A-scope as the distance on the trace between a reference point and the echo pulse. What is this reference point? How is it obtained?

f. What are the major differences, both in presentations and circuits, between the B- and the C-scopes?

g. How is the bearing of a transmitter shown in a radio direction finder display?

h. Explain how a ship using a loran receiver and indicator can determine its position.

i. How is the time difference of arrival between the master and slave pulses determined on the loran display?

j. Where is the signal which initiates the horizontal and vertical sweeps in the television display system obtained? What is it called?

CHAPTER 3

SWEEP-GENERATING CIRCUITS

Section I. GAS-TUBE GENERATORS

36. General

a. Need for Sweep.

(1) A sweep-generating circuit is required in equipment which uses the cathode-ray tube. This circuit produces the waveform which deflects the electron beam in a certain direction. The spot of light on the screen is made to move in a steady continuous stroke across the screen. It can be described as having been swept across the screen. Consequently, the waveform is referred to as a *sweep* while the circuit which produces the waveform is called a sweep generator.

(2) In most applications, a sweep voltage or current causes the electron beam to move *horizontally* in accordance with the amount of deflection force. At the same time, another signal is applied to the cathode-ray tube in such a way as to cause *vertical* deflection. These two forces are at right angles. The spot of light can be moved to any point on the fluorescent screen by varying the magnitude of these perpendicular forces. Therefore, a graph involving two dimensions is produced. The sweep is responsible for one of these dimensions; the signal to be observed is responsible for the other dimension.

(3) In an ordinary graph, one variable quantity is plotted along a vertical axis while another variable quantity is plotted along a horizontal axis. A number of points are produced which, when connected, form a curve. Every point on this curve represents the resultant of two quantities. For example, one graph can show the instantaneous values of voltage at various instants of time. Another graph can show the gain of an amplifier at various frequencies.

(4) One of the two quantities plotted on the graph depends on the other. Consequently, in a graph showing voltage versus time, the amount of voltage which exists depends on the particular time at which the observation is made. Voltage is referred to as the *dependent variable*, and time as the *independent variable* in this case. In brief, voltage depends on time. In the second graph showing gain versus frequency, the amount of gain depends on the particular frequency at which the measurement is made. Gain is the dependent variable while frequency is the independent variable.

(5) The spot on the screen of a cathode-ray tube traces a graph of two variables. One of these variables depends on the other. It is the purpose of the sweep-generating circuit to produce a waveform which moves the beam in accordance with the independent variable. Just as it is common practice to plot the independent variable on the horizontal axis of a graph, the sweep voltage produces horizontal deflection in a cathode-ray tube.

(6) By far the most common independent variable is *time*. In electronics, we are interested in voltage or current at various instants of time. When an oscilloscope shows a pattern of a particular electrical waveform, the pattern is a graph of voltage or current amplitude versus time. In order that equal amounts of horizontal deflection can represent equal intervals of time, a *linear sweep* is required, as explained in paragraph 10. The trace produced by a linear sweep on the screen of the cathode-ray tube along

which time can be measured is called the *timebase.*

(7) A sawtooth wave is the most common type of waveshape used to produce a straight-line linear sweep. If an electrostatic cathode-ray tube is used, a sawtooth voltage is applied to the horizontal-deflection plates. An electromagnetic tube requires a sawtooth current through the horizontal-deflection coils. The sawtooth wave can be produced mechanically as described in paragraph 10. However, this method is not too satisfactory because of the possibility of mechanical failures. High sweep frequencies require electronic circuits using gas or electron tubes. These circuits will be discussed in the following subparagraphs.

b. Sweep Requirements.

(1) The voltage produced by the potentiometer previously described is shown in A of figure 63. This voltage begins at zero potential and falls rapidly to its most negative value. It then rises linearly at a much slower rate toward zero potential. This uniform rise continues through zero to the most positive value of voltage. Then, the voltage falls rapidly back to zero. The beginning of the sweep usually is considered to be at the extreme left rather than at the center of the screen. Because of this, it will be more convenient to redraw 1 cycle of sawtooth sweep voltage as shown in B of figure 63. This waveform is the same as has been described except that the cycle is considered to begin at its most negative point.

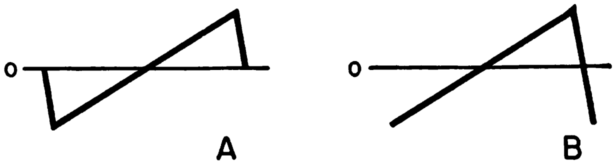

Figure 63. Single cycles of sawtooth sweep voltages produced by potentiometer.

(2) This gradually rising voltage causes the spot to move slowly and linearly from left to right across the screen. A horizontal line of light is produced if the spot motion is rapid enough. This line often is called the *trace.* When the spot has moved to the extreme right, the voltage falls rapidly through zero to its original negative starting potential. This causes the spot to move quickly from right to left, back to its original starting position. The spot motion during this *retrace* or *flyback* is much more rapid than the left-to-right motion, therefore, the brightness of the retrace line is less than the trace line.

(3) Assume that a sine-wave signal is applied to the vertical-deflection plates and that a sawtooth sweep voltage is applied to the horizontal-deflection plates of a cathode-ray tube. Figure 64 shows how the screen pattern consisting of 1 cycle is produced. At the time marked 0, there is no vertical deflection because the sine-wave voltage is 0. The sawtooth sweep voltage is at its maximum negative value and the spot is deflected to the extreme left. At the times marked 1, 2, and 3, the amount of upward vertical deflection increases as a result of the increasing amplitude of the sine-wave signal. At these same times, the sawtooth sweep voltage causes the spot to move toward the center of the screen. The spot passes through the points marked 1, 2, and 3 on the screen. At the times marked 4, 5, and 6, the amplitude of the sine wave decreases. This causes the spot to move downward from the top of the screen. During these same times, the sawtooth wave still is increasing, causing a continuing left-to-right horizontal deflection. The spot passes through the points marked 4, 5, and 6 on the screen. When the time marked 7 is reached, the sine-wave amplitude has been reduced to zero and there is no vertical deflection. The spot has moved to point 7 on the screen. The first alternation has now been traced on the screen.

(4) From the times marked 7 through 12, the sawtooth voltage continues to increase. Therefore, the spot moves toward the right side of the screen. During these same times, the sine-wave signal swings negative. This causes a downward de-

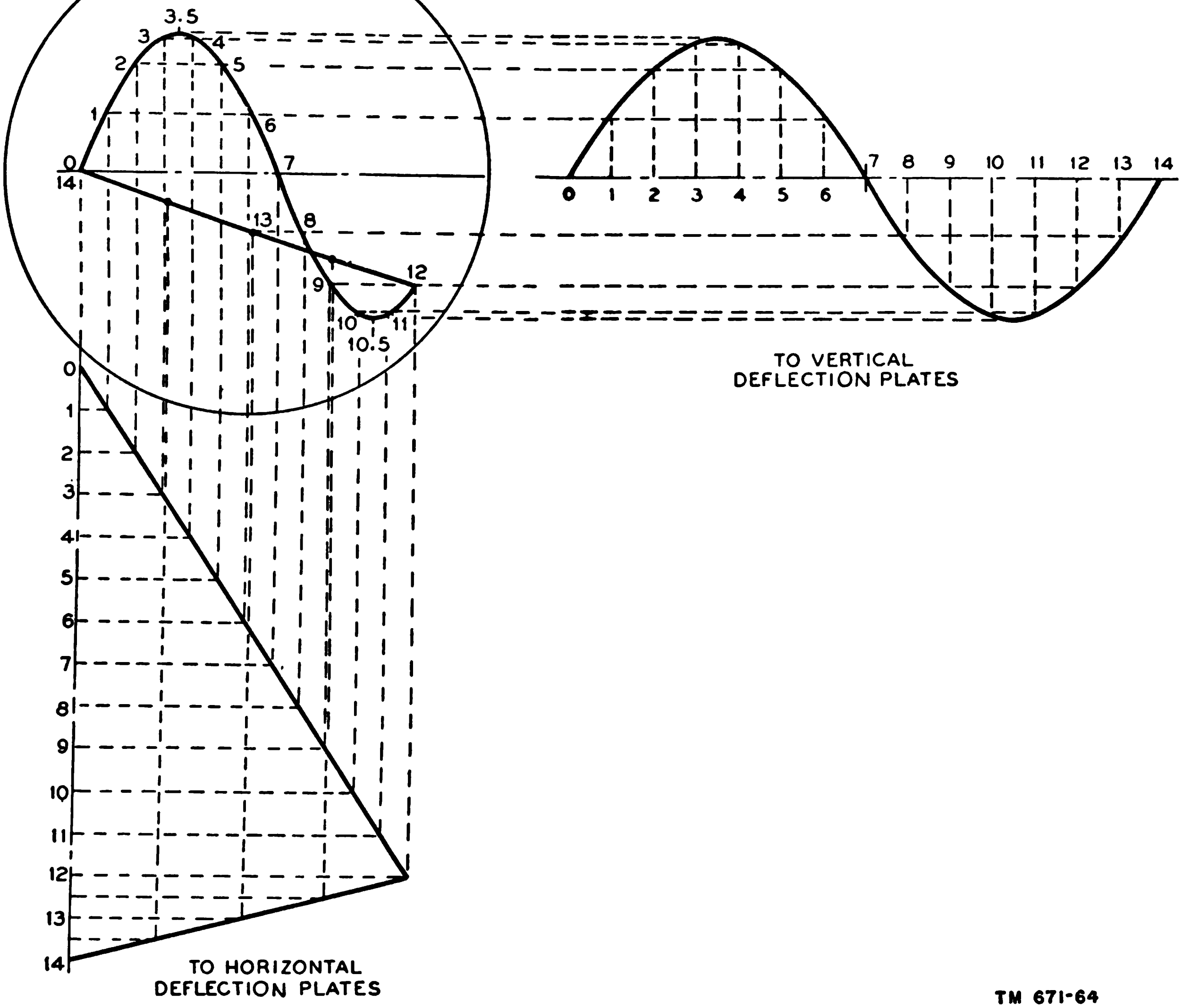

Figure 64. Production of a single cycle of a sine-wave signal when sweep frequency equals the signal frequency.

flection from the times marked 7 through 10 and the spot moves toward the bottom of the screen. From the times marked 11 and 12, the spot moves upward toward the center. The spot has moved through points 7 to 12 on the screen.

(5) When the time marked 12 is reached, the sawtooth voltage begins to fall rapidly. This causes the spot to move back toward the left and to produce the retrace. The retrace occurs during the times marked 12 to 14. At these same times, the sine-wave signal still is causing the spot to move upward toward the screen center. The spot moves through points 12 to 14 on the screen during this fly-back time. After the retrace has been completed, the entire process is repeated. The spot redraws the pattern shown above once each cycle. In this way, a rapidly moving spot continually reforming the same pattern of light produces a stationary waveform on the screen. The actual appearance of the cathode-ray tube screen under these conditions is shown in figure 65. Many oscilloscopes use special circuits to remove the retrace from the screen completely. These circuits will be discussed in chapter 5.

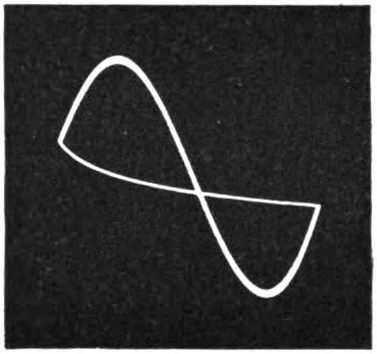

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Figure 65. Screen pattern showing one sine-wave signal.

(6) Assume that the sweep frequency is now readjusted to one-half its original value. The frequency of the sine-wave signal is kept the same. Under these conditions, the time required to complete 1 sawtooth cycle is doubled. In the period of time from 0 to 14, only ½ cycle of sawtooth voltage is completed. Therefore, 1 complete sine-wave cycle is traced on the screen as the spot moves from the extreme left to the center. A second sine-wave cycle is traced as the spot moves from the center of the screen to the extreme right. The pattern produced on the screen is shown in figure 66.

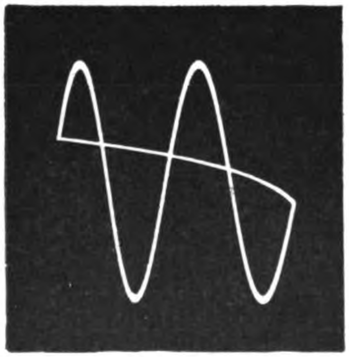

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Figure 66. Screen pattern produced when sweep frequency is one-half the frequency of sine-wave signal.

(7) If the sweep frequency is further reduced to one-third of the signal frequency, then a pattern consisting of 3 cycles will appear on the screen. The graphical method used previously can be used again to show the development of this waveform (fig. 67).

(8) It has been shown that in order to produce 1 or more cycles of a signal on the screen, it is necessary for the sweep frequency to be equal to the signal frequency or a submultiple of it. If the sweep frequency is a multiple of the signal frequency, stationary patterns can also be produced (fig. 68). However, these patterns are not commonly used as they are difficult to interpret.

(9) In A of figure 68, the sweep frequency is equal to twice the signal frequency. During one sweep from left to right, the positive alternation of the the sine-wave signal is traced on the screen from a to b. After a rapid retrace from b to c, the negative alternation of the sine-wave signal is traced on the screen from c to d. A second retrace from d to a occurs and the process is repeated. In B of figure 68, the sweep frequency is equal to three times the signal frequency. The first left-to-right trace draws one-third of one sine-wave cycle, from a to b. The second trace draws the second third of the same cycle, from c to d. The final third of the cycle is drawn on the screen by the third trace, from e to f. Similarly, it can be shown that C of figure 68 is the resultant pattern when the sweep frequency equals four times the signal frequency.

(10) In an oscilloscope, it is necessary for the sweep generator to be adjustable over a wide frequency range. This is required for several reasons. First, it enables the operator to see almost any number of cycles of an input waveform that he desires. Second, it permits the observation of a wide range or input signal frequencies. In other applications, such as in synchroscopes and certain radar displays, several fixed sweep times are required.

(11) The sawtooth sweep should be as linear as possible. This is necessary for several reasons. First, considerable pattern distortion results when the sweep is not linear (fig. 69). The sweep voltage moves the spot more rapidly at the beginning of the trace than at the ending. The pattern is stretched out at the left and squeezed together at the right. A

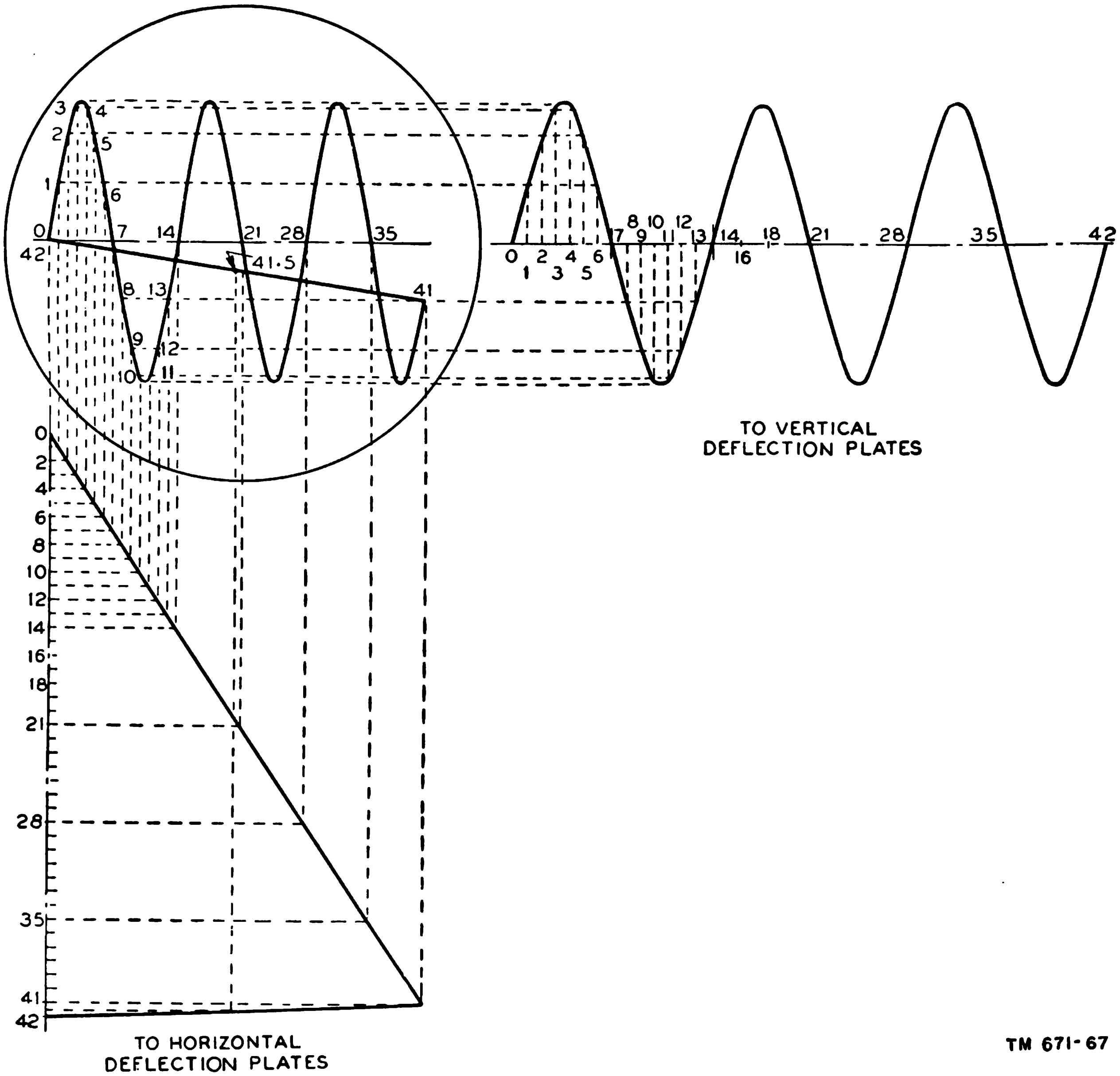

Figure 67. Graphical representation showing a sweep frequency of one-third the signal frequency.

second disadvantage of the nonlinear sweep is that equal amounts of horizontal deflection no longer correspond to equal intervals of time. In the interval of time from 0 to 1 (C of fig. 69), the spot travels a much greater distance than it does in the equal time interval from 7 to 8. It is no longer possible to measure time along the horizontal axis by means of a simple linear scale.

(12) It is desirable to have a short retrace time. The effects of various lengths of retrace times are shown in figure 70. In the illustration, the sweep and signal frequencies are the same. It can be seen that with a short retrace time, a greater percentage of the single cycle of signal is shown on the screen. As the retrace time is increased, two effects are noted. First, an increasing amount of the signal to be observed occurs during the retrace. Second, the reduced spot speed causes the brightness of the retrace to approach that of the forward trace. Consequently, not

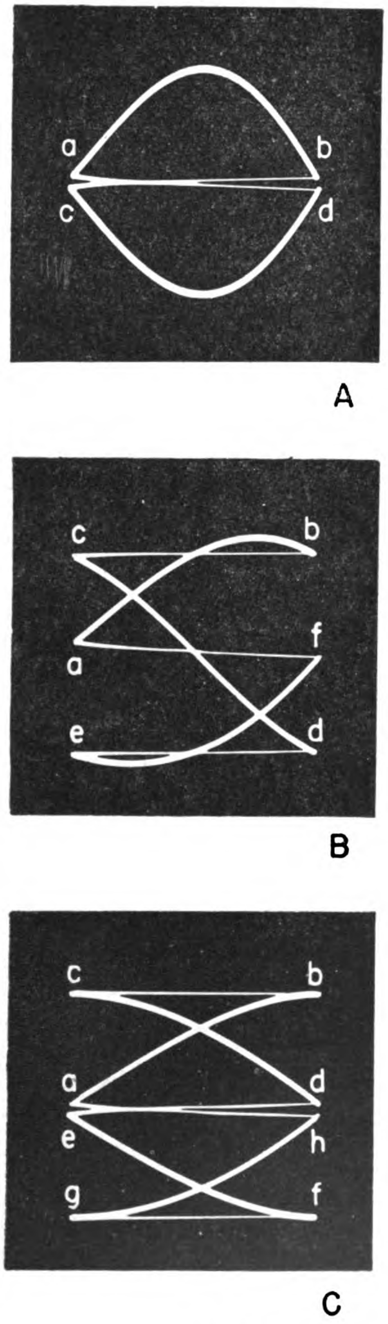

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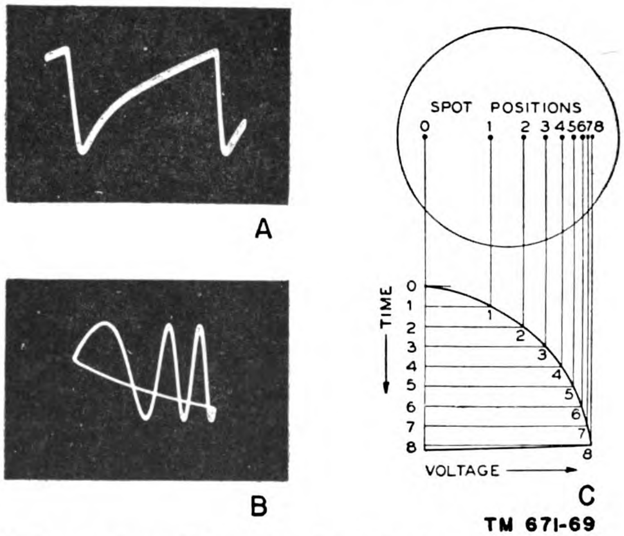
Figure 68. Patterns produced when sweep frequency is higher than signal frequency.

only is a considerable amount of the signal displayed during retrace, but it is displayed with greater brightness. If a special blanking circuit is used to cut off the electron beam during the retrace, retrace effects will not be seen. However, when high sweep frequencies must be generated, it is necessary for the retrace time to be reduced to a minimum. This is true in order that the greater percentage of the available time be used for producing the useful part of the sweep voltage.

(13) In many sweep generators, the retrace time is constant regardless of the frequency generated. Assume that the re-



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A, Sweep voltage; B, Resultant distorted pattern; C, Graphical representation of the spot travel caused by the sweep.

Figure 69. Distortion produced by a nonlinear sweep voltage.

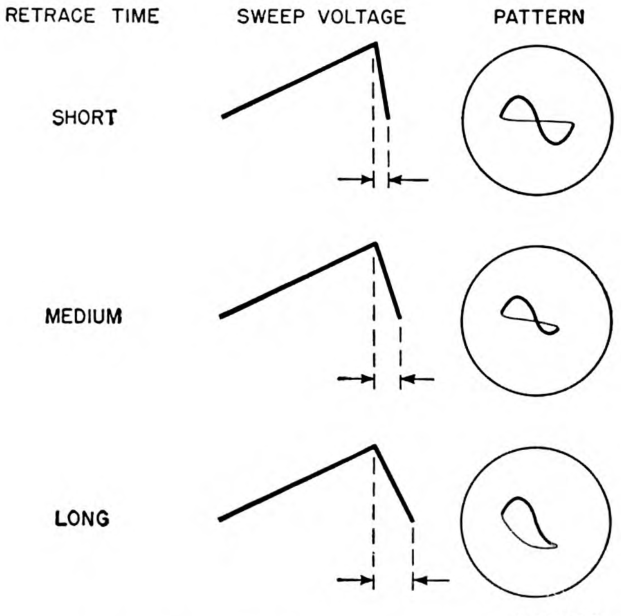

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Figure 70. Effects of various retrace times.

trace time is 10 usec and that the sweep frequency is 2,000 cps. The time required for one sweep cycle is 1/2,000 second or 500 usec. Under these conditions, the retrace time amounts to only 2 percent of the entire cycle. However, if the sweep frequency is increased to 40,000 cps, the time required for one sweep cycle is 1/40,000 second or 25 usec. Now the 10–usec retrace time amounts to 40 percent of the cycle. Therefore, the effect of the retrace time becomes increasingly evident as the sweep frequency is increased.

37. Basic Circuit

a. Relaxation Oscillator. A relaxation oscillator is one whose fundamental frequency is determined by the time of charging or discharging a capacitor or inductor through a resistor. The output waveform is abrupt in shape and rich in harmonics. Most relaxation oscillators produce either a rectangular or a sawtooth waveform. Some relaxation oscillators use gas tubes while others use electron tubes. Both types are important sweep-generating circuits. Most relaxation oscillators use R-C (resistance-capacitance) rather than R-L (resistance-inductance) circuits to produce the required waveform. The operation of these basic circuits will be reviewed below.

b. Operation.

(1) In figure 71, a simple circuit is shown consisting of an R-C combination, a voltage source, and a switch. When the switch is placed in position 1, the battery voltage is applied to the series R-C circuit. Charging current I_c begins to flow in the direction indicated A certain amount of time is required for the charge to be built up in the capacitor. This charge cannot change instantaneously. In the beginning, a small charge is on the capacitor and the full battery voltage causes current to flow. Consequently, a large amount of current flows.

(2) In due time, the capacitor charge is increased. The resultant voltage across the capacitor opposes the battery voltage. This reduces the effective voltage in the circuit and the charging current is reduced. Later, after an additional accumulation of charge, the circuit voltage is reduced further. The charging current is reduced still more. Therefore, the voltage across the resistor, E_r, is maximum at time 1 when the switch is in position 1. The amplitude of this voltage is then reduced exponentially. The voltage across the capacitor, E_c, is zero at time 1. This voltage rises exponentially. The rate at which the voltage changes is greater in the beginning. As time progresses, the rate of change is reduced. When the capacitor becomes fully charged and its voltage equals the supply voltage, the effective circuit voltage is reduced to zero. No more charging current flows. The voltage across the resistor is reduced to zero while the voltage across the capacitor is a maximum.

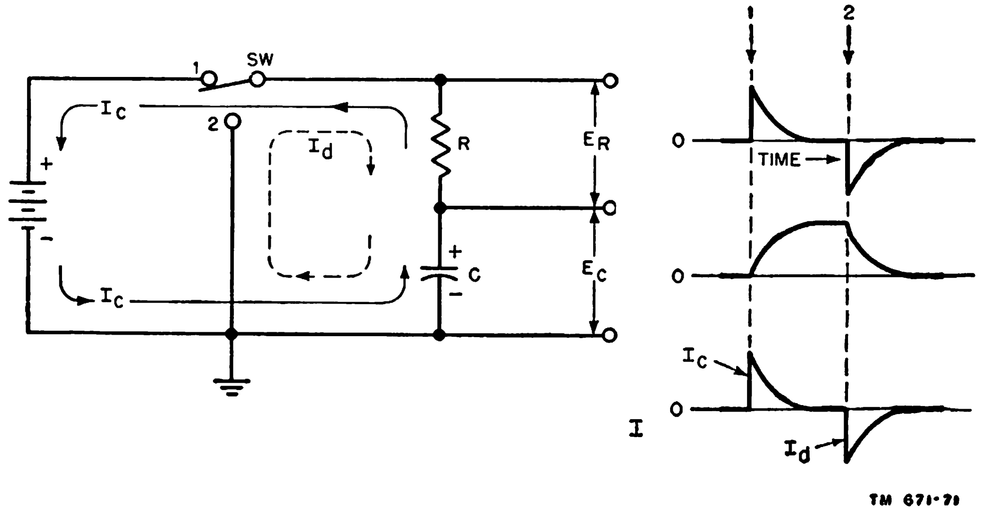


Figure 71. Basic R-C circuit.

(3) At time 2 in figure 71, the switch is moved instantaneously from position 1 to position 2. The capacitor begins to discharge exponentially through the resistor. The discharge current, I_d, is very large at first. As time goes on, the capacitor loses its charge, and the amount of current is reduced. The capacitor voltage falls rapidly at first. As the rate of discharge is reduced, the rate of reduction in capacitor voltage is lowered. The shape of the curve of capacitor voltage during the charging period is exactly the same as during the discharging period. The direction of the discharge current is opposite to that of the charge current. Consequently, the polarity of resistor voltage E_r is reversed when the discharge occurs.

(4) The amount of time required for the capacitor voltage to reach a certain value is determined by the time constant of the circuit, which is directly proportional to both resistance and capacitance. If either capacitance or resistance is increased, the time constant is increased. In this case a greater amount of time is required for the capacitor voltage to rise or fall.

(5) Most sweep voltages for electrostatic cathode-ray tubes are derived from this capacitor voltage. Several modifications of this waveform are required before it can be used. First, the rise rate of capacitor voltage is not linear. However, if only a small portion at the beginning of the voltage rise is used, the departure from linearity is not great (fig. 72). Second, the time required for the capacitor voltage to fall is the same as the time required for the rise in voltage. If this condition is not changed, the trace and retrace times will be equal. To prevent this, it is necessary to reduce the time constant of the circuit when the discharge occurs. When this is done, a more rapid voltage fall is produced. Consequently, the retrace time is reduced. The method of changing the time constant of the circuit during the discharge will be discussed shortly.

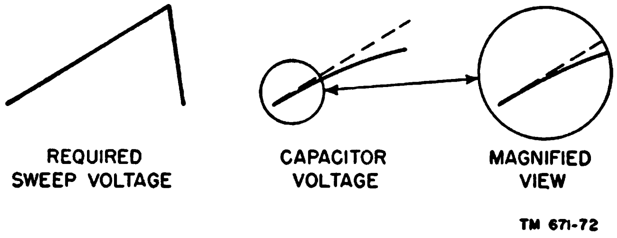


Figure 72. Generation of required sweep.

(6) An **R-L** circuit can be used to produce a sawtooth sweep current for an electromagnetic cathode-ray tube. A basic **R-L** circuit is shown in figure 73 with the associated waveforms. When the switch is placed in position 1, current I_c begins to flow. In the beginning at time 1, the counter electromotive force produced by the inductance is maximum. Therefore, the amount of current flow is minimum. As time goes on, the counter electromotive force is reduced and the current builds up to a maximum value. Once this maximum steady value of current has been reached, the counter electromotive force is reduced to zero. Under these conditions, maximum voltage appears across the resistor. At time 2, the switch is placed instantaneously in position 2. The collapsing magnetic field around the coil induces a voltage of opposite polarity. This voltage tends to sustain the current flow after the source of voltage has been removed. As time progresses, the induced voltage is reduced and the current decays to zero.

(7) The time required for the current to build up or decay a certain amount depends on the time constant of the circuit. An increase in the inductance or a reduction in the resistance will increase the time constant. Reducing the inductance or increasing the resistance will reduce the time constant. The current waveform can be used as the sweep signal for an electromagnetic cathode-ray tube. If a small portion of the current rise is used, the departure from linearity is not great. To reduce the retrace time, it is necessary to reduce the time constant during the decay of current so that this can occur quickly.

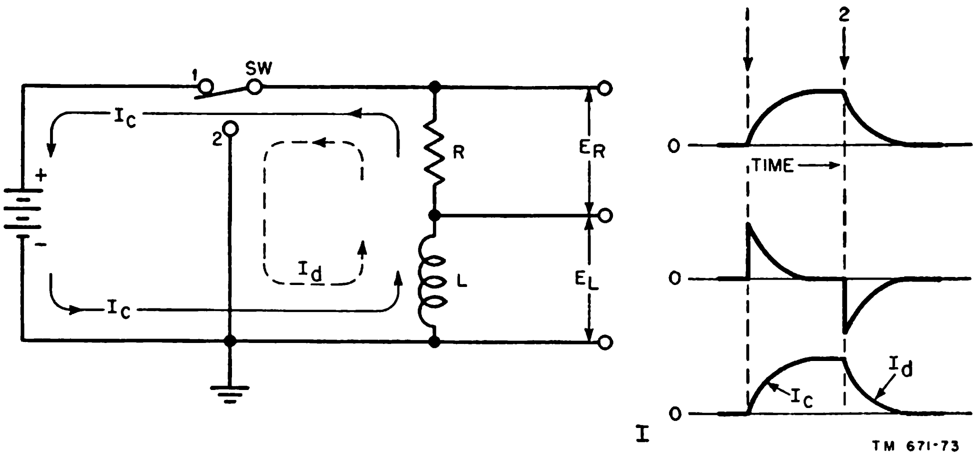


Figure 73. Basic R-L circuit.

38. Neon-Tube Sawtooth Generator

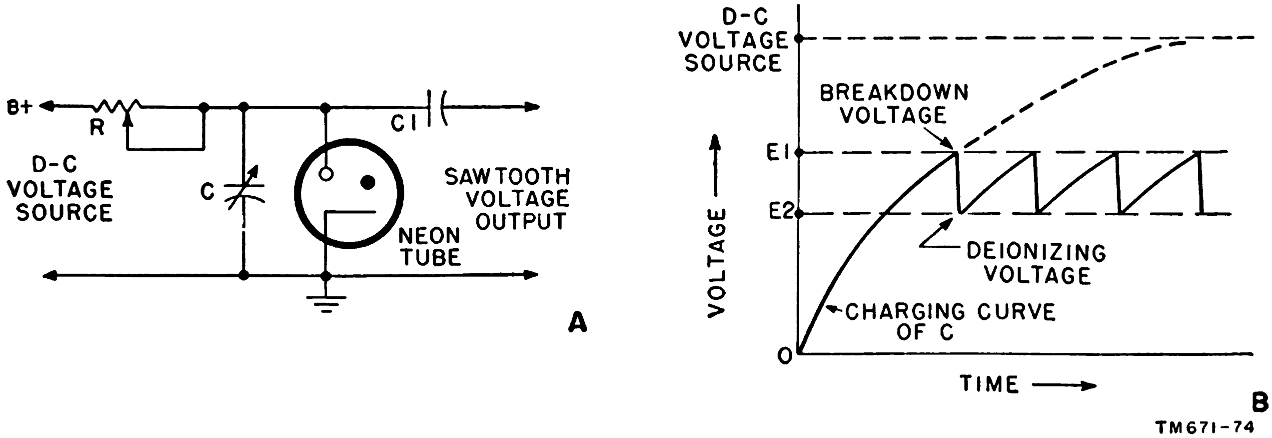
a. Circuit Operation (fig. 74).

(1) A d-c voltage is applied to a simple R-C circuit. A neon tube is shunted across the capacitor. The capacitor begins to charge exponentially toward the value of the voltage source. When the capacitor voltage reaches a value, E1, which equals the breakdown voltage or the ionization potential of the neon tube, the neon gas ionizes and the tube conducts. During conduction, the resistance of the neon tube drops to a very low value and the capacitor discharges rapidly through the tube. When the capacitor voltage drops to a value, E2, which no longer can maintain ionization (deionization potential), the neon tube is extinguished. The tube now acts as an open circuit and the entire process is repeated starting from E2.

(2) Because the resistance of R is much greater than the resistance of the conducting neon tube, the time constant of the circuit during charge is much greater than the time constant during discharge. Therefore, a gradually rising and rapidly falling voltage is produced. A blocking capacitor, C1, is used to remove the d-c component of the sawtooth voltage before it is applied to the horizontal amplifier.

b. Variation of Frequency and Linearity.

(1) If the series resistor is varied the frequency of the sawtooth output is changed. A variation in frequency also can be produced by making capacitor C variable. When the variation of either resistance or capacitance is such as to increase the time constant of the circuit, the output frequency will be lowered. Under these



A. Neon-tube sawtooth generator; B, Voltage time characteristic.

Figure 74.

conditions, a longer time is required for the capacitor to charge to the breakdown voltage. Each cycle of sawtooth voltage uses a longer time interval; therefore its frequency is reduced. If the time constant of the R-C circuit is lowered the output frequency is raised. The capacitor now charges more rapidly and each cycle is completed in a shorter period of time.

(2) A second method of changing the output frequency is to change the magnitude of the d-c voltage applied to the circuit. If the d-c voltage is increased the capacitor charges to this higher voltage. With the same time constant as before, the same *percentage* of the full charge voltage is reached in the same amount of time. Under these new conditions of higher applied voltage, the breakdown voltage of the neon tube is reached more quickly and a higher frequency is generated (fig. 75). If the supply voltage is lowered, the frequency will be reduced.

(3) A second important change occurs when the supply voltage is increased. The linearity of the voltage rise is improved. This is true because a smaller portion of the charging curve is used (fig. 75).

c. Characteristics. The neon-tube sawtooth generator is the simplest circuit which can be used to produce a sweep voltage for a cathode-ray tube. However, small variations in operating temperature or gas pressure change the amount of breakdown voltage required. The dependability of ionization is not great and, as a result, the circuit is unstable. Also, the time required for deionization is long. This causes the retrace time to be long and reduces the sweep effectiveness at high sweep frequencies.

39. Thyratron Sawtooth Generator

a. Review of Circuit Operation (fig. 76). A more satisfactory sawtooth generator can be made if a thyratron is substituted for the neon tube. The circuit operation is the same as that of the neon tube. The capacitor C is charged exponentially through the resistor R. When the capacitor voltage reaches the ionization potential of the thyratron, it conducts. The capacitor discharges rapidly through the tube. When the capacitor voltage drops to the deionization potential, the thyratron stops conducting and the capacitor holds its charge. The entire cycle is then repeated.

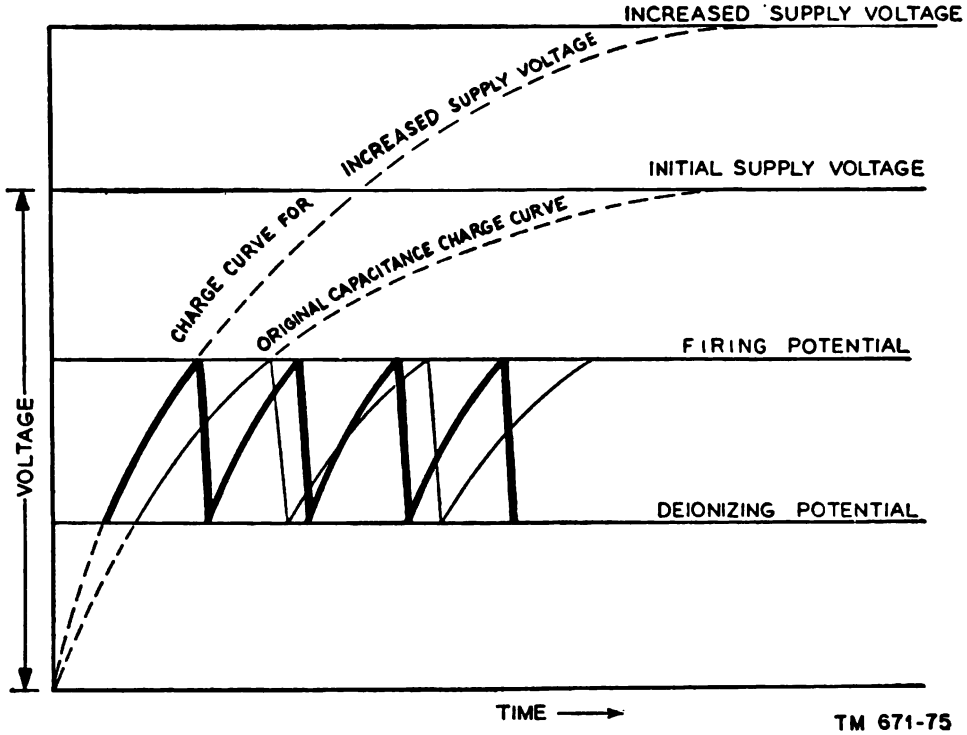


Figure 75. Frequency and linearity changes caused by variation in supply voltage.

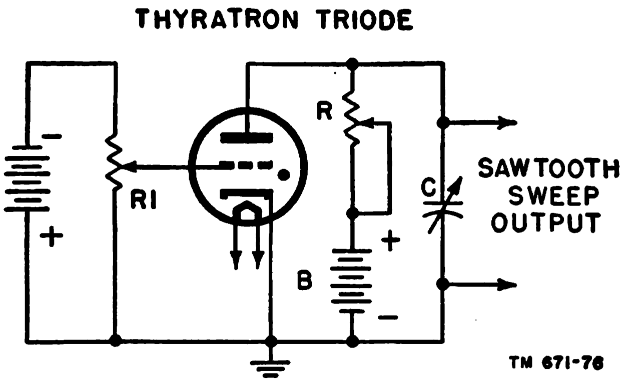


Figure 76. Basic thyratron sawtooth generator.

b. Variation of Frequency and Linearity.

(1) A change in the circuit time constant will affect the output frequency of the thyratron circuit. If the time constant is increased, the frequency is decreased. A reduction in the time constant will raise the frequency. These effects occur for the reasons given in the discussion of the neon-tube circuit. A change in supply voltage also produces the same effect as in the previous circuit. An increase in plate voltage will increase the frequency and the linearity of the output waveform.

(2) Another variable is possible in the thyratron circuit. The grid voltage of this tube can be changed. Normally, the grid is negative with respect to the cathode and no grid current flows. If the fixed voltage applied to the grid is made more negative, it becomes more difficult to ionize the gas within the tube. A higher ionization voltage is required. If the grid voltage is made less negative, the amount of ionization voltage needed is reduced. Therefore, one important factor which determines the amount of voltage required for ionization is the amount of grid potential.

(3) A method of varying the amount of negative grid voltage is provided by R1 in figure 76. When the grid bias is large, the capacitor voltage can increase to a higher value before the thyratron conducts (fig. 77). A longer time is required for the capacitor voltage to reach this higher value, therefore, the time required for 1 cycle is increased and the frequency is lowered. Another effect of a large negative grid-bias voltage is that the amplitude of the sawtooth output is increased. The capacitor voltage varies between the fixed deionizing potential and the increased ionizing (firing) potential. A third effect is that a larger portion of the capacitor charging curve is used with its attendant nonlinearity. A small negative grid bias has the opposite effects. The frequency is increased, the amplitude is reduced, and the linearity is improved.

c. Characteristics. The thyratron uses a hot cathode and has a different physical construction than the neon tube. Also argon, krypton, or xenon can be used as the filler gas instead of neon. For these reasons, several advantages can be obtained

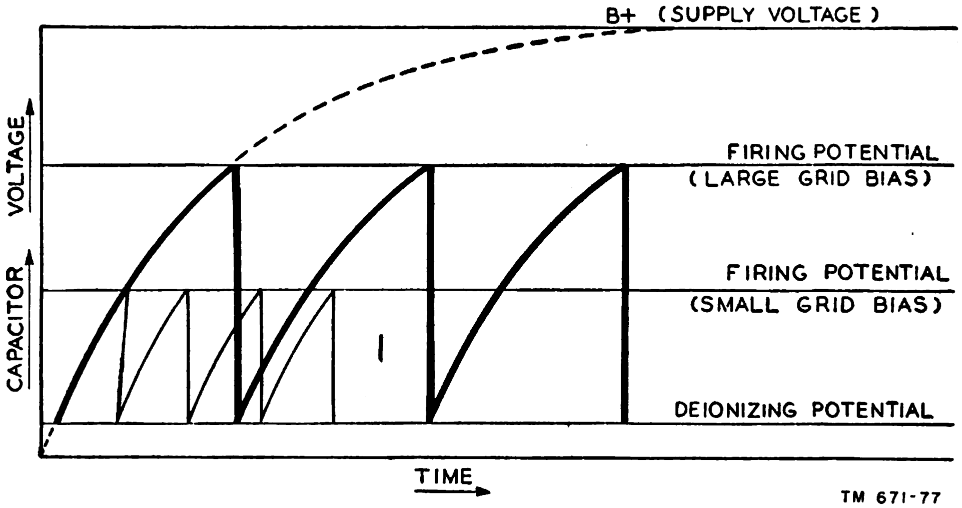


Figure 77. Variation in frequency, amplitude, and linearity of a thyratron sawtooth generator by change in grid bias.

by its use. A smaller voltage drop appears across the thyratron and it will pass a larger instantaneous current than the neon tube. Greater dependability of ionization makes for a more stable output frequency. A faster deionization time results in a shorter retrace. Because the thyratron passes a larger instantaneous current and deionizes rapidly, high sweep frequencies can be generated. These characteristics make the thyratron sawtooth generator popular for general-purpose oscilloscopes.

d. Practical Circuit.

(1) A typical circuit showing the thyratron as a sweep generator is shown in figure 78. In this circuit the cathode of the thyratron is maintained at a potential of +3.1 volts through the voltage divider consisting of R34 and R31. Since the grid is grounded through R29 and R30, its voltage is −3.1 volts with respect to the cathode. This voltage is the fixed negative bias on the thyratron. A regulated supply is used as the source of this bias voltage so that a minimum amount of variation will be caused by line voltage changes. If this were not done, a change in sweep frequency, amplitude, and linearity would result.

(2) A bank of eight capacitors is used with switch S3 to provide a means of making a coarse frequency adjustment. The capacitors used vary in size from 40 uuf (micromicrofarads) to 1 uf (microfarad). These capacitors in conjunction with resistors R32 and R33 form the R-C charging circuit. R32 is made variable to provide a means of making fine frequency adjustment. With the particular R-C circuits used, the sweep frequency is continuously variable from about 2 cps to 50,000 cps. A synchronizing signal is applied through the coupling capacitor C14 to the grid of the thyratron. The purpose of this signal will be discussed later.

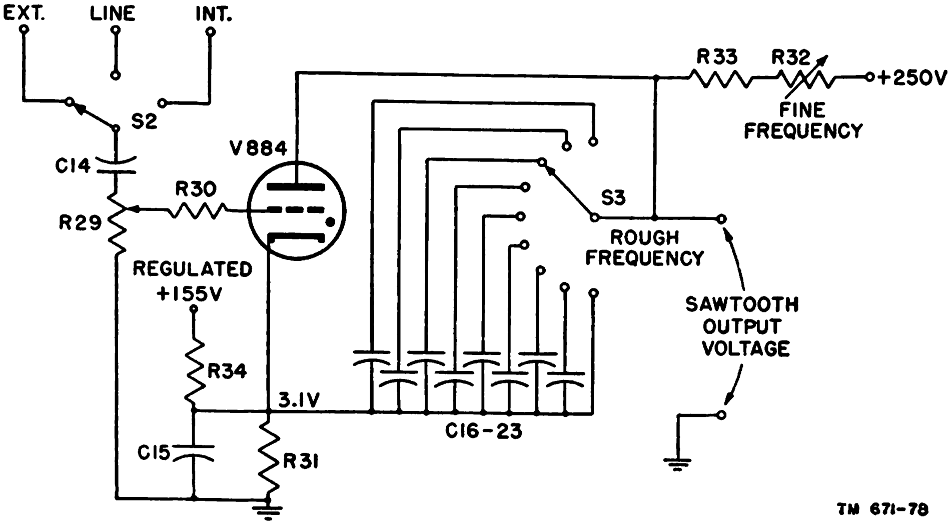


Figure 78. Thyratron sawtooth sweep-generator circuit.

Section II. ELECTRON-TUBE SAWTOOTH GENERATORS

40. Discharge Tube Actuated by Pulse

a. Basic Circuit (fig. 79).

(1) The gas-tube circuits shown previously were free-running relaxation oscillators. When the proper supply voltages are used, the circuit begins to oscillate and produces a sawtooth waveform. The circuit to be described differs in many respects from the previous circuits. An electron tube is used to discharge the capacitor. The resistance of the hard tube, when it is conducting, is higher than that of a gas tube. However, its resistance is lower than that of the series resistor. Consequently, a slow charge and a rapid discharge can still be pro-

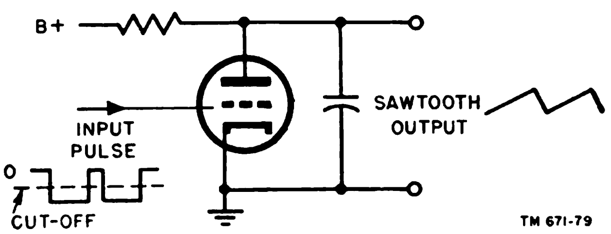


Figure 79. Discharge tube actuated by pulse.

duced. This circuit is not a free-running oscillator but it must be driven by a rectangular input pulse. The pulse drives the electron tube below cut-off. Under these conditions, the tube behaves like an open circuit and the capacitor charges through the resistor in the normal manner. A slow exponential voltage rise is produced.

(2) At the end of the negative alternation, the grid voltage is raised above cut-off. The tube conducts heavily and discharges the capacitor rapidly. When the next negative rectangular alternation is applied, the process is repeated. If there is a considerable time delay before the second negative pulse is applied, there will be a delay between the sweeps. The discharge tube must wait for a negative pulse to cut if off again so that the capacitor can begin its normal charge.

(3) In some displays, such as those used in radar sets or synchroscopes, the waiting period exceeds the active sweep period. The discharge tube, therefore, conducts for a longer period of time than it is cut off. At the beginning of the conduction period, the charged capacitor discharges rapidly toward the plate voltage of the electron tube. Since the value of series resistance used is much larger than the plate resistance of the tube, the effective plate voltage is far below that of the plate-supply source. This low value of steady output voltage is maintained until the next negative alternation arrives. This negative alternation is often called the *sweep gate*. The capacitor begins its charge at the beginning of this gate when the discharge tube is first cut off. The voltage across the capacitor continues to rise toward the value of the power-supply voltage during the cut-off period. At the end of the gate, the discharge tube conducts, the charging stops and the sweep voltage terminates.

b. CHARACTERISTICS. The circuit described above is used when it is desired to have a sweep voltage that is controlled rigidly by some external pulse generator. The stability of this sweep generator is determined solely by the stability of the incoming pulses. The sweep voltage produced is called a *driven* or a *gated* sweep.

41. Plate-Coupling Multivibrator Sweep Generator

a. CIRCUIT OPERATION (fig. 80).

(1) The circuit shown is a symmetrical multivibrator in which the output of V1 is coupled through the circuit C2R2 to the input of V2. The output of V2 is coupled through the circuit C1R1 to the input of V1. The operation of the circuit is such that one section of the electron tube is cut off while the other section is saturated. These conditions reverse periodically. V1 is cut off when the plate potential of V2 falls. This voltage drop is coupled through the coupling circuit C1R1 to the grid of V1. Capacitor C1 discharges through resistor R1 and produces a negative voltage across the resis-

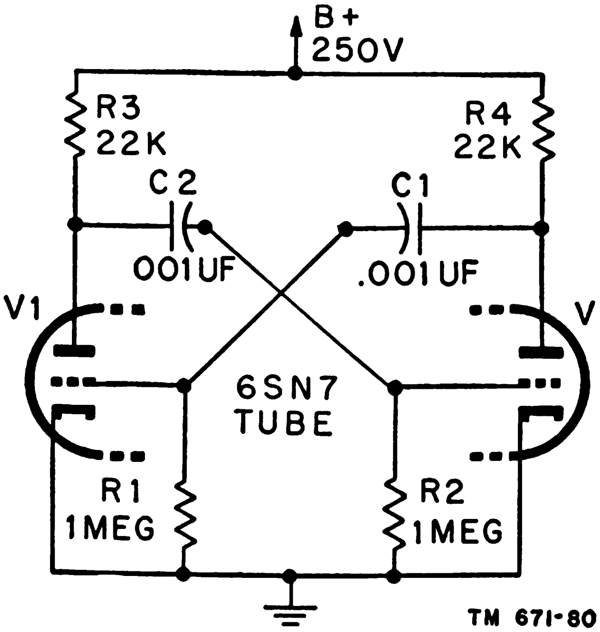


Figure 80. Circuit of symmetrical plate-coupled multivibrator with typical component values given.

tor. This voltage keeps V1 cut off. As the discharge current is reduced, the amplitude of the negative grid voltage is decreased. When this voltage is no longer sufficiently negative to hold V1 cut off, the tube conducts.

(2) The resultant fall in the plate potential of VI is transmitted through C2R2 to the grid of V2. V2 now is cut off by the negative voltage at its grid resulting from the discharge of C2. In due time, the discharge current falls and the amplitude of this negative voltage is reduced. When this voltage is no longer sufficiently negative to maintain V2 below cut-off, this tube conducts. In the circuit shown, the rate of discharge in both R-C circuits is the same. Therefore, both V1 and V2 are alternately cut off and saturated for the same periods of time. This circuit is a balanced multivibrator since the duration of both alternations is the same. Free-running relaxation oscillations are produced when the operating voltages are applied. The frequency of these oscillations is determined by the component values, the characteristics of the tubes, and the voltages applied. In general, the factors which affect frequency do so in the same manner as in the previous relaxation oscillators. An increase in the time constants of the circuit reduces the output frequency; a reduction in the time constants increases the frequency.

(3) The waveforms produced by such a circuit are shown in figure 81. The two plate-voltage waveforms (A and C of fig. 81) are approximate square waves which are 180° out of phase. The slight peaks and rounded corners are caused by the charging of circuit capacitances. The two grid-voltage waveforms illustrated in B and D show the effect of the slow discharge of the coupling capacitors through their respective grid resistors.

b. Sawtooth Output.

(1) Several modifications are needed to convert this circuit into a sweep generator. First, a fairly large capacitor is shunted across one of the sections of the double triode electron tube, say V2. Second, the multivibrator usually is unbalanced or

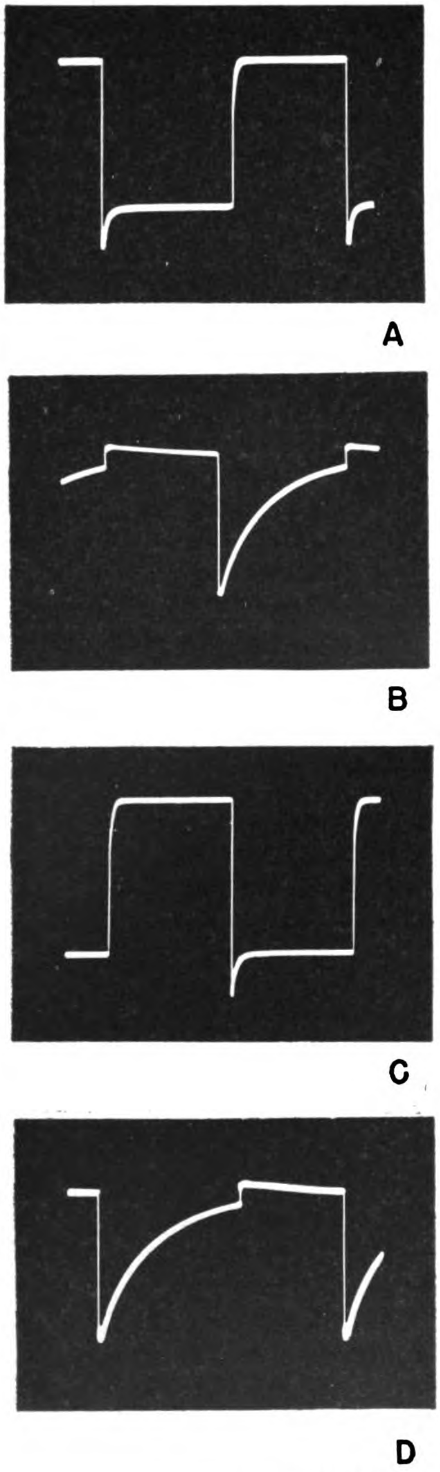


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Figure 81. Waveforms produced by symmetrical multivibrator.

made to produce an *asymmetrical* output. In such a circuit the time required for each alternation is unequal and the output waveform is a rectangular rather than square wave.

(2) The capacitor which is added is the component across which the sawtooth sweep voltage is obtained. The multivibrator serves as a discharge device for the capacitor. Actually, the section of the multivibrator across which the capacitor is connected operates in the same manner as the simple discharge tube actuated by a pulse. In the multivibrator circuit, the pulse is generated by the circuit itself rather than supplied externally. The capacitor voltage rises gradually toward the value of the plate-supply voltage. This rise continues as long as the section of electron tube across which the capacitor is connected remains cut-off. When the section of electron tube is made to conduct, the capacitor discharges rapidly. In this way, a gradually rising and rapidly falling sawtooth sweep voltage is produced.

(3) A balanced multivibrator generally is not used in the circuit. The one exception is when a gated sweep is needed in which the time of the sweep and the time between sweeps are to be exactly the same. More frequently, an asymmetrical multivibrator is used. With this circuit a simple recurring sweep can be generated as shown in A of figure 82. During the time that high plate current flows in the section of the double triode which shunts the capacitor its plate voltage is reduced. The capacitor discharges rapidly. However, before the discharging voltage reaches the low value of plate potential, the tube section is cut off and the capacitor begins to recharge. In B of figure 82, a gated or driven sweep is generated in which the time between sweeps is longer than the actual sweep time. When the tube section is cut off, the rising sweep voltage is generated. When the tube begins to conduct heavily, the capacitor quickly discharges. This produces the rapid retrace. The capacitor voltage then remains at the low plate-voltage value until the next cut-off period occurs.

(4) The usual method of converting a symmetrical plate-coupled multivibrator to one that is asymmetrical is to change the time constant of one of the R-C coupling circuits. A shorter time constant reduces the time required for the capacitor to discharge through the resistor to a specific voltage. Therefore, the cut-off tube section remains in that condition for a shorter period of time.

c. PRACTICAL CIRCUIT (fig. 83). In this circuit, the time constant of R1C1 is 350 usec and the time constant of R2C2 is 1,000 usec. The time constant R1C1 is determined by the values of R, and C, and also the value of C3. Therefore V2 remains cut off for a longer period of time than does V1. While V2 is cut off, the capacitor C3 charges through R4. During this time, the gradually rising sawtooth sweep voltage is generated. When V2 conducts, C3 discharges rapidly through V2, thereby producing the rapid retrace. The period of conduction for V2 is short compared to its cut-off period. The brief pulse of plate current soon ends, V2 again is cut off and the charging of C3 begins again. In this way, a recur-

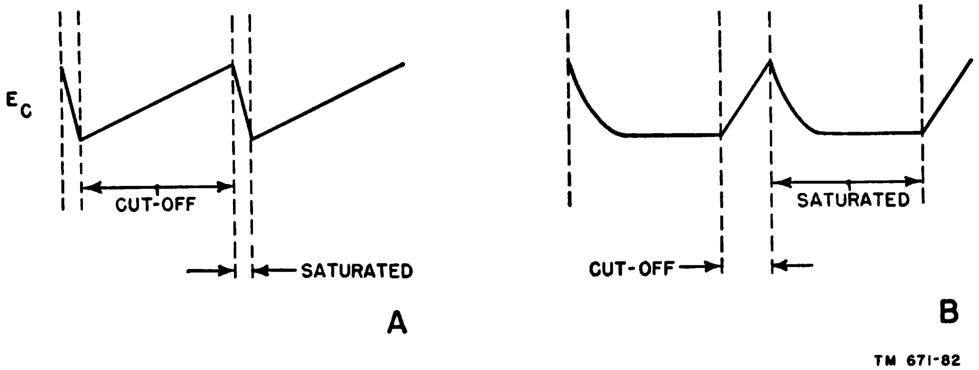

Figure 82. Asymmetrical multivibrator sweep voltages when capacitor is shunted across output.

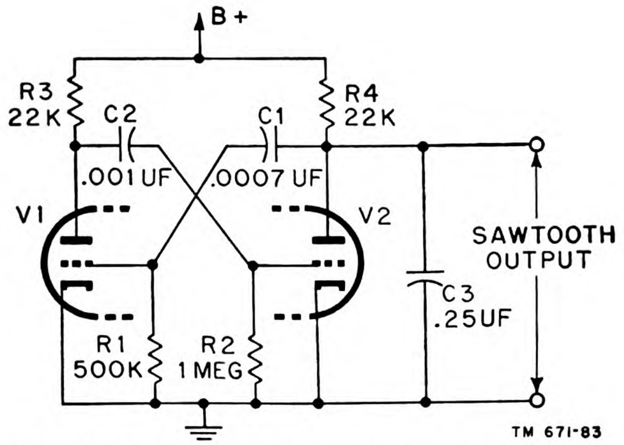

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Figure 83. Practical circuit of asymmetrical multivibrator used as a sweep generator.

ring sawtooth sweep voltage is generated across C3. The waveforms which can exist in this type of circuit along with the output waveform are shown in figure 84. The plate voltages are shown at A and C, the grid voltages at B and D, and the sawtooth output at E. Of course, to obtain the voltage waveform from the plate of V2 as in C capacitor C3 must be removed.

d. Other Multivibrator Sweep Generators.

(1) Any free-running multivibrator can be converted into a sweep generator by shunting a capacitor across one of the electron tubes used. The function of the multivibrator is to provide the capacitor with a shunt resistance which is alternately high and low. Another popular multivibrator which has been used frequently in oscilloscopes is the cathode-coupled free-running circuit. In this circuit a conventional R-C coupling is used along with cathode coupling.

(2) A practical cathode-coupled multivibrator is shown in figure 85. The circuit uses a duo-triode with a common cathode resistor. The output of V1 is coupled through an R-C coupling circuit consisting of C1, R6, and R1 to the input of V2. The output of V2 is coupled to the input of V1 through the common cathode resistor. The sawtooth sweep voltage is obtained across C2. The coarse frequency adjustment, C1, actually consists of a number of fixed capacitors which range in value from 100 uuf to .5 uf. A variation in the capacitance of C1

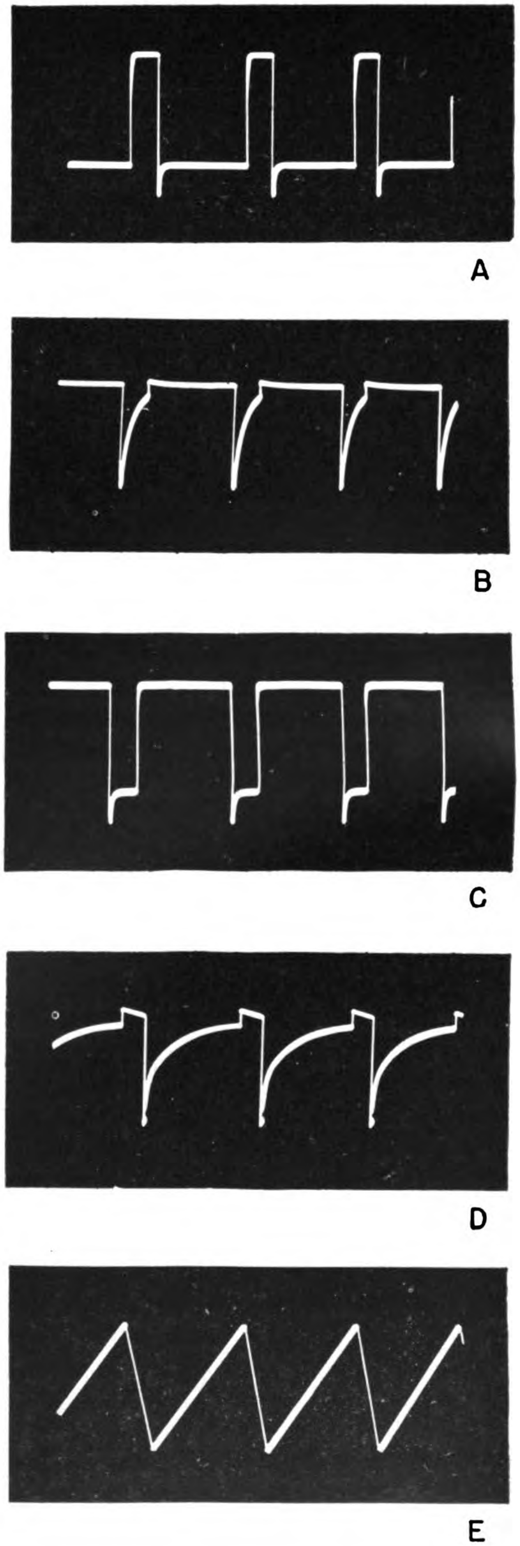

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Figure 84. Plate, grid, and output voltage oscillograms obtained from an asymmetrical multivibrator.

changes the time constant of the coupling circuit. This alters the output frequency of the multivibrator which, in turn, varies the sawtooth sweep frequency. As the capacitance of C1 is increased, the frequency of the output is reduced. Capacitor C2 is ganged with C1. This is done so that the shape of the output sawtooth signal does not vary with changes in frequency. The fine frequency control consists of R1 and R4, which are ganged. The size of the resistances used is such that a variation in the fine frequency control will not affect the amplitude of the sawtooth output.

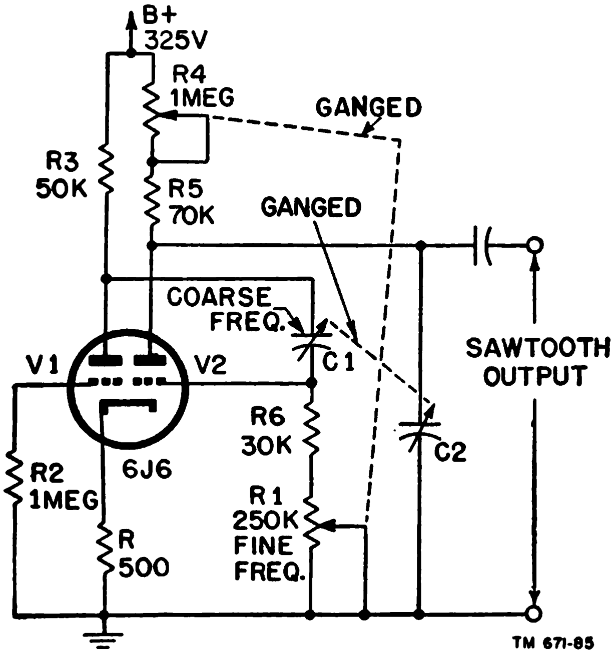

Figure 85. Typical cathode-coupled multivibrator sweep generator.

42. Blocking-Oscillator Sweep Generator

a. Circuit Operation.

(1) In addition to the multivibrator, another relaxation oscillator can be used as a sweep-generating circuit. This is the blocking oscillator. The type of blocking oscillator frequently used is sometimes called the single-swing blocking oscillator. This circuit, which is discussed in detail in other technical manuals, appears to be an ordinary tuned-grid tickler feedback oscillator (fig. 86). However, a special design of transformer is used. This transformer uses close coupling so that the signal coupled back to the grid drives it very positive. The transformer also has a low Q so that sustained oscillations are not produced. In addition, the resonant frequency formed by the transformer inductance and the stray capacitance is several megacycles so that a narrow output pulse is generated. The circuit consisting of R1C1 has a long time constant so that any charge which accumulates on the grid capacitor requires a long time to leak off through R1.

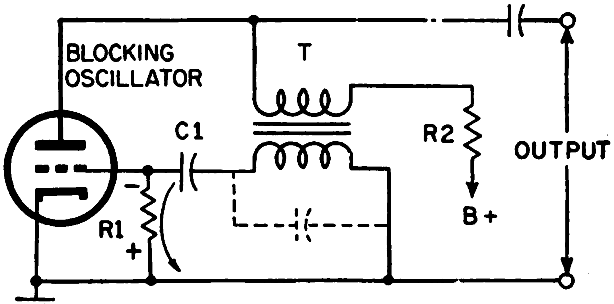

Figure 86. Typical circuit of a free-running blocking oscillator.

(2) The grid and plate voltages are shown in figure 87. Sufficient charge accumulates on capacitor C1 to block the oscillator after 1 cycle of oscillation. The oscillator remains blocked until the negative bias voltage developed across R1 rises to the cut-off level. When this occurs, another single cycle is generated. In this manner, a single radio-frequency oscillation, which is repeated at a much lower rate, is produced. If the time constant of the R-C circuit is increased still further, even more time is required for the discharge to occur. Under these conditions, a longer time interval will elapse between cycles. The plate current in this circuit flows in narrow, widely spaced pulses. This type of plate-current flow is well suited for the production of a recurrent sweep having a short retrace time.

(3) All that is required for the generation of a sawtooth sweep is the addition of a shunt capacitor, such as C2 in figure 88.

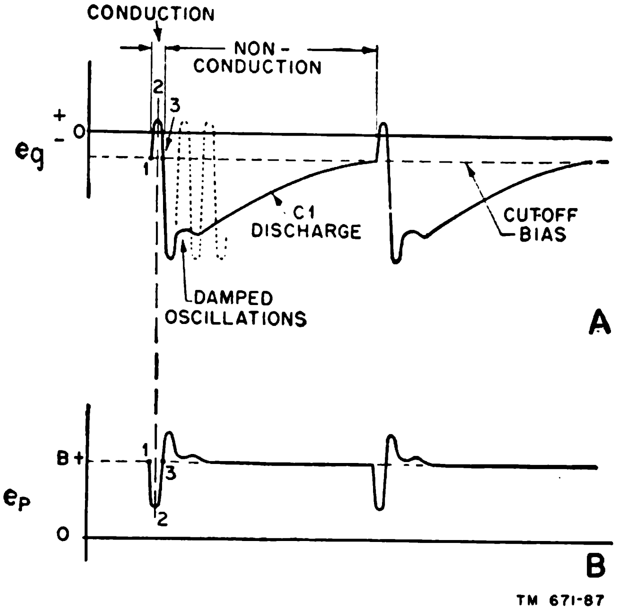

Figure 87. Waveforms produced by blocking oscillator.

In this circuit, the capacitor C2 charges toward the value of the plate-supply voltage through resistor R2. This charging continues as long as the oscillator is cut off. During the brief period of conduction, the resistance of the electron tube is lowered and the capacitor discharges through the tube rapidly. The variable resistor R3 is used to alter the frequency of the sawtooth output voltage. As the value of this resistor is increased, the time constant of the R-C circuit is increased. A longer time interval elapses between plate-current pulses. This lowers the frequency of the sawtooth output.

(4) Resistor R2 is made variable so that it can serve as an amplitude control. As the value of this resistor is increased, the capacitor C2 charges at a slower rate. The sawtooth voltage does not rise to as large a magnitude before the plate-current pulse occurs which discharges the capacitor. Consequently, the amplitude of the sawtooth voltage is reduced. A damping resistor, R4, is occasionally used in this circuit to damp out resonant oscillations. Although the blocking-oscillator transformer has a low Q, the rapid current change through the windings can shock the transformer into oscillation without this resistor.

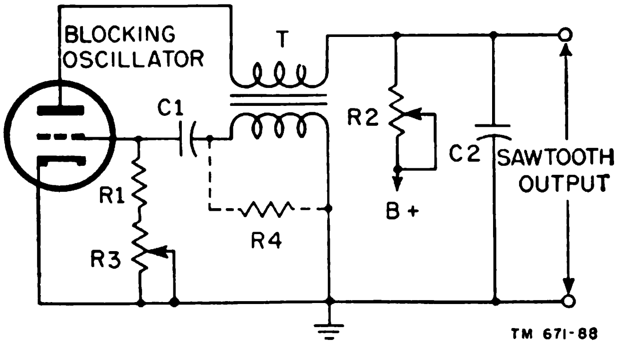

Figure 88. A simple blocking-oscillator sweep-generating circuit.

b. Blocking Oscillator and Discharge Tube.

(1) The previous circuit has several disadvantages. These arise because the discharge path for the capacitor C2 includes the plate winding of transformer T. It is difficult to produce the required rapid discharge which is needed for a short retrace. The inductance of the transformer has a definite retarding effect on the rate of capacitor discharge. When the capacitor is not allowed to discharge sufficiently, the amplitude of the sawtooth output is reduced. Also, if a large amplitude sweep voltage is required, the retrace time will be too long. This is true because the charge and discharge of the capacitor must cover a large voltage range.

(2) These disadvantages are overcome by the use of an additional tube as the discharging device. The blocking oscillator is then used to trigger the discharge tube. Common practice is to use a duo-triode so that both functions are accomplished by a single tube.

(3) A practical circuit, which is used in some television displays, is shown in figure 89. In this circuit, V1 is a conventional blocking oscillator. The repetition frequency is determined by the circuit consisting of C1, R1, and R3. This last resistor is made variable to provide a frequency adjustment. A decoupling filter, consisting of R2 and C3, is used in the plate circuit of the oscillator. The two grids are connected so that the voltage which appears on the grid of V1 also appears on the grid of V2. Both sections of the electron tube

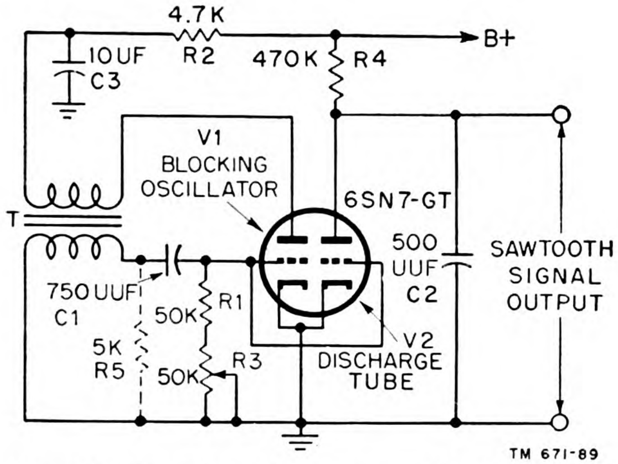

Figure 89. Schematic diagram of a practical blocking oscillator and discharge tube which generates a sawtooth sweep voltage whose frequency is about 15 kilocycles.

have about the same cut-off voltage requirements, so that both sections are cut off and conducting at the same time.

(4) Assume that C1 is discharging through R1 and R3. The negative bias voltage developed across these resistors cuts off both V1 and V2. During this time the capacitor C2 begins to charge through R4 toward the value of the plate-supply voltage. When the negative bias voltage is no longer sufficient to cut off both sections, they conduct. The conduction of V1 initiates the single oscillation which is generated by that circuit. The conduction of V2 serves to discharge the capacitor C2. The discharge path of C2 is through V2 only. No transformer inductance can impede this rapid discharge so that practically the entire charge is removed from capacitor C2. The retrace time is then satisfactorily short and the amplitude of the sawtooth sweep voltage is not reduced.

(5) If the waveforms of this circuit are examined, it can be seen that they follow the theoretical waveforms quite closely. In A of figure 90, the voltage at both grids is shown. The single cycle of oscillation can be seen along with the exponential rise of grid voltage. This rise of voltage is produced as the grid capacitor discharges through the grid resistors. When this voltage rises to the cut-off voltage, another oscillation is seen. Note the low amplitude damped oscillations which are the result of an insufficiently low transformer Q. In B of figure 90, the plate voltage of the blocking oscillator is shown. The large amplitude single oscillation is seen. This waveform is of opposite polarity to the grid-voltage waveform. The effect of minor damped oscillations is still seen. C shows the resultant sawtooth output waveform at the output of the discharge tube V2.

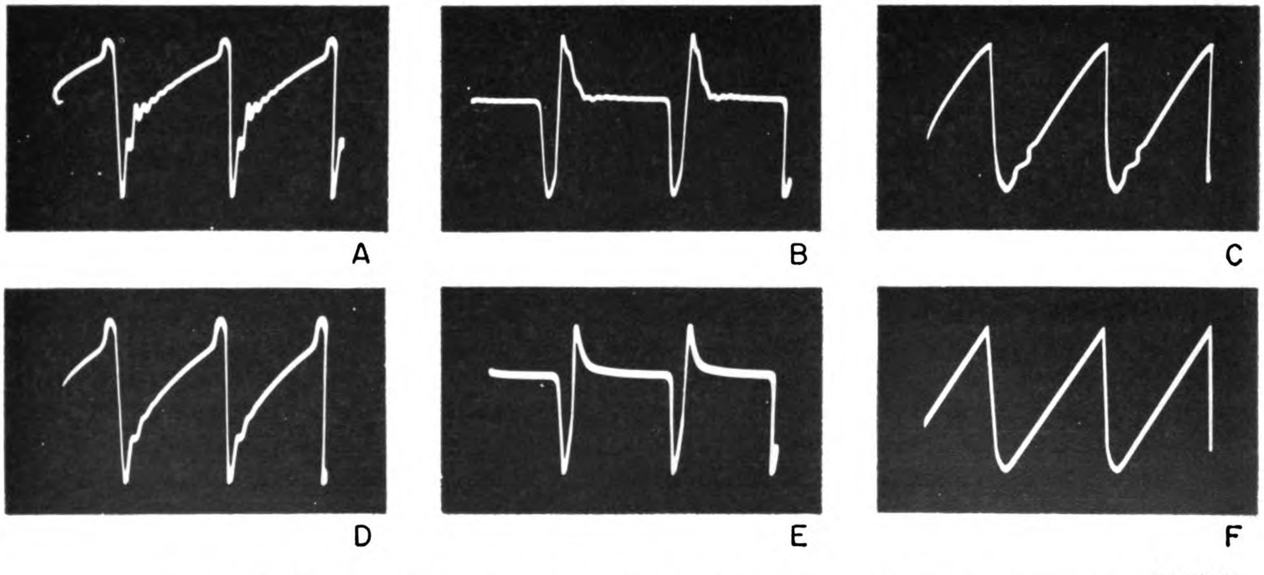

Figure 90. Oscillograms of operating waveforms obtained in circuit shown in figure 89.

(6) If a damping resistor, R5 (fig. 89), is inserted in the circuit, a slight improvement is produced. The waveforms shown in D, E, and F of figure 90 show the effect of adding the damping resistor. These waveforms were obtained from the same points as were A, B, and C. Complete damping in the plate-voltage waveform is evident in E. As a result, minor irregularities at the beginning of the sawtooth sweep are prevented. The addition of the damping resistor reduces the amplitude of the resulting waveforms and changes the frequency of operation. The design engineer must decide whether the advantages to be gained outweigh the disadvantages.

43. Triggered Sweep Generator

a. NEED FOR TRIGGERING.

(1) All the relaxation oscillators discussed so far for sweep generation have been free-running oscillators. The neon-tube or thyratron circuit, the multivibrator, and the blocking oscillator all begin to generate an output voltage soon after the correct operating potentials are applied. The frequency at which these oscillators operate depends on the component values, the operating voltages, and the characteristics of the tubes and circuits used. None of these oscillators are particularly stable, although the electron-tube circuits are better in this respect than the gas-tube circuits.

(2) Frequently, it is required to produce a sweep voltage whose frequency is controlled rigidly by some externally produced signal. This signal can be repeated periodically or it can be transient. If the signal is periodic, the frequency can be constant or it can vary slightly. The sweep frequency must always follow the frequency of the externally applied signal.

(3) One method that is used to accomplish this involves the triggered sweep. In this method, an input trigger whose repetition frequency is the same as the required sweep frequency is applied to a special type of multivibrator or blocking oscillator. These circuits are operated in such a way as to produce no output voltage until the input trigger is applied. One complete cycle of operation and one complete sweep occur upon the receipt of each input trigger. If the input triggers are repeated periodically, the sweep also will be repeated periodically. If the frequency of the input trigger varies, so will the sweep frequency. A single transient trigger will cause a single sweep to be generated.

(4) Another method of causing the sweep frequency to be controlled closely by some externally applied signal frequency is known as *synchronization.* In this method a conventional free-running relaxation oscillator is used. The frequency of the oscillator can be changed slightly by applying a suitable synchronizing voltage. This voltage causes the oscillator frequency to be altered to the frequency of the synchronizing signal. Synchronization frequently is used with recurrent sweep circuits and those in which the sweep frequency can be adjusted reasonably close to the desired frequency by the operation of a free-running relaxation oscillator. The entire subject of synchronization will be discussed in detail in section III.

(5) Frequently, the input trigger required for a triggered sweep has the same waveform as a synchronizing signal. Several methods can be used to determine whether a driven or triggered sweep is being used or whether synchronization is taking place. First, if the input pulse is removed and the sweep generator stops operating, the input pulse is a true trigger and the sweep is a driven or triggered sweep. If, however, the sweep generator continues to operate but at a slightly different frequency when the input pulse is removed, synchronization was being used. A second method can be used to distinguish triggering from synchronization. A relaxation oscillator which is suitable for synchronization is usually a conventional free-running oscillator. The circuit can be recognized as such. A circuit which is suitable for triggering, however,

must be modified in such a way as to prevent its operation until the input trigger is applied.

(6) The terms *gated sweep generator* or *triggered sweep generator* are sometimes used interchangeably. However, a distinction can be made between them. A true triggered sweep circuit is one in which the sweep-circuit operation is merely started by the input pulse. This pulse is known as the trigger and usually is a peaked waveform. The sweep-generating circuit terminates the sweep. A gated sweep circuit is one in which the sweep circuit is started, maintained for a certain specified time, and then terminated. The input pulse in the latter case is known as a gate and is usually a square or rectangular waveform. The generation of a true gated sweep has been discussed in the basic electron-tube sweep generator that was actuated by a pulse.

b. Triggered Circuits.

(1) Special types of multivibrators, called *start-stop multivibrators*, and also, by some authors, one-shot multivibrators, are used to generate triggered sweeps. These multivibrators normally are inoperative but go through one complete cycle when triggered. A common start-stop multivibrator is shown in figure 91. In this circuit, the cathode bias voltage developed across the common cathode resistor R is applied to the grid of V1 only. The grid of V2 is returned to its own cathode through R2.

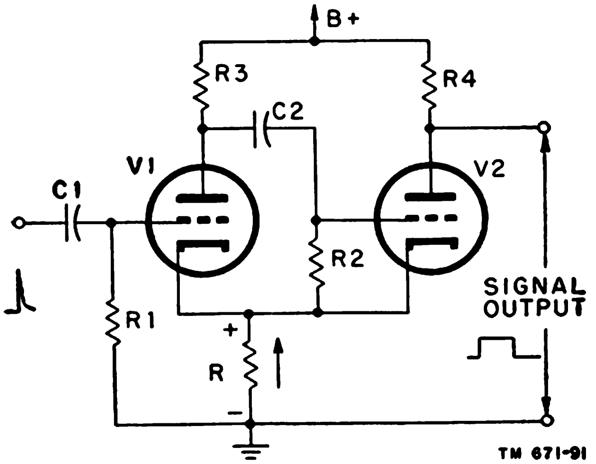

Figure 91. Schematic diagram of a start-stop multivibrator.

(2) When the operating voltages are applied to this circuit, V2 conducts heavily and V1 is cut off because of the large cathode bias. This condition is maintained until the positive input trigger is applied. The trigger drives V1 into conduction and causes its plate potential to fall. The drop in voltage is transmitted through a conventional coupling circuit, C2R2 to the grid of V2, which is driven negative. The resultant reduction in plate current through V2 reduces the amount of current through resistor R which reduces the amount of cathode bias applied to V1 so that its plate current rises. A regenerative switching action occurs which causes V1 to become saturated and V2 to become cut off.

(3) As time progresses, the charge continues to leak off C2 through R2. When the grid voltage of V2 is no longer sufficiently negative to hold the tube cutoff, it conducts. This conduction increases the cathode bias applied to V1. The regenerative action which occurs causes V1 to be cut off and V2 to become saturated. This is the original condition of the circuit prior to the application of the trigger. The circuit remains in this condition until the next trigger is applied, at which time the entire cycle begins again. In order for the circuit to operate, an input trigger is required. Without the driving trigger the circuit remains in a state of equilibrium.

(4) To convert the multivibrator into a sweep generator, a capacitor is connected between the plate of V2 and ground. As long as V2 conducts, the capacitor is shunted by the low plate resistance. When a trigger is applied to the multivibrator, V2 is cut off. This allows the capacitor to charge through R4, the plate resistor of V2, thereby generating the saw-tooth sweep voltage. When V2 conducts once more, the capacitor discharges rapidly through the tube. In this way, the trigger that is applied to the start-stop multivibrator begins the sweep.

The sweep voltage continues to increase as long as V2 is cut off. The time constant of the coupling circuit C2R2 largely determines the amount of time that V2 remains cut off. The sweep terminates when V2 conducts.

(5) In some applications several sweep lengths are required. A switching arrangement permits various sizes of resistance to be inserted as R2. If this resistance is increased, then V2 remains cut off for a longer period of time and a longer sweep duration voltage is generated. If R2 is reduced, the sweep duration also is reduced. The switching arrangement which alters the size of R2 also changes the value of the capacitor across V2 where the sweep voltage is generated. This is necessary in order to maintain the same amplitude of sweep when its time duration is changed.

(6) Some radar applications use the output of the start-stop multivibrator to gate a discharge tube. This tube produces a gated sweep which has already been described.

(7) Another triggered sweep generator uses a special blocking oscillator (fig. 92). This circuit differs from the circuit described earlier in one important respect. The grids of the tube are returned through R1 and R3 to a source of large negative bias. The amount of negative voltage is far beyond plate-current cutoff. As a result, no current flows in either section of the electron tube. When a sufficiently large amplitude positive trigger is applied to the grids, the negative bias is overcome and plate current flows. The circuit now operates normally and produces the single oscillation. The negative alternation of grid voltage is far below the original bias voltage. After the single cycle has been generated, the oscillator is again blocked.

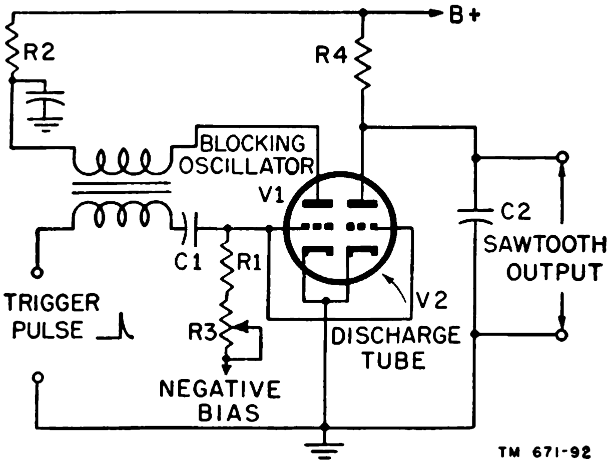

Figure 92. Typical circuit of a triggered blocking oscillator and discharge tube.

(8) In due time, the additional negative charge resulting from oscillation leaks off capacitor C1. In an ordinary blocking oscillator, this voltage discharges toward ground potential. When the cut-off bias is reached, another oscillation occurs. In the circuit shown in figure 92, however, the capacitor discharges toward the large value of initial negative bias. Even when this large value of voltage is reached, no oscillation is generated since the grid voltage still is below cut-off. A trigger voltage is required to drive the tube into conduction to produce the next oscillation.

(9) As long as both tubes are cut off, the output capacitor C2 charges through R4 toward the value of the plate-supply voltage. When the trigger is applied, the tube conducts. Capacitor C2 discharges rapidly through the low resistance of the discharge tube. Consequently, the trigger initiates the retrace and the sweep begins when the tube has been cut off.

Section III. SYNCHRONIZATION OF TIMEBASE CIRCUITS

44. Need for Synchronization

a. The frequency of most signals that are applied to the cathode-ray tube is such that the electron beam must move across the screen rapidly in order to trace them. If a single cycle of a 60-cps waveform is to be produced, the electron beam must produce the pattern in 1/60 second. Although the beam has no difficulty in moving rapidly enough, the pattern produced would be lost to the eye in so brief a time. At higher frequencies, the time required for a cycle is even shorter.

b. Several methods are used to make the pattern, which is traced in so brief a time, useful to the eye. First, a long-persistence phosphor can be used as the screen material. This method has several drawbacks. First, the writing-speed characteristics of most long-persistence phosphors are such as to require a fairly long excitation period in order to produce a large light output. Consequently, a rapidly moving beam of electrons cannot produce a sufficiently bright pattern. Second, if the pattern changes, the long persistence will produce a serious smear on the screen.

c. A more satisfactory method is to cause the cathode-ray tube to redraw the same pattern rapidly. If a single cycle is retraced on the screen in such a way that the pattern always occupies the same position, the eye sees a stationary image. This is true whether the frequencies involved are 60 cycles per second or several million cycles per second. The persistence of human vision is such that when more than about 16 complete patterns are produced in a second, the moving spot can no longer be seen.

d. It already has been pointed out that if a single cycle of signal is to be observed, the sweep frequency must be equal to the signal frequency. Also, if more than 1 cycle is to be viewed, the sweep frequency must be an exact submultiple of the signal frequency. If the exact frequency relationships are not maintained, a different portion of the signal is traced during each sweep. The pattern is then not stationary but moves across the screen. When the sweep frequency is only slightly incorrect, the motion of the pattern is slow enough to see. However, if the sweep frequency is considerably in error, the motion of the pattern is so rapid that a meaningless blur appears.

e. Assume that a 60-cps test signal is applied to the vertical plates of a cathode-ray tube. In order to see a stationary pattern on the screen consisting of 1 cycle, a 60-cps sawtooth sweep voltage is applied to the horizontal-deflection plates. If the sweep generator is unstable, its frequency changes. Assume that the drift is such as to increase the sweep frequency slightly. The time required to complete 1 sweep cycle is now slightly less than the time required to complete 1 signal cycle. The effect on the pattern is seen in figure 93.

f. In the first sweep, slightly less than 1 complete signal cycle is traced on the screen (A of fig. 93). After a rapid retrace, the second sweep begins when the signal is still below the reference line. The second sweep ends still earlier in the signal cycle and the pattern in B is produced. The third sweep begins when the signal is still more negative and terminates at the negative peak. This produces the pattern shown in C of figure 93. By the time the fourth sweep starts, its phase has

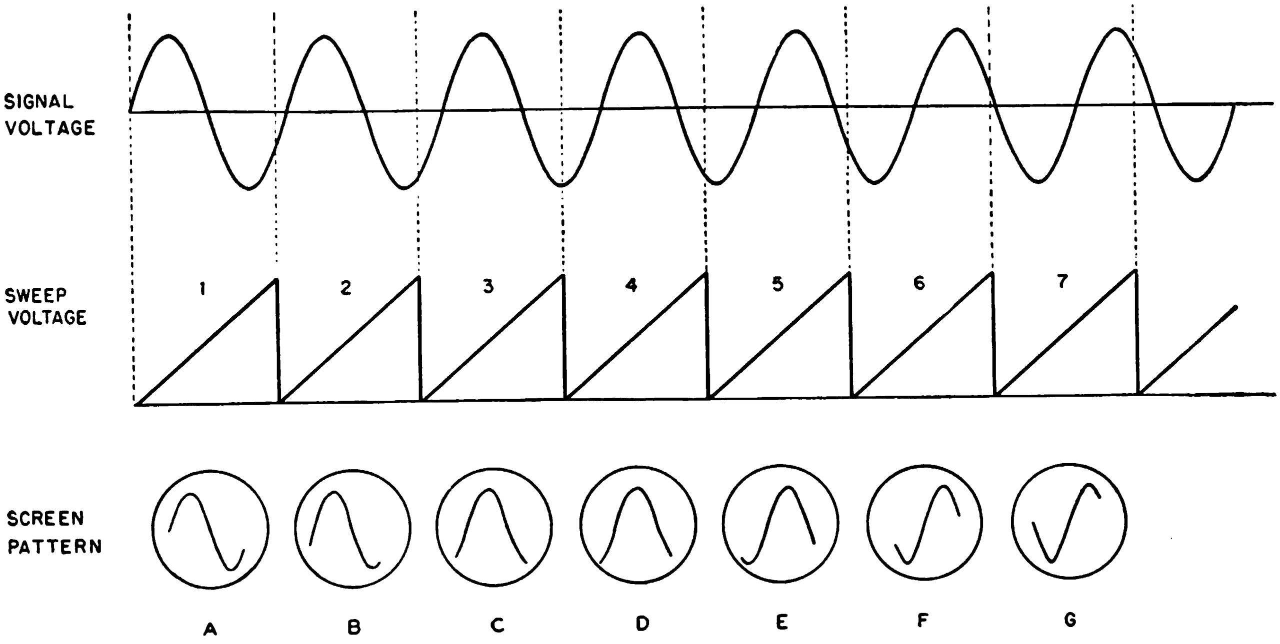

Figure 93. Drifting of pattern from left to right on cathode-ray tube screen when sweep frequency is slightly higher than signal frequency.

been shifted 90° with respect to the signal. The pattern on the screen, shown in D begins at the most negative portion of the signal. The screen patterns in A through G are traced in rapid succession. The result is that the pattern appears to drift across the screen from left to right. It can also be shown graphically that a drift of sweep frequency in the opposite direction will cause the pattern to move across the screen from right to left.

g. A photographic record which shows the effect of sweep generator drift is shown in figure 94. The sweep frequency was adjusted initially to one-third the signal frequency. After a short period of time the sweep generator began to drift and the pattern started to move. A series of 1-second time exposures was taken to show the amount of pattern motion as the sawtooth generator drifted farther from the correct operating frequency.

h. In order to prevent the sweep-generator frequency from changing with respect to the signal frequency, a *synchronizing* signal is used. The synchronizing signal is a control voltage which is injected into the relaxation oscillator circuit in such a way as to stabilize the frequency of operation. The process is referred to as *synchronization* and the synchronizing signal voltage often is called simply the *sync* signal. The result of synchronization is to cause the frequency of the relaxation oscillator to *lock-in* with the frequency of the sync signal or its harmonic. Synchronization maintains the pattern in a stationary position by preventing the sweep generator from drifting. In addition, if the signal frequency changes slightly, synchronization will alter the sweep frequency so that a stationary pattern is maintained.

45. Sources of Sync Signal

a. The most common signal, which is used for synchronization, is the signal to be observed. Usual practice is to apply some of this signal to the sweep generator in such a way that synchronization results. In this way, the sweep frequency is synchronized with the incoming signal frequency. In some oscilloscopes, this is referred to as *internal synchronization.* The sync voltage is obtained from the vertical-deflection amplifier.

b. Occasionally, it is desired to operate the sweep generator at the frequency of the power line or a submultiple thereof. A low amplitude voltage from the power line is then used as the sync

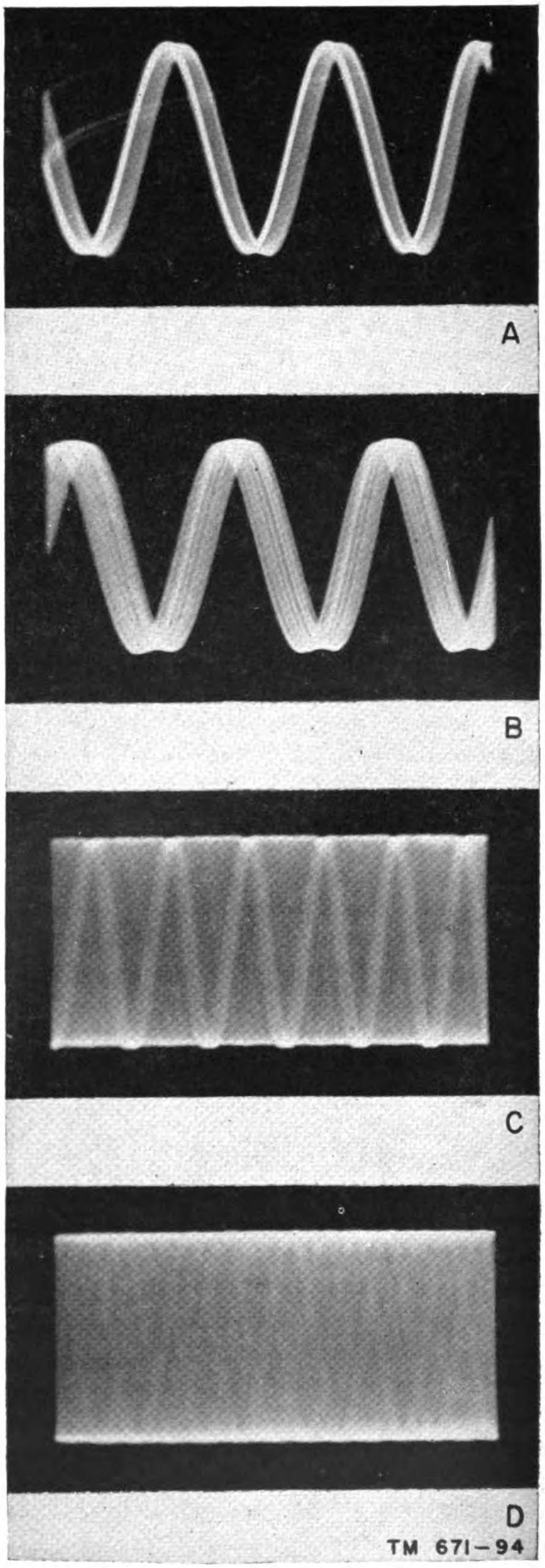

Figure 94. Effect of sweep generator drift.

signal. When this is done, the sawtooth generator frequency is accurately locked-in with that of the power source. This type of synchronization, sometimes called *line sync* is useful when signals to be observed recur at the frequency of the power source or its harmonic.

c. When the nature of the signal to be observed is such that it will not synchronize the sweep generator properly, some external source of sync signal must be used. Also, it sometimes is required that the sweep generator be synchronized with some remotely located oscillator or other device. For example, in a television display, it is necessary that the sweep generators used in the receiver operate at exactly the same frequency as is used in the original scanning process. To accomplish this, synchronizing signals sent out by the transmitter are used to control the operating frequency of the sweep circuits in the receiver.

46. Synchronization of Gas-Tube Sweep Generator

a. NEON-TUBE SYNCHRONIZATION. A neon-tube relaxation oscillator can be synchronized by applying a large amplitude voltage in series with the tube. The frequency of this synchronizing voltage must be slightly higher than the natural operating frequency of the oscillator. This sync voltage alternately raises and lowers the potential applied to the neon tube. The tube is made to conduct at the peak of the sync signal, just a little before the tube would have conducted without the sync signal. This circuit is rarely used, however, because of the advantages of the thyratron circuit.

b. THYRATRON-TUBE SYNCHRONIZATION.

(1) The thyratron relaxation oscillator can be synchronized readily. First, the oscillator is adjusted near to or slightly lower than the desired operating frequency. Then, a sync signal is applied to the control grid of the thyratron. It has been shown that when the grid bias is made less negative, the ionization potential is reduced, and when the grid bias is made more negative, the ionization potential is increased. The sync signal, therefore, raises or lowers the voltage at which the tube ionizes.

(2) The sync signal is applied through a conventional R-C coupling circuit to the grid of the thyratron (A of fig. 95). The resistor is made variable in order to permit a variation in the amplitude of the sync signal. Certain types of sweep circuits require a specific polarity of sync signal for proper operation. The circuit shown in A does not allow a reversal of polarity to be made in case the sync signal polarity is incorrect. Some oscilloscopes use the circuit shown in B for this purpose. The circuit is a single-tube paraphase amplifier in which a center-tapped potentiometer is used. An inverted sync signal appears across R1 while a noninverted sync signal appears across R2. As the potentiometer arm is moved away from its midposition the amplitude of the sync signal which is applied to the thyratron grid is increased. Opposite-polarity sync signals are obtained from opposite sides of the grounded center tap. In this way, the polarity of the sync signal may or may not be reversed and its amplitude can be varied by means of a single control.

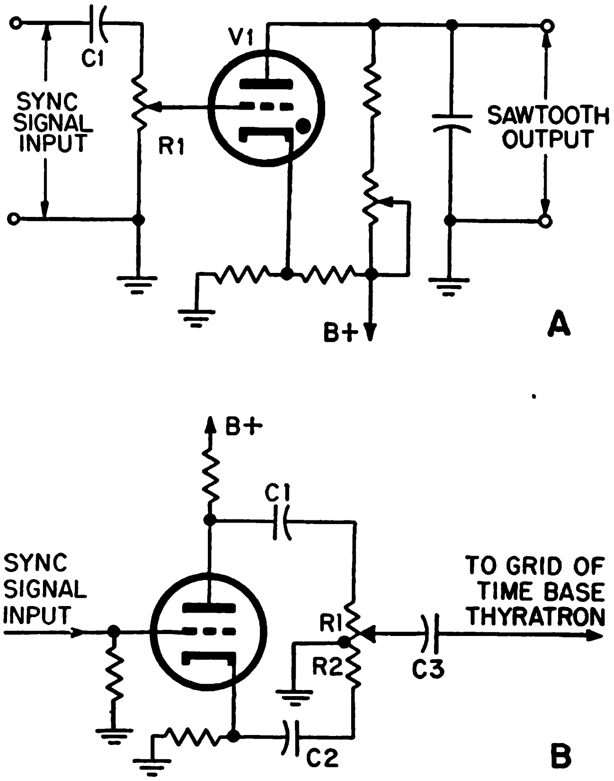

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Figure 95. Circuits used for application of sync signals to grid of thyratron sawtooth generator.

(3) Before the sync signal is applied, the capacitor across the thyratron charges up normally until the ionization potential is reached. The capacitor then discharges rapidly through the tube and the normal free-running sawtooth sweep is generated. However, when a sync signal, such as a simple sine wave, is applied to the grid of the thyratron, the operation of the circuit is changed. The ionization potential of the tube is alternately lowered and raised in accordance with the variation of sync signal. Assume that the sweep generator is operating at a slightly lower frequency than the sync signal. The operation of the circuit is seen in figure 96.

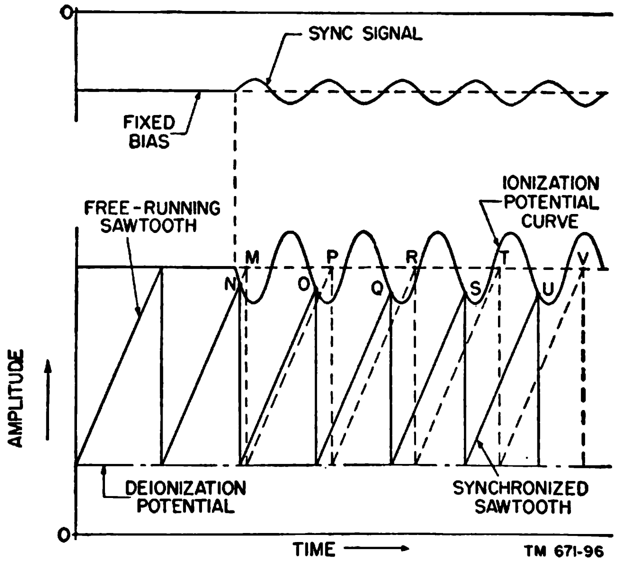

Figure 96. Graphical analysis of sychronization of a thyratron sawtooth generator by means of a sinusoidal sync signal.

(4) When the sync signal is applied, the capacitor voltage does not build up to point M, but instead the charge is interrupted at point N. The ionization potential is reduced during the first positive alternation of sync signal. The second sawtooth ends a short period of time before it normally would have ended without synchronization. The capacitor discharges rapidly, and the third sweep begins. The sweep normally would terminate at point P if the oscillator were allowed to free-run. However, because the ionization potential is again reduced, the tube conducts at point O. Succeeding sawtooth cycles are terminated at points Q, S, and U rather than at points R, T, and V.

(5) Synchronization does not occur instantly. In figure 96, it can be seen that a few cycles must elapse until proper lock-in occurs. Each one of the first four sawtooth waveforms shown has a slightly different frequency. The length of each sawtooth cycle is reduced slightly compared to the previous cycle. A gradual increase in frequency occurs during these first four cycles of operation. Point O represents a greater reduction in the free-running ionization potential than does point N. This same point O represents a smaller reduction than does point Q. While these first few cycles are being produced, the frequency of the sawtooth waveform is increasing gradually toward the frequency of the synchronizing signal. Once the fourth sawtooth cycle has occurred, however, all succeeding cycles end at identical points on the ionization potential curve. The frequency of the sawtooth voltage is exactly the same as the frequency of the sine-wave sync signal. When this occurs, the sawtooth voltage is said to be *locked-in* with the applied sync signal and synchronization is complete.

(6) Synchronization can also occur when the sync signal frequency is an exact harmonic of the required sawtooth frequency. Figure 97 shows the effect of applying a sync signal whose frequency is twice the required sawtooth frequency. Before the sync signal is applied, the sawtooth generator is adjusted to produce a frequency that is slightly lower than one-half the frequency of the sync signal. In other words, the frequency of the sync signal is slightly higher than twice the free-running sawtooth frequency. After a few cycles of adjustment, the sawtooth signal is locked-in at a frequency which is exactly one-half the sync signal frequency. The figure shows that synchronization has occurred on every second cycle of the sync signal.

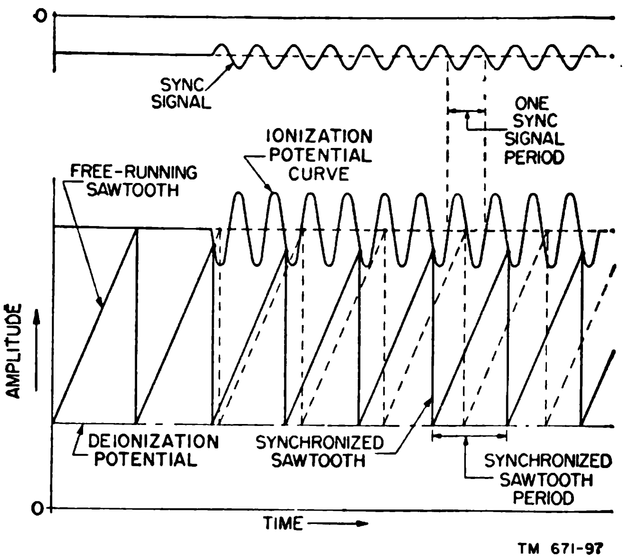

Figure 97. Synchronization of a thyratron sawtooth generator by means of a sync signal whose frequency is the second harmonic of the desired sawtooth frequency.

(7) If the frequency of the sync signal were three or four times the sawtooth frequency then synchronization would occur on every third or fourth cycle. Consequently, synchronization can occur at the fundamental or subharmonic frequency of the sync signal. In general, however, as the order of the subharmonic of the sync signal increases, synchronization becomes more difficult. Sine-wave synchronization generally is not used when the sync frequency is more than three or four times the sawtooth frequency required. When greater frequency division of the sync signal must be used, peaked sync waveforms are more satisfactory. Counting circuits are also used. Almost any waveform can be used for synchronization if the ionization voltage of the gas-tube relaxation oscillator can be modified in accordance with that waveform to produce a frequency modification.

c. Effect of Incorrect Sync Signal Amplitude.

(1) Some means usually is provided to vary the amplitude of the sync signal that is applied to the gas-tube relaxation oscillator. This usually takes the form of a potentiometer as shown in A of figure 95. As the potentiometer arm is moved toward ground, the amplitude of the sync signal is reduced. When the arm is moved in the opposite direction, the amplitude of the sync signal is increased. If the amplitude of the incoming sync signal were fixed, a fixed adjustment could be used to obtain the correct amplitude of sync signal. Because of the wide range of amplitudes of sync signals, a variable adjustment is required so that the correct amplitude of sync signal is applied to the oscillator.

(2) The correct amplitude of sync signal is that amount which properly synchronizes the relaxation oscillator without causing oversynchronization. If the amplitude of the sync signal is too low, the resultant variation in ionization potential will not be sufficient to lock-in the pattern on the screen. This low amplitude of sync signal can cause proper synchronization for a short time but the sweep frequency will soon pull away from the sync frequency. The pattern on the screen of an oscilloscope will remain stationary for a short time. Then the pattern will begin to move across the screen. Following this the pattern will again stop for a short time. This stop-and-go motion indicates that an insufficient amplitude of sync signal is being applied at the particular sweep frequency used. A slight increase in the amplitude of sync signal will result in the desired stationary pattern. However, if the amplitude is increased still further, the harmful effects of *oversynchronization* may occur.

(3) Oversynchronization often results in severe pattern distortion, erratic pattern jumping, superimposition of one pattern over another, or excessive change in sweep generator frequency. A of figure 98 shows an analysis of oversynchronization. With the proper amplitude of sync signal applied, the ionization voltage rises and falls normally as indicated by waveform A. The correctly synchronized sawtooth voltage is shown at B. Assume that the amplitude of the sync signal is increased several times. A large variation in ionization voltage is produced which causes this voltage to swing downward almost to the value of the low deionization poten-

tial. The upward swing of ionization voltage on the opposite alternation of sync signal carries it to practically twice its normal value without synchronization. The waveform at C shows the large variation in ionization potential. This wide swing of ionization voltage causes the sawtooth voltage to be produced as follows. The second sawtooth cycle shown normally rises to S, then begins the retrace. However, because of the increased sync signal amplitude, the thyratron conducts at T instead. The sawtooth voltage falls normally to U and third sweep begins. The rise in voltage continues for only a short time because of the great reduction in ionization voltage during this alternation. The sawtooth rise is terminated at V, and the retrace begins. A low-amplitude, high-frequency sweep voltage is generated.

(4) The next sweep cycle, D, rises to X; then the retrace occurs. The following sweep cycle is another low-amplitude, high-frequency voltage whose rise terminates at Z. Consequently, the sweep generator oscillates alternately in two conditions. Every second sweep cycle is large in amplitude and low in frequency, while the alternate sweep cycles are low in amplitude and high in frequency. Under these conditions, an unsatisfactory pattern will be produced on the screen.

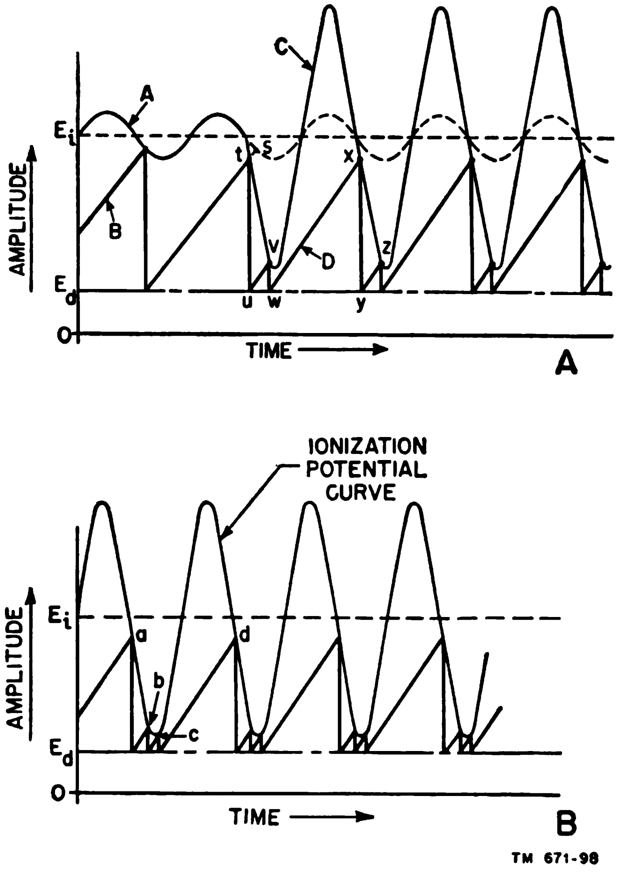

Figure 98. Graphical analysis of oversynchronization.

(5) B of figure 98 shows another possible effect of oversynchronization. The frequencies involved here are somewhat different than those shown in A. Here, three different sweep frequencies of widely differing amplitudes are produced. The first cycle rises to point a, where ionization occurs. The second cycle rises to point b, while the third cycle can rise only to point c before the retrace begins. If the sync signal amplitude were increased further the thyratron would continue to conduct for a longer period of time. Under these conditions, the capacitor charge could not occur and a time interval between sweeps would result.

(6) The effect of gradually increasing the amplitude of the sync signal can be seen in the series of oscillograms shown in figure 99. In A the sync signal amplitude has been increased so that a small amount of oversynchronization occurs. Alternate sweep cycles are seen to have a lower amplitude and a higher frequency. As a result there will be superimposed on the desired 3-cycle pattern a 2-cycle pattern whose width is less than that of the desired pattern.

(7) B shows the effect of a further increase in the amplitude of the sync signal. The effect of further increasing the sync signal causes the sweep generator to jump frequency completely so that the screen pattern has only 2 complete cycles. Also, the amplitude of the sweep voltage is reduced so that the pattern width is decreased. Again, a sweep voltage is produced having two different frequencies and amplitudes. In C the sync amplitude is increased to a point where the sweep frequency again jumps. Here the ampli-

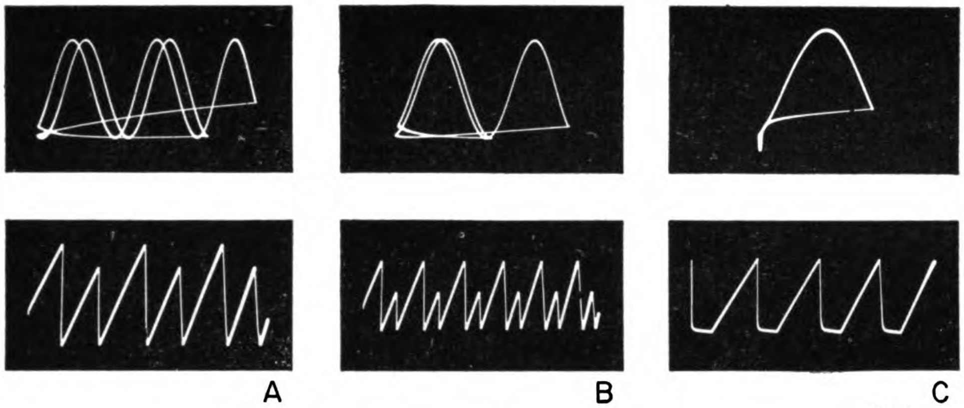

Figure 99. Effect of increasing sync signal amplitude.

tude is so great that a time interval occurs between sweeps. Under these conditions, the spot of light remains at the left of the screen for part of 1 cycle. Some vertical deflection occurs but no horizontal deflection can take place until the sweep voltage begins its rise.

(8) To prevent the harmful effects of oversynchronization, the free-running frequency of the sweep generator should be very near the desired operating frequency. The amount of sync signal should then be increased until the pattern is stationary. Any further increase in the amount of sync signal should be avoided because oversynchronization will result.

47. Synchronization of Vacuum-Tube Sweep Generator

a. General. Both the free-running multivibrator and the blocking oscillator can be synchronized. In general, the manner in which synchronization occurs is the same as with the gas-tube oscillator. A synchronizing signal is applied to the grid of the electron-tube oscillator. This sync signal causes the oscillator frequency to be stabilized with that of the sync signal rather than to continue to free-run. Synchronization usually operates by raising the grid voltage of the blocking oscillator momentarily, or of one section of multivibrator. This causes that tube or section to be driven above cut-off somewhat earlier than normal. The result is that the frequency is raised slightly and is closely locked-in with the frequency of the sync signal or its submultiple.

b. Multivibrator Synchronization.

(1) The normal grid-voltage waveform of most free-running multivibrators is a negative peaked wave with an exponential rise toward ground. The exponential voltage rise is the result of an R-C discharge. When this voltage is no longer sufficiently negative to cut off the tube to which it is applied, conduction occurs. As stated previously, for each cycle of square-wave output, 1 cycle of sweep voltage is produced. If one section of the multivibrator circuit is made to conduct in accordance with a sync signal rather than the normal exponential voltage rise, a change in frequency will result.

(2) Figure 100 shows the grid voltage of a multivibrator. From time marked A to C, 1 cycle of free-running oscillation is generated. At time C a higher frequency sine-wave signal is inserted in series with the grid voltage. This sine wave will be used as the sync signal. It alternately raises and lowers the value of the grid voltage. The average value of the grid voltage is the same as it was prior to the application of the sync signal. The sync signal is now superimposed on the normal R-C voltage. The first 2 cycles of sync voltage have no effect on the operation of the circuit. At the positive peak of the third sync cycle, the grid voltage is raised above cut-off and the associated tube conducts. Consequently, one alteration of the square wave ends at D rather than at E.

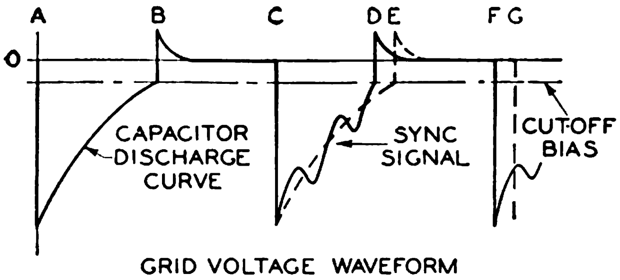

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Figure 100. Grid voltage of multivibrator showing the effect of sine-wave sync signal

(3) Although the sync signal still is applied from D to F, it has no effect. The reason for this is: Grid limiting is caused, since grid current flows; this flattens the positive alternations of the sync signal. The negative alternations do not have sufficient magnitude to cut off the conducting tube. Consequently the time from D to F will be the same as from B to C. The effect of the sync signal has been to raise the frequency of the multivibrator and cause it to lock-in at some submultiple of the sync signal. Synchronization can also occur when the sync frequency is equal to the multivibrator frequency rather than several times higher, as was illustrated.

(4) By far the most common sync signal for multivibrators is a sharply peaked wave. When the free-running frequency of the multivibrator is slightly lower than the frequency of the sync signal, the multivibrator will be synchronized at the exact frequency of the sync signal. The grid-voltage waveform and the sync signal are illustrated in A of figure 101. The first sync pulse occurs at some random phase with respect to the grid waveform. The first 2 cycles of multivibrator operation are free-running from A to C. This is true because the first three sync pulses do not happen to fall at a point on the grid-voltage waveform where they can produce any effect.

(5) The first sync pulse occurs when the grid voltage is negative; however, the amplitude of the pulse is not sufficient to drive the tube into conduction. Both the second and third sync pulses occur when the grid voltage is above cut-off. They can have no effect on the tube, which is already conducting at saturation. The fourth sync pulse occurs just before the cut-off bias is reached. The pulse momentarily raises the grid voltage above cut-off. This starts the regenerative switching action that ends an alternation of square-wave output at D. Every succeeding sync pulse occurs at the correct time in the cycle to terminate 1 square-wave cycle and begin the next. In this way, the frequency of the multivibrator as well as the sweep frequency controlled by the multivibrator operation is synchronized to the same frequency as that of the sync pulses.

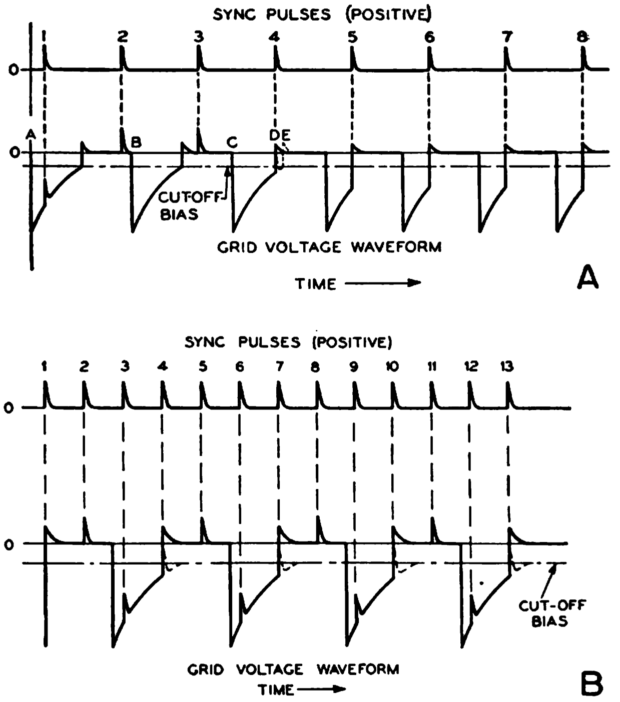

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Figure 101. Multivibrator synchronization by means of sharply peaked pulses.

(6) B of figure 101 shows the operation of the circuit when it is synchronized at a frequency which is one-third the sync signal frequency. In this case the sync pulses numbered 1, 4, 7, 10, and 13 are responsible for proper synchronization.

(7) Free-running blocking oscillators which are used in sweep-generating circuits can be synchronized in the same manner. The R-C discharge curve with only a slight modification is found also as the

grid-voltage waveform of the blocking oscillator. If a series of sync pulses is introduced in the grid circuit of the oscillator, it can drive the tube into conduction. The single oscillation is then repeated, not at some free-running frequency but at the frequency of the sync signal or its submultiple.

Section IV. LINEARIZATION

48. Need for Linearization

a. A linear timebase is required in order that equal amounts of deflection can represent equal intervals of time. By the amount that the sweep departs from true linearity it fails to show accurate graphs of voltage or current versus time. In some radar applications, a linear sweep is required to measure the range of a target. If the sweep is not linear it is difficult to estimate the exact range of a target. In television displays, the effects of a nonlinear sweep are obvious immediately. The resultant pattern is squeezed together if the sweep speed is reduced. If the sweep speed is increased, a stretched out pattern results.

b. Most sweeps are produced by a charge or discharge of a capacitor through a resistor. Since the rate of current flow is not truly linear but is exponential, it is not possible to obtain true linearity from such a simple circuit. If only the beginning of the exponential charge is used and if only a very small portion of the charging curve is used for the sweep, the amount of nonlinearity can be unimportant. However, when more accurate linearity is required, special methods and circuits must be used to improve the sweep linearity. The use of these methods and circuits is known as *linearization.*

c. Linearization of the sweep is not used in ordinary general-purpose oscilloscopes. However, special-purpose oscilloscopes, radar and television sets generally use some type of linearization in order to improve the display. Occasionally, more than one means of linearization is used when necessary.

49. Methods of Linearization

a. CONSTANT-CURRENT PENTODE.

(1) When using the constant-current pentode method of linearization, the resistor through which the sweep capacitor charges is removed. A pentode electron tube is substituted for the resistor. The screen-grid voltage of a pentode can be chosen so that the plate current remains constant over a wide range of plate voltage. If the charging current which flows into the capacitor is made constant, the charge accumulates at a linear rate. The resultant capacitor voltage rise is, consequently, made linear.

(2) A thyraton sawtooth generator which uses a constant-current pentode is shown in figure 102. When the plate voltage is applied to this circuit, the capacitor C charges up through the pentode, V2. The voltage across the capacitor rises as the charge accumulates. Since the plate current of V2 remains fairly uniform, the voltage across the capacitor increases at a linear rate. Discharge of the capacitor occurs when the ionization voltage of the thyratron is reached. The coarse frequency control consists of several capacitors which are switched in across the thyratron. The fine frequency control is a bias adjustment on the grid of the pentode. A variation of bias alters the plate resistance of the tube which determines the amount of charging current that flows into C. The effect on frequency is the same as though the resistance of a series resistor were varied to change the frequency.

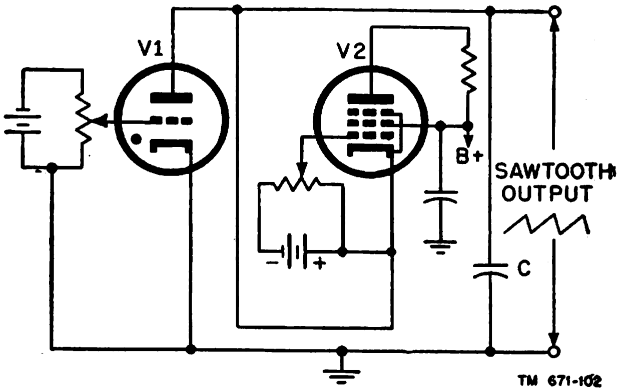


Figure 102. A thyraton relaxation oscillator using a constant-current pentode for linearization.

(3) Another circuit using the constant-current pentode with a pulse-operated triode, V1, is shown in figure 103. In this circuit, a series of rectangular pulses is applied to the grid of V1. Plate current flows through this tube in a series of short pulses. V1 is cut off for a much longer period of time than it is allowed to conduct. The sweep capacitor C is in the cathode circuit of the triode while the constant-current pentode is shunted across the capacitor.

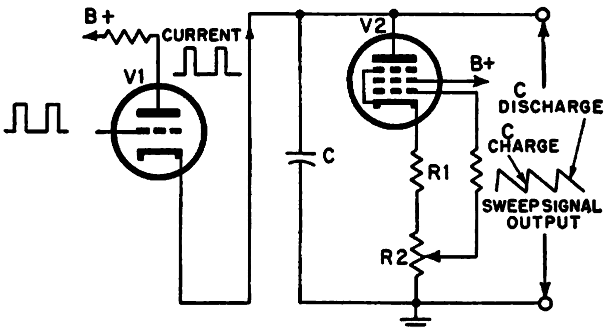


Figure 103. A pentode in conjunction with a triode which is actuated by a pulse.

(4) During the brief intervals when V1 conducts, the capacitor *charges* through the triode. The current through the pentode is negligible because of its high internal resistance. Because the plate resistance of the triode is low, the time constant of the charging circuit is short. Consequently, the capacitor charges rapidly. This produces a rapid rise of capacitor voltage. When the pulse which had caused V1 to conduct ends, the triode is cut off. The capacitor C now begins to discharge through the pentode. Because of the high plate resistance of the pentode, the time constant of the discharge circuit is long. A rather slow capacitor discharge occurs. Because of the characteristics of the pentode, the plate current which flows is uniform. Consequently, the discharge of the capacitor is a linear rather than an exponential one.

(5) Most sweep generators use a slow charge and a rapid discharge of a capacitor in order to produce a slowly rising and rapidly falling waveform. In this circuit, however, the reverse method is used. The capacitor is made to charge rapidly and discharge slowly at a linear rate through the pentode. The voltage produced rises rapidly and falls slowly. The rapid rise is used to produce the sweep retrace while the slow fall is used to produce the sweep trace. This waveform is applied to the opposite deflection plate of a cathode-ray tube. An ordinary electron-tube amplifier can be used to invert the polarity of this sweep waveform if desired.

(6) Potentiometer R2 is a means of varying the amount of cathode bias that is applied to the pentode. As the grid is made more negative with respect to the cathode, the plate resistance of the pentode is increased. This increases the time constant of the discharge circuit which lowers the sweep frequency produced.

b. Nonlinear Amplifier.

(1) A common method of improving the linearity of a sawtooth sweep is to use a nonlinear amplifier. No amplifier is perfectly linear since it introduces some distortion into the waveform which is being amplified. It is common practice in electronic circuits to introduce one nonlinearity which compensates for another circuit nonlinearity.

(2) If the transfer characteristic curve A of a tube as shown in figure 104 is examined, considerable nonlinearity is seen. This curve is a portion of the transfer characteristic of a variable-mu tube. The shape of the characteristic curve of this tube is most suitable for linearization, although sharp cut-off tubes are also used. The degree of curvature in the characteristic of a sharp cut-off type is much less than for a variable-mu type. However, if only a small amount of nonlinearity is to be corrected, ordinary sharp cut-off amplifiers are used. The operating voltages of the nonlinear amplifier are adjusted so that the curvature of the transfer characteristic of the amplifier is approximately opposite to that of the input exponential sawtooth waveform. In this way the input signal (B of fig. 104) produces a linear rise in plate current; the output signal C is used to produce a linear sweep.

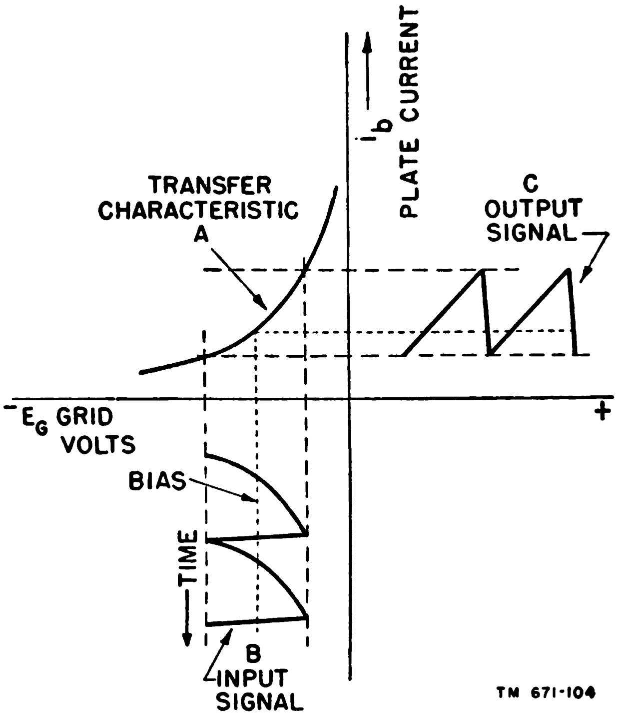


Figure 104. Analysis of linearization of sawtooth sweep by means of a nonlinear amplifier

(3) A typical circuit is shown in figure 105. Here V1 is a discharge tube which is actuated by a pulse. When V1 is cut off, the capacitor C1 charges up exponentially through R1. When V2 is made to conduct it discharges C1 rapidly. The exponential sawtooth waveform is applied to the grid of V2 through the coupling circuit C2R2. V2 operates as a nonlinear amplifier whose plate load is R4. Potentiometer R3 allows the bias on the amplifier to be adjusted so that operation can occur on the most satisfactory portion of the characteristic curve. When the adjustment of bias is correct, a linear sawtooth sweep voltage is obtained at the output of V2.

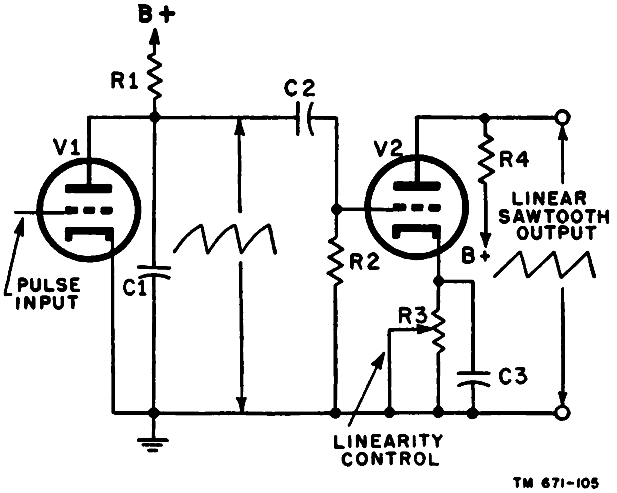


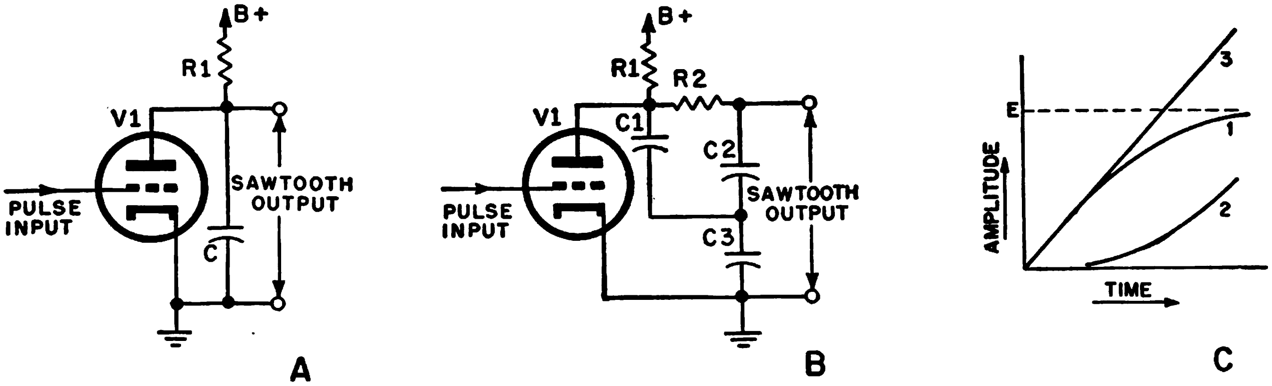
Figure 105. A typical sweep circuit which uses a nonlinear amplifier to produce a linear sweep.

c. ADDITIONAL TIME CONSTANT.

(1) Another method of improving the linearity of the sawtooth sweep is to insert an additional R-C circuit at the output of a conventional sweep circuit. If the capacitor in this additional circuit is made to discharge for part of the time that the main sweep capacitor is charging normally, the output voltage waveform will be altered. The usual sweep voltage is a convex voltage as it bulges upward away from the reference line. The discharge of the additional capacitor is a concave voltage as it bulges downward toward the reference line. These two waveforms are added together to produce the sweep. If these voltages have the proper amplitude and curvature, a linear sawtooth sweep voltage is generated.

(2) A sweep circuit which incorporates this principle is shown in B of figure 106. For comparison the conventional circuit is shown in A of figure 106. In the conventional circuit, C charges through R1 from the power supply while V1 is cut off. This produces the exponential rise in voltage. The electron tube is then made to conduct briefly, during which time the capacitor discharges quickly through the tube. In B of figure 106, capacitors C1 and C3 take the place of capacitor C. An additional time-constant circuit made up of R2C2 is added in parallel with C1. The capacitors C1 and C2 usually are about the same values. Resistor R2 is made fairly large, approximately .5 meg (megohm). The sawtooth output voltage is the sum of the voltages across C2 and C3.

(3) Assume that all capacitors are fully charged by the power supply. Both C1 and C3 charge through R1; C2 charges through R1 and R2. When V1 starts



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A, Simple sweep generator; B, Modified sweep generator which uses an additional R-C circuit to improve linearity; C, Idealized make-up of linear output voltage.

Figure 106.

conducting, all capacitors begin to discharge through the tube. Capacitors C1 and C3 discharge rapidly since the low plate resistance of the tube is directly in parallel with this series combination. However, C2 discharges slowly because of the large resistance R2 through which its discharge current flows. As a result, when V1 is again cut off, both C1 and C3 have lost practically their entire charge. C2, however, has lost only a small part of its charge.

(4) With V1 cut off, C1 and C3 begin to recharge. At first, when the voltage across C2 is still larger than the voltage across C1, C2 continues to discharge through R2 and into C1. Consequently, at the beginning of the sweep, C1 and C3 are being charged by the power supply, C1 is also being charged by C2, and C2 is discharging. In due time, the voltage across C1 rises and the voltage across C2 falls. When the voltage across C1 exceeds the voltage across C2, then C2 begins to charge. This occurs considerably later in the sweep cycle.

(5) The sawtooth output voltage is taken across C2 and C3. The voltage across C3 is the usual nonlinear sawtooth sweep. However, the voltage across C2 is considerably different. At the beginning of the sweep, C2 discharges. This reduces the rate of sweep rise. Near the ending of the sweep when the charging current which flows into C3 tapers off to produce a flattened sawtooth, C2 charges. This rise of voltage increases the rate of sweep rise. The voltage across C2 takes the form of an approximate semicircle or parabola which is concave upward. If the time constants of the circuits chosen are correct, the sum of the voltages across C2 and C3 is a linear sawtooth.

(6) C of figure 106 shows the waveforms required for proper linearization. Curve 1 is the conventional exponential voltage rise toward the maximum charging voltage E; this is the waveform produced by C3. Curve 2 is the required compensating voltage which must be added to curve 1 to produce true linearity. Curve 2 is the approximate waveform produced by C2. When curves 1 and 2 are added, the resultant is curve 3.

(7) Several modifications of the method described above are used for sweep linearization. In A of figure 107, the operation of the circuit is as follows: Assume that both C1 and C2 are fully charged. When V1 is made to conduct, both capacitors begin to discharge. Capacitor C1 discharges rapidly through the low plate resistance of the triode. Capacitor C2 discharges slowly through R1 and the tube. By the time the tube is driven beyond cut-off, capacitor C1 has lost most of its charge. C2, however, has lost only a small amount of its charge. When the tube is cut off, capacitor C1 begins to charge through resistors R1 and R2. Because of the large amount of charge still on C2, this capacitor continues to dis-

charge into C1. After a short time, the voltage across C2 drops below that of C1. Then capacitor C2 begins to charge from the power supply.

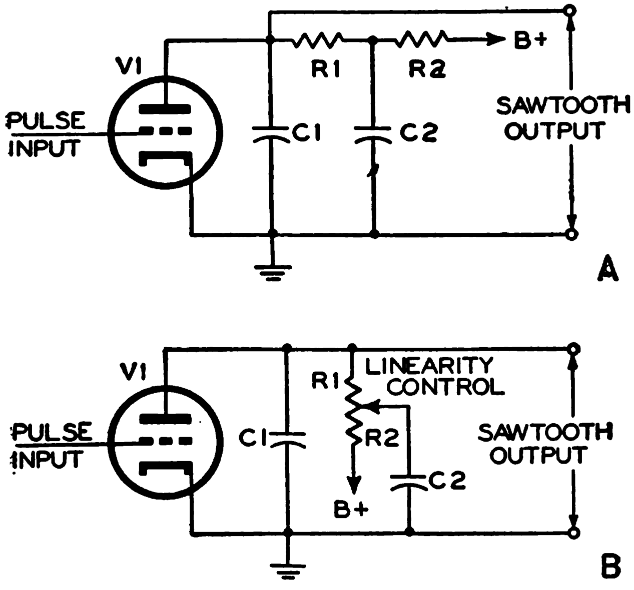

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Figure 107. Typical circuits which use additional R-C circuits for improved linearity.

(8) The sweep voltage is obtained only across C1. This capacitor is charged not only by the power supply but also by means of the discharge of capacitor C2. The voltage of charge from the power supply is the usual convex exponential rise. The charge voltage from capacitor C2 is a concave waveform. The total voltage across C1 is the result of these two waveforms. When the time constants of the circuits are chosen properly, the resultant is a linear rise.

(9) Frequently, a potentiometer is used in place of fixed resistors R1 and R2 (B of fig. 107). The potentiometer provides a means of changing the time constants of both R-C circuits so that the most linear waveform is produced. The potentiometer is called the linearity control.

d. FEEDBACK NETWORK.

(1) Still another method of improving the linearity of a sawtooth sweep voltage is to use a feedback network. Many feedback circuits are used but one of the most popular is the *bootstrap* sweep circuit. The sweep voltage within the circuit appears to raise itself by its own bootstraps.

(2) A simplified schematic diagram of the bootstrap sweep circuit is shown in figure 108. The electron tube V1 is the discharge tube for capacitor C1. This capacitor charges from the power supply through resistors R1 and R2. The sawtooth voltage across C1 is coupled directly to the grid of the cathode-follower V2. The output of the cathode-follower is the voltage across R_k. This is where the sawtooth sweep voltage is obtained. The cathode-follower is operated with a gain very close to unity. Therefore, almost the same amplitude of sawtooth voltage which is applied to the grid of V2 appears at the cathode.

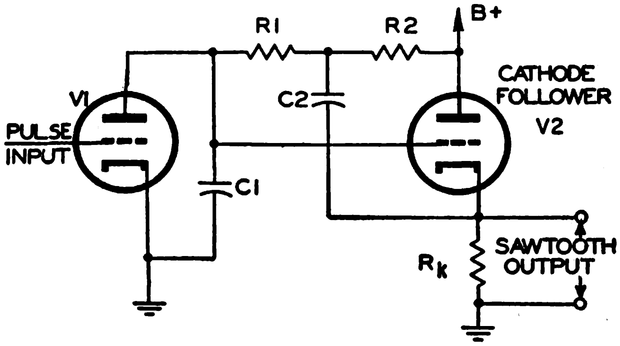

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Figure 108. Bootstrap sweep circuit in which feedback is used to improve linearity.

(3) The sawtooth output voltage is coupled back to the junction of R1 and R2 through capacitor C2. Since this capacitor is large, the potential across it remains fairly constant as the sawtooth voltage increases in amplitude. Therefore, the sawtooth voltage is fed back to the junction of R1 and R2 with a minimum amount of loss. As capacitor C1 charges, the voltage at the end of R1 connected to C1 rises. The feedback sawtooth voltage, which is applied to the other end of R1, also rises by almost the same amount. If the voltages applied to both ends of R1 increase by the same amount, the difference of potential across the resistor remains constant. As a re-

sult, the current through R1, which is the charging current for C1, remains constant. Consequently, the accumulation of charge by C1 is linear and a linear sweep is generated.

(4) By taking the sawtooth output voltage across the cathode resistor R_k instead of across C1, the cathode-follower can act as a buffer and as an impedance matching stage to the following circuit.

Section V. SINUSOIDAL AND CIRCULAR SWEEPS

50. Sine-Wave Sweeps

a. Method of Obtaining. A sine-wave sweep is obtained by applying a simple sine wave to the horizontal-deflection plates of a cathode-ray tube. The electron beam is swept alternately across the screen in one direction and then in the opposite direction. The speed at which the spot moves varies at a sinusoidal rate. The same amount of time is required for retrace as is required for the trace. This sweep voltage can be obtained from any sine-wave oscillator. Frequently, the power-line is used as the source of the sine-wave sweep. A connection usually is made to one of the low-voltage secondary windings of a power transformer within the oscilloscope. This voltage is amplified by the horizontal-deflection amplifier, and is then applied to the horizontal-deflection plates.

b. Characteristics. When a sine-wave sweep is used, the speed of the spot varies continuously. The rate of change of a sine wave is greatest when the voltage passes through zero. At the extreme positive or negative peak of the waveform, the rate of change is the least. Therefore, the spot travels most rapidly in the center of the screen. At each end of the sweep, the spot speed is the lowest. Since the retrace is produced in exactly the same speed and duration, a reversed waveform can be traced during the flyback of the beam.

c. Uses.

(1) If the amplitude of the sine-wave sweep is increased so that only a small part of sweep voltage occupies the entire screen, some degree of linearity is achieved. This is sometimes done when there is not enough space in a piece of equipment to permit a sweep-generator circuit to be built. The sine wave can be obtained from any convenient power transformer. Certain special types of simple indicators showing pulse phenomena that occur once a cycle use the sine-wave sweep.

(2) An important use of a sine-wave sweep is for an oscilloscope that is used to trace a frequency-response curve. A frequency-modulated signal generator must also be used. Most such signal generators use sine-wave modulation of the frequency-modulated signal. The sweep frequency must be a sine wave of the same frequency used as the modulating signal. With this system, a response curve is traced out as the frequency rises and the spot moves from left to right. An identical response curve is traced over the first as the frequency falls and the spot moves from right to left. This process will be described in detail in chapter 7.

51. Circular Sweeps and Radial Deflection

a. General. A sweep which traces a circle centered at the screen center is used in some special displays. Such a sweep can display more information than can be displayed on a simple linear trace which cannot occupy a distance greater than the screen diameter. As the sweep ends at the same point on the screen where it begins, no retrace appears. Many circular sweeps are produced by precision sine waves which permit these sweeps to be used for accurate time measurement.

b. Basic Lissajous Circular Pattern.

(1) The most common method of producing a circular or elliptical trace on the screen of a cathode-ray tube is by the use of two pure sine waves having the same frequency. These waves must be equal in amplitude of deflection but 90° out of phase. When one sine wave is applied to the vertical-deflection plates and the other is applied to the horizontal-deflection plates, a circular trace is produced. If the amplitudes are not the same, an elliptical trace occurs.

(2) The generation of a circular sweep is shown in figure 109. Assume that the

sine wave shown at A is applied to the upper vertical-deflection plate and that the lower vertical-deflection plate is grounded. This waveform begins at the reference line and increases to its maximum positive value in the first 90°. A second sine wave, shown at B, is applied to the left-hand horizontal-deflection plate, while the right-hand horizontal-deflection plate is grounded. This waveform begins at its most positive value and decreases to the reference line in the first 90°. Consequently, the sine wave at B leads the sine wave at A by 90°. The amplitude and frequency of these two waveforms are the same.

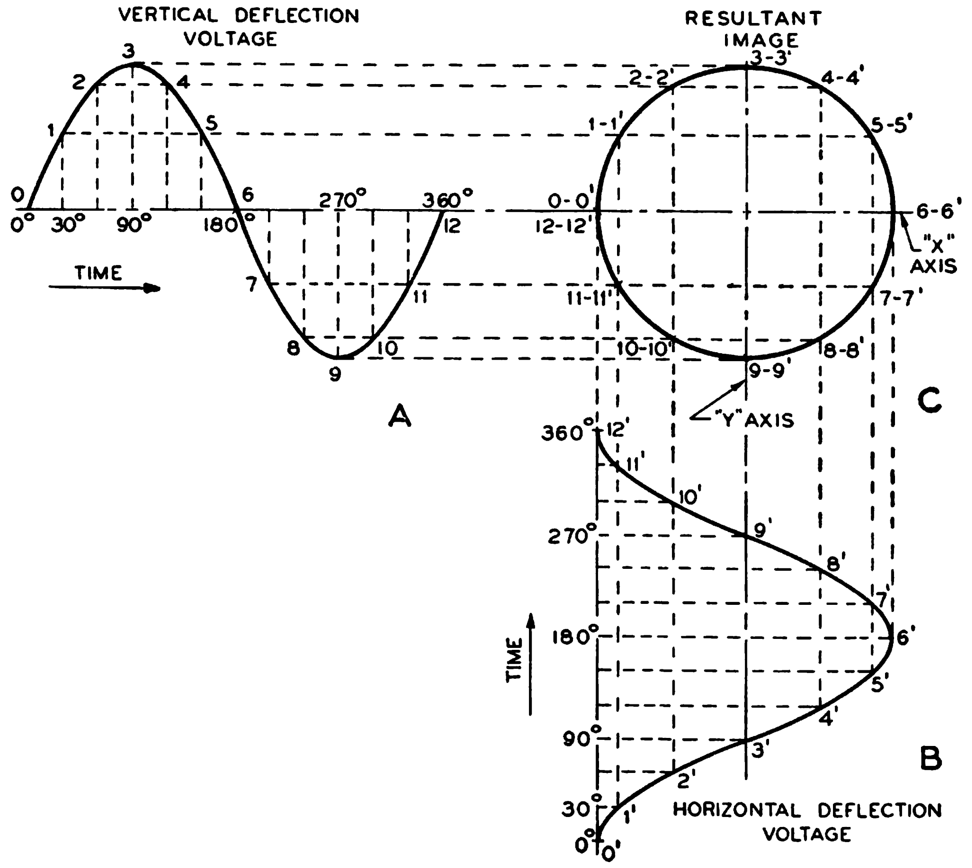

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Figure 109. Production of a circular sweep by two sine waves of equal frequency and amplitude but 90° out of phase.

(3) At the beginning of the sweep, there is no vertical deflection as voltage A is at zero amplitude. At the same time, voltage B is at its maximum positive value. Consequently, the spot moves horizontally to the extreme left-hand side of the screen. The spot is located at point 0–0′ in C of figure 109. During the first quarter-cycle of operation, the vertical-deflection voltage moves the spot upward, while the horizontal-deflection voltage moves the spot from the extreme left toward the center of the screen. Therefore, the spot passes through the points 1–1′, 2–2′, and 3–3′ to form the first quarter of the circular sweep. These points correspond to similarly numbered points on the two deflection waveforms. They represent the resultant deflection at 30°, 60°, and 90° of the deflection voltages.

(4) During the second quarter-cycle, voltage A passes from its maximum positive value back toward the reference line, while voltage B changes from zero toward its maximum negative value. During this time, the spot is deflected downward from

the top of the screen toward the center by voltage A and at the same time is being deflected toward the right horizontally. The spot passes through the points 4–4′, 5–5′, and 6–6′ to form the second quarter of the circular sweep. During the third and fourth quarter-cycles of operation, the horizontal-deflection voltage causes the spot to travel across the screen from right to left. At the same time, the vertical-deflection voltage moves the spot downward from the screen center and then back upward to the center. Consequently, the spot travels through points 7–7′, 8–8′, 9–9′, 10–10′, 11–11′, and 12–12′. The spot is now back to its original starting point and the next sweep is started. Patterns such as this, produced by two simple harmonic motions at right angles to each other, are called *Lissajous figures*.

(5) The time required for one circular sweep is the same as the time required to complete 1 cycle of the sine-wave deflection voltage. If low frequencies are used, the spot moves slowly. When high deflection frequencies are used, the spot moves rapidly. Crystal oscillators frequently are used so that a very precise frequency is maintained. When this is done, the time interval represented by one circular trace can be fixed to a high degree of accuracy. For example, a specific radar set generates a constant-speed circular sweep representing a time duration of 12.2 Usec. To produce this sweep, an 82-kc crystal-controlled oscillator is used which varies only ± 2 cycles under extreme temperture variations.

(6) A phase-splitting circuit is used to produce the required 90° phase shift. When a sine wave is applied to such a circuit, two sine-wave output voltages are obtained which are 90° out of phase. The most common phase-splitting circuit is a simple series R-C circuit, shown in A of figure 110. The resistor voltage E_R is in phase with the circuit current. This current leads capacitor voltage E_C by 90°. Consequently, E_R leads E_C by 90°. These are the two output voltages that are used to produce the circular sweep. In order to make the amplitudes of these voltages the same, the reactance of the capacitor must be equal to the resistance of R. Under these conditions, the current leads the input voltage E_{IN}, which is the sum of E_R and E_C, by 45°. These phase relations are shown in B of figure 109. The resistor is made variable so that the circuit resistance can be made equal to the capacitive reactance over a range of input frequencies. The variable resistor also compensates for any changes of circuit resistance or capacitive reactance.

(7) An R-L circuit can also be used as a phase-splitting circuit. However, because of the resistance of the coil, a complete 90° phase difference is more difficult to produce. Another method of producing the required phase shift is by the use

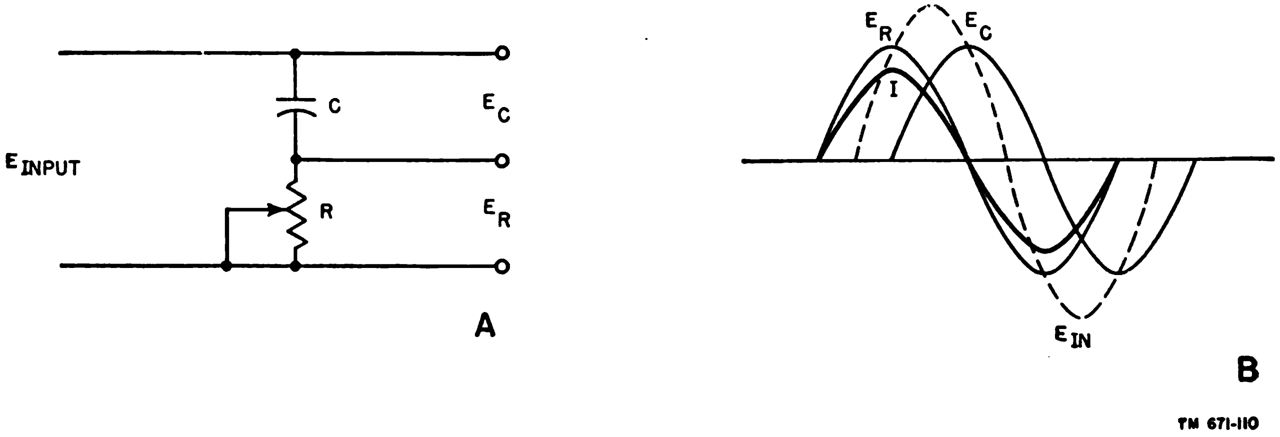


Figure 110. R·C phase-splitting circuit.

of a phase-splitting transformer. A circuit in which such a transformer is used is shown in figure 111. In this circuit, the output of a crystal oscillator is applied to the tuned circuit, C1L1. This circuit is tightly coupled to L3 and loosely coupled to the tuned circuit, C2L2, which is tightly coupled to L4.

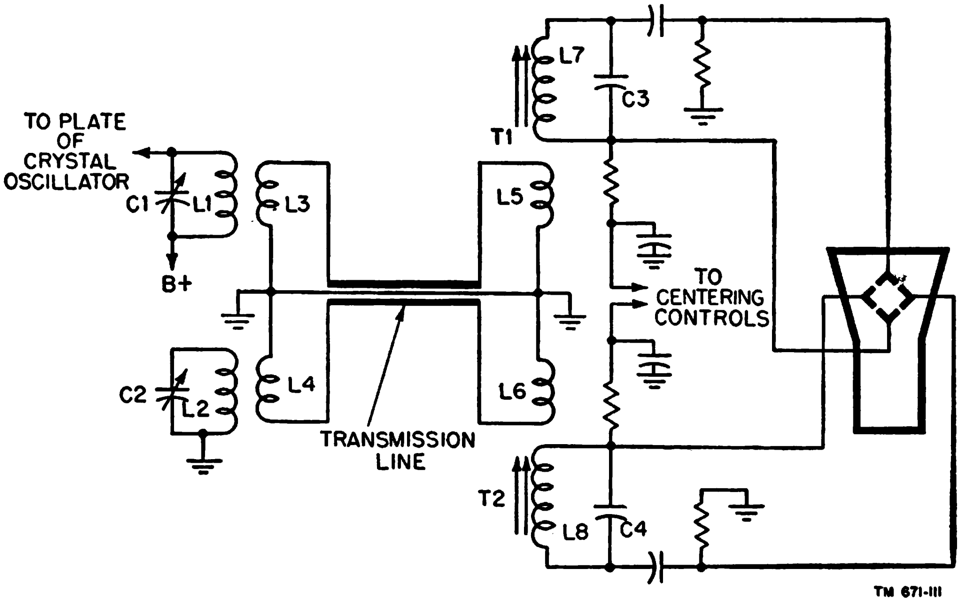


Figure 111. Circuit used to produce a circular sweep using a special phase-splitting transformer.

(8) The voltage induced in the secondary of a transformer is 180° out of phase with the primary voltage. Therefore, the voltage across L3 is 180° out of phase with the voltage across L1. Because of the tight coupling between these windings, the amplitude of the induced voltage is large. The induced voltage in circuit C2L2 is also 180° out of phase with the primary voltage across L1. The amplitude of this induced voltage is small because of the loose coupling. However, a large current flows because C2L2 is a resonant circuit. This large current produces a *reactive* voltage across L2 which leads the current by 90°. (Voltage leads current by 90° in an inductor.) Therefore, the reactive voltage across L2 lags the primary voltage across L1 by 90°.

(9) The voltage across L4 is 180° out of phase with the voltage across L2. Because of the tight coupling between these windings, the amplitude of the induced voltage is large. The total phase difference between the voltages across L1 and L4 is 270°. This is the sum of the 90° phase shift from L1 to L2 and the 180° phase shift from L2 to L4. The total phase difference between the voltages across L1 and L3 is 180°, as explained in (8) above. Therefore, the phase difference between the voltages across L3 and L4 is the required 90°. This phase relationship is maintained by the balanced circuit all the way to the deflection plates where the desired circular sweep is produced.

(10) The physical construction of the unit is such that two widely separated chassis are used. A long transmission line connects the two units. Because of the low impedance of the line, a step-down turns ratio is required from L1 to L3 and from L2 to L4. At the other end of the line, the voltage is stepped up by the transformers T1 and T2. These are used to deliver a high voltage to the deflection plates of the cathode-ray tube. Centering controls supply d-c voltages to position the resultant circle on the screen properly. In order to obtain voltages

producing equal deflection amplitudes, a symmetrical circuit is used with the proper degree of coupling in the various transformers.

c. Radial Deflection Methods.

(1) With a circular sweep, radial deflection commonly is used. Figure 112 shows the difference between radial deflection and ordinary vertical deflection. A was produced by means of a circular sweep. A higher frequency sine-wave signal was also applied to the vertical-deflection plates of the cathode-ray tube. The signals produce ordinary vertical deflection. With this arrangement, the shape of the waveform and its exact location on the sweep are difficult to determine. The sine waves numbered 12, 1, 2, and 6, 7, 8 are in a particularly bad location on the circular sweep. The vertical deflection produced by these sine waves is almost at a tangent to the sweep.

(2) When radial deflection is used (A of fig. 112) all the sine waves have the same appearance. Their exact positions along the circular sweep can be seen easily. In this case, the deflection is always at right angles to the sweep. There are two methods of producing radial deflection. One involves the use of special types of cathode-ray tubes and the other requires special amplifier circuits with ordinary cathode-ray tubes.

(3) Two special types of cathode-ray tube are used to produce radial deflection on a circular sweep. One of these has a thin rod electrode which extends through the center of the cathode-ray tube screen. The rod is mounted at right angles to the screen. These tubes are used widely in J-scan radar displays. This display is described in chapter 6. A circular sweep is generated by applying sine waves which are 90° out of phase to the usual deflection plates of this tube. The electron beam moves between the center electrode and the coating on the inside of the envelope. When an input signal is applied to this electrode (A of fig. 113), a radial electrostatic field is produced. This produces the required radial deflection. If a single negative pulse is applied, the beam moves away from the center electrode. The spot of light moves away from the screen center. If the polarity of the input signal is reversed, the beam moves in toward the center electrode.

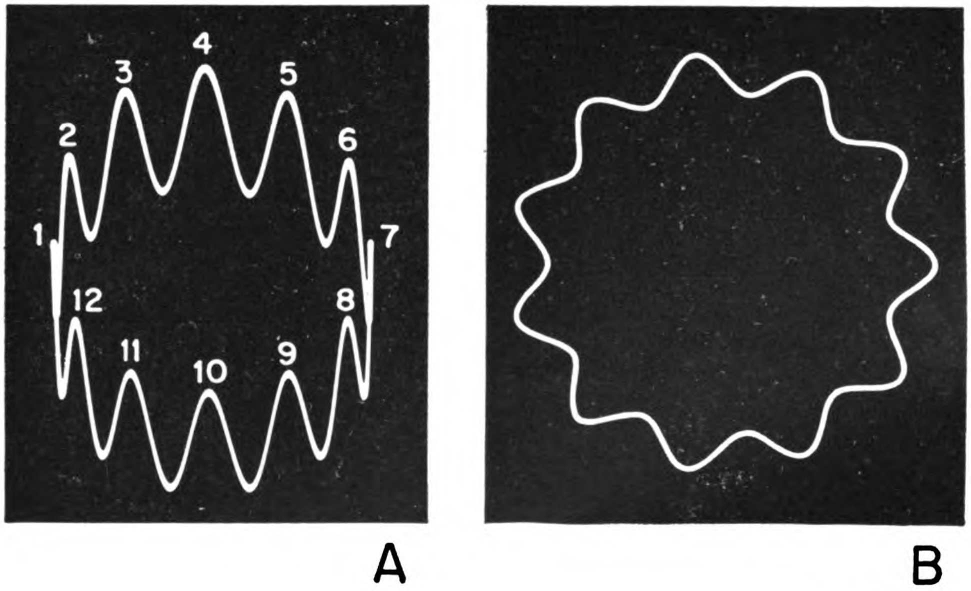


Figure 112. Radial and nonradial deflection produced by sine waves on a circular trace.

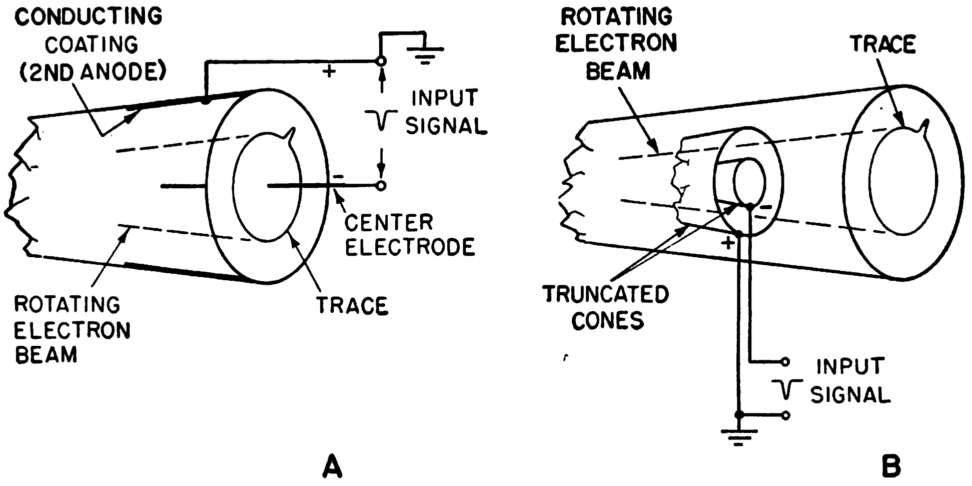


Figure 113. Radial deflection using special cathode-ray tubes.

(4) If more radial deflection sensitivity is needed, another special cathode-ray tube is used. This tube uses a set of truncated metal cones which are mounted beyond the usual deflection plates (B of fig. 113). The outer cone is connected to the accelerating anode, which is at ground potential. An input signal is applied to the inner cone. The electron beam is made to trace a circular pattern on the screen by the usual method. The beam moves in the space between the cones. When the signal is applied to the inner cone, a radial electrostatic field is set up between the cones. If the input signal is negative, the beam moves away from the inner cone. An opposite polarity signal will cause the beam to move toward the inner cone. In this way the spot of light is deflected radially on the screen of the cathode-ray tube.

(5) The special circuit shown in figure 114 is used to provide a circular sweep and radial deflection. A sine wave is applied to the input R-C circuit. The voltage across capacitor C1 is 90° out of phase with the voltage across R1. These two out-of-phase voltages are applied to V1 and V2 by transformer T1 and to V3 and V4 by transformer T2. The impedances of transformers T1 and T2 must be high compared to those of C1 and R1. The transformers provide voltages which are equal in amplitude but opposite in polarity for the push-pull amplifiers. Common cathode resistor R2 provides bias for V1 and V2; common cathode resistor R3 provides bias for V3 and V4. The push-pull output of V1 and V2 is applied through R-C coupling circuits to the vertical-deflection plates of the cathode-ray tube. The push-pull output of V3 and V4 is coupled similarly to the horizontal-deflection plates. In this way, balanced horizontal and vertical deflection is provided and a circular sweep results.

(6) The screen voltage for the four amplifiers is controlled by the voltage at the plate of V5. This stage serves as an amplifier for the input signal which is to produce radial deflection. So long as no input signal is applied to the grid of V5, the voltage at its plate remains steady. Therefore, the screen voltage of amplifiers V1, V2, V3, and V4 is constant. This results in a constant amplifier gain and the normal circle is traced on the screen. If a negative pulse is applied to V5, its plate current is reduced and a smaller voltage drop appears across R14. Consequently, the plate voltage of V5 and the screen voltage of the push-pull amplifiers increase. This rise in screen voltage raises the gain of the push-pull amplifiers. The result is that the size of the circle on the screen is increased for the duration of the negative input pulse.

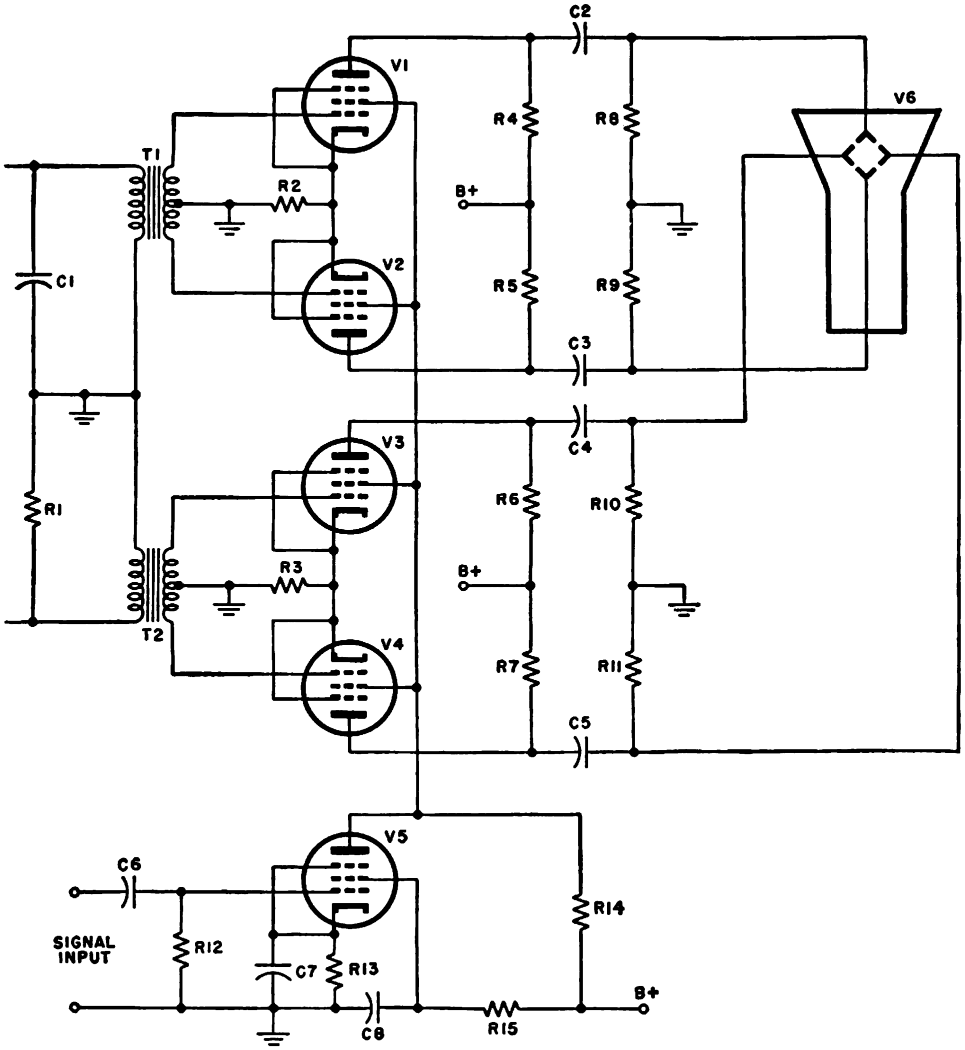


Figure 114. Circular sweep generator with radial deflection.

(7) If the input pulse has a short duration, the size of the circle increases for the same short time. The result is a radial deflection outward from the center of the screen. A positive input signal has the opposite effect. The screen voltage is reduced and the gain of the push-pull amplifiers is decreased. The size of the circle is reduced momentarily so that an inward radial deflection occurs. If an alternating voltage is applied to V5, the gain of the amplifiers is raised and lowered alternately. The result is an alternating outward and inward radial deflection on the circular sweep.

(8) When the electron beam can be moved circularly and radially at the same time as in the circuit described above many interesting and unusual patterns can be produced. Two of the most useful are the *radial sweep* and the *spiral sweep* (fig. 115). The radial sweep is useful in certain types of radar displays. Several methods of generating a radial sweep are discussed in detail in chapter 6. The spiral sweep is used when the circular sweep is not long enough to display certain data. The circuit shown in figure 114 can be used to illustrate the production of these two special sweeps.

(9) Assume that a sawtooth voltage is applied to the amplifier tube V5 in figure 114. The frequency of the sawtooth is about 100 times higher than the frequency

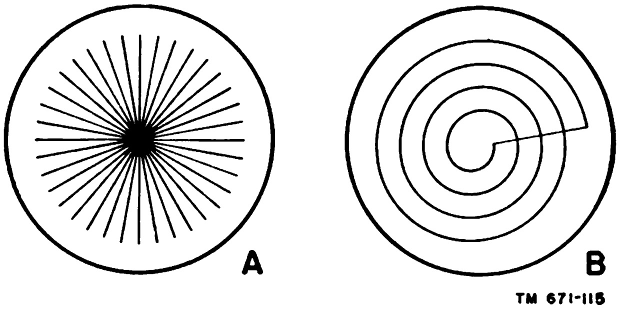


Figure 115. Radial and spiral sweeps.

of the sine wave that is producing the circular sweep. The amplitude of the sawtooth is such that a considerable change in gain of the push-pull amplifiers results. The variation in gain is sufficient to produce a radial deflection that moves the spot into the center of the screen and outward near the periphery. The spot moves radially outward at a slow rate as the sawtooth voltage rises. It then moves radially inward toward the center at a rapid rate as the sawtooth voltage falls. Because the sawtooth frequency is a hundred times higher than the sine-wave frequency, 100 cycles of the radial deflection voltage occur during a single cycle of the circular deflection voltage. As the electron beam moves in a circle, it is being radially deflected by the sawtooth voltage. A series of 100 spokes appears on the screen. Each spoke will be curved in the direction of sweep rotation. If the sawtooth frequency is increased still more, a greater number of spokes will be seen. These spokes will be closer together and less curvature will be evident.

(10) In order to produce a spiral sweep, it is necessary only to reduce the sawtooth frequency so that it is lower than the sine-wave frequency. If the frequency of the sawtooth is adjusted to one-fourth that of the sine wave, then a four-turn spiral is produced. The time required for one sawtooth cycle is now four times that required for a sine-wave cycle. Consequently, four loops are traced by a spot which at the same time is being deflected radially outward by the sawtooth voltage.

Section VI. EXPANDED TIMEBASES

52. Need for Expansion of Timebase

a. A time base is expanded when a portion of it is spread out on the screen of a cathode-ray tube. When this is done, the speed of the electron beam is not constant for the duration of the sweep. Instead, the beam moves rapidly when the expansion occurs and more slowly at all other times. Occasionally, an expanded timebase is produced in which the expansion is gradual so that the speed of the spot is changing constantly.

b. The more common expanded timebase, however, is one in which two distinct rates of spot travel are used. Two different sweep rates then occur during each trace. The spot can travel slowly across the screen until it has covered perhaps the first third of the screen diameter. Then the speed increases considerably so that the second third of the screen diameter is covered in a much shorter period of time. Next, the speed is reduced to its original low value. The last third of the screen diameter is covered in the same long time which was required for the first third. Consequently, the center of the sweep is expanded and the beginning and ending are traced normally.

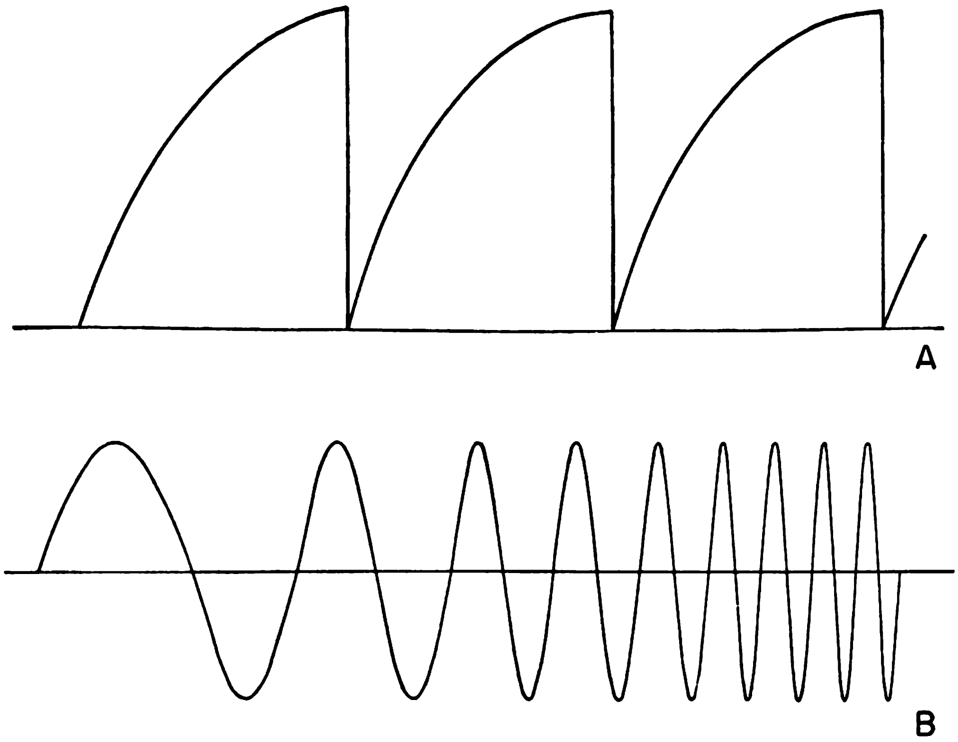
c. Expansion of the timebase is useful for a number of reasons. It permits a waveform which occurs at a particular location along the timebase to be examined more closely. This can be done without removing other signals which appear at different locations along the sweep. Also, an expanded timebase is useful in certain radar displays. When very long range sweeps are used, the scale on the indicater screen can become too large to measure range accurately. If a target signal can be placed in that portion of the sweep which has been expanded, its characteristics and exact range can be determined more readily.

53. Methods of Producing Timebase Expansion

a. Exponential Sweep Generator.

(1) A simple method of producing an expanded timebase is by the use of an exponential sweep generator. The circuits

that have been described previously in this chapter for the generation of a linear sweep depend on the charge and discharge of a capacitor. The voltage rise across a capacitor is normally an exponential rise. Only by using a small portion of this rise and by adding special linearization circuits is some degree of linearity produced. If a sawtooth generator is designed so that a large portion of the capacitor charging curve is used, an exponential sweep voltage is produced (A of fig. 116).



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A, Exponential sweep voltage; B. Series of sine waves on an exponential sweep.

Figure 116. Exponential sweep.

(2) When such a sweep voltage is applied to the horizontal-deflection plates of a cathode-ray tube, the speed of spot travel is not uniform. At the beginning of the trace, the spot moves rapidly. In due time the rate of voltage rise is reduced and the speed of spot travel is lowered. When a higher-frequency sine-wave signal is applied to the vertical-deflection plates, the pattern shown in B of figure 116 results. The first few cycles are spread out, because of the fast sweep speed at this time. As the sweep progresses, the sine-wave cycles are squeezed together.

b. OTHER CIRCUITS.

(1) If it is desired to expand only a small portion at the center of the sweep, other circuits are used. Both circuits to be discussed generate a sawtooth sweep voltage having two distinct rates of change. The sweep voltage changes at a slow rate at the beginning and ending of the trace. At the center of the trace, the rate of change is increased so that expansion occurs here. The resultant pattern on the screen of the cathode-ray tube is shown in figure 117.

(2) During the times that the sweep is traveling at its normal speed, an intense trace is produced along which the signals are spaced closely. During the fast sweep. however, a less intense trace is produced because of the rapid spot movement. The signals that appear in this portion of the sweep are spread out considerably.

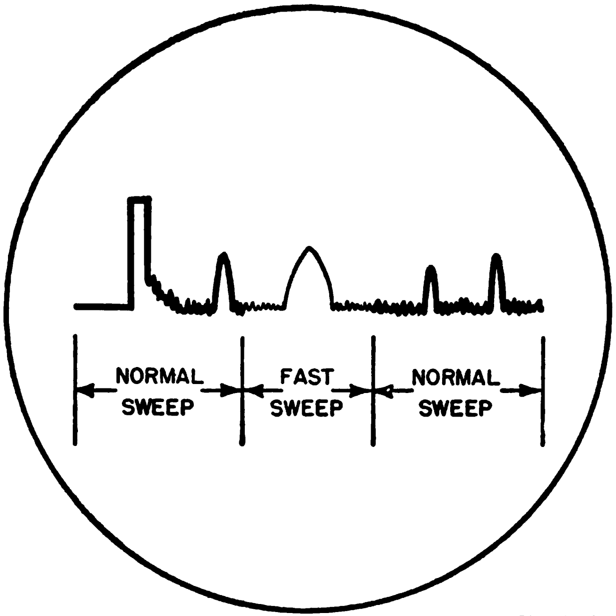

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Figure 117. Radar A-scan presentation with expanded sweep.

(3) One circuit which can produce this type of expanded sweep is shown in figure 118. Before the sweep gate is applied to the grid of V1, this tube conducts heavily. Capacitor C6 rapidly charges up through V1 so that its cathode side is highly positive as compared to ground. When V1 is cut off by the negative sweep gate, capacitor C6 begins to discharge slowly through V2. This tube operates as a constant-current pentode which maintains a steady discharge current during the discharge of C6. Therefore, a linearly falling voltage is generated across C6. The rate of change of this voltage can be varied by resistor R4 which alters the bias on V2.

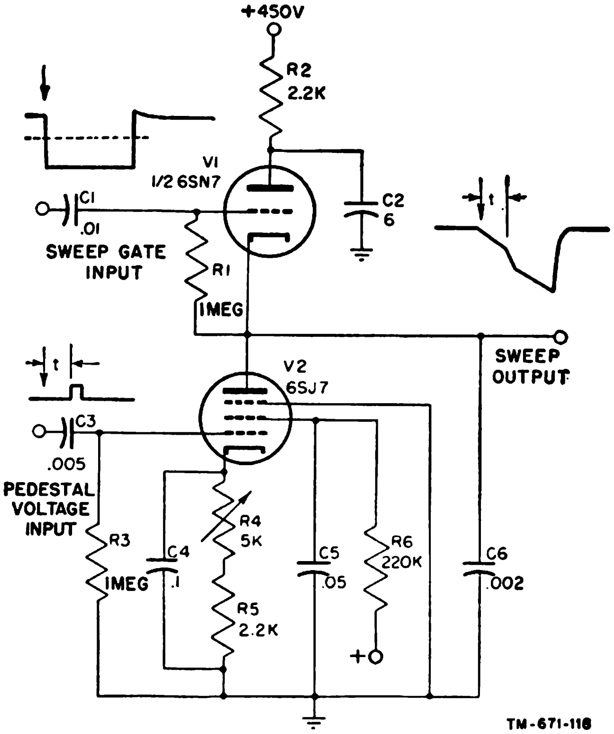

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Figure 118. Circuit for producing an expanded sweep at the center of the trace.

(4) After a time t has elapsed which is equal to slightly less than one-half the time required for the entire sweep a short positive pedestal voltage is applied to V2. The pentode V2 conducts a larger amount of current for the duration of the pedestal voltage. Therefore its plate resistance is reduced and the sweep capacitor discharges more rapidly for the duration of the positive pedestal voltage. This more rapid discharge produces the fast sweep that is required. After the pedestal has terminated the grid voltage of V2 is restored to its normal level and the plate resistance of the tubes increases to its original value. Consequently the normal slower sweep is resumed as capacitor C6 continues to discharge at its original slow rate. At the end of the sweep gate, V1 conducts heavily. Capacitor C6 recharges rapidly, thereby producing the rapid retrace. Except for the application of the pedestal voltage to produce sweep expansion, the operation of this circuit is similar to that of the circuit shown in figure 103.

(5) Another circuit, which has been used to produce the same effect, is shown in figure 119. In this circuit a slow linear sweep is produced by the charging of capacitors C5 and C6 through R5, R6, and R7. A sweep trigger applied to the grid of the thyratron V1 causes it to conduct and to discharge the sweep capacitors through R2C2, V1, and R4. This produces the rapid retrace because of the low resistance path. The slow charging of the sweep capacitors now begins and the trace is produced.

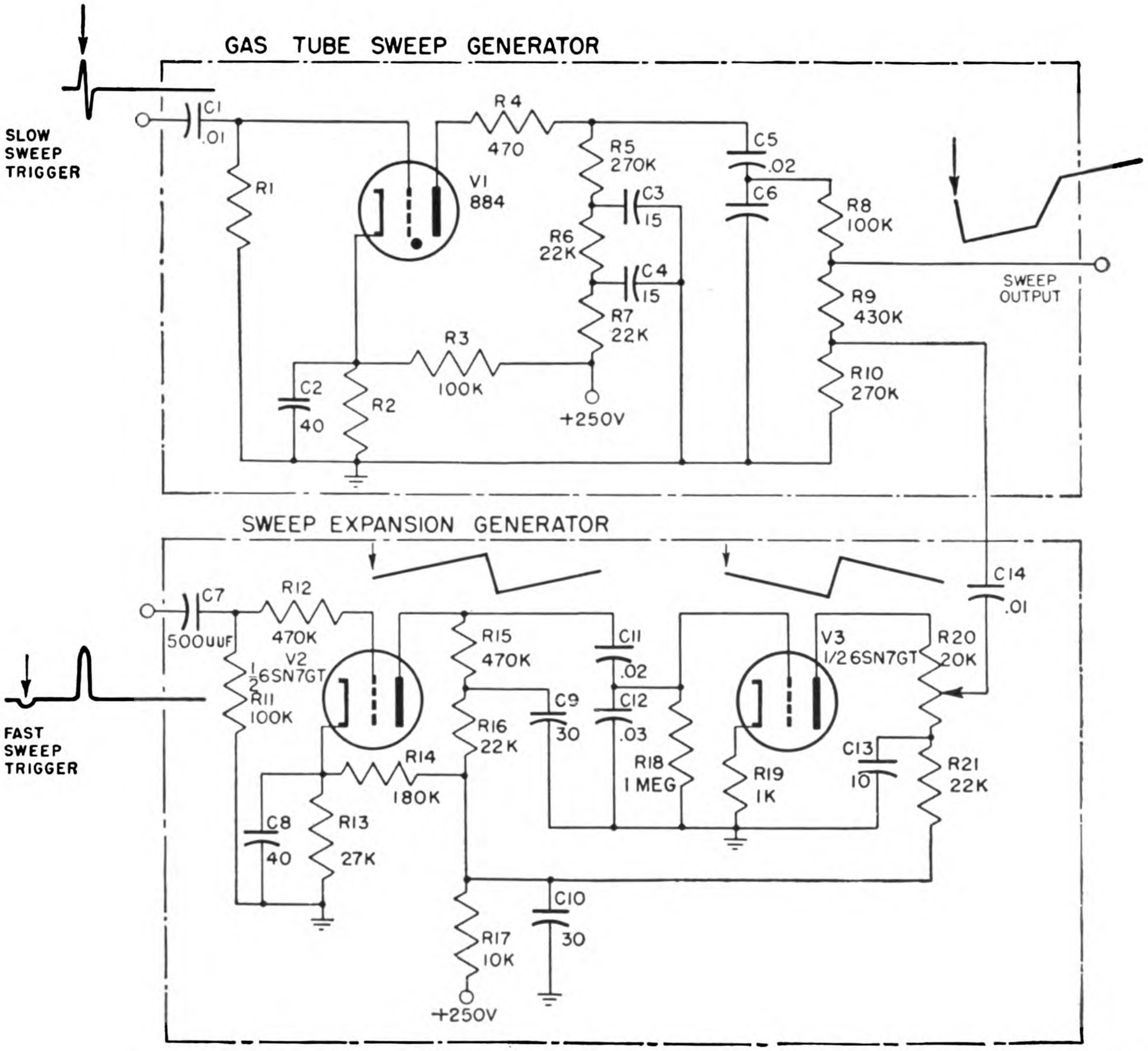

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Figure 119. Alternate circuit for producing expanded sweep at the center of the trace.

(6) Sometime during the charge of these capacitors a positive pulse is applied to the grid of V2. The interval between the beginning of the sweep and the start of the positive pulse is slightly less than one-half the time required for the entire sweep. V2 normally is cut off because of the large negative bias developed as a result of the voltage divider composed of R13 and R14. During this time, capacitors C11 and C12 charge slowly through R15, R16, and R17 because of their high resistances. When the positive pulse arrives at the grid of V2, it drives this tube into conduction. Capacitors C11 and C12 then discharge rapidly through R13 and C8, and V2, producing a fairly linear and rapid fall in voltage.

(7) The output of V2 is coupled to V3 which amplifies and inverts the waveform. The rapid fall in voltage is now a voltage *rise* which is used as the fast sweep portion of the final output. The two sweep voltages are combined in the resistance network composed of R8, R9, and R10. The final

sweep output is the sum of the slow sweep voltage developed by the gas-tube sweep generator and the fast sweep voltage developed by the sweep expansion generator. This output appears at the junction of R8 and R9 in figure 119 and is similar to the output in figure 118.

c. Delayed Sweeps.

(1) It is possible to accomplish the foregoing expansion effect by another method. If a small portion of the linear sweep is made to occupy the entire screen diameter, any signals which occur during that small portion will be enlarged considerably. A simple method of accomplishing this is to increase the gain of the horizontal-deflection amplifier to such an extent that a large portion of the sweep voltage deflection moves the spot *off* the screen. A wide-range horizontal-positioning circuit is then used to move the pattern horizontally so that any portion of the horizontal trace appears on the screen.

(2) A delayed sweep is used occasionally in some radar displays to produce the effect of expansion. In this system (fig. 120), a small section of the sweep is expanded to cover the full screen of the cathode-ray tube. In the block diagram shown, a conventional sawtooth generator delivers its output to the plate of the diode VI. This diode commonly is called the *pick-off* diode. The cathode of the diode is operated at a positive potential. The exact potential is determined by the settings of R, R1, and R2. The sawtooth voltage begins when the radar transmitter pulse is generated and lasts for a period of time that is required to display the entire range. This process is described in detail in chapter 6.

(3) Because of the positive potential on the cathode of VI, the diode does not conduct until the input sawtooth amplitude rises above this potential. Assume that the cathode voltage equals the sawtooth voltage at time t2. From time t1 to t2 the plate voltage of the diode is less than its cathode voltage; consequently, it does not conduct. No output voltage is applied to the following two-stage amplifier. When the input sawtooth voltage rises above the cathode voltage of V1, the diode conducts. The output of V1 is a sawtooth voltage whose amplitude is less than that of the input. This output sawtooth voltage begins at time t2.

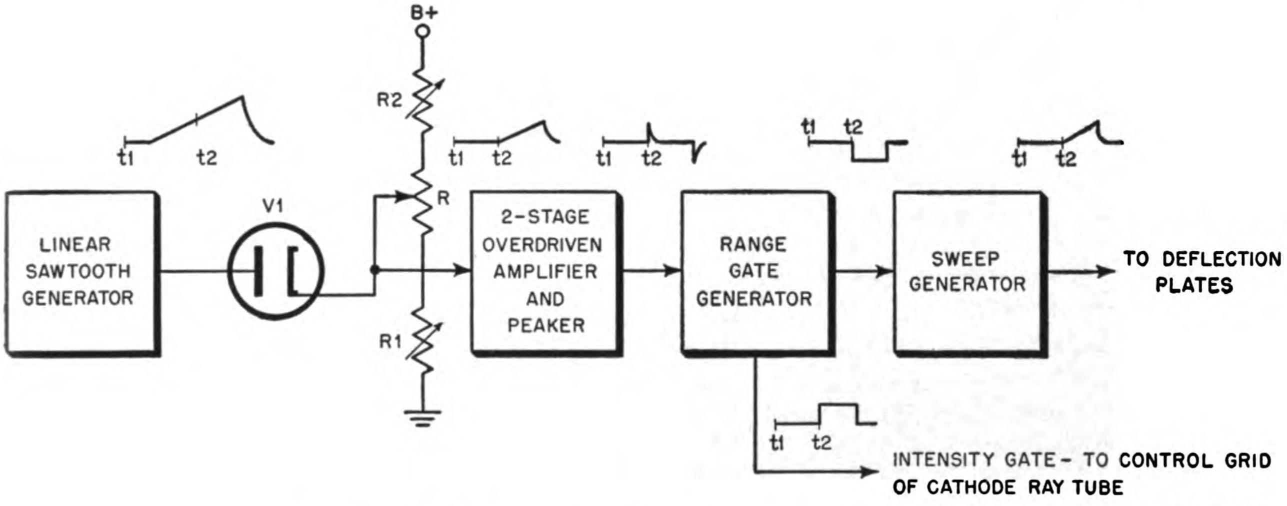

Figure 120. Pick-off diode method of producing a delayed sweep.

(4) The delayed sawtooth voltage is applied to the input of a two-stage overdriven amplifier and peaker. This circuit incorporates an input differentiating circuit which produces an approximate square wave that begins at time t2. After limiting has occurred, an additional differentiating circuit is used to produce a

sharp positive peaked wave at time t2. This peaked wave triggers a start-stop multivibrator which is called the range-gate generator. The output of this circuit is a negative square wave which begins at time t2. The square wave gates a sweep generator whose output is applied to the horizontal-deflection plates of the cathode-ray tube. The range-gate multivibrator also delivers an intensity gate to the grid of the cathode-ray tube. The purpose of this gate is explained in chapter 6.

(5) The setting of the potentiometer R can be varied to change the amount of time delay provided by the circuit. As the potentiometer arm is moved toward a higher positive voltage point, the diode V1 starts to conduct at a later time. Consequently, the time delay of the final sweep is increased. If the arm is moved in the opposite direction, a smaller delay occurs. The potentiometer frequently is calibrated in yards or miles so that the exact amount of the delay can be present. Resistors R1 and R2 are adjustable so that the calibration of the potentiometer R is correct. The delayed sweep voltage cannot be obtained directly from V1 because the amplitude of the sweep voltage varies at this point as the amount of delay is changed. With the circuit shown, the length of the range gate is constant for any delay and the sweep amplitude is uniform. Also an intensity gate is required and this cannot be obtained if the circuit terminates at the diode.

(6) Several modifications of this circuit are used. A stepped voltage divider sometimes is used in place of the continuously variable delay potentiometer. When this is done, the taps on the voltage divider provide definite time delays. A cathode-coupled multivibrator occasionally provides a continuously variable delay in place of the pick-off diode. A variable resistance changes the d-c voltage applied to the grid of the tube which normally is nonconducting. Two separate cathode-ray tubes can be used with this circuit. One tube displays the entire range; the other displays only a small portion of the entire range.

Section VII. SAWTOOTH CURRENT GENERATORS

54. Required Waveform for Linear Electromagnetic Deflection

a. Sweep Current. When an electromagnetic cathode-ray tube is used, the sweep generator must be modified. The reflection produced in an electromagnetic cathode-ray tube depends on the magnetic field strength. This is determined by the amount of current which flows through the deflection coils. When a linear sweep is required, the magnetic field must increase in intensity at a linear rate, and then must decrease quickly to produce a rapid retrace. A sawtooth *current* is required to produce a linear spot motion.

b. Sweep Voltage.

(1) When a sawtooth sweep is required in an electrostatic cathode-ray tube, a sawtooth *voltage* is applied to the deflection plates. A small amount of capacitance exists between these plates but its effect is negligible except at very high frequencies. The deflection produced is directly proportional to the exact amplitude of the deflection voltage applied to the plates. This is not the case when electromagnetic deflection is used.

(2) The deflection coils of an electromagnetic cathode-ray tube usually consist of many turns of fine wire. The inductance of such coils can be several hundred millihenrys and the resistance of the winding can be several hundred ohms. The exact values of inductance and resistance depend on the particular deflection yoke used. In any case, the deflection coil inductance and resistance usually cannot be disregarded. In addition, a small amount of distributed capacitance exists across the deflection coil. This capacitance usually can be neglected except when high-frequency or very short time-duration sweeps are required.

(3) Because of the above-mentioned electrical constants, the shape of the volt-

age waveform that must be applied to the deflection coils to produce a sawtooth sweep current is *not* a sawtooth voltage. If a sawtooth voltage were applied to the deflection coils a nonlinear sweep current would result. In order to produce a linear sweep and a sawtooth current, the voltage that is applied to the deflection coils is *trapezoidal*. A trapezoid is a four-sided figure in which two sides are parallel and the other two are nonparallel. The reason for using this particular voltage waveform is illustrated in figure 121.

(4) When a sawtooth voltage is applied to a simple resistor, as in A of figure 121, the current which flows through it has the same waveform as the applied voltage. The current varies directly with the applied voltage in accordance with Ohm's law and no phase shift occurs. Assume that a sawtooth of current is required to flow through the inductor. A linear rise of current through a pure inductance is produced only when a uniform voltage is applied. As long as the voltage applied is steady, the current rises linearly toward an infinite value. When the applied voltage suddenly drops to zero or reverses its polarity, the current through the pure inductance decays at a linear rate toward zero. If the circuit constants remain the same during the build-up and decay of current, the time required for the rise and fall is equal. A triangular waveform of current results.

(5) In the usual practical circuit, however, some constant is changed during the decay time so that the rate of current fall is much greater than the rate of rise. Consequently, when the rectangular waveform shown in B of figure 121 is applied, a slow nearly linear rise of current occurs during the first alternation of the applied voltage. During the next alternation, a rapid current decay occurs.

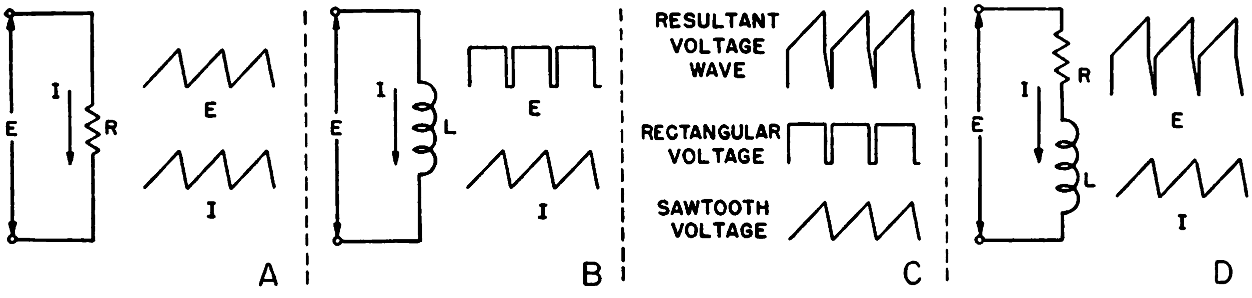

Figure 121. Development of required trapezoidal voltage needed to produce a linear sweep in electromagnetic cathode-ray tube.

(6) The total voltage applied to the deflection coils is made up of two components. One of these is a sawtooth voltage which is required for the resistance of the deflection coil. The other component is the rectangular voltage which is required for the inductance of the deflection coil. When these two voltages are added, the resultant voltage is a trapezoidal waveform (C of fig. 121). Therefore, in order to produce a sawtooth current through a deflection coil, it is necessary to apply a trapezoidal voltage, as in D.

(7) In practice, there will be considerable variation in the relative magnitudes of inductive reactance and resistance, depending on the design of the particular deflection coil used. When the inductance is large so that the reactance is greater than the resistance, then the amplitude of the rectangular component is greater than the sawtooth component. The resultant trapezoidal waveform appears as in A of figure 122. This waveform approaches the shape of the simple rectangular wave.

(8) When the inductance of the deflection coil is low so that the reactance is smaller than the coil resistance, the sawtooth component is larger. The resultant trapezoidal waveform is shown in B of figure 122. This waveform approaches the

shape of a simple sawtooth wave. Even when a fixed relationship exists between reactance and resistance, it is necessary to alter the shape of the trapezoidal waveform when different sweep frequencies are required. In general, the waveform required for a fast sweep resembles that shown in A of figure 122. The effect of the inductance then is large because of the rapid changes in sweep current required to produce a fast sweep. For slow sweeps, the trapezoidal waveform resembles that shown in B. Here, the effect of the inductance is low because of the slow changes in sweep current required.

(9) When rapid sweeps are used and good linearity is desired at the very beginning of the sweep, the shunt capacitance of the deflection coil must be taken into account. The steep rise that occurs at the beginning of the trapezoidal voltage waveform charges the shunt capacitance. This rounds off the leading edge of the voltage waveform and causes a delay in the starting of the sawtooth sweep current (A of fig. 123). To compensate for the effect of the shunt capacitance, a sharp spike of voltage occasionally is added at the leading edge of the trapezoidal voltage. This sudden large amplitude rise of voltage supplies a large current at the beginning of the sweep. This charges the shunt capacitance. The resultant sawtooth current starts at the proper time without delay.

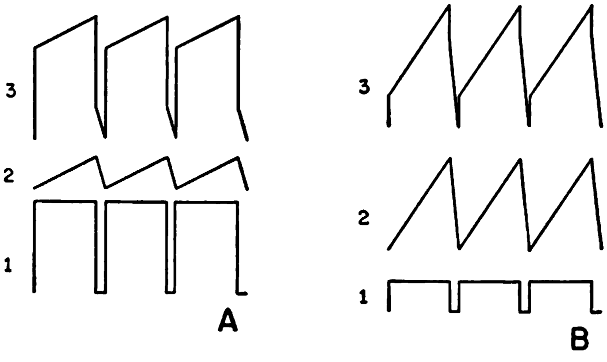

Figure 122. Resultant trapezoidal voltages required when the inductive reactance of deflection coil is not the same size as the resistance of the coil.

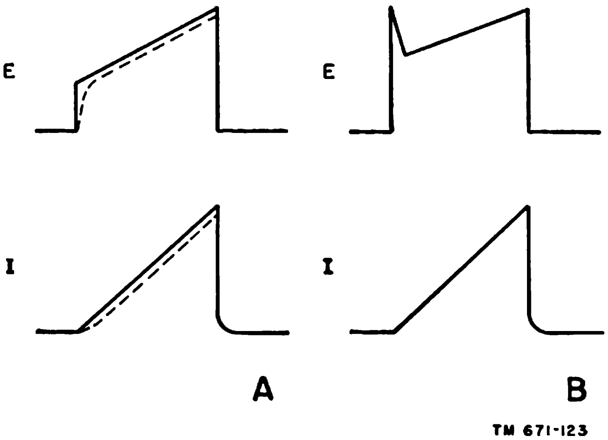

Figure 123. Effect of shunt capacitance of deflection coil.

55. Sweep Generators for Electromagnetic Cathode-Ray Tube

a. TRAPEZOIDAL VOLTAGE GENERATOR CIRCUIT (fig. 124).

(1) In the circuit shown, V1 is used to generate the required trapezoidal sweep voltage. This voltage is coupled to a power amplifier which delivers the required current to the deflection coil. A series of rectangular waves is used to trigger the trapezoidal generator. These triggers (A of fig. 125) cause V1 to conduct for a much shorter period of time than it is cut off by the large negative bias.

(2) When V1 is cut off, capacitor C1 begins to charge from the power supply through R2 and R3. The voltage across the capacitor rises at an exponential rate. Since only a small part of the charging cycle is used, a fairly linear rise is produced. This linear voltage rise is shown between times t1 and t2 in B of figure 125. The charging current is constant during the linear rise of capacitor voltage and its magnitude is low because of the combined resistance of R2 and R3. As a result, a constant low voltage is produced across R2 which is positive in respect to ground.

(3) At time t2, the trigger causes V1 to conduct. The low resistance of the triode is shunted across the circuit composed of C1 and R2. The capacitor discharges quickly through R2 and V1. The voltage

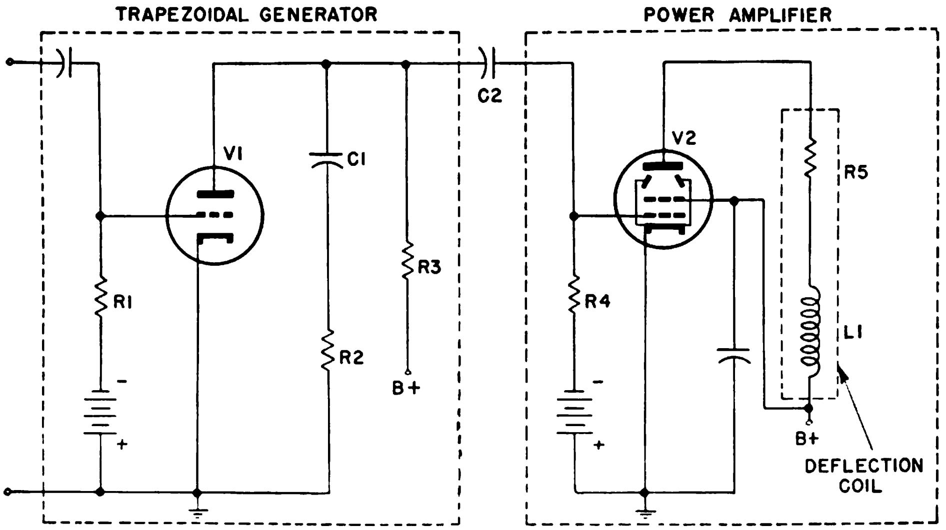

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Figure 124. Trapezoidal voltage-generator circuit.

across C1 falls rapidly (B of fig. 125) from time t2 to t3. During the discharge a voltage drop appears across R2 whose polarity is opposite to that which is produced during the charging time of the capacitor. The negative voltage has a greater magnitude than the positive voltage produced during the charging time. This is true because the discharge current is considerably greater than the charge current (the resistance of R3 is much larger than the resistance of V1 when it conducts). The charge current is limited by R2 and R3, and the time constant of the charge circuit is long. The discharge current is limited by R2 and the low plate resistance of V1. The time constant of the discharge circuit is short. C of fig. 125 shows that the negative voltage across R2 is reduced in amplitude somewhat from time t2 to time t3. This occurs because of the decrease in discharge current at time t3.

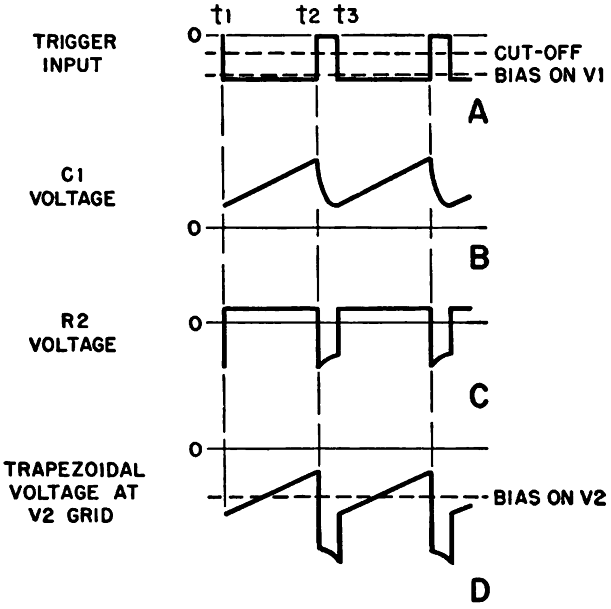

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Figure 125. Waveform in circuit of figure 124.

(4) When the sawtooth voltage across the capacitor C1 is added to the approximate rectangular voltage across the resistor R2, a trapezoidal waveform is produced (D of fig. 125). This trapezoidal voltage is applied to the grid of V2 through the coupling circuit C2R4. Sufficient negative bias is applied to the grid of V2 to prevent the grid voltage from going positive. V2 is a beam power amplifier which is used because of its high power sensitivity. Power amplification is required so that sufficient current is available for the deflection coil. This coil may require 50 or 100 ma (milliamperes) for maximum deflection.

(5) The trapezoidal voltage that is applied to V2 is amplified by the power amplifier. The output of V2 is applied to the proper deflection coil of the electromagnetic cath-

ode-ray tube. The deflection coil is shown in figure 124 as a circuit composed of inductance L and resistance R5. When the trapezoidal output voltage is applied to this circuit, a sawtooth current flows through the deflection coil. This produces the required linear sweep.

(6) The preceding circuit differs in two important respects from a circuit which is used for electrostatic cathode-ray tubes. First, the addition of R2 causes the required rectangular waveform to be produced. This is added to the sawtooth waveform produced across C1 to form the required trapezoidal voltage. Second, a power amplifier instead of a voltage amplifier is used. This is done to furnish the deflection power required in an electromagnetic deflection system.

(7) Any of the circuits discussed earlier in this chapter which produce a sawtooth voltage for electrostatic deflection can be converted to trapezoidal voltage generators. This is done, as shown above, by the insertion of a resistor in series with the capacitor that is used to produce the sawtooth voltage. Frequently, blocking-oscillator and multivibrator sweep generators are used to produce trapezoidal voltages for electromagnetic deflection with this simple modification.

b. SAWTOOTH CURRENT GENERATOR.

(1) Another circuit used which does not require a trapezoidal voltage generator is shown in figure 126. In this circuit a rectangular waveform is applied to the grid of a power amplifier, V1. Sufficient bias voltage is developed by the voltage divider consisting of R2 and R4 to maintain V1 normally cut off. When the first positive alternation is applied to the grid of V1, this tube conducts.

(2) The plate current of V1 flows through a large inductor, L1, and through the deflection coil L2. The current through these coils builds up exponentially toward some steady value limited only by the circuit resistance. This exponential current rise, shown by the dotted line in figure 126, is interrupted so that only a small portion of it is used. Therefore, the departure from linearity is not great. The interruption occurs at the end of the positive alternation of the rectangular input waveform. V1 is cut off and the current through the deflection coil decays toward zero.

The current through the deflection coil builds up slowly and decays rapidly. The time constant (L/R) of the circuit during the current build-up is long. This is true because of the large inductance and, therefore, the large reactance of L1 and L2, and the small resistance of the circuit. The resistance through which the current flows is resistor R2 and the relatively low plate resistance of the conducting tube, VI. The time constant of the circuit during the current decay is short. Although the inductance remains the same, tube V1 no longer conducts. Its plate resistance is increased, and a rapid current decay results.

(4) Inductor L1 is added to the circuit to increase the time constant. Therefore, a slow current build-up can occur. If faster sweeps are required, L1 is shorted out. This reduces the time constant of the circuit so that a more rapid current build-up can occur.

(5) If a long resting time is required between sweeps, the input waveform is altered so that a longer time interval exists between positive alternations. The same effect can be accomplished in the circuit shown in figure 124 by changing the input waveform. Here, the trapezoidal generator is cut off for a period of time which equals the required sweep duration. Then the generator is made to conduct for the duration of the resting time.

(6) Many other circuits are used to generate linear sweeps for electromagnetic cathode-ray tubes. These are used in special applications. Some of these circuits are discussed in chapter 6.

56. Damping in Electromagnetic Sweep Circuits

a. NEED FOR DAMPING. When the rapid retrace occurs, the current in the deflection coils decays from its maximum value to its minimum value in a very short period of time. The magnetic field

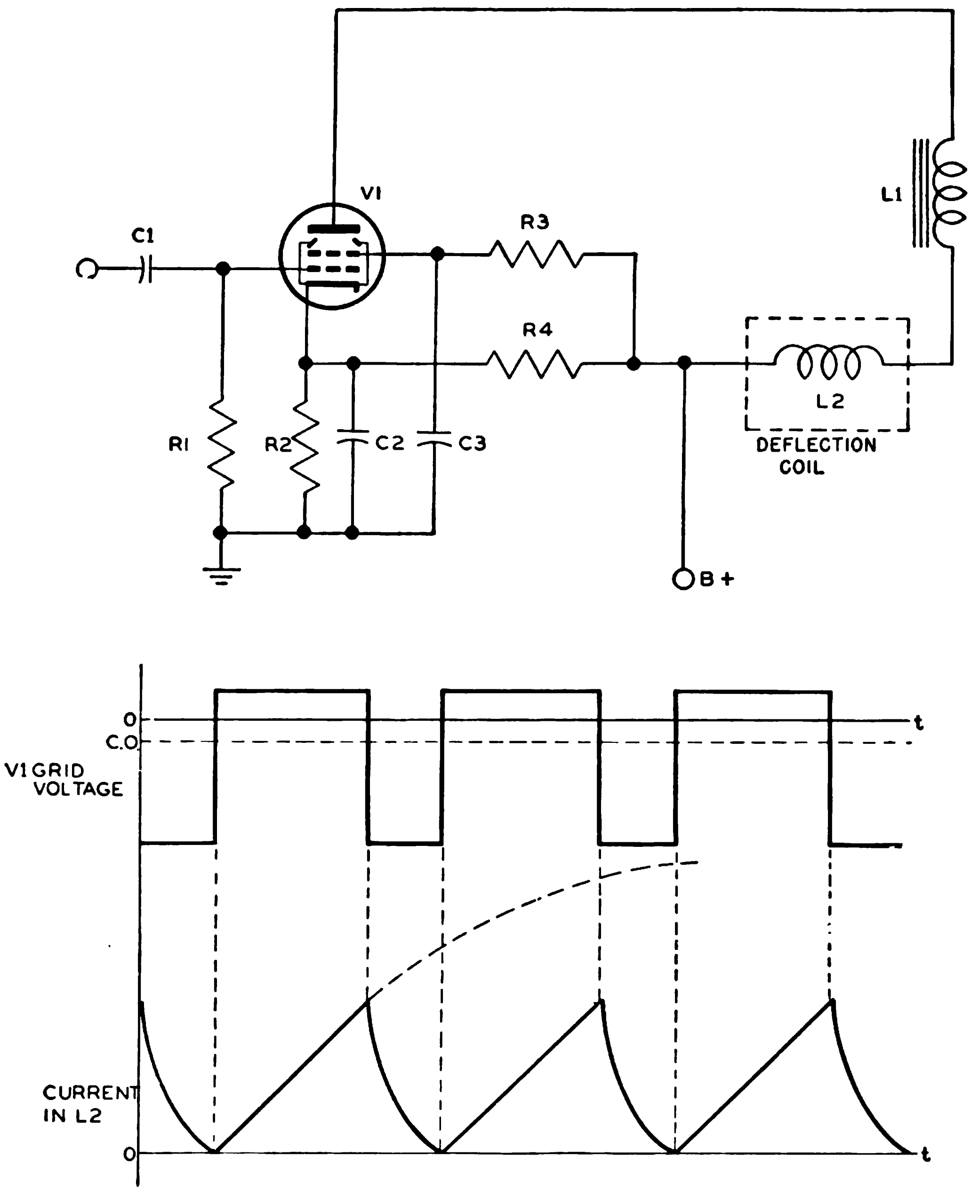


Figure 126. Sawtooth current generator.

associated with the current collapses rapidly. As a result, a large counter electromotive force is produced which tends to prevent the current from falling to zero. Also, the inductance of the deflection coils forms a parallel-resonant circuit with the shunt capacitance. This circuit often is shocked into oscillation by the sudden change of current through the deflection coil. These oscillations gradually die away but the Q of the circuit can be so high that they continue well into the following sweep. As a result the beginning of the sweep is noticeably nonlinear as shown in figure 127.

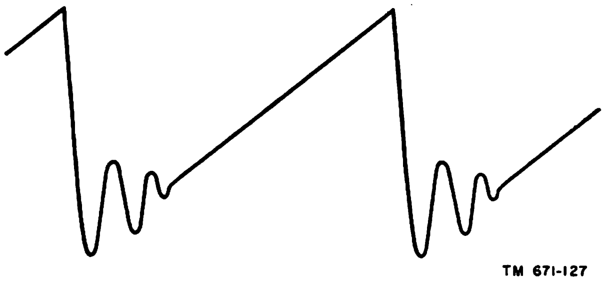


Figure 127. Oscillations in deflection-coil current.

b. Damping Methods.

(1) A resistor can be shunted across the deflection coils. This resistor has two pur-

poses. First, it damps out the resonant oscillations by lowering the Q of the circuit. The resistor is a load which absorbs the energy contained in the rapidly collapsing magnetic field. Second, the resistor limits the voltage that appears across the deflection coil to a safe value. This prevents breakdown of insulation and arc-over in the deflection coils. The disadvantage of this method is that the resistor wastes some of the current which would otherwise be used to produce deflection. Some of the deflection current flows through the resistor at all times.

(2) A more satisfactory method is to use a *damping diode*. This diode is connected across the deflection coil (fig. 128). During the time that the sweep current rises, the voltage at the plate of V1 is less positive than the supply voltage by the amount of voltage drop across the deflection coil. The plate of the diode, V2 is less positive than its cathode and the tube does not conduct.

(3) When the retrace occurs, a large counter electromotive force is produced by the inductance of the deflection coil. The polarity of this voltage tends to maintain the current flow through the coil. The voltage at the plate of V1 and V2 rises above the potential of the plate supply. The plate of V2 is now more positive than its cathode and the diode conducts. The oscillations are damped out rapidly by the low plate resistance of the diode and the series resistor R. The diode must be able to handle high currents and must have suitable internal insulation to prevent arc-over. This is necessary as reactive voltages produced can be much higher than the d-c voltages used in the circuit.

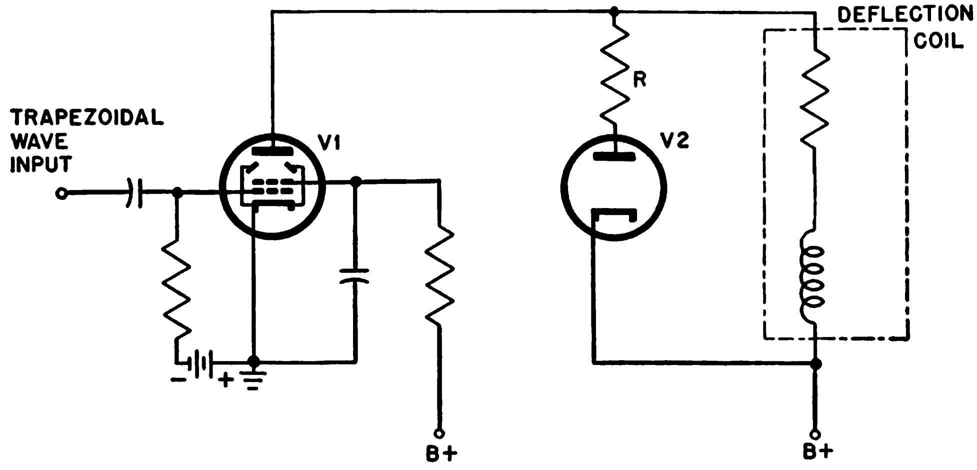


Figure 128. Damping diode connected across deflection coil.

Section VIII. SUMMARY AND REVIEW QUESTIONS

57. Summary

a. A sweep voltage produces a deflection of the electron beam in one direction, usually horizontal, while the signal to be observed causes a deflection which is at right angles to this direction.

b. A linear sweep produces equal amounts of deflection in equal periods of time. Time can be measured along the trace produced by a linear sweep. This trace is referred to as a timebase.

c. The sweep frequency must be exactly equal to or a submultiple of the signal frequency to be observed in order to see 1 or more cycles of the signal on the screen .

d. A rapidly moving spot, which continually reforms the same pattern of light on the screen, produces a stationary pattern on the screen.

e. In a conventional oscilloscope, it is necessary for the sweep generator to be adjustable over a wide frequency range and to produce a linear sweep voltage with a short retrace time.

f. The gradually rising voltage across a charging capacitor can be used to produce a sawtooth sweep voltage. The gradually rising current through an inductor can be used to produce a sawtooth sweep current.

g. A neon tube or thyratron circuit can be used to produce a sawtooth sweep. The frequency of the sweep varies inversely with the time constant of the charging circuit and directly with the applied voltage.

h. An electron tube used as a discharge tube actuated by a pulse can produce a gated sweep whose duration is controlled rigidly by the length of the negative input pulse.

i. A multivibrator can be used as a sweep generator. The circuit is usually asymmetrical and one of the tubes is used as a discharge device for a capacitor.

j. The blocking oscillator is well suited for the generation of sweep voltages. It produces a series of widely spaced narrow pulses of plate current.

k. The blocking oscillator often is used with a discharge tube so that the inductance of the blocking-oscillator transformer does not increase the retrace time and reduce the sweep amplitude.

l. Triggered sweep generators are used when the sweep frequency must be controlled rigidly by some externally produced signal.

m. A synchronizing signal is a control voltage which is used to stabilize the sweep frequency so that a stationary pattern is produced on the screen. Synchronization causes the sweep-generator frequency to lock-in at the exact frequency or subharmonic of the synchronizing signal.

n. An excessive synchronizing voltage can result in pattern distortion, erratic pattern jumping, superimposition of one pattern over another, or excessive change in sweep frequency.

o. A nonlinear timebase produces pattern distortion and results in inaccuracy in measuring time on the cathode-ray tube screen. Some methods of improving the linearity of the sweep include the use of a constant-current pentode, a nonlinear amplifier, an additional time-constant circuit, or feedback networks.

p. A circular sweep is used when a longer trace is to be produced on the cathode-ray tube screen. Precise measurement of short time intervals is made possible when sine waves, whose frequencies are controlled closely, are used to produce the sweep.

q. Radial deflection generally is used on a circular sweep to prevent pattern distortion and permit observation of the exact location of signal voltages on the sweep.

r. Expansion of the timebase is used when it is desired to examine closely signals appearing on a portion of the normal sweep.

s. An exponential sweep produces a nonuniform speed of spot motion. A high speed sweep occurs at the beginning of the trace and this speed is reduced gradually as the spot reaches the end of its travel.

t. A delayed sweep can be produced by a pickoff diode or a delay multivibrator. This allows a small portion of the sweep to occupy the entire screen of the cathode-ray tube.

u. In order to produce a linear sweep for an electromagnetic cathode-ray tube, a sawtooth current must flow through the deflection coils. This is produced by applying a trapezoidal voltage to the deflection coils.

v. A sawtooth voltage generator can be converted to a trapezoidal voltage generator by inserting a resistor in series with the sweep-generating capacitor so that both charge and discharge currents flow through the resistor.

w. Damping must be used to prevent large-amplitude, shock-excited oscillations from destroying the linearity of the sweep. These oscillations are caused by the rapid change of current through the deflection coils of an electromagnetic cathode-ray tube during the rapid retrace.

58. Review Questions

a. What is the purpose of a sweep voltage or current?

b. Along which axis of the screen is the dependent variable usually displayed?

c. What is meant by a linear sweep? What is a timebase?

d. What is meant by the terms retrace or flyback?

e. Why should the retrace time be as short as possible?

f. What frequency relation must exist between the sweep signal and the signal to be observed on the screen in order to see a pattern consisting of one or more cycles?

g. Describe the screen pattern which is produced when the sweep frequency is twice that of the signal frequency.

h. Give several reasons why an adjustable sweep frequency is required for an ordinary oscilloscope.

i. Why must a sweep voltage be linear?

j. Why is the effect of the retrace time greater when high sweep frequencies are used?

k. In a gas-tube sweep-generator circuit, explain why the capacitor voltage rises more slowly than it falls. What determines the frequency of the sawtooth waveform produced?

l. How does an increase in the applied voltage improve the linearity of a neon-tube sawtooth generator?

m. Give some operating characteristics of the gas-tube sweep generator?

n. What is the purpose of the sweep gate which is used in some electron-tube sweep generators? What determines the sweep length in the sweep generator which uses a discharge tube actuated by a pulse?

o. How can a free-running multivibrator be used as a sweep generator? Why is the multivibrator usually asymmetrical?

p. Why does the blocking-oscillator sawtooth generator produce a sweep voltage whose retrace time is short?

q. How is the sweep frequency changed in the blocking-oscillator sweep generator?

r. What is the purpose of the discharge tube used with the blocking oscillator for sweep generation?

s. What is the function of the damping resistor used in some blocking oscillator sweep generators?

t. Distinguish between a sweep generator that is triggered and one that is synchronized. What differences exist in these two methods of frequency control?

u. What is the difference between triggered sweeps and gated sweeps?

v. Why does the input trigger applied to a driven blocking-oscillator sweep generator initiate the retrace rather than the trace?

w. What is the effect of a *drift* in the frequency output of the sweep generator?

x. What is the purpose of synchronization of the sweep generator? Give some common sources of sync signals.

y. Why is it necessary to control the amplitude of the sync signal used? What are the results of insufficient amplitude of sync signal? Excessive amplitude of sync signal?

z. What is meant by sweep linearization and why is it important?

aa. What characteristic of a pentode allows it to be used for sweep linearization?

ab. How can a nonlinear amplifier be used to improve the linearity of a sweep? Of an additional time-constant circuit?

ac. At what portion of a sine-wave sweep voltage is the motion of the electron beam fastest?

ad. How can a circular sweep be produced? Give some uses of the circular sweep.

ae. Give an application of the sine-wave sweep.

af. Why is a radial deflection on a circular sweep desirable?

ag. Give several methods of producing radial deflection on a circular sweep.

ah. What is an advantage of a spiral sweep?

ai. Why can an exponential sweep generator be used to produce an expansion of the timebase?

aj. Give another method of expanding the timebase.

ak. For what purpose is an expanded sweep used?

al. What is meant by a delayed sweep?

am. Why is a trapezoidal voltage required to produce a linear sweep in an electromagnetic cathode-ray tube?

an. Why is the shape of the voltage required for fast sweeps in electromagnetic cathode-ray tubes different from that required for slow sweeps?

ao. How can a conventional sawtooth generator be modified to produce a trapezoidal output voltage?

ap. Why must damping be used with electromagnetic cathode-ray tubes?

aq. Give several methods of producing damping.

CHAPTER 4
VERTICAL AND HORIZONTAL AMPLIFIERS

Section I. VERTICAL-AMPLIFIER SYSTEM

59. Input Signal Voltage

a. Oscilloscope Displays. The signals to be observed on a cathode-ray oscilloscope are conventionally applied to the vertical-deflection circuits. Because the deflection sensitivity of the cathode-ray tube is usually too low to apply the signal directly to the deflection plates, a vertical amplifier is needed. These signals are voltages whose waveforms or instantaneous values are to be determined by viewing them on the cathode-ray tube screen. For some special types of oscilloscope displays, both linear and nonlinear sweep voltages can be applied to the vertical-amplifier input.

b. Other Displays. There are other displays, such as appear on radar and television scans, in which the waveform of the input signal voltage cannot be observed directly on the cathode-ray tube screen. Instead, the signal will cause a vertical deflection whose shape will be determined by other circuits. For example, in one type of radar display the vertical deflection of the sweep depends on the elevation of the antenna. In other systems, a simple timebase is applied to the vertical amplifier. The exact signals which can be delivered to the input of the vertical amplifier vary with the purpose and function of each type of display.

60. Circuit Requirements

a. Input Impedance.

(1) A *perfect* vertical amplifier has an infinite input impedance. This amplifier draws no current from the vertical signal source. With an infinite input impedance, the vertical amplifier does not load the output circuit supplying the signal. In practice, an infinite input impedance cannot be obtained. However, input impedances of several megohms are common in typical vertical amplifiers.

(2) In some special displays, the input signal to the vertical amplifier is coupled from a low-impedance source. Unless the input impedance of the vertical amplifier matches the low source impedance, serious distortion in the waveform display results. The input impedance then must be made low. A typical value is 50 to 70 ohms.

(3) The input capacitance of the vertical amplifier should be as low as possible. This capacitance shunts the vertical signal source. It bypasses the high-frequency components of any complex input signal and distorts the waveform. Typical values of input capacitances in vertical amplifiers are from 10 to 30 $\mu\mu f$.

b. Frequency Response.

(1) The vertical-amplifier circuit is designed for the cathode-ray tube display desired. Its frequency response requirements are determined by the frequency characteristics of the signals used. If different types of oscilloscopes are examined to determine the frequency response of their vertical amplifiers, widely differing results are found (fig. 129). In general, the cost and complexity of an amplifier increase as frequency response is increased. An oscilloscope for examining signal frequencies up to 100 kc (kilocycles), does not require a vertical amplifier with good response up to 1 mc. Also, a field maintenance technician probably would not require as wide a frequency response to examine a specific waveform as a laboratory engineer examining the same waveform.

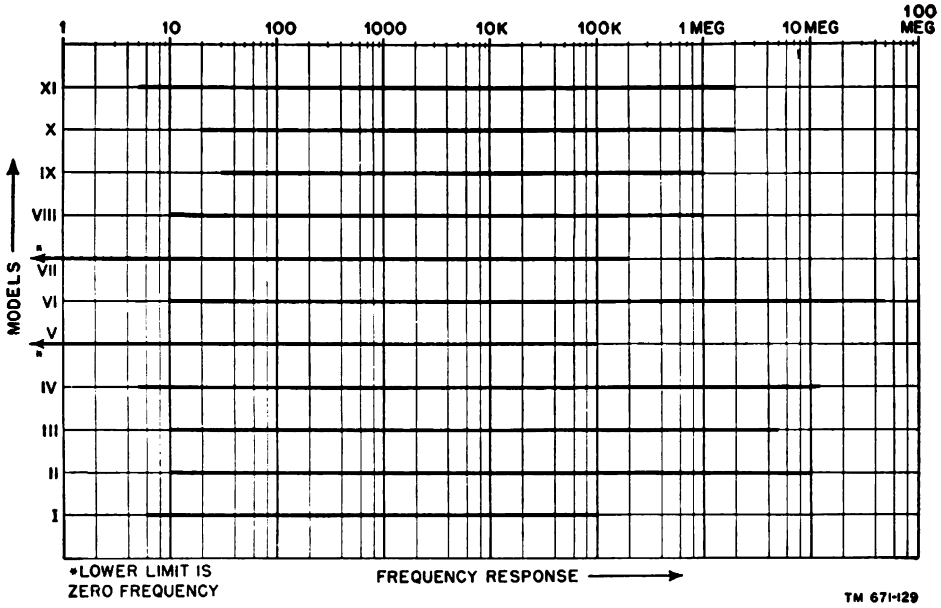


Figure 129. Usable frequency ranges of various oscilloscopes.

(2) Frequency-response requirements increase considerably when complex waveforms must be examined. A vertical amplifier with a good response from 10 cycles to 1 mc can be used for sine waves within and somewhat beyond this frequency response. However, it seriously distorts a square wave whose fundamental frequency is 100 kc. This is true because the amplifier is not able to handle higher than the tenth harmonic of the complex waveform.

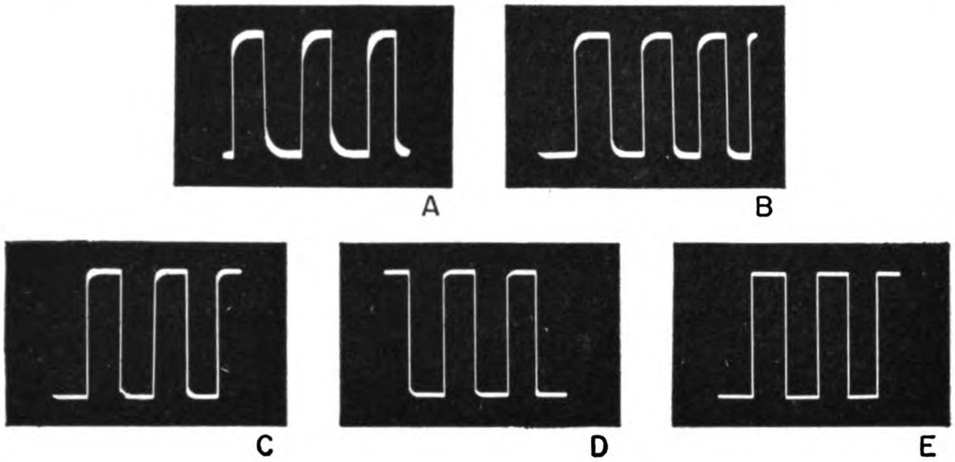
(3) The most common complex waveform of voltage applied to the vertical amplifier is the square wave. A perfect square wave contains an infinite number of odd harmonics of its fundamental frequency. This waveform has zero rise and decay times as well as a perfectly flat top and bottom. The voltage changes from a maximum positive plateau to a maximum negative plateau instantaneously. To amplify a waveform containing an infinite number of harmonics without distortion requires an amplifier with an infinite bandwidth. Such a waveform and such an amplifier do not exist. Any change in voltage, no matter how abrupt, requires a certain amount of time to occur. If there is any shunt capacitance in a circuit, as there always is, the rate of change of voltage is reduced further. The voltage across a capacitor cannot change instantaneously. Also, every amplifier introduces some distortion, no matter how carefully designed.

(4) The actual square wave applied to a vertical amplifier contains several hundred odd harmonics. Figure 130 illustrates the effect of adding more harmonics. In order to reproduce a square wave with reasonable fidelity, the vertical amplifier should have a bandwidth which will pass the tenth odd harmonic of the fundamental frequency. This is a frequency of 21 times the fundamental. For more accurate work, the vertical amplifier should have a bandwidth which can pass the fortieth odd harmonic. The low-frequency response of the vertical amplifier also is important. In general, the lowest frequency square wave which is satisfactorily passed by an amplifier is about 10 times the low-frequency cut-off of the amplifier.

(5) If the waveform applied to the vertical amplifier has a very short time duration (fig. 131), a different method of calculating the required frequency response is used. The minimum upper limit of the amplifier response is inversely proportional to the pulse duration:

$$f_{\max}=\frac{1}{d}$$

where $f_{\max}$ is the required minimum upper limit of amplifier response in megacycles and d is the pulse duration in microseconds. For example, a 1-microsecond rectangular pulse requires that the vertical amplifier have a minimum uniform frequency response up to 1mc. A ¼-microsecond rectangular pulse requires a minimum upper frequency response to 4 mc.



A, contains 10 harmonics; B, 25 harmonics; C, 100 harmonics; D, 500 harmonics; and E, over 500 harmonics.

Figure 130. Square waves containing various numbers of odd harmonics.

(6) The vertical-amplifier frequency-response requirements also are affected by the rise time of a pulse. The rise time is the time the pulse takes to go from 10 percent to 90 percent of its maximum amplitude (**fig.** 132). Shorter rise times require higher frequency response in the vertical amplifier.

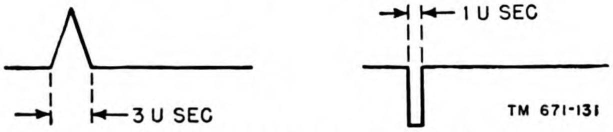


Figure 131. Complex waveforms of short time duration.

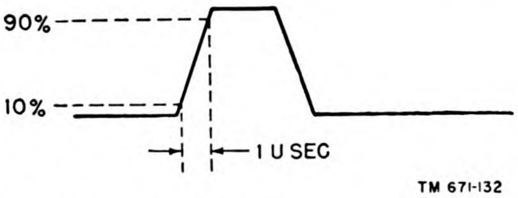


Figure 132. A short pulse whose rise time is 1 usec.

c. Phase Shift and Delay.

(1) Complex waveforms consist of a fundamental plus harmonic frequencies which are added in a certain phase relationship. If the phase of some of the harmonics is shifted with respect to the fundamental frequency, a change in waveform results. To prevent this distortion, the vertical amplifier must have a phase shift which is proportional to the frequency of the components. Each component of a complex wave will then be delayed by the same time interval, thus reproducing the original waveform.

(2) For example, a certain complex wave is composed of a fundamental sine wave and its second harmonic (fig. 133). The waveform passes through the amplifier, where the fundamental is delayed by an interval of time which equals ¼ cycle or 90°. In order to maintain the same relationship between the fundamental and the second harmonic, it is necessary for the second harmonic to be delayed by an equal interval of time. To obtain the same interval of time delay, the second harmonic must be delayed by ½ cycle or 180°. If a third harmonic were present, it would have to be delayed by ¾ cycle or 270°. Consequently, a linear phase

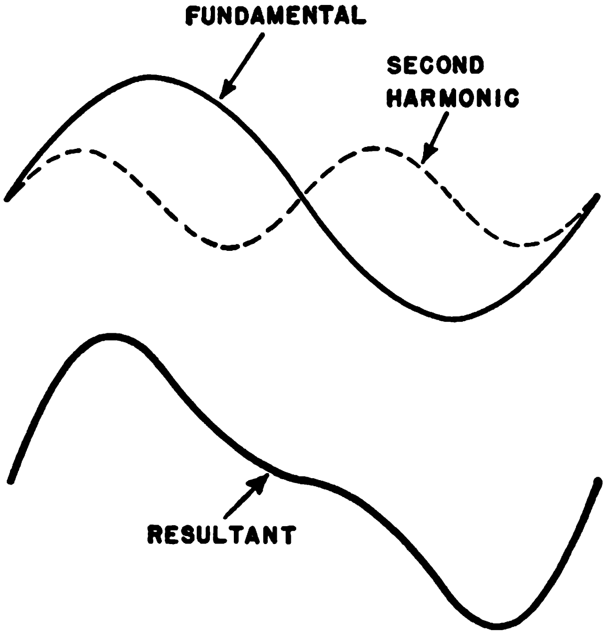


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Figure 133. Complex wave composed of a fundamental sine wave and a second harmonic.

shift is produced which is directly proportional in degrees to the frequency ratio of the harmonic to the fundamental.

d. Gain.

(1) The vertical amplifier should have enough gain to produce a good-sized pattern on the cathode-ray tube screen. This gain should allow some vertical expansion of the pattern in order to examine a small portion of the waveform. What this amount of gain will be depends on many factors. The physical size of the cathode-ray tube is one factor. A good-sized pattern on a large tube would not be the same size as the picture on a small tube. The deflection sensitivity of the cathode-ray tube is another factor. The higher the deflection sensitivity, the lower is the voltage required to produce a given vertical deflection. Still another factor is the amplitude of the input signal. An input signal whose amplitude is low requires an amplifier with a greater gain than is needed for a large amplitude signal. If an input signal is large enough, no vertical gain is necessary, and it can be applied directly to the vertical-deflection plates of the cathode-ray tube.

(2) Bandwidth has an adverse effect on gain. Almost every circuit modification that improves bandwidth does so by cutting down the gain. Where a very wide bandwidth is required, more stages of amplification usually are needed to make up the loss in gain.

(3) Two methods are used to state the amount of gain in the vertical amplifier. The first is the actual voltage gain of the amplifier. If an amplifier has a voltage gain of 60, the amplitude of the output signal voltage is 60 times the amplitude of the input. A second method is more common. In this method, the deflection factor is the amount of a-c input voltage in rms (root means square) values necessary to produce 1 inch of deflection on the cathode-ray tube screen. This is equal to the reciprocal of the gain of the amplifier times the deflection factor of the cathode-ray tube for 1 inch of deflection on the screen.

(4) A certain oscilloscope has a deflection factor of .8-volt a-c (rms) per inch deflection. The peak value of this voltage is 1.13 volts, and the peak-to-peak value is 2.26 volts. With no horizontal deflection, a vertical line of light 1 inch in length is produced by this voltage (fig. 134.). Typical values of deflection factors range from .01- to 1-vole a-c (rms) per inch deflection for general-purpose oscilloscopes.

(5) Excessive gain is not desirable in the vertical amplifier. Such an amplifier is unstable and susceptible to excessive noise and interference pick-up. The input circuit is more sensitive to improper grounding or shielding and to external fields.

61. Attenuators for Oscilloscope

The purpose of the attenuator is to provide a means for controlling the signal level. As the amplifier is a fixed-gain device, the output can be changed by changing the amplitude of the input signal voltage. The smaller the input signal, the smaller the output voltage. The attenuator also serves to prevent the amplifier from being overloaded as a result of excessive input signal voltages.

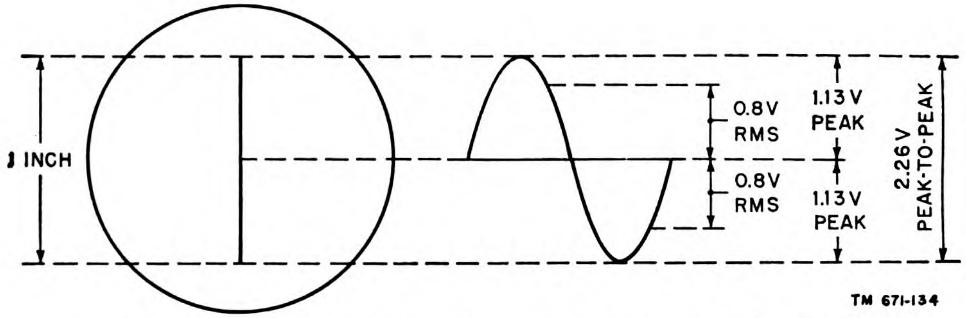

Figure 134. A deflection factor of .8-volt a-c (rms) per inch deflection.

a. Potentiometer Gain Control.

(1) Two systems of attenuation are used which are based on the simple potentiometer gain control (fig. 135). One of these (A of fig. 135) uses a conventional R-C coupling circuit. The resistor is variable, so that the amount of signal voltage applied to the input of the constant-gain amplifier can be controlled. Frequently, the amplitude range of signal voltages to be applied to the vertical amplifier is very broad. At the same time, smooth control over small changes in signal level is required. These requirements cannot be met with a single control. A step-voltage divider can be used to produce large fixed changes in the amplitude of an input signal, while the potentiometer is used to produce small changes in input signal level. With this method (B of fig. 135) both coarse and fine control of input signal level is obtained (fig. 136).

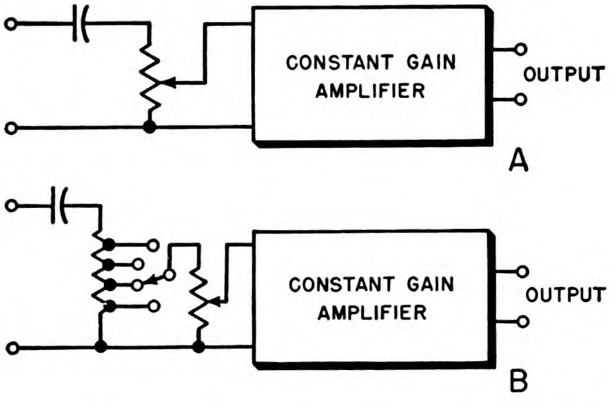

Fig. 135. Two systems of attenuation based on the simple potentiometer gain control.

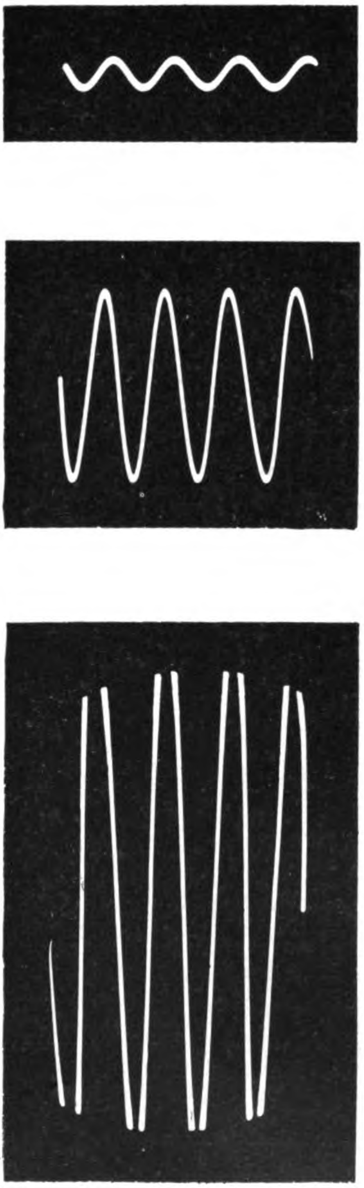

Figure 136. Effect of various settings of the vertical input attenuator.

(2) In some applications, the peak amplitudes of the input signal remain constant. The amplifier then can be designed to produce a fixed amount of gain. If an attenuator is used, its setting is fixed, and fixed resistors take the place of the potentiometer.

b. CATHODE-FOLLOWER ATTENUATOR.

(1) A cathode-follower stage sometimes is inserted between the input terminals and the potentiometer. The signal voltage is developed across a resistance and applied directly to the grid of the cathode follower, or a step-voltage divider can be inserted (fig. 137). This stage is essentially an impedance transformer. The high input impedance of the cathode follower prevents loading of previous circuits, which distorts the input signal. Also, the low output impedance minimizes the effect of shunt capacitance. This reduces the loss of the high-frequency components when complex waves are applied to the vertical amplifier.

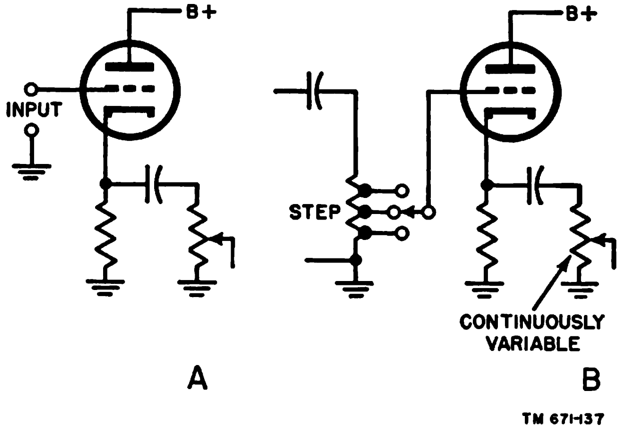

Figure 137. Two forms of cathode-follower attenuators.

(2) A low-resistance potentiometer can be used which affords a smooth control of input signal amplitude. The cathode follower serves to isolate the vertical amplifier from the circuit which supplies the vertical signal.

(3) When a step-voltage divider is used, a fixed resistor often is placed in series with the potentiometer. This prevents the variable control from reducing the signal below a certain minimum. Under these conditions, the step control must be adjusted to reduce the amplitude of the signal applied to the cathode follower. This arrangement reduces the possibility of overloading the input stage with an extremely strong signal.

c. FREQUENCY-COMPENSATED ATTENUATOR.

(1) The attenuator potentiometer is frequency sensitive because of the distributed capacitance between the moving arm of the potentiometer and the wiring and circuit elements. Also, there is stray capacitance and vacuum-tube input capacitance between the moving arm and the ground. There is only one setting of the attenuator arm where the resistance division and the capacitance division are in the same ratio. Figure 138 shows the distortion produced at various potentiometer settings.

(2) The resistance of the potentiometer should be as high as possible to maintain maximum input impedance. However, the greater the resistance, the greater is the effect of stray capacitance. The use of a small resistance minimizes the distortion caused by capacitance; it can, however, seriously load the input circuit. Also, if the resistance is made small, the time constant of the R–C coupling circuit is reduced. This introduces distortion at the low frequencies unless the input coupling capacitance is increased by using a capacitor of larger physical size with consequent increase in stray capacitance.

(3) Some means must be provided to compensate for the frequency sensitivity of the attenuator. It is difficult to compensate a simple potentiometer used alone as the attenuator. Usually, the step attenuator or cathode-follower attenuator is used instead. In the first case, the potentiometer has low resistance, and compensation is applied to the step-voltage divider (fig. 139).

(4) Shunt capacitors C1 and C2 are added to the attenuator to provide frequency compensation. When the attenuator is set to position 2, the input to the amplifier is reduced to one-tenth of the total signal across the voltage divider. R2 is then one-tenth of R1 plus R2. The ratio of

capacitive reactances must be in the same order to minimize frequency distortion. The reactance of C2 and the stray capacitive reactance caused by C3 must be one-tenth the total reactance of C1 in series with the parallel combination of C2 and C3. Values of C1 and C2 are so chosen as to produce the required ratio.

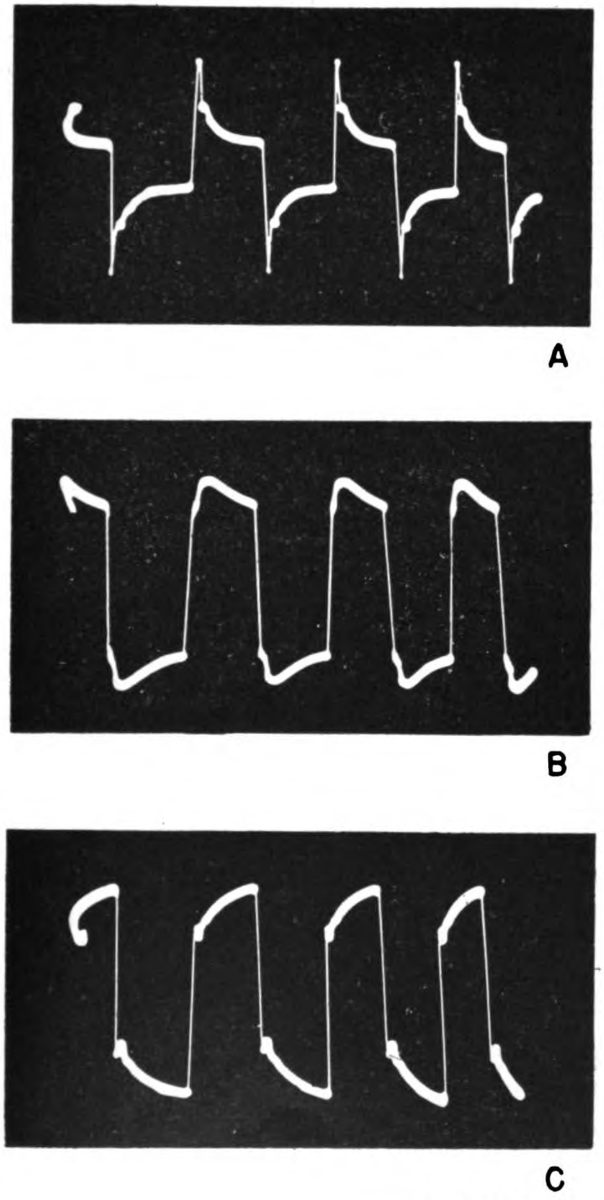

Figure 138. Oscillogram showing distortion to square-wave input at different potentiometer settings. A very low setting of the potentiometer produced the top waveform; the midposition setting produced the center waveform; the maximum setting produced the bottom waveform.

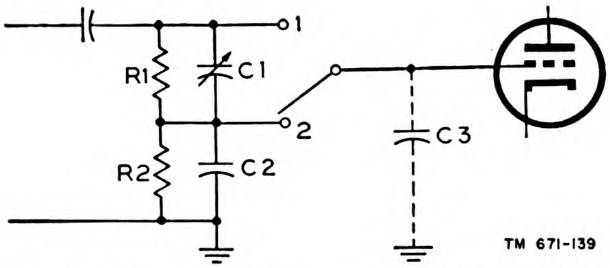

Figure 139. Schematic of a compensated step attenuator.

Because of the difficulty of measuring the value of C3, C1 is made variable. This permits adjustment while the circuit is operating. The effect of proper and improper adjustment of C1 can be seen in figure 140.

(5) Most attenuators and amplifiers have reduced high-frequency response because of the shunting effect of stray capacitance, and a high-frequency compensating circuit is usually inserted. It is located at the input of the attenuator, and consists of a parallel R-C circuit in series with the input lead. This circuit boosts the relative response of the attenuator at high frequencies.

Figure 140. Effect of incorrect adjustment of C1 is shown when a square-wave input is applied.

62. Input Probes

a. A probe sometimes is used at the end of a special connecting cable which applies a signal to the vertical amplifier (fig. 141). The probe houses a frequency-compensated voltage divider. It is so constructed as to reduce to a minimum the amount of shunt capacitance existing at its input terminals.

b. The purpose of the probe is to increase the input impedance and reduce the shunt capacitance of the vertical amplifier. The probe attenuates the signal considerably; therefore, greater gain or a larger signal is required. The connecting cable to which the probe is attached is made short and is shielded. This is done to prevent stray signal and noise pick-up.

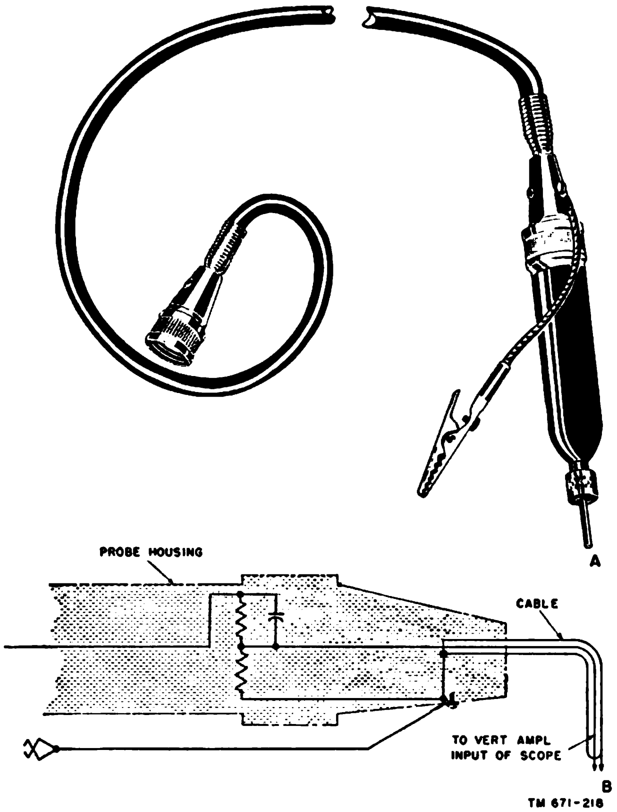

Figure 141. Input probe for vertical amplifier and schematic diagram of a typical probe circuit.

63. Typical Circuit
(fig. 142)

a. An input signal is applied to a cathode-follower attenuator stage. The input circuit contains a two-step voltage divider which uses frequency compensation. C202 is adjusted so that the time constant of the circuit consisting of R201 and C202 is the same as the time constant of the circuit consisting of R203, R202, C203, and the shunt capacitance from the grid of V201A to ground. When this adjustment is made, the attenuation is practically constant for all frequencies. This attenuation is in the circuit only when the attenuator switch is in the INPUT UNDER 250V RMS position. No input attenuation is provided for signals under 25 volts. The input impedance is constant at about 2 meg for either setting of the attenuator switch. The input capacitance is about 40 $\mu\mu$f.

b. The purpose of the cathode-follower stage has already been discussed. Although the cathode of V201A is returned to a −280-volt connection, the plate current flowing through R205 and R204 makes the cathode positive with respect to ground. The output of this stage, which is obtained across R204, is coupled through a large coupling capacitor to the potentiometer R206. This control is used to vary the amplitude of the signal that is applied to the first stage of vertical amplification. This control is the Y-AXIS GAIN VERNIER.

c. A two-stage, wide-band voltage amplifier follows. Frequency-compensation networks extend the range of this amplifier down to about 2 cycles and up to about 1 mc. High-frequency compensation is provided by means of peaking coils L201 and L202. These coils provide inductive reactance which increases with frequency. The normal amplifier response drops at higher frequencies because of the shunt capacitances, and the peaking coils tend to compensate for this effect. The use of small plate-load resistors, R213 and R214, further reduces the effect of shunt wiring and tube capacitances. The value of the cathode bypass capacitor, C209, is small enough to cause degenerative feedback at low frequencies. This flattens the response at low frequencies by decreasing the signal input.

d. The low-frequency response of the amplifier is improved by the use of R-C filter circuits which are in series with the peaking coils. These circuits are composed of R211 and C207 in the first stage of amplification and R212 and C208 in the second stage of amplification. When the frequency of the signal applied to the amplifier is low, the reactance of C207 and C208 is high, and resistors R211 and R212 are less effectively bypassed. The plate-load impedance is increased and a greater output voltage is produced. Therefore, the normal drop in amplifier response which would ordinarily occur at about 30 cycles is compensated for. The low-frequency response of the amplifier is extended down to about 2 cycles by these low-frequency compensation circuits.

e. Good low-frequency response is also maintained by the use of long time-constant coupling circuits. The coupling circuit between the first and second stages of amplification consists of C210 and R215. The time constant of this circuit is 1 second. The coupling circuit between the second stage and V201B is composed of C206 and R209. The time constant here is also one second. Degenerative feedback in the second stage improves the frequency response and the stability of the amplifier.

f. The output of V202B is coupled to a cathode

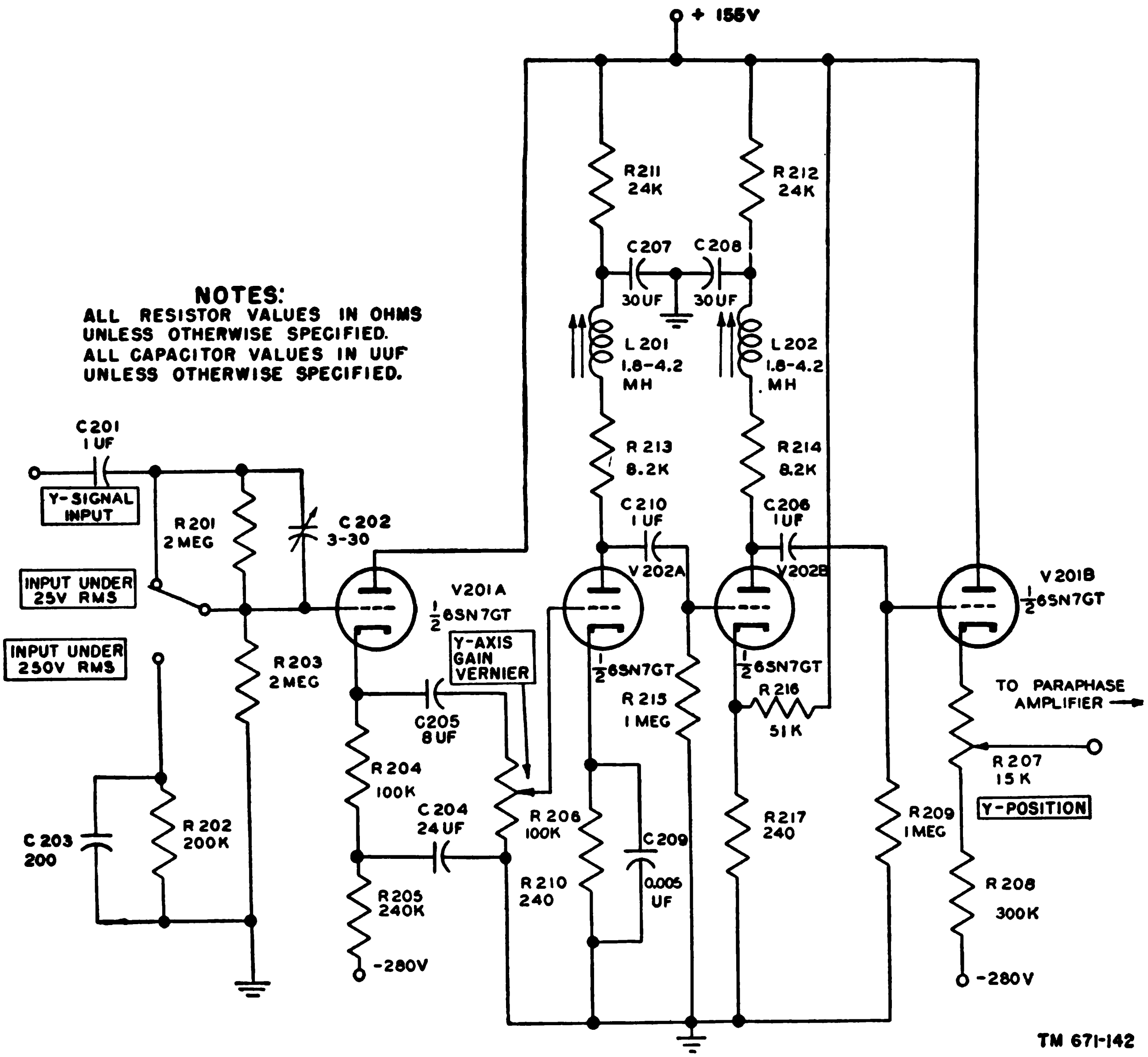

Figure 142. Schematic diagram of a vertical amplifier excluding output stage.

follower. This stage is used as a wide-range isolating stage which employs direct coupling to the paraphase amplifier which follows. The function of the amplifier and the Y-POSITION control will be described later.

64. Paraphase Amplifiers and Balanced Output

a. Reason for Use.

(1) Earlier it was shown that a nonuniform deflection field would defocus the electron beam in a cathode-ray tube. Instead of a small, sharply defined round spot of light, the electron beam produces a large, elliptical spot. The deflection field can be fairly uniform near the axis of the cathode-ray tube, but away from the axis considerable nonuniformity can exist. This produces defocusing of the pattern near the periphery of the screen. In addition to spot defocusing, the pattern itself can be distorted by nonuniform deflection fields. If the horizontal-deflection field is not quite horizontal and the vertical-deflection field is not exactly vertical, a distorted pattern is produced. To prevent defocusing and pattern dis-

tortion, uniform deflection fields are needed.

(2) The positive side of the high-voltage power supply usually is grounded. This maintains a minimum difference of potential between the accelerating anode and the deflection plates. If this is not done, the deflection field is extremely nonuniform. Another reason for this connection is that high-voltage insulation between the accelerating anode and the deflection plates and circuits is not required.

(3) In simple circuits, unbalanced or single-ended deflection is used. In this arrangement, one deflection plate of the cathode-ray tube is grounded and the deflection voltage is applied to the other plate. This voltage is positive or negative with respect to ground. As the accelerating anode is at the same potential as the other deflection plate, a nonuniformity in the deflection field is produced. Defocusing of the beam and pattern distortion result.

(4) In balanced or push-pull deflection, neither deflection plate is grounded. Signals are applied to both deflection plates. These signals are equal in amplitude and opposite in polarity. When one deflection plate is charged to a potential that is above that of the accelerating anode (ground), the opposite deflection plate is charged to an equal potential that is below that of the accelerating anode. Under these conditions, the equipotential line midway between the two charged plates is maintained at ground potential. The effect of the accelerating anode potential in distorting the deflection field is minimized. With balanced deflection, beam defocusing and pattern distortion are reduced.

(5) Another advantage of balanced deflection is that the amplitude of the deflection signal required is one-half that required for unbalanced deflection. In single-ended deflection, a 20-volt positive signal applied to the upper deflection plate may produce a 1-inch vertical deflection. In push-pull deflection, the same amount of deflection is produced by the application of a 10-volt positive signal to the upper deflection plate and a 10-volt negative signal to the lower deflection plate. In both cases, the difference in potential between the charged plates is 20 volts. In unbalanced deflection, one plate is 20 volts above ground and the opposite plate is grounded. In balanced deflection, one plate is 10 volts above ground and the other plate is 10 volts below ground.

(6) Another advantage of balanced deflection is the greater linearity of the deflection. This is accomplished by the reduction of even-harmonic distortion in the push-pull amplifier and by the symmetrical application of deflection voltages.

b. SIMPLE PHASE INVERTER.

(1) An ordinary vacuum-tube amplifier has a plate output which is opposite in polarity to its input signal. If a positive peaked wave is applied to the grid of the amplifier, plate current rises. This increases the voltage drop across the plate-load resistor. The effective plate voltage of the amplifier is therefore reduced by the amount of voltage drop across the load. This drop in effective plate voltage can be coupled through an R-C coupling circuit to another stage. The coupling circuit removes the d-c component. The remaining signal is a negative peaked wave. Thus, an ordinary vacuum-tube amplifier is a phase inverter because it produces an output voltage which is opposite in polarity to the input.

(2) If balanced deflection is used, two voltages of equal magnitude and opposite polarity are required. A phase inverter following an amplifier can be used (fig. 143). The output of the amplifier is applied to one of the vertical-deflection plates, and also through a fixed attenuator to the phase inverter. The attenuator reduces the amplitude of the amplified signal which comes from the amplifier so that the output of the phase inverter will have the same magnitude as the output of the amplifier.

c. PARAPHASE AMPLIFIERS.

(1) This circuit produces two output voltages which are equal in amplitude but opposite in polarity. The circuit is used

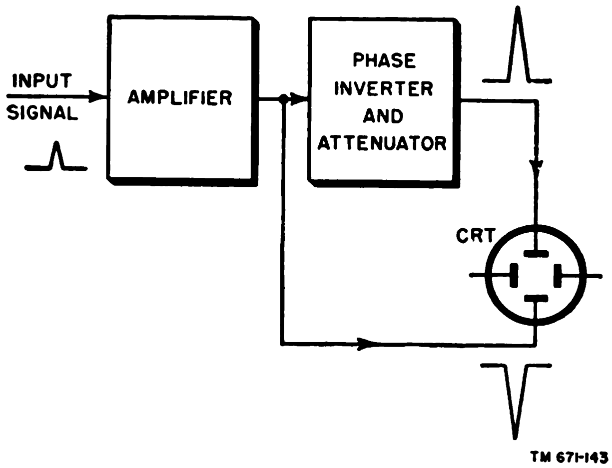

Figure 143. Simple phase inverter used to produce balanced vertical deflection.

to obtain balanced deflection. There are many different paraphase amplifier circuits. Two examples are shown in figure 144.

(2) In the single-tube circuit, the positive input signal is inverted at the plate because of conventional amplifier phase-inverter action. This negative peak is coupled to the upper vertical-deflection plate of the cathode-ray tube. A signal of opposite polarity is coupled to the other deflection plate. This is obtained at the cathode circuit as a result of the change in voltage across R2. The voltage obtained at this point is of like polarity to the original input signal. The circuit behaves like a combination of ordinary amplifier and cathode follower. To obtain two deflection voltages which are equal in amplitude it is necessary to make R1 and R2 equal. The current through R1 and R2 is the same; therefore the voltage drops across them are equal.

(3) In the cathode-coupled paraphase amplifier, the signal is applied to the grid of V1 through the coupling circuit C1–R1. This tube operates as a conventional amplifier whose output is coupled to one vertical-deflection plate. If a positive peaked wave is applied to the input of this tube, its output is an amplified negative peaked wave. The voltage at the cathode end of R2 with respect to ground has the same polarity and waveform as the input signal. If tubes V1 and V2 are similar and the values of load resistors R3 and R4 are the same, the no-signal currents through the tubes will be equal. The sum of these currents flowing through R2 will develop a bias voltage for both tubes of a value that will maintain this current flow. Then the application of a positive signal voltage to the grid of V1 will increase the plate current in this tube and tend to increase the bias voltage across R2. However, because of the grounded grid of V2, an increase of the bias voltage at the cathodes will decrease the current through V2,

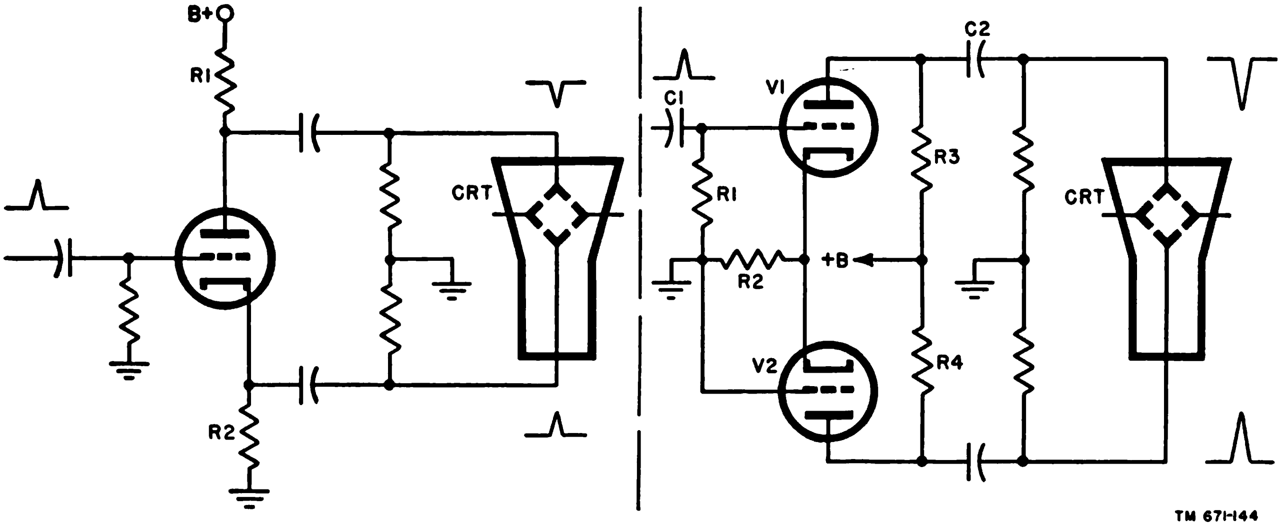

Figure 144. Paraphase amplifiers used to produce balanced vertical deflection.

thus tending to reduce the bias voltage across R2. This reduction in bias voltage caused by reduction in V2 current cannot be equal to or greater than the increase in bias voltage caused by increase in V1 current, or there would be no bias change across R2 to cause the reduction in V2 current. This means that the change in current in V2 must always be less than the change in current in V1, whether caused by a positive or negative input signal. As a consequence, the voltage change across R4 will be less than that across R3, or the amplification of V2 will be less than that of V1. In order to obtain equal output voltage changes from the two tubes, it is necessary either to make R4 larger than R3 or to use a higher gain tube for V2 than for V1.

(4) The output signal from V2 is reversed in polarity from the input signal, as in any ordinary vacuum tube amplifier. The input voltage to V2 is the voltage developed across the bias resistor R2, which is of the same polarity as the input signal. Because the signal is applied to the cathode of V2 and the grid is grounded, the output signal at the plate of V2 has the same polarity as the input signal at the cathode of V2 or the input signal at the grid of V1. Therefore, the signals applied to the vertical deflection plates of the cathode-ray tube are opposite in polarity.

(5) The paraphase amplifier usually serves as the final stage of amplification in the vertical-amplifier system. In order that these amplifiers do not restrict the bandwidth, they also must have wide frequency response, low distortion, and time delay proportional to frequency. Compensation circuits similar to those discussed earlier are used in the paraphase amplifier. For simplicity, these networks are not shown in the schematic diagrams.

65. D-C Amplifier

a. Need for D-C Amplifier.

(1) A d-c amplifier is one which amplifies very slow variations in voltage. It is used when the signals applied to the vertical amplifier are low in frequency and when good low-freqency response is required, or when changes in the level of a d-c voltage are to be amplified. Usually the high-frequency response of the d-c amplifier is limited. When an extended high-frequency response is required, the d-c amplifier generally is not used. This circuit responds to voltage changes with practically no delay, and no distortion resulting from differentiating action occurs. The use of d-c amplifiers also permits a d-c voltage to be superimposed on an a-c signal in the vertical amplifier. This is one method of centering or positioning the pattern and will be discussed later.

(2) Any component which prevents the passage of d-c from the plate to the following grid must be removed if d-c amplification is used. R-C coupling circuits cannot be used; direct coupling must be used.

b. Simple D-C Amplifier Circuit (fig. 145). The plate-load resistor of V1 also acts as the grid resistor for V2. The plate current of V1 flows through R and produces a voltage drop of 55 volts. The d-c voltage applied to the grid of V2 is then 185 volts. The cathode of V2 is connected to a point on the voltage divider whose potential is 190 volts. Under these conditions, the grid operates at a potential of minus-5 volts. Very low frequencies are amplified satisfactorily by this circuit.

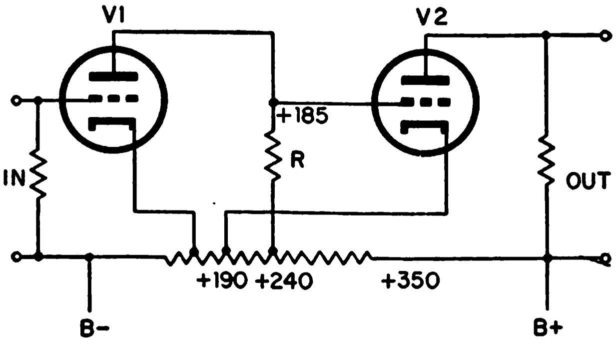

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Figure 145. Schematic of simple d-c amplifier.

c. Disadvantages. In view of the excellent low-frequency response and absence of undesirable phase distortion in the d-c amplifier, it would seem that it should be more widely used. The most serious disadvantages are that the bias settings are very critical and subject to drift, causing large d-c changes in the output, and the fact that in most d-c amplifier circuits the input and output circuits appear at very different voltage levels for d-c; that is, the input circuit may have one side grounded, but then the output circuit is at a high d-c positive potential, or vice versa. Circuits designed to prevent this and to allow both input and output to be grounded do so at a sacrifice of gain and frequency response.

Section II. HORIZONTAL-AMPLIFIER SYSTEM

66. Signal Requirements

a. Oscilloscope Displays. The most common horizontal input signal to the horizontal-deflection plates is the sawtooth sweep voltage. This sweep voltage produces the horizontal timebase on the cathode-ray tube screen. The horizontal amplifier is required to increase the amplitude of the sawtooth sweep so that it produces sufficient horizontal deflection. For special types of oscilloscope displays, nonlinear voltages are applied to the horizontal amplifier.

b. Other Displays. Many radar displays require a horizontal timebase. A sawtooth signal is applied to the horizontal amplifier just as in the oscilloscope. Other radar displays use a special form of sawtooth sweep which is triangular in shape. In television displays, a horizontal timebase is also required.

67. Circuit Requirements

a. Input Impedance. As with the vertical amplifier, it is desirable for the horizontal amplifier to have a high input impedance to prevent loading the preceding circuit. Also, the input capacitance should be as low as possible to prevent undesired shunting effects.

b. Frequency Response.

(1) If the same types of signal are applied to the horizontal amplifier as to the vertical amplifier, the frequency responses of both amplifiers should be the same. Usually, however, the frequency-response requirements of the horizontal amplifier are much lower. The sweep frequency is usually a submultiple of the vertical signal frequency. Consequently, the horizontal amplifier bandwidth can be lower than that of the vertical amplifier. If the lowest vertical signal frequency is 30 cps and more than 1 cycle is to be observed on the cathode-ray tube screen, the sweep frequency must be 15 cps or 10 cps. The horizontal amplifier must handle these low frequencies with a minimum of distortion.

(2) The high-frequency response usually is limited as compared to the required high-frequency response of the vertical amplifier. There are two reasons for this. First, the sweep frequency need not be as high as the signal frequency. Second, the nature of the sawtooth waveform is such that the number of harmonics required to produce reasonable reproduction is less than for other complex waves. As explained earlier (par. 60*b* (4)) at least 10 odd harmonics are required for adequate square-wave reproduction. This is the twenty-first harmonic of the fundamental. Consequently, an amplifier must respond to a frequency of 21 times the fundamental. Unlike the square wave, the harmonics which constitute a sawtooth wave are both odd and even. Frequencies up to the tenth harmonic are required for adequate sawtooth reproduction. Consequently, an amplifier must respond to a quency of 10 times the fundamental.

(3) In an actual sawtooth wave, harmonics above the seventh have been found to contribute little to the linearity of the waveform. Therefore, if the horizontal amplifier has a high-frequency response up to the seventh harmonic, adequate linearity is obtained.

(4) A 15-kc square wave is applied to the vertical amplifier. It is desired to observe 3 cycles. The sweep frequency must be adjusted to produce a 5-kc sawtooth wave. For reasonable reproduction, the bandwidth of the vertical amplifier must be 300 kc. However, the bandwidth of the horizontal amplifier need be only 35 kc. If it is desired to observe

1 cycle, the sweep rate is raised to 15 kc. The horizontal amplifier must now have a high-frequency response up to 100 kc.

(5) Several typical oscilloscopes were examined to discover the comparative bandwidths of their vertical and horizontal amplifiers. These bandwidths are as follows:

Model	Vertical amplifier band width (cps)	Horizontal amplifier band width (cps)
I	2 to 200,000	1 to 100,000.
II	10 to 1,000,000	5 to 250,000.
III	5 to 11,000,000	2 to 500,000.
IV	20 to 2,000,000	10 to 100,000.

c. GAIN.

(1) The horizontal amplifier should have sufficient gain to produce an adequate horizontal deflection. There should be sufficient reserve gain to permit horizontal expansion of the pattern.

(2) The horizontal input signal frequently is a locally generated sawtooth sweep. The amplitude of the sweep-generator output often is sufficiently great that little amplification is needed to produce adequate horizontal deflection. This amplifier need not be as flexible as the vertical amplifier because the horizontal input is a fixed amplitude signal. The vertical amplifier can be required to amplify signals having amplitudes of a fraction of a volt. This usually is not true for the horizontal amplifier. The voltage gain of the horizontal amplifier is, at most, equal to that obtained in the vertical amplifier. In some oscilloscopes it can be as little as one-hundredth of the vertical gain.

(3) There are special applications in which the amplitude of the horizontal input signal is very low. Under these conditions, a high-gain horizontal amplifier is needed. The exact frequency and gain requirements for this amplifier, as for the vertical amplifier, are determined by the particular input signals which are applied.

d. ATTENUATORS. The horizontal amplifier is a fixed-gain device. It requires an input attenuator for the same reasons as the vertical amplifier. An attenuator permits an adjustment of input signal level (which determines the amplitude of the output), and prevents overloading the amplifier. As the attenuator, a simple potentiometer gain control, a step-voltage divider, as in the vertical amplifier (fig. 146), or a cathode-follower attenuator can be used.

68. Balanced Output

The need for a balanced output in the horizontal amplifier is just as great as in the vertical amplifier. An unbalanced output causes beam defocusing and pattern distortion. Consequently, a simple phase inverter or a paraphase amplifier often is used as the output stage in the horizontal amplifier.

69. Typical Circuit

a. It is not necessary to show a separate schematic diagram of a typical horizontal amplifier. The circuit described previously can be used for purposes of discussion. The amount of high-frequency compensation can be reduced and the low-frequency response can be increased. A reduction in gain can be tolerated.

b. Some oscilloscopes use identical circuits for both the horizontal and the vertical amplifiers. Usually, however, the horizontal circuits are much less elaborate.

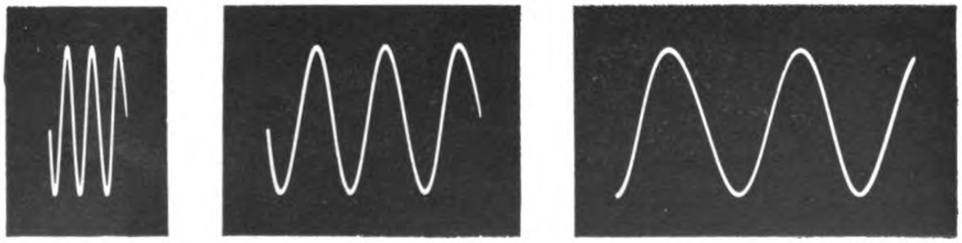

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Figure 146. Effect on the cathode-ray tube pattern of various horizontal attenuator settings.

Section III. POSITIONING CIRCUITS

70. Need for Positioning Circuits

a. One reason for using a positioning circuit is to center the undeflected electron beam properly. If the cathode-ray tube electron gun were perfectly alined, the undeflected electron beam would follow the axis of the tube. The spot of light would then be positioned at the exact center of the screen. A slight manufacturing misalinement of only a few degrees can displace the spot as much as one-half inch or more from the center of the screen. When deflection voltages are applied, the resultant pattern will not be centered properly. A positioning circuit enables the picture to be centered. For this reason, these circuits often are called *centering* circuits. The controls associated with the circuits are called centering controls.

b. A second use for a positioning circuit is to shift the pattern to any desired location on the screen. For example, assume that a slight distortion is observed on the positive peak of the observed waveform. It is desired to examine the distortion closely. The amplifier attenuators are adjusted to produce large amplitude deflection voltages. The positioning control is then adjusted to move the entire pattern downward. The positive peak can be centered on the screen, where it can be observed closely.

c. Both horizontal—and vertical—positioning circuits are used. These circuits are often identical in a particular piece of equipment. The output of one circuit affects the vertical position of the pattern or spot, allowing the pattern to be moved up or down. The output of the other circuit affects the horizontal position of the pattern or spot, allowing the pattern to be moved to the left or right.

71. Method Used to Accomplish Positioning

a. Positioning circuits operate by applying d-c voltages to the deflation plates or direct current to the deflection coils. In the absence of any other deflection signal, this d-c voltage or current sets up a field of constant intensity which moves the electron beam.

b. When deflection voltages are applied to the deflection plates, the d-c positioning voltages are added to the deflection signals. In this way, these signals are given a d-c component. Assume that an a-c sine wave is applied to the vertical-deflection plates of a cathode-ray tube. A sawtooth sweep of equal frequency is applied to the horizontal-deflection plates. There is an equal amount of deflection above and below the axis of the cathode-ray tube. The pattern on the screen appears as in A, figure 147.

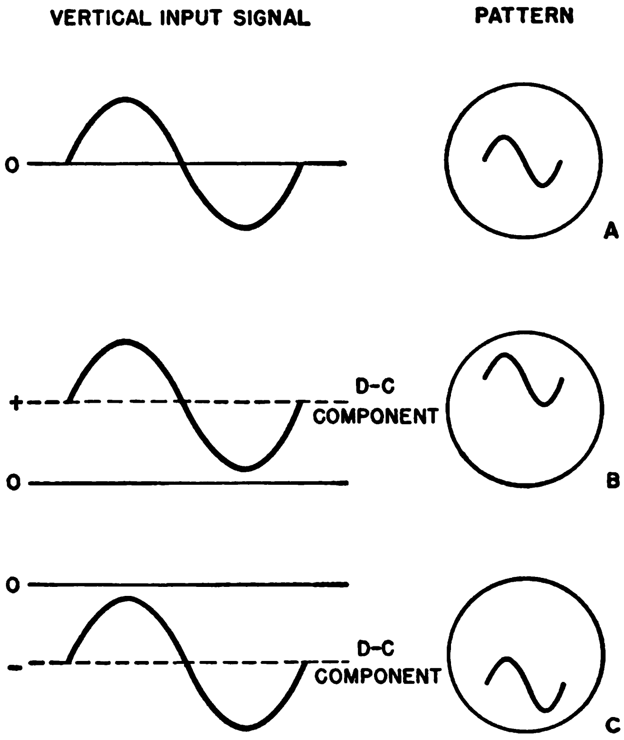

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Figure 147. Effect of vertical-positioning voltage.

c. If a positive d-c voltage is inserted in series with the a-c signal that is applied to the upper vertical-deflection plate, this symmetrical condition no longer exists. Instead, the deflection voltage varies above and below an average positive d-c value. Assume that this average d-c value is of such amplitude as to cause the beam to move vertically upward 1 inch (B, fig. 147). The entire pattern is displaced upward by this amount. If a negative d-c voltage is inserted, the entire pattern is moved vertically downward (C, fig. 147). The distance the pattern is displaced is directly proportional to the amplitude of the positioning voltage.

d. In single-ended deflection systems, one deflection plate is grounded. The d-c positioning voltage is inserted in series with the signal applied to the opposite deflection plate. In balanced systems, positioning voltages must be applied to both deflection plates. These voltages are equal in magnitude but opposite in polarity. Similar requirements apply to the horizontal-positioning voltages.

72. Typical Circuits

a. Positioning in Output Stage.

(1) The circuit shown in figure 148 can be used for vertical positioning when unbalanced deflection is used. The amplified signal from the last stage of vertical amplification is coupled through capacitor C1 and appears across resistor R1. This a-c voltage is the vertical-deflection signal. Resistors R3 and R4 form a voltage divider across a power supply. R2 is a potentiometer which acts as the vertical-positioning (or centering) control. As the potentiometer arm is moved, it taps off a d-c voltage ranging from −400 to +400 volts. This d-c voltage is the positioning voltage and it is inserted in series with the a-c signal voltage developed across R1. When the arm is at its midposition, no positioning voltage is applied, as the arm is at ground potential. When the arm is moved toward the negative end of the potentiometer, the pattern moves down. As the arm is moved toward the positive end, the pattern moves up. Capacitor C2 is a low-reactance path to ground for the a-c deflection signal and a block to d-c. It also serves as a filter to reduce the effect of power-supply voltage changes or transients produced by the action of the moving contact.

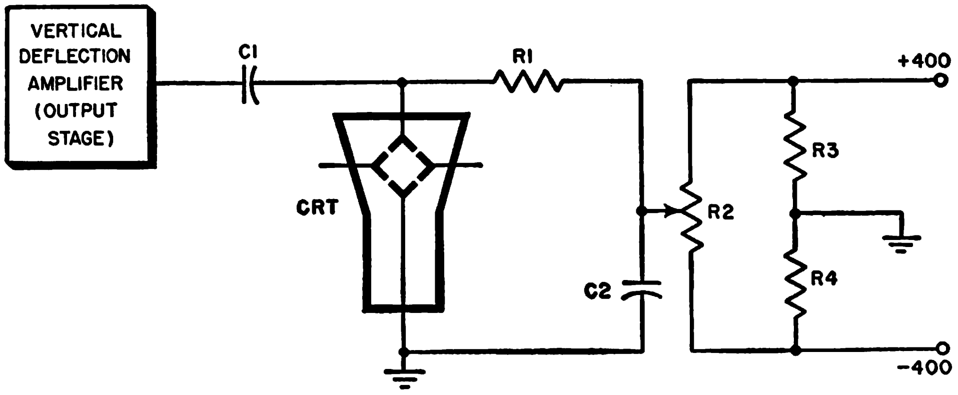

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Figure 148. Positioning circuit with unbalanced deflection.

(2) With balanced deflection, a dual or *back-to-back* potentiometer is used. This potentiometer applies equal but opposite polarity voltages to opposite deflection plates. A simple circuit is shown in figure 149. Deflection signals from a paraphase amplifier are applied to the vertical-deflection plates by means of coupling circuits C1–R1 and C2–R2. Capacitors C3 and C4 are bypass and filter components. Resistors R5 and R6 form a voltage divider across the power supply. The vertical-positioning control consists of the potentiometers R3 and R4, which are ganged together. As the arms on this dual control are moved to the left, a negative d-c voltage is applied to the upper vertical-deflection plate. At the same time, a positive d-c voltage is applied to the lower vertical-deflection plate. This causes the pattern to move down. When the arms on the dual potentiometer are moved to the right, the polarity of d-c voltage is reversed. A positive potential is applied to the upper deflection plate and a negative potential is applied to the lower deflection plate. This causes the pattern to move up. A similar circuit is used with the horizontal-deflection plates to produce horizontal positioning.

b. Positioning Between Stages.

(1) A drawback of the two positioning circuits described above is the sluggishness of the positioning controls. When

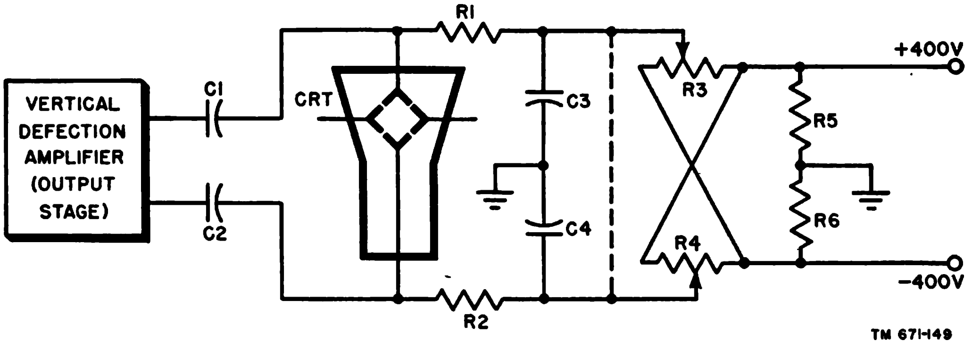


Figure 149. Positioning circuit with balanced deflection.

good low-frequency response is needed, the time constant of the R-C coupling circuits must be very long. This requires that R1–C1 (figs. 148 and 149) and R2–C2 (fig. 149) be made very large. Any change in the setting of the positioning control must change the amount of charge on these coupling capacitors.

(2) Until the capacitors can readjust their charge to the new voltage level, charging current will flow through the resistors. The voltage drop produced opposes the positioning voltage. This retards the action of the positioning potential until the capacitors change their charge to the new value. The amount of time required for this depends on the time constant of the R-C combination. The longer the time constant, the more sluggish is the operation of the positioning controls.

(3) To overcome this drawback, the circuit shown in figure 150 is used in the vertical system. The sawtooth sweep voltage is applied to the grid of the cathode follower V9. The plate of this stage is connected to a +155-volt regulated power source, while the lower end of the cathode resistor R38 is connected to a −280-volt source. The sizes of resistors R37 and R38 are so chosen that, with normal plate current flowing through V9, the midpoint of potentiometer R37 is at ground potential.

(4) V10 and V11 serve as a paraphase ampli-

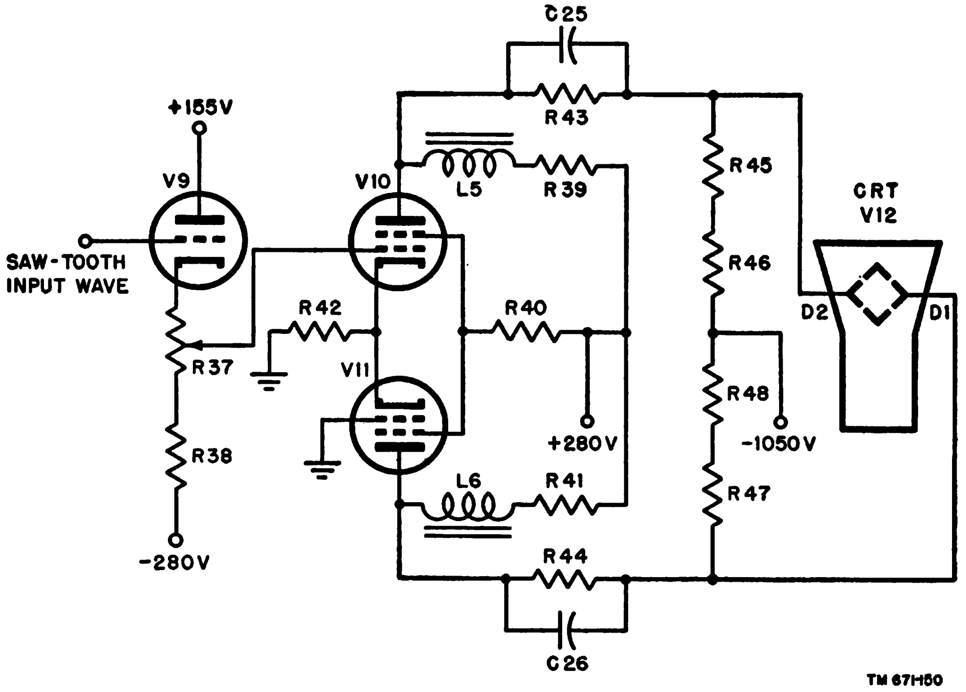
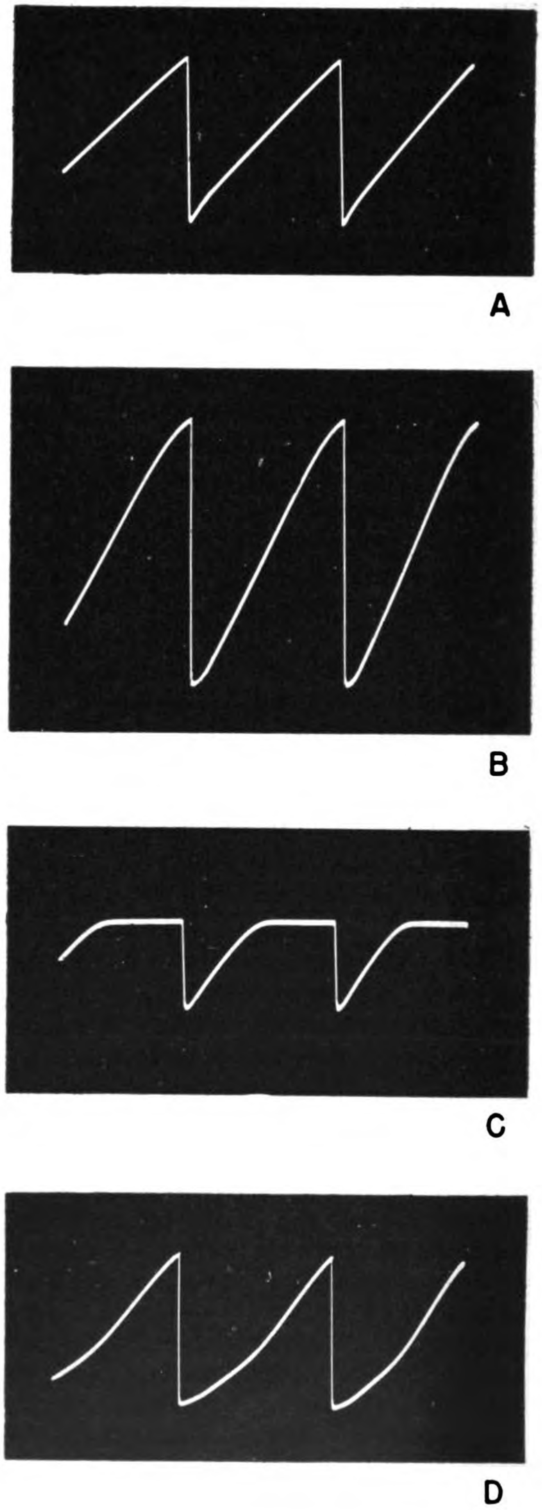


Figure 150. Horizontal-deflection paraphase amplifier with horizontal positioning between stages.

fier, whose operation has already been described. This amplifier uses a combination of peaking coils, L5 and L6, and the circuits R43 C25 and R44 C26 to extend the high-frequency response of the circuit. The impedance of the R-C combination is lower at high frequencies than at low frequencies. Consequently, the higher frequencies are coupled to the deflection plates with less attenuation. Direct coupling is required from the paraphase amplifier to the deflection plates so that the d-c component at the plate circuits will not be lost. This d-c component is to be used as the positioning potential.

(5) With the arm of the horizontal-positioning potentiometer, R37, at its midposition, no d-c component is added to the sawtooth signal applied to the grid of V 10. Under these conditions, the average plate currents of both tubes in the paraphase amplifier are the same. The average d-c plate voltages of both tubes are also the same and no positioning results. The only horizontal deflection is the result of the opposite-polarity sawtooth signals applied to the deflection plates.

(6) Assume that the arm of the positioning potentiometer is moved toward the cathode of V9. Now, a positive d-c component is added to the signal voltage applied to the grid of V10. This causes the average plate current of V10 to rise. The voltage drop across R42 increases, making the cathodes of both V10 and V11 more positive. When this occurs, the amount of negative bias voltage applied to the grid of V11 is increased and its plate current is reduced. The amount of plate current reduction of V11 is not as great as the original amount of plate current increase in V10. Therefore, the voltage drop across R42 is maintained at a larger value than when the potentiometer arm was at its midpoint. Since V10 is passing a larger amount of plate current and V11 is passing a smaller amount, the average plate voltage of V10 is reduced, while the average plate voltage of V11 is increased. The signal volt-



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A and B show substantially linear sawtooth sweep voltages resulting from ordinary positioning control settings. C and D show nonlinear sawtooth sweep voltages resulting from extreme settings of the positioning control.

Figure 151.

age at the plate of V11 varies around a more positive value than that at the plate of V10. Under these conditions, the pattern is displaced toward deflection plate D1.

(7) If the potentiometer arm is moved toward the negative end of the control, the pattern is displaced toward deflection plate D2. Under these conditions, a negative d-c component is added to the signal that is applied to V10. Its plate current is reduced and a smaller negative bias voltage is applied to the grid of V11. The plate current of V11 rises. Now the average positive potential at the plate of V10 is larger than that at the plate of V11. Positioning occurs in the opposite direction to that described in the previous paragraph.

(8) If the resistance of the horizontal-positioning potentiometer is too large, excessive change in operating bias occurs at extreme settings of this control. As a result, the linearity of the sawtooth sweep voltage that is applied to the horizontal-deflection plates suffers (fig. 151). The principal reason for making R37 much smaller than R38 and returning R38 to a high negative voltage is to get a reasonably large d-c voltage change at the arm of R37 without greatly sacrificing signal amplitude from the cathode follower.

(9) Capacitors C25 and C26 are in a position to introduce sluggishness in this system. This is prevented, however, because the maximum voltage change across R43 and R44 is not more than 10 percent of the change in plate voltage. Consequently, since these capacitors are not required to change their charge by a large amount, the lag is not noticeable.

(10) Direct coupling to the deflection plates introduces the problem of maintaining the deflection plates at d-c ground potential. Deflection plate D1 is at ground potential because of the voltage-divider circuit R48, R47, R44, and R41 connected between the −1,050-volt supply and the +280-volt supply. Deflection plate D2 is at ground potential because of the voltage-divider circuit R46, R45, R43, and R39 connected between the same two supplies.

Section IV. SUMMARY AND REVIEW QUESTIONS

73. Summary

a. Amplifiers are required to increase the amplitude of deflection signals so that sufficient deflection is obtained.

b. The deflection amplifier should have a high input impedance and a low input capacitance. It should have a sufficiently wide frequency response to handle the expected signal inputs with reasonable fidelity.

c. When short duration pulses are applied to an amplifier, the minimum upper limit of frequency response should be inversely proportional to the pulse duration.

d. The deflection amplifiers should have a phase shift proportional to frequency, resulting in a constant time delay for the expected frequencies.

e. Sufficient gain should be available to produce the required amount of deflection. Gain usually varies inversely with frequency response.

f. An attenuator is used to provide a means of varying the amount of deflection and to prevent amplifier overloading.

g. Frequency-compensated attenuators improve the frequency response by offsetting the effect of stray circuit capacitance.

h. Input probes are used to increase the input impedance and reduce the shunt capacitance of deflection amplifiers.

i. A cathode-follower attenuator provides a means of obtaining wide range response and isolation of the signal source.

j. Balanced deflection is required to prevent spot defocusing and pattern distortion at locations away from the screen center. To obtain balanced deflection, two voltages which are equal in amplitude but opposite in polarity are needed. A paraphase amplifier provides such an output.

k. D-c amplifiers are used when good low-frequency response is required. These amplifiers require direct coupling between stages.

l. Horizontal-deflection amplifiers usually have a better low-frequency response than vertical-deflection amplifiers. However, the high-frequency response requirements are much lower.

m. Positioning circuits are used to compensate for electron-gun misalinement and to move the pattern to any desired screen location.

n. Positioning is accomplished by applying d-c voltages to the deflection plates or coils in series with the normal deflection signals. These d-c voltages can be applied directly between the output amplifier and the cathode-ray tube or they can be applied indirectly by means of interstage controls and circuits.

74. Review Questions

a. Why is it desirable to have a high input impedance and a low shunt capacitance in a deflection amplifier?

b. Why is a wide frequency response required in a deflection amplifier?

c. What is the purpose of the vertical- and horizontal-deflection amplifiers?

d. If a 400-cps square wave is applied to the vertical-deflection amplifier, what should be the high-frequency response for reasonably good reproduction?

e. Which amplifier must have the greater high-frequency response, one which is to amplify a 2-usec pulse or one which is to amplify a one-half-usec pulse?

f. Would it be desirable to have more gain in the vertical- or the horizontal-deflection amplifier?

g. A certain oscilloscope has a deflection factor through the vertical amplifier of .5 volt a-c (rms) per inch deflection. What value of d-c voltage will result in exactly the same amount of deflection?

h. What is the purpose of an attenuator in a deflection amplifier?

i. Why are attenuators frequency compensated? How is attenuation usually accomplished?

j. What is the purpose of an input probe as used with the vertical-deflection amplifier?

k. What advantages are obtained by using balanced deflection as compared with unbalanced deflection?

l. How can balanced deflection be obtained?

m. Why are d-c amplifiers sometimes used as deflection amplifiers?

n. Compare the frequency response required in the horizontal- and the vertical-deflection amplifiers.

o. If a 400-cps sawtooth signal is applied to the horizontal-deflection amplifier, what should be the high-frequency response for reasonably good reproduction?

p. For what purpose are positioning circuits used?

q. Why are positioning circuits often called centering circuits?

r. How is positioning accomplished?

s. What advantage is obtained in using the positioning circuit in which the control is located between stages rather than the circuit in which the control is beyond the last stage?

CHAPTER 5

AUXILIARY CIRCUITS

Section I. BLANKING AND INTENSIFYING

75. Definitions

a. Blanking. The process of removing all or a portion of the pattern that is displayed on the screen of a cathode-ray tube is known as blanking.

b. Intensity Modulation. This is the process of varying the intensity of the pattern produced by the electron beam in such a way that information is presented.

76. Blanking

a. General.

(1) Usually blanking is used to remove a *part* of a screen pattern that is undesirable. This portion of the pattern may contain some useful information. However, when this information is displayed it may obscure another part of the screen pattern which contains more pertinent information. The blanked portion of the pattern may contain signals which, if not removed, would convey incorrect information. When it is desired to keep the equipment in a stand-by position, blanking also can be used to remove the entire pattern from the screen. All operating voltages then are applied but no pattern appears on the screen.

(2) The most common purpose of blanking is to prevent the sawtooth retrace from appearing on the screen of the cathode-ray tube. The retrace is produced by an electron beam that travels at a greater speed during the retrace than during the trace. As a result, the intensity of the retrace is less than that of the trace. Because of this reduced intensity, the retrace may not be objectionable and in many simple oscilloscopes no blanking is used.

(3) When the retrace is blanked, any information presented during the retrace time is not displayed on the screen. For example, assume that a 5-kc sawtooth sweep voltage is applied to the horizontal-deflection plates of a cathode-ray tube and that a 70-kc sine-wave signal is applied to the vertical-deflection plates. Because the sweep frequency is one-fourteenth of the signal frequency, a pattern consisting of 14 cycles appears on the screen. If the time required for the retrace is one-sixth of the time required for the trace, then 12 cycles of the sine wave appear on the trace and 2 cycles of the sine wave appear on the retrace. When no blanking is used, the 2 cycles that occur during the retrace appear as in A, figure 152. With the retrace blanked, the pattern appears as in B, figure 152.

(4) In the previous example, if it is desired to observe the waveform of the applied signal the use of blanking does not destroy the usefulness of the presentation. However, if a frequency comparison is to be made, the use of blanking can lead to an incorrect conclusion. In B, figure 152, it appears that the sweep is operating at a frequency that is one-twelfth of the signal frequency rather than one-fourteenth of the signal frequency. In this case it is not desirable to use blanking.

(5) Blanking the retrace also may remove some required information when a short-duration pulse is to be observed on certain

synchroscopes. Assume that the leading edge of the pulse is very abrupt and that this same pulse is used to trigger the sweep. Suppose that the triggered sweep circuit is a type in which the leading edge of the pulse begins the retrace, as described in chapter 3. Under these conditions, the leading edge will be displayed on the cathode-ray tube screen during the time of the retrace. If blanking is used, the leading edge of the pulse cannot be seen. When the blanking circuit is removed, the start of the pulse appears on the screen.

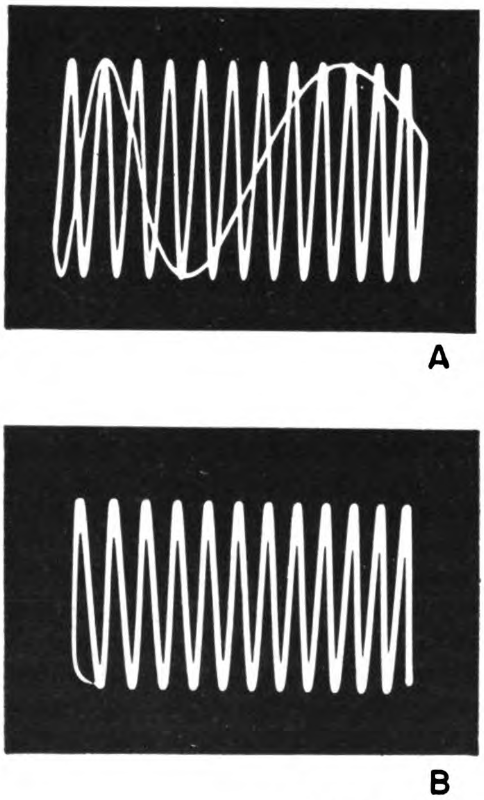

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Figure 152. Effect of blanking the retrace.

(6) However, the amount of information present during the retrace usually is small. A retrace time that is one-sixth of the time required for the trace, as in the example cited in subparagraph (3) above, is unusual except at very high sweep frequencies. With a much shorter retrace time, less information is lost because of blanking. Also, in the same example, if the sweep frequency were increased so that 1 or 2 cycles of the applied waveform appeared on the screen, only a small portion of 1 cycle would occur during retrace.

(7) In certain radar displays, the retrace must be blanked out in order to prevent target signals from being displayed at incorrect ranges. Consider an A-scan display in which the presentation is adjusted to a range of 20,000 yards. The time required for the trace is 122 usec (radar waves travel 328 yards per usec). Assume that the retrace time is one-tenth of the trace time or 12.2 usec, which represents 2,000 yards. Suppose that no retrace blanking is used and that a target signal appears at the exact center of the screen. The signal might have been applied during the trace or during the retrace. In the former case, the range of the target is 10,000 yards and in the later case, the range is 21,000 yards (20,000+2,000/2). When blanking is used and the retrace is removed, no such error in range can occur.

(8) Blanking of the retrace is required in television displays. An increase in background brightness, a reduction in pattern contrast, and the appearance of *retrace lines* through the pattern occur without proper blanking.

b. METHODS OF SIGNAL APPLICATION.

(1) Blanking is accomplished by applying a voltage to the proper electrode of the cathode-ray tube in such a way that the beam current is cut off. With no current to excite the fluorescent screen, no light output is produced. The most common method of cutting off the beam is to apply a large negative bias to the control grid of the cathode-ray tube. The exact value of voltage required depends on the particular tube used and the operating voltages. Typical values of cut-off bias vary from 25 volts to 75 volts for most tubes. When the bias voltage is more negative than the cut-off value of the cathode-ray tube, blanking occurs.

(2) A blanking voltage can also be applied to the cathode of the cathode-ray tube. In this case, the polarity of the blanking

voltage required is reversed. For example, assume that the negative bias voltage required to cut off the beam and blank the pattern in a certain cathode-ray tube is 50 volts. If the cathode of the tube is operated at some fixed high negative potential, such as −1,500 volts, the negative blanking bias is applied to the grid as in A, figure 153. The voltage at the grid with respect to ground is now −1,550 volts. Under these conditions, the grid voltage is 50 volts negative with respect to the cathode voltage and blanking results.

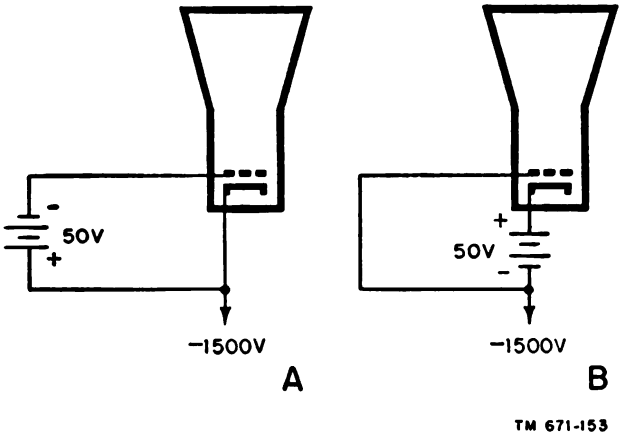

Figure 153. Two methods of making grid negative with respect to cathode.

(3) A blanking voltage also can be applied to the cathode of the cathode-ray tube. The polarity of the blanking voltage required is reversed (B, fig. 153) and placed in the cathode circuit. The control grid of the tube is operated at the fixed negative potential of −1,500 volts. A *positive* blanking bias is applied to the cathode of the cathode-ray tube. The cathode voltage is −1,450 volts because the polarity of the blanking voltage is such as to oppose the supply voltage. Under these conditions, the grid voltage is 50 volts more negative than the cathode voltage, and blanking results. Therefore, when the blanking voltage is negative, it is applied directly to the control grid. When the blanking voltage is positive, it is applied directly to the cathode. In either case, the grid is made more negative than the cathode and blanking results if the voltage is large enough to cut off the electron beam.

(4) Occasionally, a negative blanking voltage is applied to the screen grid of the cathode-ray tube. The amount of blanking voltage required under these conditions is considerably greater than is needed in the grid-cathode circuit since it is operating at a higher voltage than the bias voltage.

c. Signal Sources.

(1) A common source of obtaining a blanking signal is the sweep voltage. The sawtooth sweep voltage is applied to an R-C differentiating circuit, and the resultant square-wave output is used as a blanking signal. If a sawtooth voltage is applied to an R-C circuit whose time constant is short with respect to the period of the input wave, the voltage across the resistor will appear as in B, figure 154. During the time that the sweep voltage rises from A to B (A, fig. 154) a constant small current flows through the resistor in the differentiating circuit because the small rate of change of the sweep voltage induces a small displacement current in the capacitor to maintain a constant voltage across the capacitor. This produces a low-amplitude constant voltage across the resistor. During the time of the retrace from B to C, a large current flows through the resistor in the opposite direction because the large rate of change of the sweep voltage induces a large displacement current in the capacitor to maintain a constant voltage across the capacitor. This produces a large-amplitude voltage across the resistor whose polarity is opposite to that produced during the trace. The amplitude of the resistor voltage is proportional to the rate of change of the sawtooth voltage. The large negative-going voltage shown during retrace times in B, figure 154, is applied to the control grid of the cathode-ray tube to drive it beyond cut-off, thus blanking the tube.

(2) A simplified circuit which uses the foregoing principle is shown in C, figure 154. The sawtooth sweep voltage is applied to the R-C circuit consisting of C29 and R49. The time constant of this circuit is

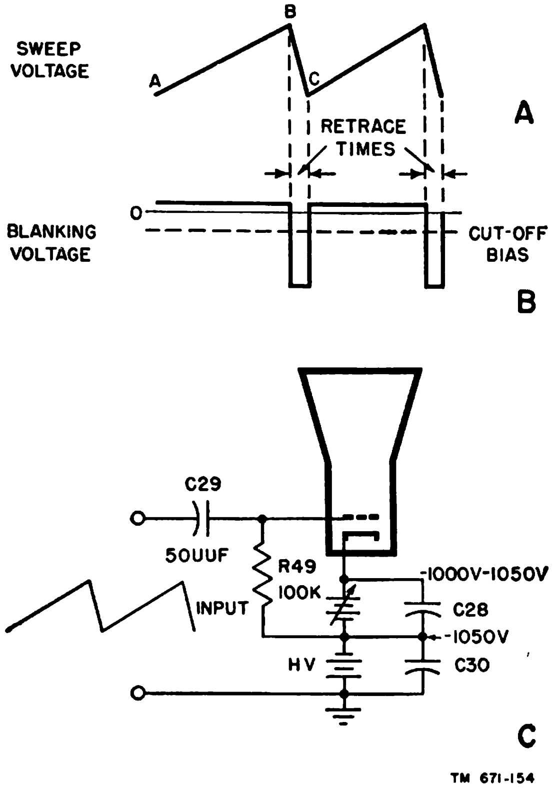

Figure 154. Blanking signal obtained by differentiating sweep voltage.

5 usec which is short as compared to the period of the sawtooth waveform. The voltage across R49 is a rectangular wave having large-amplitude negative pulses that occur during the retrace time. Capacitors C28 and C30 are large cathode bypass capacitors which do not affect the differentiated waveform. The average grid voltage on the cathode-ray tube is −1,050 volts. This voltage is obtained from a high-voltage power supply which is represented by a battery in the figure. A variable voltage source is inserted in the cathode to provide a means of varying the brightness of the pattern. This voltage can be varied from 0 to 50 volts and is connected in such a way as to oppose the high voltage. Therefore, the voltage from cathode to ground can be varied from −1,000 volts to −1,050 volts. As a result, the grid bias can be varied from 0 to −50 volts with respect to the cathode. As the voltage applied to the grid is made more negative, the beam current is reduced and the pattern brightness is decreased. The large-amplitude negative pulses which are produced across R49 increase the bias on the cathode-ray tube beyond cut-off during the retrace times. As a result, the electron beam is cut off during the retrace, and blanking occurs.

(3) Another source of blanking signals is the same circuit that produces the pulse that drives the sweep generator. When the sweep generator is an electron tube actuated by a pulse, some circuit must be used which produces the pulse that controls the operation of the discharge tube. An input rectangular waveform alternately cuts off the tube and drives it into conduction. While the tube is cut off, its plate capacitor charges slowly to produce the trace. When the tube conducts, the plate capacitor discharges rapidly to produce the retrace. This circuit has been discussed in chapter 3. The rectangular waveform can be applied to the cathode of the cathode-ray tube to produce the required blanking.

(4) During the time that the waveform is highly negative, the trace is produced and no blanking is required. During the time that the waveform is less negative (A, fig. 155), the retrace is produced and blanking is required. If the waveform is applied directly to the cathode of the cathode-ray tube, the voltage is shifted toward a less negative voltage during the retrace. With the control grid at a fixed potential, the effect of raising the cathode voltage is the same as the effect of lowering the control-grid voltage. If the amplitude of the rectangular voltage is large enough and the control grid is driven beyond beam cut-off, blanking of the retrace occurs.

(5) In some radar and synchroscope displays, the time between sweeps is greater than the time required for the sweep. In this case the blanking period exceeds the period when no blanking occurs (B, fig. 155). Therefore, the cathode-ray tube can be blanked normally at all times except during the brief times when the trace is produced. An *unblanking pulse*, or intensity gate, is used to overcome the effect of the normal blanking voltage. The po-

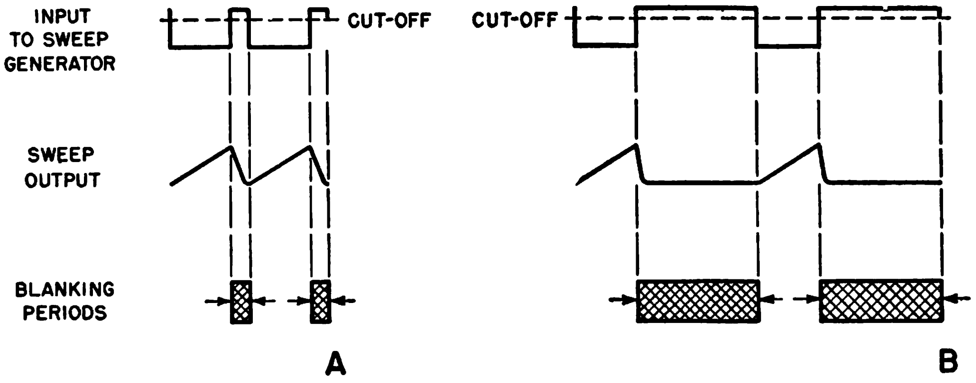

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Figure 155. Blanking signals obtained from sweep-generator input.

larity of the voltage required to unblank or intensify the pattern produced on the screen of a cathode-ray tube is opposite to that required to produce blanking. If the grid voltage normally is beyond cut-off, blanking occurs. When the grid voltage is raised above cut-off, unblanking occurs. In order to unblank the pattern, a positive voltage is applied to the grid of the cathode-ray tube or a negative voltage is applied to the cathode.

(6) When the sweep generator is a multivibrator circuit, the sweep voltage is obtained across a capacitor that is connected from the plate of one tube, or a section of a tube, to ground. A blanking voltage can be obtained from the other tube or section. This voltage is a rectangular waveform in which the length of one alternation is the same as the sweep length. The length of the next alternation is equal to the time between sweeps. When the sweep generator is a blocking-oscillator circuit, the blanking voltage can be obtained by differentiating the sawtooth output as previously explained. Alternately, the trigger voltage produced by the blocking oscillator can be used to drive a multivibrator. The output of the multivibrator is then used for blanking.

(7) Blanking signals can also be supplied to a cathode-ray tube from some external source. In the television display, for example, the television transmitter sends out blanking signals as part of the radiated signal. These signals are amplified and detected by the receiver along with the video signals that produce the actual picture on the cathode-ray tube screen. Blanking occurs at the end of each horizontal scanning line while the electron beam moves from right to left. This eliminates the horizontal retrace. Blanking also occurs at the end of each complete field while the electron beam moves from the bottom of the screen to the top. This eliminates the vertical retrace.

d. MARKERS.

(1) Occasionally, it is necessary to produce a series of evenly spaced markers along a trace. These markers provide a linear scale for the measurement of equal periods of time. If the time interval between markers is constant, they provide a means of checking the linearity of the trace along whose length they are displayed. With a linear trace, equal amounts of deflection occur in equal periods of time. Therefore, if the sweep is linear, the markers, which are repeated at a constant rate, will be displayed with equal spaces between them.

(2) Markers can be applied by blanking the trace at regular intervals. The blanking signal, in this case, is a series of peaked waves whose frequency is constant. This signal can be obtained from a stable sine-wave oscillator whose output is limited to produce a square wave. The square wave is differentiated and applied to a limiter which removes the positive peaks. The resultant waveform is applied to the control grid of a cathode-ray tube to produce the markers required (fig. 156).

The negative peaks have sufficient amplitude to cut off the electron beam. As a result, a series of blank spots appear along the trace. If the trace is linear, the spacing between blank spots will be uniform all along the trace.

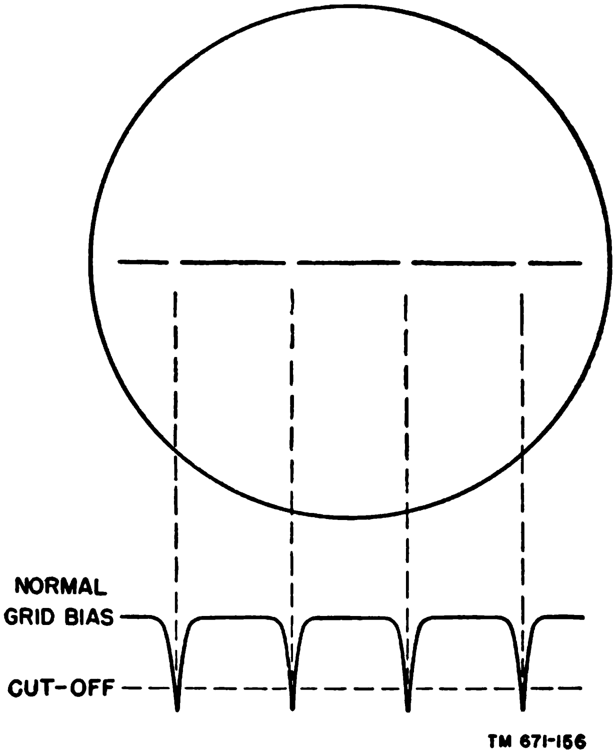

Figure 156. Markers by blanking.

77. Intensity Modulation

a. General.

(1) Information can be presented on the screen of a cathode-ray tube by means of a moving spot of light which has a constant brightness. This spot of light can be deflected horizontally and vertically to produce a pattern on the screen. If a third dimension is added to the pattern, more information can be displayed. The screen of a cathode-ray tube is a plane or two-dimensional surface. Although actual physical depth cannot be displayed, it is possible to represent a third dimension on the screen by varying the density of the electron beam. The beam is at right angles to the screen and any variation of beam density represents a change along an axis which is perpendicular to both horizontal and vertical screen axes. Such an axis is referred to as a Z-axis.

(2) A variation in the density of the electron beam produces a change in the intensity or brightness of the spot of light. If the intensity is made to change in accordance with some intelligence, the result is intensity modulation. In certain radar displays, the presence of targets is disclosed by an increase in the intensity of the pattern. The brightness of the pattern depends on the amplitude of the target signal. When there is no target signal, the intensity of the pattern is zero and no effect is noted. A strong target signal, which can be an echo from a large target, increases the intensity of the pattern considerably. A very intense spot or area of light appears on the screen. A weak signal will produce some increase in brightness. Therefore, the brightness of the pattern is determined by the amplitude of the signal. In this way, information concerning the presence or absence of a target and concerning the amplitude of the echo signal is displayed on the screen.

(3) Intensity modulation is also used to produce a pattern having shades ranging from black to white on the screen of a cathode-ray tube used in a television display. A phosphor is used whose color of fluorescence is white. When the density of the electron beam is maximum, an intense spot or area of white light is produced on the screen. A reduction in the beam density reduces the brightness of the white light so that a gray area appears on the screen. If the beam density is reduced to zero, no fluorescence occurs and darkness results. In this way, a pattern containing all shades from black to white can be produced. The pattern is similar to a black and white photograph or motion picture. The presence of light produces whiteness; the absence of light produces darkness.

b. Methods of Signal Application.

(1) The signal voltage which varies the intensity of the pattern is applied to the control grid or cathode of the cathode-

ray tube. In order to increase the intensity, a positive voltage is applied to the control grid or a negative voltage is applied to the cathode of the cathode-ray tube. This increases the electron beam density and the pattern brightness. A reduction of intensity is produced by applying a negative voltage to the control grid or a positive voltage to the cathode of the cathode-ray tube. This reduces the electron beam density and the pattern brightness.

(2) If the amplitude of the signal is large enough, it can be applied directly to the control grid or cathode of the cathode-ray tube through an ordinary R-C coupling circuit. However, amplification usually is required. One or more stages of video amplification are inserted between the signal source and the proper electrode of the cathode-ray tube. These video amplifiers sometimes are called Z-axis amplifiers.

c. SIGNAL SOURCES.

(1) When intensity modulation is used in an ordinary oscilloscope, it generally is used in conjunction with other waveforms with which a comparison is to be made (fig. 157). The oscillogram in A is produced by applying a sine-wave signal to the vertical-deflection plates of a cathode-ray tube and a sawtooth sweep to the horizontal-deflection plates. The frequency of the sweep voltage is one-third the signal frequency so that a pattern consisting of 3 cycles appears. Another sine wave whose frequency is six times the signal frequency is applied to the control grid of the cathode-ray tube. This waveform produces intensity modulation of the screen pattern. The trace brightness is increased during the positive alternations of grid voltage and is reduced during the negative alternations. In this way, the intensity is varied in accordance with an input signal. Eighteen bright spots are produced on the 3-cycle pattern. The frequency ratio is therefore 18 to 3 or 6 to 1.

(2) In B, figure 157, a circular pattern is produced by applying two sine waves having equal frequency and amplitude but 90° out of phase to the deflection plates. At the same time, a sine wave whose frequency is four times higher is applied to the control grid of the cathode-ray tube. The higher-frequency signal intensity modulates the circular trace. During the positive alternations, the intensity is

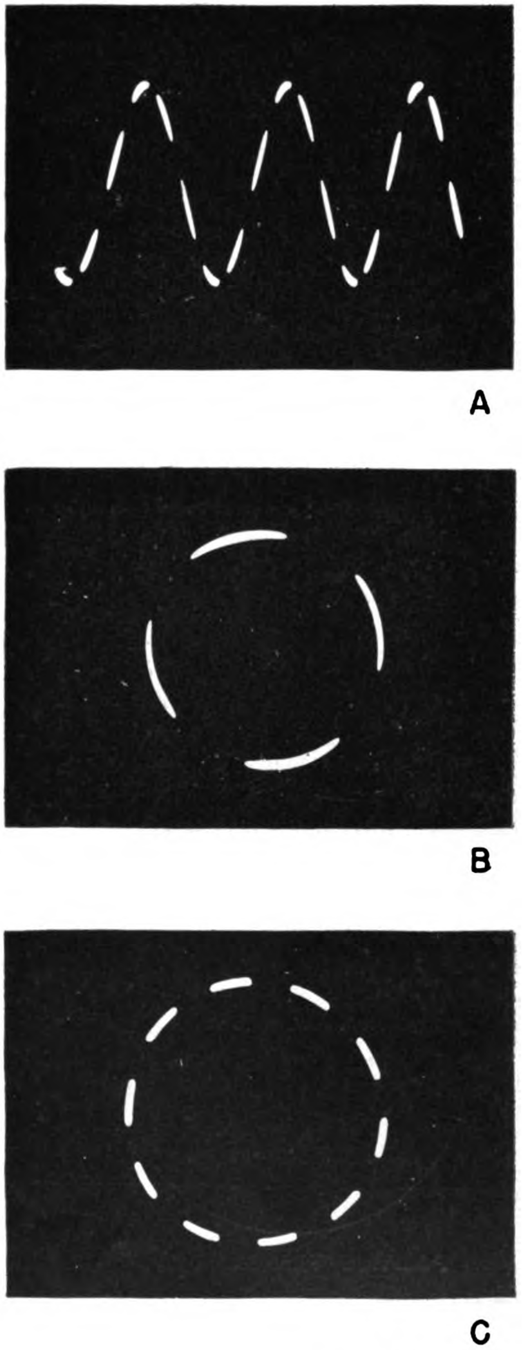

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Figure 157. Intensity-modulated patterns on oscilloscope.

increased and during the negative alternations, it is reduced. In C, figure 157, the intensity-modulation signal frequency is increased to ten times the sweep frequency.

(3) In radar displays that use intensity modulation for signal display, the signals are obtained from the radar receiver. Echo signals which are picked up by the antenna are amplified and detected by the receiver. The output of the receiver is applied through several video amplifiers to the cathode-ray tube. If the polarity of the echo signals is positive after amplification, they are applied to the control grid of the cathode-ray tube. If the polarity is negative, the signals are applied to the cathode of the tube. Video limiting is used frequently to prevent blooming. This will be discussed in greater detail in paragraph 101*e*.

(4) In a television display, the signals that produce intensity modulation are generated at the television transmitter. Special tubes are used which convert variations of light intensity into voltage variations. These changes in voltage are amplified and combined with the blanking and synchronizing pulses. The entire combination amplitude modulates a radio-frequency carrier which is radiated by the transmitting antenna. The receiver picks up these signals, amplifies and detects them, and separates the synchronizing pulses from the other components. The synchronizing pulses are applied to the sweep generators as described in chapter 3. The remaining elements are applied to the control grid or cathode of the cathode-ray tube. The blanking pulses remove the retraces while the rest of the waveform produces inten-

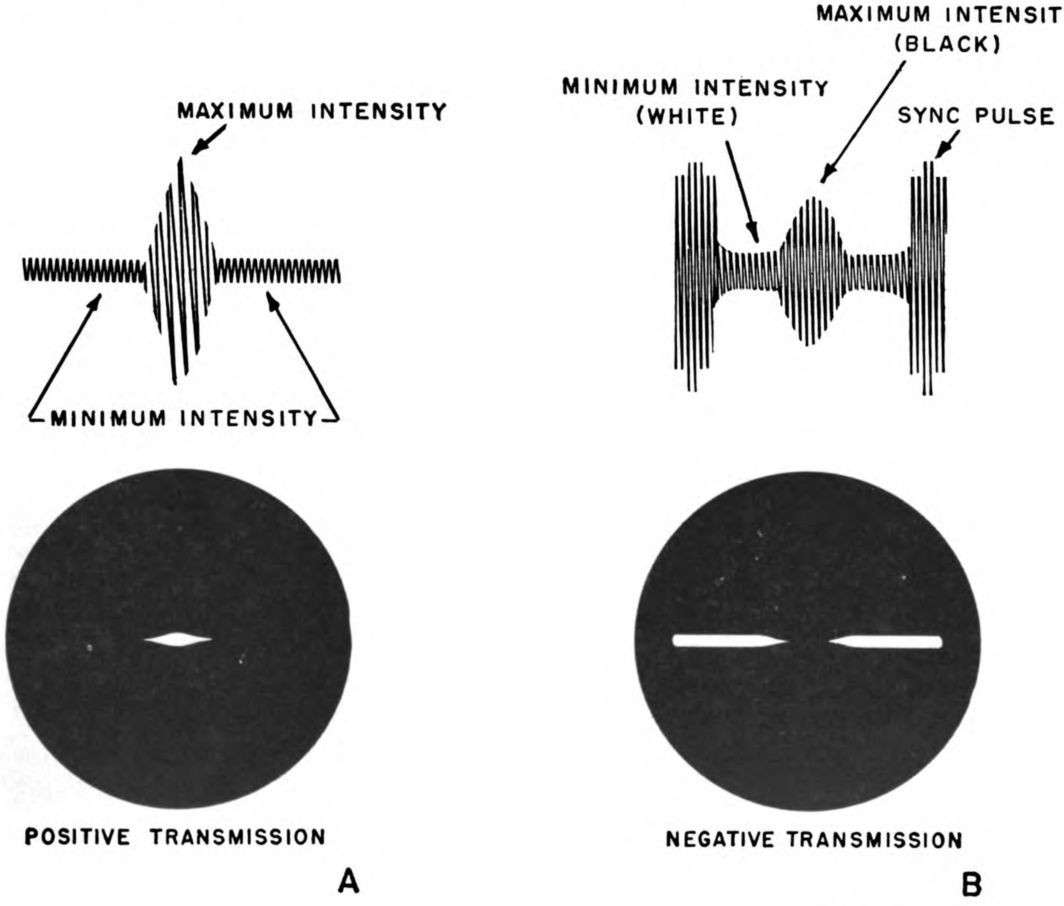

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Figure 158. Comparison between amplitude-modulated carrier waves in which positive and negative transmission are used.

scale is so calibrated as to indicate equal intervals of time along the trace. The zero time calibration point occurs at the beginning of the sweep. When sweep clamping is used, the start of the sweep always coincides with the zero time calibration point. As a result, the accuracy of time measurement is maintained.

(3) Certain types of radar displays require rotating radial sweep. One method of producing the required sweep current is to apply a trapezoidal voltage to the stator of a rotary transformer as described in paragraph 100 *a* (6). As with an ordinary transformer, the output has no d-c component and the average voltage over a cycle is zero (fig. 160). Each trapezoidal cycle should begin at the reference line. The start of the trapezoidal cycles is below the reference line from time 0 to time 1, above the reference line from time 1 to time 2, and below the reference line from time 2 to time 3. In addition, the voltage between sweeps varies in magnitude from cycle to cycle. As a result, different values of current flow in the deflection coils between sweeps and the start of each sweep is at a different point on the screen.

(4) To prevent this undesirable condition, sweep clamping must be used. The circuit cannot be a simple diode or grid clamping circuit because voltage variations both above and below the reference line must be produced. Therefore, a two-way clamping circuit is used. It is made inoperative during sweeps so that no clamping action occurs at this time. The clamping tubes are cut off during sweeps by means of large-amplitude negative pulses. Between sweeps, the clamping circuit is not cut off and normal clamping occurs. This action is known as *synchronized* clamping.

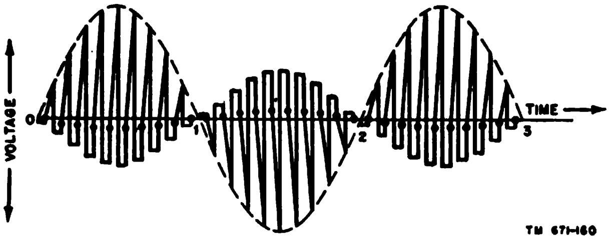

Figure 160. A-c output of rotary transformer.

c. Unblanking Voltage Clamping.

(1) In radar and synchroscope displays, several fixed sweep lengths are used. The blanking time can be longer than the time during which unblanking occurs. The unblanking pulses have several fixed durations to coincide with the sweep lengths. Clamping of this waveform is required so that the same unblanking level is maintained regardless of the length of the pulse. If no clamping circuit is used, the intensity of the pattern would change when the sweep length is changed.

(2) In figure 161, several unblanking pulses are shown. The unblanking time indicated in A is equal to the time during which blanking occurs; in B, the unblanking time is shorter than the blanking time, and in C, the unblanking time is longer than the blanking time. When these waveforms are applied to the grid of the cathode-ray tube through an R-C coupling circuit, the d-c component is removed. The coupling capacitor charges up to the average value of voltage. The voltage across the resistor varies above and below this average value.

(3) The average value of the waveform shown in A, figure 161 is one-half the peak-to-peak value. Therefore, the voltage across the resistor rises just as much above the average value during the first alternation as it falls below the average value during the second alternation. With a short unblanking pulse (B, fig. 161), the average value of the voltage is closer to the blanking level than one-half the peak-to-peak value. Therefore, the resistor voltage rises above the average value much more during the unblanking time than it falls below the average value during the blanking time. With a long unblanking pulse (C, fig. 161), the average value of the voltage is farther from the blanking level than one-half the peak-to-peak value. Therefore, the resistor voltage rises above the average value much less during the unblanking time than it falls below the average value during the blanking time.

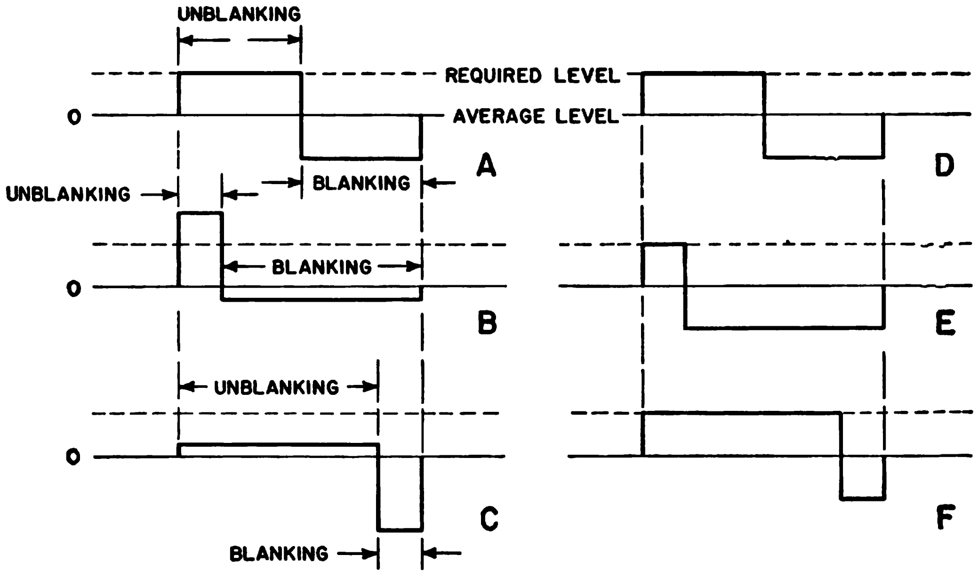

Figure 161. Variation in unblanking level for different unblanking pulses.

(4) Assume that the peak level of the unblanking voltage is set properly to the required level when the waveform shown in A, figure 161 is applied to the grid of the cathode-ray tube. When the sweep length is reduced, the peak level of the unblanking pulse is too high (B, fig. 161); the brightness of the pattern is higher during the time that the short sweep is applied. When the sweep length is increased, longer unblanking pulse is required (C, fig. 161). The peak level of the unblanking pulse is now too low and the brightness of the pattern is lower. Therefore, the pattern brightness changes when the sweep length changes. A clamping circuit can be inserted at the grid of the cathode-ray tube. This circuit will maintain the required level constant in spite of changes in the length of the unblanking pulse (D, E, and F, fig. 161). Therefore, no variation in pattern brightness occurs at different sweep lengths.

d. VIDEO SIGNAL CLAMPING.

(1) Clamping circuits often are used to stabilize the level of video signals. When these signals produce vertical deflection, as in oscilloscopes, synchroscopes, and A-scan radar displays, clamping prevents the trace from shifting vertically. This vertical shift occurs when the average signal level changes. For example, consider an A-scan radar display on which a single signal appears. The average voltage level of this video signal is very low. When a large number of signals occur, the average voltage level is increased.

(2) If the video signals pass through an R–C coupling circuit before being applied to the deflection plates of the cathode-ray tube, a change in level occurs as in figure 161. This results in a vertical shifting of the trace as the average signal content changes. When it is necessary to compare the amplitudes of pulses that appear at different times, this shift is undesirable.

(3) Most R-C coupling circuits used in video amplifiers have long time-constants so that low-frequency distortion and undesired phase shift are reduced. Assume that a large amplitude pulse is applied to such a coupling circuit. A large negative charge accumulates on one plate of the capacitor. This charge can leak off through the large resistor only at a slow rate. A negative bias can be developed which is great enough to cut off the video amplifier for a short time after the large pulse. A clamping circuit provides a low-impedance path for removing the charge when it exceeds a certain reference level. In this way, the loss of signals which follow immediately after large-amplitude signals is prevented.

(4) Clamping circuits are also used to prevent the loss of small-amplitude signals which immediately follow long pulses. When a long pulse is applied to an R-C coupling circuit, the amplitude of voltage across the resistor can be lower at the end of the pulse than at the beginning. This occurs because during a very long pulse there is enough time for the charge on the coupling capacitor to change. At the end of the pulse, an *undershoot* occurs during which a voltage of opposite polarity is produced. During this time, weak signals will not be displayed properly and, in some cases, may not appear at all. A clamping circuit prevents this effect.

(5) When intensity modulation is used, such as in PPI-scan radar and television displays, clamping performs the same functions as were given in (1) through (4) above. When clamping of the video signals is used, the loss of weak signals immediately following strong or long pulses is prevented. Also, the correct range of intensity is maintained when the average value of the video signal varies. This is particularly important in a television display. Assume that such a display has been adjusted to produce a pattern having the proper intensity. A sudden change in scene to one which is mostly dark or mostly light changes the average level of video signal voltage. The black portions of the patterns do not remain black and the white portions do not remain white. Instead, changes in the intensity of portions of the pattern occur so that the average pattern brightness tends to remain constant.

79. Clamping Circuits

a. Sweep Clamping.

(1) The circuit shown in figure 162 is used to clamp the beginning of each electromagnetic sweep to a fixed reference level, when the sweep signal applied to the amplifier tube grid goes more positive during the sweep. A trapezoidal voltage is applied to the control grid of the triode sweep amplifier. The current which flows through the deflection coil in the plate circuit has a sawtooth waveform. The current in the coil begins to increase from a certain value which is determined by the grid voltage at the beginning of each trapezoidal waveform. If every cycle of this waveform begins at a fixed voltage level, every cycle of sweep current begins at the same value. In this way, each sweep starts at the same point on the screen. The fixed reference voltage level in the circuit shown in figure 162 is −60 volts. The diode is a negatively biased positive clamper in which the clamping level is below ground.

(2) A common sweep-clamping circuit used in oscilloscopes with bilateral deflection is shown in A, figure 163. Here, V1 is a negative clamper whose clamping level is above ground and V2 is a positive clamper whose clamping level is at ground potential. Equal amplitude sawtooth voltages of opposite polarity are applied to the horizontal-deflection plates D1 and D2 to produce bilateral deflection. The spot of light moves from A to B on the screen at a slow linear rate to produce the trace. It then moves rapidly from B to A to produce the retrace. The action of the clamping circuit is such as to fix the beginning of each sweep at point A on the screen regardless of variations in the amplitude of the sweep voltages.

(3) Assume that the diodes are not connected and that the arm of potentiometer R3 is set at +50 volts. The undeflected electron beam is moved to the left toward plate D1 by this centering voltage. When the sawtooth sweep voltage is applied through coupling capacitor C1, the deflection voltage applied to D1 varies equally above and below +50 volts. When the sawtooth sweep voltage is applied through coupling capacitor C2, the deflection voltage applied to D2 varies equally above and below ground. As long as the amplitude of the sweep voltages is constant, each sawtooth cycle begins at the same voltage level and the beginning of the trace occurs at the same point on the screen. However, any slight variations in sweep-voltage amplitude causes the sawtooth waveform to begin at slight-

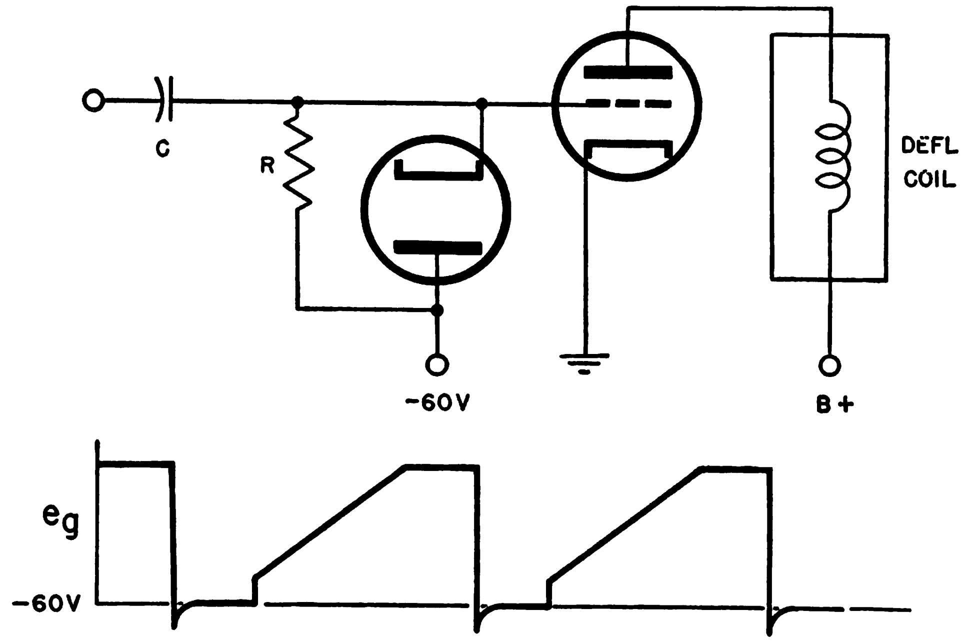

Figure 162. Diode clamping circuit used in electromagnetic sweep system.

ly different voltage levels. As a result, the entire sweep changes its position on the screen.

(4) To prevent any variations in the point at which the trace begins, the diodes V1 and V2 are connected across R1 and R2 as shown in A, figure 163. Assume that the peak-to-peak amplitude of the sawtooth sweep voltage is 100 volts. The potentiometer R3 is now readjusted to +150 volts to maintain the same 50-volt average difference of potential between the deflection plates. This difference of potential is the original centering voltage that was applied before the clamping diodes were connected. It is required to maintain the same centering voltage with the diodes in the circuit.

(5) B and C of figure 163 shows the voltages at the deflection plates. In figure B, the first sawtooth cycle is shown unclamped so that it can be compared with the clamped waveform. The average value of the first cycle is +150 volts because of the new setting of R3. The cathode of the clamping diode V1 is at a potential of +150 volts because of its connection to R3. When the plate voltage of V1 attempts to rise above this value, the diode conducts and capacitor C1 charges rapidly. The voltage on the deflection plate D1 does not rise above +150 volts. During the rest of the sawtooth cycle, the voltage falls by an amount that equals the peak-to-peak value of sawtooth voltage. Diode V1 puts a charge on C1 which changes the average voltage of the sawtooth waveform to +100 volts for the remaining sweeps. The small charge which leaks off C1 during the sweep causes the beginning of such sawtooth cycle to rise slightly above +150 volts. The diode V1 immediately conducts and replaces this charge. As a result, the points A in B of figure 163 are clamped to the +150-volts reference level.

(6) Before diode V2 is connected, the 100-volt sweep voltage varies about ground potential. This is shown in the first cycle of C of figure 163. The clamping diode is connected with its plate at ground potential. Any tendency for the sawtooth voltage to go negative causes the cathode of V2 to become negative with respect to its plate and the diode conducts. The diode puts a charge on C2 which changes the average voltage of the sawtooth waveform to +50 volts for the remaining

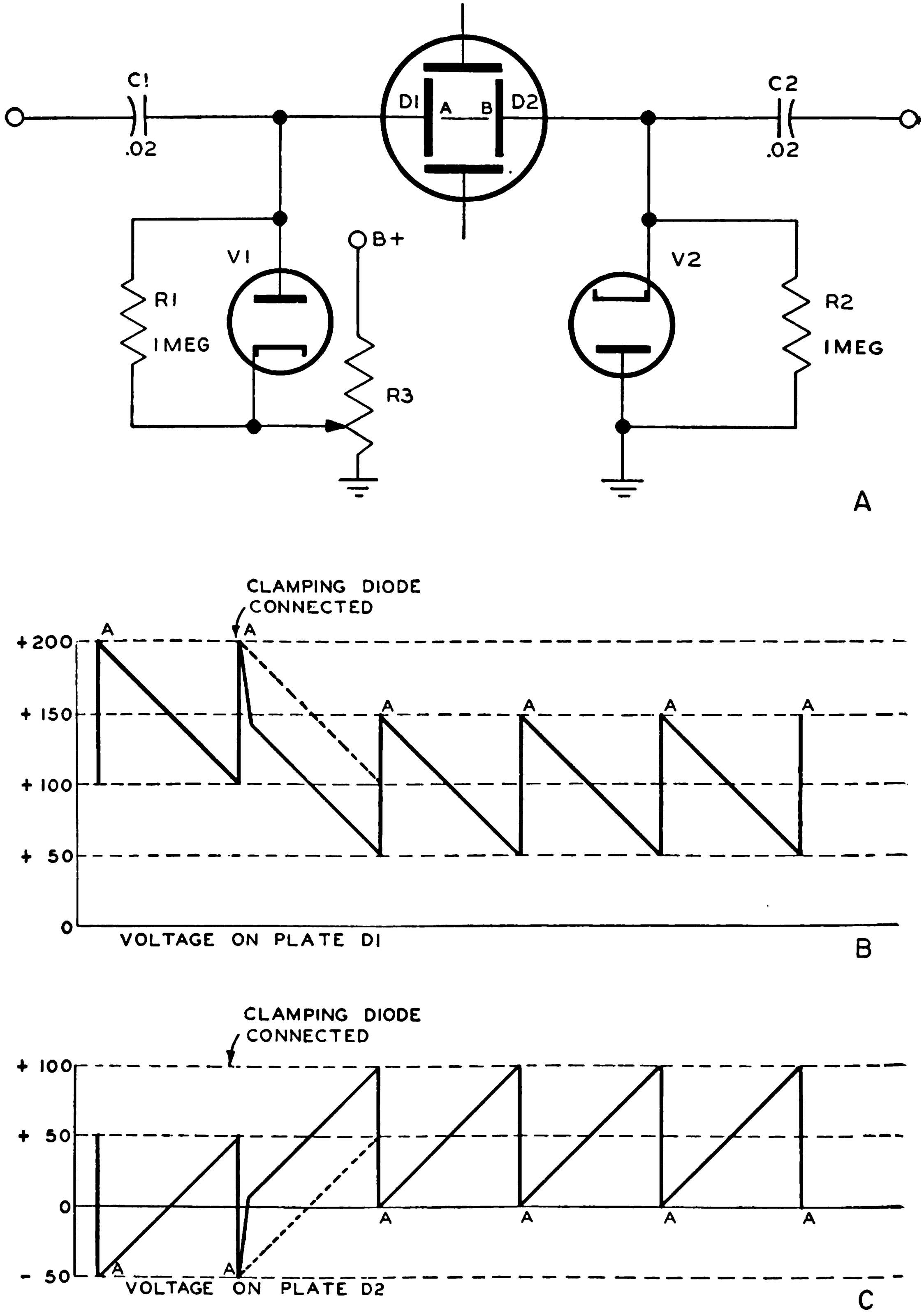

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Figure 163. Diode clamping circuit used with electrostatic cathode-ray tube with balanced deflection.

sweeps. As a result, the points A in C, figure 163 are clamped to the ground reference level. The average potential of the deflection plate D1 is +100 volts and the average potential of plate D2 is +50 volts. As a result, the average voltage of D1 still is 50 volts higher than that of D2. In this way, the same centering effect is produced as when the clamping diodes are not used and potentiometer R3 is set to its original +50-volt value. When the clamping circuit is used, any changes in sweep amplitude change the length of the trace only since point B of the trace is not held constant. The beginning of each trace is fixed at point A on the screen.

b. Synchronized Sweep Clamping.

(1) A synchronized two-way clamping circuit is shown in figure 164. The need for such a circuit has already been discussed. V3 is a sweep amplifier whose bias is controlled by V1 and V2, except when V1 and V2 are cut off by a synchronizing pulse. The input voltage to V3 is a sawtooth waveform when an electrostatic cathode-ray tube is used or a trapezoidal waveform when an electromagnetic tube is used. With electromagnetic deflection, V3 is usually a beam power amplifier rather than a triode as shown in figure 164. To indicate that either polarity of sweep voltage can be applied to this circuit, two sawtooth waveforms which are opposite in polarity are shown. In this circuit, no clamping occurs during the sweep. At this time, negative synchronizing pulses are applied to the clamping tubes, V1 and V2. The negative pulses are coupled to both grids through C2. Since amplitude of the negative pulses is great enough to cut off the clamping tubes, no clamping action takes place during sweeps. Between sweeps, however, these tubes are not cut off and normal clamping occurs as described in (2) below.

(2) The operation of V1 and V2 is such as to maintain the voltage at the grid of the sweep amplifier, V3, fixed at a constant reference level between sweeps. If this constant reference level is maintained, each cycle of sweep voltage, whether positive or negative, begins at exactly that reference potential. V1 and V2 are connected in series between B+ and ground and form a voltage divider across the plate supply. The grid of V3 is connected to the cathode of V1 and to the plate of V2. The voltage applied to the grid of V3 is determined by several components: the voltage across V1, the voltage across V2, and the cathode bias voltage developed across R. The voltages across V2 and R are relatively constant. Therefore, the grid voltage of V3 is determined largely by the voltage across V1.

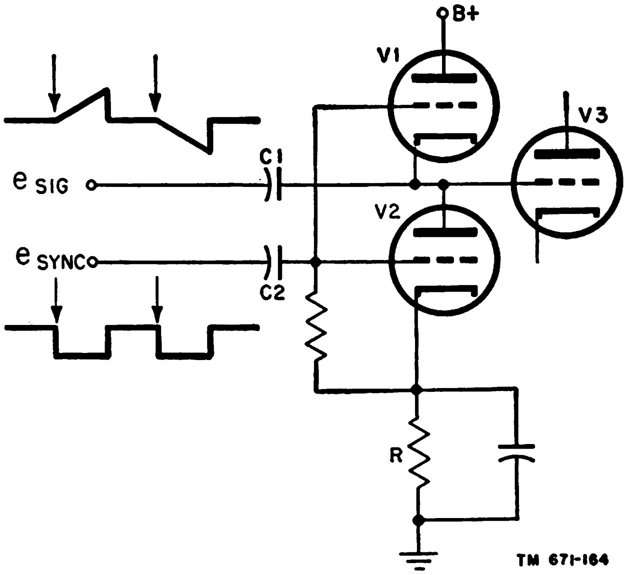

Figure 164. Synchronized clamping circuit.

(3) The grid of the clamping tube V2 is returned to its own cathode. Therefore, V2 operates at zero bias and can be considered as a simple rectifier. However, such is not the case for clamping tube V1. The grid of V1 is connected to the grid of V2 which is effectively returned to the cathode of V2 when no synchronizing potential is applied. The cathode of V1 is connected to the plate of V2. As a result, the bias voltage of V1 is the voltage drop across V2.

(4) The sweep voltage to be clamped is coupled to the circuit through capacitor C1 to the grid of V3. Assume that the voltage between sweeps attempts to rise above the reference level (becomes more positive). This increases the plate volt-

age on V2 and also increases the bias voltage of V1. A greater effect is noted in V1 than in V2, since changing the bias voltage of a tube has a greater effect than changing the plate voltage by the same number of volts. As a result of the increased bias on V1, its plate resistance is increased. At the same time the conductivity of V2 is increased. This reduces the voltage at the cathode of V1, the plate of V2, and the grid of V3. The bias voltage at the grid of V3 is thereby reduced and the output of V3 is returned to its original value.

(5) Assume that the voltage between sweeps attempts to fall below the reference level (becomes more negative). This reduces the plate voltage on V2, reducing its conductivity, and also reduces the bias voltage applied to V1. As a result, the plate resistance of V1 is reduced. The effect is to raise the voltage at the cathode of V1, the plate of V2, and the grid of V3. The bias voltage at the grid of V3 is thereby increased and the output of V3 is returned to its original value. V1 acts as a variable resistance which controls the fraction of B+ voltage that appears across V2 and is applied to the grid of V3.

(6) If a synchronizing pulse is applied as a negative rectangular wave, V1 and V2 are cut off for a period of time which coincides with the sweep time. During this time interval, the grid of V3 is left free to follow any changes in input-voltage amplitude. Capacitor C1 had no path to discharge through, except the very high resistance of V2. Therefore, the voltage at the grid of V3 follows exactly the input voltage. At the completion of the negative synchronizing pulse, V1 and V2 again conduct, returning the voltage at the grid of V3 back to the proper reference voltage level.

c. OTHER CLAMPING CIRCUITS.

(1) Clamping circuits are also used to maintain a fixed reference level for blanking voltages and video signals. These are usually simple diode or grid clamping circuits that are inserted at the point in the circuit where clamping is required. The circuits are similar to the one-way clamping circuit shown in figure 162. The diode can be inverted to produce negative clamping if needed. The particular reference voltage is used that is required in the specific application.

(2) Germanium crystals are used in some diode clamping circuits because of their small size and convenience. The use of grid clamping does not require a special clamping tube but uses the grid circuit of an amplifier that is already in the circuit. Because of this, it may not be obvious immediately that clamping is being used.

Section III. TIMING CIRCUITS

80. General Purpose

a. Timing circuits are used to produce the signals that synchronize the various circuits in a cathode-ray tube display system. These circuits are needed so that the proper time relationship exists among the various waveforms used.

b. Sometimes, most of the timing circuits used in a particular system are grouped together in one unit. This unit can be referred to as the *timer*, *keyer*, *synchronizer*, or *control central.* More often, however, the timing circuits are grouped with the particular component or circuit with which they are associated. Because of this, it sometimes is difficult to draw a line between the circuit that does the timing and the circuit that is timed.

c. Timing circuits accomplish their purpose by applying specially shaped waveforms to the circuit that is to be timed. These waveforms can be wholly generated within the timing circuit or the timing circuit can change the shape of some externally applied waveform to make it suitable for use.

d. The specific timing circuits used and the exact timing waveforms applied are subject to a wide variation. In simple oscilloscopes, for example, the timing requirements are not complicated. In more complex display systems, the timing requirements and circuits are many and varied. Because of the possible differences in the type and number of circuits used in complex display systems, it is natural to expect a wide variety of timing circuits. Since this is true, specific schematic diagrams of timing circuits will not be discussed. Instead, these circuits are discussed from a general point of view.

81. Timing Signals

a. Difference Between Driving Signals and Sync Signals. A circuit can be timed either by the application of driving signals or by the application of sync signals, provided they have the proper characteristics. The two signals are not similar. When the driving signal is removed from a circuit whose operation it times, the circuit stops operating. When the sync signal is removed, however, the circuit continues to operate although at perhaps a different frequency.

b. Trigger and Gate.

(1) A driving signal can be either a trigger or a gate. A *trigger* is a waveform which initiates the operation of another circuit. The timed circuit terminates its own operation. The important characteristics of a trigger are its amplitude and the shape of its leading edge. The amplitude of a trigger should be sufficient to cause the required operation. For example, if a vacuum tube must be cut off to start the operation of a circuit, the trigger should have sufficient amplitude to drive the tube beyond cut-off. If saturation must be produced, the trigger should have sufficient amplitude to produce this required condition. The leading edge of the trigger voltage is made as nearly vertical as possible to insure accurate timing. If a sloped leading edge is used, the triggering action can occur at a different time on successive cycles of operation. If the slope of the leading edge changes from time to time, erratic or random timing can result.

(2) The time duration of trigger waveforms usually is short. Typical trigger pulse widths range from 1 to 10 usec. The most commonly used trigger waveform is a sharply peaked voltage, although a short duration rectangular or sine wave also is used. The polarity of the trigger depends on the requirements of the circuit that is to be triggered. Both positive and negative triggers are used.

(3) A *gate* is a waveform that initiates the operation of a circuit, continues the operation of the circuit for a certain definite period of time and finally terminates the operation. A gate can also be used to make a circuit inoperative, maintain this condition for a certain amount of time, then allow the circuit to operate once more. The important characteristics of a gate are its duration and amplitude. The duration of the gate must be correct so that the circuit controlled is turned on or off for the required amount of time. The amplitude of the gate must be sufficient to produce the required operation. In some cases, the amplitude of the voltage must not vary. In other cases, such as when a tube is driven below cut-off, the gate amplitude can change just so long as the cut-off condition is maintained. The negative synchronizing pulse shown in figure 164, whose function is to cut off V1 and V2, is an example of a gate.

(4) Long gating voltages can be produced by mechanical switches or contacts. Voltages which gate other circuits for shorter time intervals require the use of electronic switches. The most common gating waveform is a square or rectangular wave.

82. Required Circuits

a. Repetition Rate Circuits.

(1) Timing voltages usually are repeated periodically. A circuit commonly is included in the timing system which establishes the repetition rate of the timing signals. This circuit is an oscillator whose output is converted into the required timing voltages. Both sine-wave and relaxation oscillators are used. Because the repetition rate usually is fairly low, audio-frequency oscillators are common. In radar displays, for example, typical repetition rates can vary from 500 to 3,000 cps.

(2) Phase-shift and Wien bridge oscillators are sine-wave oscillators frequently used in timing circuits. Blocking oscillators and multivibrators are also used to establish the repetition rate of the timing signals.

b. Shaping Circuits. A timing system must include some means of shaping the required timing signals with the proper time relations, amplitudes, and reference levels. Common circuits that are used include driven multivibrators, amplifiers, limiters, peakers, clampers, and artificial transmission lines.

c. Isolating and Amplifying Circuits. Because of the large number of timing waveforms required in complex display systems, some means are provided to protect one circuit or component from being excessively loaded by another. Sharp pulses sometimes must be transmitted over long interconnecting cables from one unit to another. An impedance-matching circuit is required to prevent undesired reflection and distortion. Isolation or buffer amplifiers and cathode followers are used to accomplish this purpose.

83. Typical Timing Systems

a. To illustrate a number of typical timing methods used in a complex display system, consider some arrangements for timing radar displays (fig. 165). The display illustrated is chosen because of the wide variety of timing voltages used. In such a system, timing voltages are required for circuits in the radar transmitter, indicator, and occasionally in the radar receiver. In A, figure 165, a stable audio-frequency sine-wave oscillator establishes the system repetition rate. This waveform is applied to an overdriven amplifier which converts it to a square wave. The square wave is differentiated by means of an R-C circuit having a short time constant. The resulting peaked waveform is applied to a limiter circuit which removes the negative alternations. The output of the limiter is applied to the transmitter, where proper timing is desired. The indicator circuits are timed by the sine wave directly.

b. In B, figure 165, a multivibrator relaxation oscillator establishes the system repetition rate. The square-wave output is peaked by a differentiator. The output of this circuit is applied to a limiter circuit which removes the negative alterna-

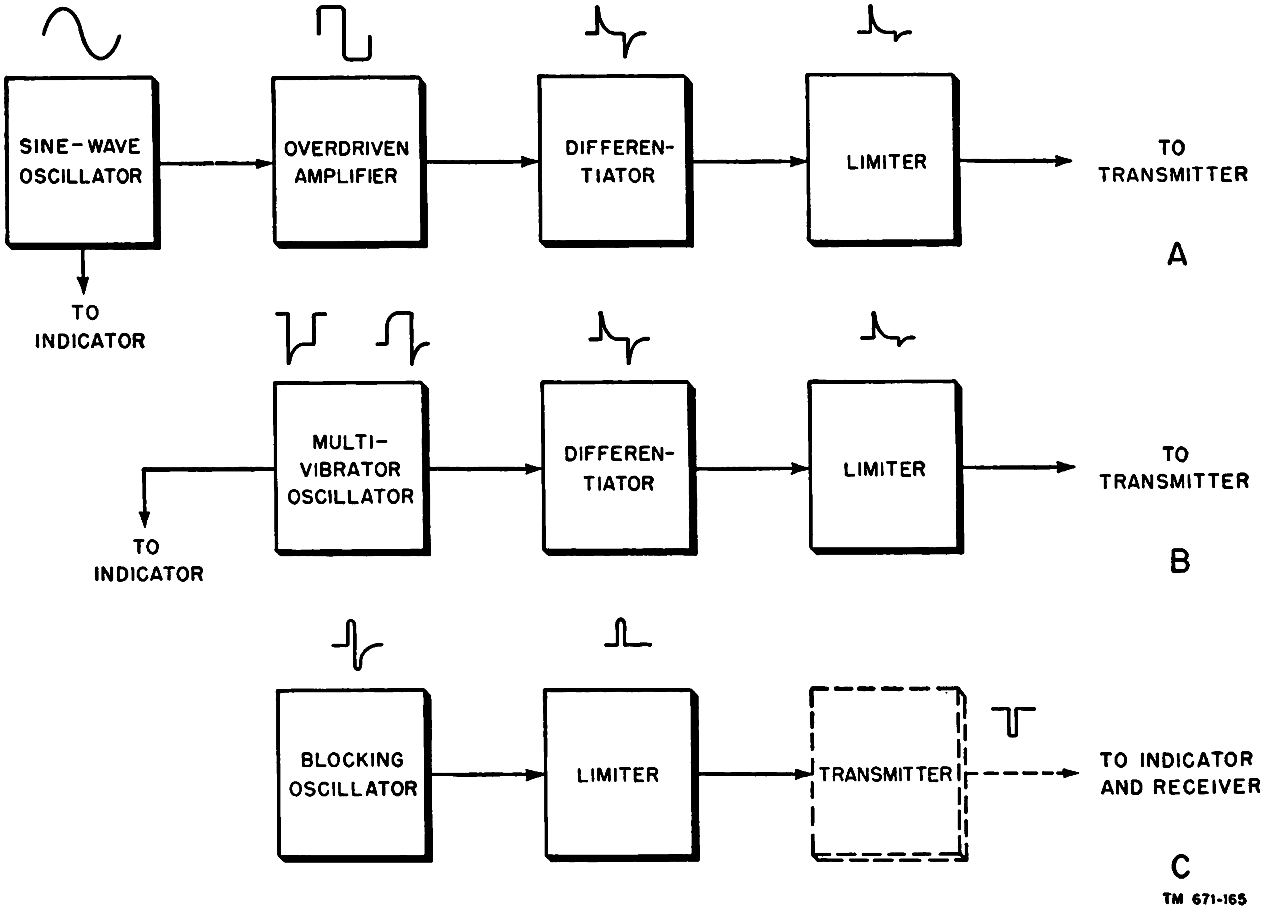

Figure 165. Typical timing systems.

tion. The resultant output is applied to the transmitter. The square-wave output of the multivibrator is also applied to the indicator. In C, figure 165, a blocking oscillator establishes the repetition rate. The output of the oscillator is applied to a limiter which removes the negative alternation. The output is applied to the transmitter. The transmitter contains a shaping circuit which converts the input waveform to a rectangular waveform. This waveform is applied to the indicator and receiver to time the circuits contained in those parts of the system.

c. Figure 166 shows the time relationship of some specific radar timing voltages. The transmitter trigger is a sharply peaked positive signal which is applied to the radar transmitter. The purpose of this trigger is to begin the generation of the r-f transmitter pulse. Circuits contained within the transmitter itself determine the pulse width of the r-f pulse. A rectangular receiver gate is applied to the receiver in such a way that normal operation can occur only during the time that the gate voltage is most positive. This gate puts the receiver into normal operation after the end of the transmitter pulse and maintains that condition for the proper amount of time.

d. The sweep trigger is applied to the sweep generator in the indicator. The trigger causes the

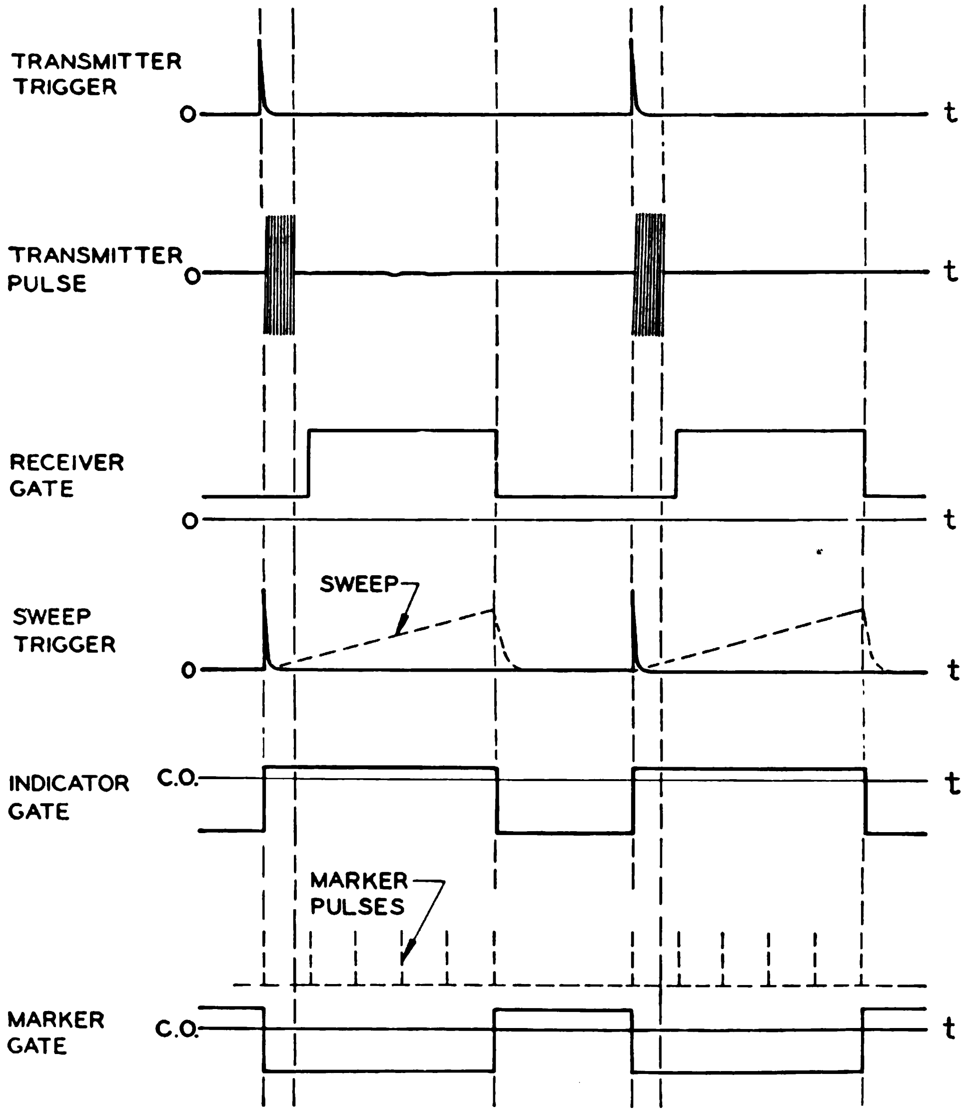

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Figure 166. Time relationship of voltages delivered by timing circuits.

sweep to begin at the same time that the transmitter pulse begins. The constants of the sweep generator are such that the retrace begins at the end of the receiver gate. The indicator gate is applied to the cathode-ray tube in such a way that unblanking occurs from the beginning of the transmitter pulse to the end of the sweep. The cathode-ray tube is driven below cut-off by this gate during the retrace time when blanking is desired and lasts until the next transmitter pulse occurs. A marker gate, which has the same time duration but opposite polarity, is applied to a range-marker generator. This circuit produces a series of uniformly spaced markers. The first marker occurs at the beginning of the sweep and the last marker occurs at the end of the sweep.

Section IV. POWER SUPPLIES

84. General

a. The power-supply requirements for cathode-ray tube display systems vary considerably. In general, a high voltage is required for the accelerating anode of the cathode-ray tube. The current needed for this purpose is very low. In addition, a lower voltage is wanted for the other electrodes of the cathode-ray tube and for the auxiliary circuits. The current required for this purpose is much greater, especially if a large number of circuits are used with the cathode-ray tube.

b. In simple displays, a single power supply is used. This supply can utilize a single power transformer, rectifier tube, and filter circuit to deliver all the voltages needed in the display. More frequently, however, two rectifiers are used with a special power transformer. This transformer has several secondary windings and multitapped windings to produce the required voltages. One rectifier delivers the high voltage, while the other supplies the low voltage. In addition, a low-voltage, high-current supply is required for the heaters of the tubes. With complex displays, separate power supplies may be needed for separate portions of the system. For example, in a radar display, separate supplies can be used for the receiver, for the local oscillator in the receiver, for the timer, for the modulator and transmitter, for the T/R (transmit-receive) switch, and for the cathode-ray tube and its auxiliary circuits.

c. Most of the power supplies used are conventional circuits which have been discussed in other technical manuals. Voltage regulation is common, and adequate shielding and filtering are important to prevent ripple voltages from modulating the trace.

85. High Voltage

a. The high voltage required for the accelerating plate of the cathode-ray tube imposes some special problems. Typical voltages range from 2 to 15 kv (kilovolts), and certain cathode-ray tubes require accelerating voltages as high as 30 kv. The current needed, however, rarely exceeds several hundred microamperes. Therefore, the power output required is very low. Adequate insulation and proper placement of parts are used to prevent *corona* or *arc-over*. The construction of the high-voltage supply is such as to minimize danger to personnel. Protective shields and interlocks are commonly used.

b. A conventional half-wave rectifier sometimes is used to deliver the high voltage required. A high-voltage transformer steps up the line voltage and applies it to a diode rectifier. This diode has a high peak inverse voltage rating so that it does not arc-over when the high voltage is applied to it in the nonconducting direction. Because of the existing low current, an R-C filter can be used instead of the conventional L-C (inductance-capacitance) filter. The value of the filter resistor is large and the capacitance of the filter capacitor(s) is small as compared to low-voltage power supplies. This prevents large charges from being stored by the capacitors, although a dangerous shock hazard still exists. A bleeder resistor is used to discharge the filter capacitors when the input voltage is removed. A limiting resistor sometimes is used between the plate of the rectifier and the secondary winding of the transformer. This resistor protects the transformer by limiting the current flow in the event that a short-circuit occurs in the capacitor(s) or rectifier tube.

c. An r-f oscillator can also be used in a circuit that provides high voltage for the accelerating plate. A power pentode receiving tube is used in a conventional oscillator circuit. The frequency of operation usually is approximately 100 kc. The output of the oscillator is applied to an r-f transformer which steps up the voltage to a high value. The secondary winding of the transformer is connected to a half-wave rectifier which converts the r-f to direct current. An R-C filter circuit is used to smooth out the r-f ripple. Because r-f is used rather than the low frequency of the power line, the physical size of the high-voltage transformer and filter capacitor is smaller. The small capacitance of the filter capacitors (about 500 uuf) and the limited power output of the oscillator minimizes the danger of injury due to electrical shock. Also, if accidental contact is made, the circuit is detuned and the output voltage drops rapidly. Adequate shielding must be used to prevent undesired coupling to other circuits.

d. Another method of obtaining a high voltage is frequently found in television displays that use electromagnetic cathode-ray tubes. This circuit is the kick-back or fly-back high-voltage supply. During a rapid retrace, the quick collapse of the magnetic field surrounding the deflection coils induces a large-amplitude voltage pulse in the coils. The peak amplitude of this pulse can be approximately 1,000 volts in a typical television display. This voltage is stepped up by means of a transformer from 5 to 15 kv. The output voltage of the transformer is applied to a half-wave rectifier which converts it to direct current. An R-C filter smooths out the ripple. Sometimes a powdered graphite coating is applied to the outside of the glass envelope of the cathode-ray tube. A capacitance of about 1,500 uuf exists between the outer coating and the inner coating of the tube. The capacitance serves as the output filter capacitor in the power supply. This scheme for obtaining high voltage is advantageous because it reduces the number of components required in the equipment.

e. In addition to the above-mentioned circuits, conventional voltage doublers, triplers, and quadruplers are used to produce the required high voltage. These multipliers can be used with any of the foregoing circuits to increase the magnitude of the voltage, or they can be operated from a power transformer that is connected directly to the a-c line.

86. Requirements for Electrostatic Cathode-Ray Tubes

a. The accelerating plate of the electrostatic cathode-ray tube must be highly positive with respect to the cathode. The deflection plates are mounted close to the accelerating anode. For several reasons there must be a minimum difference of potential between the accelerating plate and the deflection plates. A large difference of potential here would produce electrostatic fields which would produce defocusing of the electron beam. Also, it would be necessary to provide high-voltage insulation between these closely spaced electrodes. It is necessary to operate the deflection plates as near to ground potential as possible since one side of most signal circuits is grounded. When this is done, the danger of high voltage at the signal input terminals is avoided. Also, operating the deflection plates near ground potential permits the centering controls to be located in low-potential circuits. In order to satisfy these requirements, the accelerating plate is grounded and the other electron-gun electrodes are made highly negative. The cathode is connected to one side or to the center tap of the heater supply transformer winding. Therefore, this winding must be well insulated because of the high negative voltages used.

b. A typical electrostatic cathode-ray tube used in oscilloscopes is the 5UP1. This tube usually is operated with about 2,000 volts on the accelerating plate. This accelerating plate is operated at ground potential and the cathode is operated at a potential of −2,000 volts with respect to ground. The screen grid and powdered graphite coating are connected to the accelerating anode internally. The voltage applied to the focusing anode is from 340 to 640 volts with respect to the cathode for proper focus. The control-grid voltage required for cut-off is approximately −90 volts with respect to the cathode. D-c positioning voltages also are required for both sets of deflection plates. The magnitude of these voltages is several hundred volts. The current requirements for all these electrodes are negligible. The heater requires 6.3 volts at .6 ampere.

c. The voltages applied to the focusing anode, the control grid, and the deflection plates can be regulated. This prevents changes in pattern focus, intensity, and position caused by variations in line voltage. The same regulated supply often is used to deliver several hundred volts to the sweep circuit, amplifiers, and other circuits required for the display. The current requirements for this supply depend on the needs of these circuits.

87. Requirements for Electromagnetic Cathode-Ray Tubes

a. Higher accelerating voltages are used for electromagnetic cathode-ray tubes. These voltages are obtained from any of the power supplies mentioned in paragraph 85. Because the deflection system uses externally mounted coils, the problems of high-voltage insulation and grounding of signal input connections do not occur. For these reasons, the accelerating anode is not grounded. Instead, the cathode is operated at or near ground potential as in ordinary tubes. The current required in the accelerating anode circuit rarely exceeds several hundred microamperes. However, considerably more current is needed for the focus coil and deflection coils.

b. A typical electromagnetic cathode-ray tube used in radar displays is the 7BP7. The accelerating voltage commonly used is 4,000 volts. The screen-grid voltage is 250 volts and the grid voltage required for cut-off is approximately −70 volts. The current for the focus coil is obtained from a several hundred volt power supply. Frequently, this is the same supply that is used for the screen grid. The amount of current required for the focus coil depends on the number of turns and the construction of the coil. About 400 ampere turns are required for proper focus. Typical currents required range from 15 to 30 ma in one certain focus coil. Regulation is used frequently for all voltages except the high voltage. The same regulated supply also can be used for the other circuits required for the display.

c. Power amplifiers are used to deliver the currents needed for deflection. Therefore, the output power of the power supply required for these circuits is considerably greater than is needed for the voltage amplifiers used with electrostatic cathode-ray tubes. Several hundred milliamperes of current may be required for adequate deflection.

Section V. SUMMARY AND REVIEW QUESTIONS

88. Summary

a. Blanking is the process of removing all or a portion of the pattern that is displayed on the screen of a cathode-ray tube.

b. Intensity modulation is the process of varying the intensity of the pattern produced in such a way that information is presented.

c. The most common use of blanking is to remove the retrace.

d. The polarity of a blanking voltage is negative when applied to the control grid of the cathode-ray tube or positive when applied to the cathode.

e. Markers can be produced on the screen of a cathode-ray tube by blanking or by intensity modulation.

f. Clamping circuits are used to fix the beginning of the trace on the screen of a cathode-ray tube.

g. Clamping of unblanking signals prevents a change in pattern intensity when various sweep lengths are used.

h. Video signal clamping prevents any change in the pattern when the average content of the video signals vary. It also prevents the loss of weak signals immediately following strong signals.

i. Timing circuits produce the signals that synchronize and maintain the proper time relationship between the various circuits in a cathode-ray tube display system.

j. A trigger is used to initiate the action of another circuit, while a gate maintains the action for a definite period of time.

k. A high-voltage, low-current supply is needed for the accelerating anode of the cathode-ray tube. Lower voltages are required for the other electrodes. Electromagnetic cathode-ray tubes need a greater current for focus and deflection. Negligible current is required for these purposes in the electrostatic tube.

89. Review Questions

a. Why is blanking required?

b. Give several cases where blanking the retrace should not be used.

c. How is blanking accomplished?

d. How can a blanking signal be generated from the sawtooth sweep voltage?

e. Give some other sources of blanking signals.

f. For what purpose can markers be used along the trace on the screen of a cathode-ray tube?

g. To which electrodes of the cathode-ray tube can the intensity modulation signal be applied?

h. Why is sweep clamping important? Why are unblanking signals frequently clamped?

i. What is synchronized clamping and when is it used?

j. How do timing circuits accomplish their purpose?

k. Distinguish between driving signals and sync signals.

l. What is the difference between a trigger and a gate?

m. Give several methods of producing the high voltage required for the accelerating anode of the cathode-ray tube.

n. Why is the positive side of the high-voltage power supply for an electrostatic cathode-ray tube usually grounded?

CHAPTER 6

VOLTAGE AND CURRENT REQUIREMENTS FOR RADAR SCANS

Section I. A-SCAN DISPLAY

90. Information Presented

a. The A-scan radar display presents information about the range of detected target signals (par. 28*a*). Range is the distance, usually in yards or miles, from the radar set to the target. The target echo signal is applied to the radar indicator in such a way that *deflection modulation* of the cathode-ray tube electron beam results. The beam is made to move vertically upward in accordance with the amplitude of the target signal. Examination of the pip produced also gives much information about the size, shape, and nature of the detected target.

b. The chief use of the A-scan is for accurate range determination. This type of display permits target observation in spite of much interference and receiver noise. Because this display does not supply information about the bearing (azimuth) of a target, it seldom is used alone. Some device which indicates the antenna bearing frequently is associated with the A-scope. Such a device shows the bearing of targets that are displayed on the cathode-tube. A-scans can also be used with other radar scans which give bearing information.

91. Type of Cathode-ray Tube

a. The highly directional radar beam, which is scanning, passes over each target in a comparatively short period of time. This causes the signals that appear on the A-scope to appear and disappear rapidly. Therefore, a medium—or short—persistence screen is required for the cathode-ray tube. Also, not too much is gained by using a large screen diameter, and the A-scope usually is limited to about 5 inches.

b. Most A-scan displays use electrostatic cathode-ray tubes with P1 or P4 phosphors. These tubes require simple associated circuits.

92. Signal Requirements

a. Horizontal Signals and Circuits.

(1) In order to measure range along the horizontal axis of the display, a timebase is required. The velocity of electromagnetic waves is known to a high degree of accuracy and this velocity does not vary under normal conditions. The velocity has been found to be slightly over 186,000 miles per second or .186 mile per microsecond. This is equivalent to 328 yards per microsecond. If an electromagnetic wave travels 328 yards in 1 usec it requires 6.17 usec for energy to travel 2,024 yards or 1 nautical mile.

(2) The basic principle of radar is the transmission of pulses of radio energy and their reception as echoes. This energy is concentrated into a narrow beam by a highly directional antenna. When a pulse strikes a target, reflection of some of the energy occurs. Consequently, an echo pulse is produced which travels back to the radar receiving antenna. If an object is located at a distance of 2,000 yards from the radar transmitter, the radio pulse requires 6.1 usec to reach the target. An additional 6.1 usec is required for the echo to *return* to the radar receiver. Consequently, a total time interval of 12.2 usec is required to detect the presence of an object which is at a range of 2,000 yards. If an object is located at twice that distance, twice the amount of time would be required to detect it.

Consequently, range is determined by measuring the interval of time which elapses between the transmission of the pulse and the reception of the echo.

(3) If the electron beam is made to move horizontally at a linear rate, equal distances correspond to equal time intervals. As equal time intervals correspond to equal target ranges, a linear calibrated scale can be placed under the horizontal timebase and range can be measured directly.

(4) A sawtooth sweep voltage is applied to the horizontal-deflection plates of the cathode-ray tube. This voltage begins at the same time that the transmitter pulse starts. It ends after the time interval required to detect an object at the maximum range of the radar system. For example, if the radar system is designed to display signals up to a maximum range of 20,000 yards, the duration of the sweep must be at least 122 usec. In addition, the amplitude of the sweep must be sufficient to permit adequate spot deflection. Almost the full screen diameter should be swept in order to use the cathode-ray tube screen to maximum advantage.

(5) If the maximum range setting is to be changed, for example, from 20,000 yards to 100,000 yards, the sweep duration must be increased accordingly. The sweep must now last for 610 sec. Some means must be provided to change the sweep duration. Also, if balanced deflection is required, a phase-inverter or paraphase amplifier must follow the sweep generator. Sweep clamping is used in order to permit every sweep to start at the same point on the screen.

(6) In order to time the sweep start and duration properly, a gated sweep is always used. This circuit frequently takes the form of a triggered multivibrator which gates the sweep generator.

(7) Horizontal centering usually is provided by the application of a d-c voltage to the horizontal plates. The magnitude of this voltage is determined by the setting of the centering controls.

b. VERTICAL SIGNALS AND CIRCUITS.

(1) The target echo signals which are amplified and detected by the radar receiver are applied to the vertical-deflection plates of the cathode-ray tube. These signals are applied in such a way as to produce an upward deflection for each target. The output of most radar receivers usually is only a few volts. This low-amplitude signal does not produce sufficient vertical deflection. Consequently, a wide-range video amplifier must be inserted between the receiver and the vertical-deflection plates. This voltage amplifier can consist of one or more stages to obtain the necessary gain. It must have a wide frequency response to handle the high-frequency components of the receiver output pulse. A typical frequency response is from several hundred cycles to several megacycles.

(2) Fixed range markers often are used to permit more accurate estimation of target range on the A-scope. These markers are *uniformly spaced*, sharply peaked waveforms. They are applied to the vertical-deflection plates in such a way as to cause an upward deflection. The range markers can be distinguished from received echoes in two ways. In some radar systems the range markers are not applied to the cathode-ray tube at the same time as the target signals. As these two vertical-deflection signals are not applied simultaneously, no confusion results. Other radar systems present range markers and target signals at the same time. The markers can be recognized by their unvarying amplitude, short time duration, and uniform spacing.

(3) A block diagram of a circuit which can generate fixed range markers is shown in figure 167. In this circuit, the shock-excited oscillator is gated by the timer. A series of slightly damped sine waves is produced. The period of the sine wave is chosen to be equal to the time interval required between the range markers. This series of sine waves is then applied to a two-stage over-driven amplifier whose output is a series of square waves. The square waves are then differentiated,

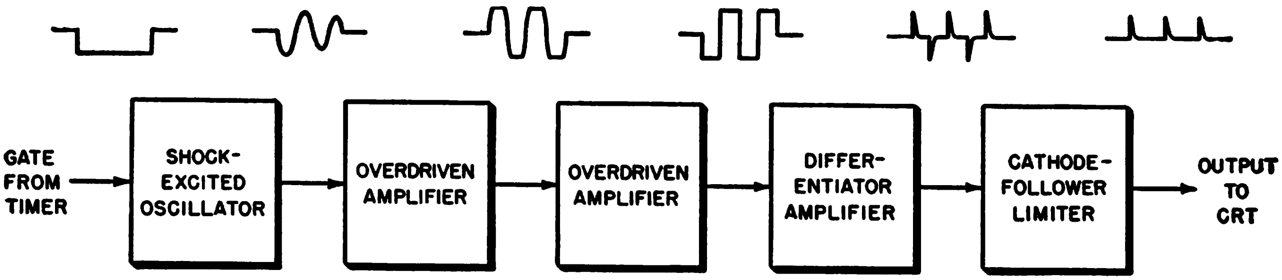

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Figure 167. Block diagram and waveforms of range-marker generator.

the negative peaks are removed, and the remaining positive peaks are applied to the upper vertical-deflection plate of the cathode-ray tube. When extreme accuracy is required, a crystal oscillator is used to synchronize the markers.

c. Z-AXIS SIGNALS AND CIRCUITS.

(1) In order to prevent the appearance of the cathode-ray tube retrace, a blanking gate is used. This gate also serves a second purpose. After the end of the sweep a rather long resting period occurs. This period frequently has a time duration which is longer than the period of time during which information is to be presented. During this resting time, the receiver is still in operation and target signals are being applied to the cathode-ray tube deflection plates. The blanking gate prevents the appearance of these received signals during the fly-back time and during the resting time until the next transmitter pulse is sent out. The blanking gate is usually a negative square wave which is applied to the cathode-ray tube control grid. It cuts off the electron beam completely during the time that information is not to be presented.

(2) The purpose of the blanking gate can be described in another manner. The gate unblanks the cathode-ray tube during the useful period of time by raising the control grid voltage above cut-off. When this portion of the cycle is referred to, the gate is called an *unblanking* or *intensity* gate. The blanking gate and the unblanking gate are merely different portions of the same waveform. The terms often are used interchangeably. Unblanking is needed when information is to be presented; blanking is required when information is not to be presented. The time duration requirement for the unblanking portion of the waveform is the same as for the sweep. The gate must begin when the sweep starts and must end when the period of time that is needed for the maximum range has elapsed.

(3) The unblanking gate usually is obtained from the same triggered multivibrator which gates the sweep generator. Sometimes an attenuator and an isolating amplifier are used between the multivibrator and the control grid of the cathode-ray tube. This prevents interaction and loading of the multivibrator and allows the proper amplitude of gating voltage to be applied. Intensity gate clamping is used frequently so that the proper reference level is maintained when the range-setting of the radar system is changed.

93. Typical A-scan Block Diagram

(fig. 168.)

a. An input trigger actuates the start-stop multivibrator. This can be the same trigger which operates the radar modulator and transmitter. In this way the transmitter pulse is transmitted at the same time that the multivibrator is triggered. The negative alternation of the square-wave output has a duration which equals the time required to display the range desired. When the operating range of the radar system is changed, the length of this alternation must be changed. This is done by changing the time constant of the multivibrator circuit.

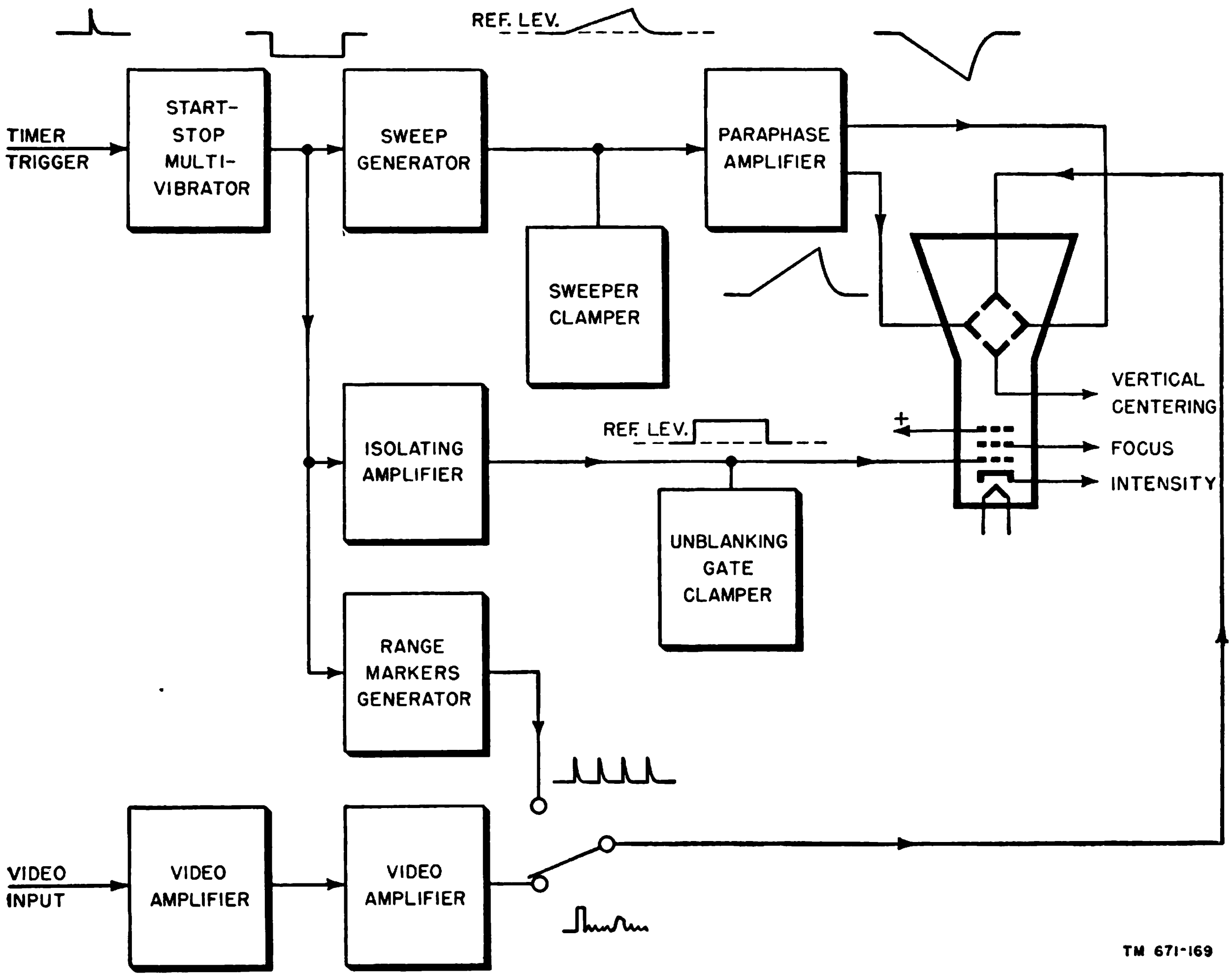


Figure 168. Block diagram and waveforms of simple A-scan display.

b. The output of the multivibrator gates the sweep generator. This circuit can be modified to produce a more linear sweep. Provision is made to change the time constant of the sweep generator when the operating range of the radar set is changed. In this way, the faster sweeps that are required for the short ranges can be generated. The reference level of the sweep voltage is kept constant by the sweep clamper.

c. The sweep voltage is amplified and inverted in the paraphrase amplifier. This circuit supplies the amplified sweep voltage to the horizontal-deflection plates of the cathode-ray tube. Consequently, the horizontal timebase along which range can be measured is produced.

d. The negative gate produced by the multivibrator is also applied to an attenuator and an isolating amplifier. The output of this circuit is a positive gate which is maintained at a certain reference level by a clamping circuit. This intensity gate is applied to the control grid of the cathode-ray tube. Here it intensifies the presentation while the sweep is moving from left to right. Blanking results at all other times.

e. The multivibrator also gates the range-marker generator. This circuit applies a series of uniformly spaced signals to the vertical-deflection plates. The spacing between the range markers usually is changed when the operating range of the radar set is changed. For example, when operating the radar set on its 20,000-yard range, it is convenient to have four range-marker intervals. The space between adjacent range markers then represents 5,000 yards distance. When switching the radar system to its 100,000-yard range, it is desirable to increase the spacing between range markers in order to prevent a large number of closely spaced markers from appearing on the screen. If four range-marker intervals are still desired, it is necessary to increase the range-marker spacing to 25,000 yards.

f. The target signals which are picked up by the radar antenna are amplified and detected by the radar receiver. The output of the receiver is applied to a two-stage video amplifier whose output is applied to the vertical-deflection plates of the cathode-ray tube. To prevent confusion, the video signals and range markers are not applied at the same time. A switch is used to select either of these deflecting signals.

Section II. J-SCAN DISPLAY

94. Information Presented

a. The J-scan display furnishes the same information as the A-scan—the range of detected targets. The method of presentation, however, is quite different. In this display, the timebase is circular. The sweep begins at the top of the screen and traces a circle whose center coincides with the screen center (par. 28*b*). The reflected echoes are applied to the cathode-ray tube in such a way that radial deflection occurs.

b. This display has certain advantages over the A-scan. First, a much greater range can be displayed on the cathode-ray tube screen because the sweep is spread out over a distance which is only slightly less that the circumference of the screen. In the A-scan, the sweep cannot occupy a distance which is greater than the screen diameter. Second, because the sweep is produced by sine waves whose frequency can be controlled closely, precise range measurements can be made.

c. The J-scan never is used alone as it does not give the bearing of a target. It must be used with some bearing indicator or other display which supplies this information.

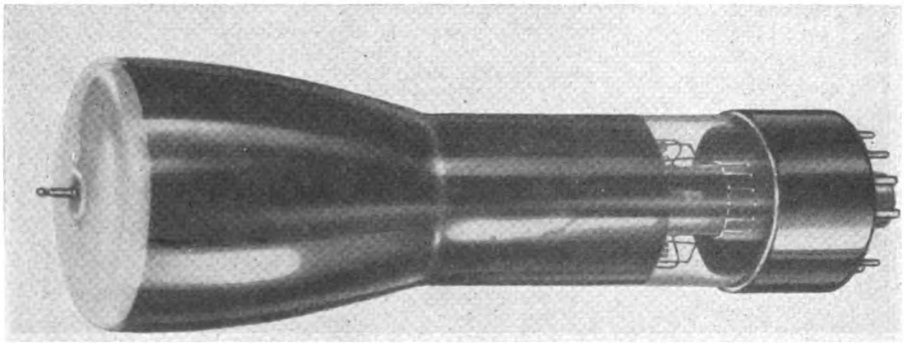
95. Type of Cathode-Ray Tube

The simplest method of producing radial deflection is to use the special electrostatic cathode-ray tube, 3DP1. This tube has a central deflection electrode to which signals are applied (figs. 169 and 170).

96. Signal Requirements

a. HORIZONTAL AND VERTICAL SIGNALS AND CIRCUITS.

(1) Range measurement is accomplished on the J-scope by noting the distance between the target signal and the transmitter pulse. The transmitter pulse appears at the beginning of the sweep as it does in the A-scan. However, this distance is not measured along a straight horizontal timebase. Instead, it must be measured along the circular sweep. A mechanically operated cursor (hairline) usually is mounted over the screen of the cathode-ray tube. When this cursor is used with the calibrated scale that fits around the circumference of the screen, range can be measured.



TM 671-171

Figure 169. Type 3DP1 electrostatic cathode-ray tube showing central deflection electrode protruding through screen.

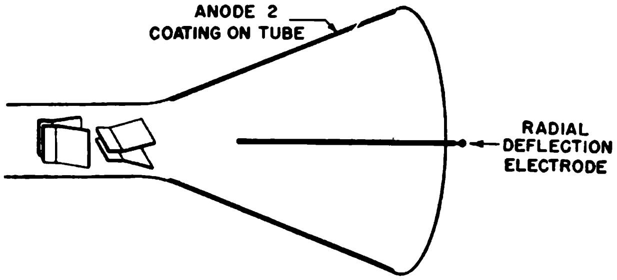


Figure 170. The internal construction of type 3DP1 cathode-ray tube.

(2) In order to produce the circular sweep, two sine waves 90° out of place are used. One of these is applied to the horizontal-deflection plates and the other to the vertical-deflection plates. If the frequency of the sine waves is 5.12 kc, the spot of light traces one complete circle on the cathode-ray tube screen in 1/5,120 second or 195 usec. In this period of time, a radar pulse can travel to a target 32,000 yards away and its echo can return to the radar-receiving antenna. Therefore, the maximum range displayed is 32,000 yards. To display a longer range, a longer time interval is required. Consequently, a lower sweep frequency is used.

(3) In order to measure range accurately, the sweep frequency must be stable. Usually stability is obtained by means of a crystal oscillator. However, since the sweep frequencies needed are quite low, the crystal oscillator is used to synchronize a multivibrator which operates at a lower frequency.

b. Radial Deflection Signals and Circuits.

(1) The echo signals which are amplified and detected by the radar receiver must cause deflection modulation. These signals are amplified by a video amplifier whose frequency range is wide enough to handle the high-frequency components of the short duration pulses that are used.

(2) The electron beam is deflected radially outward in accordance with the incoming signals. Consequently, the polarity of the video signals that are applied to the radial-deflection electrode must be negative.

c. Z-Axis Signals. An intensity gate is applied to the control grid of the cathode-ray tube. There is no flyback or retrace in the J-scan, as the electron beam returns to its starting point when the sweep is completed. However, the intensity gate is used to prevent the display of signals which are beyond the range for which the radar set is adjusted. This gate begins when the transmitter is triggered and lasts for one circular sweep.

97. Typical J-Scan Block Diagram

a. A crystal oscillator which operates at a low radio frequency (about 82kc) is the first stage in the block diagram (fig. 171). The sine-wave output is then applied to a trigger generator. This stage is a modified cathode follower which is driven beyond cut-off by the applied sine wave. A small capacitor is connected across the cathode resistor and the time constant of this network is quite short. The output of the stage is a distorted sine wave (fig. 171). This stage serves to sharpen the trigger and provide isolation between the oscillator and the first multivibrator.

b. A free-running multivibrator follows the trigger generator. This stage has a natural frequency somewhat lower than one-fourth of the crystal-oscillator frequency. The multivibrator is synchronized to exactly one-fourth of the oscillator frequency by the incoming triggers. Hence, this stage serves as a frequency divider of high stability. The output of this multivibrator is then applied through an R-C differentiating circuit to a second multivibrator. This stage functions in a manner similar to that of the first frequency divider. Its output of 5.12-kc square waves is fed to a tuned amplifier.

c. Although the input to the tuned amplifier is a square wave, the output is a reasonably good sine wave. This is true because the amplifier responds to the fundamental frequency only, thereby eliminating all the harmonics composing the square wave. The 5.12-kc sine wave is applied to a double-tuned, phase-splitting transformer. The output of this transformer consists of two sine waves which have a phase difference of 90°. The application of these voltages to the deflection plates produces a circular sweep which can display targets up to a maximum range of 32,000 yards.

d. In order to produce the still lower recurrence frequency, a third frequency-dividing multivibrator is used. The output of this circuit is then peaked and these peaks are fed into the transmitter trigger circuits. Here, after suitable shaping, the transmitted output pulse is generated.

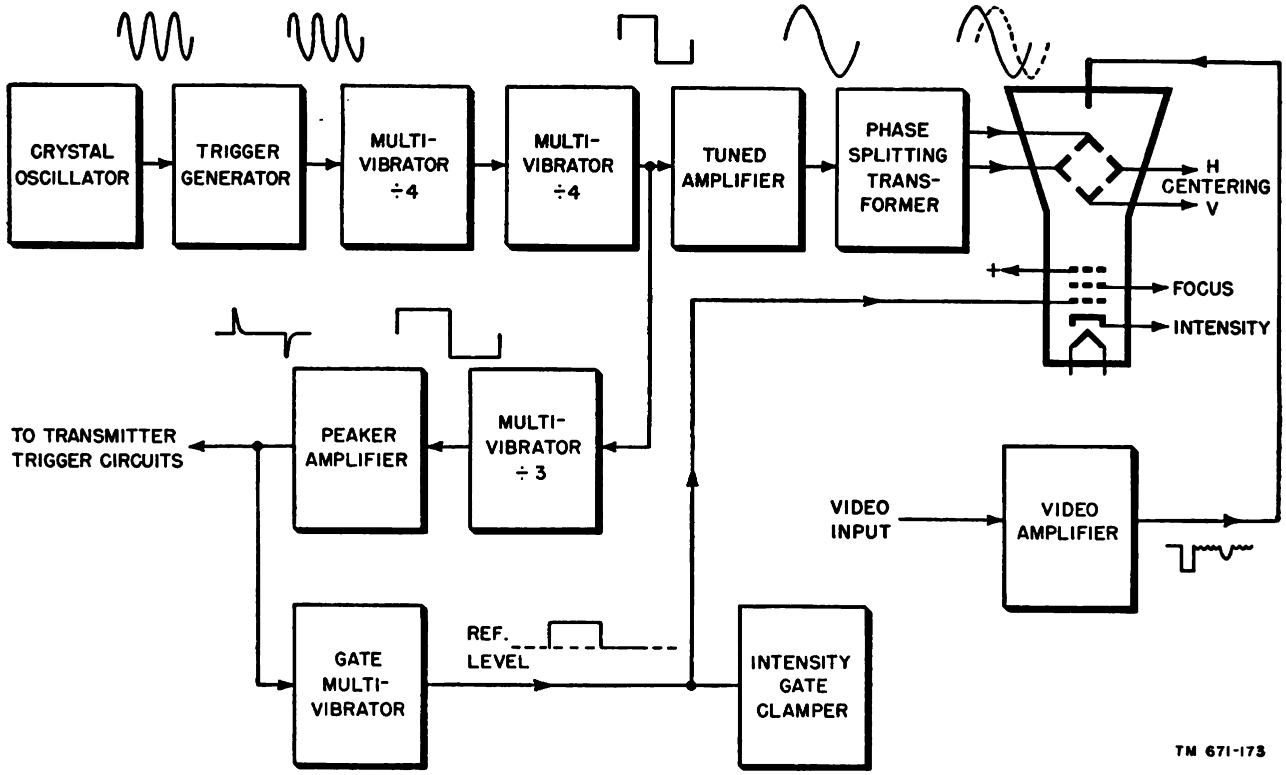


Figure 171. Block diagram of J-scan display.

The transmitted trigger is also applied to a gate multivibrator. The output of this circuit is an intensity gate which starts at the beginning of the sweep and lasts for the sweep duration. Consequently, the pattern on the cathode-ray tube screen is intensified for the first 32,000 yards of range immediately following the transmitter pulse. The intensity gate is clamped to a suitable reference level by a clamper circuit.

e. The video output of the receiver is applied through a three-stage video amplifier to the radial-deflector electrode of the cathode-ray tube. The electron beam is deflected radially outward in accordance with the received echoes from radar targets.

Section III. PPI-SCAN DISPLAY

98. Information Presented

a. One of the most useful of the radar displays is the plan-position indicator or PPI-scan. This display furnishes both range and bearing of targets in the form of a polar map (fig. 56). Received echoes from targets are applied to the cathode-ray tube in such a way as to produce *intensity modulation* of the beam. An increase in pattern brightness is produced whenever a target is detected.

b. Range measurement of targets is made by noting the distance of the bright spot of light from the center of the screen. If a target appears at the center of the screen, its range is zero. If a target appears at the periphery of the screen, its range is the maximum range for which the radar system is adjusted. Assume that the radar system is adjusted for a 20,000-yard range. A target indication is seen on the screen at a distance which is halfway between the center and the periphery. This target has a range of 10,000 yards.

c. Bearing information also is obtained by observing the position of the echo signal on the screen. On ground radar sets, the antenna and indicator usually are oriented during installation of the equipment so that the top of the screen represents true north. Consequently, a target to the east of the radar set appears as a spot of light on the right side of the screen and a target to the west of the radar set appears as a spot of light on the left side of the screen. An azimuth or bearing scale, calibrated in degrees, usually is placed around the periphery of the screen to facilitate azimuth measurements. On mobile equipments, the reference direction often is made to coincide with the direction of travel instead of true north and the targets are indicated on the scope as being dead ahead, to the right of, left of, or astern the carrier. For example, if a ship-borne radar is oriented so that its course of travel is used as the reference direction, targets dead ahead of the ship will appear as spots of light between the center and top of the screen, targets to the right of the ship (to starboard) will appear on the right side of the screen, and targets to the left of the carrier (to port) will appear on the left side of the screen.

d. In addition to bearing and range information, the PPI-scan gives much information about the nature of the target itself. The pattern produced is maplike, and such things as land-water boundaries, bridges, and target outlines can be seen. For this reason, the PPI-scan is an important aid to navigation.

99. Type of Cathode-ray Tube

a. For maximum usefulness, a large screen diameter is used. In addition, the intensity-modulated display requires a high-density electron beam. For these reasons, an electromagnetic cathode-ray tube usually is used.

b. The phosphor which is used on the screen of the cathode-ray tube must have a long persistence. Special cascade screens, such as the P7, have been especially developed for this screen. The speed of antenna rotation in most PPI-scan radar systems is quite slow. Five to twenty revolutions per minute is a typical speed range for general-purpose radar antenna systems. All portions of the screen cannot be illuminated at once. Information can be presented along only one radial sweep line at a time. Consequently, in order to present the entire screen pattern at once, the long-persistence screen is needed. Usually, an amber optical filter is fitted over the screen. This minimizes the bright blue flash produced by the first layer of the P7 screen. The observer sees only the yellow phosphorescence, which persists for several seconds after the sweep has rotated beyond a particular portion of the screen.

100. Signal Requirements

a. ROTATING SWEEP. To measure range, a linear sweep must be used. In the PPI-scan this sweep causes the beam to start at the center of the screen and move radially outward to the periphery. It is necessary that the sweep trace position be made to indicate target bearing (azimuth). As the antenna rotates, the sweep trace must rotate in synchronism. The entire process of electron deflection is as follows:

(1) The electron beam begins at the center of the screen. At the start of the transmitter pulse, the beam moves outward from the center and upward to the top of the screen. The beam moves rapidly back to the center of the tube. This concludes the first sweep. At the start of the next transmitter pulse, the process is repeated but with one difference. Instead of the second trace falling exactly on top of the first, it is displaced by a fraction of a degree. Both the antenna and the sweep have rotated slightly. The amount of displacement of the sweep depends on the number of transmitted pulses per second and the speed of antenna rotation. By the time the antenna has completed one revolution, the entire screen has been covered with a series of very narrowly separated radial sweeps.

(2) Two methods are used to produce the rotating sweep which characterizes this display. In both of these, the magnetic deflection field is made to rotate in synchronization with the radar antenna. The first of these methods is called the *mechanical azimuth sweep*. In this system the deflection yoke is mounted on bearings and is rotated mechanically around the neck of the cathode-ray tube. The windings within the yoke are such that a single magnetic field direction is produced. As the yoke is rotated, this magnetic field also rotates. If a sawtooth sweep current is applied through slip rings, a linear sweep is produced (fig. 172). The direction of electron beam deflection is at right angles to the direction of the magnetic field. As this field rotates, the sweep is displaced accordingly.

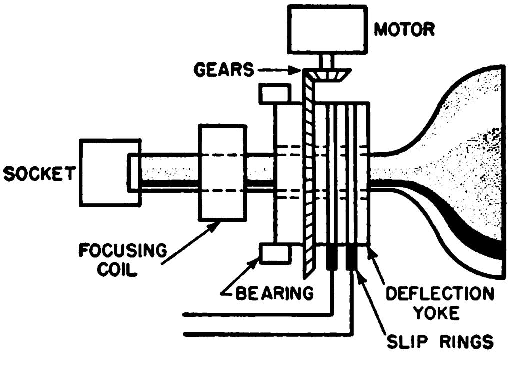


Figure 172. Mechanical azimuth sweep for PPI-scan.

(3) To synchronize the antenna and sweep rotation, several arrangements are used. One method uses synchronous motors connected to the same power supply to drive the antenna and the deflection yoke. Another method uses electromechanical repeaters, such as synchros, or more complex servo systems to accomplish proper synchronization.

(4) The second method of rotating the deflection field is called the *electrical azimuth sweep*. In this system, a fixed deflection yoke is used which contains both horizontal- and vertical-deflection coils. In-phase sawtooth sweep currents are applied to both sets of deflection coils. As the radar antenna rotates from 0° to 90°, the *amplitude* of the sawtooth sweep currents in the horizontal-deflection coils increases sinusoidally from zero to a maximum (fig. 173). During this same time, the amplitude of the vertical sweep currents decreases from maximum to zero. At 0° there is maximum vertical deflection and no horizontal deflection. The sawtooth sweep which occurs here deflects the beam upward at a linear rate. A vertical radial sweep is produced. In the 45° position of the antenna, equal horizontal- and vertical-deflection forces are produced and the beam produces a radial sweep at a 45° angle. At the 90° position, there is no vertical deflection and a maximum horizontal deflection. The sawtooth sweep which occurs here moves the beam to the right at a linear rate. A horizontal radial sweep is produced. In this way, a series of radial sweeps is produced which is displaced around the cathode-ray tube screen in accordance with antenna rotation. Note in figure 173 that the amplitude variations of the in-phase sawtooth waveforms are 90° apart in time phase, and that the amplitude vary sinusoidally.

(5) As a means of obtaining the required 90° amplitude variation, a *rotary transformer* frequently is used. This transformer, which resembles a small electric motor, has two secondary windings, which are mounted at right angles in the stator housing. The primary is wound on the rotor, which is driven by the rotating antenna. A trapezoidal-wave generator is connected to the primary winding by means of slip rings. As the rotor is turned, the voltage obtained from either stator secondary varies. Maximum voltage is obtained from one secondary winding when zero voltage is obtained from the other. The transformer is so constructed that the amplitude of the output voltage varies sinusoidally with rotor angle. The amplitudes of the trapezoidal output voltages vary sinusoidally and are 90° apart in time phase. These output voltages then are applied to separate power amplifiers. The output currents of these amplifiers have the required sawtooth sweep waveforms.

(6) Sweep clampers are used to keep the reference level constant. This permits every sweep to start at the same point on the cathode-ray tube screen.

b. Z-AXIS SIGNALS.

(1) An intensity gate is required to blank out the retrace. It also prevents signals from modulating the electron beam between the end of the sweep and the beginning of the next transmitter pulse.

(2) In addition, the video signal from the radar receiver must be applied to the control grid of the cathode-ray tube during the sweep time. This results in intensity modulation of the electron beam in accordance with the amplitude of the received echoes.

(3) Range markers can be used with this scan. Uniformly spaced peak waves are generated by a range-marker generator as pre-

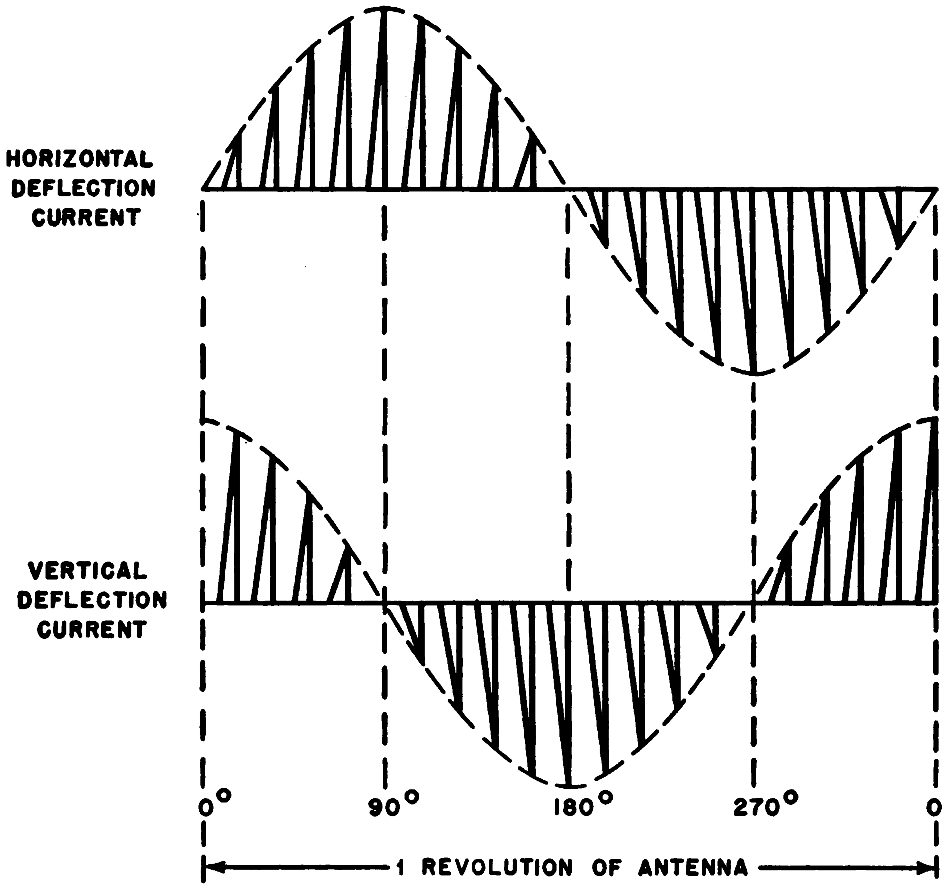


Figure 173. Deflection coil currents for electrical azimuth sweep.

viously described. These are applied to the control grid of the cathode-ray tube. The result is a series of uniformly spaced bright spots along the sweep which produce bright concentric circles as the sweep rotates. These are called *range rings* and are used to estimate target range.

101. Typical PPI-scan Block Diagram

(fig. 174)

a. A negative trigger from the timer actuates a start-stop multivibrator. This trigger also is used to begin the transmitter pulse. The multivibrator has two outputs which are of opposite polarity. The time duration of these square-wave outputs is changed when the radar range is changed. If the radar has two range settings, 20,000 yards and 100,000 yards, the gate lengths should be 122 usec and 610 usec, respectively.

b. The negative gate is applied to the sweep generator. This circuit produces a trapezoidal sweep. The constants of this circuit also must be changed when the range is changed in order to produce the two sweep rates required. This voltage is applied to a sweep power amplified whose output is fed to the rotating deflection yoke. A sawtooth of current then flows through the yoke winding to produce the sweep.

c. The negative gate is also applied to the marker generator. The output of this circuit produces the uniformly spaced concentric range rings. The output of the previously discussed marker generator consisted of a series of uniformly spaced positive pulses. These may be applied to the control grid of the cathode-ray tube to produce the intensity modulation required. A series of negative pulses produces the same result if these are applied to the cathode. In order to invert the waveform, the cathode follower in figure 167 can be replaced by a cut-off limiter which produces phase inversion.

d. The positive gate produced by the start-stop multivibrator is applied to the control grid of the

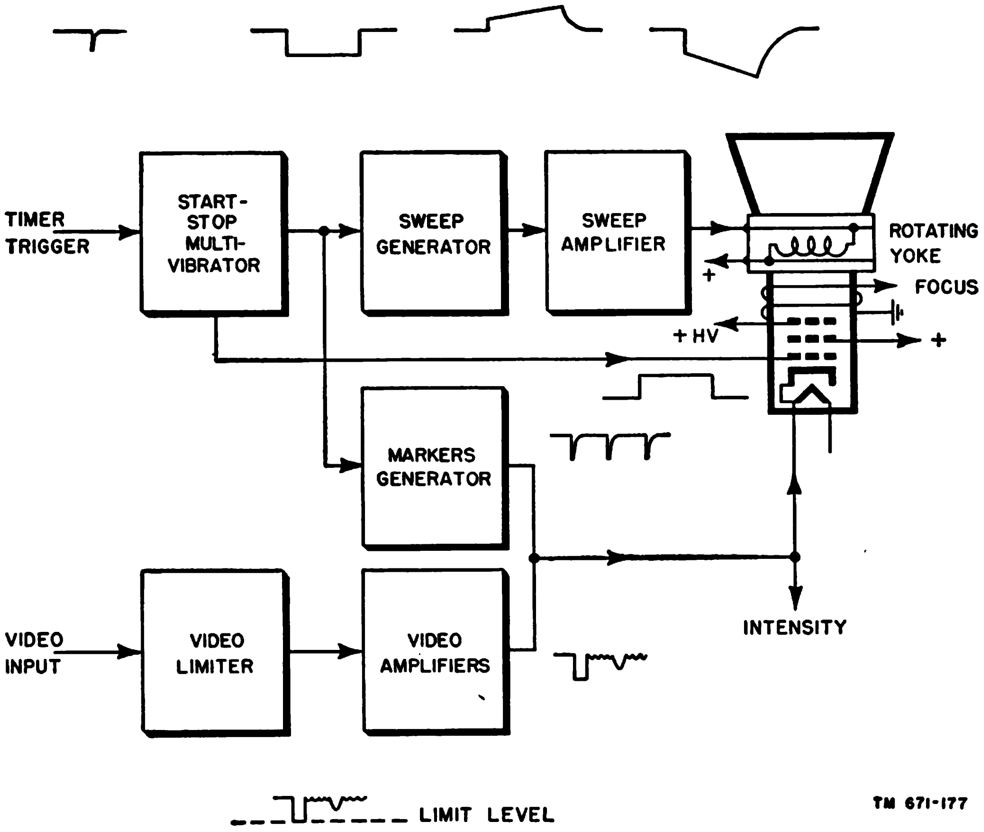


Figure 174. Simple PPI-scan block diagram.

cathode-ray tube. This is the intensity gate which intensifies the trace only during the time that information is to be presented.

e. The signals from the radar receiver are applied through a video limiter to a two-stage video amplifier. The purpose of the video limiter is to prevent strong signals from *blooming* on the screen. Blooming refers to the defocusing which occurs when an extremely bright spot is produced on the cathode-ray tube screen. The video limiter prevents signals from exceeding the limit level. When the receiver gain control is advanced to observe weak signals, strong signals are prevented from blooming and possibly obscuring weak signals nearby. The video amplifier must have a frequency response from several hundred cycles to several megacycles in order to respond to the pulses that are applied. The output of the video amplifier consists of negative echo pulses which are applied to the cathode of the cathode-ray tube. The result is intensity modulation of the electron beam.

Section IV. B-SCAN DISPLAY

102. Information Presented

a. The B-scan display furnishes information on a rectangular display pattern (fig. 54) about the range and bearing of a target. The vertical axis represents the range of the target. Zero range is located at the bottom of the rectangular pattern and maximum range is at the top. The horizontal axis represents the bearing of the target. A dead-ahead bearing is at the center of the pattern. A target that bears to the left appears to the left of the centerline, while a target whose position is on the right appears to the right of the centerline. A vertical centerline, therefore, represents a bearing of 0°, a vertical line at the extreme right represents a bearing of 90°, and a vertical line at the extreme left represents a bearing of 270°.

b. Signals are applied to the cathode-ray tube in such a way as to produce intensity modulation of the electron beam. The pattern produced is highly distorted compared to that of the PPI-scan, especially at short ranges.

103. Type of Cathode-ray Tube

Most B-scan displays use electromagnetic cathode-ray tubes with long-persistence screens, for the reasons given above in the discussion of the PPI-scan. A fixed deflection yoke consisting of horizontal- and vertical-deflection coils is used.

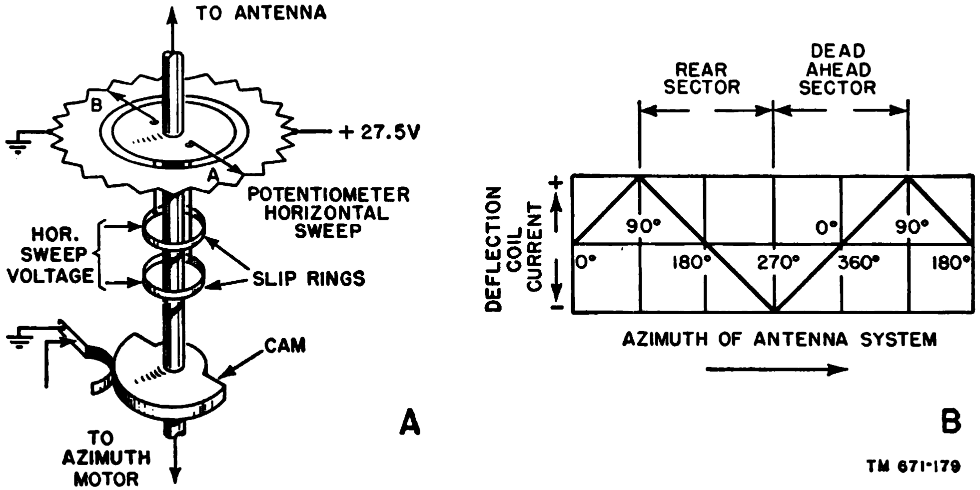
104. Signal Requirements

a. Horizontal Signals and Circuits.

(1) A horizontal sweep is required which produces deflection in accordance with the bearing of the radar antenna. With the antenna at its dead-ahead position, the sweep current must be zero. Under these conditions, there is no horizontal deflection and the electron beam is centered horizontally. If the antenna rotates continuously at a slow and uniform rate, the current through the horizontal-deflection coils must vary linearly. The amount of current flow must be determined by the exact azimuth (bearing) of the antenna. Because of the slow speeds at which most radar antennas rotate, the rate of current change through the horizontal-deflection coils is quite low. Therefore, the effect of deflection-coil inductance is neglected in designing these sweep circuits.

(2) Several methods have been used to transmit information about the azimuth of the antenna to the horizontal-deflection coils. The simplest method uses a circular-shaped potentiometer with a continuous resistance winding (fig. 175-A). A d-c voltage source is connected to two fixed taps located opposite each other. This potentiometer is mounted on the same shaft which rotates the antenna.

(3) The rotating portion of the potentiometer consists of two arms (A and B, fig. 175), with their associated slip rings. When the antenna is at its dead-ahead position, the contact arms are located midway between the fixed voltage taps. Under these conditions, there is no difference of potential between A and B and no deflection current flows. As the shaft rotates, arm B moves closer to the point of positive potential, and arm A moves closer to the point of ground potential. Deflection current flows from arm A through the horizontal-deflection coils and to arm B. When the shaft and the antenna have rotated 90°, a maximum difference of potential is produced and maximum deflection current flows. As the shaft continues to rotate, the amount of the deflection current is reduced. After 180° of rotation, arms A and B are midway between the fixed voltage points, and the deflection current is again reduced to zero. Continued rotation of the shaft reverses the positions of the arms, and current flows through the deflection



A, Sweep potentiometer for B-scan ; B, Deflection coil current.

Figure 175.

coils in the opposite direction. Consequently, the deflection coil current has a triangular waveform (B, fig. 175).

(4) When additional deflection power is required, the output voltage from the potentiometer is applied to a d-c amplifier. The output of this amplifier is then applied to the horizontal-deflection coils.

b. Vertical Signals and Circuits. A linear timebase is required which permits a measurement of range to be made. A trapezoidal voltage is applied through sweep amplifiers to the vertical-deflection coils of the cathode-ray tube. This voltage causes a sawtooth current to flow through the vertical-deflection coils. The length of the sweep is determined by the range for which the radar system is adjusted. Sweep clamping can be used to maintain the correct reference level.

c. Z-Axis Signals.

(1) Two intensity gates are required in the B-scan display. One of these occurs at the same rate as the vertical sweep. This gate intensifies the trace from the time that the transmitter pulse is generated until the maximum range of the radar system has been displayed. It prevents the vertical retrace from appearing on the screen. In addition, it reduces the intensity of the trace beyond the maximum range.

(2) A second intensity gate is needed to blank the cathode-ray tube while the antenna has a bearing which is outside the sector in which information is to be presented. For example, assume that the B-scan is to display useful information from a bearing of 270° through 0° to 90°. This is a sector 180° wide and centered at the dead-ahead position of the antenna. During the other half-revolution of the antenna, from 90° through 180° to 270°, it is necessary to prevent signals from appearing on the screen. A simple method of producing the required blanking is to use a cam arrangement mounted on the antenna shaft (A, fig. 175). The cam closes a contact which energizes a blanking relay. This relay applies sufficient negative voltage to the control grid of the cathode-ray tube to produce blanking.

(3) The video signals from the radar receiver are applied to the cathode-ray tube in such a way as to produce intensity modulation. Video limiting and amplification are required.

105. Typical B-scan Block Diagram

(fig. 176)

a. A timer trigger operates the start-stop multivibrator which generates a negative gate. The gate actuates the sweep generator and, in addition, intensifies the vertical trace. Intensity gate clamping is used to maintain the correct level of brightness in spite of any variation in signal content or range. The output of the sweep generator is applied to the sweep amplifier. This circuit delivers a sawtooth sweep current to the vertical-deflection coils in the fixed yoke.

b. A triangular wave is supplied to the horizontal-deflection coils by means of the azimuth sweep potentiometer. This potentiometer is located in the antenna assembly. Its operation has already been described. Horizontal blanking is accomplished by the cam and relay arrangement which has been discussed. Signals from the radar receiver are limited and amplified and finally applied to the control grid of the cathode-ray tube.

Section V. C-SCAN DISPLAY

106. Information Presented

a. The C-scan is a rectangular display in which the bearing and elevation of a target are given as shown in figure 54. Elevation is the vertical angle between the line drawn from the radar system to the target and the horizontal reference level. To a radar system which is installed on the ground, all angles of elevation are positive; that is, all targets will be above the horizontal ground level. To an airborne radar system, however, a target can be either above or below the level of the plane. Consequently, both positive and negative angles of elevation exist.

b. Radar targets are displayed by intensity modulating the cathode-ray tube beam. This is the only scan discussed which does not furnish information concerning the range of a target. The use of the C-scan is limited and it is always used with one or more associated radar scans.

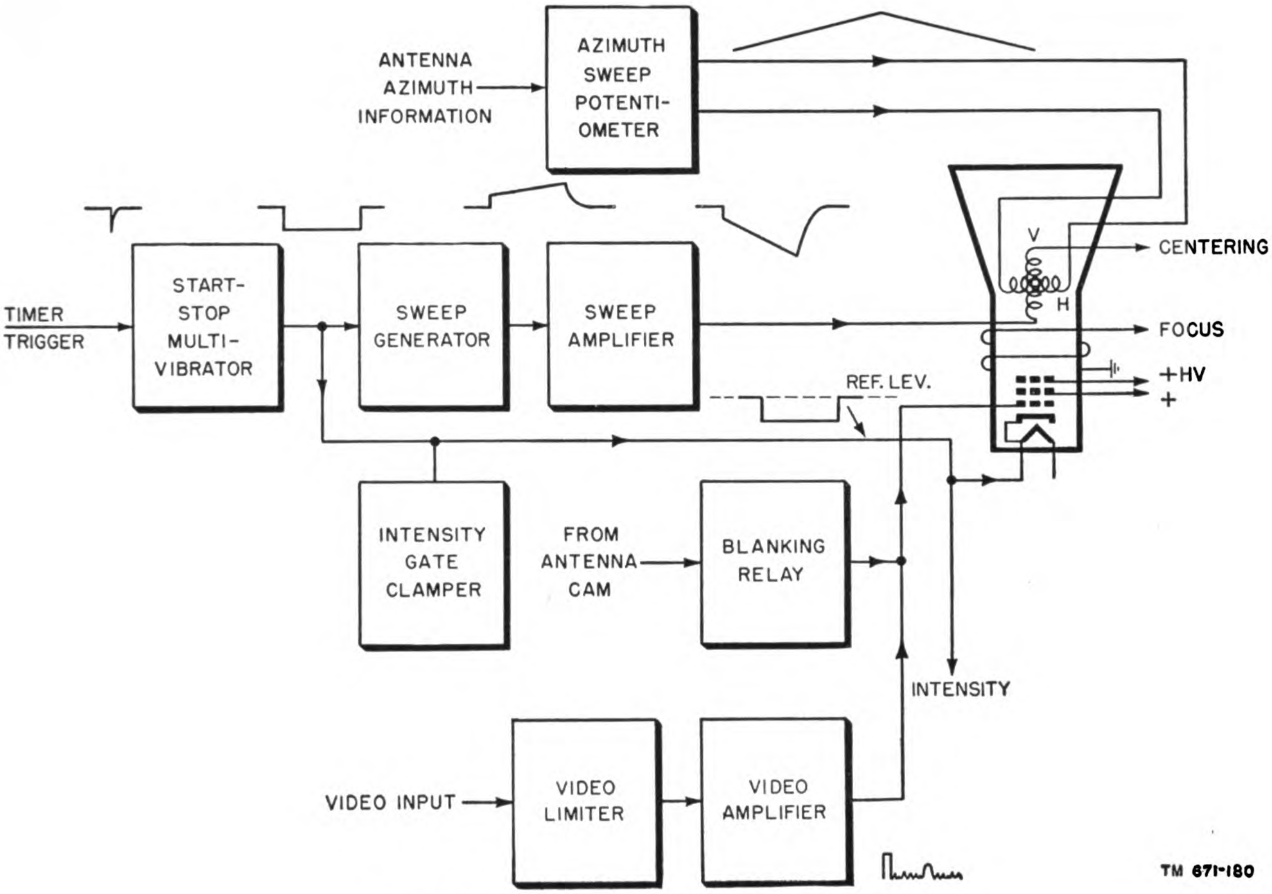


Figure 176. Simple B-scan display block diagram.

107. Type of Cathode-ray Tube

Most C-scan displays use electromagnetic cathode-ray tubes with a fixed deflection yoke consisting of horizontal- and vertical-deflection coils. A long-persistence screen, such as the P7, is used.

108. Signal Requirements

a. HORIZONTAL SIGNALS AND CIRCUITS. The azimuth sweep required can be obtained in the manner described above for the B-scan display. This sweep current is applied to the horizontal-deflection coils.

b. VERTICAL SIGNALS AND CIRCUITS. The current supplied to the vertical-deflection coils must produce a deflection which depends on the elevation of the radar antenna. As most radar antennas scan elevation angles more slowly than azimuth, a simple potentiometer can be used for the vertical sweep. A typical radar antenna can scan an area 10 to 20 times in azimuth for every scan in elevation. The angular coverage in elevation usually is smaller than the angular coverage in azimuth. Therefore, gearing is used between the antenna and the elevation potentiometer. The elevation potentiometer arm can be driven through several degrees of rotation for 1° change in elevation. This gearing increases the accuracy of the vertical deflection.

c. Z-AXIS SIGNALS.

(1) The output of the radar receiver is limited to prevent blooming. It is then applied to a video amplifier whose output is connected to the cathode-ray tube. The video signals produce intensity modulation of the electron beam.

(2) The C–scan display requires a special unblanking gate whose duration is very short compared to the time required to detect targets at the maximum range for which the radar system is set. The starting time of this gate is controlled by a range-measuring device which is part of

another radar display. This special gate is needed because of the slow sweep of the electron beam in this scan. Because the pulse repetition period of the radar set is very short, signals or noise for many range sweeps would appear at one point on the screen. The entire range is essentially piled up at one point. The brightness of any portion of the screen is determined by the total noise and echoes from targets received when the radar antenna is at a given azimuth and elevation.

(3) It would be very difficult to distinguish one target from another target at a different range, or from noise. Therefore, another radar display is required to identify a particular target and get its range. Once the range is known, the unblanking gate is delayed by the correct amount of time to intensify the electron beam for a few microseconds in the range vicinity of the target. In this way, all undesired signals and noise, except in the immediate vicinity of the desired target, are eliminated. A delay control, calibrated in yards of range, is used to position the unblanking gate properly. Therefore, the C-scan is a display of azimuth and elevation over only a small interval of range.

109. Typical C-scan Block Diagram

(fig. 177)

a. Both horizontal and vertical sweeps are obtained by means of potentiometers, as explained previously. Negative video signals from a two-stage video amplifier are applied to the cathode of the cathode-ray tube. In this way intensity modulation is produced.

b. A timer trigger is applied to a start-stop delay multivibrator. The duration of the positive square wave can be varied over a wide range. A delay control, located on the operating panel of

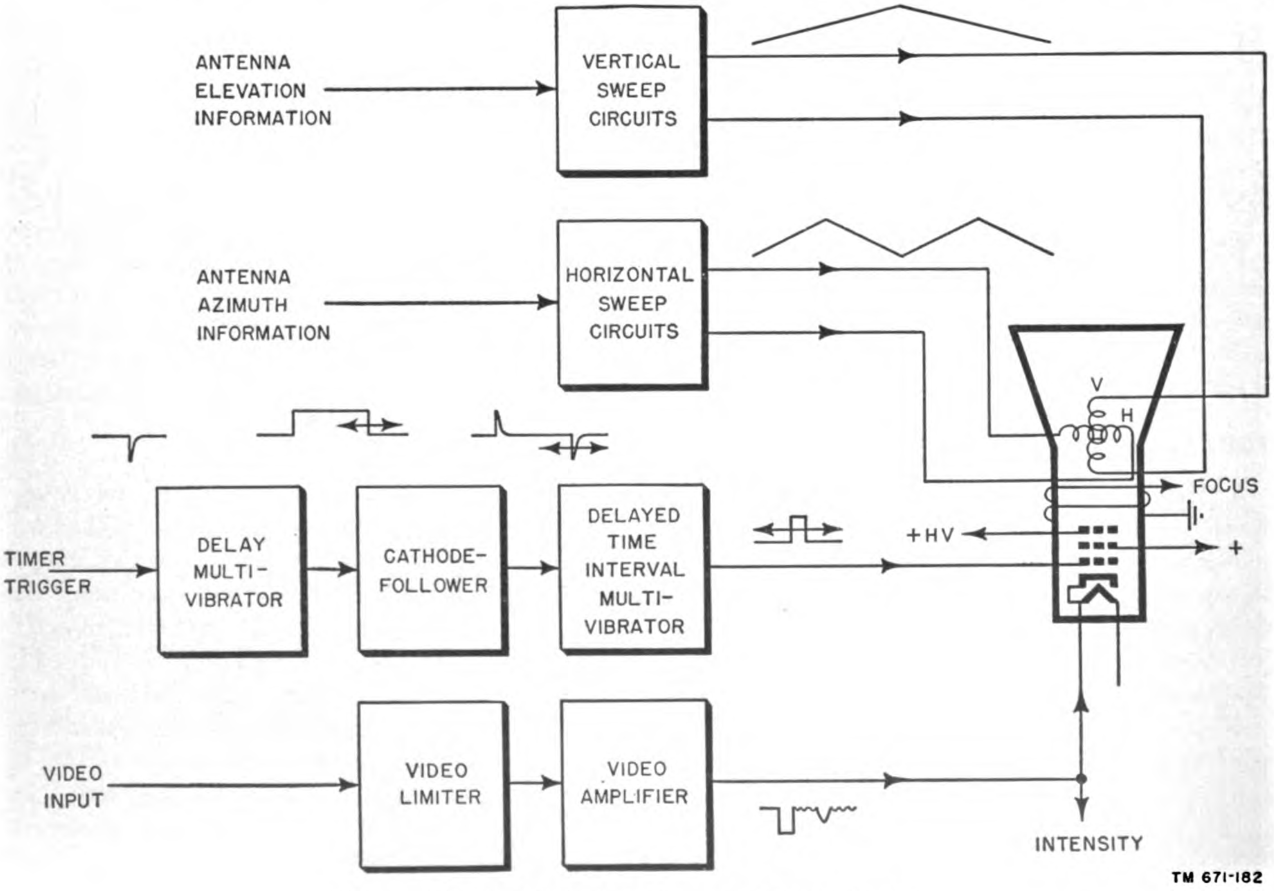


Figure 177. Simplified block diagram of C-scan display.

the radar set, changes the duration of the square wave. This waveform is peaked by a differentiating circuit in the input of a cathode-follower stage. The position of the negative peak is changed when the duration of the square wave changes. This negative peak is used to trigger a second start-stop multivibrator. The output of this circuit, called the delayed time interval multivibrator, is a narrow, positive square wave. The position of this waveform is determined by the setting of the delay control. This square wave intensifies the trace on the cathode-ray tube screen for the short period of time during which information is to be presented.

Section VI. SUMMARY AND REVIEW QUESTIONS

110. Summary

a. The A-scan is a deflection-modulated display which furnishes range information of radar targets.

b. The A-scan requires a horizontal timebase. Signals cause vertical deflection.

c. The range of a target is measured by noting the distance, measured along the timebase, between the transmitted pulse and the received target echo.

d. Range markers are used to permit more accurate measurement of range.

e. An intensity gate is required to intensify the trace only during those times when information is to be presented. Blanking of the retrace and removal of signals outside the range of the radar system are accomplished.

f. The J-scan is a radial-deflection modulated display which furnishes range information of radar targets.

g. The circular timebase on the J-scope is produced by two sine waves which are 90° out of phase. Video signals are applied to the radial-deflection electrode.

h. The PPI-scan is an intensity-modulated display which presents range and bearing information in the form of a polar map.

i. Radial timebase rotation is produced by either the mechanical or the electrical azimuth sweep system. A long-persistence cathode-ray tube screen is used.

j. The B-scan is an intensity-modulated display which presents range and bearing information in the form of a rectangular chart.

k. The C-scan is an intensity-modulated display which presents bearing and elevation information in the form of a rectangular chart.

111. Review Questions

a. What information is given by the A-scan display?

b. Why must a medium- or short-persistence screen be used in the A-scan and J-scan?

c. Explain how range can be measured on the A-scan display.

d. How can range markers be recognized?

e. What is the purpose of the unblanking gate in a radar display? Distinguish between an intensity gate and a blanking gate.

f. How is a circular sweep produced for the J-scope?

g. Give several advantages of the J-scan over the A-scan.

h. How is radial deflection usually produced in the J-scan?

i. What information is given on the PPI-scan display?

j. Why must a long-persistence cathode-ray tube screen be used for the PPI-scan?

k. How can a rotating sweep be produced?

l. To what electrode of the cathode-ray tube must the video signals be applied to produce intensity modulation?

m. What information is given on the B-scan display?

n. What deflection voltages or currents are required to produce a B-scan display?

o. What is the purpose of the cam and contact assembly on the antenna shaft of a radar set which has a B-scan display?

p. What information is given on the C-scan display?

q. What deflection voltages or currents are required to produce a C-scan display?

r. What is the purpose of the circular-shaped potentiometer which is found in the antenna assembly of radar sets using B- and C-scan displays?

CHAPTER 7

APPLICATION OF TEST OSCILLOSCOPES

112. Typical Test Oscilloscope

There are many varieties of test oscilloscopes, some designed for general purpose measurements, others for specialized tests. The measurements and tests to be discussed in this chapter are those which can be performed with the typical general-purpose instrument, and it is this oscilloscope which will be described here.

a. PANEL ARRANGEMENT. As mentioned previously, the typical test oscilloscope for general-purpose work consists of six basic sections: the vertical amplifier, the horizontal amplifier, the sync circuits, the sweep circuits, the cathode-ray tube and its circuits, and the power supply. It is the practice of most manufacturers of test oscilloscopes to locate the controls for each basic section in the same place on the front panel of the instrument. Consequently, the front panel can be divided into four zones (fig. 178). The cathode-ray tube and power-supply control zone contains the cathode-ray tube beam controls (intensity, focus, horizontal and vertical centering) and the power supply on-off switch. In the zone below are the sync and sweep controls for the selection of the frequency and type of time-base voltage. The vertical and horizontal amplifier gain controls are located on the lower third of the panel. This arrangement of the panel controls, while typical, is not invariable. For example, in some common test oscilloscopes the power-supply switch is located near the bottom of the front panel between the vertical and horizontal amplifier controls. Similarly, the vertical and horizontal amplified control sections may be located to the left and right, respectively, of the sweep and sync control zone, which may extend down the center of the panel. Furthermore, in many oscilloscopes there is a small panel in the rear with terminals for direct connection of the input signal to the vertical and horizontal deflection plates of the cathode-ray tube, bypassing the amplifiers. These terminals are used when the input signal frequency is so high or so low that passing the signal through the amplifiers results in excessive distortion. Generally, the signal to be studied is injected into the oscilloscope through the signal input and ground terminals usually found in the vertical and horizontal amplifier zones on the front panel. Each of the zones on the front panel may contain one or more manual controls depending upon the number of circuits controlled in the zone and the accuracy of the instrument. For example, the gain control of the vertical amplifier may be a single potentiometer, or a stepped resistor for coarse adjustment with a potentiometer used for fine adjustment (fig. 179).

b. OPERATION OF CONTROLS.

(1) The first indication of the function of any control or terminal of the oscilloscope is its location on the front panel. The controls themselves are labeled. However, the names for the same type controls differ with different makes of oscilloscopes. For example, such words as VERTICAL or VERT, single letters such as V, and the mathematical expression Y, which denotes the vertical axis when applied to oscilloscopes, all have the same meaning. The control, switch, or terminal that bears one of these labels is associated with the motion of the electron beam in the vertical direction. Similarly, the word HORIZONTAL or HOR, and the letters H and X, all indicate the horizontal-deflection controls. Words following these prefixes state the function of the control. In general, the controls on the front panel of the oscilloscope can be divided functionally into two classes. The first group consists of *operating controls.* These establish the

Table II. Panel Controls and Terminals on the Typical Test Oscilloscope

Control or terminal function	Names for terminal or control	Type of control	Class of control
Beam (trace) intensity	Intensity. Brilliance.	Potentiometer.	Operating.
Beam focus.	Focus.	Potentiometer.	Operating.
Position of beam (trace) along vertical axis.	Vertical position. Vert position. Vertical centering. Y position. Y centering. V position. V centering. Positioning.	Potentiometer.	Operating.
Position of beam (trace) along horizontal axis.	Horizontal position. Hor position. Hor centering. H position. H centering. X position. X centering. Positioning.	Potentiometer.	Operating.
Power supply.	Power on on-off.	Rotary. Toggle. Slide.	Operating.
Signal input level to vertical amplifier (single control).	Attenutator. Vertical gain. Vertical amplifier. V amplifier. Y amplitude. Vert amplitude. Gain.	Potentiometer.	Signal.
Signal input level to vertical amplifier, coarse adjustment on dual control.	Attenuator. Vertical gain. Vertical range. Amp ratio. Attenuation. Signal atten. V sensitivity.	Step attenuator	Signal.
Signal input level to vertical amplifier, fine adjustment on dual control.	V vernier. Y amplitude. Vert gain vernier. Y gain. V gain. V calibration. Gain.	Potentiometer.	Signal.
Signal input to vertical amplifier (terminals or pin-jacks).	Vertical input. V input Y signal input. Input. Vertical.		
Signal input level to horizontal amplifier (single control).	Attenuator. Horizontal gain. Horizontal amplifier. H amplifier. X amplifier. Hor amplifier. Gain.	Potentiometer.	Signal.

Table II. Panel Controls and Terminals on the Typical Test Oscilloscope—Continued

Control or terminal function	Names for terminal or control	Type of control	Class of control
Signal input level to horizontal amplifier, course adjustment on dual control.	Attenuator. Horizontal gain. Horizontal range. Amp ratio. Attenuation. Signal atten. H sensitivity.	Step attenuator.	Signal.
Signal input level to horizontal amplifier, fine adjustment on dual control.	H vernier. X amplitude. Hor gain vernier. X gain. H gain. H calibration. Gain.	Potentiometer.	Signal.
Signal input to horizontal amplifier (terminals or pin-jacks).	Horizontal input. H input. X signal input. X input. I input. Horizontal.		
Signal input selector to horizontal amplifier.	Hor gain/sel. Hor sel/gain. Horizontal. Sync. H sync/sel. H sync/sweep sel.	Step switch.	Signal.
Frequency range selector, coarse adjustment of timebase oscillator.	Coarse frequency. Frequency range. Sweep range. Range switch. Sweep frequency. Range.	Step switch.	Signal.
Fine frequency adjustment of timebase oscillator.	Sweep vernier. Fine frequency. Vernier. Frequency vernier. Frequency. Fine.	Potentiometer.	Signal.
Synchronizing signal amplitude adjustment.	Sweep sync. Sync. Sync adjust. Sync signal amplitude. Sync lock. Sync signal. Locking. Sync amplitude.	Potentiometer.	Signal
Synchronizing signal source selector.	Synchronizing sync selector. Sync signal selector. H sync/sweep selector. Horizontal.	Step switch.	Signal.

conditions of the electron beam necessary for proper viewing or proper display, and are related to the no-signal condition of the cathode-ray tube. In this group are the intensity, the focus, the power-supply, and the two beam-position controls. The second group consists of the *signal controls.* These affect either the input signal as it passes through the various circuits of the oscilloscope, or the

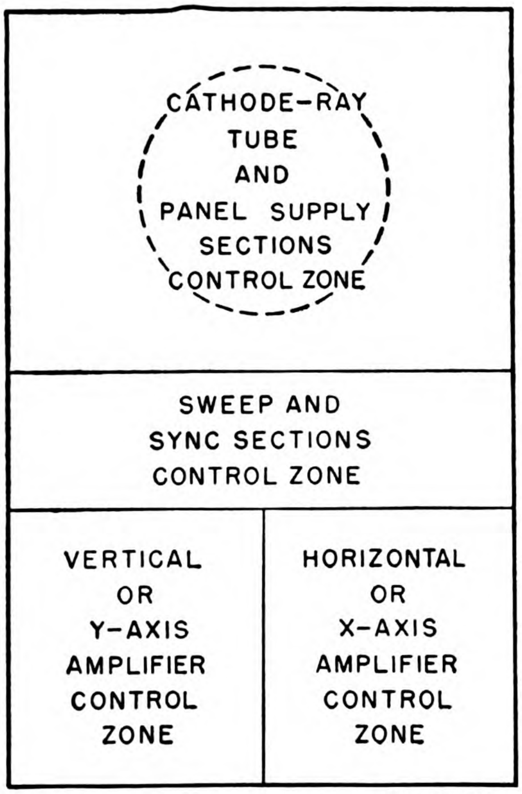


Figure 178. Panel layout of typical test oscilloscope showing zones of controls.

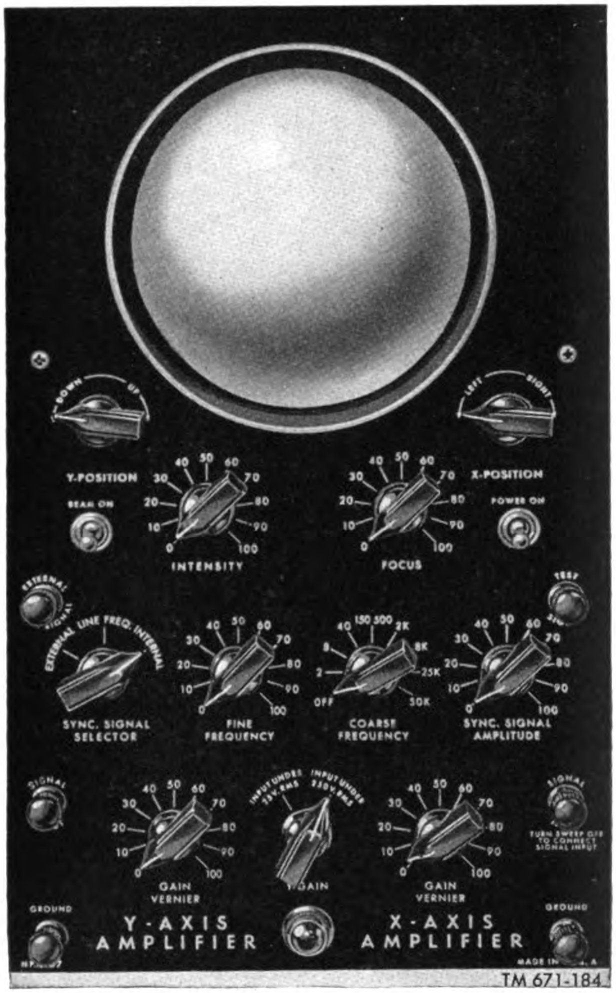


Figure 179. Front panel of typical test oscilloscope showing controls.

synchronizing and timebase voltages. All the controls on the front panel except those listed as operating controls are signal controls.

(2) Each of the operating controls is a means of controlling the electron beam by means of *operating voltages only*. For example, the intensity control, which determines the brightness of the trace by varying the operating voltage to the electron gun, should not be confused with modulation intensity, a signal control. The various operating controls with their functions and the names assigned to them on most oscilloscopes are shown in table II. The circuits used to accomplish the adjustments covered by these controls, as well as the sources of operating voltage for these controls, have been discussed previously. A separate power supply on-off switch is not always furnished on an oscilloscope. In many cases it is part of the INTENSITY control. The switch is mounted on the control and is in the OFF position when the control arm is in the extreme left position. When the control arm is advanced to the right, there is an audible click or change in tension in the arm as the power switch goes on.

(3) Signal controls can be single or double. As shown in table II, when single controls are used they are usually of the potentiometer type. When two controls are used for a particular function, one generally is of the step type, for coarse adjustment, and the other a potentiometer, for fine adjustment. The step switch has a fixed number of positions to which it may be turned. For example, the step switch used to control the voltage level of the input signal bears such calibrations as 1, 10, 100, and 1,000, or decimal values such as .1, .01, and .001, for each step or

position. The former type of numbering expresses the ratio between the input and output voltages as, for example, 1:1, 10:1, or 100:1, whereas the other kind of scale expresses the output voltage in terms of fractions of the input voltage. Such a switch is called a step attenuator. The continuously variable, or fine control, used with the step attenuator fills in the gaps between the steps. For an attenuator whose steps are calibrated as 1, 10, 100, and 1,000, the fine control would have a range of 10:1. Thus, for example, if the step attenuator is in the 100 position, one end of the fine control corresponds to 100:1 and the other end corresponds to 1,000:1. If one of the signal controls is not labeled clearly, the panel zone in which it appears is an indication of the circuit it controls, as explained previously. The switch which selects the input to the horizontal amplifier makes available to the latter the sweep voltage generated in the timebase circuits of the oscilloscope, or a 60-cps sine-wave voltage from the power supply, or an external sweep voltage. The application of these various types of timebase will be discussed later in this chapter. In connection with the control switch, however, each step of the switch may be labeled differently, even though its function is the same, for different oscilloscopes. At least five different labels are used to indicate the position which selects the sawtooth oscillator contained within the oscilloscope. These are: INT., SWEEP, SAWTOOTH, S. S. OSCILLATOR, AMP IN. The sine-wave timebase voltage position usually is labeled in one of three ways: LINE, LINE FREQUENCY, 60 CPS. The position which makes the horizontal amplifier available for signals originating external to the oscilloscope may be labeled EXT or AMP OUT. Similarly, the switch used to select the synchronization voltage for the timebase oscillator may be variously labeled.

(4) No matter how the test oscilloscope is used, the panel switches and controls must be manipulated to suit the specific purpose. For example, when setting up the test oscilloscope to observe the voltage variations of simple waveforms against a linear timebase, the various signal controls must be set to the positions indicated in figure 180. The settings of the various signal controls for specific uses will be covered more completely in the discussions of the various applications of the test oscilloscope which follow. The operating controls, on the other hand, always should be set for the clearest, sharpest, and most usable trace that can be obtained. The focus control should be adjusted in conjunction with the intensity control (changing the setting of one usually requires a change in the setting of the other), to yield a sharp, thin trace without blur, and with maximum detail. The position controls center the trace on the screen of the cathode-ray tube for ease in viewing. To obtain satisfactory detail in waveform observation, the gain controls of the verticle and horizontal amplifiers should be set to give a signal trace on the screen which is 2 to 3 inches in height for a 5-inch cathode-ray tube. Figure 181 shows properly and improperly focused and positioned traces.

113. Frequency Relationships in Waveform Observation

As explained previously, at least 3 cycles of the input signal to be observed should be displayed on the face of the test oscilloscope. This allows a proper study of the voltage waveforms. The relationship between the frequency of the signal applied to the vertical deflection plates and the frequency of the timebase determines the number of cycles of the signal which appear on the screen.

a. Frequency Relationship Between Sweep and Signal. In waveform display, the sweep frequency is kept lower than, or equal to, the frequency of the input signal, but *never higher*. If the sweep frequency is higher than the signal frequency, only a portion of the signal appears on the screen. Although the characteristics of some symmetrical waves may be derived from observation of only parts of them this practice is not recommended. To obtain 3 cycles of any waveform on the screen of the cathode-ray tube, the

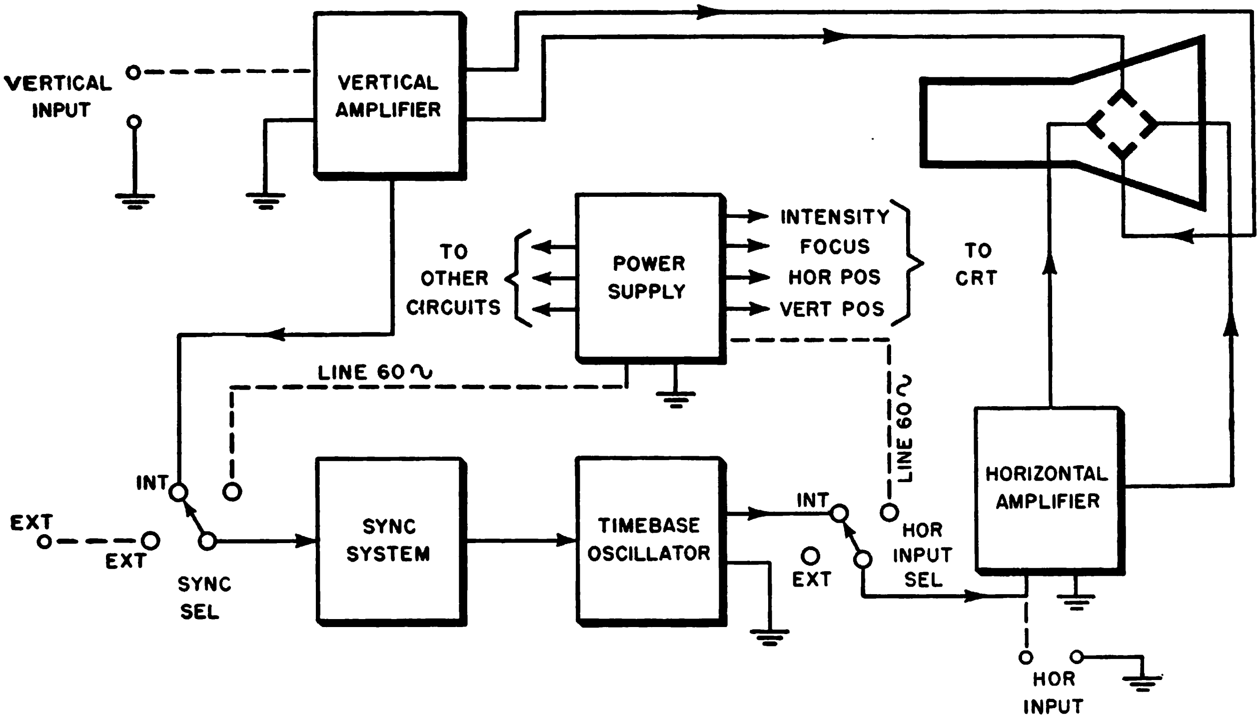


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Figure 180. Simplified block diagram of test oscilloscope illustrating arrangement of switches for waveform observation.

sweep frequency must be set to one-third the frequency of the input signal. For 3 cycles of a signal whose frequency is 30,000 cps, for example, the timebase frequency is set at 10,000 cps. To observe 2 cycles of this input signal, the sweep frequency is set to one-half the input signal frequency, or 15,000 cps; for 5 cycles, the sweep frequency is one-fifth the signal frequency (fig. 182). A trace with more than 5 or 6 cycles generally cannot give a satisfactory amount of detail for waveform observation. When the ratio of the input signal frequency to the timebase frequency is not an integer (1, 2, 3, etc.), the waveform display will consist of many lines moving across the screen. The nature of these patterns is too complex to be of any value. Setting the coarse frequency selector to the frequency which is one-third of the input signal (for 3 cycles), usually does not give a stationary waveform pattern on the screen. The frequency of the timebase oscillator may vary a little above or below the setting of the timebase frequency selector, or the input signal frequency may not be known exactly. The fine frequency control should be adjusted a little to the right or left of its original setting to stop the waveform. If there is no setting on the coarse frequency selector corresponding to one-third the signal frequency, the closest setting should be chosen, and the fine frequency control adjusted to obtain the desired waveform.

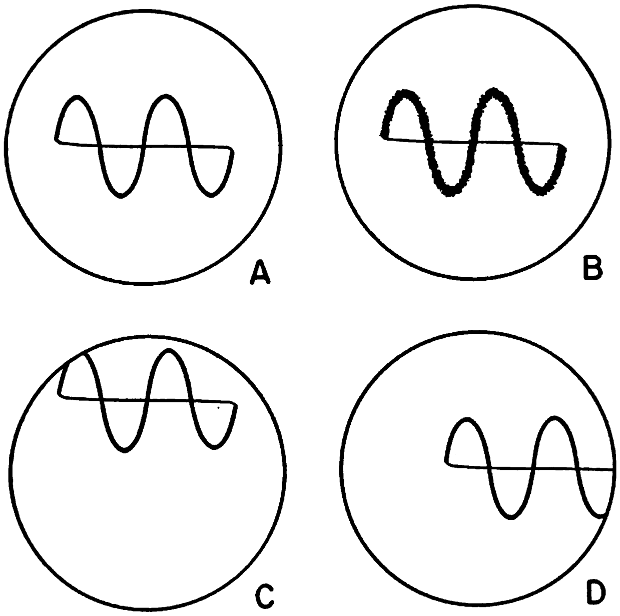

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Figure 181. Simple waveforms showing good and bad focus, intensity, and position control settings.

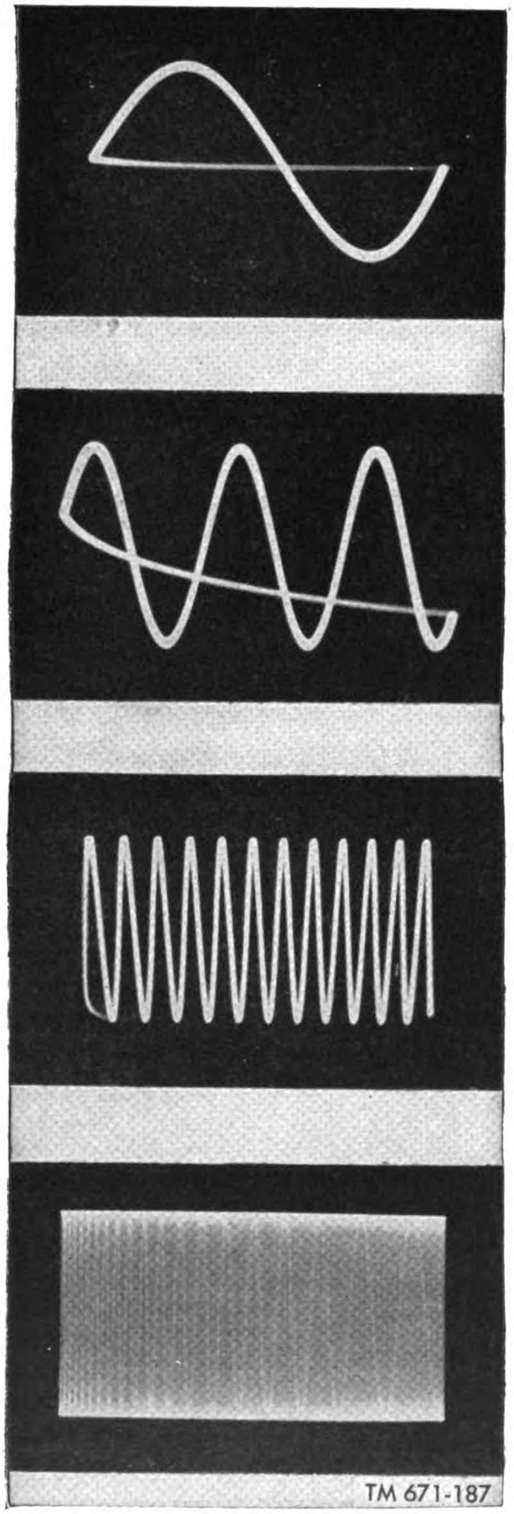

Figure 182. Various sweep-to-signal frequency ratios.

b. Signal Frequency Higher Than Sweep Frequency. As explained above, when the signal frequency divided by the sweep frequency results in a whole number, that is the number of input signal cycles that will be displayed on the screen. The reason for this is explained in paragraph 36*b*. The display presented on the screen of the cathode-ray tube may be one of the types shown in figure 183. Each of these presents 2 complete cycles of the waveform to be observed. The trace starts at different parts of the waveform, depending on how the input and the sawtooth sweep voltage are synchronized. A waveform with proper settings of horizontal and vertical gain controls is shown in A of figure 184. B illustrates the effect of increasing the gain control of the vertical amplifier. The setting of the vertical amplifier gain control is too high, resulting in a loss of the positive and negative peaks of the input signal waveform. Because the horizontal amplifier increases the voltage level of the sweep fed to the horizontal deflection plates, increasing the gain setting of the horizontal amplifier to too great a value cuts down on the number of cycles of the signal displayed on the tube face (C, fig. 184).

c. Sweep Frequency Greater Than Signal Frequency. Operation of the sweep at a frequency which is greater than the signal frequency results in odd patterns of limited usefulness (fig. 185). A shows the trace resulting from a sweep which is twice the frequency of the signal input and in phase with the signal. In B, the input signal is 90° ahead of the sweep, with the sweep twice the frequency of the signal. C and D are the patterns for a sweep frequency three times the signal frequency: In C the sweep is in phase with the signal; in D the sweep is 270° ahead of the signal. When the sweep frequency is four times the signal frequency, the patterns shown in E and F may be displayed. E results when the sweep and the signal are in phase; F results when the sweep leads the signal by 180°.

114. Waveform Analysis

a. Adjustment of Controls. After the desired number of cycles of the signal to be analyzed are obtained on the screen of the cathode-ray tube in the test oscilloscope, some operations still must be performed with the signal controls for correct waveform analysis. Through these operations, the trace is made to present the information about the input signal waveform in the clearest manner. For example, if a simple sine wave whose frequency is 30,000 cycles per second is to be observed on the test oscilloscope, the following adjustments must

Figure 183. Three traces produced with the same signal-to sweep frequency relation but with different signal-to-sweep-phase relations.

be made on the oscilloscope controls: First, before the signal is fed into the oscilloscope, the focus, intensity, and positioning controls are set to the midpoint of their range. The power is switched on, the vertical and horizontal amplifier gain controls are advanced to about one-third of their full range, and the sync selector is set to internal sync. The signal to be observed then is connected to the vertical input terminals of the oscilloscope, and the coarse sweep frequency control set to the position covering 10,000 cycles per second to observe 3 cycles of the input waveform. The fine frequency control of the sweep generator then is set to stop the wave. At this point, the gain controls of the horizontal- and vertical-amplifier circuits are readjusted so that the trace is as high as it is wide, and covers about 60 to 70 percent of the screen. Next, the intensity, focus, and positioning controls are reset to center and sharpen the trace. Now, although 3 cycles of the input waveform appear on the screen, they may be too crowded for easy examination (A, fig. 186). Consequently, the horizontal gain control should be advanced to spread out the waveform (B, fig. 186). It is now much easier to study the waveform. For more detail, the waveform can be spread out even more by further increasing the horizontal gain control (C, fig. 186). The electron beam is still tracing the 3 complete cycles, but parts of the first and last cycles are not visible because they are traced by the beam off the screen of the tube. The display of 3 cycles of the input waveform on the screen of the tube is advisable because even if the first and last cycles are not displayed fully, the center cycle gives a complete picture of the signal waveform. The effect of increasing the vertical-amplifier gain control to too great a value was shown in B, figure 184. The gain control of the vertical-amplifier circuits not only controls the amount of voltage fed to the vertical deflection plates by the vertical amplifier, but also partially determines the amount of synchronizing voltage fed to the timebase generator. Therefore, whenever the vertical-amplifier gain is lowered, the sync control must be advanced to increase the amount of synchronizing voltage fed to the sweep generator, if the signal waveform is

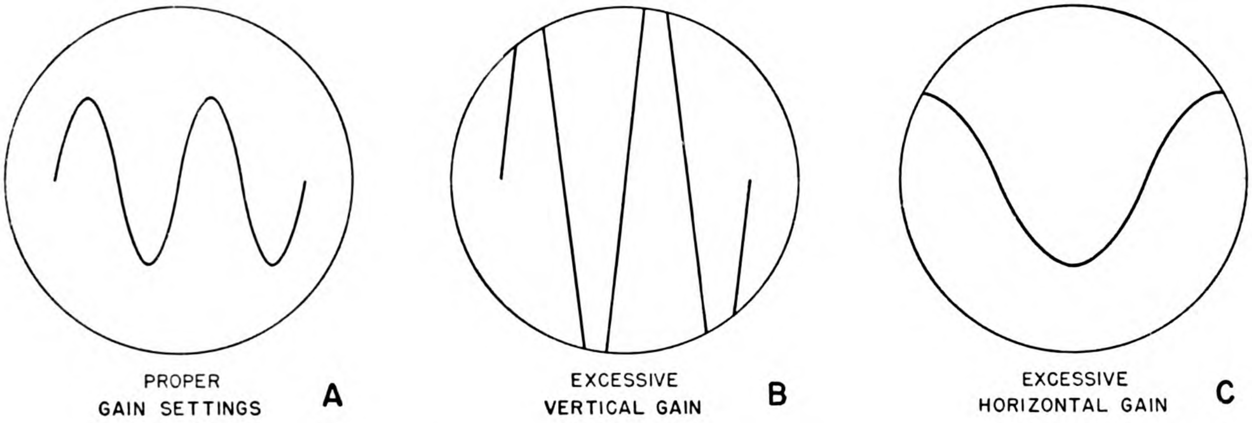

Figure 184. Effect of various vertical and horizontal gain setting on trace.

to remain stationary on the screen. However, feeding excessive synchronizing voltage to the sweep oscillator results in distortion of the pattern on the screen (fig. 187). Besides the effect of the settings of the signal controls on the trace of the waveform, another important factor is the linearity of the sweep voltage.

b. Use of Linear Sweep. As discussed previously, the study of signal waveforms consists of determining the way in which the signal voltage to be observed varies with time. For accurate observations, the voltage versus time relationship of the signal waveform shown on the test oscilloscope screen must correspond exactly with the voltage versus time relationship of the signal itself. Therefore, the timebase voltage generated in the test oscilloscope is made as linear as possible. For this purpose, a sawtooth voltage is used, as explained in paragraph 36*a* (7). If the rising part of the sawtooth, that part reproducing the input signal, is not linear, the signal waveform observed on the screen will not be an exact reproduction of the input. A nonlinear sweep voltage (A, fig. 188), will space out the input wave cycles unevenly on the screen, resulting in the type of trace shown in B. Of the 3 cycles of signal waveform in B (signal-frequency to sweep-frequency ratio is 3:1), only 1 cycle appears normal, the one in the middle. The last quarter of the cycle at the extreme right appears on the retrace. In most cases, when the sweep is not strictly linear, the signal waveforms reproduced on the extreme left of the trace (the first cycles) are the accurate ones. The greater the number of cycles of the input waveform displayed on the screen, the greater the likelihood that 1 or more cycles will give an accurate representation of the true waveform of the input signal.

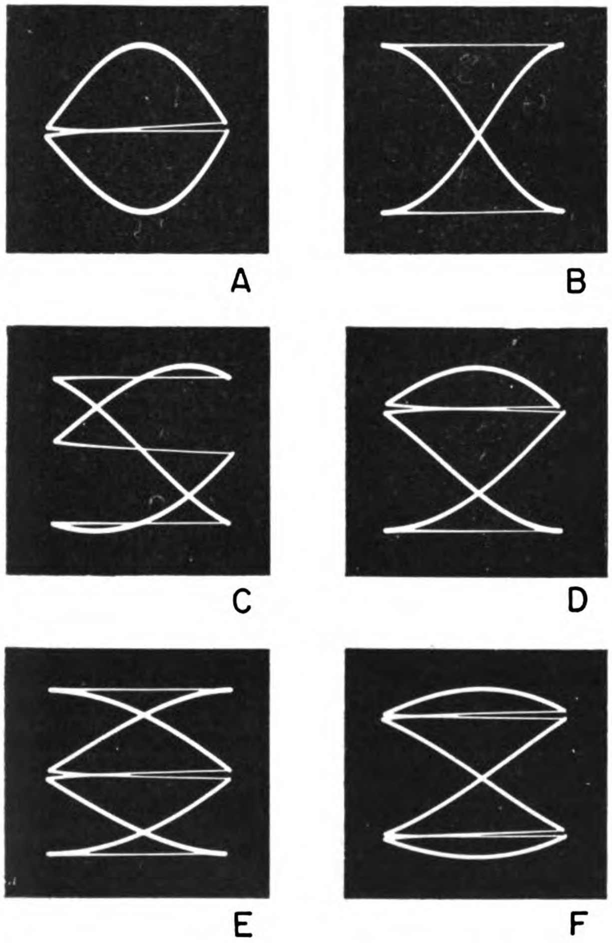

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Figure 185. Various traces produced when frequency of sweep is greater than that of signal.

c. Sine Wave to Complex Wave. Waveforms are analyzed to discover the type of voltage existing at various points in a circuit. The voltage or frequency of the waveform is measured or it is compared with known patterns. Qualitative comparison can provide information concerning the function and the operation of a circuit. In the testing and analysis of electronic circuits, both sinusoidal and nonsinusoidal waveforms are encountered. The nonsinusoidal or complex waveform can be analyzed in terms of a sine wave and its harmonics. Each complex waveform is the resultant of a sine wave at the fundamental fre-

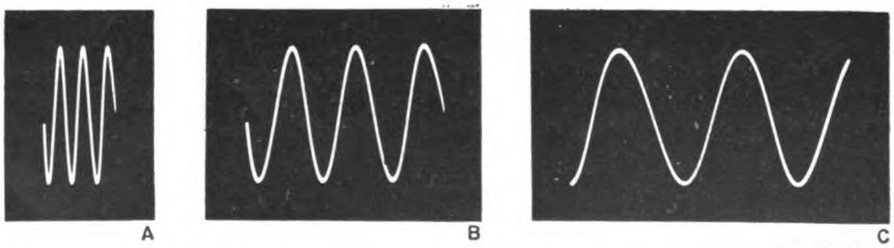

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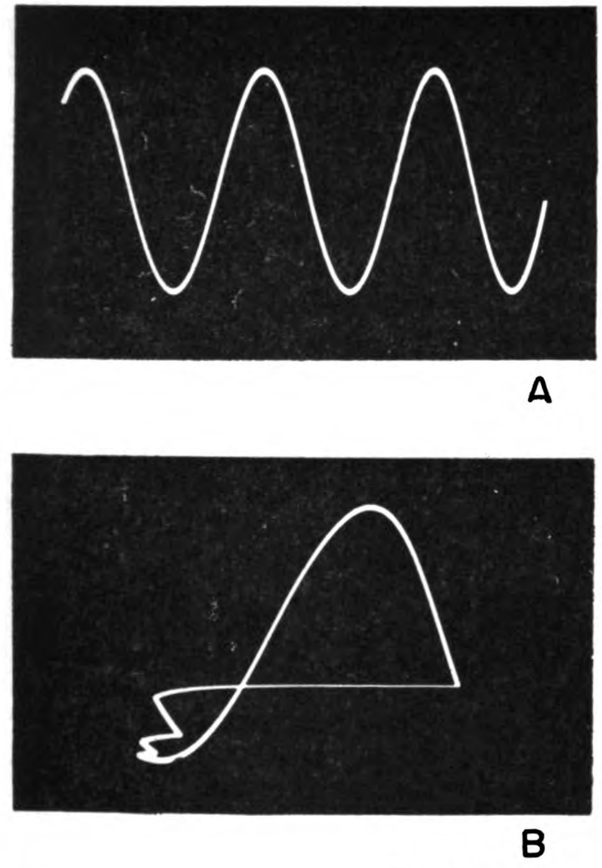
Figure 186. A 3-cycle sweep is made easier to view by increasing sweep amplitude.



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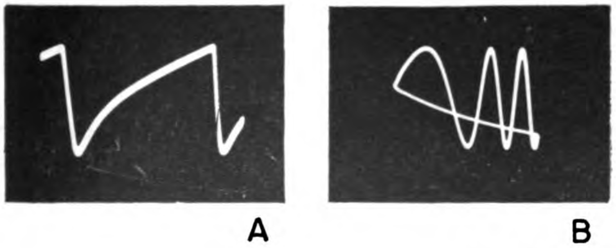
A, Normal trace produced by proper synchronization; B, Trace produced for the same three cycles by oversynchronization (horizontal gain increased).

Figure 187.

quency plus certain of its harmonics in certain amplitude and phase relations to the fundamental. Complex waveforms can be analyzed on the cathode-ray tube screen by using Fourier analysis, or by comparing the waveform to another whose characteristics are known from experience, or by using a harmonic wave analyzer. The development of complex waveforms is shown graphically in figure 189. The complex waveform in A is composed of the fundamental plus the second harmonic. The second harmonic has an amplitude equal to one-half the amplitude of the fundamental. In B the third harmonic is added to the fundamental to produce another type of complex waveform.



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A, Nonlinear sweep; B, Distorted sine-wave trace as a result of using sweep shown in A.

Figure 188.

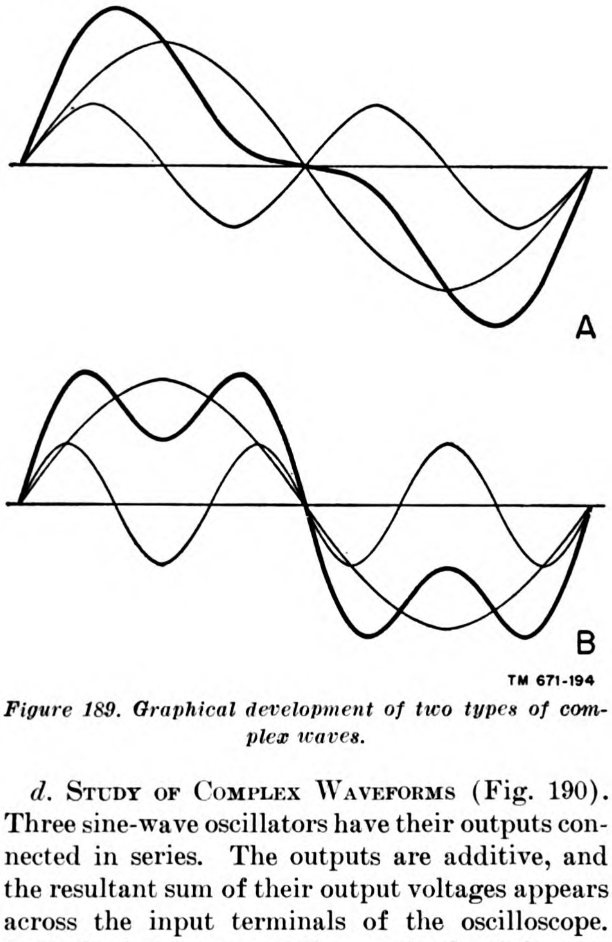

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Figure 189. Graphical development of two types of complex waves.

d. Study of Complex Waveforms (Fig. 190). Three sine-wave oscillators have their outputs connected in series. The outputs are additive, and the resultant sum of their output voltages appears across the input terminals of the oscilloscope. Both the frequency and the amplitude of the output of each oscillator can be varied. To study the waveforms resulting from the addition of the fundamental and any additional harmonics, oscillator A is set to some frequency, called the fundamental, and the other two oscillators are set to frequencies of whatever harmonics are desired. The sync selector switch of the oscillo-scope is set at internal sync, and the sweep frequency selector is set at one-third the frequency of oscillator A. If oscillator A is set to 1,000 cps, oscillator B to 2,000 cps, and oscillator C to 3,000 cps, the resultant is the complex waveform shown in D, figure 191. Oscillator B (Fig. 190) produces the second harmonic with an amplitude equal to 50 percent

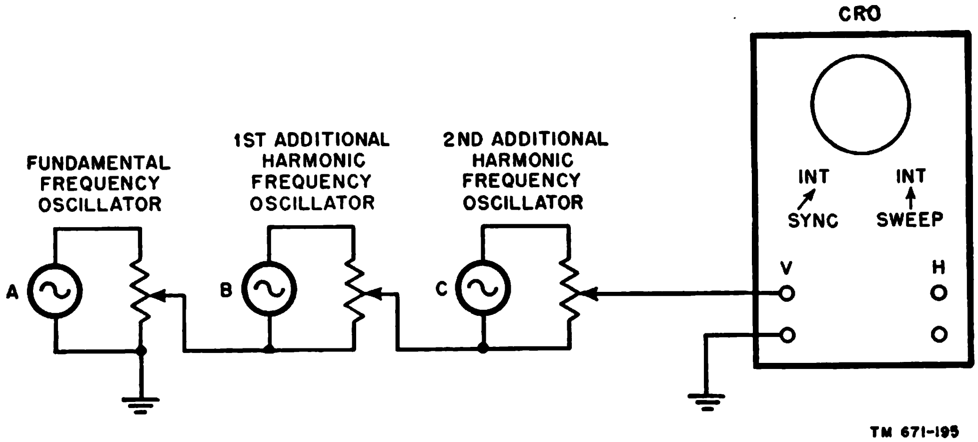

Figure 190. Circuit set-up for complex waveform analysis with test oscilloscope.

of the fundamental. Oscillator C produces the third harmonic with an amplitude equal to 100 percent of the fundamental. For the complex waveform in D, figure 191, the outputs of all three oscillators are in phase, as shown in A, B, and C. Complex waveforms in which the harmonics are *not* in phase with the fundamental are shown in A and B, figure 192. These waveforms are generated by much more complex circuit arrangements than that of figure 190. Most complex waves contain many more harmonics than were used to produce the waveforms just discussed, but the lower orders of harmonics (third, fourth, fifth) play the greatest part in determining the general shape of the complex waveform. The analysis of complex waveforms in connection with the testing of circuits and equipment is covered later in this chapter.

e. Direct Connection to Scope. In many cases where complex waves are to be studied on the oscilloscope, the output of the circuit under observation must be fed directly to the deflection plates of the oscilloscope. To accomplish this, the signal input leads are connected to the terminals provided on a small panel at the back of the oscilloscope. This is necessary when the harmonics present in the complex wave are above the frequency limit of the vertical amplifier; 20,000-cps square waves, for example, require a vertical amplifier with flat response up to 200,000 cps. This is above the upper frequency limit of most vertical amplifiers in test oscilloscopes, making the direct connections a necessity for accurate observation.

115. Sine-wave Testing

One of the most useful waveforms for testing purposes is the sine wave, because distortions of its shape are followed easily on the screen of the test oscilloscope. Even vertical amplifiers with limited frequency response will reproduce a sine wave, although it will be distorted.

a. Input and Output Signal Relationship. In sine-wave testing, the two major properties of the input signal, amplitude and shape, are used to determine different characteristics of the circuit under test. If a sine-wave voltage is applied to a circuit and a distorted waveform is obtained at its output, the circuit usually is the cause of the distortion. A sine-wave voltage applied to an amplifier, for example, may undergo the various types of distortion shown in figure 193. These distorted sine waves will be considered in detail later. The amplitude of the output sine wave as observed on the oscilloscope, in comparison with the amplitude of the input sine wave, indicates the gain characteristics of the circuit under test. The amplitude of the input sine wave is also important in considering the distortion caused by a circuit under test. For example, if the voltage level of the input signal is so high as to overdrive the amplifier, amplitude distortion results (C, fig. 193).

b. Checking Audio Amplifiers.

(1) A simple test set-up for checking audio amplifiers with a sine-wave voltage is shown in figure 194. The signal generator used should have a range from 20 cps

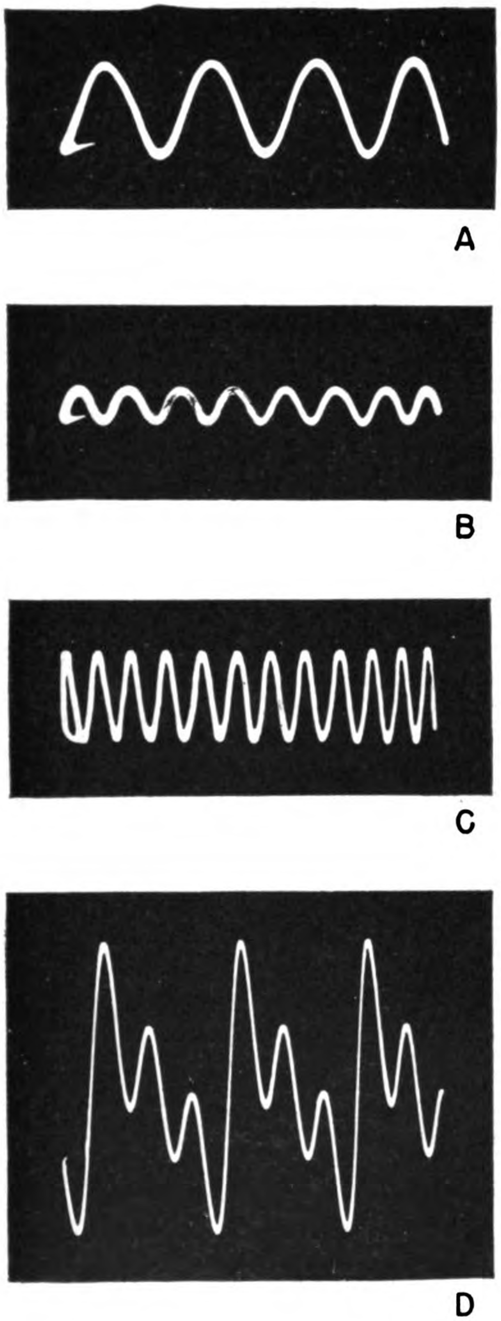

Figure 191. Development of complex wave showing the fundamental, second, and third harmonics of which it is constructed.

to about 20,000 cps. The output of the generator should be adjusted to a level which will not overdrive the audio amplifier. The input waveform to the audio amplifier then is checked at point 1 and compared to the output waveform at

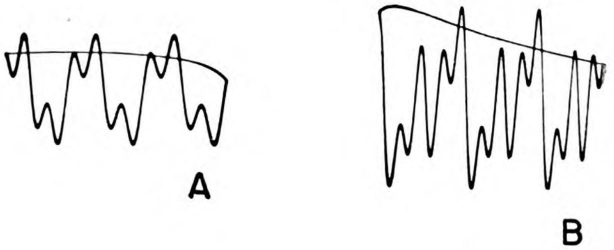

Figure 192. Complex waveforms whose harmonics are out of phase with the fundamental.

point 2 in the circuit of figure 194. Comparisons should be made at settings such as 40, 120, 240, 400, 2,400, 4,000, and 10,000 cps to cover the audio frequency range of the amplifier. If the output of the signal generator is kept constant over this range, the audio output waveform trace on the screen of the oscilloscope should remain about the same height for all the settings. For most cases the output impedance of the signal generator can be adjusted to allow matching to the input impedance of the audio amplifier. The output impedance of some audio oscillators, for example, is adjustable for matching to 50-ohm, 200-ohm, 500-ohm, 5,000-ohm, 50,000-ohm, and even higher impedances. If in these tests the oscilloscope is to be shifted from point 1 to point 2 after every setting of the signal generator in order to make a running comparison between the signal input and the output, some method must be used to keep the

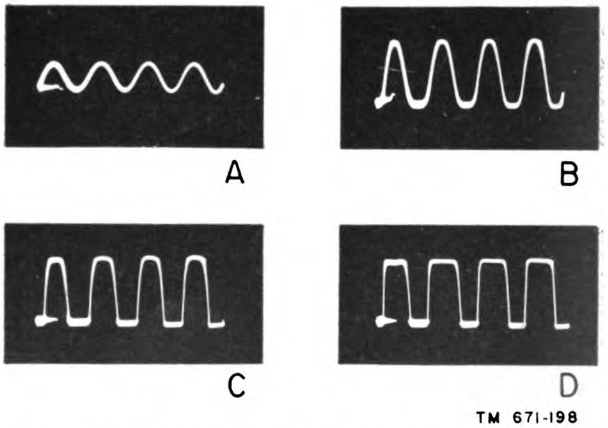

Figure 193. Sine wave, A, fed into amplifier can come out distorted as in B, C, and D.

amplitude of the image on the screen constant. Otherwise, it will be difficult to analyze the waveform properly. This is so because the output of the amplifier will be higher than the output of the signal generator (the output voltage will be the gain of the amplifier times the input voltage). A voltage divider can be placed across the output of the amplifier in parallel with the load and the input to the oscilloscope tapped off at various positions to keep the signal voltage constant at the vertical-deflection plates of the oscilloscope. This voltage divider should have a resistance of about 1 megohm. After checking the output at point 2 for the audio-frequency range, the output to the oscilloscope can be taken off the next to the last stage of the amplifier for various frequencies. In succeeding tests, the output to the oscilloscope is taken off the stages closer and closer to the input to find what stage is defective, if any.

(2) The waveforms shown in B and C, figure 193, are the distorted patterns observed at the output of an audio amplifier using the test set-up shown in figure 194. B indicates a flattening of the negative peaks of the signal cycle caused by excessively high grid bias on a voltage or power amplifier tube, or too low a plate or screen voltage on these same tubes. C indicates too large an input signal, as explained previously. In the testing of multistage amplifiers using triodes and pentodes, if the output is a complex wave consisting of the input sine-wave plus even harmonics, a triode stage usually is defective; if the output contains odd harmonics plus the fundamental sine-wave, a pentode stage usually is defective.

c. Checking Phase Inverter and Push-Pull Systems. The use of push-pull amplifiers is very common in audio systems, oscilloscope deflection systems, and other circuitry where a high degree of *balanced* power amplification is required as explained in paragraph 64*a*. Phase-inversion stages are used in many amplifiers to obtain the polarity opposition of the two signals fed to the push-pull amplifier stage. Unbalanced operation of phase-inversion stages is indicated by the difference in amplitude of the signal output as obtained from both grids of the following push-pull amplifier tubes. If one of the tubes of a push-pull amplifier is inoperative, the output waveform from plate to ground of the operative tube shows a gradual rounding of the negative peaks. This results from the addition of even harmonics to the signal fed to the amplifier, which would normally be balanced out by the now inoperative tube. A leaky coupling capacitor in the output-tube grid

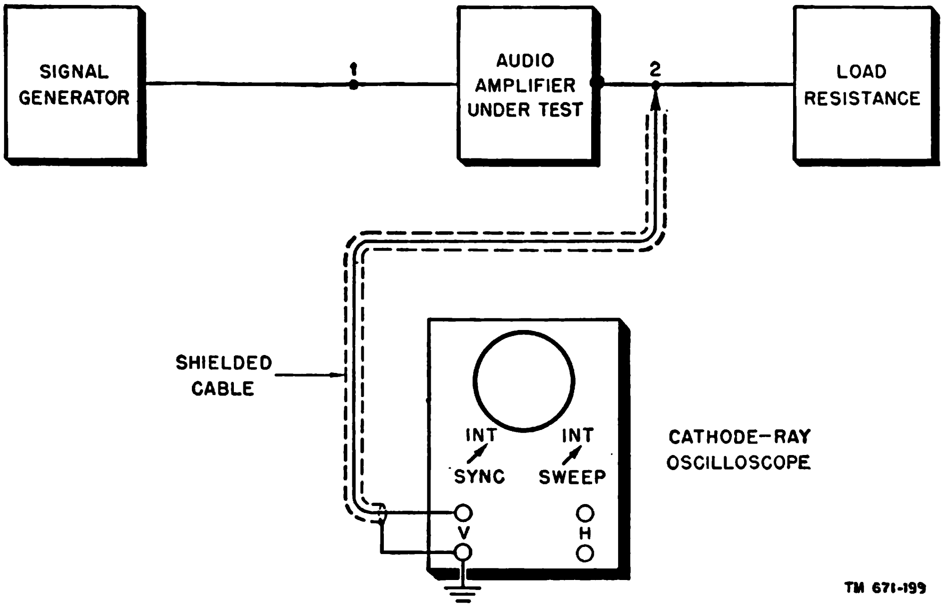

Figure 194. Basic test set-up for audio amplifier testing.

circuit results in a slanting flat-top on the positive peaks of the output waveform. Excessive bias on the push-pull tubes results in the type of distortion shown in B figure 193. These distortion patterns are typical for most defective push-pull circuits. A different distortion pattern should be expected for each particular element defect in a particular circuit.

d. Checking Class-B Amplifiers. Class-B amplifiers are used in audio circuits where high-power amplification is required with comparatively low plate dissipation. Generally, the Class-B amplifier is coupled to the preceding driver stage by a step-down transformer, so that the input signal at the grids of the class-B amplifier tubes (connected in push-pull across the secondary of the transformer) is smaller than the signal across the transformer primary. Therefore, if the signal-generator output is followed from the driver to the input of the class-B stage, using the test set-up shown in figure 194, the waveform at the plate of the driver tube should be of greater amplitude than the waveform at the grids of the class-B amplifier tubes. At the plate of one of the class-B amplifier tubes only the positive half cycles of the signal input are reproduced; the negative half cycles are obtained at the plate of the other tube. If there is no distortion in the class-B amplifier stage, the class-B amplifier output waveform taken off across the secondary of the output transformer is the same as the driver stage waveform.

116. Square-wave Testing

a. Composition of Square Wave. Square waves are complex waves composed of a fundamental and at least 10 odd harmonics of various amplitudes. The greater the number of odd harmonics in the square-wave signal, the sharper are the corners of the square wave. The use of square (or rectangular) waves for testing circuits has definite advantages over the use of sine waves. Square-wave signals passed through a circuit are more sensitive to circuit instability than are sine-wave signals. Square waves can be used to check for hum and motorboating in circuits, as well as oscillating amplifiers. The operation of compensating networks can be shown directly with square waves.

b. Input and Output Signal Relationship. An ideal square wave is one which rises abruptly from zero to some positive value, stays there for some fixed period of time, falls abruptly to some negative value, stays there for the same length of time as for the positive value, and then passes through zero to start the cycle over again (A, fig. 195). If a square wave is fed to an amplifier, for example, the sudden rises and drops in voltage test the response of the circuit to instantaneous signal changes (transients). If an amplifier reproduces the input signal without rounding the corners, it indicates that the amplifier responds immediately to instantaneous signal changes. If the amplifier under test has a tendency to oscillate, this will show up on the output waveform as pips on the positive and negative plateaus (D, fig. 195). In this case, the waveform indicates that the circuit is highly damped, since the oscillations appear for only a short time of each half of the output cycle. Nonlinear distortion in a circuit under test is indicated in the output waveform by asymmetrical positive and negative half cycles.

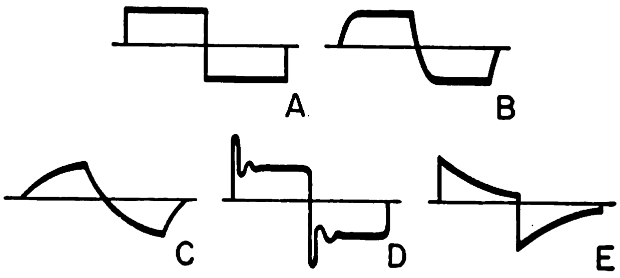

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Figure 195. Square-wave input to an amplifier and typical output patterns.

c. Fundamental Test Set-up.

(1) The basic test set-up for square-wave testing is the same as that shown in figure 194. A square-wave generator is substituted for the sine-wave generator. For the testing of any circuit, the signal generator with its normal load, or a device equivalent to its normal load, should be inserted where the audio amplifier and load are shown in the illustration. If an audio amplifier is tested without its usual load, a 500-ohm resistor should be inserted for the substitute load. The frequency range of a typical generator used for these tests is from 20 to 10,000 cycles, with an output impedance of 500 ohms. Because the square wave generated by such equipment contains at least the twenty-first harmonic (the tenth odd

harmonic) of the fundamental frequency, when the generator is set to 10,000 cps the square wave generated can be used to test the response of the circuit to a signal of about 200 kc. A square-wave signal of constant amplitude should be fed to the input of the circuit under test. The oscilloscope should then be placed across the *input* of the circuit to make certain that the oscilloscope itself responds to the waveform. If the oscilloscope does not reproduce the generated waveform perfectly, the actual waveform it does give can be used for comparison with the output. If the circuit tested consists of more than one stage, the oscilloscope probe should be moved from stage to stage in succession, to check the output of each stage against its input.

(2) In square-wave testing with the oscilloscope, it is particularly important that the vertical-deflection amplifier have a frequency-compensated attenuator. Figure 138 shows the effect of feeding a 15,000-cps square-wave signal to the vertical amplifier of an oscilloscope through an uncompensated attenuator. Here it is shown that, although the vertical amplifier of the oscilloscope is rated to pass a a 15,000-cps square wave without distortion, the attenuator cuts down on the frequency range for which measurements can be made with the oscilloscope. In such cases, the input signal to the oscilloscope should be fed directly to the vertical-deflection plate terminals on the small panel on the rear of the oscilloscope.

d. RESPONSE CHECKING OF CIRCUITS. The response characteristics of most circuits are limited by the lowest and the highest frequencies that the circuit passes. The high-frequency transmission determines the shape of the transient at the instants that the signal is applied and removed. The low-frequency transmission of the circuit determines the value and the shape of the waveform after some time has elapsed (between the application and the removal of the square wave for each half cycle). If a square wave is fed to a circuit and the output wave is rounded off as in B, figure 195, it indicates that the response of the circuit to high frequencies is poor. If the output waveform has sharp corners, however, and the center of the waveform plateau has a dip or slant as in E, the low-frequency response of the circuit is poor. This indicates that the circuit passes the high-frequency components of the input waveform and only a limited portion of the low-frequency components. C shows the response of a circuit having poor high-frequency response.

e. CHECKING AUDIO AMPLIFIER.

(1) Because the square wave is composed of a fundamental frequency and a large number of odd harmonics, passing a square wave through a circuit immediately gives information about the frequency response of the circuit to a wide band of frequencies. As mentioned previously, the square waves generated by most square-wave generators contain the fundamental and about ten odd harmonics of appreciable amplitude. (Actually, the square wave contains many more harmonics, but their contribution to the shape of the wave is almost negligible.) If an amplifier cannot pass any of the harmonic frequency components of the square wave, the output waveform will not be square, and its shape will depend on the remaining harmonics. To cover the frequency response of a circuit, therefore, it is necessary to use only two different frequency settings on the square-wave generator. To test the frequency response of an audio amplifier from 20 to 20,000 cps, a 20-cycle square wave should first be fed to the circuit. This tests the low-frequency response of the amplifier. If the amplifier passes equally all frequencies from 20 to about 400 cycles, the out-put waveform will be square; that is, there will be no appreciable difference between it and the input waveform. To test the high-frequency response of the circuit, the signal generator should be set to about 1,000 cps. If the circuit amplifies all frequencies equally up through the tenth-odd harmonic (that is, up to 20,000 cps), the square-wave output should be exactly like the input. This would indicate good response in the upper audio-frequency range from 1,000 to 20,000 cps.

(2) Besides furnishing information on frequency response, square-wave testing of an audio amplifier uncovers a great va-

riety of circuit defects. If the output waveform at any stage exhibits a thickening of the flat-top portion of the wave, it indicates the presence of hum voltage superimposed on the signal. Oscillation in the high-frequency range is shown by an output waveform like that shown in *D*, figure 195. If oscillation occurs in the low-frequency range of the amplifier, the pips occur nearer the right end of the waveform plateau.

f. CHECKING VIDEO AMPLIFIER.

(1) The testing of a video amplifier requires the use of a square-wave generator capable of furnishing a square-wave signal with a fundamental frequency of about 100 kc. If such a signal is fed to a video amplifier, its response to 2 mc, the twentieth harmonic, can be observed. To observe the response to higher signal frequencies, higher-frequency square waves must be used.

(2) The test set-up for checking video amplifiers by square-wave testing is the same as in figure 194 where a square-wave generator is used. The generator should first be set to 60 cps to observe low-frequency response, and then to some higher value (from 25 kc to 100 kc, depending on the range of the amplifier) for the high-frequency response of the amplifier. The generator output should be kept low to prevent the video amplifier from limiting the input signal and giving a misleading output pattern. For such tests it generally is necessary to use the direct connection to the vertical-deflection plates of the oscilloscope, as mentioned previously. Most general-purpose oscilloscopes do not have vertical amplifiers whose frequency range exceeds about 300 kc. When used to pass signals of higher frequency, the vertical amplifier introduces distortion, attenuating the signal to such an extent that good analysis is impossible. At the high frequencies, the attenuating probe furnished with the oscilloscope should be used to increase the input impedance of the oscilloscope and reduce losses. Some of the output waveforms observed for video amplifiers and the defects causing them are shown in figure 196.

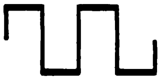
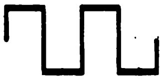
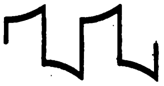
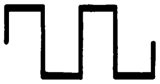
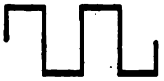
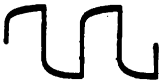
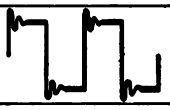
INPUT TO VIDEO AMPLIFIER	SHAPE OF OUTPUT WAVE SEEN ON CRT SCREEN	INTERPRETATION
 60-CPS SQUARE WAVE		GOOD LOW-FREQUENCY RESPONSE AND NEGLIGIBLE PHASE SHIFT
		LEADING LOW-FREQUENCY PHASE SHIFT AND LOW-FREQUENCY ATTENUATION
		LAGGING LOW-FREQUENCY PHASE SHIFT
 25-KC SQUARE WAVE		GOOD HIGH-FREQUENCY AND TRANSIENT RESPONSE
		POOR HIGH-FREQUENCY RESPONSE
		EXCESSIVE HIGH-FREQUENCY RESPONSE (OSCILLATION) AND NONLINEAR TIME DELAY
		EXCESSIVE OR INSUFFICIENT MIDFREQUENCY RESPONSE AND NONLINEAR TIME DELAY

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Figure 196. Output waveforms from video amplifiers with a square-wave input, showing defects causing distortion.

117. Voltage and Current Measurements

a. VALUE OF OSCILLOSCOPE. The cathode-ray oscilloscope also is used for measuring instantaneous a-c and d-c voltages and currents. Since the height of a trace on the screen is proportional to the amplitude of the signal input voltage to the oscilloscope, the height can be used to measure the input. This is particularly applicable to transient and a-c peak voltage measurements because the electron beam deflection occurs immediately with a change in voltage on the deflection plates. In conventional meters, the meter movement does not respond to rapid changes in voltage and current because of its inertia, and cannot give instantaneous values.

b. A-C VOLTAGES.

(1) Before voltage or current measurements can be made, the oscilloscope must be calibrated so that the relationship between input voltage and trace height is known. Two considerations are important in this calibration: one, the range of voltages to be measured by the oscilloscope; two, the maximum usable height of the trace. The measurement range determines what the setting of the vertical-amplifier attenuator will be for maximum height of the trace. Once set, the attenuator should be kept in that position for all further operations.

(2) Cathode-ray oscilloscopes are useful primarily for indicating peak-to-peak voltages because these are shown directly on the screen. To convert peak-to-peak voltage values of sine waves to rms values, the peak-to-peak value is divided by 2.83. Therefore, if a 100-volt (rms) signal is fed into an oscilloscope, the peak-to-peak voltage is 2.83 times 100 or 283 volts, which corresponds to the distance between the positive and negative peaks on the trace of the input signal. If the maximum usable trace on the screen is 4 inches in height for a 5-inch tube, the 4-inch trace corresponds to 283 volts and each vertical inch of trace corresponds to 283 divided by 4 or 70.8 volts. Consequently, if an input voltage produces a 3-inch trace peak-to-peak on the screen, the input voltage is 3 times 70.8 or 212.4 volts (peak-to-peak). To obtain the rms value, divide the peak-to-peak value by 2.83; in the example given here, the rms value is 212.4 divided by 2.83 or 75.1 volts. It should be noted that 2.83 is the conversion factor for rms to peak-to-peak only for *sine-wave voltages*. For complex waves, only peak-to-peak values are used. The larger the face diameter of the tube, the greater the accuracy of calibration and measurement.

(3) To aid in reading voltage values directly from the screen of the cathode-ray tube, calibrated scales are used. Usually these are plastic discs, which fit over the face of the cathode-ray tube, ruled in the same manner as rectangular-coordinate graph paper. If there are four spaces to an inch and the screen is calibrated so that each inch represents 70.8 volts, the space between two horizontal lines corresponds to 70.8 divided by 4, or 17.7 volts. If, therefore, an a-c voltage is applied to the scope and the image covers six spaces from peak-to-peak, the amplitude of the input signal is 17.7 times 6 or 106.2 volts peak-to-peak. Many scales are not cross-ruled into boxes but have only horizontal lines; the same method of calibration and interpretation applies to them.

(4) For making a-c voltage measurements, the sweep and sync switches are set to INTERNAL, and the calibrating and unknown voltages are fed successively to the vertical-deflection amplifier terminals. Generally, the sweep-frequency selector is set to the frequency of the measured voltage in order to obtain a single-cycle trace on the screen for ease in measurement. A voltage whose rms or peak-to-peak value is known is fed to the oscilloscope. Attenuation and gain controls are adjusted to bring the peaks of the calibrating trace up to a convenient horizontal line on the plastic scale. The scale then is calibrated in the manner discussed above, and the calibrating voltage is removed. Probes for increasing the input impedance of the oscilloscope (to decrease circuit loading) and for increasing the voltage range measureable with the oscilloscope (multiplier probes) generally are available and similar in de-

sign and construction to those used with conventional voltmeters.

c. D-C VOLTAGES.

(1) Unless the oscilloscope has a d-c low-frequency limit of 0 cps, a d-c input voltage to be measured must be connected directly to the vertical deflection plates. This is necessary because a-c oscilloscopes usually are capacitance coupled at the input and block d-c voltages at the input to the vertical amplifier. The horizontal plates can either be grounded (together with one vertical plate) or connected to the internal sweep generator. When the plates are grounded, an input d-c voltage on the vertical deflection plates results in a vertical displacement of the spot on the screen; the distance between the original position of the spot and the new position represents the d-c voltage value. If the sweep is connected to the horizontal plates, the original no-input condition of the beam results in a horizontal trace across the screen (positioned low if it is desired to measure large voltage values, and at the center of the screen for medium measurements). When a d-c voltage is applied to the vertical deflection plates, the trace is displaced upward for positive values, downward for negative values. Reversing input connections reverses the direction of the displacement. The vertical distance between the new and old positions of the trace represents the value of the d-c voltage input.

(2) The screen can be calibrated, as explained previously, in a-c voltage measurements, except in this case a battery or a regulated power-supply system should be used to furnish the calibrating voltage. A potentiometer is placed across the d-c source and voltages from various positions on it are applied to the oscilloscope, at the same time being measured by a conventional d-c voltmeter in parallel with the oscilloscope input. The measurement sensitivity of the instrument depends on the deflection sensitivity of the cathode-ray tube. For example, if the deflection sensitivity of a particular oscilloscope is .2 mm (millimeter) per volt dc, d-c voltages lower than about 10 volts cannot be measured accurately by applying them directly to the vertical-deflection plates. This is because .2 mm is equal to about .008 inch, and 10 times .2 mm is only about .08 inch. Spot deflections less than .1 inch are too small to be measured accurately on the screen of the cathode-ray tube. Similarly, for this deflection sensitivity, voltages exceeding about 350 volts for 3-inch tubes and 600 volts for 5-inch tubes are not measurable unless a multiplier probe is used. A 700-volt d-c voltage, for example, results in a beam deflection of 700 times .008, or 5.6 inches, which is not observable on the face of a 5-inch cathode-ray tube.

d. CURRENT MEASUREMENTS.

(1) Cathode-ray oscilloscopes cannot measure current directly. An unknown current must be measured by passing it through a resistor whose value is known. The voltage drop across the resistor then is measured by the oscilloscope and the current is found by using Ohm's law:

$$I=\frac{E}{R}$$

For d-c measurements a low-value resistor is connected across the vertical-deflection plates. Then a known d-c calibrating voltage is applied to this resistor and the screen of the oscilloscope is calibrated as described previously. The input voltage then is applied across the resistor as for d-c voltage measurements.

(2) For a-c measurements, the calibrating source may be a variable-frequency audio generator capable of being set to any desired frequency (to match the frequency of the voltage to be measured), or the secondary of a transformer furnishing a low 60-cps voltage. This voltage is applied to a small resistor in parallel with the input to the vertical-deflection amplifier of the oscilloscope. An a-c voltmeter is connected in parallel with the input, and the height of the trace on the screen for various input voltages is correlated with the readings on the voltmeter. Once the oscilloscope has been calibrated, the resistor remains in place for all measurements. It can be changed only if the os-

cilloscope is recalibrated. These resistors should be of the noninductive (composition) type.

118. Amplifier Response Testing

a. Frequency Range. To judge the performance of the amplifier it is necessary to know the range of frequencies that an amplifier can pass with minimum allowable attenuation. One standard for stating the frequency range of an amplifier includes all the frequencies which can be amplified to not less than about 70 percent, or within 3 db (decibles) of the maximum gain level of the amplifier. For example, if an amplifier is said to have a frequency response from 0 to 200 kc, this indicates that the amplifier gain for signals from 0 cps (d-c) to 200 kc is within about 70 percent of the maximum possible with that amplifier. In other words, the gain falls off only 3 db at 200 kc. The amplifier can handle signal voltages with frequencies above 200 kc, but the gain is considerably less than the maximum gain of the amplifier. When a sufficiently high frequency is reached, no amplification is possible. In terms of response, amplifiers can be divided into two categories: those used in the audio-frequency range (20 to 20,000 cps) and those used to amplify signal voltages with frequencies from 20,000 cps to 1 mc and higher. Although the methods used for testing the frequency response for both of these categories are in general the same, some of the equipment used with the oscilloscope in each frequency range is different.

b. Checking Frequency Response of Audio Amplifiers.

(1) The test set-up shown in figure 194 can be used to check the frequency response of an audio amplifier. The voltage output of a sine-wave signal generator is kept constant and the gain control of the amplifier under test is set at about half its maximum. The height of the trace on the oscilloscope screen should be set at some convenient level with a signal-generator frequency of about 1,000 cps. The amplifier output for other test frequencies (from 20 to 20,000 cps) is then noted with reference to this initial level. The various values are plotted on semi-logarithmic graph paper (relative gain vertically versus frequency horizontally) to get the frequency response curve of the amplifier.

(2) For a continuous frequency response check in one operation, sweep-signal generators are used. These are signal generators whose output frequency changes automatically and continuously from 20 to 20,000 cps, or another frequency range according to the design of the generator. The output of the sweep-signal generator is fed into the amplifier under test. Also, a timebase signal from the sweep-signal generator is fed to the horizontal input terminals of the oscilloscope. The timebase selector of the oscilloscope is set to OFF, or EXTERNAL. The trace on the screen shows relative gain of the amplifier versus the frequency for the frequency range swept by the generator.

(3) Another method for checking the frequency response of an audio amplifier in one operation is by using a square-wave generator. This method has been described previously.

c. Checking Frequency Response of Video Amplifiers.

(1) The frequency range of video amplifiers extends from 0 cps to 1 mc or higher. However, the frequency range which can be checked with an oscilloscope is limited by the latter's vertical amplifier. If the vertical amplifier has a high-frequency limit of about 300 kc (typical for most general-purpose oscilloscopes), the response of a video amplifier from 300 kc up cannot be tested with this oscilloscope. However, the video amplifier can be tested by connecting its output directly to the vertical-deflection plates of the oscilloscope. This can be done if the video amplifier can furnish a sufficiently large voltage output to give a sizable trace without being overdriven. This is possible when the voltage applied to the video amplifier and the deflection sensitivity of the cathode-ray tube are both large.

(2) Square-wave generators are used to test the frequency response of video amplifiers. The fundamental frequency of the square-wave input must be 50 kc or higher. The tenth odd harmonic of a

50-kc square wave is approximately 1 mc, so that the frequency response of the amplifier to 1 mc can be tested. The test set-up used for square-wave response testing has been described earlier in this chapter. In general, square-wave response testing does not give enough exact information to make it possible to plot a frequency-response curve for the amplifier. However, it does present the response characteristics of the amplifier, which is usually all the information necessary for trouble shooting.

(3) Sweep-signal generators also are used to check video-amplifier frequency response. The test set-up is the same as for audio-amplifier response testing, except that the frequencies covered by the generator for video testing range from 0 to 5 or 10 mc. For oscilloscopes whose vertical-amplifier response extends only to about 300 kc, a rectifier probe is used. The probe rectifies the signal output of the video amplifier at the amplifier output terminals and feeds a rectified signal into the vertical amplifier of the oscilloscope. The curve presented on the screen of the oscilloscope resembles a continuous frequency-response curve with relative gain plotted vertically and frequency horizontally.

119. Alinement of Tuned Circuits

Tuned circuits are used in communication and radar equipment because of their selectivity characteristics. A tuned circuit allows signals of only a certain frequency band to pass. The process by which tuned circuits are adjusted to pass the proper frequencies is called alinement. A tuned circuit is properly adjusted when it is resonant at the frequency desired.

a. Resonance Curve.

(1) If an input signal of constant amplitude is fed to a tuned circuit and the frequency of the signal is varied, the output voltage of the tuned circuit varies with frequency in one of the ways shown in figure 197. These curves show the frequencies at which particular circuits are resonant and the *resonance* or *response* curves for the tuned circuits. The output voltage is plotted on graph paper against frequency. The frequency of the input is then varied in steps and the output amplitude is recorded for each frequency setting (with the input amplitude constant). When all these output voltage points are connected, the resonance curve results. The shape of the curve depends upon the Q of the tuned circuit. A typical resonance curve for a high-Q tuned circuit is shown in A, figure 197. For lower values of Q, the sides of the curve are not so steep. The peak value on the curve represents the maximum relative amplitude of signal voltage passed by the tuned circuit. The frequency at which this peak occurs is the resonant frequency of the tuned circuit. In adjusting a tuned circuit, the value of inductance or capacitance is changed. This results in a change in the frequency at which the circuit is resonant, and in the shape of the curve. A narrow, sharply peaked curve (A and D, fig. 197) indicates that the circuit passes a narrow band of frequencies with minimum attenuation. A wide, flat-top curve as in F indicates that the circuit passes a wide band of frequencies at peak amplitude.

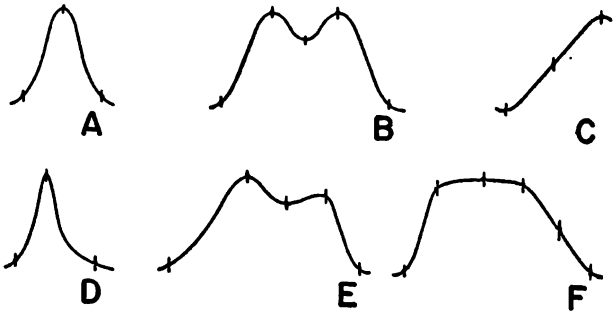


Figure 197. Typical resonance curves for single- and multiple-tuned stages. Possible marker points for aid in alinement appear on each. These markers are generated by a marker generator which is generally part of the sweep-signal generator.

(2) Sometimes the resonance curve shows two or more peaks (B and E fig. 197). This results when the tuned stage has an overcoupled transformer, or when there is more than one tuned circuit in the stage. The actual resonant point for such circuits is indicated by the mark in the

trough between the two peaks if the circuits all have the same resonant frequency. The curve of C is the response curve of an f-m detector. Here, the response curve must rise linearly for a fixed band of frequencies (those between the lower and upper marks on the curve). The symmetry characteristics of a resonance curve also are important. In most circuits it is desired that the shapes of the curve on both sides of the resonant point be alike, as in A and B. In television receivers, however, it is important that the over-all video i-f response curve be of the type shown in F. This asymetrical response curve fulfills the requirements of these circuits for proper operation.

(3) The shape of the response curve needed for tuned circuits which are to be alined must be known before alinement can proceed. The technical manual furnished with the specific equipment under test reproduces or describes the response curve required for each stage or group of stages. This response curve can then be obtained on the oscilloscope by feeding the output of a sweep-signal generator into the circuit under test. The vertical deflection amplifier of the oscilloscope is connected across the output of the circuit after it is rectified, and the timebase is obtained from the output of the sweep-signal generator. The trace on the screen represents the amplitude of the output of the tuned circuit versus the frequency of the input signal.

b. Sweep-Signal Generators.

(1) The use of sweep-signal generators for circuit testing has been mentioned previously. These generators provide a voltage of constant amplitude with frequency changes from the low limit to the upper limit of a preselected continuous frequency band. The variable frequency signal fed to a tuned circuit to measure its resonance characteristic must extend beyond both the lower and the upper limits of the frequency response of the circuit. The center frequency of the varying-frequency signal should be approximately equal to the resonant frequency of the tuned circuit.

(2) The basic method for producing a varying frequency signal uses an a-f or r-f oscillator with a L-C tank circuit. The inductance or capacitance of the tank circuit is varied continuously by either mechanical or electronic means. This results in a continuous change in the frequency of oscillation of the oscillator. One of the mechanical methods uses a 60- or 120-cps signal to activate a vibrating mechanism attached to the rotor plates of the variable capacitor of the oscillator-tuned circuit. Each vibration of the vibrator changes the capacitance of the tank circuit to produce a whole range of frequencies. Since the vibrator is actuated 60 or 120 times per second, the complete range of varying-frequency oscillations is produced 60 or 120 times per second. Another mechanical method uses a vibrator to change the inductance of the circuit by vibrating a metal plate close to the inductor. This varies the effective inductance of the tank circuit, producing the varying-frequency oscillations.

(3) The electronic sweep-signal generator uses a reactance tube. This is a pentode whose plate impedance (either inductive or capacitive) varies with the variations in the 60-cps input fed to its control grid. The output impedance of the reactance tube is connected in parallel with the tank circuit of the sweep-generator oscillator. Consequently, changes in the output impedance result in changes in the capacitance or inductance of the tank circuit, which varies the frequency of oscillation.

(4) Many sweep-signal generators incorporate a marker generator. This is a variable-frequency generator, which injects an unmodulated r-f signal into the sweep-generator output to produce a sudden change in amplitude of the test signal at a particular frequency. In this way marker *pips* are produced at various frequencies along the response curve of a tuned circuit (fig. 197). These aid in determining the frequency values at various other points on the resonance curve.

If the marker generator is not part of the sweep-signal generator, a separate signal generator can be used to provide the marker pips. The output of the marker generator can be fed into any point of the circuit under test.

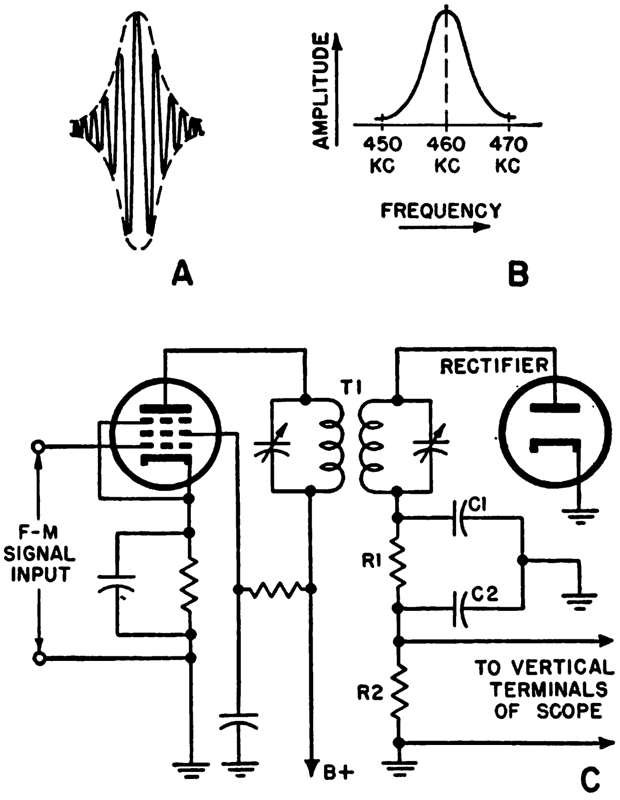
c. Rectification of Tuned Circuit Output.

(1) It was mentioned previously that the output of a tuned circuit must be rectified before the signal is fed to an oscilloscope to produce a resonance curve. The reason is that the output from a tuned circuit whose signal input comes from a sweep-signal generator actually looks like the pattern shown in A, figure 198. The frequency of the output varies in accordance with the frequency of the input, but the amplitudes of some frequencies are attenuated more than others. The dotted line (the envelope) showing the outline of the output pattern is the actual response curve of the tuned circuit (both in the positive and in the negative direction). If the lower half is cut off and only the peaks of the signal are used, the result is the curve shown in B, figure 198. This is done by detection.

(2) If a detector stage follows the tuned circuit under test, the signal fed to the oscilloscope is taken across a resistor in the plate circuit of the detector (C, fig. 198). This is a simplified schematic of the final i-f and detector stages of a radio receiver. If a detector stage does not follow the tuned circuit under test, a detector circuit using either a conventional diode or a crystal is incorporated in the probe unit discussed in paragraph 62.

d. How Alinement is Accomplished.

(1) To check on whether a tuned circuit or a group of tuned circuits in a particular piece of equipment has the correct resonance characteristics, resonance curves are obtained on the oscilloscope. If the correct resonance curves for the equipment are included in the equipment technical manual, the curves obtained can be compared to them. If correct curves are not available, the curves obtained must be analyzed to determine whether the response is correct for the circuits. The alinement procedures given in the technical manuals should be followed.



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A, Unrectified response patterns for tuned circuit; B, Rectified response patterns; C, Circuit furnishing a rectified output to an oscilloscope.

Figure 198.

(2) The method for varying the resonant frequency of a tuned circuit consists of changing either the capacitance or the inductance (or both) of the circuit. In most cases, small variable capacitors in series (*padders*) or in parallel (*trimmers*) with the tuned-circuit capacitor are adjusted for alinement. Sometimes the only capacitance in the tuned circuit is that of the trimmer. The trimmer or padder is adjusted to add capacitance to or subtract it from the tuned circuit. By changing the capacitance, the capacitive reactance for all frequencies is changed. This means that the capacitive reactance will be equal to the inductive reactance at a new resonant frequency. This results in a shift of the resonance curve. In many receivers permeability-tuned coils are used. These are inductors which have

adjustable, powdered iron cores. Varying the position of the core in the coil varies the inductance of the latter. This varies the inductive reactance of the tuned circuit and changes the resonant frequency in the same manner that changing the capacitive reactance does.

(3) In a-m receivers the i-f stages generally are alined first (final stage first working backward to first stage). The oscillator section is alined next, then the r-f section. In f-m receivers, the detector transformer is alined first, followed by the limiter stage or stages, the i-f stages, the oscillator, and finally the r-f section. The actual procedure for alining the tuned circuits is described in the applicable equipment manual.

(4) Distorted response curves result when the input coupling capacitance of the oscilloscope is too low. This causes one side of the resonance curve to be lower than the other. If the sweep-signal generator output is too high, overloading occurs in the equipment under test, and the resonance patterns appear as double curves, with each of the sloping sides consisting of two lines instead of one. Regeneration can occur as a result of high input signal amplitude. This distorts one of the slopes of the resonance curve and decreases the broadness of the response while increasing the amplitude of the curve. Undesired voltages introduced into the circuit under test can distort the resonance curve and make analysis difficult. Insufficient filtering action can produce this result. Special alinement tools, which are insulated, should be used for alining so that the constants of the circuit are not disturbed.

120. A-m Transmitter Testing

Test oscilloscopes are used with transmitters for modulation monitoring, alinement, neutralization of r-f amplifiers, and general trouble-shooting. For modulation monitoring, the oscilloscope presents the instantaneous changes in modulation percentage.

a. Typical Test Set-Up. For most a-m transmitter tests, the r-f output of the transmitter (modulated or unmodulated) is fed directly to the vertical deflection plates of the oscilloscope. For alinement, neutralization, and similar operations, the output is fed to the vertical amplifier. A-m transmitters have high operating voltages in the r-f and modulator systems. The leads from the oscilloscope to these sections must be well insulated. The r-f voltages should be inductively coupled to the oscilloscope. Connections should be insulated against flashover to ground.

Note. **Disconnect or otherwise disable the high-voltage supply to the transmitter while connections are made.**

b. Block Pattern. The block pattern is one of the three types of pattern displayed on the oscilloscope for the output of an a-m transmitter. This pattern (A, fig. 199) is produced when the carrier is fed to the vertical-deflection plates of the oscilloscope with the internal sawtooth sweep of the oscilloscope set to a very low frequency. The modulating frequency is much greater than the sweep frequency. Consequently, the number of cycles

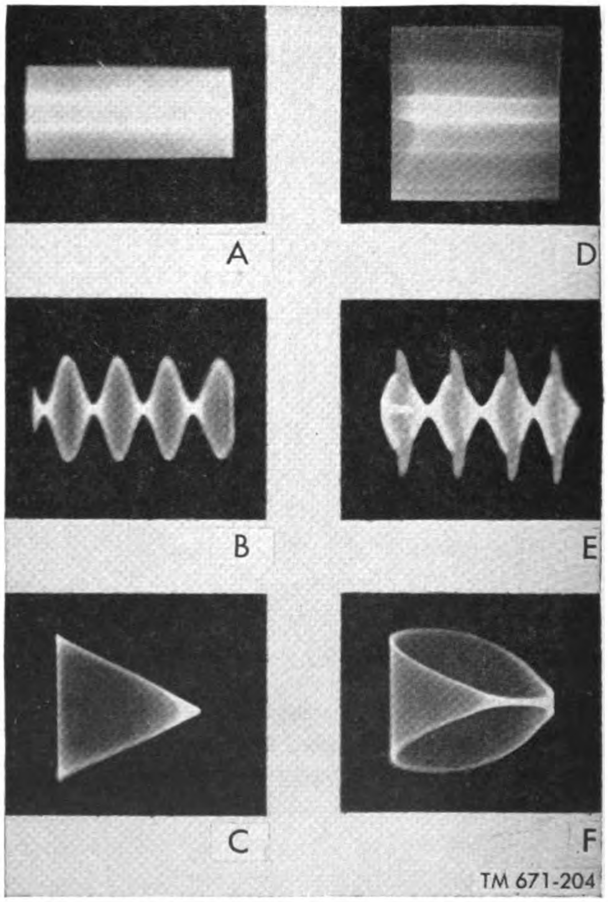

Figure 199. Three types of pattern used for transmitter modulation testing.

of modulation displayed is too great to be observed individually. However, the presence of modulation is visible as horizontal light streaks across the rectangular block of light. This is shown in A, where two bright lines traverse the block pattern and divide it into three equal areas. This indicates 50 percent sine-wave modulation. One-hundred percent sine-wave modulation results in one light streak through the center of the block. These streaks result from the compression of many downward modulation peaks. Complex-wave modulation produces many more light streaks as in D. An unmodulated carrier has no light streaks.

c. MODULATED-WAVE PATTERN. The second type of pattern presents the modulated-wave envelope. It shows the changes in carrier amplitude with time (B and E, fig. 199). This display is produced by feeding the carrier signal to the vertical-deflection plates of the oscilloscope and adjusting the internal time-base sweep to some submultiple of the modulation frequency. In B, the sweep frequency is one-fourth the modulation frequency. This trace shows 100 percent sine-wave modulation of the carrier. If the modulation percentage were less, the downward modulation peaks would be farther apart. The percent modulation is obtained from the following formula:

$$\text{Percentage} = \frac{B-A}{B+A} \times 100$$

where B is vertical height of the pattern at its widest point, and A is the vertical height of the pattern at its narrowest point.

d. TRAPEZOIDAL PATTERN. The third type of pattern is shown in C and F, figure 199.

(1) This display presents changes in r-f carrier amplitude vertically against changes in modulating amplitude horizontally. The r-f voltage is applied to the vertical-deflection plates and the modulating voltage is applied to the horizontal-deflection amplifier input. To obtain the modulating voltage, connect a .1-Uf coupling capacitor to the modulation connection on the r-f amplifier. Also connect a voltage-divider resistor (about 5,000 ohms) between the capacitor and ground. Adjust the tap on the voltage divider to tap off a few volts of the modulator output voltage. The sweep-frequency selector of the oscilloscope is set to the OFF position. The percentage modulation formula for this pattern is the same as for modulated-wave patterns.

(2) The graphical development of the trapezoidal pattern is shown in figure 200. One cycle of the modulated-wave envelope combines with 1 cycle of the modulation voltage to form the pattern. The electron beam moves from left to right across the screen as a result of the change in voltage from 0 to 6 on the modulation (horizontal deflection) signal. During the same time, the beam sweeps across the screen vertically many times because of the rapid changes in vertical-deflection voltage. These changes are a result of the changes in amplitude of the modulated r-f voltage. On the vertical-deflection wave, the points 2′ on the positive half and 2 on the negative half do not occur simultaneously. During the small time difference between them, the voltage on the vertical-deflection plates changes from the value which positioned the beam at 2 to the value of the modulated wave at 2′. This causes the beam to move upward and slightly to the right on the face of the tube to point 2′. The actual time difference between 2 and 2′ depends on the frequency of the r-f voltage fed to the vertical channel. In most cases it is very high, and the time difference between two corresponding points on the wave is small, making the line between them seem to be vertical. Each of the other lines of the trapezoidal trace is formed in the same way.

(3) After the beam reaches the right side of the screen, it moves from right to left because of the change in horizontal-deflection voltage from 6 to 12 on the modulating wave. Corresponding to these new horizontal-deflection voltages, the voltages on the vertical-deflection plates change according to the voltages 6′ to 12′ and 6 to 12 on the modulated r-f wave. For position 9 on the horizontal deflecting wave, for example, the line traced is 9 to 9′ on the trapezoid. The amplitude of the line is the same as the amplitude of the line from 3′ to 3, and it falls in the same place on the screen because of the symmetry of the modulat-

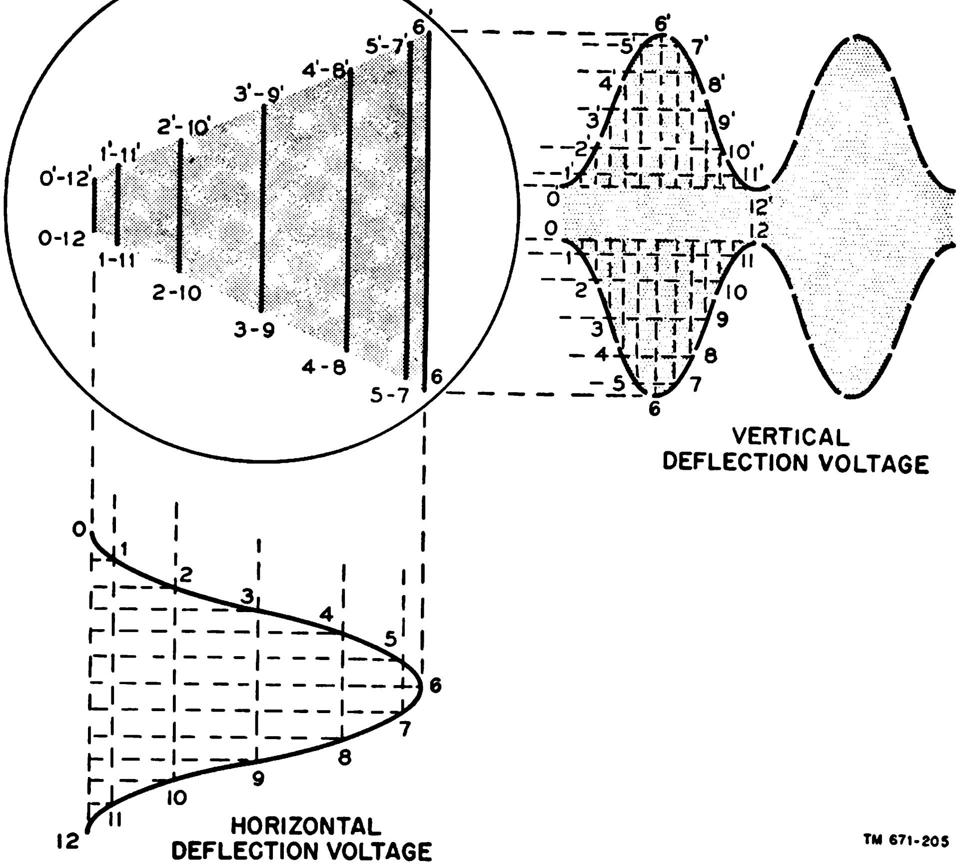

Figure 200. Graphical development of trapezoidal pattern.

ing wave. For the pattern to have straight sides, the amplitude of the carrier must change linearly with the modulating voltage. Differences in phase between the modulator output and the modulated carrier result in the type of trace shown in F, figure 199.

e. Correct and Defective Operation. Proper transmitter operation results in patterns similar to those shown in A, B, and C, figure 199. If the amplitude-modulation percentage is less than 100 percent, the modulated-wave pattern shows shallower troughs than those in B. The trapezoidal pattern resembles the final trace shown in figure 200. Trapezoidal patterns generally are more useful for tracing defects than other types of patterns. Some of the causes for improper operation are too high or too low plate voltage in the final r-f stage, insufficient r-f excitation on the final r-f stage, mismatch between modulator and r-f final stage, imperfect neutralization, and distorted modulation voltage, shown in D. These produce distorted patterns which can be correlated with the transmitter defect.

121. Vibrator Testing

The vibrator is used in electronic equipment to change d-c to a-c. Basically, it is a high-speed reversing switch. When one set of contacts is closed, the voltage output is in one direction; when the second set of contacts is closed and the first set is open, the voltage output is in the opposite direction. The time during which a set of contacts is closed is called closure time. The vibrator output is fed to the primary of a step-up transformer. The stepped-up voltage across the secondary is rectified and filtered and serves as the plate-voltage power supply for the equipment of which it is a part. If the vibrator itself rectifies the output of the transformer it is called a synchronous vibrator. If a rectifier tube is used to rectify the transformer output, the vibrator is a nonsynchronous one.

a. Nonsynchronous-Vibrator Power Supply. In A of figure 201 is the schematic diagram of a typical nonsynchronous-vibrator power supply. This type of power supply often is used in motor-vehicle communication equipment. In such cases, the storage battery of the vehicle furnishes the low-voltage d-c supply to the vibrator. The stationary vibrator contacts are 1 and 2. The vibrating contact is 3. Faulty vibrators can result in lowered B-supply output voltage, increased battery drain, arcing, and noise. For testing a nonsynchronous vibrator, use a 5,000-ohm load resistor to simulate normal operating conditions. When testing vibrators with an oscilloscope, the internal sync and sweep voltages are used. The input is fed to the vertical amplifier. The sweep is set to some submultiple of the vibrator frequency. The test leads should be shielded to prevent stray pick-up.

b. Patterns of Operation. The traces in B and E, figure 201 were obtained at various test points in the circuit of A. These are normal operating patterns for the nonsynchronous-vibrator power supply. B shows the voltage taken from P1 to P3 of the primary of the step-up transformer. The voltage across P2–P3 is shown in C. The vibrator producing these patterns had a relatively high closure time. The sum of the time durations of both the positive and negative plateaus is almost the total time for the whole cycle, showing that the contacts are close together. If the contacts are far apart, the vertical lines slope more gradually. D and E show the voltage output across S1–S3 and S2 and S3 of the secondary of the step-up transformer.

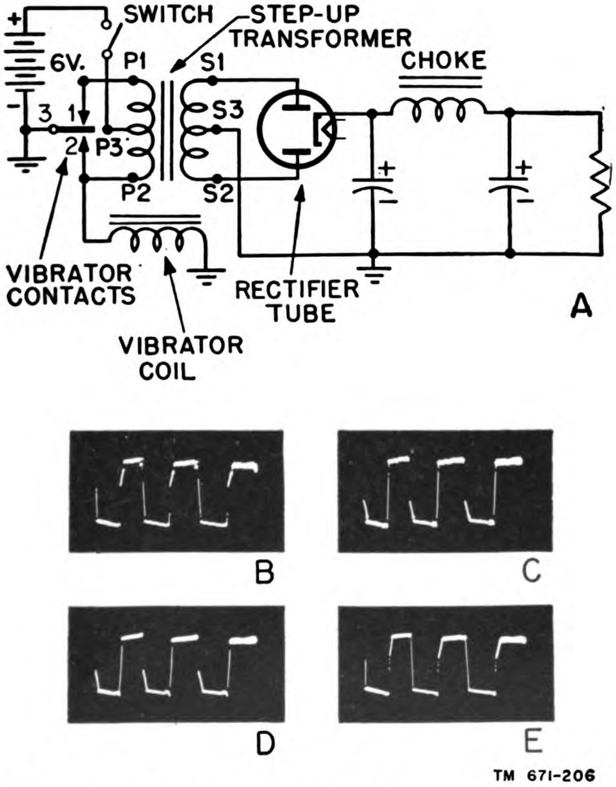

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Figure 201. Nonsynchronous vibrator power supply circuit and typical operating patterns.

122. Lissajous Figures

a. General. The normal input to the horizontal channel of the oscilloscope is a sawtooth voltage which has a linear relation with respect to time. The sawtooth sweep, however, cannot be used for the precise determination of the frequency and the phase of a signal. For this application of the oscilloscope, a standard signal of power-line frequency or the output of a calibrated signal generator is applied to the horizontal channel of the oscilloscope. The signal to be observed is applied to the vertical channel. If both these signals are a-c voltages, the resulting pattern is called a *Lissajous figure.* The circular J-scan produced by two sine waves figure 109 is an example of a Lissajous figure.

b. Signals on Both Plates. Lissajous figures present the frequency or the phase relationship (or both) between the two a-c signals forming them. The amplitudes of the two signals applied to the oscilloscope are made equal in order to produce a pattern based on frequency and phase relationships. If it is not possible to have the amplitudes equal, the amplitude relationship should be held constant. If the amplitudes of the signals are large enough, they can be applied directly to the deflection plates.

c. Phase Measurement.

(1) To measure the phase difference between two signals, a Lissajous figure is set up. If the input signals are fed to the vertical and horizontal deflection amplifiers, these must both have the same number of stages. The output of an amplifier stage is opposite in polarity to the input. If the two channels do not have the same number of amplifier stages, the apparent phase shift introduced by the extra stage

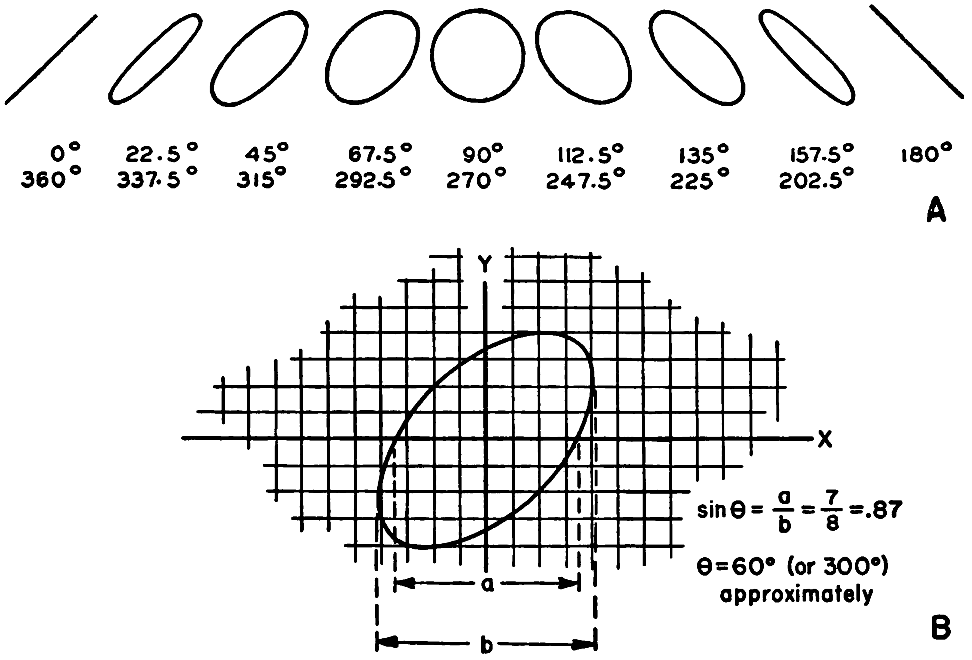
or stages must be taken into consideration.

(2) If the signals are two sine waves of equal amplitude and frequency, the phase difference between them can vary from 0 to 360°. As shown in figure 109, a 90° phase difference produces a circular trace on the screen of the cathode-ray tube. The addition of these two sine waves produces a trace which starts at the top of the screen and moves clockwise to produce a circle. A phase difference of 270° also produces a circle, the trace starting at the bottom and moving counterclockwise. These two circles are indistinguishable. If such a pattern is produced in comparing two signals on the oscilloscope, the phase difference is taken to be either 90° or 270°.

(3) A of figure 202 shows the patterns resulting from the addition of two sine waves with phase differences from 0 to 360° in steps of 22.5°. Sine waves of equal amplitude and frequency produce straight line images for phase differences of 0°, 180°, and 360°. Phase differences between 0–90°, 90–180°, 180–270°, and 270–360° produce ellipses of continuously varying characteristics, illustrated in A. Phase differences other than those shown produce similar ellipses.

(4) For more precise calculation of the phase difference between two sine waves of equal amplitude and frequency, two measurements must be made on the Lissajous figure. These consist of measuring the two distances a and b indicated in B, figure 202. For the ellipse shown, a is equal to seven spaces along the X axis and b is equal to eight spaces along the X axis; a divided by b gives the sine of the phase angle. In this example, the sine is seven-eighths, or .87, and the phase angle is approximately 60° or 300°.

(5) Phase differences between signals other than sine waves can also be measured. Two triangular waves result in a slanted line, a slanted rectangle, or a square standing on one of its corners, for phase differences of 0°, between 0° and 90°, and 90°, respectively. The same patterns are produced in reverse order from 90° to 180° phase differences. The same order is followed for the phase differences



A, Different resultant patterns when the phase difference between the unknown and standard signals varies in steps of 22.5; B, Method of calculating the phase difference of two input signals from the pattern.

Figure 202.

between 360° and 180°. Sine waves can be compared to triangular waves and square waves. Square waves can be compared with the other two types of waveforms.

d. **Frequency Measurement.** Two input signals of different frequency produce a characteristic Lissajous pattern on the screen. These patterns are used to determine the frequency of one of the signals when the frequency of the other is known. The signal of unknown frequency is applied to the vertical amplifier of the oscilloscope. Signals from a generator capable of precise frequency settings are applied to the horizontal amplifier. If the two signals are sine waves, the pattern produced is a Lissajous figure similar to those shown in A, figure 203. If the two signals have the same phase and amplitude and if their frequencies are the same (that is, if the ratio of their frequencies is 1:1), the result is a circle on the screen. Frequency ratios are expressed in terms of vertical (unknown) frequency to horizontal (standard) frequency. If the unknown signal has a frequency twice that of the signal generator, the ratio of the frequencies is 2:1; the resulting pattern is shown in A, figure 203. To obtain the ratio from the pattern, count the number of horizontal tangent points and divide it by the number of vertical tangent

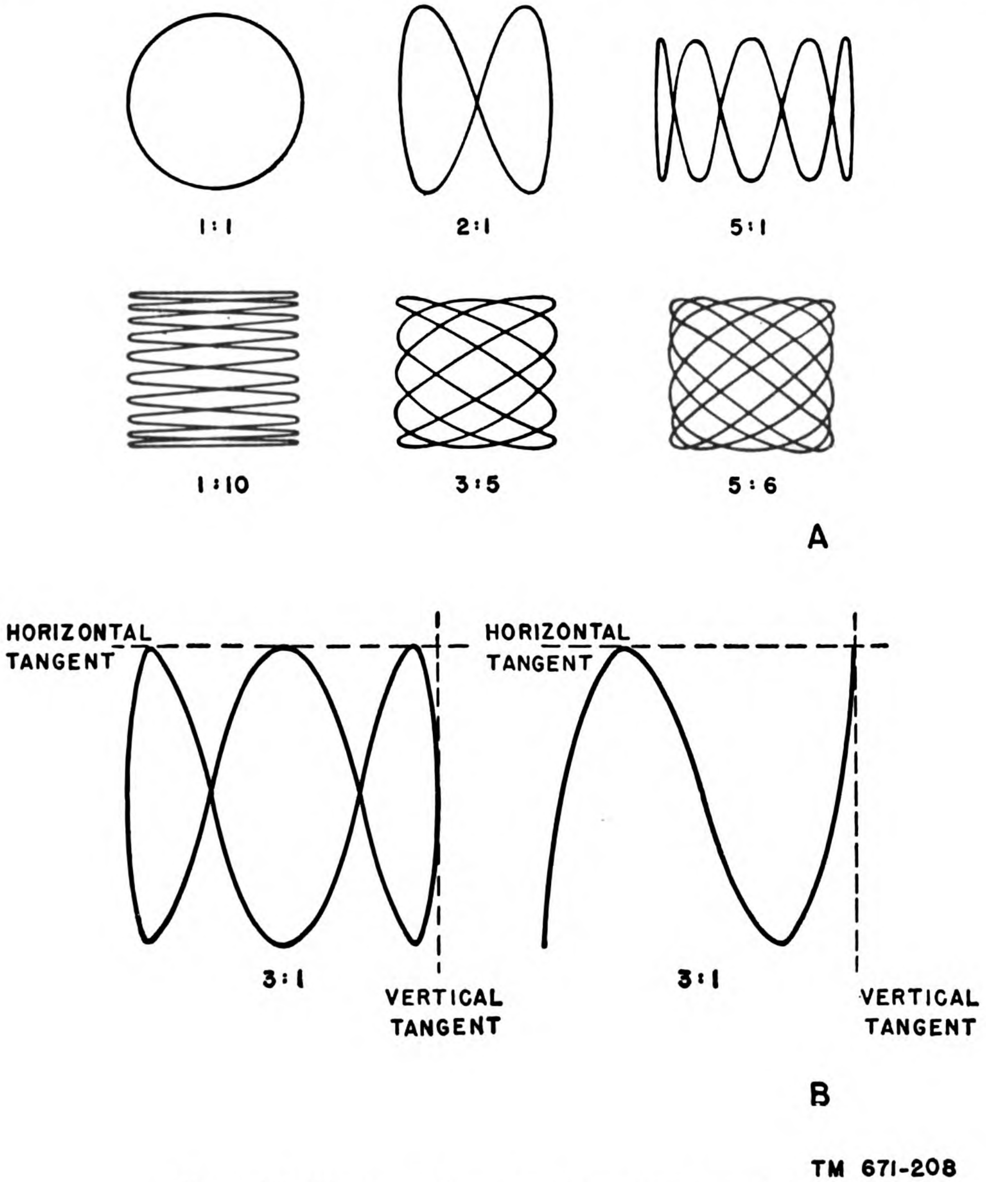


Figure 203. Lissajous patterns for various frequency ratios.

points. If the unknown signal frequency is three times the signal generator frequency, the pattern will appear as one of those in B, figure 203. The pattern observed depends on the phase relationship between the two signals. In the closed pattern, the frequency relation is determined by counting the loops touching the horizontal tangents and dividing this by the number of loops touching the vertical tangents. To obtain the 3 : 1 ratio for the open pattern in B, divide 1½ (the open end of the pattern is called a one-half loop) by ½. This gives 3 : 1. To obtain the frequency of an unknown signal which forms a 3 : 1 Lissajous pattern with a frequency standard of 2,000 cps, multiply the standard frequency by the ratio—in this case, 2,000 times 3. The result is the unknown frequency. In this example it is 6,000 cps. The same method is used with other ratios.

e. COMBINED OBSERVATIONS. Lissajous patterns can be produced for two sine-wave voltages differing in both frequency and phase relationship. A sine-wave vertical signal whose frequency is twice that of the standard sine-wave horizontal signal produces the patterns shown in A through E, figure 204, depending on the phase conditions. The phase difference for each Lissajous figure is shown immediately under each pattern. Similarly, a vertical unknown signal whose frequency is one-half that of the standard horizontal signal produces the patterns shown in F through J, depending on the phase difference between the two signals. For phase differences between 180° to 360° the patterns are reversed. Characteristic Lissajous patterns such as these are produced for other ratios and for other waveforms.

123. Radar Testing

a. GENERAL. A radar set uses many circuits that produce a wide variety of waveforms. The normal waveforms for proper operation usually are shown in the equipment manuals. The oscilloscope can be used to observe the waveshapes at various points in the radar set. The observed waveshapes then are compared with the known normal waveshapes. In this way an oscilloscope enables the user to locate quickly circuits and components which are not operating properly. In an equipment as complex as a radar set this use of the oscilloscope simplifies trouble shooting and reduces the amount of time required to locate faulty circuits.

b. USES AND MEASUREMENTS

(1) The oscilloscope must be set up and operated in exact accordance with the instructions given in the equipment technical manual. If this is not done, the appearance of the displayed waveforms may be completely different from those shown in the radar equipment manual. The sweep frequency of the oscilloscope is adjusted to an exact submultiple of the repetition rate of the radar set so that a pattern consisting of several cycles is produced. For greater detail, the sweep frequency can be increased until 1 cycle appears. However, if this is done the waveform may appear at the beginning of the trace or during the retrace. Because many of the waveforms are narrow pulses, the lower sweep-frequency ad-

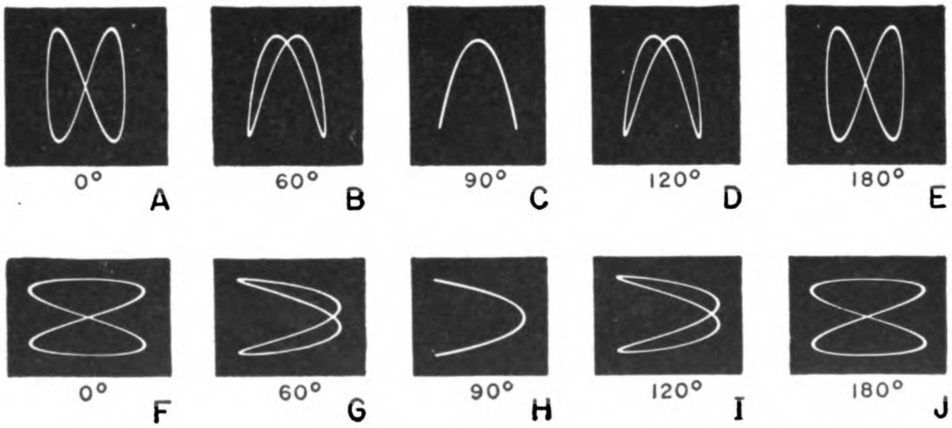


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Figure 204. Lissajous patterns for two signals varying in frequency and phase.

justment causes the pulse to appear at the center of the trace as well as at the beginning. Oversynchronization should be avoided because it distorts the pattern.

(2) The oscilloscope changes the actual waveforms because of its shunt capacitance and loading. The waveforms as displayed still can be used if the reference waveforms shown in the radar equipment technical manual were produced under the same conditions. Makeshift test leads or twisted leads should be avoided, because the shunt capacitance introduced by them distorts the pattern. The ungrounded test lead must be kept away from other circuits to avoid feedback and undesired coupling. Short leads must be used, especially when connections are made to high-impedance circuits. To prevent stray pick-up of power line voltage, the ungrounded test lead must not be handled. A signal can be picked up by the test lead even through opened coupling capacitors by means of stray coupling to the test leads. This effect can occur particularly in radar circuits which carry narrow pulses. When stray coupling occurs, the pulse amplitude is reduced and pattern distortion results because the high-frequency components of the pulse are emphasized. The amplitude of voltage can be measured if the oscilloscope is calibrated.

(3) The waveforms in the r-f portions of the radar transmitter and receiver are in a frequency range outside the response of the oscilloscope. Special connectors and fittings which include crystal detectors can be used to convert the frequency to a much lower value so that it can be applied to the oscilloscope. Because of the special nature of the waveforms to be observed in radar circuits, oscilloscopes are specifically designed for use with radar sets. These special oscilloscopes are known as *synchroscopes* and are discussed in chapter 8.

124. Summary

a. The front panel of the typical test oscilloscope can be divided into four control zones. Each zone contains all of the controls for one or more of the basic sections of the oscilloscope.

b. The deflection plates of the cathode-ray tube are connected directly to terminals on a small panel on the rear of the oscilloscope. These connections are used when the input signal frequency is beyond the limits of the oscilloscope amplifiers.

c. The front-panel controls are divided into signal and operating controls. Signal controls select the timebase and synchronizing voltages and increase or decrease the amplitude of these and the input signal voltages. Operating controls establish the proper electron beam conditions for a satisfactory display.

d. The vertical and horizontal gain controls generally consistent of a step switch for coarse adjustments and a potentiometer for fine adjustments. This also is true for the sweep-frequency selector.

e. For proper waveform observation, the sweep frequency should be one-third the input-signal frequency. This results in a trace with 3 cycles of input signal.

f. The vertical-amplifier gain control adjusts both the height of the trace on the screen and the amount of synchronizing voltage fed to the timebase generator. Consequently, the vertical gain and the synchronizing controls must be adjusted with respect to one another.

g. If the timebase voltage is not linear, the variation with time of the trace is not the same as for the original signal waveform. If many signal cycles are displayed, the ones at the extreme left of the trace are the most nearly linear.

h. A complex wave is the sum of a number of sine waves with various frequency and phase relationships. The component with the lowest frequency is the fundamental. The rest are harmonics of the fundamental.

i. The number and the type of harmonics in a complex wave determine the size and the shape of the wave. The lower order harmonics have the greatest effect.

j. If a pure sine wave is fed into an audio amplifier and the output is a complex wave with predominant even harmonics, a triode stage is defective. If the output has odd harmonics, a pentode stage is defective.

k. Unbalanced operation of a push-pull systems results in a difference in the waveform of the voltage at both plates.

l. To reproduce square waves, wide-band amplifiers are necessary. If these are not included in the oscilloscope, connections must be made directly to the deflection plates.

m. If an amplifier rounds the corners of a square wave, the high-frequency response is poor. If the amplifier distorts the plateau of the square wave, its low-frequency response is poor.

n. Calibration of an oscilloscope consists of correlating the height of the trace with known input voltage values. This must be done before voltage or current measurements can be made with the oscilloscope.

o. The oscilloscope indicates peak-to-peak voltages for sine- and complex-wave inputs. Dividing the peak-to-peak value of a sine wave by 2.83 gives the rms value.

p. For d-c voltage measurements, the input must be connected directly to the vertical-deflection plate terminals of an oscilloscope, unless a d-c amplifier is provided.

q. For current measurements, a resistor of known value is shunted across the vertical input or deflection terminals of the oscilloscope. The current in the circuit is read in terms of the voltage drop developed across the resistor.

r. The frequency response of an amplifier is the range of frequencies which the circuit amplifies within a stated percentage of maximum gain. To obtain the frequency response for an amplifier, a constant-amplitude signal at various frequencies, obtained from a single-frequency, sweep-signal, or square-wave generator, is fed into the amplifier and the output is observed on the oscilloscope.

s. For alinement of a tuned circuit, the resonance curves of the circuit are reproduced on the oscilloscope and checked against the normal curves for the circuit. To reproduce the resonance curve, the r-f or i-f from the circuit is passed through a detector and applied to the vertical input of the oscilloscope.

t. The modulated output of an a-m transmitter is checked by its block, modulated-wave, or trapezoidal pattern as displayed on the oscilloscope. These patterns show the percent modulation and also the distortion resulting from phase differences, overdriven amplifiers, etc.

u. Lissajous figures show the frequency and phase relationships between signals fed to the vertical and horizontal channels of an oscilloscope. For accurate phase-difference measurements, the frequency of both signals should be the same.

v. For measurement of phase difference, the sine of the phase-difference angle is given by the ratio of the horizontal width of the elliptical pattern when the vertical defection is zero to the total horizontal width of the pattern. For frequency calculation, the ratio of the vertical frequency of the Lissajous figure to the horizontal frequency is given by the ratio of the number of tangencies at the top or bottom of the figure to the number of tangencies at either side.

w. To trouble shoot a radar set with the oscilloscope, the normal waveforms for the circuit tested must be known beforehand. The oscilloscope and other test equipment must be set up as recommended in the equipment technical manual to obtain these same waveforms.

x. Because of the high frequency of radar signals, test leads must not be shielded and must be handled carefully to prevent too great a drop in input impedance of the oscilloscope.

125. Review Questions

a. What are the major sections of the typical test oscilloscope that are controlled in each of the four zones of controls?

b. What are the functions of the operating controls?

c. Name four operating controls and tell how they accomplish their function.

d. How do the coarse and fine adjustment controls operate together to attenuate the input signal to the vertical channel?

e. What is the procedure for adjusting the controls of the oscilloscope to obtain a good trace?

f. If a 30,000-cps signal is fed to the vertical input terminals of the oscilloscope, what sweep frequency should be selected? Why?

g. When is it necessary to feed an input signal directly to the deflection plates of an oscilloscope?

h. What is the procedure for checking an audio amplifier with a sine-wave signal generator?

i. Name three distortion effects introduced by defective push-pull amplifiers. How they are recognized by sine-wave testing?

j. How does a square-wave test the high-frequency response of amplifier? How does it indicate low-frequency response?

k. How are parasitic oscillations in a circuit indicated on the output waveform?

l. Give a method for calibrating an oscilloscope for a-c voltage measurements.

m. How are d-c voltages measured on an a-c oscilloscope?

n. What is meant when it is said that an amplifier has a frequency response of from 30 to 40,000 cps within 5 db?

o. How is a sweep-signal generator used for testing the response of amplifiers? How is the sweep signal generated?

p. How is the resonance curve of a tuned circuit obtained on an oscilloscope?

q. What type of transmitter output pattern gives the most information about the modulation percentage? How is the modulation percentage calculated for a trapezoidal pattern?

r. If the contacts on a nonsynchronous vibrator are too far apart, how will this be indicated by an oscilloscope?

s. If two signals of equal frequency and amplitude are fed to the vertical and horizontal channels of an oscilloscope, how can their phase difference be calculated from the pattern?

t. If a 30,000-cps sine wave is fed to the vertical channel of an oscilloscope, and a 20,000-cps sine wave is fed to the horizontal channel, how many horizontal and vertical tangent points will the Lissajous pattern have?

CHAPTER 8

SYNCHROSCOPE

126. Basic Synchroscope

The synchroscope is an oscilloscope designed especially for the study of periodic and nonperiodic pulses of short duration by means of fast sweeps. The name *synchroscope* derives from the fact that the sweep is generated only when a synchronizing signal is present. This signal can be from an external or an internal source. Several calibrated sweep speeds are available for making precise measurements.

a. Vertical (Signal) Channel.

(1) The block diagram in figure 205 shows the vertical channel for the signal input and the horizontal channel for the sweep input to the deflection plates of a cathode-ray tube. The vertical channel consists of an input impedance selector, a coupling amplifier, a delay network, a signal attenuator, a vertical amplifier, and the vertical deflection plates. A voltage applied to one vertical deflection plate provides vertical positioning of the display. With the switches in the positions shown, the horizontal channel consists of a synchronizing pulse amplifier, a start-stop multivibrator used as a sweep generator, a sweep amplifier and both horizontal deflection plates. A voltage applied to one horizontal deflection plate provides horizontal positioning.

(2) The pulse to be observed is applied to the *signal input* terminal of the vertical channel. If this pulse is large, an *attenuator probe* can be inserted between the signal source and the input signal terminal. The probe acts as a voltage divider. A typical voltage reduction ratio between the tip of the probe and the signal input terminal is 10 to 1.

(3) The *input impedance selector* is a device used to match the output impedance of the signal source to the input impedance of the coupling amplifier. A control on the operating panel permits switching from low to high input impedance. An *attenuator* sometimes is associated with this control to provide fixed reductions of the signal voltage while maintaining a constant input impedance.

(4) The negative pulse is fed to the control grid of the *coupling amplifier.* The coupling amplifier serves two functions. First, it operates as a cathode follower, providing an impedance match for the low-impedance input of the delay network. The negative pulse is taken at the cathode without amplification. A potentiometer is used instead of a fixed cathode resistor. By changing the setting of this potentiometer, the vertical image size is controlled. Second, the coupling amplifier supplies a positive pulse to the *synchronizing pulse amplifier* when internal sync is used. The positive pulse is obtained in the plate circuit of the coupling amplifier and coupled through the INT-EXT sync switch. This positive pulse is used to trigger the start-stop multivibrator in the horizontal channel.

(5) The negative pulse taken at the cathode of the coupling amplifier is applied to a *delay network.* The delay network is an artificial transmission line which prevents the pulse from causing a vertical deflection of the electron beam until shortly after the sweep has started. A typical delay time is ½ usec.

(6) The *signal attenuator,* through which the delayed pulse is fed to the vertical amplifier, is a tapped voltage divider. It controls the amount of signal voltage input to the vertical amplifier.

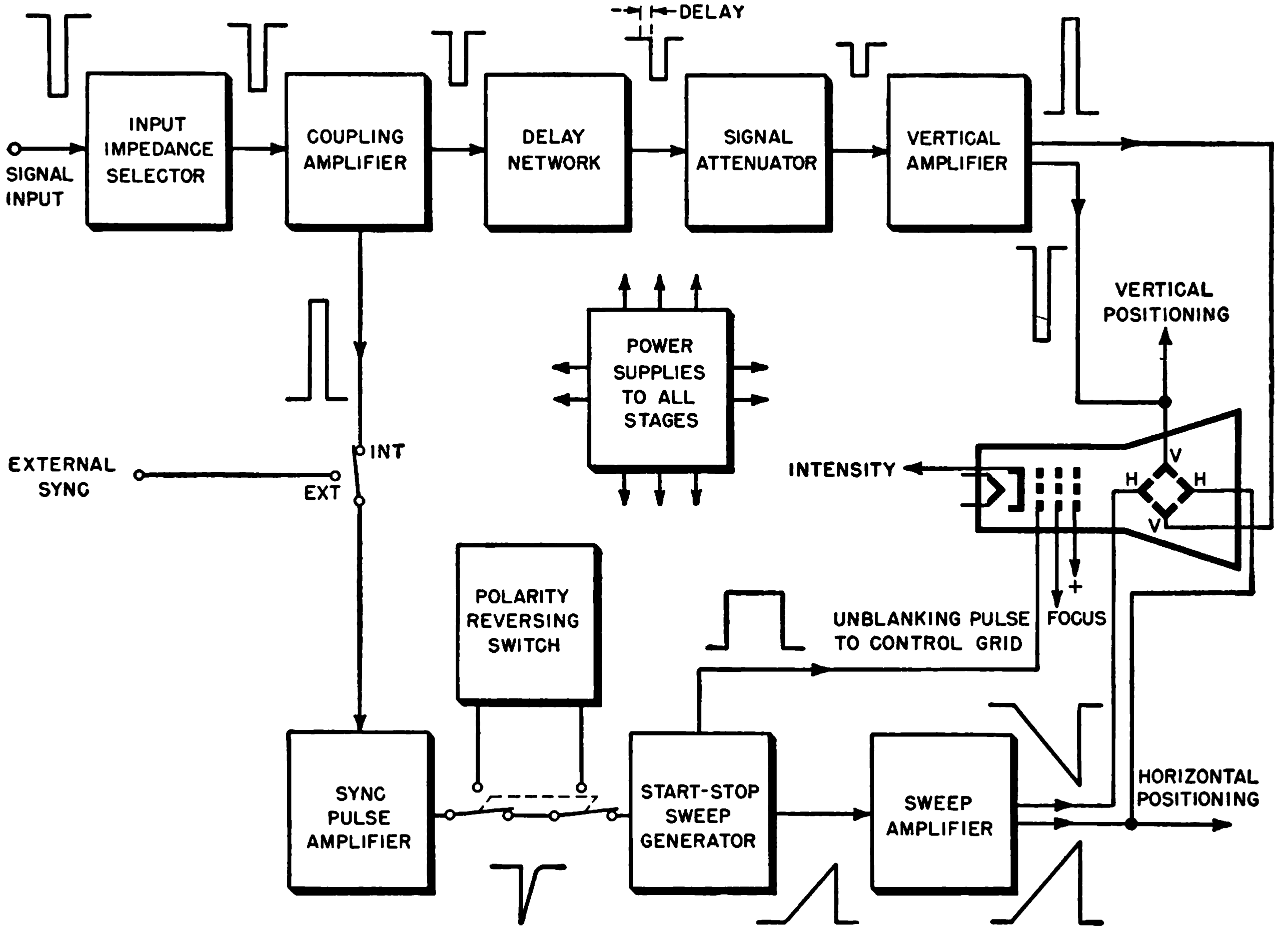


Figure 205. Block diagram of basic synchroscope.

(7) The *vertical amplifier* usually consists of several stages of amplification in which frequency compensation is used. The relative response of the vertical channel must be wide enough to pass square waves of short duration. A typical vertical channel has a uniform frequency response from about 20 cps to 4 mc. The output of the vertical amplifier is applied to the vertical deflection plates, resulting in balanced deflection.

b. Horizontal (Sweep) Channel.

(1) Two types of sync signal input are available at the input of the horizontal channel. A positive pulse derived from the signal input may be taken from the coupling amplifier, or some external sync may be applied by means of the external sync input terminal. As with the signal input, an attenuator probe may be used for reducing the amplitude of an external sync voltage.

(2) With the switch in the *internal sync* position, a positive pulse is taken from the plate of the coupling amplifier in the vertical channel. This pulse is the amplified signal, and it is fed to the *synchronizing pulse amplifier.* Here, it is amplified and shaped so that a sharp negative pulse appears at the output. The size of this pulse is controlled by a variable potentiometer in the cathode circuit of the amplifier.

(3) A typical sweep generator is a *start-stop multivibrator.* This circuit is activated by the negative pulse from the sync pulse amplifier. A sweep is generated only when it is triggered by a negative pulse. In some types of synchroscopes, a separate internal trigger generator is provided. The sweep generator serves two functions.

First, a sweep voltage is generated and fed to the sweep amplifier. Second, an unblanking pulse is produced which is applied to the control grid of the cathode-ray tube. This permits the trace to be visible for the time of the sweep. The sweep speed is controlled in the output circuit. Typical sweep speeds are 6 usec, 35 usec, and 200 usec.

(4) Sometimes a free-running sawtooth generator is provided so that the instrument can be used as a general test oscilloscope. Such a circuit is shown in figure 47. Because the sweep generator is free-running, it usually cannot be used with nonperiodic pulses. However, it can be synchronized with a periodic pulse. A typical sawtooth frequency range is 10 to 50,000 cps.

(5) The output of the sweep generator is applied to the *sweep amplifier*. This is a paraphase amplifier which produces two amplified sweep voltages. These voltages are opposite in polarity. They are applied to opposite horizontal-deflection plates in the cathode-ray tube, producing balanced deflection of the electron beam.

(6) The cathode-ray tube usually is an electrostatic type. A typical tube has a P1 phosphor screen which produces a green trace of medium persistence. For easy portability a tube with a face diameter as small as 2 inches can be used. Generally, face diameters range from 2 to 7 inches, as in test oscilloscopes.

(7) The power supplies for the synchroscope are the same as for the oscilloscope. The high-voltage supply depends on the type of cathode-ray tube used.

c. Control Panel Operation. Figure 206 shows the control panels for a simple, compact, military synchroscope designed for field testing of radar sets.

(1) *Horizontal channel controls.* The horizontal channel controls, in A, are located on a strip along the right side of the unit. By means of these controls the conditions for observing a particular signal are chosen.

(*a*) If the start-stop sweep generator is used, a trigger signal is required. With the SWEEP SELECTOR in the START-STOP position, either external or internal synchronization can be used. With the sync signal selector switch in the EXT SYNC position, a pulse from an external source can be coupled to the synchronizing pulse amplifier through the EXT SYNC jack. With the sync switch in the INT SYNC position, the sync voltage is the signal itself. This voltage is taken at the plate of the coupling amplifier and applied to the grid circuit of the sync pulse amplifier. The amplitude of sync voltage triggering the start-stop sweep generator is controlled by means of a potentiometer in the cathode circuit of the sync pulse amplifier. The potentiometer is the SYNC VOLTAGE control on the panel. Turning the knob clockwise increases the sync voltage. The start-stop multivibrator is triggered by a negative pulse only. If the external sync pulse has the opposite polarity, the SYNC POLARITY switch must be operated. This

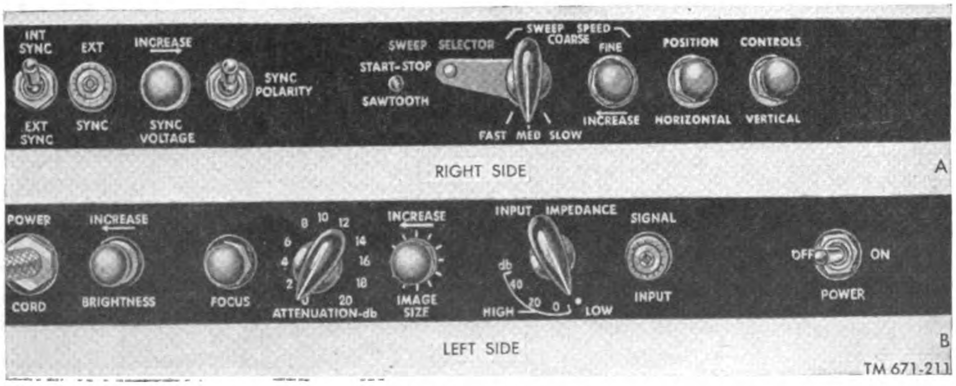


Figure 206. Control panels of a military synchroscope.

reverses the connections of the pulse amplifier output transformer, inverting the polarity of the sync pulse.

(*b*) This equipment incorporates two types of sweep generators. Depending upon the signal to be observed, either the start-stop multivibrator or the free-running sawtooth generator is chosen by means of the SWEEP SELECTOR. With the free-running sawtooth generator in the circuit, three ranges of sweep speeds are available. The COARSE sweep speed control switches-in the selected sweep speed, and the FINE sweep speed control provides adjustment of the sweep speed within range limits. Using the free-running sawtooth generator, the FAST sweep speed range includes sweeps from 20 to 200 usec (5,000 to 50,000 cps), the MEDIUM sweep speed range from 200 to 4,000 usec (250 to 5,000 cps), and the SLOW sweep speed range from 4,000 to 100,000 usec (10 to 250 cps). Therefore, the sawtooth generator provides a continuous sweep speed range from 20 to 100,000 usec (10 to 50,000 cps) in three steps, with fine control available within each step. The sawtooth generator requires no trigger voltage to produce a sweep. It can be synchronized easily with periodic pulses, but is unsatisfactory for nonperiodic pulses. Its value consists in allowing the instrument to be operated as a general test oscilloscope.

(*c*) With the SWEEP SELECTOR in the START-STOP position, the sweep is is supplied by a start-stop multivibrator. Unlike the free-running sawtooth generator, the multivibrator requires a trigger pulse to cause a sweep to be generated. A negative trigger pulse disturbs the normally stable condition of the circuit, one sweep is generated, and then the circuit returns to the stable condition until the next negative pulse arrives. A negative pulse is needed to generate each sweep. Using the start-stop sweep generator, the sweep speed controls make available three sweep speed ranges different from those available with the free-running sawtooth generator. The FAST sweep speed range supplies driven sweeps whose duration is from 4½ to 8 usec, the MEDIUM sweep speed range is from 20 to 50 usec, and the SLOW sweep speed range is from 120 to 280 usec. The FINE control functions in the same way as for the sawtooth sweep ranges, adjusting the sweep duration within the limits of each coarse step. In these positions both periodic and nonperiodic pulses of short duration can be observed. These three sweep speed ranges are chosen for their value in observing short pulses in microwave equipment such as radar.

(2) *Vertical channel controls.* The control strip on the left side of the unit has the vertical channel controls (B, fig. 206). The signal to be observed is coupled to the SIGNAL INPUT jack. The characteristics of this signal determine the settings not only of the signal channel controls but also of the sweep channel controls. If the signal is a nonperiodic negative square wave of 5-usec duration, for example, certain settings are required on the horizontal channel controls. For a 5-usec nonperiodic pulse, the START-STOP generator is selected. The FAST sweep speed is used. If no external sync is used, the switch must be in the INT SYNC position, where the pulse triggers the sweep.

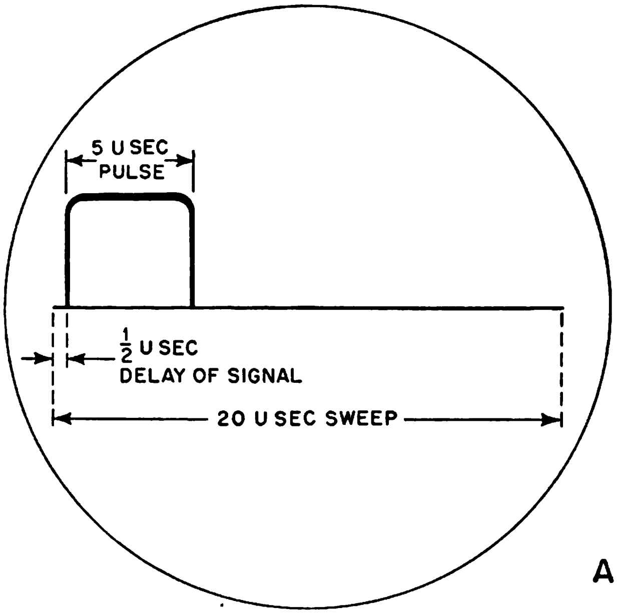
(*a*) If the signal source has a low impedance, the INPUT IMPEDANCE selector is set in the LOW position. There is no attenuation in this circuit, and the signal voltage should be within 0.1 to 1 volt. If the signal source has a high impedance, the HIGH range of INPUT IMPEDANCE is selected. In the HIGH position, three steps of attenuation marked in db loss are provided. The O db position provides no attenuation, and the signal voltage limits are the same as for the LOW impedance position. In the 20-db position, a 10-to-1 voltage divider allows signal inputs from 1 to 10 volts, and the 40 db position allows inputs from 10 to 100 volts. With an input-attenuated probe, the upper limit can be extended to 450 volts. If the 5-usec pulse has a peak amplitude of 20 volts and is applied from a high-impedance source, the INPUT IMPEDANCE selector is set in the HIGH range in the 40-db attenuator position.

(*b*) The pulse appears at the grid of the coupling amplifier. The sync voltage is obtained directly from the plate circuit. The signal is obtained from the cathode circuit. A smooth control of the amount of signal voltage applied through the delay network to the vertical amplifier is provided by the IMAGE SIZE control. This is a potentiometer in series with the coupling amplifier cathode circuit. By decreasing the resistance, the amplitude of the signal is increased on the cathode-ray tube screen.

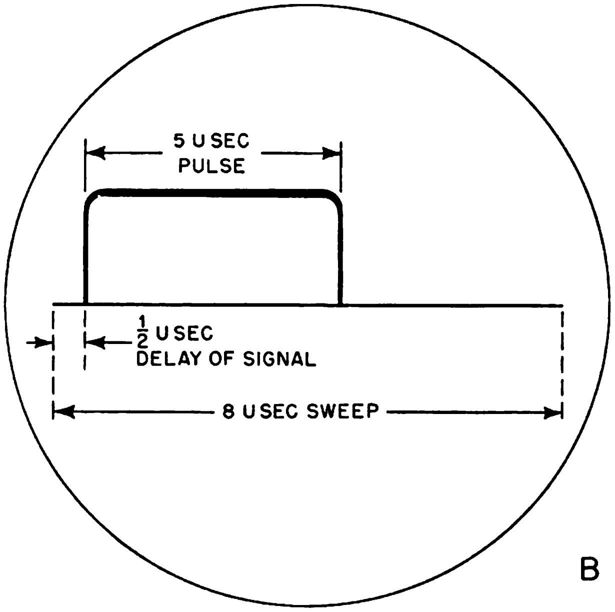
(*c*) The signal passes through the delay network, which prevents the appearance of the pulse on the screen until ½ usec after the sweep starts. This delay network provides a fixed amount of delay which cannot be changed.

(*d*) Before the signal is fed to the vertical amplifier, it passes through another attenuator. This provides 11 steps of signal attenuation for each setting of the attenuator in the INPUT IMPEDANCE selector. Eleven taps are arranged to provide attenuation in 2-db steps. By providing attenuation in two separate controls, distortion is minimized. The attenuator controls must be set properly to achieve good fidelity in displaying the pulse on the screen. For every signal there is an optimum setting of these controls. Improper settings result in distortion of the waveform. The pulse then is applied through the vertical amplifier to the vertical-deflection plates.

(3) *Cathode-ray tube controls.* A BRIGHTNESS potentiometer controls the intensity of the trace. FOCUS control also is provided, along with controls for HORIZONTAL and VERTICAL positioning. With all the controls at their proper settings, the signal appears as a positive square wave whose width is 5 usec on a sweep whose duration can be varied from 20 to 50 usec. With the FINE sweep control set for a 20-usec sweep, the pulse appears as shown in A, figure 207. If the sweep speed range is set at FAST,



MEDIUM SWEEP SPEED



FAST SWEEP SPEED

Figure 207. 5-usec pulse at two sweep speeds of the synchroscope.

the pulse appears on a sweep which can be varied from 4½ to 8 usec. With the FINE control set for an 8-usec sweep, the pulse appears as in B figure 207.

d. Military Oscilloscope-Synchroscope Panel Operation.

(1) This specialized unit combines the functions of a standard test oscilloscope and a synchroscope. When used as an oscilloscope, a thyratron sweep generator whose frequency range is from 25 to 1,000 cps is in the circuit. When used as a synchroscope, a multivibrator is used as a sweep generator. Two sweep speeds, 5 and 250 usec, are available when the multivibrator is used.

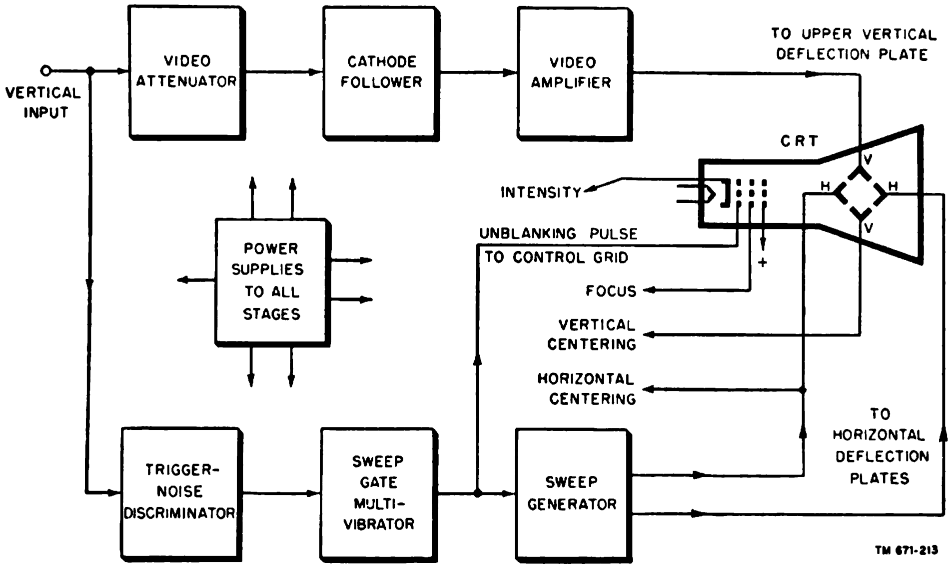


Figure 208. Block diagram of the oscilloscope-synchroscope for synchroscope operation.

(2) Figure 208 is a block diagram of this unit set up for synchroscope operation. The controls used are discussed below. The operating panel, which includes both synchroscope and conventional oscilloscope controls, is shown in figure 209.

(3) The input signal is used to trigger the sweep circuits of the horizonal channel. This signal is applied to the *trigger-noise discriminator*, which distinguishes between the signal and any noise that may be present. The signal is applied to the horizontal channel by operating the TRIGGER SELECTOR switch to V. D. (vertical deflection). The TRIGGER NOISE DISCRIMINATOR control is adjusted until the sweep just appears on the screen. It operates by clipping the input at the highest average noise level and allowing only the signal to appear at the output. The sweep gate multivibrator generates either a 5– or a 250-usec square wave when a trigger is applied. The pulse width depends on the setting of the SWEEP SELECTOR. The sweep gate supplies an unblanking voltage to the control grid of the cathode-ray tube and gates the sweep generator. By means of a push-pull amplifier, the output of the sweep generator is converted into two sweep voltages of opposite polarity. These are applied to the horizontal-deflection plates, producing balanced deflection of the electron beam.

(4) The signal input is fed through the vertical channel to produce unbalanced deflection. COARSE and FINE VIDEO GAIN controls are provided to control image size. If the signal is large enough, switching the VERTICAL AMPLIFIER control to OUT allows the signal to be applied directly to the vertical-deflection plates.

(5) Pulse width may be determined by means of a transparent calibrated screen placed over the face of the cathode-ray tube. By

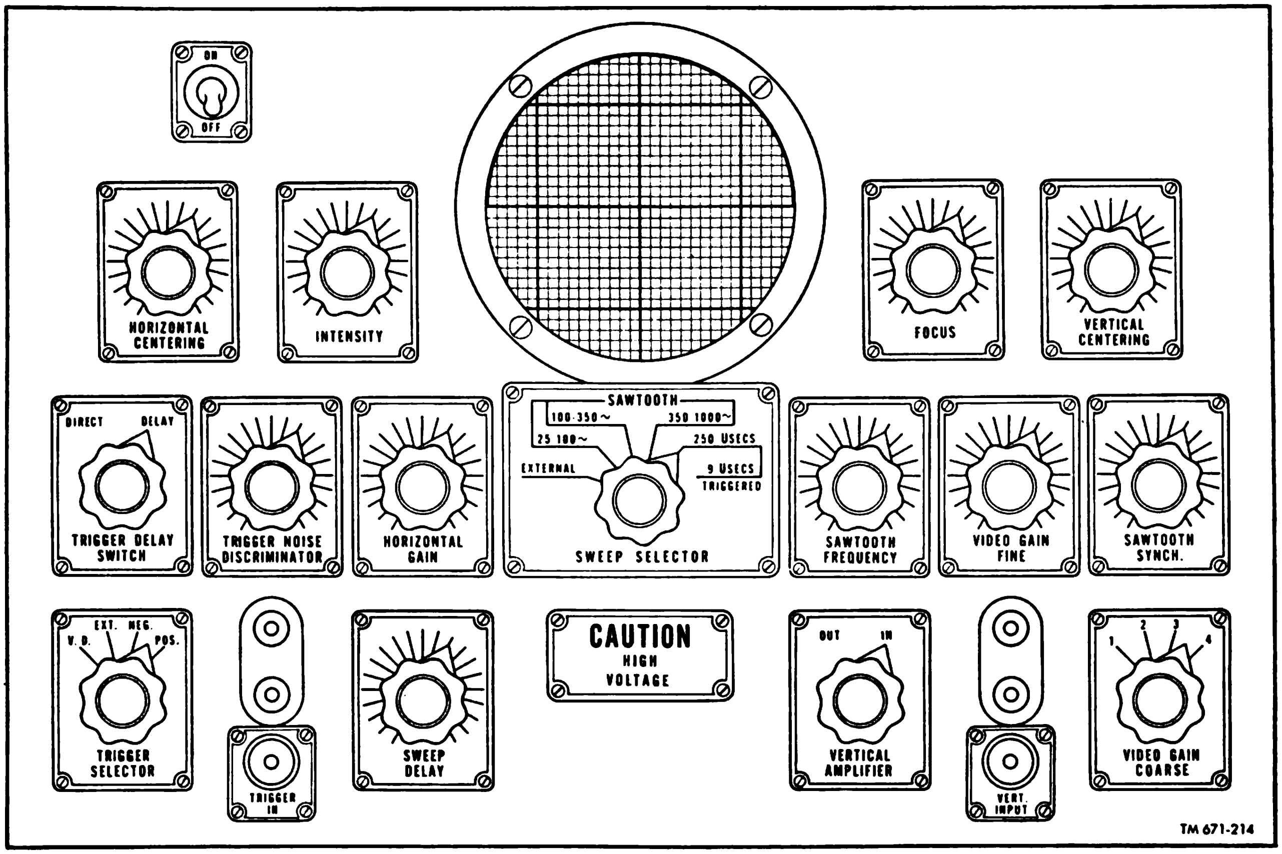


Figure 209. Control panel of oscilloscope-synchroscope.

using the calibrated screen and the deflection sensitivity value, the amplitude of a pulse can be determined. The deflection sensitivity is determined by applying a known voltage to the vertical channel and measuring the deflection on the calibrated screen. The signal voltage then can be applied and its amplitude measured.

127. Timing Measurements

The synchroscope provides a means of determining accurately the duration of short pulses. It also can be used to measure the elapsed time between two pulses. The latter use is similar to A-scope operation, wherein the time elapsed between a radar transmitter pulse and an echo is interpreted as range.

a. Pulse Duration. One of the characteristics of a pulse is its duration. A pulse whose duration is 5 usec was shown in figure 207. A synchroscope may incorporate a circuit which superimposes markers on the trace against which pulse duration may be measured. The circuit which generates these markers must be of a constant frequency for precise measurement. An external marker generator also can be used. The same trigger that causes a sweep may be used to synchronize the timing circuit. Figure 210 shows 12-usec timing pulses superimposed on a 50-usec sweep. The pulse is seen to have a width of 10 usec.

b. Time Between Pulses. As mentioned above, the time between pulses may be used to indicate range (radar A-scope operation). The time between pulses is measured in microseconds. These pulses may be periodic, in which case the time between pulses helps to determine the pulse-recurrence time and frequency. The time relationship between a specific pair of pulses also can be investigated. This application is important in the operation of loran. By measuring the difference in time between two pulses transmitted from different locations, the position of a plane or ship can be ascertained.

c. Velocity of a Projectile. An application of pulse-recurrence time measurement is one method of calculating the velocity of a projectile.

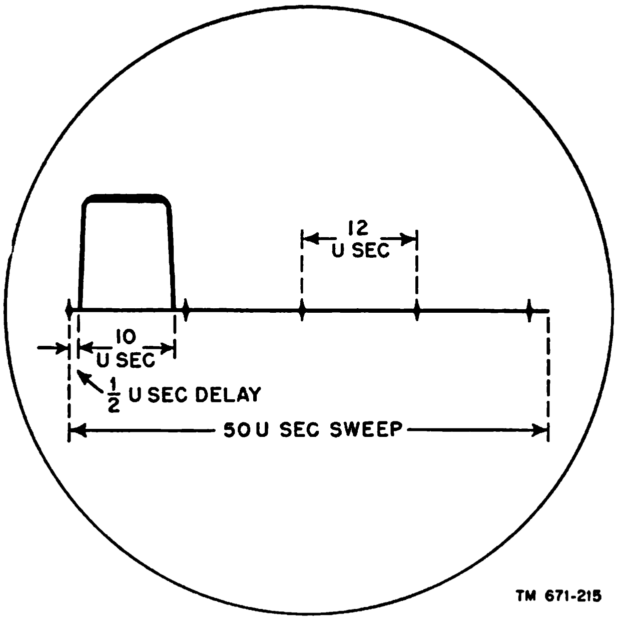


Figure 210. Pulse width measurement on a synchroscope.

The test arrangement is shown in figure 211. A magnetized shell is fired through the two coils. The shell induces a voltage in the coils as it passes through them. When the shell passes the first coil, a pip appears on the screen. When it passes the second coil, another pip appears on the screen. If the distance between the coils and the time elapsed between the pips are known, the velocity can be calculated. Assume that the distance between the coils is 2 yards and the time between pips is 1,000 usec; then the velocity is equal to 2 yards/1,000 usec, or 2,000 yards/sec.

d. Voltage Measurement. The instantaneous voltages of pulses may be measured by applying voltages of known value to the vertical-deflection plates along with the signal. The calibrating voltage may be of any frequency or waveshape provided that it does not exceed input limits. However, it is convenient to have a waveform similar to the signal.

e. Power Measurement.

(1) Measurements of pulse width and of time between pulses may be combined to help calculate the average power of a radar transmitter. Consider the relationships shown in figure 212. The pulse recurrence time is equal to the time from the start of the first pulse to the start of the second pulse. The transmitter produces power only during the time duration of the pulse. Because the pulse is a square wave, this time is equal to the pulse width. During the resting time, the transmitter does not operate. The average power during 1 cycle (pulse recur-

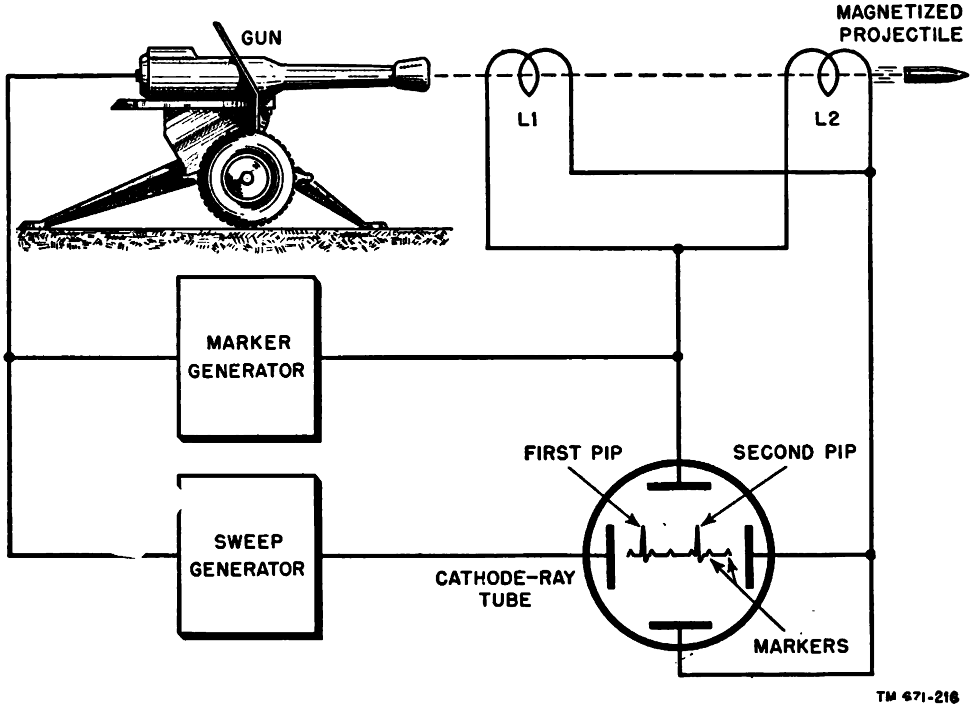


Figure 211. Measuring velocity of a projectile.

rence time) is some fraction of the peak power. This fraction is the ratio of the pulse width to the pulse-recurrence time and is known as the *duty cycle.* The pulse width and the pulse-recurrence time are measured on the calibrated sweep of the synchroscope. If the average power is known, the peak power can be calculated by dividing the average power by the duty cycle. Conversely, if the peak power is known, the average power can be calculated by multiplying the peak power by the duty cycle.

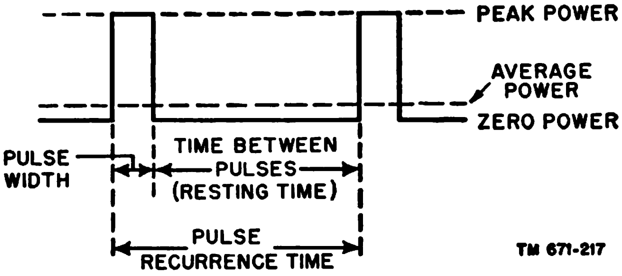


Figure 212. Power measurement of a periodic pulse.

(2) For example, a radar transmitter sends out 2-usec pulses repeated every 2,000 usec. The pulse width is 2 usec, and the pulse-recurrence time is 2,000 usec. The duty cycle, therefore, is .001. If the average power is .2 kw (kilowatt), the peak power is .2 kw divided by .001, or 200 kw.

(3) The power in a pulse can be found by comparing the unknown pulse to a pulse of known power. The synchroscope is substituted for the device which usually receives the pulse, and the input impedance is adjusted to the same value as that of the normal load. Attenuation controls are set to 0, and the known pulse is applied to the signal channel. The amplitude of the image produced on the screen is noted. Then, the unknown pulse is applied to the signal channel. The attenuation controls are adjusted until the image of the unknown pulse has the same amplitude as that of the known pulse. The amount of db attenuation needed to achieve equal amplitudes is noted on the attenuation control. The db reading then is converted to the power ratio of the unknown to the known pulse power. The power of the unknown pulse can now be calculated. If pulses of higher radio frequency are the unknown to be measured, a rectifying device, such as a crystal detector, is necessary to supply to the signal channel a pulse within its frequency range. Because the rectifier device is usually not linear, attenuation adjustments should be made only on the input side of the detector.

f. OTHER APPLICATIONS. The synchroscope also can be used to measure radar receiver sensitivity and the minimum signal discernible on a radar screen.

128. Summary

a. The synchroscope is an oscilloscope especially designed for the study of periodic and nonperiodic pulses of short duration. A trigger signal from either an internal or an external source is needed to generate a sweep. Vertical and horizontal channels are comparable to those in the standard test oscilloscope.

b. A typical vertical amplifier in a synchroscope has a bandwidth of 20 cps to 4 mc.

c. The synchroscope is capable of measuring the width of narrow pulses in microseconds.

d. The synchroscope can be used to measure the pulse-recurrence time from the start of one pulse to the start of another. This application is of importance in connection with radar, loran, and velocity measurements.

e. By means of a calibrating voltage, the instantaneous voltages of a pulse can be measured.

f. The ratio of the pulse width to the pulse-recurrence time is known as the duty cycle. This is also the ratio of the average power to the peak power of a pulsed transmitter.

g. When pulses of higher radio frequency energy are to be observed, a detector is necessary before the pulse can be applied to the signal channel.

129. Review Questions

a. Give two differences between the general test oscilloscope and the synchroscope.

b. What is the reason for inserting a delay network in the signal channel?

c. Compare the types of signals handled by the general test oscilloscope and the synchroscope.

d. Why is it necessary for the vertical signal channel to have a large bandwidth?

e. What are the differences in the sweep frequency controls of the synchroscope compared to those of the general test oscilloscope?

f. Name three characteristics of a periodic pulse that can be observed and measured on a synchroscope.

g. How can a nonperiodic pulse be made to appear in the same position on the trace in the synchroscope?

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