BASIC TELEVISION

1. GENERAL

1.01 This section is prepared to familiarize service and maintenance personnel with the principles of operation of television station apparatus. Experience with similar services has demonstrated the value of knowledge on the part of testroom personnel of the principles of operation of the customer's station apparatus. Such knowledge assists greatly in the making of quick and accurate analyses of reported trouble conditions and is reflected in improved plant results, better service to the customer, and more cordial customer relations.

1.02 It is expected that a wide variety of apparatus designs will be employed by customers for television transmission service. For this reason information in this section is not based upon any specific manufacturer's apparatus. The mechanics of image diasection and scanning are the foundation of the descriptive material. However, considerable attention is given to the essential components of a practical television system. The principles underlying the operation of several types of cathode-ray television tubes, scanning generators, DC restorers, etc., are presented in such fashion as to facilitate the understanding of present and future devices used in the television industry.

1.03 Television principles are explained largely through the medium of visual devices, chiefly sketches, block diagrams and simplified theory schematics. A good practical knowledge of vacuum tubes and vacuum tube equipment is assumed. Experience in telephone repeaters and telephone or telegraph carrier systems and equipment is desirable.

1.04 The material which follows is reproduced in part from the Long Lines Plant Department Training Course D-28, entitled "Basic Television". All drawings have been assembled on pages following the text material. The number of the figure under discussion in the text has been indicated on the margin to the right of the applicable paragraph, for rapid cross-reference.

I. Requirements for electrical transmission of visual information.

A. Conversion of light energy into electrical energy. Photoelectric cells.

Figure

1. Photoconductive type. (Selenium cell). 1(a)
One of the earliest forms of photoelectric cell consists of a double grid of metal on which a thin layer of selenium is deposited to form a conducting path between the grids. The resistance of the selenium decreases with increase of the intensity of illumination. If the selenium cell is connected in series with a battery and a large value of resistance, the voltage across the resistor is roughly proportional to the intensity of the light striking the selenium cell.

2. Photovoltaic type. The photoelectric 1(b)
cell used in many photographic exposure meters consists of a layer of red cuprous oxide on a copper base and a thin, transparent film of gold, silver, or platinum over the cuprous oxide. Light transmitted by the transparent metallic film causes the oxide to emit electrons, more copiously on the illuminated side, giving the transparent film a negative charge with respect to the copper base. A microammeter connected between the transparent film and the copper base will indicate current, in conventional sense, flowing from the copper to the metallic film proportional to the illumination. The Westinghouse Photox cell is an example of this type of cell. Effects similar to these occur in the Weston Photronic cell, which employs iron selenide on iron instead of cuprous oxide on copper. Similar cells employing different arrangements of these and many other active materials are also used.

3. Photoemissive type. The type of photo- 1(c)
electric cell used in telephotography and sound-on-film reproduction consists of a thin layer of cesium-silver-oxide on a semicylindrical silver plated support and a coaxially located cylindrical nickel rod, all enclosed in a glass bulb, usually evacuated. Upon incidence of light, the cesium-silver-oxide releases electrons in somewhat the same manner that the cathode in an amplifier vacuum tube releases electrons when heated. Electrons are released at each point in proportion to the intensity of the incident light energy at that point. The electrode carrying the cesium-silver-oxide is called the photocathode and the rod electrode is called the anode. If a battery is connected through a resistor as shown, and the voltage is high enough to

Figure

draw all the electrons to the anode as they are released, the voltage drop across the resistor is proportional to the intensity of illumination on the photocathode as a whole. This type of vacuum cell is relatively insensitive but may be employed at practically any frequency, is very stable, and will give faithfully proportional conversion from light values to electrical values when properly used.

B. Conversion of electrical energy into light.

1. Incandescent lamp. Will not follow very rapid variations in voltage because of thermal lag.

2. Gaseous discharge tube (neon lights). A critical voltage must be exceeded for ionization of the gas; the tube does not have a linear conversion characteristic, and will follow voltage variations up to only about 15,000 c.p.s., the frequency being limited by the de-ionization time of the gas.

3. Fluorescent lamp. Employs screen of chemical substances (e.g., zinc sulphide) which emits light when bombarded by high-speed electrons. The response of this lamp to rapid variations of voltage is limited only by the persistence characteristic of the luminous substance and can be adjusted by choice of material. No critical voltage is involved, and the conversion characteristic has no discontinuities and is approximately linear.

C. Elementary television system.

1. An image of the scene being televised is focussed on a photoelectric cell by an optional lens. The photoelectric cell is connected via an electrical transmission channel to a lamp. An image of the lamp is focussed on a screen. 2

   The system fails to work as desired.

2. Observations: (a) The photoelectric cell delivers a voltage proportional to the total cathode illumination at any instant.
   (b) The electrical channel can deliver only one kind of information at a time, in terms of voltage (or current).
   (c) The distribution of light from the lamp is characteristic of the lamp alone, although the brilliance of the lamp varies with the voltage received from the transmission channel.

Figure

(d) Net result: The brilliance of the lamp at the receiving point is proportional to the integrated or average scene brightness without regard to the distribution of light values in the scene.

3. A flat (plane) black-and-white scene requires the specification of at least four quantities, viz;

   (a) The brightness at a point of interest in the scene;

   (b) and (c) The co-ordinates of this point (x and y, for example);

   (d) Time, if the brightness of the point varies from instant to instant, as in a living scene.

4. All three basic components (Fig. 2) of a television system are limited to the transmission of only two of the above four quantities at a time, whereas all four are necessary for the complete reproduction of a picture.

D. Dissection.

1. For the television of a point in the scene, only two kinds of information need be transmitted and reproduced; i.e., "how much" (quantity or amplitude) and "when" (time), because the brightness of the point is the same all over. All the basic components of the elementary television system are capable of handling these two items of information.

2. Therefore, a workable system may be established if the scene is dissected into minute areas or elements, each so small that the brightness is sensibly the same in every part of it, and a complete elementary television system is assigned to the exclusive transmission of brightness information of each such element. 3(a)

   (E.g., the Schaefer Beer sign at Times Square, N.Y.) 4
   Such a system, illustrated in Fig. 4, is known as a parallel transmission television system.

3. The optical system of the human body is an example of a parallel television system. The nerve endings, or rods and cones, of the retina are connected individually to separate fibers (transmission channels) of the optic nerve and each delivers to its nerve fiber a stimulus proportional to its average illumination. The image formed by the crystalline lens is thus broken up into elements the size of the nerve endings. For this reason, the smallest object that can be seen by the naked eye (resolving power) corresponds to the size of the rods and cones of the retina.

Figure

The fibers terminate in the brain of a geometric order corresponding to that of the nerve endings to which they are joined.

4. The reproduction of a televised scene by such a system consists of an aggregation of minute areas, each of uniform brightness but generally differing in brightness from one another. 3(b)

5. The smaller the size of the elements and thus the greater the number of elements into which the scene is dissected, the closer will be the correspondence between the scene and the reproduction. To meet modern standards, there must be about 288,000 elements. These in turn would require 288,000 complete elemental television systems. Obviously, this type of system is unsuitable for transmission over any but the very shortest distances.

6. Instead of having a separate television system for each scene element, a single television system may be used if means are provided for assigning it to the scanning, transmission and reproduction of <u>all</u> the elemental areas of the scene, <u>taken one at a time</u>, in rapid succession. If the scanning and reproduction of all the elements is completed in 1/30 of a second and this process is continually repeated, the eye of the observer at the receiving end of the system will see the reproduction as a continuous presentation. Note that the instantaneous positions of the scanning device and the reproducing device must correspond. Means for synchronization must be provided. Such a system, employing a single set of the three basic parts of a television system, together with means for assigning them to the individual scene elements in rapid succession, is known as a successive transmission television system. All modern television systems employ this principle. 5

E. Scanning.

1. It is difficult and unnecessary to make the scanning device jump from element to element. Approximately the same results are obtained if the scanning device itself is made to have an area of view, or aperture, corresponding to the size of a scene element and passes smoothly over one elemental area after another until the entire scene is scanned. 6(a)

2. To simplify control of the motion of the scanning device, it is made to move in parallel lines across the scene, the width of the lines corresponding to the height of the aperture. The entire scene is thus scanned in a series of parallel lines.

Figure

3. The instantaneous positions of the scanning aperture and the reproducing aperture must correspond. The instantaneous brightness of the reproducing aperture corresponds to the instantaneous average illumination of scanning aperture. 6(b)

4. Nipkow disc scanning system. An image of the scene is formed on a rotating disc by an optical lens. The disc has holes arranged in a spiral at approximately equi-angular distances around the periphery of the disc. The radial distance between the holes is equal to the width of a hole. A limiting aperture is placed over the disc so that the image is limited to a definite size corresponding in width to a peripheral distance between holes in the disc and in height to the width of the spiral. Behind the disc is a photoelectric cell connected to the electrical transmission channel. At the receiving end of the channel is a neon lamp, covered by a similar disc, limiting aperture, and optical lens (if reproduced image is to be enlarged). The discs at both terminals rotate in synchronism. Light from the scene is admitted to the photoelectric cell only through the hole at a time. The holes act as scanning apertures and serve to dissect the scene into elements. At the receiving terminal, the observer sees light only through the hole in the disc which is in a position corresponding to that of scanning aperture. Since light is admitted through only one hole at a time, the rotation of the disc at the transmitting terminal is equivalent to making an aperture scan the entire area of the scene in a series of parallel lines. The reproduction of the scene at the receiving terminal is accomplished in a similar manner. Among the many drawbacks of this system is the very low optical efficiency. Since the holes must be small to provide acceptable resolving power (reproduction of small details of the scene), very little of the light reflected by the scene is received by the photoelectric cell at any one time. 7

5. The Flying spot system was developed to provide greater optical efficiency. This system uses rotating scanning discs as above, the entire receiving terminal equipment being identical. At the transmitting terminal, a bank of photoelectric cells views the scene continuously. The scene is illuminated only by a sharply defined beam of light which is transmitted through the aperture of the scanning disc. The photoelectric cells receive light from only the small area of the scene illuminated at any instant by the "flying spot" of light. The spot of light on the scene serves as the scanning aperture and scene dissector. Because all the light reflected by the scene is received by the photoelectric cells, the optical efficiency of this system is much greater. However, the system is limited in use to indoor scenes only, where illumination is under the complete control of the operator. 8

Figure

6. All systems employing mechanical means of scene dissection and scanning suffer from mechanical difficulties involved in high-speed rotation and synchronization of bulky equipment.

7. Modern television systems use electron beams which, consisting of minute particles, have so little inertia that they can be moved back and forth at tremendously high speeds without difficulty. 9

Figure

II Television Tubes and Associated Circuits.

A. Formation of Electron Beams. Electron Gun.

1. Electrons are released by an indirectly heated cathode similar to that of a radio vacuum tube. The cathode consists of a metal cylinder (of the order of 1/8" diam.) with a coating of active material (barium or strontium oxide, etc.) on the end and a heater filament inside. 10

2. If the cathode is placed in vacuum and heated and a battery is connected between it and another electrode, the latter being connected to positive pole, the electrons released from the cathode are accelerated toward the other electrode (anode).

3. If a baffle plate with a small aperture is placed in front of the cathode in the attempt to form a fine beam of electrons, it will be found that mutual repulsions among the electrons will cause the beam to spread out away from the cathode.

4. The motion of the electrons may be influenced by electric fields. In the space surrounding a pair of bodies of opposite electric charge is a field of force similar to the magnetic field surrounding the opposite poles of a horseshoe magnet. The lines of electric force, or electric flux, show the path which an individual electron would <u>tend</u> to take if placed in the electric field. An electron approaching the electric field at constant velocity would tend to follow along a line of force and will be accelerated toward the positive charge. Momentum due to initial velocity and to acceleration will prevent its actually following any line of force, but its path of motion will be deflected in the direction of the lines of force toward the positive charge. The amount of deflection will depend on the initial velocity and the strength and direction of the electric field. 11

5. Electric flux may be arranged to direct electrons as desired by proper choice of electrode shapes, spacings, and potentials. Two coaxial conducting cylinders connected to opposite poles of battery will set up electric flux lines as shown by the fine dotted lines in Fig. 12. Electrons approaching from the left will be accelerated in the direction of the flux. Electrons on the axis will continue to move in straight line. Those not on the axis will be de- 12

Figure

flected toward the axis as shown by dashed lines. By choice of battery voltage and initial electron velocity, the electron paths may all be made to intersect a specified point on the axis. Because of this focussing action, electrodes in this arrangement are called an "electric electron lens".

6. The source of an electron beam is called an electron gun. 13
The electric type of gun consists of a cathode and an electron lens with an additional baffle electrode in front of the cathode which provides a means of control of the electron density like the grid in an amplifier vacuum tube. The electron gun shown in Fig. 13 has baffle plates within the lens cylinders to help sharpen the beam and prevent some secondary emission effects.

7. An electron travelling in space is influenced by a magnet- 14
ic field like a conductor carrying a current. By Fleming's right-hand rule, an electron moving perpendicularly to magnetic flux lines (equivalent to a current in the opposite direction) will experience a force perpendicular both to the direction of motion and the direction of magnetic flux. This fact is used in the "magnetic electron lens", as shown in Fig. 15.

8. As shown, the elementary electron gun consists of a cathode 15
and accelerating anode in the form of a baffle with a central hole. Acceleration due to the electric flux causes the electrons near the axis to shoot through the hole, the other electrons being stopped. Current through the coaxial coil sets up magnetic flux parallel to the axis. Electrons travelling parallel to the axis do not cut across flux lines and so are not affected. However, electrons tending to diverge from a parallel path have a component of velocity perpendicular to the flux lines. By Fleming's rule, these electrons are urged to move in a direction perpendicular to the figure (in addition to forward direction). When an electron begins to move in this direction it again is urged to move perpendicular to its normal direction, etc. As a result, the electron path becomes a spiral of helix tangent to the axis. The helix touches the axis at points depending on the initial forward velocity and the strength of the magnetic field. Viewed along the axis, the electron paths look like circles of different diameters (depending on relative deviations from parallelism) all touching the axis at the same point. Thus, a magnetic field may be used to make all elec-

Figure

trons leaving the gun come together at the desired point.

9. Beam diameters at the target plane are obtained of the order of 0.005 inch and smaller. Modern television tubes are all high vacuum types, but some low pressure gas filled tubes are occasionally used in oscillograph work. The gas assists in focussing the beam.

B. Electric Deflection of Electron Beams.

1. Electron beams formed as in II A may be bent or deflected by similar applications of electric or magnetic lines of force. If parallel conducting plates are connected to a source of electric charge, electric flux is set up perpendicular to the plates. An electron beam directed between the charged plates will be deflected toward the positive plate by an amount proportional to the strength of the electric field (i.e., voltage difference between the plates). The amount of deflection is inversely proportional to the velocity of the electrons, and, therefore, inversely proportional to the accelerating voltage. The average deflection sensitivity is of the order of 1 inch on the target plane per 100 to 300 volts difference between the deflection plates. 16

2. (a) With deflection plates at the same potential (i.e., zero voltage between plates), the beam is undeflected and strikes target plane at a certain point. 17

   (b) Application of voltage between the plates causes a deflection of the beam toward the left (for example).

   (c) Reversal of the voltage on the plates then causes a de-deflection toward the right.

   (d) The beam is made to traverse a target from left to right at a uniform rate of speed by applying between the deflection plates a voltage of polarity as in (b) above and making this voltage decrease at a uniform rate (volts per second) to zero and then increase, with reversed polarity, at the same uniform rate. Having reached the extreme position toward the right, the beam is returned to the starting position at the left by a rapid change of voltage between the deflecting plates to the starting value. The time taken to return the beam, or "fly-back" time, is equal to the time required for the voltage to change. The name of "sawtooth voltage" comes from the appearance of the curve 18

Figure

of deflection voltage plotted versus time. The beam makes one excursion from left to right (or vice versa) and back in each cycle of the sawtooth wave.

3. One pair of deflection plates (fixed in vertical planes) is provided to give horizontal deflection, or sweep, of the beam. Another pair of deflection plates is set at right angles to the first pair to give vertical sweep. Simultaneous application of sawtooth voltages, of frequency f to the vertical deflection plates and frequency nf to the horizontal deflection plates causes the beam to make n horizontal sweeps for each vertical sweep. The beam, therefore, traces n parallel lines on the target plane during each cycle of the vertical sawtooth wave. In Fig. 19, the solid lines are traced during the scanning time intervals t_{HS} and the dotted lines during the flyback intervals, t_{HF} of the horizontal sweep voltage. The dashed line, ha, occurs when the vertical flyback period, t_{VF} coincides with the horizontal flyback period. 19

4. Practical circuits for generating sawtooth waves use a principle based on charging and discharging a condenser. In Fig. 20, for example, when switch S is opened, condenser C is charged by current flowing through the high resistance R. The voltage, e, across the condenser rises from zero expotentially as shown by the dotted curve OA. When S is closed, the condenser discharges through the low resistance r. (Battery E is, in effect, short-circuited.) If S is closed when e is only a small fraction of E, the portion of the curve OB is substantially straight. By removing the DC component of the voltage wave (by use of condenser or transformer coupling), a close approximation to the sawtooth waves of Fig. 18 may be obtained. In practice, automatic devices take the place of switch S, the basic circuit remaining as in Fig. 20. 20

(a). The high-vacuum triode in Fig. 21 is normally biased to cut-off so that no current flows from the plate to the cathode. Steep positive driving pulses are applied at point x periodically to drive the grid positive and make the tube act like a small resistance (equivalent to r in Fig. 20) being periodically switched across the condenser. Thus the condenser is alternately charged through a high resistance and discharged through a low resistance to produce voltage wave as in Fig. 20. The driving pulses are often derived from a "blocking oscillator" shown in Fig. 22. This is a feedback oscillator with close coupling between the plate and the grid through the transformer T. C is a large 21 22 capacitance, R is a large resistance. The circuit starts to oscillate when operating voltages are applied. Feedback voltage to the grid is so large as to drive grid positive, cause DC current to flow in the grid circuit, and charge C as shown. R is so large that the condenser C is discharged only slowly. The accumulated charge on the condenser biases the tube to cut-off and prevents further activity until the charge leaks off through R, at which time oscillation again commences and the cycle of events is repeated. Condenser voltage e_o is obtained as shown. The pulse repetition rate, or frequency, is determined by the time constant, RC. The sharpness of the pulses is determined by the resonant frequency of the transformer, the higher the resonant frequency the sharper the pulses. The frequency may be synchronized by the insertion of a small voltage of the desired frequency at y and the adjustment of R and C to make the unsynchronized or natural frequency slightly lower than desired. The synchronizing voltage then acts by speeding up the instant at which the grid bias is reduced to a value which allows oscillation to recommence.

The oscillator may be synchronized by a synchronizing voltage of two, three or any integral multiple of the natural oscillator frequency. In such cases, the positive half of every second or third, etc. cycle of the synchronizing voltage occurs at the correct instant to hasten recommencement of oscillation. The other cycles have no effect. Thus, the oscillator frequency may be "locked in" with the higher synchronizing frequency.

Pulses obtained from blocking oscillator are fed to terminals x of sawtooth generator of Fig. 21.

(b). A self-excited sawtooth oscillator may be obtained 23
from Fig. 21 by replacing the high-vacuum tube with a gas-filled arc-discharge tube, as in Fig. 23.

Plate current does not flow in this tube until the plate-cathode voltage, which is the same as the condenser voltage in this case, exceeds a critical value determined by the grid bias. At this value of plate-cathode voltage, called the "ignition" voltage, the gas becomes ionized and the tube acts like a short-circuit between plate and cathode. Having become ionized, the gas remains ionized until the plate-cathode voltage falls to a relatively low "extinction" voltage, at which time the tube returns to its original non-conducting state.

Figure

In the circuit of Fig. 23, the tube initially is non-conducting. Condenser C is charged through the resistance R, making voltage e, and consequently the plate-cathode voltage, rise exponentially. When e reaches the value e_i the ignition voltage determined by the grid bias, the gas is ionized and the tube acts like a short-circuit across C. The condenser voltage falls rapidly to the value e_e, the extinction voltage (usually independent of grid voltage -- depends on tube design). The tube returns to the non-ionized non-conducting state, and the cycle repeats.

The repetition rate or frequency is governed by the RC time
constant, the grid bias, and the plate supply voltage, in
order of relative importance. Ignition occurs at lower 24
values of plate voltage for lower (less negative) values
of grid voltage. Therefore, if the natural frequency is
slightly below that desired, the insertion at x of a small
voltage of the desired frequency or an integral multiple
of the desired frequency, will cause synchronization by
speeding up the instant of ignition in each cycle.

(c). Note that for the rise of voltage to be linear, the maximum voltage attained must be small in comparison with the battery voltage E. Since the deflection sensitivity of a deflection plate system is comparatively small (100 to 300 volts per inch), the sawtooth waves obtained from the above sources may require amplification. Since a sawtooth wave is equivalent to the sum of an infinite series of harmonics of the fundamental sine wave, amplifiers for this purpose must meet rigid requirements as to linearity of amplitude and phase characteristics.

Linear rise of condenser voltage may be obtained by replacing
R with a device which keeps the current flowing through
it constant. Then the increase of charge on C and the
corresponding increase of e will be linear. A pentode
vacuum tube is such a device. To facilitate its use, the 25
basic circuit of Fig. 21 or Fig. 23 is modified slightly
by changing R to the other side of the plate battery, as
in Fig. 25 (a). Fig. 25(b) shows a pentode vacuum tube replacing R.

C. Magnetic Deflection of Electron Beams.

1. Moving electrons may be deflected from their normal paths
by magnetic fields as indicated in II A 7. For linear deflection of an electron beam, magnetic deflection coils 26
may be arranged to produce a magnetic field (of limited
extent) perpendicular to the normal direction of the

Figure

electron beam. Then the deflection of the beam will be perpendicular to the plane defined by the normal direction of the beam and the direction of the magnetic field (and, therefore, parallel to the plane of the coil windings). 27

2. The amount of deflection is proportional to the strength of the magnetic field. Therefore, linear deflection of the beam is obtained by linear variation of the magnetic field strength, which in turn is obtained by linear or sawtooth variation of the current through the deflection coils. 28 If the coils have considerable inductance as well as resistance (as in the low-frequency vertical sweep circuit) a complex impressed voltage is required to produce a sawtooth current. Thus, assume a sawtooth wave of current through a resistance and an inductance in series. The voltage across the resistance is in phase with and proportional to the current. The voltage across the inductance is proportional to the *rate of change* of the current and is constant when the current is *changing* at a constant rate. The direction of the voltage across the inductance depends on whether the current is increasing or decreasing. The sum of the voltages across the resistance and the inductance is the impressed voltage required to give the sawtooth current wave.

3. Circuits for generating the voltage wave required for magnetic deflection systems are basically the same as those for electric deflection. 29 Note that the fundamental circuit of Fig. 29 is same as Fig. 20 with the addition of the "peaking" resistor, R'. As in Fig. 20, R is a high resistance, r is a low resistance, representing the minimum obtainable resistance when an electronic device is used in place of the switch, S.

   Assume S closed and condenser C uncharged. Assume S opens at time $t=0$. Since C is uncharged, it momentarily does not oppose the flow of current through R and R', so that the voltage e is the same as that across R' alone. However, R and R' are in series across E, so that the voltage across R' at instant when S opens is $\left[\frac{R'}{R+R'}\right] .E$, as shown. Subsequently, C becomes charged, so that the voltage e rises exponentially. However, at time t_1, S is closed again, effectively shorting out E through R because of the low resistance r. Meanwhile, C has been charged to a voltage approximately equal to e_0. The closing of S places R' and r in series across C so that the voltage e is that across r. Therefore, at the instant of closing S the voltage changes from the value e_0 to approximately $\left[\frac{r}{r \quad R'}\right] e_0$ as shown. S remains closed after t_1 allowing C to discharge exponentially, as shown, until t_2, at which time S again opens and the process is repeated.

If the DC component is removed, the similarity of the voltage wave of Fig. 29(b) to that of Fig. 28(d) is apparent. In practice, a vacuum tube supplied with positive pulses of the desired frequency takes the place of the switch, S, as in Fig. 30, or a self excited generator is obtained by the use of a gas tube. 30

D. Image Dissector.

1. The image dissector is one of the simpler types of television camera tubes. It is characterized by low light sensitivity and freedom from spurious signal effects. It is now used only for transmission from motion picture film, where the light level can be maintained at a very high value.

2. As shown in Fig. 31, an image of the scene is formed by an optical lens on the surface of a photo-cathode inside an evacuated glass tube. The photo-cathode is a coating of silver-cesium-oxide on a conducting plate. The photo-cathode releases electrons from various points on its surface in proportion to the strength of the incident light. An electric field set up by the battery E, between the photo-cathode and an accelerator anode coated on the glass wall causes the photo-electrons to be accelerated away from the photo-cathode. The coating has a window for the passage of light. A focussing coil sets up a magnetic field which prevents the electrons scattering from mutual repulsions. The result is a stream of electrons from the photo-cathode in which the distribution of electrons over the cross-section is proportional to distribution of light energy in the optical image. This stream of electrons is known as an "electron image". 31

Figure

3. All the elctrons moving down the tube are collected by the accelerator anode and prevented from further activity, except those which enter the small aperture, A. These electrons strike electrode 1, and in giving up their kinetic energy cause the emission of several times as many electrons (secondary emission). The latter electrons in turn strike electrode 2 where again several electrons are released by the energy given up by each incident electron. This process of electron multiplication is repeated until at the collector there are approximately 100,000 electrons for each electron entering at A. These electrons passing through R cause a voltage which constitutes the signal.

4. Sawtooth currents through the horizontal deflection coils D_{H1} and D_{H2} and the vertical deflection coils (latter not shown) cause the electron image to sweep horizontally and vertically. The effect is the same as leaving the electron image stationary and sweeping the aperture A, instead. In this manner, the electron image is dissected and scanned. A signal voltage is obtained which is proportional to the brightness of the optical image at the point whose electronic counterpart is being scanned. The smallest picture element is the same size (approx.) as the aperture, A. If the illumination of the photo-cathode is uniform, a constant flow of electrons takes place into the multiplier and a constant (DC) voltage is obtained across R.

E. Iconoscope.

1. The Iconoscope is the prototype of modern camera tubes using the charge storage principle. It has a higher light sensitivity than the image dissector, but this, too, is low by present standards. It requires illumination equivalent to direct sunlight and a large aperture, long focus optical lens. It is prone to spurious shading effects.

2. The Iconoscope employs a beam of electrons for image dissection and scanning. The beam is formed by an electron gun of the electrically focussed type placed in the side arm of the evacuated glass tube. Magnetic deflection coils are usually used for sweeping the beam horizontally and vertically. The beam scans the surface of an image plate, as shown. 32

3. The image plate consists of a thin insulating support (mica) with a conducting coating on the rear side, called

Figure

the "signal plate", which is connected to the external circuit. The front surface is covered with the "mosaic". The mosaic consists of tiny particles (up to .0002 inch diam.), of cesium-silver-oxide, close together but insulated from one another. Thus, the transverse resistance of the mosaic is very high. Also, because the support is thin, the capacitance between each particle of mosaic and the signal plate is considerable (net capacitance = approx. 100 mmf/cm^2).

4. The collector anode consists of a conducting coating on the inside walls of the tube in front of the mosaic.

5. An external lens forms an optical image of the scene on the mosaic.

6. Assume the scanning beam not present. The incidence of light then causes the mosaic particles to emit electrons, which are attracted to and removed by the collector anode. Since the electron emission by mosaic particles is proportional to the incident light intensity, the mosaic acquires a distribution of positive charge over its surface corresponding to the variation of brightness in the optical image.

7. Electrons continue to be emitted from the mosaic particles as long as particles are illuminated (assuming collector is maintained at sufficiently high potential to remove the emitted electrons and prevent space charge effects). Therefore, the charge on each illuminated particle continues to build up as long as the illumination persists. The charge configuration of the mosaic surface is maintained because of the high transverse resistance of mosaic.

8. When the scanning beam sweeps over a mosaic particle which has acquired a positive charge by photoemission, it would seem that the beam functions as a commutator, discharging the particle and causing a current to flow in the external circuit of the signal plate by virtue of the capacitive coupling.

9. However, the action is more complex, since there is evidence that the scanning beam cannot conduct current in the usual sense (resistance of beam is practically infinite - change of 1000V. in potential of target produces no change in the beam current at the electron gun). The impact of the beam electrons causes secondary emission of electrons from the particle in an amount inversely proportional to

the initial charge. This change in charge of the particle causes the current in the signal plate circuit by virtue of the capacitive coupling.

10. Some of the secondary electrons are attracted to and removed by the collector anode. The remainder are attracted to and absorbed by positively charged areas of mosaic and thus tend to neutralize the charges resulting from photo-emission. Also, as the scanning process is continued, electrons released by secondary emission continue to shower down on the mosaic surface. The distribution of this shower is not uniform and it varies with the illumination. Therefore, it gives rise to spurious signals and shadings in the televised picture which require special corrective measures.

11. In addition, the electric field is not sufficiently intense to draw away from the mosaic all the electrons released by light energy. Some of these electrons return to the mosaic, so that the net charges developed are not as great as expected.

12. The efficiency of the Iconoscope is, therefore, very much less than the simple theory of paragraphs 7 and 8 would indicate. The practical efficiency is only 5 to 10 percent.

13. Assume that the mosaic illumination is uniform. Assume, also, that the scanning beam, while sweeping, is in contact with any one elemental area long enough to discharge it completely (the charge on the area having increased at a uniform rate since the preceding discharge). Then there is a transfer of electrons in the external circuit away from signal plate. However, during the same interval, the remining elemental areas of mosaic are discharging electrons and causing a transfer of electrons in external circuit toward the signal plate. This action goes on continually during the scanning process, the action of scanning beam causing a transfer of electrons away from the plate and the action of the light causing a transfer of electrons toward the signal plate. Further analysis shows that the rates of transfer of electrons in the two directions are equal. The net result is that no signal current flows in the external circuit when the mosaic is uniformly illuminated. Signal current flows in the external circuit only when the illumination of the mosaic differs from point to point. Hence, the signal from the Iconoscope-type tubes is proportional to the element-by-element variations in brightness from the average or background brightness of the scene.

Figure

14. A simpler view of the mechanism by which the Iconoscope-type tube is prevented from delivering a signal representing the average scene brightness if the following: Since every scene has some degree of average brightness, no matter how small, the external circuit would be called upon to conduct electrons continually toward the signal plate; however, since the signal plate has no other connection, the charge on the signal plate cannot increase indefinitely but must stabilize at some average value about which instantaneous variations may take place upward or downward.

F. Image Iconoscope.

1. Developed from the Iconoscope, the Image Iconoscope has a higher light sensitivity and can be used successfully with moderate studio illumination. 33

2. It consists essentially of an Iconoscope plus an "electron telescope", as in the Image Dissector, to convert the optical image to an electron image.

3. The photocathode is a semitransparent conducting layer of photoemissive material (cesium-silver-oxide) on the glass wall. An image of the scene is formed by an optical lens on the photo-cathode. Since the light penetrates to the inner surface of the photo-cathode, electrons are released from the photo-cathode in proportion to the illumination at each point. These electrons are accelerated toward the mosaic and the distribution of the electrons in the stream is maintained by an electron lens consisting of Image Anode #1 and a conducting coating on the glass wall. A magnetic electron lens may be used instead.

4. The electron image is brought to focus on the mosaic. This mosaic is not required to be photoemissive and is, therefore, of different construction than in the Iconoscope. It consists of a thin sheet of insulating material backed by a single plate, such as thin mica sheet with a conducting coating, or a thin layer of china clay baked on a metal plate. The insulating material must have a high secondary emission ratio.

5. The impact of each photo-electron of the electron image causes the release of several secondary electrons from the mosaic surface. The secondary electrons are attracted to the collector coating and are removed. A distribution of

Figure

positive charge is thus built up on the mosaic surface corresponding to the brightness distribution in the optical image.

6. Scanning of the mosaic by the scanning beam causes generation of a signal in the signal plate circuit as in the Iconoscope. Intensity of charge on mosaic is increased by the strong accelerating field directly in front of the photo-cathode and by the high secondary emission ratio of the mosaic. The signal current and voltage are, therefore, much greater than in the Iconoscope. Placing the photo-cathode at the end of the tube allows the use of a short-focus optical lens, which is cheaper and provides greater depth of focus in the televised image. The greater sensitivity of the Iconoscope permits the use of a smaller aperture optical lens.

7. Like the iconoscope, the image iconoscope suffers from spurious shadings and reduction of efficiency by secondary emission caused by the impact of the scanning electrons.

G. Orthicon.

1. The orthicon resulted from the attempt to avoid the secondary emission which causes spurious signals by the use of low velocity electron beams for scanning. It is characterized by high signal-to-mask (noise, spurious signals) ratio and theoretically 100% efficiency; has been used successfully at ordinary levels of illumination; does not give as good definition of picture detail as other types of tubes. 34(a)

2. Low velocity electrons used for scanning must approach the target at right angles. Then, if the target has a positive charge, the electrons are absorbed; if the target has a negative charge or is uncharged, electrons are not absorbed but are accelerated in the direction from which they come.

   However, if low velocity electrons approach the target obliquely, they are accelerated toward or away from target but not in the direction of approach. The result is a blurring of detail and distortion. The orthicon is designed to keep the scanning beam perpendicular to the target at all times while scanning takes place.

Figure

3. The scanning beam electrons are given velocities corresponding to an accelerating potential of about 25 volts at the electron gun (as compared with 1000 volts in the Iconoscopes). Focussing is magnetic, the entire tube being immersed in a longitudinal magnetic field. Because the electron velocity is low the electrons tend to move in tight helical paths whose axes are magnetic lines of force.

4. Magnetic deflection for sweeping the beam is accomplished by adding a transverse field due to current in the deflecting coils. The longitudinal field is distorted, as a result, in the vicinity of the deflecting coils, as shown in Fig. 34(b). Therefore, the electrons travel in paraxial paths except in the vicinity of the deflecting coils. On emerging from the influence of the deflecting coils, the electrons resume their paraxial path and approach the target perpendicularly. The forward velocity of the electrons is unaffected. Note that the deflection of the beam in this case is <u>perpendicular</u> to the plane of the deflecting coils. (Cf. II C 1.) 34(b)

5. Electric deflection of the beam is illustrated in Fig. 34(c). When the voltage between the deflecting plates is zero, an electron passes between A and B without deviation. When the upper plate is positive, the electron is first deflected upward; in moving upward, it moves across magnetic field and is, therefore, deflected to the side and somewhat downward. Thus, again moving across the magnetic field, the electron is again accelerated at right angles to its intended motion. This action and reaction continue until the influence of the electric field overcomes the tendency of the electron to move downward, at which time the cycle is repeated. With each repeated cycle, the electron moves further toward the side of the deflection plates until it emerges at C moving in a path parallel to the original path but displaced from it. The forward velocity of the electron is unaffected and the electron approaches the target perpendicularly. Note that the deflection of electrons in this case is <u>parallel</u> to the plane of deflecting plates. (Cf. II B 1) Note also that the plates must be as wide as the distance over which the electron beam is to be swept. 34(c)

The Orthicon illustrated in Fig. 34(a) uses electric horizontal and magnetic vertical deflection.

Figure

6. The target is similar to the image plate of the Iconoscope, except that the signal plate is a semi-transparent conducting coating and the mosaic likewise is semi-transparent. The mosaic faces the gun, and the signal plate faces the optical lens at the right end of the tube. An optical image of the scene is formed on the mosaic by a lens, the light passing through the signal plate.

7. The mechanism of signal generation is similar to the elementary theory of the Iconoscope (II E 1 - 8). Electrons are released from the mosaic by photoemission and are removed by the collector electrodes, so that a charge distribution is developed on the mosaic surface corresponding to the brightness distribution of the optical image. The scanning beam electrons are either repelled by the mosaic particles (and removed by collector electrodes) or are absorbed by these particles. If absorbed, the charge on the particles is neutralized and a corresponding displacement current flows through the capacitance to the signal plate.

H. Image Orthicon

1. The image Orthicon combines the image electron amplifier features of image iconoscope and the secondary emission electron multiplier of the image dissector with the low-velocity-beam scanning of the orthicon. This tube is still in the developmental stage but gives promise of extreme sensitivity and freedom from spurious signals and mask (noise). Adjustments are critical with regard to operating temperature and illumination level of scene. Also, the tube has non-uniform spectral response and signal frequency characteristics.

I. Miscellaneous

1. In both Image Dissector and Iconoscope-type tubes (i.e., tubes using some type of mosaic or employing the storage principle), the polarity of signal voltage is the same when connected as shown in the figures. Increase of brightness causes increase of negative voltage on the ungrounded end of the load resistor.

2. This is not true, however, in the case of the Image Orthicon. When this tube is employed, the signal is not derived from the neutralization of charge on the mosaic, but from the scanning electrons that are not absorbed. Therefore, the polarity of the signal is the opposite of that in the earlier tubes.

Figure

3. The signal voltage derived from any of the camera tubes is small, being of the order of several hundred microvolts in the more sensitive tubes and less in the others. The load resistance into which the tube works is of the order of several tens to several hundreds of thousands of ohms, the higher values resulting in a larger signal voltage but poorer high-frequency characteristics.

J. Picture Tubes (Kinescope, Teletron, etc.).

1. Tubes for the reproduction of television images are variously named by the manufacturers but employ identical principles. 35

2. The picture tube incorporates an electron gun using, usually, electrostatic focussing (II A 5). Operating voltages, electron velocities and scanning beam current are much higher than in camera tubes because of the different objectives.

3. The electron gun usually incorporates an addition electrode known as grid #2, or accelerator grid. As in guns previously discussed, the cathode supplies electrons for the beam, grid #1 is used to control the beam current according to the signal voltage, and anodes #1 and #2 constitute the electron lens. Anode #2 is often in the form of a graphite coating on glass wall of tube and extends to a short distance from the screen. Grid #2 is situated between Grid #1 and anode #1 and is kept at a fixed voltage with respect to the cathode and serves to prevent interaction between the control grid and the electron lens.

4. The flared end of the tube is coated with one of many substances which become luminous when bombarded with high speed electrons. This coating is called a "phosphor". Luminescence during electron bombardment is called "fluorescence", and the persistence of luminescence after bombardment is called "phosphorescence". All screen materials used in television are phosphorescent to some degree. Spectral characteristics, luminous efficiency, and persistence characteristics of phosphor vary with the substance employed, impurities used as activators, and treatment during manufacture. The spectral characteristics of the phosphor may be adjusted also by a combination of substances in proper proportions. In television tubes, persistance is generally chosen to be short; that is, the luminosity decreases to 1% of the initial value in less than .03 second after excitation ceases.

Figure

5. The luminosity of the phosphor increases approximately linearly with the voltage of anode #2 (i.e., the velocity of the scanning beam electrons) above 1000V. In practice, the voltages on the electron gun electrodes are kept fixed after being adjusted for focus. 36

6. The luminosity of the phosphor increases approximately linearly with the density of the beam current. The beam current density is controlled by grid #1, which is used as the signal or control grid. 37

7. Grid #1 normally is biased by a negative voltage approximately to cut-off of the beam current. The beam current increases approximately as the 3/2-power of the control grid voltage, as this voltage increases in a positive direction. Consequently, the screen brightness increases approximately as the 3/2-power of the control grid voltage as the control grid is made more positive. With accelerating voltages of the order of 5000 volts, a voltage swing of 20 to 40 volts on the signal grid of the picture tube will vary the screen brightness between total darkness and maximum brilliance. 38

8. There is no connection to the screen of the picture tube. The impact of the beam electrons causes the screen material to emit secondary electrons. The secondary electrons are attracted to and removed by the second anode. The result is that the screen acquires a positive charge with respect to the cathode and stabilizes at a potential within a few hundred volts of anode #2.

9. Deflection of the scanning beam is accomplished by means of deflection plates or coils. The deflection sensitivity is much less than in camera tubes because of the higher electron speeds and is of the order of .004 inch per volt between deflecting plates.

10. In contrast to the cathode ray tubes used for oscillographic purposes, beam velocities and beam current densities in television reproducing tubes are so great that, if the beam remains at one spot on the screen for an appreciable fraction of a second, the phosphor is destroyed at that spot.

11. In use, the signal voltage which originates at the camera tube is amplified and applied to grid #1. Normal grid bias is obtained by inserting a bias voltage in series with the 39

Figure

cathode when grid #1 is directly connected to the plate of the preceding video amplifier (Fig. 39a), or in the grid leak when grid #1 is coupled to the signal through a capacitor (Fig. 39b).

12. Since the scanning beam strikes the screen on the inner surface, the resulting light must pass through the phosphor to reach the observer's eye. Because of transmission loss through phosphor, reflection loss at the glass surfaces and the scattering of light by multiple reflections, the brightness and the contrast between dark and light areas are thereby reduced. Some reproducing tubes, therefore, suitable for optical projection of the image, have been designed in shape similar to the iconoscope to permit the observer to see the side of the phosphor where the luminescence occurs. 40

A more recent development places a smooth film of aluminum on top of the phosphor, the aluminum layer being thin enough not to hinder the passage of the beam to the phosphor but thick enough to cause all the light developed to be reflected outward through the phosphor instead of into the tube. The luminous efficiency is thus increased about 50 per cent or more. 41

13. The deflection sensitivity decreases as the accelerating voltage of the beam is increased because of the greater electron momentum. In order to obtain high beam velocity, for good brilliance without loss of deflection sensitivity, some tubes are designed for "post-deflection acceleration". That is, the electron gun is operated at relatively low accelerating voltage, but a ring shaped "intensifier" electrode formed on the glass walls a short distance in front of the phosphorescent screen is operated at high voltage in order to accelerate the beam electrons to the required velocity after having been deflected.

Figure

III. Frequency Requirements.

A. Image Analysis.

1. The normal human eye is just able to distinguish as separate objects 1/60-inch squares 1/60-inch apart at a distance of 4 to 5 feet, if the objects and the eye are perfectly stationery. This limit is due to the structure of the retina. (Resolving power of eye = 1 minute of angle.) 42

2. If the objects above are subject to a slight random motion (as may be due to fortuitous variations in scanning operations), the distance at which they cannot be seen separately reduces to 2 to 3 feet.

3. At this distance, the angle of view of the normal eye is such as to permit constant viewing of an area approximately 8 inches high by 10 inches wide. The proportions of 8 to 10 are generally considered to be a desirable "aspect ratio".

4. Therefore, a television picture 8" x 10" for viewing at 2 to 3 feet (or a larger picture at proportionally larger distance), in order to appear sharp, must be made up of at least 288,000 picture elements; that is, 480 lines with 600 elements in each line (I C 4). 43

B. Scanning.

1. It may appear that the scene to be televised may be scanned by an electron beam in 480 lines by making the horizontal deflection or sweep frequency 480 times as great as the vertical sweep frequency (II B 3). However, some of these lines would then occur during the interval t_{VF}, Fig. 18, when the vertical deflecting voltage is returning to the initial value for the beginning of the next vertical sweep (flyback time). Therefore, the ratio of the horizontal sweep frequency to the vertical sweep frequency must be somewhat greater than 480.

2. To facilitate synchronization, it is desirable to derive one sweep frequency from the other sweep frequency by the use of frequency multipliers or dividers (harmonic generators, multivibrators or blocking oscillators). This process makes it desirable to choose for the ratio between the frequencies an odd number which is the product of small odd prime numbers. The nearest odd number which is

Figure

a product of small odd numbers and is somewhat larger than 480 is 525 (3x5x5x7 = 525). This number has been adopted as standard for the ratio of horizontal to vertical sweep frequencies.

3. Of the 525 horizontal lines described during one vertical sweep, approximately 480 are used in the scanning process and are known as active scanning lines. The remaining 45 lines are known as inactive scanning lines and occur during the time allowed for the vertical sweep voltage to return to the initial value for the beginning of the next vertical sweep. 44

4. In motion picture work, a picture or frame is presented to the eye 24 times per second to give the illusion of continuity. In television practice, the frame repetition rate has been standardized at 30 per second in order to minimize effects due to inadequate filtering of the 60 cycle rectified power supply at radio transmitting stations.

5. A simple scanning sequence is the scanning of the horizontal lines in consecutive order until the entire scene has been scanned, thus completing the scanning of one frame in one vertical sweep. This process is called progressive or sequential scanning. 45

6. In motion picture practice, although a new frame is presented to the eye at a rate of 24 frames per second, the presentation of each frame is divided in two equal parts by a short interruption during the presentation. This is done to reduce flicker to a negligible value.

   For the same reason, the scanning of one frame in television is done in two fields; first, the odd field, consisting of all the odd-numbered lines; second, the even field, consisting of all the even numbered lines. One frame, therefore, consists of two interlaced fields. This process is called interlaced scanning. 46

   In order to avoid the necessity of making alternate cycles of the vertical sweep voltage of different duration or amplitude, the two fields are each made to be 262-1/2 lines, including both active and inactive scanning lines. Thus, the odd field starts in the middle of a line and ends at the end of a line; the even field starts at the

Figure

beginning of a line and ends in the middle of a line. Both the vertical and horizontal sweep frequencies being derived from a common source, the relative phases of the sweep voltages, once adjusted, stay fixed.

7. In interlaced scanning, therefore, the vertical sweep frequency is twice the frame repetition rate or frame frequency. In the standard 30 frames-per-second system, the vertical sweep frequency (and the field scanning rate) is, therefore, 60 cycles per second.

C. Frequency Analysis.

1. Each complete frame of a televised picture consists of 525 horizontal scanning lines, active plus inactive.

2. Since 30 frames are scanned per second, the horizontal sweep frequency is 525x30 = 15,750 cycles per second. That is, in one second, the scanning beam makes 15,750 horizontal sweeps.

3. Each horizontal line is equivalent to 600 picture elements (III A 4). Therefore the <u>rate</u> at which picture elements are scanned is 600x15,750,=9,450,000 elements per second. (Note: The 288,000 elements are scanned, not in 1/30 second, but in 1/30 x $\frac{480}{525}$ = .0305 second.)

4. The finest picture detail which a television system is required to transmit is represented by alternate black and white squares each 1/600 of a line in length. The resulting signal from the camera tube, however, is seen to consist of one square-wave cycle for each two such successive elements. The fundamental frequency of this square wave is considered to approximate the square wave with sufficient accuracy, in consideration of the distortion due to finite aperture size. The signal resulting from the scanning of this fine detail is, therefore, one-half the element scanning rate, or 4,725,000 cycles per second (roughly, 5 megacycles). 47

5. The coarsest picture detail consists of a scene of uniform brightness. The signal obtained in scanning such a scene by the interlaced method, therefore, consists of square waves at rate of the field scanning, or 60 waves per second. This wave consists of a fundamental sine wave of 60 cycles per second plus a long series of harmonics. 48

Figure

6. Thus, a television system must be able to accommodate signals of all frequencies from 60 cycles per second or less to 5 million cycles per second or higher.

D. Camera Signal.

1. In traversing one line of a scene, the scanning beam scans elements of various degrees of brightness. Translated directly into terms of signal current or voltage, this variation results in a signal like that in Fig. 49. This signal contains frequencies derived directly from the visual data of the scene, and visual intelligence may be derived from it directly. It is, therefore, called a *video* signal. In general, the range of frequencies (III C 6) is known as the video range. The signal delivered by the television pick-up tube is modified in the process of transmission. Therefore, to distinguish this signal from the modified signal, it is called the *camera* signal. 49

2. The curve of Fig. 49 is equivalent to a constant DC voltage equal to the average height of the curve, representing the average brightness or background brightness of the scene, plus an AC voltage representing the element-by-element deviations from average brightness, as in Fig. 50. 50

3. Correct reproduction of the scene requires transmission of information concerning average brightness together with information concerning deviations from this average brightness. For example, a given scene superimposed on a bright background gives impression of sunlight and warmth; whereas the same detail superimposed on a dark background conveys the idea of moonlight and cold.

4. As noted in II D 4 and II E 13, the Image Dissector delivers a signal which contains a DC component representing background brightness, but Iconoscope-type tubes do not. Also, where video amplifiers are used with capacitive coupling between stages, the DC component of the signal is lost. In the latter cases, it is necessary to provide other means of transmitting information concerning average scene brightness. At the receiving point, the information concerning average scene brightness must be translated in terms of DC and added to the video signal in order that the picture tube (Kinescope, etc.) may reproduce the scene with its proper background brightness.

The process by which this result is achieved is known as DC restoral or DC reinsertion.

5. When the video signal is to be transmitted by means of amplitude modulation of a high frequency carrier, the transmitting carrier terminal is designed for "negative" transmission. That is, the design is such that maximum visual brightness of a scene element produces a minimum of transmitting carrier power and decrease of scene brightness produces increase of carrier power. Spurts of extraneous power, such as noise, entering such a system cause dark spots in the received picture. Since dark spots are psychologically less objectionable than white spots, negative transmission has been adopted as standard in the United States. Note that the term does not refer to the polarity of the video signal, although the modulator in such a system usually does require that the video signal be poled so that increase of brightness causes increase of negative voltage applied to the modulator.

Figure

IV. Transmitting Terminal.

A. Average Scene Brightness.

1. In preceding sections, means have been described for translating visual information into electrical form and vice versa. A simple schematic of a television system based on principles thus far discussed is shown in Fig. 51. 51

2. As previously stated, the signal voltage delivered by the camera tube is minute, whereas the signal voltage required for operating the picture tube is very large by comparison. It is apparent, then, that many amplifier stages are required between the camera tube and the picture tube for transmission over even short distances.

3. It is a matter of fact that amplifiers which properly amplify DC voltages as well as AC voltages throughout the video range are difficult to build and to maintain. Consequently, video amplifiers used in practice employ some form of capacitive coupling between stages and do not recognize DC voltages. As a result, the DC component of the camera signal is lost, even if it is initially present (III D 3 et seq.). Other means must therefore be found for transmission of information regarding average scene brightness.

4. It has been shown (II B2, etc.) that during each cycle of the sweep voltage a small portion of time must be allowed for fly-back. The fly-back interval is relatively short and the sweep voltage during the interval is difficult to control. Therefore, little is lost by discarding the picture information which may be transmitted during fly-back. The fly-back interval may then be used for the transmission of information concerning average scene brightness.

5. Assume, then, that a scene is being televised with an Image Dissector as the camera tube. Then the camera signal voltage will appear as in Fig. 52. 52

6. Suppose, during the fly-back period, the scene were blacked out, as by a shutter closing over the lens. Then the signal voltage will appear as in Fig. 53. The signal is said to be "blanked out" during the fly-back period. 53

Figure

Note that, as a consequence, the signal during the blanking period becomes zero. Therefore the same result could have been achieved by turning off the scanning beam or cutting off the camera tube during fly-back.

7. Note, also, that as a consequence of blanking there is a rectangular pulse of voltage during the blanking period, relative to the rest of the signal. Since the voltage during the blanking period corresponds to total darkness, or black, it follows that the amplitude of the rectangular voltage pulse - relative to the rest of the signal - is proportional to the average brightness of the scene.

8. If then the DC component of the signal is removed, as in passing through a capacitively coupled amplifier, the signal will appear as in Fig. 54. It is apparent that the amplitude of the rectangular voltage pulse which was caused by blanking - relative to the remainder of the signal - still is proportional to the average scene brightness. 54

9. It is necessary somewhere in the path between camera and picture tube to invert the signal because, as shown in II J 7, the screen of the picture tube becomes brighter when the applied signal voltage becomes more positive, whereas the signal of Fig. 54 has the opposite polarity. The necessary inversion may be accomplished by a conventional type of amplifier, since such an amplifier causes 180 degree shift in the phase of the amplified voltage. An odd number of such amplifiers will have a like effect. An even number of such amplifiers will restore the amplified voltage to its original phase.

10. After inversion, the signal appears as in Fig. 55. It is apparent that, whether the signal is amplified, inverted, or attenuated, the pulse of voltage resulting from blanking will always represent the average scene brightness in relation to other details of the signal. The fact that the height of this pulse of signal voltage has special significance, together with other use of this pulse which will be described later, has led to the term, "blanking pedestal". In section V B 4, etc., it will be shown how the blanking pedestal is put to use to restore the DC component of the signal. 55

Figure

11. In practice, Iconoscope-type tubes are employed most frequently and, since the signal from these tubes does not contain a DC component, a more obtuse method must be used for inserting the blanking pedestals and properly adjusting their height.

12. In one practical system, the signal from the Iconoscope (DC component lacking) is amplified in an odd number of stages and obtained in the opposite phase to Fig. 54, but the blanking pedestals are not yet added. This is shown in Fig. 56. To this signal are added large negative rectangular pulses of voltage, synchronized with the fly-back intervals, from two blanking pulse generators. One of these generators supplies blanking pulses which are synchronized with the horizontal fly-back periods and the other supplies blanking pulses synchronized with the less frequent but longer vertical fly-back periods. These are known as horizontal and vertical blanking generators, respectively. With these pulses added, the signal voltage has the appearance given in Fig. 57. 56

13. It should be noted that the amplitudes of the blanking pulses have not been adjusted and depend only on the voltages from the blanking generators. All that has happened thus far is that the level of signal voltage has been greatly increased in a negative direction during the blanking periods. But during these periods there is still some picture information gathered during fly-back. 57

14. The signal wave of Fig. 57 is then amplified by a two stage amplifier. The first stage functions simply to increase the signal voltage. The second stage is provided to correct the phase reversal introduced by the first stage. It employs a power type of amplifier tube so as not to be over-driven by the large signal voltages occurring during the blanking periods. Except for increase in amplitude, the signal wave emerging from the phase reversing amplifier is identical with that of Fig. 57. It is shown again in Fig. 58. 58

15. The signal thereafter goes to a "clipper" amplifier which is a conventional amplifier operated with a large negative bias so that it cuts off at a value of negative input 59

Figure

voltage indicated by the dashed line in Fig. 58. That is, the clipper amplifier delivers an amplified version of only that part of the signal which is more positive than the cut-off value (below the dashed line, Fig. 58). The picture information occurring during the blanking pulse is, therefore, wiped out and the signal during this period leveled off. At the output of the clipper amplifier the signal voltage is, of course, inverted and appears as in Fig. 59. Note that the blanking pedestals, i.e., the black level, is positive with respect to the rest of the signal. Information concerning average scene brightness is now contained in the AC signal by virtue of the blanking pedestal height relative to the remainder of the signal.

16. It is evident that the height of the blanking pedestals, which indicate the average scene brightness relative to the rest of the video signal, is determined by the grid bias of the clipped amplifier. Therefore, this grid bias is adjusted by an operator at the transmitting terminal to give the correct average scene brightness on a monitoring viewer. If the average scene brightness is fixed or changes slowly, the operator can make the necessary adjustments in bias as required.

17. However, if the average scene brightness varies rapidly as in the television of motion pictures, the changes in grid bias are effected automatically. For this purpose, the entire scene is viewed continuously by a simple type of photo-electric cell. The signal voltage from this cell, which is a DC voltage proportional to the average scene brightness, is amplified if necessary and used as the required variable grid bias for the clipper amplifier. In this case, also, the operator must make the initial adjustment of the grid bias, but the photo-electric cell takes care of subsequent changes.

18. The block schematic of the transmitting terminal may now be expanded to take care of transmitting the average scene brightness information. The expanded block schematic is shown in Fig. 60. 60

19. The pre-amplifier shown in Fig. 60 is a multi-stage amplifier contained within the camera case. It functions: to raise the minute signal from the camera tube to a level high enough to over-ride noise in the cable connecting the

Figure

camera with the heavier stationary equipment; to compensate for non-uniform frequency characteristic of the camera tube; and to match the high impedance of the camera tube to the low impedance of the connecting cable. Other portions of Fig. 60 have been described in the preceding paragraphs. The numbers refer to the figures portraying the shape of the signal wave at different points in the circuit.

20. Fig. 61 shows simplified schematics of the amplifiers following the camera. It will be recalled that the AC part of the camera signal represents the variation of brightness from one element of the scene to another. In photography, this relationship among the elements is known as "contrast". Therefore, a change in amplitude of the camera signal relative to the blanking pedestal produces a change in the contrast of the televised scene. For this reason, a manual gain adjustment is provided in the first video amplifier of Fig. 61 and is known as a contrast control. Shown also are a manual brightness control (IV A 16) and an automatic brightness control which function as described above. As stated in IV A 12, the transmitting terminal described is only one of several possible designs. However, although various means are employed in practice to generate the camera signal, amplify it, and insert and properly adjust the blanking pedestals, the objective and the final result are the same as given above. 61

21. It should be emphasized that the wave of Fig. 59 is an AC wave. In any integral number of cycles, the areas included between the time axis and the lower, or "white", portions will, therefore, always equal the areas included between the time axis and the upper, or "black", portions of the wave. Consequently, as the average scene brightness changes and the amplitude of the blanking pedestals changes, the height of the blanking pedestals will not remain constant with respect to the zero axis but will vary with the background brightness of the scene. However, in later sections it will be shown that a variable DC component of the correct amount is automatically added to the wave at the receiving terminal to restore the pedestals to a constant voltage level corresponding to black. Thus the remainder of the signal is automatically restored to its proper level with respect to the black level and the average scene brightness is correctly reproduced.

Figure

Because successive changes of wave shape are confusing, the conventional representation of the composite video signal usually omits the zero voltage axis and shows the blanking pedestals always at the black level. The reader must determine from his knowledge of the functions of the circuit whether the signal existing at a point of interest is purely AC, so that successive blanking pedestals may be at different voltage levels, or whether the signal contains a DC component placing all the blanking pedestals at the same voltage level.

B. Synchronizing Signals

1. As shown in the block diagram of Fig. 51, sweep voltages are provided at the sending and receiving terminals for scanning. The sweep frequencies at the two terminals, as previously discussed, must be alike to avoid distortion in the televised picture. However, not only must the frequencies be alike but the sweep voltage cycles must start at the same instant (allowing for propagation time) and keep in phase thereafter. Very little deviation from exact synchronism is permissible. Therefore, it is necessary to transmit, together with the camera signal and the blanking pedestals, information which will keep the sweep voltages at the receiving terminal in step with those at the transmitting terminal. 51

2. It was stated in II J 10 that the scanning beam in the picture tube is sufficiently powerful to destory the luminescent screen if allowed to remain stationary for any length of time. For this reason, self-excited sweep generators are provided at the receiving terminal, so that the scanning beam will be kept in motion even in the event of failure of the synchronizing information.

3. The self-excited sweep generators whose principles were described in II B, it was pointed out, may be synchronized with an external source of voltage pulses if the un-forced or free frequency of the generator is slightly lower than that of the external voltage. Therefore, if pulses of the desired sweep frequencies can be mixed with the picture signal at the transmitting terminal in such a way that they can be separated from it at the receiving terminal, the pulses may be employed to synchronize the self-excited sweep generators at the receiving terminal.

Figure

4. It will be recalled that no picture information is transmitted during the blanking periods. Therefore, synchronizing voltage pulses may be transmitted during the blanking periods without interfering with the picture information contained in the video signal. Furthermore, if the synchronizing pulses are given the same polarity as the blanking pedestals, they will be in the "blacker-than-black" voltage region as regards the picture tube and will not produce any visible effect on the fluorescent screen.

5. However, if the synchronizing pulses are superimposed on the blanking pedestals, some means must be devised which will permit separating the synchronizing pulses from the remainder of the signal at the receiving terminal. The necessary means are provided by an amplifier which is biased to cut-off at the blanking pedestal level so that the output current of the amplifier contains only the synchronizing pulses (V A 3 et seq.). It is a relatively simple matter to arrange that the bias voltage of the amplifier be made to follow the variations in the blanking pedestal level (IV A 21).

6. Because of its simplicity and economy of signal space, the above method of transmitting synchronizing information is employed in all modern television systems.

7. It remains, however, to decide on the shape of the synchronizing pulses. Obviously, there must be two kinds of pulses so that they may be distinguished apart: one for synchronizing the vertical sweep generator, the other for synchronizing the horizontal sweep generator. For the sake of brevity, the term "sync" is usually employed instead of "synchronizing." The term "sync signal" refers to the combination of horizontal and vertical sync pulses.

8. The two kinds of sync pulses may be of the same geometric shape but of two different amplitudes. Then suitably biased amplifiers may be used to distinguish between them. The sync signal would then appear somewhat as in Fig. 62(a). The composite video signal, consisting of camera signal, blanking pedestals, vertical and horizontal synchronizing pulses, then appears as in Fig. 62(b). This variable-amplitude type of synchronizing signal is simple and reliable and has been successfully used in Europe. However, some of the power-handling capacity of the transmission channel must be set aside to allow for the extra amplitude 62

Figure

of the vertical synchronizing pulse. Consequently, the picture information cannot be transmitted at as high a level as desired and so the signal-to-noise ratio of the overall system is reduced.

9. In the United States, standard practice is to make the vertical and the horizontal sync pulses approximately rectangular and of equal amplitude but of very different durations, as shown in Fig. 63. The duration of a horizontal sync pulse is not more than 8% of a scanning line (8% of $\frac{1}{15,750}$ second or 5 micro-seconds). The duration of a vertical synchronizing pulse is equivalent to 3 scanning lines (3 x $\frac{1}{15,750}$ second or 190 micro-seconds). Since the vertical and horizontal sync pulses are of the same amplitude, separation between the two kinds of pulses cannot be effected by biased amplifiers. Instead, use is made of the properties of resistance-capacitance networks. 63

10. Thus, if the synchronizing signal of Fig. 64(b) is applied to terminals 1 and 2 of the circuit of Fig. 64(a), the voltage obtained across terminals 3 and 4 will be as shown in Fig. 64(c). In the circuit, R is a large value of resistance and C is a large value of capacitance such that the time constant RC (seconds) is somewhat greater than the duration of the long pulses and therefore much longer than the duration of the short pulses. The condenser C can receive a charge only through the large resistor R. Hence, when a pulse arrives, the condenser charges slowly, because the resistor limits the flow of current. Consequently, the voltage across the condenser, which is proportional to the charge, does not have sufficient time to build up to more than a small fraction of the full pulse voltage when the pulse is short. When the pulse is long, the voltage across the condenser has sufficient time to build up almost to the full pulse voltage. Because the useful voltage obtained is proportional to the time-integral of the applied voltage, this circuit is known as an "integrator" circuit. Several such circuits may be connected in tandem to reduce the small voltage waves due to the short pulses to a relatively neglibible value. 64

Figure

The larger waves due to the long pulses are applied to the vertical sweep oscillator for synchronization, as described in II B 4. It should be observed that the shape of the vertical pulse after passing through the integrating circuit appears to be broad only because of the time scale chosen for Fig. 64. Actually, this selected pulse is very steep and short in relation to one cycle of the vertical sweep voltage.

11. The short horizontal sync pulses are selected by the somewhat similar resistance-capacitance circuit shown in Fig. 65(a). Here the capacitance C and the resistance R are chosen so that the time constant RC (seconds) is of the order of only 1% of the horizontal sweep period. The synchronizing signal shown in Fig. 65(b) is applied to the input terminals 1 and 2, and the selected synchronizing voltage pulses are obtained across the resistor R. The selected pulses are shown in Fig. 65(c). 65

Voltage appears across R only when current in flowing through the condenser. When a sudden change of voltage occurs in the applied sync signal, the condenser momentarily behaves like a short circuit so that the full voltage of the applied pulse is reproduced across the resistor. However, because the time constant is small, the condenser is quickly charged to the full voltage, with the result that the current, and, therefore, the voltage across the resistor, rapidly falls to zero. Likewise, when the applied pulse voltage suddenly changes to zero, the condenser quickly discharges, producing a current, and a corresponding pulse of voltage across the resistance, in the opposite direction. The selected voltage pulses are applied to the horizontal sweep generator for synchronization. Because the useful voltage obtained across the resistor is proportional to the time-derivative of the applied voltage, this circuit is known as a "differentiator" circuit. The synchronizing signal applied to the differentiator is arranged to have the polarity shown in Fig. 65(b) so that the output pulse occurring on the leading edge of each synchronizing pulse will be positive. Then, when the output voltage is applied to the sweep oscillator, the oscillator will "fire," or discharge will occur, on the positive pulses and will be synchronized with the leading edges of the synchronizing pulses.

Figure

Having fired on a positive pulse, the oscillator is insensitive to the negative pulse immediately following. Therefore, no measures need be taken to eliminate the negative pulses derived from the differentiator circuit.

12. It will be recalled (III B 6) that in interlaced scanning the odd field starts at the middle of a line and ends at the end of a line and that the even field starts at the beginning of a line and ends at the middle of a line. Therefore, following the odd field, the vertical synchronizing pulse will be preceded by a horizontal synchronizing pulse at an interval of one scanning line; whereas, following the even field, the vertical pulse is preceded by a horizontal pulse at an interval of only one-half scanning line. Consequently, in the latter case the pulse derived from the integrator circuit will build up somewhat earlier in the cycle because of the small voltage remaining from the preceding horizontal pulse. The effect is illustrated in Fig. 66. As a result, the vertical sweep oscillator fires slightly sooner than it should and causes the scanning lines of the following field to be slightly higher on the reproducing screen. The net effect is a pairing of scanning lines which gives the appearance of streaks in the reproduced picture. To avoid pairing of lines, the timing of the vertical sweep oscillator must be kept within extremely close limits (1 part in 5000). 66

13. The above difficulty is avoided by inserting between the end of a field and the vertical sync pulse following it a number of short pulses of double the line frequency. These additional pulses are known as equalizing pulses and serve to "condition" the intergrator for the arrival of the vertical sync pulse. Thus, following either the even or the odd field, the residual voltage in the integrator circuit is the same when the vertical sync pulse arrives, and the selected output pulse has the same timing and shape in both cases. The equalizing pulses are of the same amplitude as the horizontal and vertical sync pulses but have one-half the duration and twice the frequency of the horizontal sync pulses. A group of six equalizing pulses is superimposed on the vertical blanking pedestal immediately preceding and also immediately following the vertical sync pulse, as in Fig. 67. 67

Figure

14. The differentiator circuit will, of course, deliver selected synchronizing pulses as a consequence of the equalizing pulses, just as it does for the horizontal synchronizing pulses. However, they will be of double the frequency. Therefore, since the horizontal oscillator has a natural frequency approximately one-half as great, it will fire on those equalizing pulses occurring at line scanning intervals and be insensitive to those in-between (II B 4). The effect on the horizontal sweep generator of the equalizing pulses is the same as when horizontal sync pulses are received.

15. No mention has been made up to this point about the behavior of the receiving horizontal sweep generator during transmission of the vertical sync pulse. It is clear that, since the natural frequency of the horizontal oscillator is somewhat below the desired frequency, this oscillator is quite liable to drift so far off frequency that it will not fall into step when transmission of the horizontal sync pulses is resumed. In order to maintain control of the horizontal sweep oscillator, the vertical sync pulse is periodically interrupted, or serrated, so as to cause the differentiator circuit to deliver selected synchronizing pulses to the horizontal sweep generator. As a matter of convenience, the serrations in the transmitted vertical synchronizing pulses are made at twice the horizontal sweep frequency, so that the differentiator circuit delivers double-frequency pulses to the horizontal sweep generator, as in the case of the equalizing pulses (IV B 14). The serrated vertical sync pulse and the corresponding selected pulses delivered by the differentiator and integrator circuits are shown in Fig. 68. 68

16. The net result of adding together the horizontal sync pulses, the serrated vertical sync pulses, and the equalizing pulses, which ultimately are superimposed on the blanking pedestals, is the composite synchronizing signal, shown at (a) and (b) in Fig. 68.

C. Block Diagram of Transmitting Terminal.

1. The horizontal sync pulses, the serrated vertical sync pulses, and the equalizing pulses are generated in complex vacuum tube circuits which are shown as separate 69

Figure

blocks in Fig. 69. Actually, however, because of the necessity for absolute synchronism, the pulse generators are closely interrelated with one another and with the generators of the camera sweep voltages and the blanking pulses.

2. The various generators operate continuously even when not in use in order to minimize temperature effects on the frequencies and shapes of the pulses. Each kind of pulse is produced in a steady succession of such pulses without interruption. 70

3. Each kind of pulse is fed to its own so-called "keying" amplifier. The outputs of the three keying amplifiers are connected in parallel with each other and, through a sync phasing amplifier, with the output of the clipper amplifier, where the pulses are added to the AC portion of the camera signal and the blanking pedestals.

4. The keying amplifiers are normally blocked by high negative grid bias so that the synchronizing pulses are not transmitted.

5. The keying amplifiers are periodically un-blocked, however, by appropriate keying impulses from still another group of pulse generators, so that each of the different synchronizing pulses is transmitted at its proper time. The keying impulses act to overcome the high blocking grid bias. Fig. 70 illustrates the manner in which the keying signals operate to produce the composite synchronizing signal, and Fig. 71 shows parts of the block diagram in greater detail. 70 71

6. By proper choice of initial polarity and the number of conventional-type amplifiers in the chain, the phase of the composite synchronizing signal, where it is added to the video signal, is made the same as that of the blanking pedestals. The effect of the synchronizing pulses is then to increase the instantaneous signal level in the direction of black.

7. Of course, the superposition of the synchronizing pulses in their correct positions on the blanking pedestals requires careful design and adjustment of the several pulse generators. However, all the required frequencies are derived from a common source, so that once the adjustments for pulse amplitude, duration, and phase have been

Figure

correctly make, the various pulses keep their relative positions exactly.

8. The complete composite video signal has the appearance given in Fig. 72. The signal now contains all the information required at the receiving terminal to reproduce the brightness variations and the average brightness of the televised scene and to synchronize the sweep voltages with those at the transmitting terminal. It will be noted that in Fig. 72 durations of various portions of the signal are indicated. Those durations, together with such other details as the steepness of the sides of the sync pulses, must correspond with the design of the receiving equipment, the frequency width of the transmission channel, etc., and have, therefore, been standardized by the Federal Communications Commission. The allowable deviations are very small, indeed. 72

D. Miscellaneous.

A number of controls, beside the contrast and brightness controls, are omitted from the block schematic of the transmitting terminal for the sake of clearness. This number is considerable and would include adjustments for the operating voltages for the camera tube, adjustments of the average (DC) deflecting voltages to center the scanning beam on the target of the tube, adjustments for regulating the amplitude of the deflecting voltages, etc.

Figure

V. Receiving Terminal.

A. Synchronization.

1. It was pointed out (IV A 21) that, although usual representations of the wave do not emphasize the fact, the video signal is a pure AC wave and that the height of the blanking pedestals, relative to any arbitrary axis, will vary according to the average brightness of the televised scene. The composite video signal received at the receiving terminal is such a wave.

2. In order that the synchronizing pulses may be used for synchronizing the sweep circuits associated with the picture tube, it is necessary first to separate them from the remainder of the signal.

3. Although there are several methods of effecting this separation, all of them consist, in principle, of applying the composite video signal to an amplifier vacuum tube, or equivalent device, whose grid bias is automatically adjusted so that it cuts off always at the blanking level. Then the amplifier will deliver a signal which consists only of the synchronizing pulses. A biased rectifier tube may be used in place of an amplifier. The several methods of producing the variable bias are also basically alike and may employ amplifier or rectifier tubes. One of the most common methods combining the production of the bias and the clipping action in the same vacuum tube, is described below.

4. A simplified schematic of a common sync separator is shown in Fig. 73. The amplifiers which perform the separating function are indicated as SYNC SEP #1 and SYNC SEP #2. The SYNC AMP, also shown, corrects for the phase reversal caused by SYNC SEP #1 and increases the amplitude of the signal to aid SYNC SEP #2 in performing its function. The input composite video signal is poled so that the synchronizing pulses are positive. 73

5. It will be observed that SYNC SEP #1 is operated with no grid battery and with low plate voltage. Consequently, the grid of this amplifier tube is driven positive by the "black" portions of the input signal, i.e., the blanking pedestals and sync pulses.

<u>Figure</u>

6. When the grid of an amplifier tube becomes positive with respect to its cathode, some of the electrons that ordinarily travel to the plate are attracted to and lodge on the grid. The condenser <u>C</u> prevents the flow of direct current and the resistor <u>R</u> has a large value of resistance. Therefore, the electrons which are attracted to the grid of SYNC SEP #1 cannot quickly leak off. As a result, in the first few cycles of the applied signal, a considerable negative charge builds up on the grid. Since the charge is able to leak off, although slowly, the amount of the charge adjusts itself in the course of a few cycles to correspond with the prevailing height of the sync pulses above the zero voltage axis of the signal. Consequently, since the height of the sync pulses relative to the blanking pedestals is fixed, the charge on the grid becomes proportional to the nominal height of the blanking pedestals and follows the variations in the latter.

7. The charge which thus accumulates on the grid has the same effect on the operation of the amplifier as a grid battery; but, whereas the grid battery would provide a fixed bias, the bias provided by the above condenser and grid leak method varies in proportion to the amplitude of the applied signal. Moreover, the plate supply voltage is made small, so that the tube cuts off sharply at a value of input signal voltage not much more negative than the grid bias which is developed. Therefore, the plate current of the amplifier contains little more than the amplified version of the sync pulses.

8. The operations described above are illustrated graphically in Fig. 74. Fig. 74(a) shows how the negative charge is built up on the grid and Fig. 74(b) shows how this developed grid bias causes separation of the sync pulses. 74

9. The video signal voltage applied to SYNC SEP #1 may not be sufficient to develop the necessary grid bias for completed separation of the sync pulses. The process is, therefore, repeated by SYNC SEP #2. However, the voltage output of SYNC SEP #1 is reversed in phase and must be corrected. The SYNC AMP effects the necessary phase correction and also amplifies the partially separated signal. The SYNC AMP is operated without fixed grid bias because it is a high-mu triode and does not require such bias when the input signal is small and the plate voltage is large. It should be noted that, in the arrangement illustrated, a single vacuum tube containing two triodes acts as sync separator and as amplifier.

Figure

10. SYNC SEP #2 completes the operation of separating the sync pulses from the composite video signal. This tube is a power amplifier and is operated with a small amount of fixed bias in addition to the developed bias so that the plate current will not be excessive when there is no signal. Here again the plate and screen voltages are made small so that cut-off occurs sharply at a low value of negative signal voltages.

11. The separated synchronizing signal derived from SYNC SEP #2 is again reversed in phase and must be corrected. For this purpose, the signal is divided between two amplifiers. One of these amplifiers feeds into a differentiator circuit to select the pulses for synchronizing the horizontal sweep generator. The other feeds into an integrator circuit to select the pulses for synchronizing the vertical sweep generator. A block schematic of the arrangement is shown in Fig. 75. 75

B. Reproduction and DC Reinsertion.

1. As indicated in Fig. 75, the composite video signal is applied to the synchronizing circuits and also, indirectly to the control grid of the picture tube. In the example here assumed, it will be recalled that the output of the transmitting terminal has such polarity that the blanking pedestals, i.e., the black level, are positive (IV A 15). Consequently, increasing voltage in a negative direction corresponds to increasing brightness. However, as shown in II J 7 and IV A 9, the picture tube response is in the opposite direction. Therefore, an amplifier or an odd number of amplifiers must be interposed before the picture tube to effect the necessary phase correction. 75

2. If the phase of the input video signal were the opposite of that assumed, amplifiers would not be necessary for phase correction for the picture tube, but such correction would then be necessary in the synchronizing amplifier chain. However, one or more amplifiers are always used in the picture tube circuit because of the gain or contrast control thus provided (IV A 20).

3. With the sweep voltages properly synchronized, a video signal of the proper phase applied to the control grid of the picture tube, and the necessary static operating voltages applied to the picture tube, it still remains to restore the DC component of the picture signal so that the

Figure

background brightness of the scene is correctly reproduced. Correct reinsertion of the DC component will make the blanking pedestals correspond to zero volts and produce the least brightness, or black, on the picture tube screen. Also, the sync pulses will then be negative in polarity and consequently the scanning beam will be cut off during the fly-back intervals. The lines scanned during these intervals, or "scanning raster", as they are called, will, therefore, not be visible.

4. Basically, the problem of reinserting the DC component of the video signal is essentially the same as the separation of the synchronizing signal, and several types of circuits may be employed. The simplest and most common DC restorer circuit is almost identical with that of the sync separator previously described (V A 5).

5. The circuit of a combined video amplifier and DC restorer is shown in Fig. 76. As in the sync separator, the composite video signal is applied with such polarity that the blanking pedestals and sync pulses are positive. This, of course, is the wrong polarity for operating the picture tube, but the video amplifier makes the necessary phase correction. Also, as in the sync separator, the gird of the amplifier is coupled to the signal through the condenser C and grid leak resistor R, and the grid, being driven positive by the blanking pedestals and sync pulses, acquires a negative charge or bias that varies with the height of the blanking pedestals. However, in this case the grid leak resistance is smaller in value, so the developed grid bias is not so great. Furthermore, the operating plate voltage is very much larger, so that the developed grid bias can never cause cut-off of the plate current and consequent clipping of the signal. 76

6. The AC video signal and the developed grid bias add together to constitute the total voltage acting on the grid of the amplifier tube. This total voltage is shown in Fig. 77(a). In the process of being amplified, the voltage is reversed in phase and appears across the load resistor R_L as shown in Fig. 77(c). Fig 77(b) shows the intermediate action occurring within the video amplifier tube. 77

Figure

7. The signal voltage across R_L is, of course, an AC voltage due to the AC video signal plus a varying amount of DC voltage due to the developed grid bias. It will be observed that the AC component is in the correct phase for reproducing the contrast information and that the DC component is in the correct phase for reproducing the average brightness of the televised scene. Thus, the desired DC component is restored to the picture tube signal as a consequence of the blanking pedestals. 77

8. The total signal voltage across R_L is applied to the picture tube, since the coupling is direct. The potentiometer marked "Brightness Control" affords a means of setting the black level of the reproduced picture by its control of the net grid bias of the picture tube itself.

9. The DC restorer described above has two objectionable features; if the amplifier tube or its plate supply should fail, the picture tube control grid bias becomes very small or slightly positive, and the scanning beam current may, therefore, become so great as to cause damage to the fluorescent screen; and, in the absence of a video signal, no grid bias is developed for the amplifier tube, so that the amplifier plate current may be excessive.

10. A DC restorer which avoids these drawbacks is shown in Fig. 78. Here, the amplifier tube acts simply as an amplifier, and a separate diode rectifier develops the DC component as required. 78

11. The polarity of the input video signal is the same as in the preceding type of circuit, namely, inverse to that required for operation of the picture tube. If the diode were not present, only the amplified AC video signal would exist between picture tube grid and ground, because coupling is through the condenser C_1. The polarity of the amplified signal would be correct, its phase having been inverted in passing through the amplifier. The amplified AC video signal is shown in Fig. 79(a). The condenser C_2 receives that portion of the AC voltage which appears across R_2. 79

12. When the diode is present, however, it conducts current and acts as a short circuit across C_2 when the instantaneous AC voltage is negative. Consequently, C_2 acquires a charge

Figure

only when the instantaneous AC voltage is positive. C_2 can discharge only through R_2, which is a large value of resistance, so that the discharge is comparatively slow. As a result, the voltage across R_2 is a DC voltage which varies with and approximates the positive peaks of the AC video signal, as shown in Fig. 79(a).

13. The total signal voltage acting on the grid of the picture tube is therefore the sum of the AC video signal and the DC voltage developed by the diode, as in Fig. 79(b). Thus the DC component proportional to the blanking pedestals is restored to the picture signal. The "Brightness" control, as before, permits adjusting the black level on the picture tube.

C. Block Diagram of Receiving Terminal.

1. The block diagram of Fig. 75 may now be completed to include the DC restorer, as shown in Fig. 80. — 80

2. It will be observed that several controls are shown, in addition to the contrast and brightness controls, as follows:

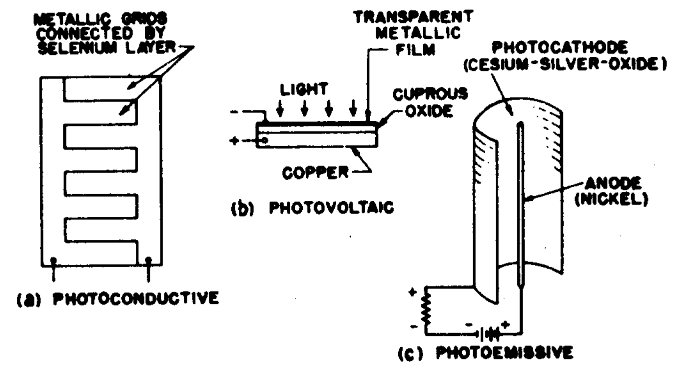
   a. Gain Control: Permits adjustment of received signal level.

   b. Vertical and Horizontal Hold: Regulate the amount of synchronizing voltage applied to the respective sweep oscillators (II B 4 etc.). If the amplitude of the synchronizing voltage is too great, the sweep voltage delivered by the oscillator may be distorted. If too small, the oscillator will not synchronize. The controls permit necessary adjustments.

   c. Vertical and Horizontal Linearity: Where the sweep circuits employ magnetic deflection coils and a serrated saw-tooth voltage wave is generated by means of a peaking resistor in series with the charging capacitor, the peaking resistor is made variable to permit adjustment to the best value for linear deflection.

d. Height, Width: The amplitude of the sweep voltage determines the distance of scanning beam travel on the screen and thus determines the corresponding dimension of the reproduced picture. These controls regulate the amounts of sweep voltage in their respective circuits.

3. In practical cases, other controls may be provided, such as a control for the synchronizing circuit input voltage, adjustments for centering the scanning beam, etc., and some of the controls shown may be omitted. When electrostatic deflection is used in the picture tube, for example, linearity controls are generally omitted.



(a) PHOTOCONDUCTIVE

(b) PHOTOVOLTAIC

(c) PHOTOEMISSIVE

FIGURE 1. TYPES OF PHOTOELECTRIC CELLS

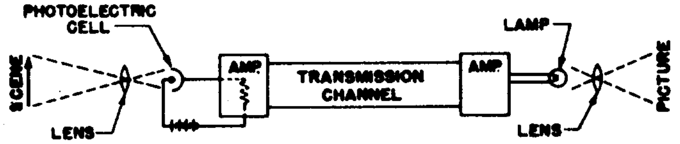
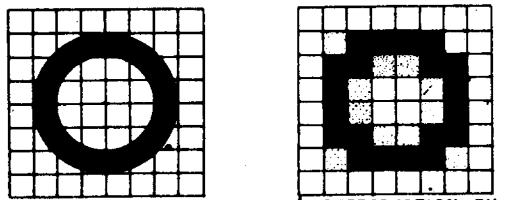


FIGURE 2. ELEMENTAL TELEVISION SYSTEM



(a) SCENE DISSECTED INTO ELEMENTAL AREAS

(b) REPRODUCTION BY ELEMENTS OF UNIFORM BRIGHTNESS

FIGURE 3. (a) DISSECTION AND (b) ELEMENTAL REPRODUCTION OF A SCENE

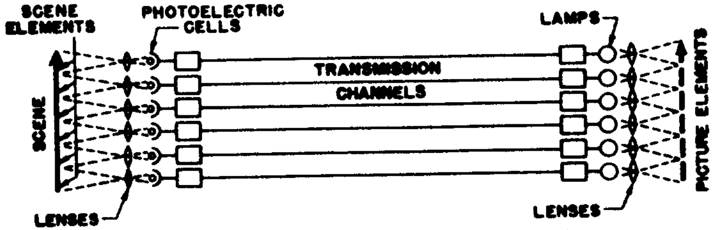


FIGURE 4. TELEVISION BY PARALLEL TRANSMISSION

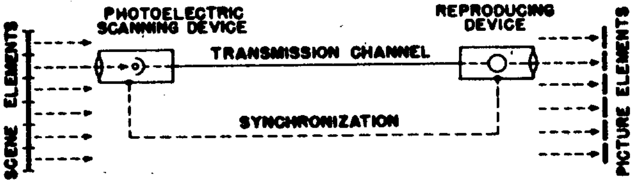
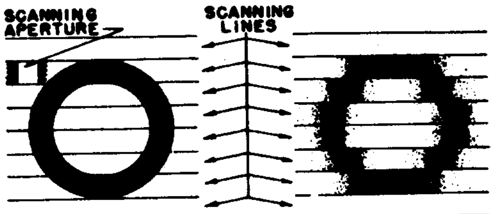


FIGURE 5. TELEVISION BY SUCCESSIVE TRANSMISSION



(a) SCANNING AND DISSECTION OF SCENE BY MOVING APERTURE

(b) REPRODUCTION OF SCENE SCANNED BY MOVING APERTURE

FIGURE 6. SCANNING, DISSECTION AND REPRODUCTION

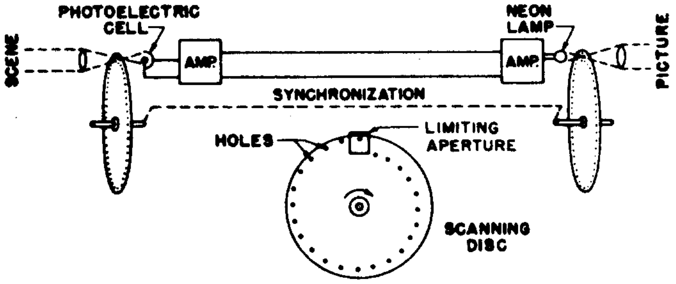


FIGURE 7. TELEVISION SYSTEM WITH NIPKOW SCANNING DEVICE

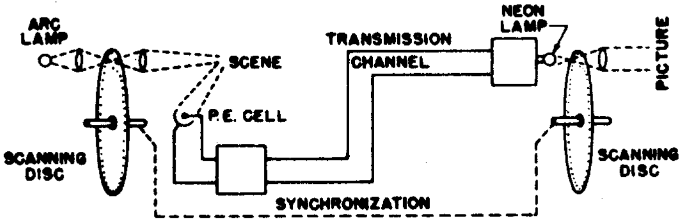


FIGURE 8. TELEVISION SYSTEM USING "FLYING SPOT"

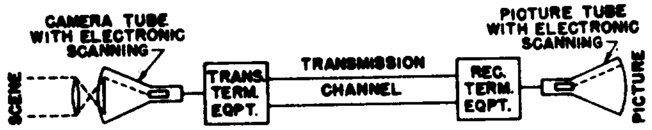


FIGURE 9. TELEVISION SYSTEM USING ELECTRONIC SCANNING

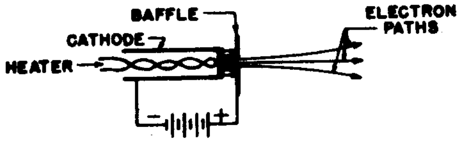
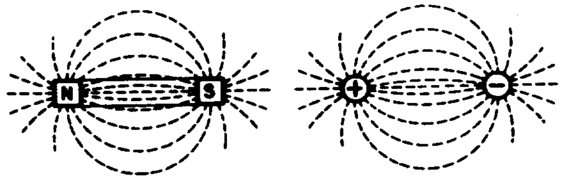


FIGURE 10. BASIC ELECTRON GUN



(a) MAGNETIC LINES OF FORCE

(b) ELECTRIC LINES OF FORCE

FIGURE 11. SIMILARITY OF MAGNETIC AND ELECTRIC FIELDS

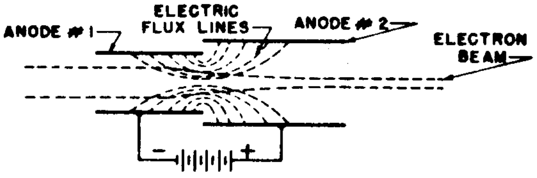


FIGURE 12. ELECTRIC ELECTRON LENS

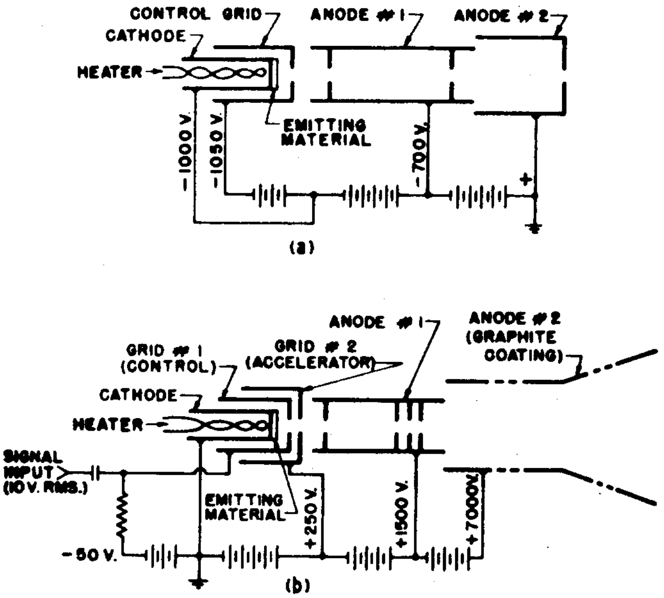


FIGURE 13. TWO TYPES OF ELECTRON GUNS USING ELECTRIC FOCUSING

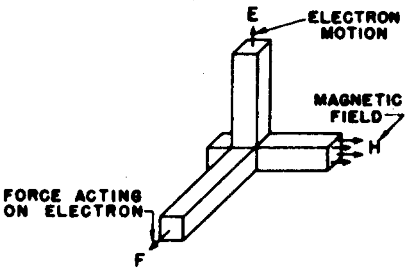


FIGURE 14. ILLUSTRATION OF FLEMING'S RULE

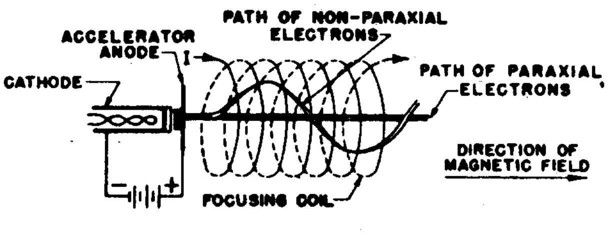


FIGURE 15. MAGNETIC ELECTRON LENS

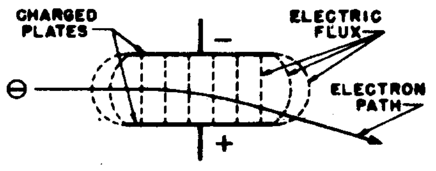
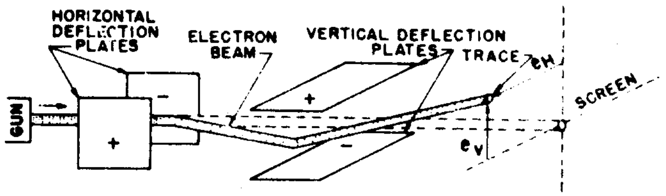
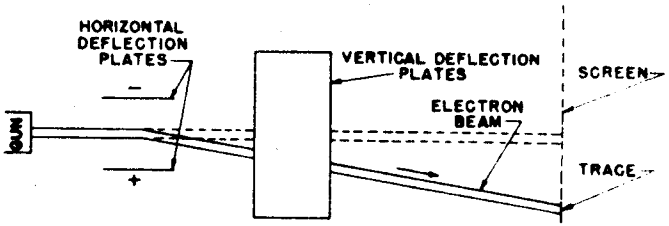


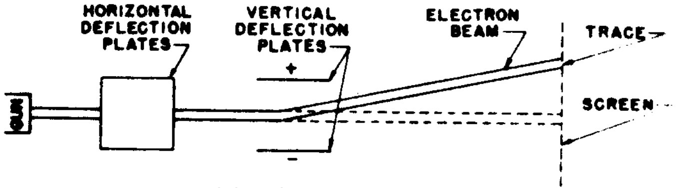
FIGURE 16. DEFLECTION OF MOVING ELECTRON BY TRANSVERSE ELECTRIC FIELD



(a) PERSPECTIVE

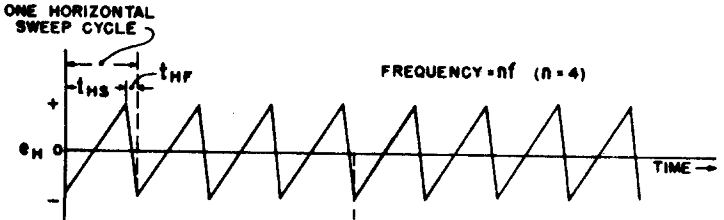


(b) TOP VIEW

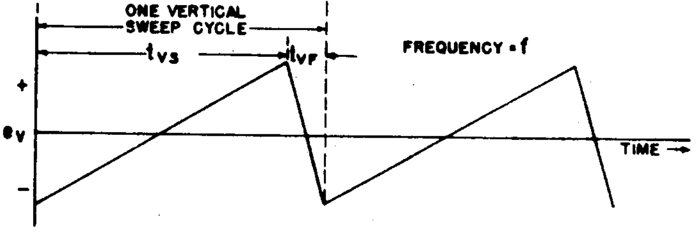


(c) SIDE VIEW

FIGURE 17. ELECTRIC DEFLECTION SYSTEM



(a) HORIZONTAL SWEEP VOLTAGE



(b) VERTICAL SWEEP VOLTAGE

FIGURE 18. SWEEP VOLTAGES FOR ELECTRIC DEFLECTION SYSTEM

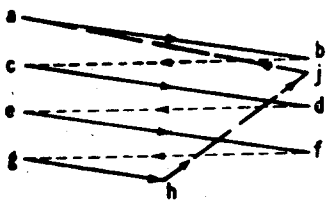
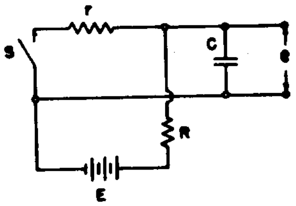
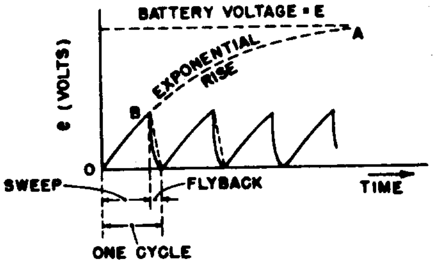


FIGURE 19. TRACE PRODUCED BY VOLTAGES OF FIGURE 18



(a) BASIC SAWTOOTH GENERATOR



(b) CONDENSER VOLTAGE

FIGURE 20. PRODUCTION OF SWEEP VOLTAGE

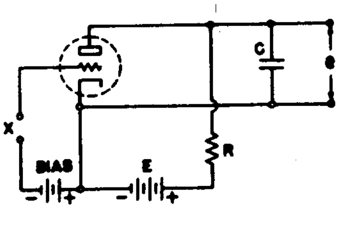
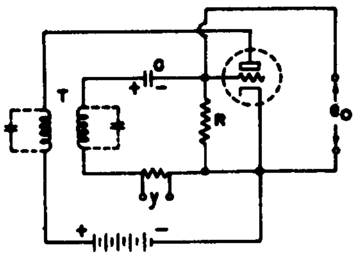
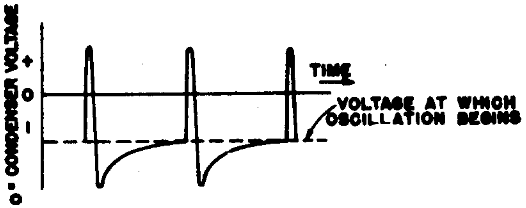


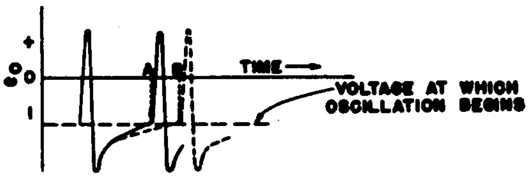
FIGURE 21. PRACTICAL FORM OF FIGURE 20



(a) CIRCUIT FOR PRODUCTION OF VOLTAGE PULSES (BLOCKING OSCILLATOR)

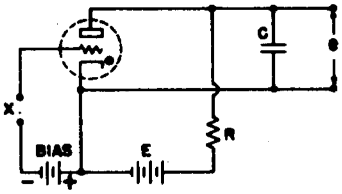


(b) VOLTAGE ACROSS CONDENSER C

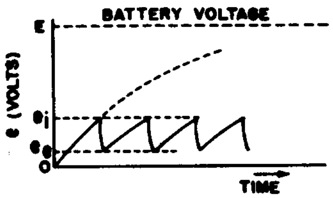


(c) SYNCHRONIZING VOLTAGE CAUSES OSCILLATION TO BEGIN AT A INSTEAD OF B

FIGURE 22. PRODUCTION AND SYNCHRONIZATION OF VOLTAGE PULSES

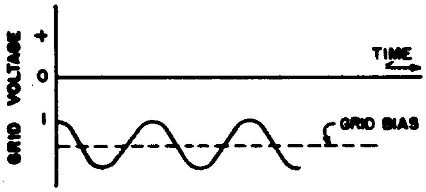


(a) CIRCUIT

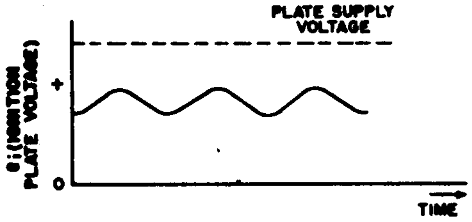


(b) CONDENSER VOLTAGE

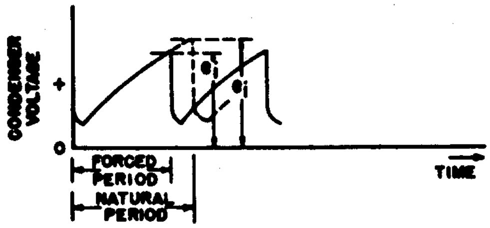
FIGURE 23. SELF EXCITED SAWTOOTH GENERATOR USING GASEOUS DISCHARGE TUBE



(a) GRID VOLTAGE WITH SYNCHRONIZATION

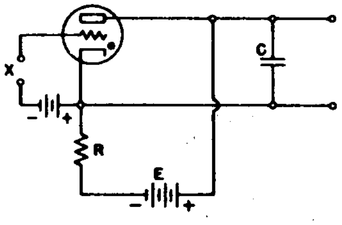


(b) PLATE VOLTAGE REQUIRED FOR IGNITION: VARIATION WITH NET GRID VOLTAGE

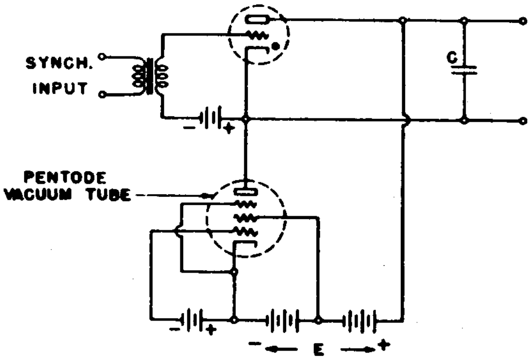


(c) CHANGE IN CONDENSER VOLTAGE CAUSED BY SYNCHRONIZING VOLTAGE

FIGURE 24. SYNCHRONIZATION OF SELF-EXCITED SWEEP OSCILLATOR

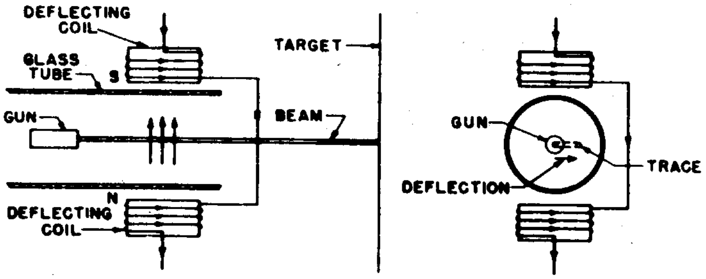


(a) BASIC CIRCUIT



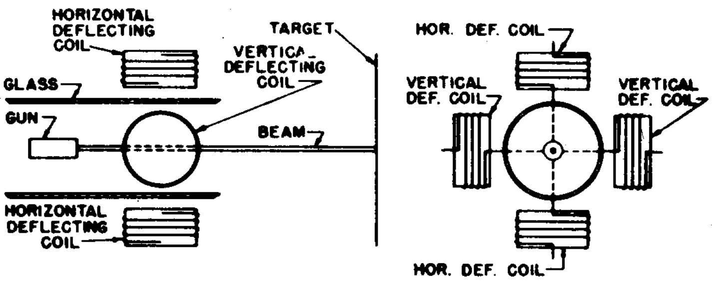
(b) PENTODE REPLACING R IN BASIC CIRCUIT

FIGURE 25. SAWTOOTH OSCILLATOR USING PENTODE TO CONTROL CHARGING CURRENT

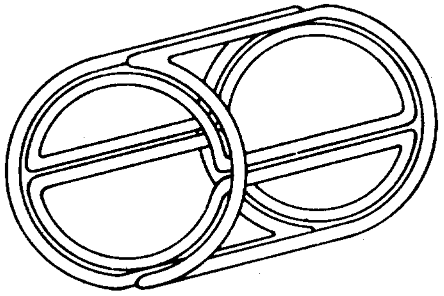


(a) SIDE VIEW (b) END VIEW

FIGURE 26. MAGNETIC HORIZONTAL DEFLECTION SYSTEM

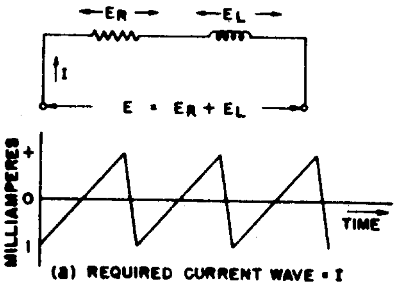


(a) SIDE VIEW (b) END VIEW

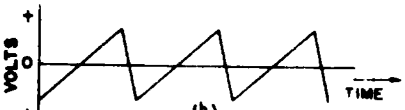


(C) ONE FORM OF YOKE COMBINING HORIZONTAL AND VERTICAL DEFLECTION COILS

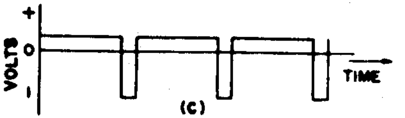
FIGURE 27. COMPLETE MAGNETIC DEFLECTION SYSTEM



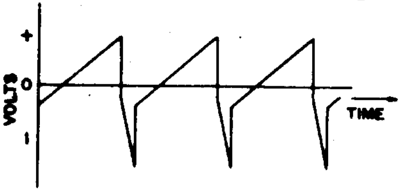
(a) REQUIRED CURRENT WAVE = I



(b) VOLTAGE ACROSS RESISTANCE = $E_R = IR$



(c) VOLTAGE ACROSS INDUCTANCE = $E_L = L\frac{dI}{dt}$



(d) TOTAL VOLTAGE = $E = E_R + E_L$

FIGURE 28. CURRENT WAVE SHAPES FOR MAGNETIC DEFLECTION SYSTEM

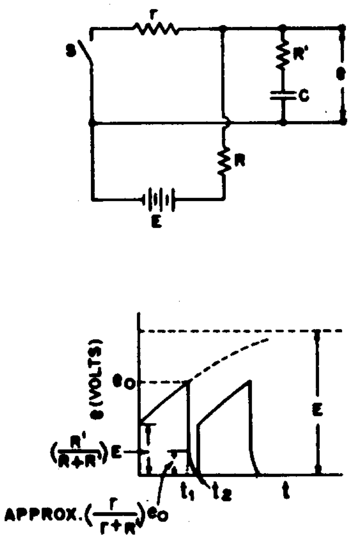


FIGURE 29. BASIC CIRCUIT FOR GENERATING VOLTAGE WAVE FOR MAGNETIC DEFLECTION SYSTEM

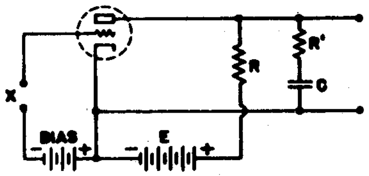


FIGURE 30. VACUUM TUBE DISCHARGE CIRCUIT FOR MAGNETIC DEFLECTION SYSTEMS

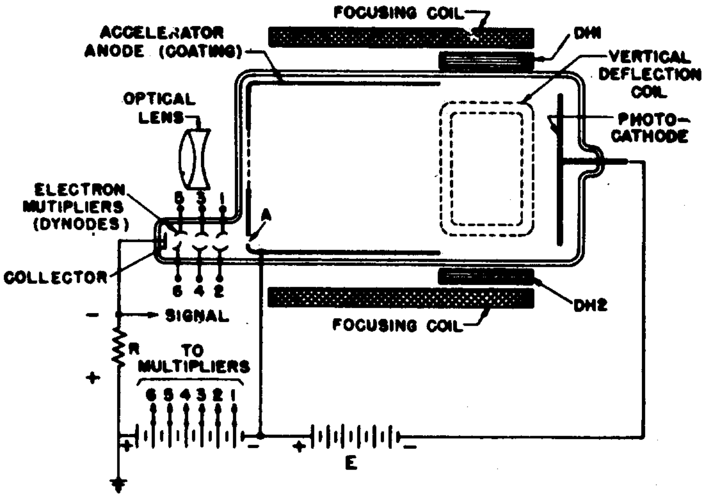


FIGURE 31. IMAGE DISSECTOR

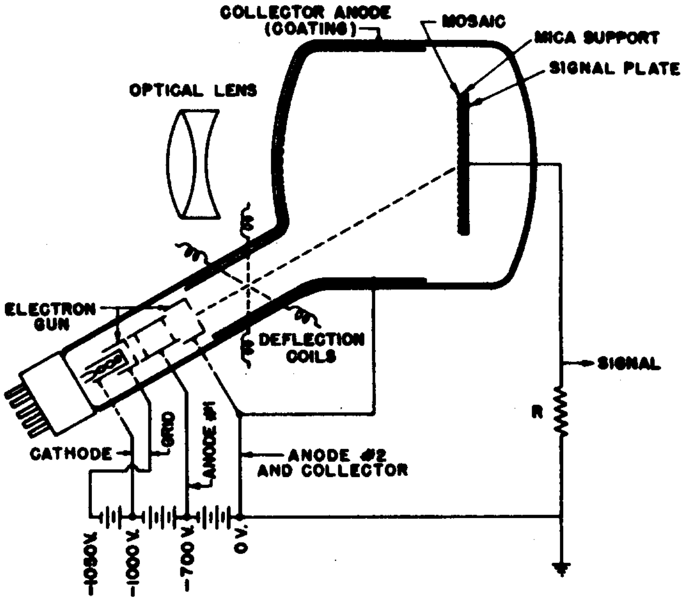


FIGURE 32. THE ICONOSCOPE

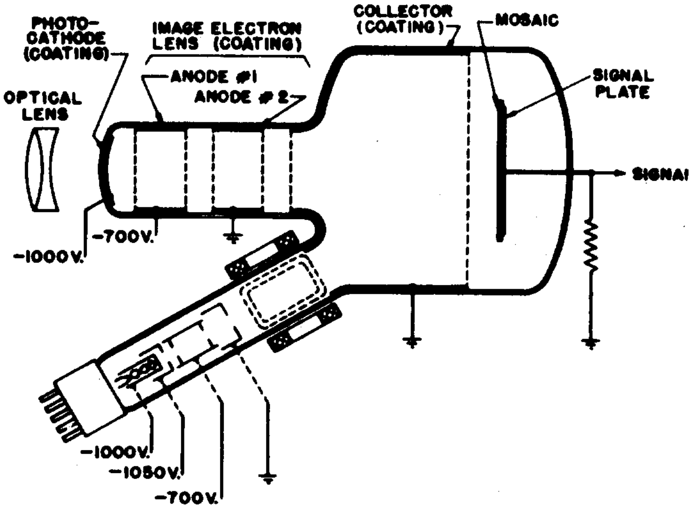
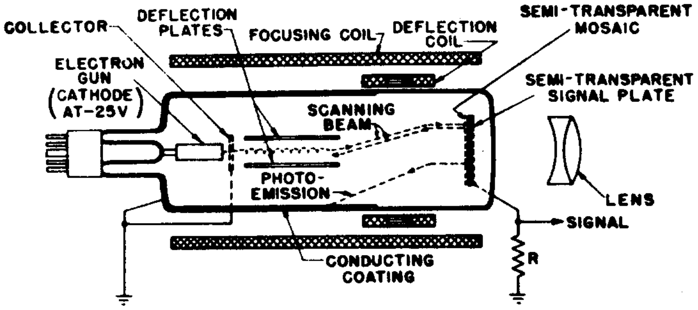
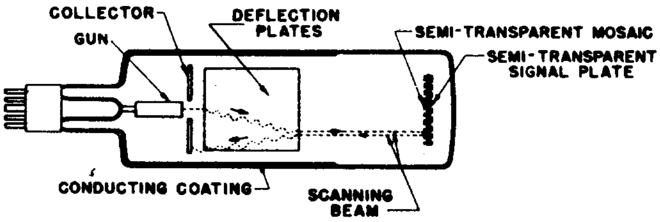


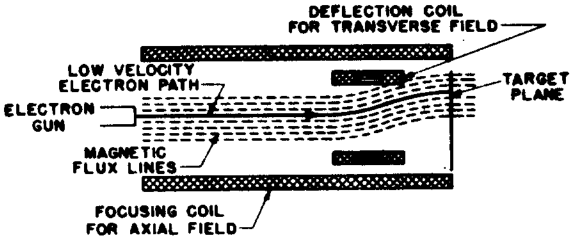
FIGURE 33. THE IMAGE ICONOSCOPE



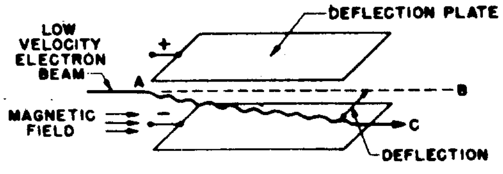
(a) ORTHICON. SIDE VIEW



(a) ORTHICON. TOP VIEW



(b) DISTORTION OF FOCUSING FIELD



(c) ACTION OF DEFLECTION SYSTEM

FIGURE 34. THE ORTHICON AND PRINCIPLES OF THE DEFLECTION SYSTEM

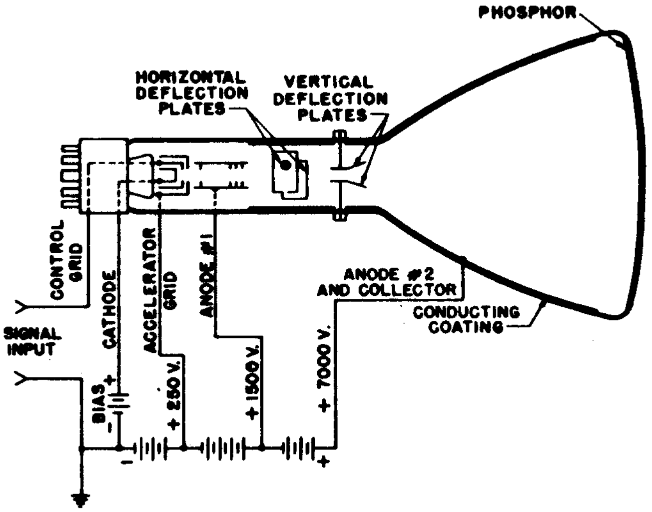


FIGURE 35. ONE TYPE OF PICTURE TUBE USING ELECTRIC FOCUSING AND ELECTRIC DEFLECTION

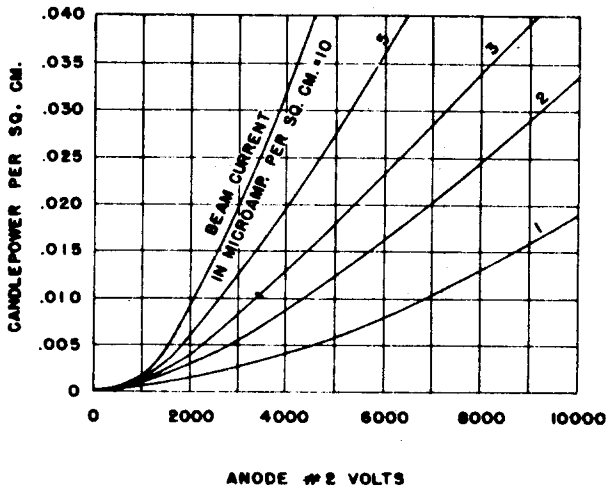


FIGURE 36. RELATIONSHIP OF PHOSPHOR LUMINOSITY TO ACCELERATING VOLTAGE

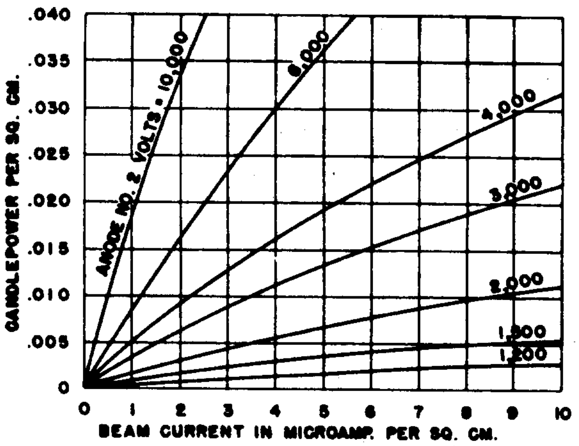


FIGURE 37. RELATIONSHIP OF PHOSPHOR LUMINOSITY TO DENSITY OF BEAM CURRENT

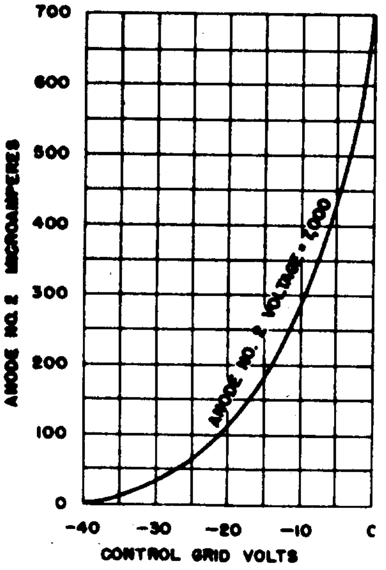
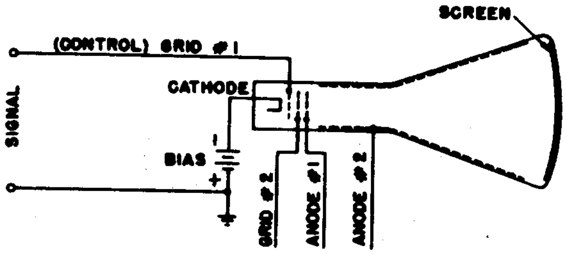
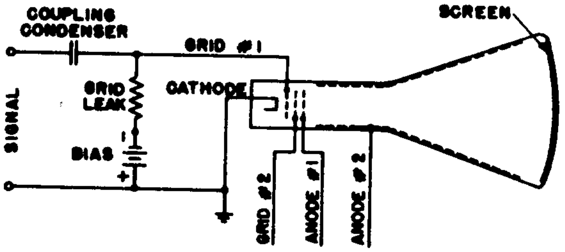


FIGURE 38. RELATIONSHIP OF BEAM CURRENT TO CONTROL GRID VOLTAGE



(a) DIRECT COUPLING



(b) CAPACITIVE COUPLING

FIGURE 39. METHODS OF APPLYING GRID BIAS TO PICTURE TUBE.

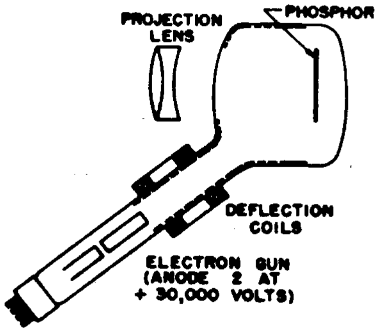


FIGURE 40. HIGH-INTENSITY PROJECTION PICTURE TUBE FOR FRONT-SURFACE VIEWING

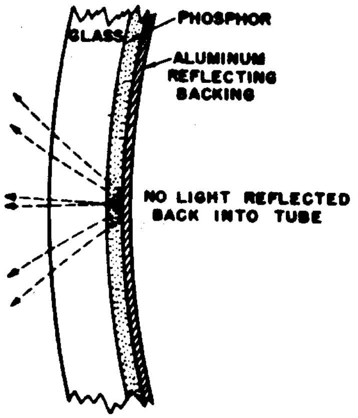


FIGURE 41. INCREASE OF BRIGHTNESS BY REFLECTIVE BACKING

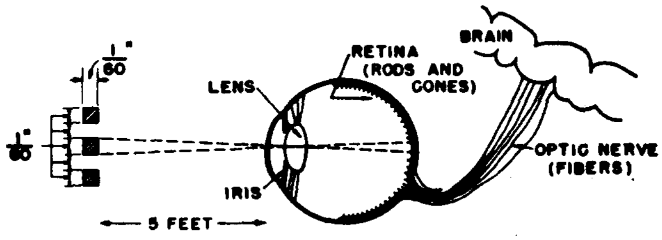


FIGURE 42. HUMAN EYE AS A PARALLEL TELEVISION SYSTEM. RESOLVING POWER.

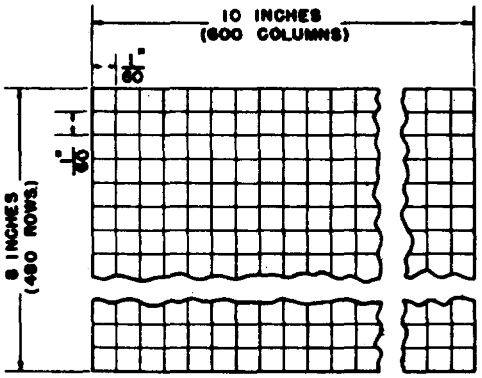
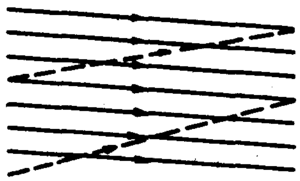


FIGURE 43. A PICTURE OF 288,000 ELEMENTS.



SOLID LINES: ACTIVE SCANNING LINES.
BROKEN LINES: INACTIVE SCANNING LINES.
FLY-BACK TRACES NOT SHOWN.

FIGURE 44. ACTIVE AND INACTIVE SCANNING LINES

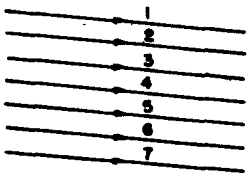
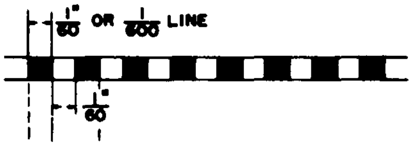
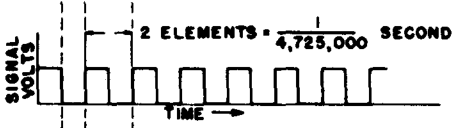


FIGURE 45. SEQUENTIAL SCANNING

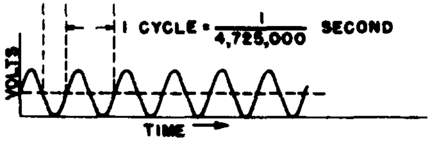
FIGURE 46. INTERLACED SCANNING



(a) ALTERNATE BLACK AND WHITE PICTURE ELEMENTS ON ONE SCANNING LINE

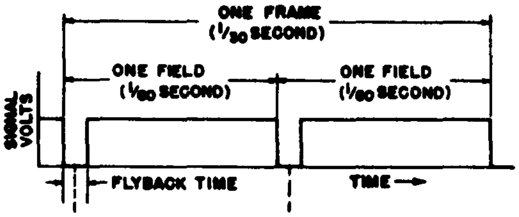


(b) SIGNAL RESULTING FROM SCANNING ABOVE

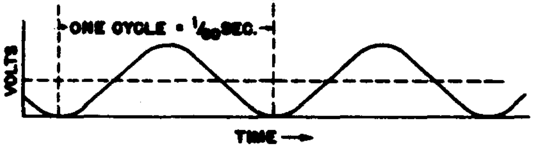


(C) FUNDAMENTAL COMPONENT OF SIGNAL

FIGURE 47. RESULT OF SCANNING FINEST PICTURE DETAIL



(a) SIGNAL RESULTING FROM SCANNING TOTALLY BLANK SCENE



(b) FUNDAMENTAL COMPONENT OF SIGNAL

FIGURE 48. RESULT OF SCANNING COARSEST PICTURE DETAIL

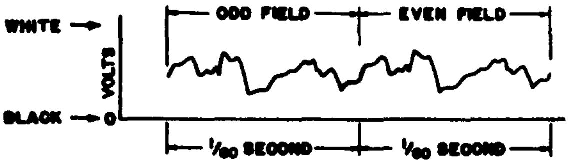
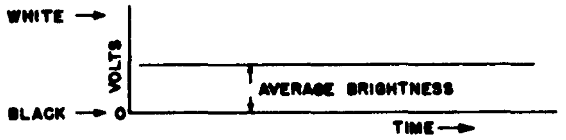
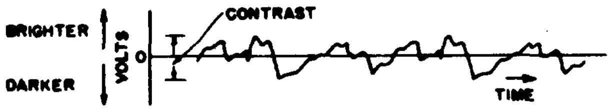


FIGURE 49. TYPICAL CAMERA SIGNAL



(a) DC COMPONENT OF SIGNAL



(b) AC COMPONENT OF SIGNAL

FIGURE 50. BRIGHTNESS AND CONTRAST COMPONENTS OF CAMERA SIGNAL

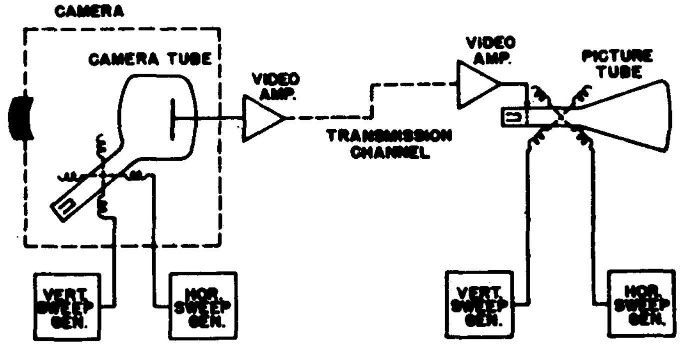


FIGURE 51. SCHEMATIC OF A TELEVISION SYSTEM

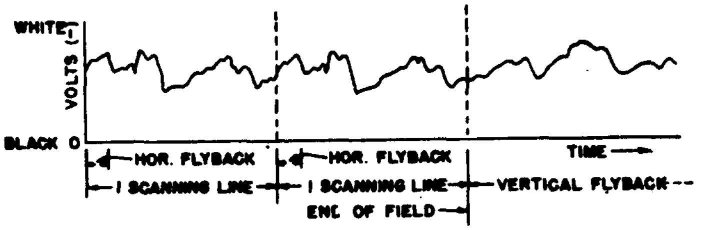


FIGURE 52. CAMERA SIGNAL (IMAGE DISSECTOR)

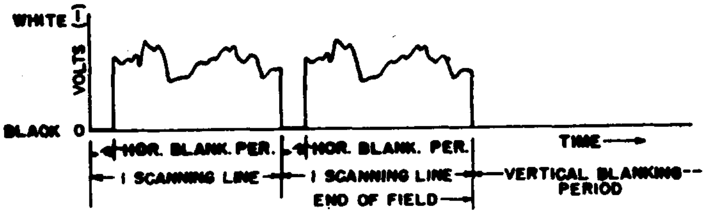


FIGURE 53. CAMERA SIGNAL WITH BLANKING

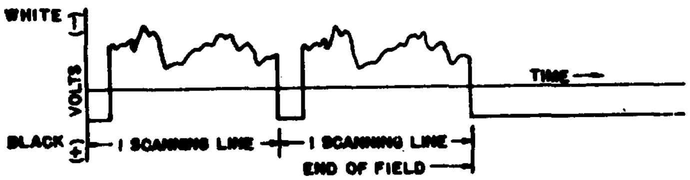


FIGURE 54. CAMERA SIGNAL WITH BLANKING, DC REMOVED

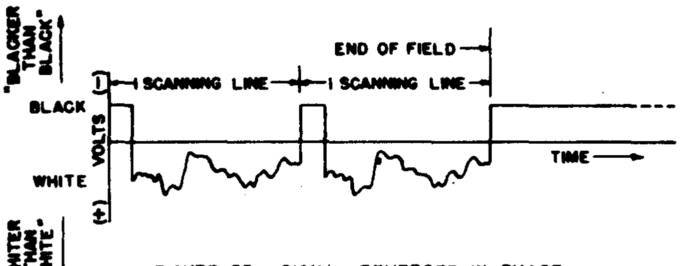


FIGURE 55. SIGNAL REVERSED IN PHASE

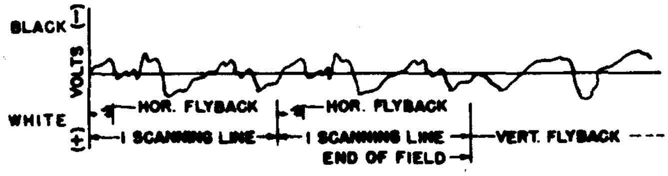


FIGURE 56. CAMERA SIGNAL (ICONOSCOPE)

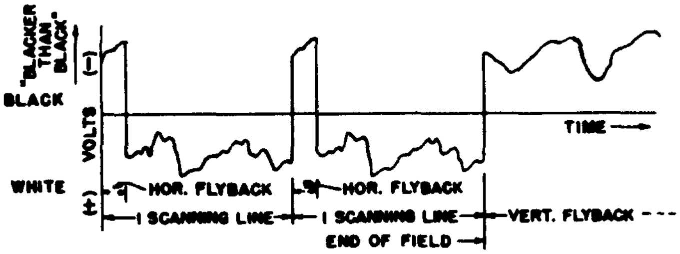


FIGURE 57. CAMERA SIGNAL WITH BLANKING PULSES

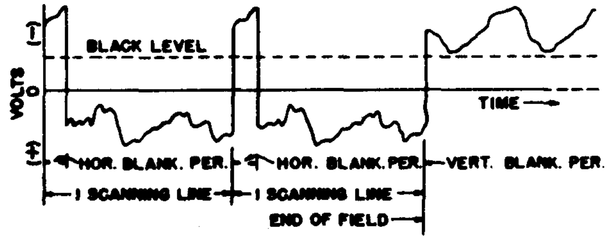


FIGURE 58. SIGNAL WITH BLANKING PULSES. RELATION OF BLACK LEVEL.

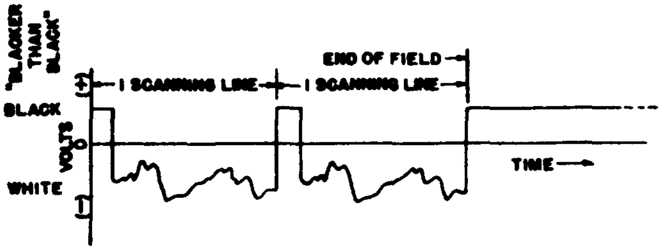


FIGURE 59. SIGNAL WITH BLANKING PEDESTALS. PHASE REVERSED

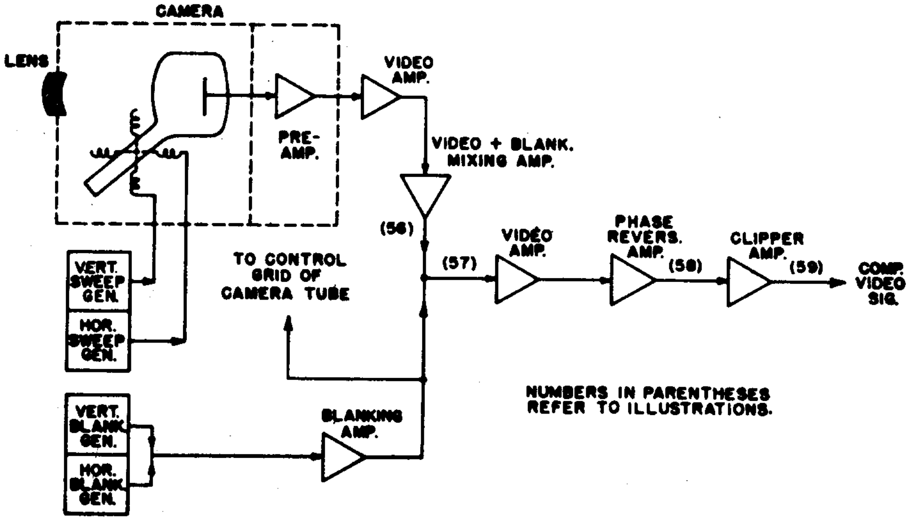


FIGURE 60. SCHEMATIC OF TRANSMITTING TERMINAL.

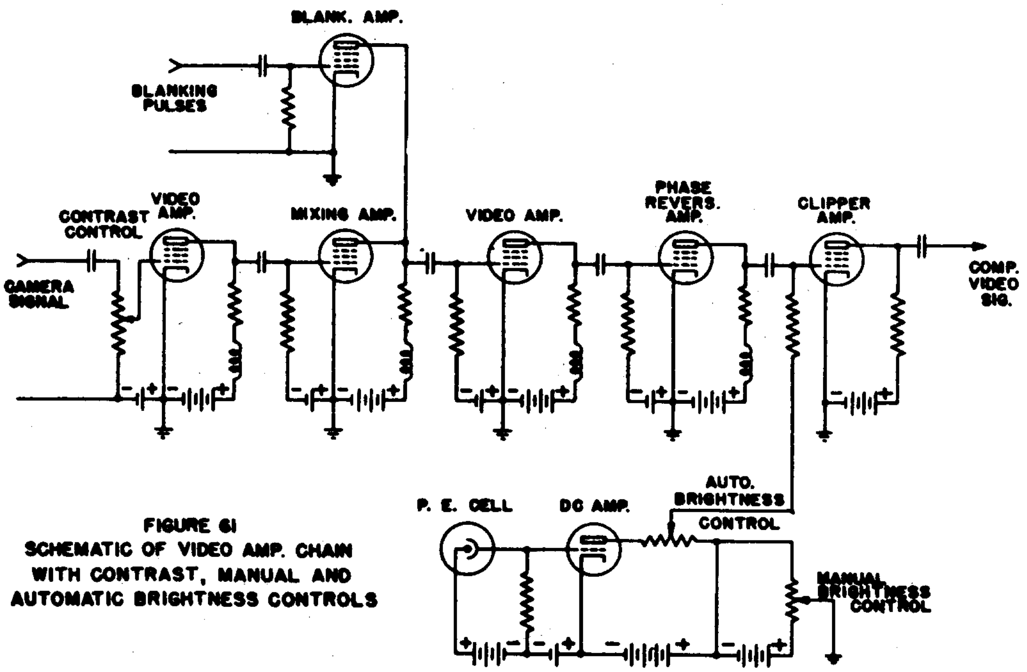
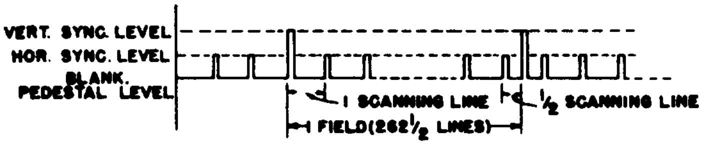
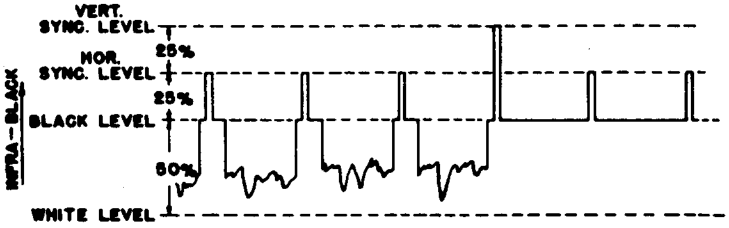


FIGURE 61
SCHEMATIC OF VIDEO AMP. CHAIN
WITH CONTRAST, MANUAL AND
AUTOMATIC BRIGHTNESS CONTROLS



(a) VARIABLE AMPLITUDE SYNC. SIGNAL



(b) COMPOSITE VIDEO SIGNAL WITH VARIABLE AMPLITUDE SYNC. PULSES

FIGURE 62. SYNCHRONIZATION WITH VARIABLE AMPLITUDE SYNC. PULSES

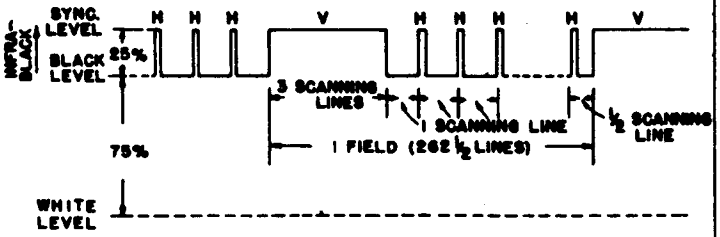
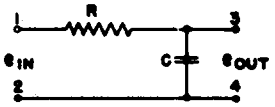
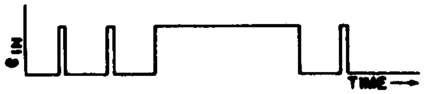


FIGURE 63. VARIABLE WIDTH SYNC. SIGNAL



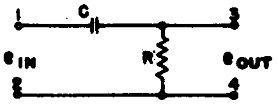
(a) CIRCUIT



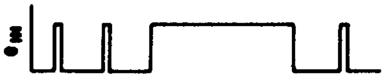
(b) INPUT VOLTAGE

(c) OUTPUT VOLTAGE

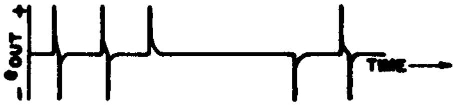
FIGURE 64. INTEGRATOR CIRCUIT



(a) CIRCUIT



(b) INPUT VOLTAGE



(C) OUTPUT VOLTAGE

FIGURE 65. DIFFERENTIATOR CIRCUIT

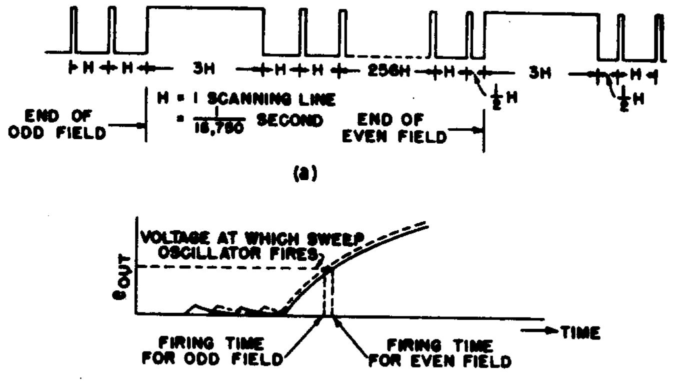


FIGURE 66. EFFECTS OF INTERLACED SCANNING

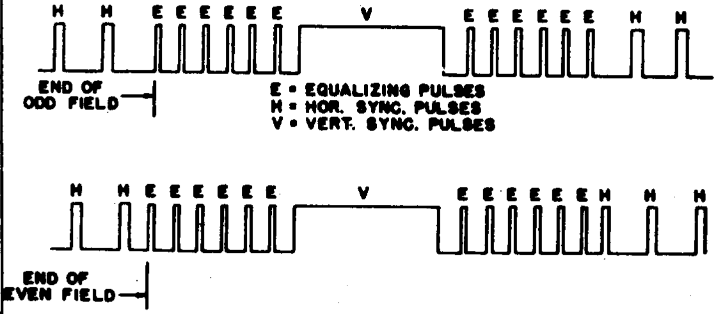


FIGURE 67. EQUALIZING PULSES

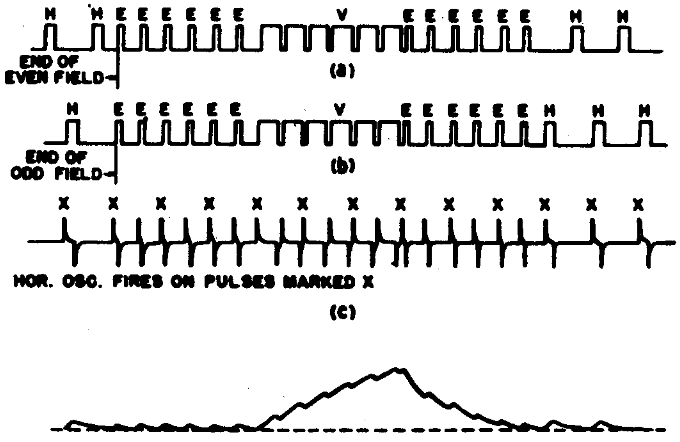


FIGURE 68. (a) AND (b): COMPOSITE SYNC. SIGNAL; (c) DIFFERENTIATOR OUTPUT CORRESPONDING TO (b); (d): INTEGRATOR OUTPUT CORRESPONDING TO (b)

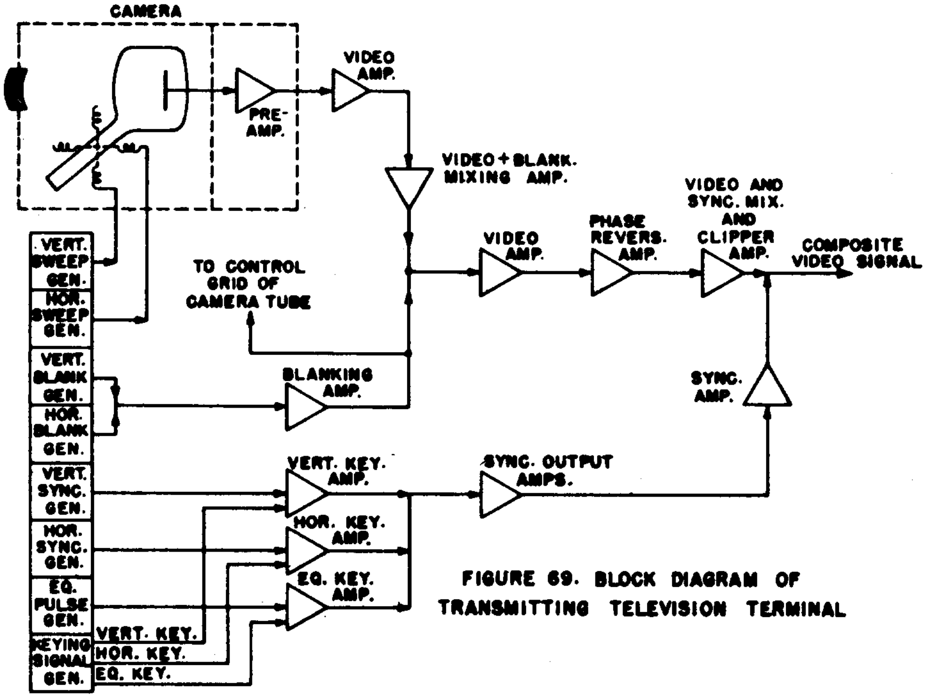


FIGURE 69. BLOCK DIAGRAM OF TRANSMITTING TELEVISION TERMINAL

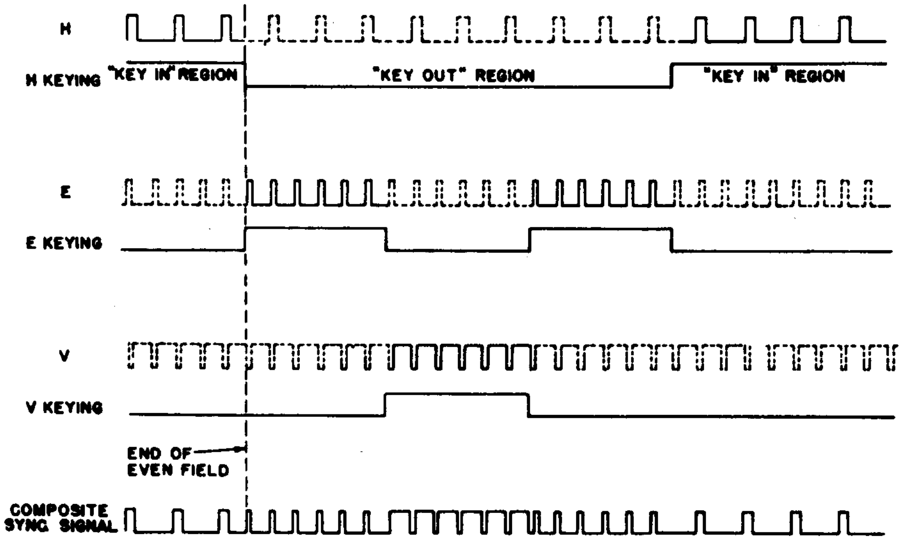


FIGURE 70. SYNTHESIS OF COMPOSITE SYNC. SIGNAL

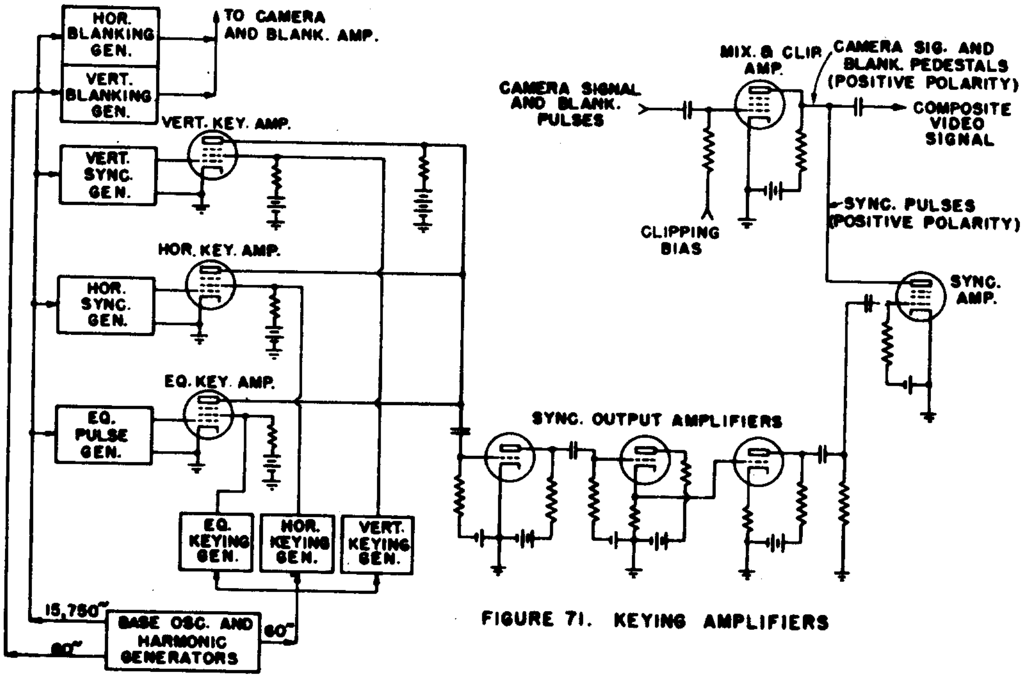


FIGURE 71. KEYING AMPLIFIERS

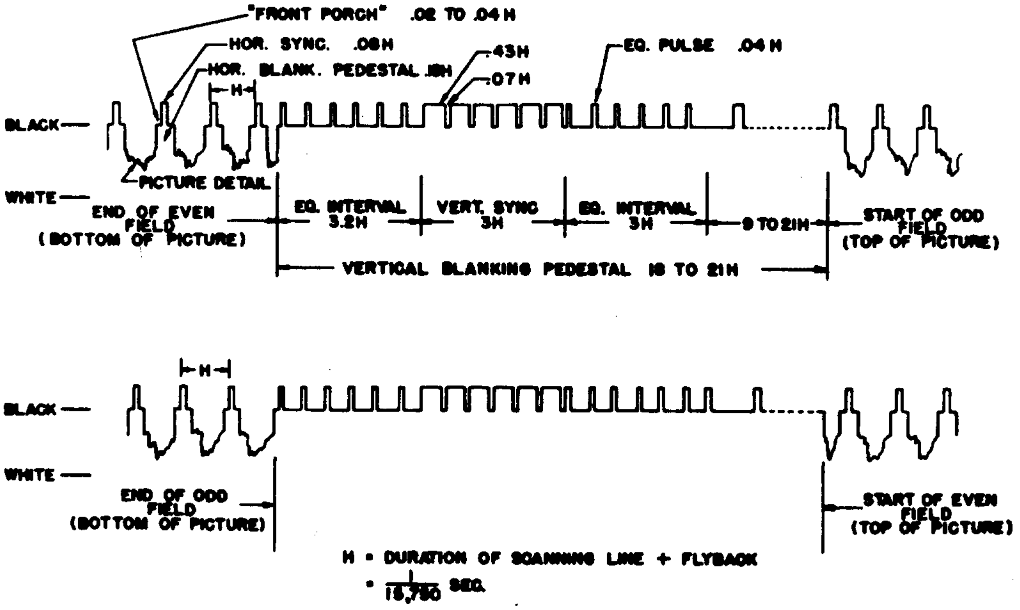


FIGURE 72. STANDARD VIDEO SIGNAL

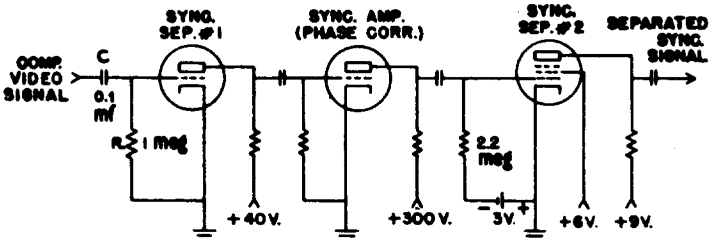


FIGURE 73. TYPICAL SYNC. SEPARATOR

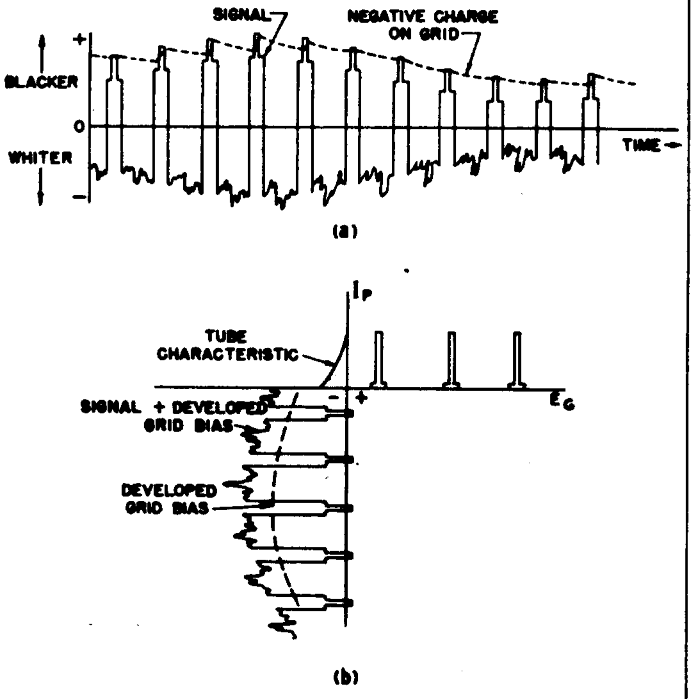


FIGURE 74. (a) DEVELOPMENT OF GRID BIAS IN SYNC SEPARATOR.
(b) ACTION OF SYNC SEPARATOR ON VARIABLE BIAS.

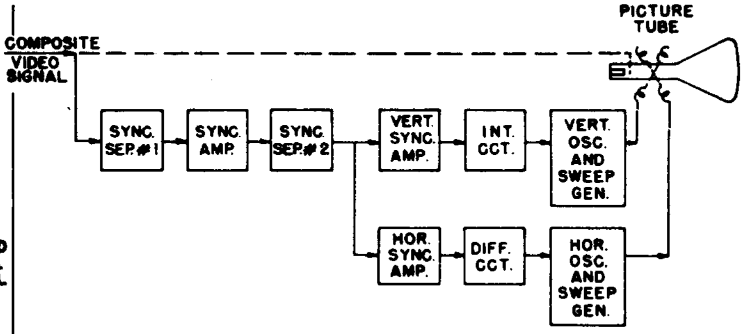


FIGURE 75. SCHEMATIC OF RECEIVING TERMINAL

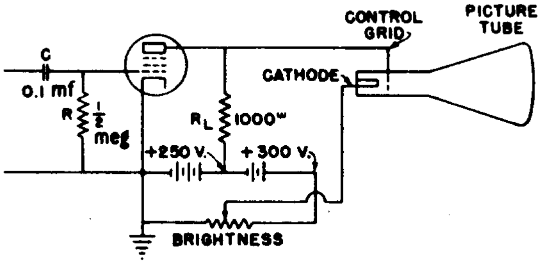


FIGURE 76. ONE TYPE OF DC RESTORER

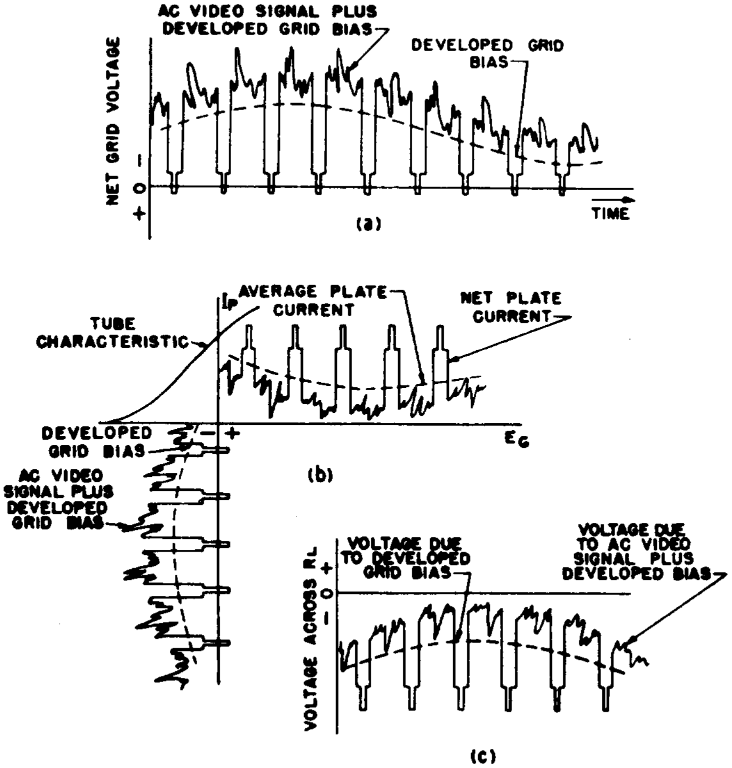


FIGURE 77. ACTION OF A DC RESTORER

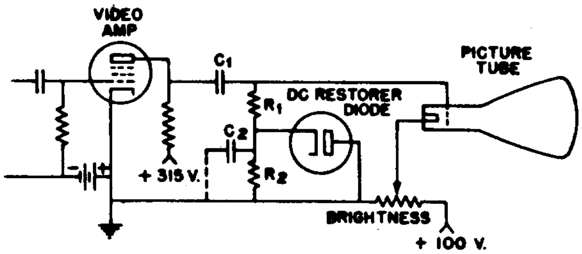


FIGURE 78. ANOTHER TYPE OF DC RESTORER

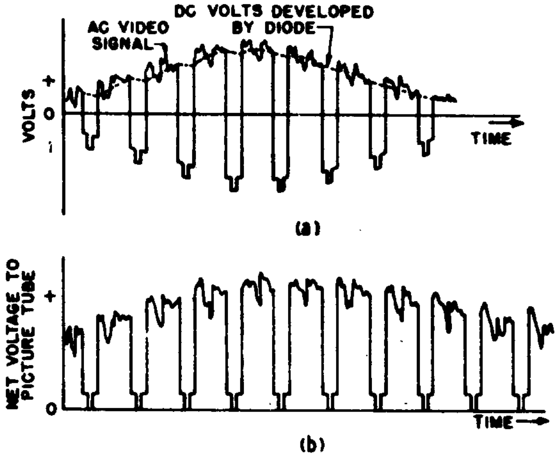


FIGURE 79. ACTION OF DC RESTORER DIODE

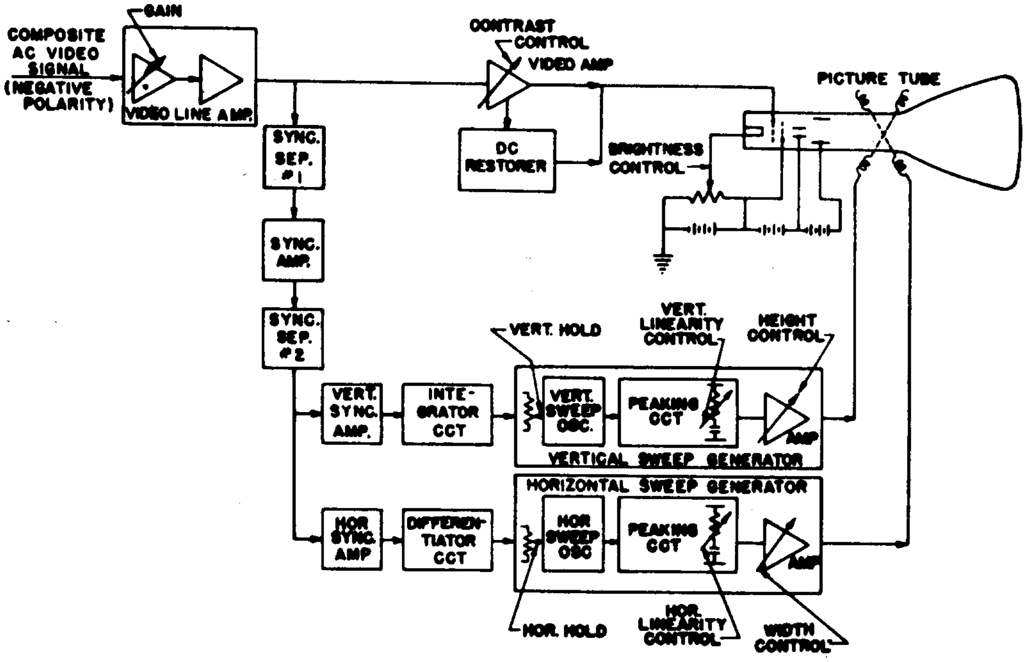


FIGURE 80. BLOCK DIAGRAM OF RECEIVING TELEVISION TERMINAL