DESCRIPTION OF AN EXPERIMENTAL TELEVISION SYSTEM AND THE KINESCOPE

BY

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Summary—*A general description is given of an experimental television system using a cathode ray tube (kinescope) as the image reproducing element in the receiver. The fundamental considerations underlying the design and use of the kinescope for television are outlined. A description of the circuits associated with the kinescope and an explanation of the application to an experimental receiver are included.*

INTRODUCTION

THE experimental television system placed in operation by RCA Victor in New York late in 1931, and on which practical tests were made during the first half of 1932, was based on the use of a cathode ray tube as the image reproducing element in the receiver. This allowed the use of a system with 120 scanning lines and a frame repetition frequency of 24 per second with adequate illumination for the reproduced image.

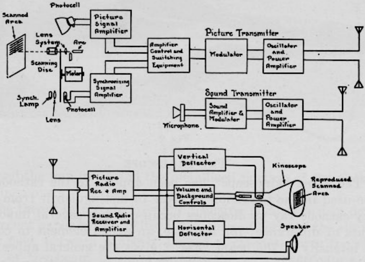

Fig. 1

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A block diagram of the system is shown in Fig. 1, where the components and their location in the system are indicated. Naming the units in order, we have for television from the studio: The photo-electric tubes, the flying spot scanning equipment, the picture signal and synchronizing signal amplifiers, the control and switching equipment, and the modulating and radio transmitter equipment. The units comprising the television receiver are: An antenna system feeding two radio receivers, one for sight, including the cathode ray unit with its associated horizontal and vertical deflecting equipment, and the other for sound, including the usual loud speaker.

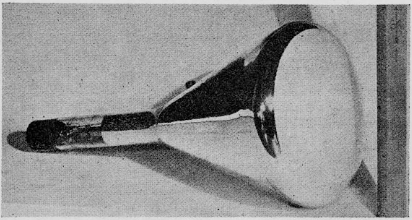

Fig. 2

THE KINESCOPE

The name "kinescope" has been applied to the cathode ray tube used in the television receiver to distinguish it from ordinary cathode ray oscilloscopes because it has several important points of difference; for instance, an added element to control the intensity of the beam. Fig. 2 gives the general appearance of the tube which has a diameter of 9 inches, permitting a reproduced image of approximately $5\frac{1}{2}\times6\frac{1}{2}$ inches. Fig. 3 is a cross-section view of one of these tubes, showing the relative position of the electrodes, especially the cathode and its surrounding assembly, which is usually referred to as the "electron gun." The indirectly heated cathode, *C*, operates on alternating current. Its emitting area is located at the tip of the cathode sleeve and is formed by coating with the usual barium and strontium oxides. The control electrode, corresponding to the grid in the ordinary triode, is shown at G. It has an aperture, O, directly in front of the cathode emitting surface, and besides functioning as the control element it also serves as a shield for the cathode.

The first anode, A_1, has suitable apertures which limit the angle of the emerging electron beam. The electron gun is situated in the long, narrow neck attached to the large cone-shaped end of the kinescope, the inner surface of the cone being silvered or otherwise metallized, and serves as the second anode. The purpose of the second anode, A_2, is to accelerate the electrons emerging from the electron gun and to form the electrostatic field to focus them into a very small, thread-like beam. The first anode usually operates at a fraction of the second anode voltage.

The focusing is accomplished by an electrostatic field set up by potential differences applied between elements of the electron gun and the gun itself and the metallized portion of the neck of the kinescope.

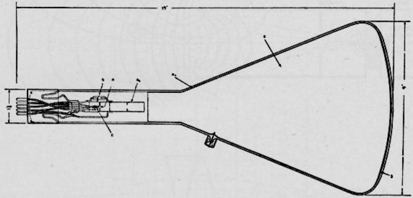

Fig. 3

The theory of the electrostatic focusing is described in detail in a recent paper by the writer.[1] The lines of force of the electrostatic field, between properly shaped electrodes, force the electrons of the beam to move toward the axis, overcoming the natural tendency of electrons to repel each other. This action is analogous to the focusing of light rays by means of optical lenses. The electrostatic lenses, however, have a peculiarity in that their index of refraction for electrons is not confined to the boundary between the optical media, as in optics, but varies throughout all the length of the electrostatic field. Also, it is

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[1] V. K. Zworykin, *Jour. Frank. Inst.*, pp. 535-555, May, (1933).

almost impossible to produce a simple single electron lens; the field always forms a combination of positive and negative lenses. However, by proper arrangement of electrodes and potentials, it is always possible to produce a complex electrostatic lens which will be equivalent to either positive or negative optical lenses.

The distribution of electrostatic fields in the electron gun of the kinescope is shown on Fig. 4. In this particular case, the total action of fields on electrons is equivalent to a combination of four lenses, as is shown in the same figure.

The first two lenses force the electrons through the apertures of the first anode and assure the desired control of the beam by the control element *G*. The final focusing of the beam on the screen is accomplished by the second pair of lenses created by the field between the end of the gun and the neck of the bulb. Thus, the final size of the spot on the screen, as in its optical analogue, depends chiefly on the size of the active area of the cathode and the optical distances between the cathode, lenses, and the fluorescent screen.

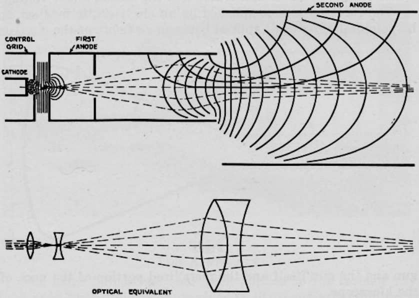

Fig. 4

The velocity of the beam is expressed by the equation

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

where v = beam velocity in centimeters per second and V is the second anode voltage. For $V = 4500$ volts, as used in kinescopes, the beam velocity is somewhat greater than one tenth that of light.

After leaving the first anode, the focused, accelerated beam impinges upon the fluorescent screen deposited upon the flat end of the conical portion of the kinescope. The fluorescent screen serves as a transducer, absorbing electrical energy and emitting light. Thus there is produced a small bright spot on the screen, approximately equal in area to the cross section of the beam. The fluorescent screen is very thin, so a large portion of the emitted light is transmitted outside of the tube as useful illumination.

In order to reproduce the light intensity variations of the original picture, it is necessary to vary the intensity of the spot of light upon the fluorescent screen. This is accomplished by means of the control element, *G*, of the electron gun. For satisfactory reproduction, the control of the electron beam intensity should be a linear function of the input signal voltage. Furthermore, it is very essential that during the exercising of this control the sharp focusing of the spot shall not be destroyed. Still

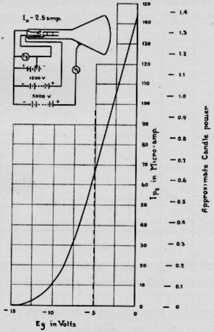

Fig. 5

another requirement is that this control will not affect the velocity of the electron beam because the deflection of the beam is inversely proportional to its velocity, and, therefore, a slight change due to picture modulation would disturb the image, making the bright lines shorter and the darker lines longer. As a result of careful design, the variation of velocity of the beam (from complete cut-off to full brilliancy) in the kinescope is so small as to be unnoticeable to the observer of the picture.

The characteristic curve of the kinescope is shown in Fig. 5. From this it will be seen that an input of 10 volts alternating current will give practically complete modulation (i.e., a change from maximum to minimum brilliancy) of the cathode ray beam. The shape of this curve gives the proportionality between input voltage and second anode current and corresponding brightness of the spot. (It is to be noted that the values of current, voltage, illumination, etc., given on Fig. 5, and all figures in this report, are illustrative rather than specific values for a particular type of cathode ray kinescope tube.) By referring to Fig. 6, which shows a graph of the relation of second anode current to the light emitted from the fluorescent screen, it will be noted that a linear proportionality exists. Therefore, we can draw the conclusion that a television picture, varying in shade from black

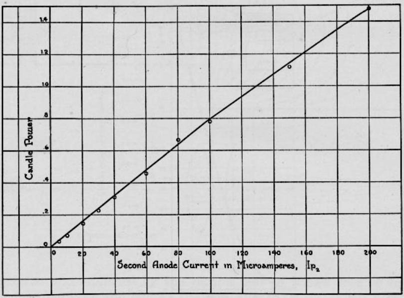

Fig. 6

to white, will have accurately reproduced all the intermediate shadings necessary for good half-tone pictures.

If we inspect the fluorescent spot by means of an enlarged photograph, we find that the light intensity is not uniform. When measured for a stationary spot, enlarged fifty times, the curve obtained from densitometer observations (see Fig. 7) shows that the light intensity increases toward the center of the spot. The actual diameter of the spot was 2 millimeters. During the scanning of a picture, when the spot is in motion, the light intensity per square unit of screen decreases proportionately to the scanned area. Therefore the edges of the spot, being less luminous, disappear and the apparent size of the spot decreases. This explains the fact that the diameter of the static spot is larger than the value calculated by dividing the picture height by the number of scanning lines. The photograph of the spot also shows why black spaces between the scanning lines of the received picture may be noticed upon close observation. This is caused by the differences in light intensity between the center and the edges of the spot.

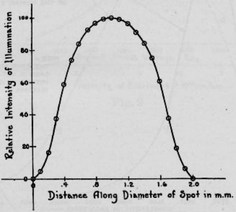

Fig. 7

The material used for the fluorescent screen is a synthetic zinc orthosilicate phosphor almost identical with natural willemite. Zinc orthosilicate phosphor was chosen because of its luminous efficiency, its short time lag, its comparative stability and its resistance to "burning" by the electron beam. The good luminous efficiency is due to the fact that the light, green in color, emitted by the zinc orthosilicate phosphor lies in the visible spectrum in a narrow band peaked at 5230A, close to the wavelength of maximum sensitivity of the eye (5560A) as shown in

Fig. 8. The luminous efficiency of incandescent tungsten lamps ranges from 2.5-4.0 per cent[2] whereas the zinc orthosilicate phosphor has an efficiency of 1.8-2.7 per cent when expressed on the basis of lumens per watt, assuming 690 lumens per watt as the maximum theoretical efficiency.[3] Fig. 9 shows candle power plotted against second anode voltage and Fig. 6 shows candle power plotted against current carried by the electron beam for the cathode excitation of zinc orthosilicate phosphor. The general relation between candle power, applied voltage, and current intensity for phosphors excited by cathode rays is given by the equation:[4]

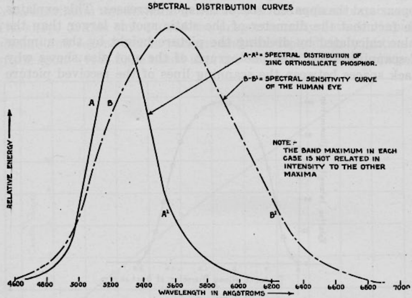

Fig. 8

$$I = AQ(V - V_0)$$

I = the intensity of emitted light in candle power.
A = a constant characteristic of the phosphor.
Q = the current intensity in the beam in amperes per cm.[2]
V = the applied voltage (in volts).
V_0 = the extrapolated minimum exciting voltage (in volts) (a constant for each phosphor).

[2] Forsythe and Watson, *Jour. Frank. Inst.*, vol. 213, no. 6; June, (1932).

[3] A. Schloemer, "Kathodenoszillograph und Leuchtmasse," *Zeit. für Tech. Physik*, vol. 13, no. 5, (1932).

[4] Wien-Harms, "Handbuch der Experimentalphysik," part 1, ch. 23, p. 158.

Fig. 10 shows the time decay curve of the zinc orthosilicate phosphor luminescence. The decay curve shows that at the end of approximately 0.06 second practically all visible luminescence has ceased. For reproducing 24 pictures per second, the decay curve of the ideal phosphor should be long enough so that the phosphor just loses its effective brilliancy at the end of 1/24th of a second. If the time of decay is too long, the moving portions of the picture will "trail," as, for instance, the path of a moving baseball would be marked by a comet-like tail. If the time of decay is too short, flicker is noticeable because of the space of comparative total darkness between the times when the fluorescent material is excited between successive pictures.

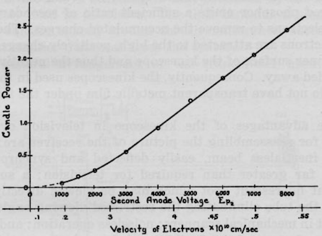

Fig. 9

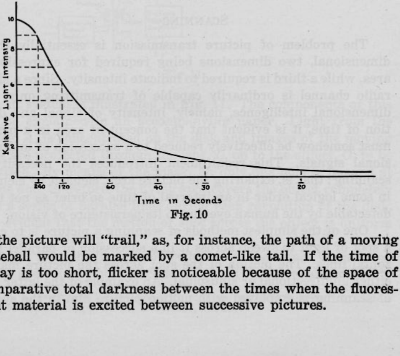

Fig. 10

When the electron beam strikes the fluorescent screen, the screen would acquire a negative charge, which, because of the good dielectric properties of the phosphor, would remain on the surface and act as a repulsive force upon the electron beam and may completely repulse the beam from the screen, thus stopping the light emission. To remove this charge, we used to have a half-transparent, metallic film between the end of the kinescope tube and the fluorescent screen. Later, we found that a properly prepared phosphor emits a sufficient ratio of secondary to primary electrons to remove the accumulated charges. The secondary electrons are attracted to the high, positively-charged, metallized inner surface of the kinescope and thus the negative charge is carried away. Consequently, the kinescopes used in this equipment do not have transparent metallic film under the fluorescent screen.

The advantages of the kinescope in television over other means for reassembling the picture of the receiver are: the use of an inertialess beam, easily deflected and synchronized at speeds far greater than required for television; a sufficiently brilliant fluorescent spot which may be viewed directly on the end of the tube eliminating the restricted viewing angle usually present in mechanical scanners; noiseless operation; and the outstanding feature of the flexibility of the cathode ray tube itself.

SCANNING

The problem of picture transmission is essentially three-dimensional, two dimensions being required for expression of area, while a third is required to indicate intensity. Since a single radio channel is ordinarily capable of transmitting only two-dimensional intelligence, namely, intensity of signal and duration of time, it is evident that the concept of area in a picture must somehow be effectively reduced to a succession of undimensional signals. This requirement introduces the necessity of scanning; that is, exploring the picture area, element by element, in some logical order in an interval of time so brief as not to be detectable by the human eye due to its persistence of vision.

One of the simplest methods of scanning a picture is to cause a spot of light to sweep across it in a succession of parallel horizontal lines. The motion of the spot across the picture may be either unidirectional or sinusoidal. An example of the latter type of scanning is employed with motion picture film in the system described in an earlier paper.[5] At the transmitter this was accomplished by means of a galvanometer mirror which reflected the scanning beam onto the continuously moving film. In the cathode ray receiver this kind of motion is easily duplicated by deflecting the beam by a magnetic field produced by a sinusoidal current identical with the one energizing the galvanometer. This was superseded by unidirectional scanning. An example of unidirectional motion in scanning is that produced by the Nipkow disk widely used in television. The disk contains a single row of holes equally spaced around the circumference, successively spaced at smaller distances from the center.

The general arrangement of the transmitter used in the

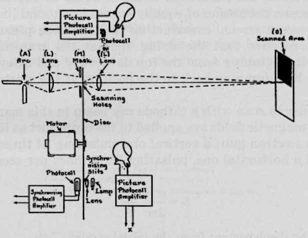

Fig. 11

present system is illustrated in Fig. 11. The components of this will be explained in an accompanying paper. Light from the source, *A*, is concentrated on the disk and images of the moving holes are projected through the lens, *L*, on to the object, *O*, to be televised. By means of the mask, *M*, only one hole is imaged at a time and, therefore, the flying spot covers the object completely with a series of parallel lines during each revolution of the disk. It is evident that the motion of spot across the object is uniform and in one direction only.

Light from the flying spot, reflected by the object, is gathered into a system of photo-electric cells and thus transformed into

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[5] V. K. Zworykin, "Television with cathode ray tube for receiver," *Radio Eng.*, vol. 9, no. 12, pp. 38-41; December, (1929).

electrical impulses. These impulses, amplified, serve to modulate the output of the radio transmitter.

In televising moving picture film, the spiral row of scanning holes is replaced by a circular row, the vertical component of scanning being supplied by motion of the film, itself, passing the scanning line with a constant velocity. Here, as before, the flying spot explores the entire picture in a series of parallel lines, the light being transmitted directly through the object into a photocell situated behind the film.

In the experimental system described, the picture is made up of 120 lines and is transmitted at the rate of 24 per second. The picture has a 5-to-6 ratio of vertical to horizontal dimensions, and, therefore, the horizontal detail is equal to 144 lines. The beam traces a succession of equally spaced horizontal lines across the fluorescent screen, constructing the television picture in the identical manner that the flying spot at the transmitter has scanned it, beginning from the top downward and after the last, or 120th line, jumping back to the position at the start of a new picture.

In order to scan with a cathode ray beam in this manner, two variable magnetic fields are applied to the beam just as it emerges from the electron gun; a vertical one, pulsating 24 times per second, and a horizontal one, pulsating 2880 times per second.

$$\delta_1 = \frac{evB}{2m}\,\frac{l^2}{v^2}$$

$\delta_1 =$ the displacement from the initial straight line.
$e =$ the charge on the electron.
$m =$ the mass of the electron.
$B =$ the intensity of the magnetic field.
$l =$ the length of path in the magnetic field.
$v =$ the velocity of the electron.

(All quantities expressed in electromagnetic and c.g.s. units.)

δ_2, the further displacement, during the time necessary to traverse the path from the magnetic field to the screen $= evBlL/mv^2$. The total displacement is given by

$$\delta = \delta_1 + \delta_2 = \frac{e}{m}\,\frac{Bl}{v}\left(\frac{l}{2} + L\right)\text{ cm}$$

$L =$ the distance from the deflecting magnetic field to the fluorescent screen.

When an electron beam passes through a magnetic field it is deflected in a direction normal to the magnetic lines of force according to the well-known equation[6]

In order that the cathode beam at the receiver follow the unidirectional scanning at the transmitter, the variation of intensity of both horizontal and vertical deflecting fields plotted against time is of a "saw-tooth" shape, as shown in Fig. 12. Each cycle consists of two parts; the first, linear with respect to time and lasting practically the whole cycle, and the second, or return period, lasting only a small fraction of the cycle. The picture is reproduced during the first part of the scanning period by varying the bias of the control element according to the light intensities of the transmitted picture, as described above.

There are a number of methods that will produce "saw-tooth"-shaped electrical impulses. A simple one has been described in an earlier paper,[5] consisting of charging a condenser through a current limiting device such as a saturated two-electrode vacuum valve and then discharging the condenser through a thermionic or gas-discharge tube. The practical limitation of this "saw-tooth" generator lies in the fact that there is no such thing as a completely saturated thermionic tube. Therefore, the condenser cannot be charged exactly linearly with time, and, consequently,

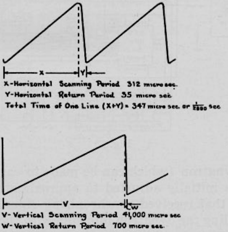

Fig. 12

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[6] J. T. Irwin, "Oscillographs," Isaac Pitman and Sons, Ltd., London, (1925).

the line reproduced on the fluorescent screen will be not exactly straight.

In order to straighten the scanning lines and improve the quality of the reproduced picture, a more complicated circuit was used, involving one dynatron oscillator and two amplifying tubes, as shown in Fig. 13. The condenser, *C*, in the horizontal deflecting circuit is charged continuously through the resistance, *R*. Periodically, at the end of predetermined intervals, the condenser is discharged. During these intervals, the accumulated charge does not reach saturation value, for the time (1/2880 of a second) is insufficient. The vacuum tube through which the discharge takes place is controlled by impulses supplied from a dynatron oscillator having a distorted wave shape. The frequency of oscillation of the dynatron (which can be made to vary over a fairly wide range) is initially adjusted to approximately 2880 cycles per second, so that received synchronizing signals will have no difficulty in pulling the dynatron into step with the synchronizing impulses generated by the transmitter scanning disk, as explained later. The charging and discharging of condenser, *C*, represent saw-tooth variations of potential, which, when applied to the grid of an amplifying tube, produce saw-tooth current impulses in deflecting coils connected in the plate of the amplifier.

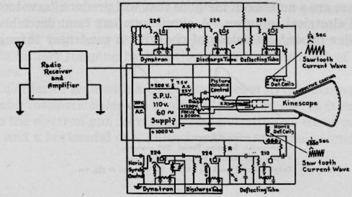


Fig. 13

The vertical deflecting circuit is similar to the horizontal circuit just described. Both vertical and horizontal deflecting systems operate on the beam by the magnetic fields generated by coils placed about the neck of the cathode ray tube.

The choice of electromagnetic deflection in preference to electrostatic was made more as a result of economical consideration than mechanical choice. The kinescope for electromagnetic deflection is much cheaper to make than the one equipped with inside deflecting plates for electrostatic deflection. On the other hand, the electromagnetic deflecting unit itself requires more power and is more costly to build than the electrostatic one. The predominance of one or more factors depends chiefly upon the frequency of deflection and velocity of the beam.

The constants of the electrical circuits for vertical and horizontal deflection are, of course, entirely different, due to the great difference in the operating frequencies of the two deflection circuits.

SYNCHRONIZATION

When both deflecting circuits are properly adjusted and synchronized with the transmitter, a pattern consisting of 120 parallel lines is seen on the fluorescent screen. The sharpness of the pattern and perfection of its synchronization with the transmitter determines to a large extent the quality of the reproduced picture. This pattern is transformed into the picture by apply-

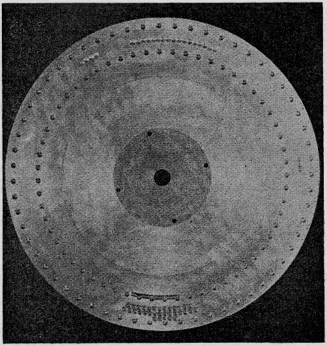


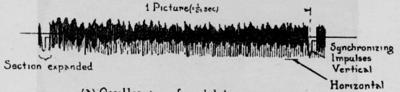
Fig. 14

ing the picture signal impulses from the transmitter to the control element of the kinescope, so as momentarily to vary the brilliancy of the spot.

For sending synchronizing impulses, the transmitting scanning disk has an auxiliary row of slits, one for each scanning aperture. (See Fig. 14.) These slits, together with a separate illuminating lamp and photocell, produce impulses, one at the end of each line and at the end of each picture frame. The synchronizing impulses are transmitted over the picture signal channel. They do not interfere with the picture signals, because they occur at an instant when the picture actually is not being transmitted.

To allow the transmission of horizontal synchronizing signals at a time when the beam at the receiver is returning to start a new horizontal trace, the generation of picture signals is cut off for ten per cent of the scanning time. This is done by simply spacing the scanning disk apertures ten per cent farther apart than the width of the scanned frame. Vertical synchronization is carried out in the same manner, synchronizing impulses for this purpose being transmitted at the completion of each frame.

There is considerable advantage gained from using a synchronizing system in which the beam at the receiver is brought into step with the transmitter at the end of each horizontal line because momentary disturbances of the nature of static do not appreciably affect the picture.



(a) Oscillogram of modulator signal
(One full picture with synchronizing)

Fig. 15

It will be seen that the transmitter is modulated by picture, horizontal synchronizing, and vertical synchronizing signals. The resulting composite signal which is fed to the modulator grid, therefore, appears as shown in Fig. 15. A clearer view of the components of this composite signal can be gathered from Fig. 16, the top curve of which represents the irregular-shaped picture signals which are often unsymmetrical about the axis, usually more positive than negative. Both synchronizing signals are arranged to have their peaks on the negative side of the axis. The difference in shape of the horizontal and vertical impulses, of course, is due to the shape of the corresponding openings in the scanning disk, and this difference in wave shape is utilized at the receiver for the purpose of separating these two synchronizing impulses. The three signals mentioned above differ in frequency and in amplitude, since the horizontal synchronizing impulses occur at a rate of 2880 per second, the vertical impulses 24 times a second and the picture signals at a widely varying rate. The peak picture signal amplitude is carefully adjusted to be always less than the horizontal and vertical impulses, the amplitude of the latter being approximately equal.

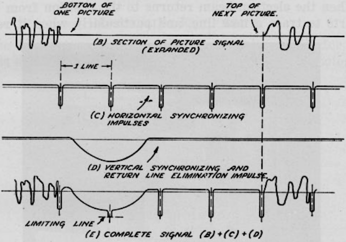


Fig. 16

The separation of the three signals at the receiver is accomplished by a very simple means which is described in detail in an accompanying paper, so that the fundamentals only will be mentioned here. If we trace the signals at the receiver from the antenna through the radio receiver and amplifier, shown in Fig. 13, we find that they are applied to three independent units, the vertical deflecting system, the horizontal deflecting system, and the input to the kinescope. The synchronizing impulses do not affect the picture on the kinescope because they are transmitted at a time when the cathode ray beam is extinguished, that is, during its return period. The picture signals do not affect the deflecting circuits because amplitude selection is utilized; that is, the amplitude of the picture signals is never sufficient to affect the input tubes of either deflecting system. The selection between vertical and horizontal synchronizing impulses is made on the basis of wave shape selection. A simple filter in each of the input circuits of the two deflecting units gives satisfactory discrimination against undesired synchronizing impulses. The plate circuits of both dynatron input tubes contain circuits approximately resonant to the operating periods of their respective deflecting circuits, thus aiding in the matter of selectivity.

When the electron beam returns to the position from which it starts to trace a new line, and particularly when it returns from the bottom of the picture to start a new frame, an undesirable light trace, called the return line, is visible in the picture. To eliminate this the synchronizing impulses which are in the negative direction are applied to the control electrode of the kinescope, so as to bias it negatively and thus eliminate the return line by extinguishing the beam during its return.

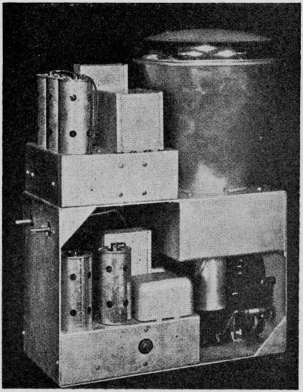


Fig. 17

To produce a picture, the intensity of light on a fluorescent screen is varied by impressing the picture signal on the kinescope control element. If the bias adjustment on the kinescope is set so that the picture signals have the maximum swing on the characteristic curve of the kinescope (shown in Fig. 5) a picture with optimum contrast is produced. The picture background, or the average illumination of the picture, can be controlled by the operator by adjusting the kinescope bias.

REPRODUCING EQUIPMENT

The arrangement of the television receiver built for these tests is shown in Figs. 17 and 18. The former is a photograph of the chassis containing the deflecting unit and kinescope. This chassis slides as a unit into the cabinet. Fig. 18 is a photograph of the complete receiver which contains a power unit, kinescope unit, two radio receivers—one for picture and one for sound signals—and a loud speaker.

Fig. 18

The reproduced image is viewed in a mirror mounted on the inside lid of the cabinet. In this way the lid shields the picture from overhead illumination. This method also affords a greater and more convenient viewing angle. The brilliancy of the picture is sufficient to permit observation without the necessity of completely darkening the room. Since this type of television receiver has no moving mechanical parts it is quiet in operation.

The operations to be performed in tuning such a receiver are as follows: After the power switch is turned on, the picture and sound receivers are tuned to their respective signals in the ordinary manner. Next, the picture "volume" control (radio sensitivity control) is increased to that point at which the picture locks into synchronism. Then the signal voltage (picture-frequency amplification) to the kinescope is adjusted to the best operating point determined by observation. The background control is adjusted to the desired value depending upon the type of picture being transmitted.