THE TELEVISION SIGNAL

Finish

49RH-4

NATIONAL RADIO INSTITUTE

WASHINGTON, D. C.

ESTABLISHED 1914

PIONEER HOME STUDY RADIO SCHOOL

STUDY SCHEDULE NO. 49

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

THE TELEVISION SIGNAL

YOU are now beginning your special training in the field of television. This first Lesson will give you an understanding of modern television, showing how it is possible to see on the screen of a picture tube in a receiver a scene that is at that same instant taking place miles away and being viewed by the television camera.

In the NRI Television Lessons you will find presented in a simple, logical, and understandable manner the important principles underlying all phases of modern television systems. After mastering these Lessons you will find it easy to understand the operation of any TV set. Then you will learn how to service TV sets. You will learn the basic techniques employed, and the difference between servicing broadcast receivers and servicing TV receivers. You will also be shown how to make installations and you will instruct the customer in the operation of his receiver.

Photograph above, courtesy RCA.

THE TV CARRIER SIGNAL

The process of scanning that breaks up a televised scene into successive signal elements results in a frequency range for picture signals of from zero to more than 4,000,000 cycles (4 megacycles, abbreviated 4 mc.) per second. Thus the television signal covers more space in the radio spectrum than the entire broadcast band. For this reason only very-high frequency carriers are suitable for transporting through space a signal that has a frequency range of over 4 megacycles. With ordinary modulation practices, such as are used in the broadcast band, this means that the frequency range of each TV station would be over 8 megacycles. However, by partially suppressing one side band, this range is reduced to less than 6 megacycles and each station is allocated a channel 6 megacycles wide.

Consistent television reception at greater-than-line-of-sight distances is now definitely a reality. This was considered impossible for many years by most engineers as well as by the Federal Communications Commission. The general theory was that the signals traveled in a straight line and that once line-of-sight distances had been exceeded, signals dropped off in strength so rapidly that they were not usable. The fact that these signals travel in a straight line is correct, but the point that was generally overlooked was that refractions (bending of the signals) occurred and that it was possible to use these refracted signals to produce satisfactory pictures at distances of two and three times line of sight. These refracted signals are a normal occurrence and are always present at distances up to approximately 100 to 125 miles, depending upon the height of the transmitting and receiving antennas.

When actual practice proved that long-distance television reception was possible, the Federal Communications Commission found it necessary to stop all television station construction permits because stations that were located less than 300 miles apart were interfering with each other. This interference manifested itself in the form of black lines running through the picture, commonly referred to as "venetian blinds," also the audio was garbled. This stoppage of construction permits was to allow time for the FCC to study and rectify the already existing situation. It appears that in the future the ultra-high frequency spectrum in the neighborhood of 500 megacycles will be opened up, and that station permits will be issued so that the number of TV stations may be increased. The higher the carrier frequency, the more the signal acts like light rays and the less chances there are of interference between stations located fairly close together.

The Federal Communications Commission originally allocated thirteen channels to television, extending from 44 megacycles to 216 megacycles. Channel No. 1 was eliminated and at the present time there are twelve TV channels, designated by their original numbers, 2 to 13, with the frequency coverage shown in Fig. 1. Additional assignments of TV channels will be in the ultra-high frequencies.

Channel Number	Channel Freq. Mc.
2	54–60
3	60–66
4	66–72
5	76–82
6	82–88
7	174–180
8	180–186
9	186–192
10	192–198
11	198–204
12	204–210
13	210–216

FIG. 1. That portion of the spectrum between channels 6 and 7 is assigned to FM and other services, and the frequencies from 54 mc. to 88 mc. and from 174 mc. to 216 mc. are reserved for TV transmission.

TV IS AN EXTENSION OF RADIO PRINCIPLES

A television camera is needed to pick up picture signals in a television studio, and a special reproducing device is required at the receiver to reproduce the transmitted picture. Between these two special devices we find a great many familiar radio circuits. At the television transmitter there is a master oscillator that generates the r.f. carrier, together with r.f. power amplifiers, a modulator, linear r.f. power amplifiers, and a transmitting antenna. At the receiving location the television signals are picked up by an antenna, and are amplified and selected in the preselector of the television receiver. The superheterodyne circuit is used in television sets and hence the receiver will have an r.f. amplifier, a mixer first detector, a local oscillator, an i.f. amplifier, a second detector, and a picture-signal amplifier, all of which prepare the received signal for the picture-producing device.

The sound accompaniment for a television program is handled in essentially the same way as in f.m. program broadcasting. However in television the frequency deviation of the sound signal is limited to ± 25 kc.

In a television receiver you will find tubes, coils, resistors, condensers, transformers, etc., just as in ordinary broadcast receivers. In many instances, as you will learn later, some of the parts do not have the same physical appearance but many are identical.

Television circuits may be exactly the same as radio circuits or there may be entirely new circuits developed to meet special requirements of picture reception.

Sounds, no matter how complex, are inherently a succession of signal intensities. Unfortunately, a scene does not exist in this desired state. Therefore a scene must be converted into a succession of signal intensities by a process of scanning, as the first step in sending images by radio or wire. The television camera provides this scanning, and feeds into the television system a signal corresponding to that fed into a radio system by a microphone. The succession of signal intensities in a television signal is handled by the transmitting and receiving systems in a more or less conventional manner. These varying intensities must be reassembled in proper order and position by an image-reproducing device at the output of the receiver in order to reconstruct the original scene. The image reproducer in a television receiver corresponds to the loudspeaker in a broadcast set.

The scene is taken apart at the transmitter so that it can be sent as a succession of signal intensities and must then be properly reassembled at the receiver. To do this the circuit that controls the scanning at the television camera must also control the scanning process at the receiver. This act of controlling the receiver scanning system so that it is in step with the picture camera is referred to as synchronization, and the signals that do this are known as synchronizing signals. (They are commonly referred to as sync signals.) The sync signals are produced by special oscillator circuits and are sent out on the carrier along with the picture and sound signals in a conventional manner. At the receiver the sync signals are separated from the picture signals by special circuits that are not found in the usual broadcast set. In the final analysis, however, all these special circuits are based upon extensions of well-known radio principles.

Once the requirements of a television system are recognized, the special circuits will seem quite natural rather than something strange and new. By studying the process of scanning first, giving special attention to the sync signals, and the circuits that handle these signals we can make television circuits seem just as logical and understandable as ordinary radio circuits. This Lesson is primarily intended to acquaint you with the important problems in television and later Lessons will go into details on the various circuits and the actions that take place in them.

Image Scanning in Television

Television involves a transmission of intelligence that reaches our brain through our eyes. First, let us consider what the eye sees when it looks at an object. Ordinarily, it looks at reflected light, made up of electromagnetic waves; occasionally, it looks directly at light sources such as electric lamps, a fire, or the sun. The eye sees color because the electromagnetic waves in the visual band have different frequencies, each frequency or group of frequencies giving, through the action of the brain, a color sensation. The human eye serves as a complicated lens (much like the lens in a camera), for it projects these electromagnetic waves on the retina, a surface at the back part of the eye. This retina has millions of nerve endings, each of which is connected to the brain. These nerve endings interpret the strength of each electromagnetic wave that hits them (determined by the brightness of the object) and they also interpret the frequency of the wave (the color of the object). Each nerve ending "sees" only a tiny portion of the entire scene; the brain reconstructs the over-all picture by assembling all the nerve impulses. Thus, the eye breaks up the scene into two elements, each of which is transmitted over a separate nerve channel to the brain.

One scientist calls the human eye nature's own television system. The object viewed acts as the transmitter system sending out electromagnetic waves. The eye, acting as a receiver, picks up the waves and relays them to the brain to give us the sensation of seeing.

A SUGGESTED TV SYSTEM

This action of our visual mechanism suggests the construction of a television system. Why not arrange thousands or millions of tiny electric eyes on a screen to pick up the light waves, and connect these by thousands of wires of radio-frequency transmitters to a receiver containing thousands of tiny glow lamps? Each of these would reproduce the amount of light picked up by its corresponding electric eye, so the combination of all the lamps would reproduce the object viewed by the transmitter. Yes, a television system like this has actually been tried for land-wire television, but only on a small scale. The scheme was found to work after a fashion, but obviously it was far from practical, for entirely too many wires were necessary.

PRACTICAL TV SYSTEMS

The television systems in use today do not attempt to pick up a complete scene and transmit it to a receiver all at once. Instead, television takes advantage of an eye characteristic known as persistence of vision—the ability of the eye to retain an impression of an object for a short time after the object has disappeared from view. This makes it possible to send a portion of a scene at a time; just so the entire scene is transmitted before the eye has had a chance to "forget" the first part of it.

The scene is broken up into elements by scanning, or by viewing a small portion of it at a time. Scanning is an operation very like what you are doing now as you read this page. You don't look at the page and attempt to read every word in one glance. Instead, you read the first line from left to right, swinging back quickly to the left-hand side of the second line, read the second line, go back to the beginning of the third, and repeat the process until you have taken in every word.

That is just about what a television camera does. (This camera is the pick-up device in a television system, corresponding to the microphone in the radio system.) In effect, an "eye" in the camera travels over the top edge of the scene from left to right, swings quickly back to the left-hand side, moves down slightly, travels horizontally over the scene again, and repeats the process until the whole scene has been scanned. As you no doubt know, or have guessed, this "eye" is really a light-sensitive surface that converts the light received from the scene into an electric current. This current, which of course varies as different parts of the scene come into view of the scanning eye, is then transmitted by radio to the receiver. At the receiver, the process is reversed, and the original scene is traced out line by line.

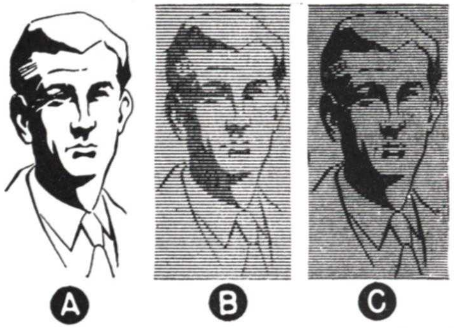


FIG. 2. The drawing at A is reproduced as a series of lines at B and C. Greater detail is obtained by using more lines, as at C.

This is a highly simplified version of how a television system works, but it will serve to show you the basic idea of operation. Right now, the important fact for you to grasp is that a scene is televised "bit by bit," and not as a whole.

Fig. 2 illustrates the general effect produced when a scene is scanned.

Suppose we wish to televise a picture like that shown in Fig. 2A. After it has been scanned by the camera, transmitted to the receiver, and reproduced on the receiver screen, it will appear as shown in Figs. 2B and 2C. That is, it will consist of a series of lines; these lines will vary in brightness along their length, and so make up the picture we see. The more lines we have in a given area, the greater the detail of the final picture. Fig. 2C, which has 120 lines, exhibits more detail than Fig. 2B which has only 60 lines.

Note that as you move the illustrations in Fig. 2 farther and farther away from you, a point is reached for each illustration where the details seem to blend into a complete and nearly perfect reproduction of the original. This brings out an important fact about television: if a reproduced picture is made larger without increasing the number of lines, the picture will have to be viewed from a greater distance to get a satisfactory eye impression. This is particularly noticeable in picture tubes 15 inches or larger. When you are close to the screen, operating the controls of the receiver, you will see the individual lines. If you move back only a few feet it will cause them to blend together and give good definition.

How Scenes are Scanned and Reproduced. Before considering the technical details of breaking up a scene into a number of lines, it will be valuable to get clearer ideas of how a scene is taken apart or scanned, and how a scene is reproduced.

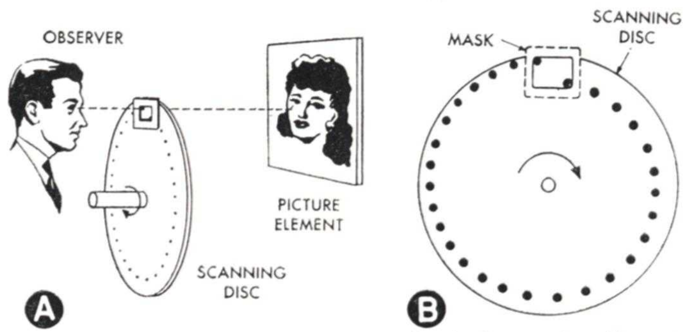


FIG. 3. This diagram shows an elementary mechanical scanning disc system. If the disc is rotated rapidly enough, the observer will be unconscious of its presence, as persistence of vision will allow him to apparently see the entire scene, although he is actually viewing only a tiny spot at a time.

MECHANICAL SCANNING METHODS

Even though mechanical methods of scanning are considered inadequate today, except for some experimental work in color television, we will consider them first since they are easier to understand and will help you to understand the electronic scanning methods.

Punch a hole with a pin in the center of a small business card and hold the card up to one of your eyes so that you can look through the hole. Turn to some object or scene. Notice that you can see only a small part of the scene through the tiny hole. Now move the card horizontally from left to right; you see all the portions of the scene along the line that you are scanning. Move the card back and forth horizontally while shifting it vertically downward a little at the end of each line and your eye will see the entire scene, piece by piece.

The Scanning Disc. In place of this card-scanning device we can use the system shown in Fig. 3A, in which a large number of holes are arranged in a spiral fashion on a rotating disc called the scanning disc. This disc really replaces the business card that we used in our previous example. One complete revolution of the disc gives one complete scanning of the entire picture, because each hole in the disc scans one line. If the disc is revolved fast enough, the visual sensation is the same as though the entire picture were being seen at one time.

The exact arrangement of the holes on the scanning disc is shown more clearly in Fig. 3B. The observer is viewing the scene through the mask, a rectangular opening in a piece of black cardboard. As the disc is rotated, each hole moves across the opening in the mask, the outermost hole in the spiral moving across the top of the opening and each succeeding hole moving across one line down. Finally, when the innermost hole has moved across the bottom of the opening, the outermost hole again scans the top line and the entire scanning process starts over again.

MECHANICAL TV TRANSMITTERS

If the observer in Fig. 3A is replaced with a light-sensitive cell, this cell will deliver a varying electric current that is at all times proportional to the amount of light that is reaching the cell, and therefore proportional to the shade of lightness or darkness of the element of the picture that is being scanned at a particular instant. This arrangement gives us a means of converting a picture or scene into a varying electrical current. This current, or picture signal, can be amplified and placed on a radio carrier for transmission through space. At the receiver, a carrier can be demodulated and the picture signal amplified sufficiently to operate a picture reproducer.

Courtesy Don Lee Broadcasting System

The engineer is holding an electronic pickup tube such as is used in television studios. Scanning is accomplished within this tube by electronic means.

MECHANICAL TV RECEIVERS

In the early television receivers, the amplified picture signal was fed to a neon glow tube like that shown in Fig. 4A. This lamp consisted of a wire anode and a rectangular flat metal piece (the same size as the reproduced picture) that served as a cathode. These elements were enclosed in a gas-filled envelope. A red glow of light formed on the plate when sufficient voltage was applied between the electrodes; the intensity of this glow varied with the applied

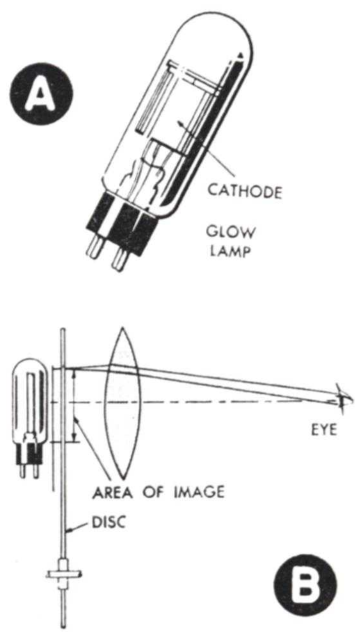


FIG. 4. An early type of mechanical television reproducer. The glow-lamp light depended on the brilliancy of the spot being scanned at the transmitter at that moment. The scanning disc is synchronized (in step) with the transmitter disc so that it arranges the light elements in their proper sequence.

voltage. The amplified picture signal was made to change the applied voltage, thus changing the intensity of the glow.

A pin-hole scanning disc was rotated before the glow lamp in such a way that the holes scanned the glowing plate. The transmitter and the receiver were so synchronized that when the scanning disc at the transmitter started to scan the top line of the scene, the receiver scanning disc likewise started to scan the top line. Line-by-line scanning discs were kept in step or in synchronization, so that the intensity of the glow lamp at any instant corresponded to the intensity of the light reflected from that same element on the actual scene. The arrangement of the scanning disc and the glow lamp are shown in Fig. 4B. The lens shown is a magnifying glass that is used to enlarge the image to three or four times the size of the glow lamp plate.

ELECTRONIC TV TRANSMITTERS

Although present-day methods of scanning in picture reconstruction differ greatly from the method just described, the principle of breaking up the picture into a number of elements that are scanned line after line is still used. Fig. 5 illustrates the basic elements of an electronic television camera. The scene is focused on the photoelectric plate by a high-grade camera lens combination. This light-sensitive photoelectric plate consists of millions of tiny light-sensitive spots, each insulated from the others and each scarcely larger than the point of a pin. Under a microscope this plate looks as if it were covered with grains of sand.

When a scene is projected on the photoelectric plate by the lens, the action of light drives out the electrons from each of the tiny light-sensitive

units. These electrons pass through the space in the tube to a conducting surface on the inside of the glass envelope, which is at a high positive voltage and therefore attracts the electrons. The action of light thus leaves the photoelectric plate elements more or less positively charged (because they have lost their electrons).

Naturally, the amount of electron loss from any given section of this photoelectric plate depends upon the amount of light reaching that section. Thus, some spots on the plate are more

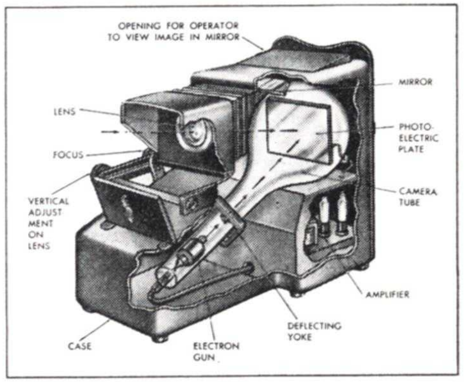


FIG. 5. A cut-away view showing the arrangement of parts inside one type of electronic television camera.

positively charged than others, and we actually have an electronic image of the scene. An electron gun now shoots a fine stream of electrons at the photoelectric plate. Electromagnetic deflection coils (here designated as the "deflecting yoke") shift the electron beam horizontally and vertically, one line at a time, to scan the entire photoelectric plate from top to bottom. When this electron stream strikes a positively charged surface, that surface recovers its electrons and, in so doing, relays the charge to a flat metal supporting electrode that is back of, but insulated from, the photoelectric plate.

In this manner, an electronic impulse is relayed from each spot that is hit by the electron beam. The size of each impulse corresponds to the amount of light striking the spot, so the sum of all the impulses (sent one at a time) constitutes a picture signal.

The supporting electrode collects the picture signal and, after a great deal of amplification, the picture signal is placed on a carrier wave and transmitted through space, just as in the mechanical television system. In addition to this, impulses are sent at the end of each vertical scan or frame of a new picture, to keep the image-reconstructing device in step with the scanning mechanism at the transmitter.

While the picture and synchronizing signals are being sent out, a sound carrier is also being transmitted. This carrier is always separated by 4.5 megacycles from the picture carrier. The sound is transmitted by f.m. modulation in essentially the same way as in f.m. program broadcasting except the frequency deviation is plus or minus 25 kc., which is much less than ordinary f.m. modulation. However, the sound signal of a TV system, if a satisfactory audio amplifier is used, is entirely adequate.

ELECTRONIC TV RECEIVERS

Fig. 6 shows a simplified diagram of a typical electronic picture reconstructor. This employs an electron gun and two sets of electromagnetic deflecting coils. Special oscillators generate the current pulses that flow through these coils; the oscillators are

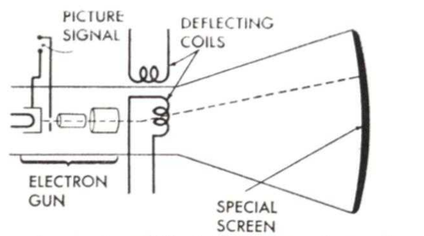


FIG. 6. A simplified diagram of an electronic picture reconstructor tube.

controlled by the synchronizing impulses sent out by the transmitter. A spot of light appears on the fluorescent screen at the end of the tube when it is hit by the electron beam that is produced by the electron gun; the brilliance of the spot increases with the number and speed of the electrons in the beam. The picture-signal voltage controls the speed and number of electrons in the beam by means of a special grid electrode, and the deflecting coils carry the current which results in the scanning of the beam across, and up and down, the screen. The combined action is such that while the beam is sweeping across the screen, its intensity is changing continually in accordance with the picture signal, and the effect of "painting" light on the screen is secured. The current through the deflecting coils is produced by special circuits that are kept in step with the scanning at the transmitter by special signals commonly called vertical and horizontal sync pulses.

During the transmission of a television signal the horizontal sync pulse exists for an instant after each line has been scanned and the vertical sync pulse exists for a longer period after each frame has been scanned. (A frame is one complete scanning of every part of the picture that is being transmitted.) It is not necessary for the video signals to exist while sync pulses are being transmitted and as a matter of fact the video (picture) signals are stopped entirely during the transmission of sync pulses.

There is sufficient difference between the horizontal and vertical sync pulses so that they may be readily separated at the receiver by R-C filters and applied to the proper control circuits. This separation can easily be accomplished, because the vertical sync pulse lasts a much longer time than does the horizontal sync pulse, and by allowing the sync pulse voltages to build up across a condenser it is possible to use capacities of such size that they will definitely discriminate in favor of either the horizontal or vertical sync pulse. This, too, will be described in detail later on. The three basic components in a television signal (the picture or video signal, the horizontal sync pulses, and the vertical sync pulses) are transmitted as shown in Fig. 7. The r.f. carrier will be considered later and hence is not shown in this diagram.

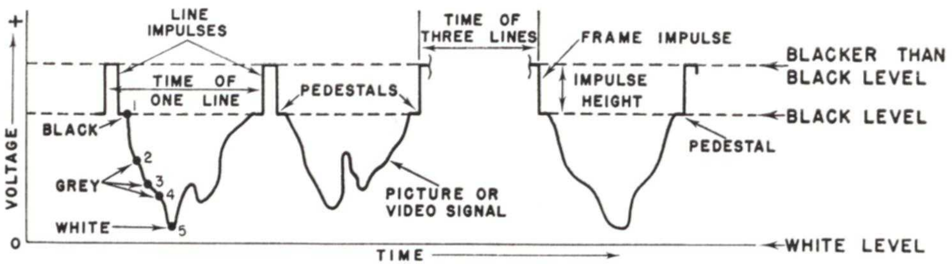


FIG. 7. This diagram shows the three essential components of a television signal—the video signal, the horizontal sync pulse, and the vertical sync pulse. This is a modulated d.c. signal. Since the picture signal voltage swings in a negative direction with increases in line brilliancy, we have what is known as a negative picture phase.

First of all, notice that this television signal is a pulsating d.c. signal with all its components above the zero voltage line, which is known as the white level. The video or picture signal is contained between the white level and the black level. The sync pulses are all between the black level and what is commonly known as the blacker-than-black level. In other words, signals that swing above the black level do not cause any lines to become visible on the face of the picture tube.

The vertical sync pulse lasts about three times as long as the time for one line. The black level is 75% of the maximum television signal amplitude.

Notice that points 1, 2, 3, 4, and 5 along the video signal, corresponding to elements along one line of the picture that is being scanned, are for increasing values of brightness, with point 1 corresponding to a black elemental area on the picture, points 2, 3, and 4 for gray areas, and point 5 for a white area. When increases in brilliancy make the picture signal voltage swing in a negative direction in this manner, we say that the picture has a negative picture phase. The sync pulses are kept in the region that is never occupied by the video signal in order to make possible the use of a biased triode or diode tube for sync separation of these pulses from the video signal. You will also notice from Fig. 7 that before and after each sync pulse the television signal voltage remains constant for a short interval of time. These constant voltage components are known as pedestals.

In a.m. broadcasting, the large carrier currents correspond to the loud sounds, and low carrier currents correspond to the weak sounds. Exactly the opposite is true in sight transmission. With a very-high frequency r.f. carrier that is modulated with a television signal as shown in Fig. 7, the white components of the television signal will exist as low carrier currents and the sync pulses will exist as large r.f. carrier currents. This type of modulation is known as negative modulation. It is necessary that the sync pulses represent the highest currents so that they will be less affected by noise pulses. Negative modulation is always used in broadcasting television programs in this country.

The Cathode-Ray Tube as an Image Reproducer

While electromechanical methods of picture scanning and reproduction are feasible, they are far more cumbersome than electrical methods. On the other hand, the electrical methods, employing various types of cathode-ray tubes, are far more satisfactory for high definition home television receivers than any mechanical system. Therefore, electronic systems are used exclusively.

The two main types of cathode-ray picture tubes in use today are the electrostatic and the electromagnetic

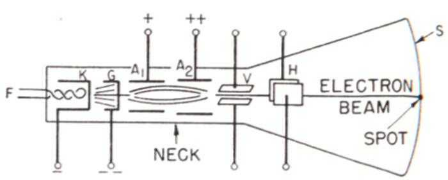


FIG. 8. Essential elements in a cathode-ray tube of the electrostatic deflection type used for image reconstruction in small inexpensive television receivers.

types. In the electrostatic type, focusing and sweeping are done by applying voltages to various electrodes in the tube. In the electromagnetic type, focusing and sweeping are done by means of magnetic fields. Both types will be treated extensively in your Course but in this Lesson we will concentrate on the electrostatic type which is widely used in the less expensive home receivers.

The essential elements of this type of cathode-ray picture tube are shown in Fig. 8. They are: K—the cathode, which emits electrons when heated; F—the filament, which heats the cathode; A_1 and A_2—anodes which accelerate the electrons and focus them into a narrow beam; S—the fluorescent screen, which glows when hit by the electron beam; G—the control electrode which controls the number of electrons entering the electron beam and thus controls the brightness of the spot on the screen. This electrode is called the control grid even though it looks entirely different from the grid in an ordinary vacuum tube; V—the vertical deflecting plates which move the beam up and down on the screen; H—the horizontal deflecting plates, which move the beam horizontally in either direction.

Electrode A_2 is always at a higher positive potential than electrode A_1. As much as 5000 or 6000 volts may be applied to electrode A_2. The voltage applied to electrode A_1 is variable and is controlled by means of a potentiometer. By varying this voltage the beam is focused to a sharp point. The high voltages applied to these two electrodes serve to accelerate the electrons in the beam, giving them greater speed and hence increasing the brightness of the image obtained on the face of the tube.

Control grid G is always negative with respect to cathode K, the value of this negative potential determines the number of electrons that the cathode can force through the control grid into the electron beam. When correct grid and anode voltages are

applied to the tube and no voltage difference exists between the two vertical plates and between the two horizontal plates, the beam travels straight out and strikes the center of the screen. The resulting spot will be in the center of the screen as indicated in Fig. 8. Increasing the negative voltage on the control grid reduces the number of electrons in the beam and reduces the brightness of the spot.

The negative bias between the control grid and cathode is adjusted so that the screen is almost dark when no television signal is present. The television signal is applied in series with the negative grid bias in such a way that the spot will be black each time a pedestal is transmitted. This condition is secured when the pedestals (sync pulses) line up with the brilliancy cut-off point on the characteristic curve of the picture tube.

Video signals make the control grid less negative, swinging the grid above the cut-off point, thus varying the brightness of the spot on the screen. The sync pulses make the control grid more negative than the cut-off voltage so that the screen will be dark during the very short intervals of their duration. Thus the retraces as the beam swings back to its starting point do not appear as lines in the picture.

The spot is in the center of the screen only when there are no voltage differences between the vertical deflecting electrodes and between the horizontal deflecting electrodes. Now let us see how these electrodes can be made to move the spot to any desired point on the screen. Referring to Fig. 9, notice that we have an electron beam traveling between two oppositely charged metal plates. Remember that the electrons in this beam have negative charges; this means that the positively charged plate will attract these electrons while the negatively charged plate repels them, thus bending the beam upward and causing it to strike the fluorescent screen at point b rather than at a, the center. The greater the voltage between these two deflecting plates, the more bending of the electron beam there will be.

The electron beam, however, must be moved in a definite manner if it is

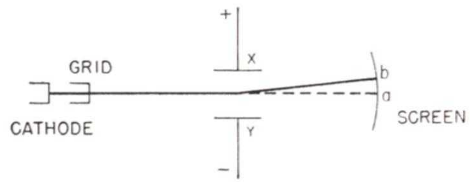


FIG. 9. An electron beam passing between two oppositely charged plates is always bent toward the positive plate.

to produce an image on the television screen. You will remember that the scanning process in a television camera involves analyzing the scene line by line in a manner exactly similar to that in which our eyes read this printed page. First of all, it is necessary to have some means for sweeping the electron beam gradually from left to right in a horizontal line, then quickly back again to the left, with this horizontal line sweeping motion being repeated continuously.

We can secure a horizontal sweeping of the beam by varying either the electromagnetic or the electrostatic field in the tube. As stated before, the magnetic method will be studied later. We will now study the electrostatic sweep which is obtained by applying to the horizontal deflecting plates of an electrostatic type picture tube a voltage having the characteristic shown in Fig. 10. Due to the shape of this curve we call this a saw-tooth voltage. A push-pull amplifier is used to drive these plates, and the signals delivered by the amplifier tubes are 180° out of phase. Thus when one plate is being driven positive, the other is being driven negative.

Observe that at points 1, 2, 3, and 4 in Figs. 10A and 10B there is no voltage difference between the two plates. The voltage on plate x is positive at points 8 and 9 and negative at points 5, 6, and 7.

Conversely, plate y is positive at points 5, 6, and 7 and negative at points 8 and 9 (see Fig. 10C). If the voltage is applied to plates x and y in Fig. 9, plate x will be positive when the voltage is following path 1-8-2 and negative when the voltage is following path 2-6-3 in Fig. 10B.

At the same time (see Fig. 10C)

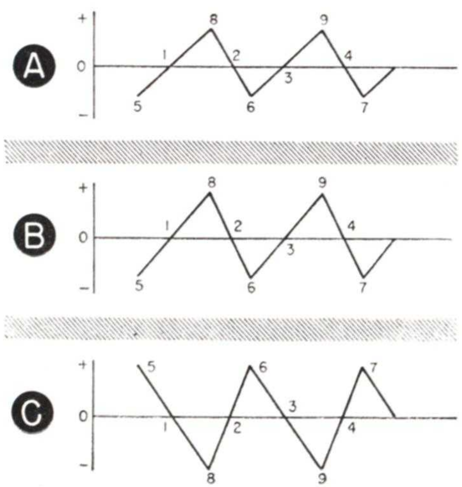


FIG. 10. (A) Wave form of saw-tooth voltage used for electrostatic sweep. (B) Sweep voltage for plate x. (C) Sweep voltage for plate y.

plate y will be negative when the voltage is following path 1-8-2 and positive when the voltage is following path 2-6-3. When plate x acts as the positive plate, then plate y is negative and vice versa.

When the charge is at point 1 the deflecting plates will have equal voltages on them and they will have no effect upon the electron beam and the spot will be in the exact center of the screen. As the charges on plates x and y approach point 8 the electron beam will be attracted gradually and uniformly toward plate x and repelled in the same manner from plate y. As the charges drop to zero again at point 2, the spot will move rapidly back to the center of the screen. From point 2 to point 6 plate x will become increasingly negative, repelling the beam and bending it toward plate y which is becoming increasingly positive. From point 6 to point 9 the beam will move gradually from plate y to plate x, and from point 9 to point 7 the beam will move rapidly back toward plate y again.

We have seen that a saw-tooth voltage of the form shown in Fig. 10A will produce the desired sweep of the electron beam. If this saw-tooth voltage is applied to horizontal deflecting plates H in Fig. 8, it will cause the spot to sweep slowly from left to right across the screen, then return rapidly to the left again. If this voltage is applied to the vertical deflecting plates V in Fig. 8, it will cause the spot to move gradually from top to bottom and return rapidly to the top again.

In the earlier part of your Course you made a preliminary study of the

special oscillator circuits used to produce these saw-tooth voltages. Later, however, we will cover them again in greater detail.

None of these circuits are absolutely steady in frequency, and it is therefore necessary to send synchronizing signals along with the television signal for the purpose of controlling and stabilizing the sweep circuits. One saw-tooth oscillator circuit is required for the horizontal sweep and another for the vertical sweep. The horizontal sweep circuit builds up its voltage uniformly from point 5 to point 1 to point 8 in Fig. 10A; at point 8, corresponding to the end of the line, a horizontal sync pulse arrives with the television signal and causes this voltage to drop back to point 6 rapidly. The building up of the voltage starts again, only to be stopped at point 9 by another horizontal sync pulse.

Since the sharp decreases in voltage are accurately controlled by the transmitter through the horizontal sync pulses, we know that the electron beam in the picture tube will be swept horizontally in exact synchronism with the scanning device at the transmitter. The vertical sweep circuit operates at a much lower frequency, and is controlled in the same manner by the vertical sync pulses broadcast by the transmitter.

Now let us follow the movement of the spot on the screen of a picture tube as it is swept back and forth and up and down by the sync-pulse controlled sweep circuits.

When the beam is under the control of the horizontal and vertical sweep voltages, we can consider its starting point to be point 1 in Fig. 11, at the

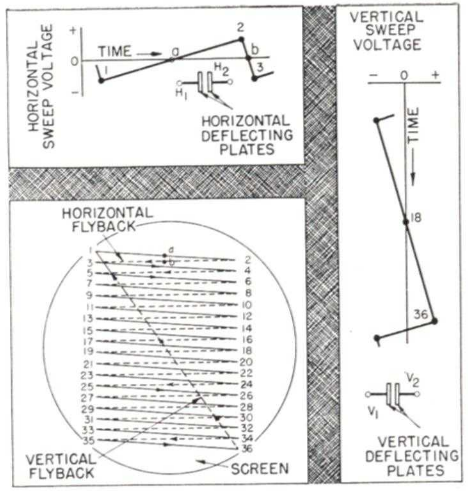


FIG. 11. The path traced on the fluorescent screen of a television cathode-ray tube by an electron beam under the influence of horizontal and vertical saw-tooth sweep voltages is shown in this diagram. The wave forms of the sweep voltages are shown above and at the right of the screen; these voltages are applied between deflecting plates in each case. Thus, when horizontal plate H_2 is highly negative at (1), the spot will be at the extreme left side of the screen at point 1; when this plate is at zero potential (a), the spot will be at a in the center of the screen; when this plate is highly positive (2), the spot will be at the extreme right side of the screen at 2; when the saw-tooth voltage drops suddenly back to the highly negative value (2 to b to 3), the spot flies back from 2 to b to 3 on the screen. Likewise, when vertical plate V_2 is highly negative (1), the spot will be at the top of the screen at point 1; when this plate is at zero potential, the spot will be halfway down the screen at point 18; when this plate is highly positive (36), the spot will be at the bottom of the screen at point 36; when the saw-tooth voltage drops suddenly back to the highly negative value 36 to 1, the spot flies up from 36 to 1 on the screen over a zig-zag path which for simplicity is shown here as a straight line.

upper left-hand corner of the screen. Here the spot has been bent far to the left. From this point the horizontal sweep voltage gradually allows the beam to "unbend" or return to the center of the top line. The beam is then gradually bent in the opposite direction until the spot reaches the right-hand edge of the screen. While this action occurs, the vertical sweep voltage is gradually moving the spot in a downward direction; a distance equal to the spacing between two lines.

At point 2 a horizontal sync pulse arrives from the transmitter, causing the horizontal sweep voltage to move the spot almost instantly back to the left-hand side of the screen along the dotted line path 2-3. This return motion is very rapid and if a trace is made it could not be seen as such, but sometimes, if the receiver is not properly adjusted, it will produce on the screen a faint haze or glow instead of a line.

This process continues for each other line until the spot is swept to point 36 at the end of the last line. At this time the vertical sync pulse arrives from the transmitter and stops the gradual building up of the vertical sweep voltage, causing the spot to move back up to the top of the screen. The vertical sweep voltage drops back to its starting value at a rapid rate, but the change takes more time than is required for a complete horizontal sweep. As a result, the spot actually takes a zig-zag path from side to side as it is being returned to the top of the screen. For simplicity the vertical retrace is shown as a straight-line path, 36-1, in Fig. 11. Actually, if the receiver is misadjusted you will see a number of diagonal lines, across the screen, which is the vertical retrace.

The scanning path just described, going from point 1 down to point 36 and then back to point 1 again constitutes one complete normal scanning of the scene or one frame. The entire process is repeated for each succeeding scanning.

When either the horizontal or the vertical sync pulse is being sent by the transmitter, no television picture signal exists and the appearance of retrace lines would only cause diagonal streaks in the picture, marring reproduction. The sync pulses are applied to the control grid of the picture tube in the receiver in such a way that they drive the grid highly negative, causing almost complete cut-off of the electron beam and thereby preventing retraces from showing.

Image Detail

A consideration of the processes of scanning and reproduction just described should make it clear to you that the video signal exists only while the spot is traveling from left to right along the line. At all other times the television transmitter is sending out pedestals with synchronizing signals. The changes in the intensity of the video signal from one instant to another produce the essential picture detail. The more changes there are per line for an actual given scene that is being scanned, the greater will be the amount of detail in the reproduction.

The more frames there are per second, the better they blend and the less chance there is for the eye to see them individually. If too few are transmitted, flickering results. Increasing the number of frames per second reduces flicker.

Greater detail can be obtained by increasing the number of lines per frame. Both the number of frames per second and the number of lines per frame contribute to high definition, or high-fidelity reproduction. However, there are definite limits to the number of lines and frames that can be handled economically. Let us first examine the factors that determine the high frequencies.

PICTURE ELEMENTS

All television equipment must be designed to handle the maximum frequency of the picture signal current. To calculate the maximum frequency of a signal it is assumed that the picture being scanned consists of a checkerboard pattern of black and white squares, as shown in Fig. 12, with each square being equal in size to one of the sensitized spots on the photoelectric plate of the television camera. Since each of these is the smallest part of the scene the camera can see, they are called picture elements. The signal current is said to go through one cycle each time the

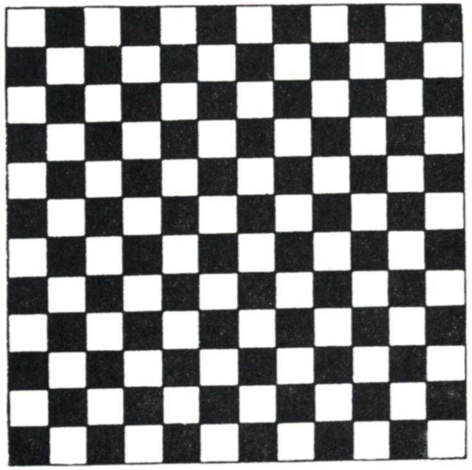


FIG. 12. The photoelectric plate can be visualized as a checkerboard of dark and light squares. Each square stands for a light-sensitive spot or picture element.

electron scanning beam passes over one light and one dark picture element as shown in Fig. 13, because the signal current goes through a maximum and a minimum value each time this happens.

To find the maximum frequency of the picture-signal current, all we have to do is compute the number of picture elements that are scanned per second and divide by two, since one cycle consists of two elements.

If each picture element is considered to be as high as it is wide, it is easy to compute the number of elements in one complete picture. For example, in a square picture with N lines there will be N picture elements per line, or N times N picture elements in the complete square picture, which is known technically as one frame. For example, at present the television standards call for a 525-line picture. Hence, in a square picture there would be 525 times 525 or 275,625 picture elements. For ordinary calculations, 276,000 elements will be sufficiently accurate.

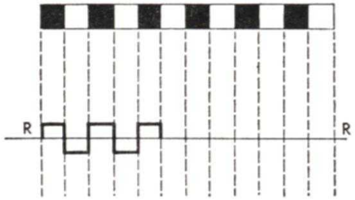


FIG. 13. The signal goes through one cycle each time the beam passes over one dark and one light element.

Aspect Ratio. The pictures that are commonly involved in television are not square, however. They are wider than they are high as shown in Fig. 14. The width of a picture divided by its height is called the aspect ratio which, in order to conform to motion picture standards, has been standardized at 4/3 or 1.33. This means that the number of elements in each line has been increased by the aspect ratio which we will designate as A. Now the number of picture elements per frame, or picture, will be N times N times A. For the example just considered, the total number of elements will therefore be 276,000 times 4/3, or 368,000.

FRAME FREQUENCY

The number of pictures sent per second is the frame or picture frequency. It is designated as F. By multiplying the number of elements in a frame by the frame frequency, we get the total number of picture elements per second. This total number of elements per second is N times N times A times F. Since it takes two picture elements to make a cycle, we get the maximum number of cycles per second by dividing this formula by two. The standard frame frequency is 30. In our example, then, we get the frequency involved by multiplying 368,000 by 30 and then dividing by 2. The result is 5,520,000 cycles per second.

SYNCHRONIZING PULSES

In practice the picture is scanned only about 85% of the time. The remainder is used for horizontal and vertical sync pulses. This increases our maximum picture frequency because it crowds our elements into 85% or 85/100 of a second. We, therefore, multiply our computed value by 1.17,

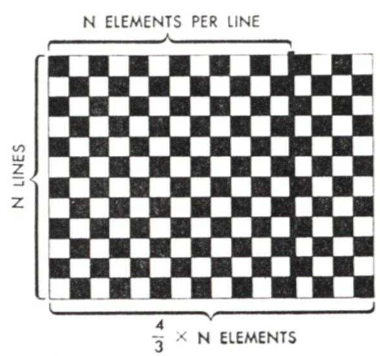


FIG. 14. When the picture is changed to the rectangular form shown here, the elements of a square picture are multiplied by 4/3.

making the maximum theoretical picture frequency 1.17 times 5,520,000, or approximately 6,460,000 cycles.

In our analysis of the theoretical maximum frequency we have assumed that there is always a sharp contrast between adjacent elements of a scene. This is not true in practice. Several adjacent picture elements may reflect the same or nearly the same amount of light. Also, in moving scenes, it is not necessary to transmit slight variations between adjacent elements. This is illustrated roughly in Fig. 15. Actually, the picture would be broken up into much smaller elements, but even here with the relatively large squares you can see that in many instances there is practically no change from one square to another. The average scene thus requires considerably less than the maximum frequency. Practice has shown that apparatus capable of sending about 60% of the maximum theoretical frequency is satisfactory. Since the maximum number of cycles was assumed in our example, we multiply 6,460,000 by .6 and get about 3,900,000 cycles or 3.9 megacycles, as the actual frequency. Any increase in this frequency up to the limit of 4.5 megacycles that is permitted within a television band gives a definite improvement in fidelity.

Monotones Require Very Low Frequencies. The upper part of an outdoor scene, like the sky, as shown in Fig. 16, is usually bright, while the lower part is considerably darker. The picture elements in such a scene vary in light intensity at a high level for the upper half of the picture and at a low level for the remainder. This gives one cycle of change from light to dark for each scanning. Transmitting these changes properly calls for a low frequency corresponding to the vertical scanning frequency (the frame frequency). However, within the background, satisfactory reproduction of the slow changes in intensity requires frequencies down to at least 10 cycles. Therefore, for a 525-line picture with an aspect ratio of 4/3 and a frame frequency of 30, the picture frequency ranges from 10 cycles to about 3.9 megacycles.

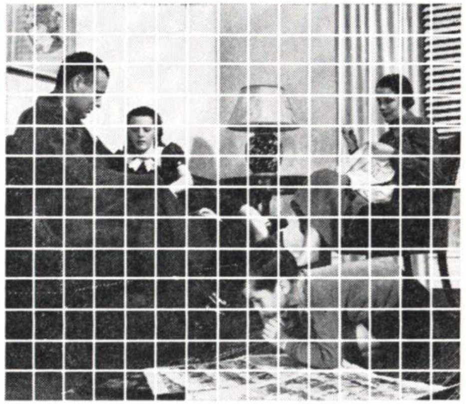


FIG. 15. Not all the neighboring spots on a line vary in shade. This reduces the necessary maximum frequency.

FLICKER

The human eye is sluggish in its response to moving objects, for it continues to see an object even after the object has disappeared. Motion pictures depend upon this persistence-of-vision characteristic of the human eye. In a motion picture projection twenty-four separate still pictures per second are flashed upon the screen in sequence, but the eye sees a continuous action rather than a series of separate pictures. The eye can detect individual views up to a rate of about

10 pictures per second, but above this rate the scenes blend together, accompanied by pulsating light impressions which give the effect of flicker. At about 20 pictures per second the blending of pictures into motion is almost perfect, but flicker is still not entirely absent. Even at 24 pictures per second, the standard in the motion picture industry, flicker can still be noticed. For this reason motion picture projectors have a shutter in front

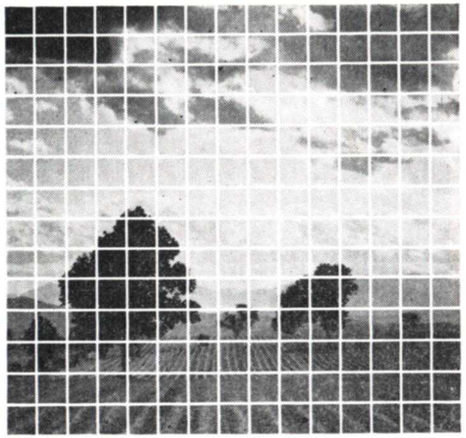


FIG. 16. Changing from a bright sky to a dark foreground once each frame, as in a scene like this, would require a 30-cycle frequency. Others with less variation could require frequencies as low as 10 cycles.

of the lens that breaks up each still picture into two separate views, giving the effect of 48 pictures per second, although only 24 of them are different. As you will see shortly, much the same thing is done in television.

In television the frequency of the available a.c. power has considerable effect upon the choice of a frame frequency (number of pictures transmitted per second). Since the power line frequency in the United States is standardized at 60 cycles, ripple voltages at this frequency or some multiple of it will get into the video signal and the sweep voltages, tending to cause ripple effects, wobbling of the picture, and random movement of bright bands on the image if the number of pictures is increased to 48, or even 72, in order to eliminate flicker. By using a frame frequency equal to some sub-multiple of 60 (such as 30 or 20) or some multiple of 60 (such as 60, 120 or 240), these ripple effects can be removed or at least made stationary so that they will be less objectionable. Frame frequencies of 20 or 30 are still too low to eliminate flicker entirely. On the other hand, a frame frequency of 120 pictures per second would increase the maximum frequency of the video signal to an extremely high value. There is left then, a scanning rate of 60 complete frames per second, which imposes quite a burden upon the transmitting system, insofar as maximum frequency range is concerned. With a 525-line image being scanned 60 complete times each second, the upper frequency limit for high definition becomes about 7.8 megacycles. It is possible to make amplifiers that will handle a range of from 10 cycles to 7.8 megacycles, but the cost of these amplifiers is so high that the production of inexpensive television receivers would become a serious problem.

Interlaced Scanning

To avoid increasing the frequency requirements of TV systems and to eliminate flicker, a simple scanning trick is used that makes the maximum video signal frequency correspond to that of a 30-picture-per-second transmission while still keeping the scanning rate at 60 pictures per second. In this system, known as interlaced scanning, only half of a picture is transmitted during one complete scanning. The other half is transmitted in the next complete scanning. Lines 1, 3, 5, 7 and all other odd lines are covered during one scanning, and lines 2, 4, 6, 8 and the other even numbered lines are covered during the next scanning. Two complete scannings are therefore required to cover every elemental dot area on the scene that is being televised.

At the receiver there must likewise be two complete scannings to give a complete reproduction of the image. With interlaced scanning, the frame or picture frequency is 30 cycles per second, since that is the number of complete pictures transmitted. For each complete picture the scene is scanned twice, so the vertical sweep frequency (field frequency) is 60 times per second. In referring to a field we mean the area covered during one vertical sweep of the scene. In ordinary scanning the field is the entire scene, but in double interlaced scanning the field is only half of the scene. By the frame we mean one complete scanning of every elemental area in a scene. In ordinary scanning this occurs for each vertical sweep, but in interlaced scanning two vertical sweeps are required for a frame.

For double interlaced scanning of a given number of lines per second at a given frame frequency there are two requirements: 1, an odd number of lines per picture; 2, a vertical scanning rate that is twice the frame frequency.

This automatically gives scanning of the odd-numbered lines during one vertical sweep and scanning of the even-numbered lines during the next vertical sweep, with odd and even line scanning alternating automatically.

Just how this may be done is best illustrated by an example, but instead of using a 525-line image that would be too cumbersome, a lower number of lines will be used to illustrate the principles involved.

Suppose we divide our picture into ten lines as shown in Fig. 17A and that we scan this complete scene ten times per second which gives a vertical sweep frequency of 10 per second. This means that one complete scanning of the scene, starting at point 1, proceeding to 2, 3, 4, 5 . . . 17, 18, 19, 20 and then returning to point 1, will take 1/10 of a second. Assuming flyback time to be negligible in these examples, we see that it will take 1/100 of a second to scan one line, moving from point 1 to point 2 and back to the starting point of the next line at point 3.

Now suppose that we scan the scene, which has an even number of lines, 20 times per second by doubling the vertical sweep frequency. We will

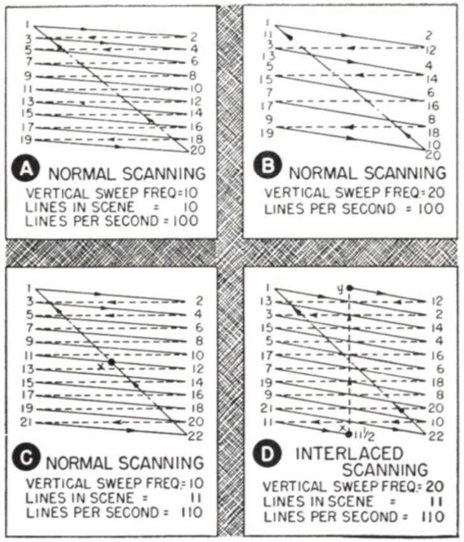


FIG. 17. These diagrams show that interlaced scanning can occur only when there is an odd number of lines in the scene and the vertical sweep frequency is twice the rate for normal scanning. Under these conditions, the same number of lines is transmitted each second with either normal or interlaced scanning.

still be scanning the same total number of lines per second, and it will still take 1/100 of a second to scan one line. But now only five lines will be covered in one complete scanning from top to bottom. Referring to Fig. 17B, the scanning path starts at 1 and goes to points 2, 3, 4, 5, 6, 7, 8, 9, and 10 during one complete scanning of the scene. Vertical fly-back now brings us to point 11 at the upper left-hand corner and we cover exactly the same scanning path for the second scanning of the scene. This shows that a television system using an even number of lines per picture could not secure interlaced scanning by doubling the vertical sweep frequency.

Now let us take an example in which we have an odd number of lines (11) per picture, and we use a vertical sweep frequency of 10 per second as indicated in Fig. 17C. All eleven lines are covered in one complete scanning, and vertical fly-back takes us directly from point 22 back to the starting point at 1.

Next, suppose we double the vertical sweep frequency, giving 20 complete scannings of the picture per second without changing the total number of lines transmitted per second. This doubles the speed at which the scanning spot is moved downward, so that we arrive at point x in Fig. 17D (at the bottom of the picture) in exactly the same time it took to reach point x in the middle of the picture in Fig. 17C.

In Fig. 17D, however, we have scanned only half the lowest line when vertical fly-back moves the spot up to point y for the following scanning. This time we scan along path 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, and 22. From point 22 the spot goes back to point 1 to start the next complete scanning. We are thus securing interlaced scanning of the complete scene.

Interlacing twice, as illustrated in Fig. 17D, is standard practice. To secure this without changing the total number of lines scanned per second, which would change the picture detail, the vertical scanning frequency must be twice the frame frequency and there must be an odd number of lines per frame.

Let us now consider interlaced scanning in terms of the standards in use for television. With 525 lines per frame, a vertical scanning frequency of 60 per second, and double interlaced scanning, the total number of lines

scanned per second must correspond to that scanned normally with a frame frequency of 30 per second. Multiplying 525 by 30 gives us 15,750 as the total number of lines scanned per second. This means that the frequency of the horizontal sweep is 15,750 cycles per second and that the vertical scanning sweep has a frequency of 60 cycles per second.

The detail in the image will correspond to that of 30 complete scannings per second of all lines in the 525-line image.

Actually a few lines at the top and bottom of each picture are blanked out by the blanking system associated with the vertical sync pulses for reasons that will be taken up later. The sync pulse itself prevents vertical fly-backs x-y and 22-1 in Fig. 17D from being visible.

Brightness and Contrast Controls

It is necessary that the television signal that is fed between the control grid and the cathode of the picture tube be pulsating d.c. and that it be applied to the tube in such a way that sync pulses will cause darkness, and picture signals will give various degrees of spot brightness. Another requirement for faithful reproduction of a scene is that the pedestals all line up with each other at the input of the picture tube despite any variations in the brightness of a scene. An example of this is shown in Fig. 18 where you will note that the pedestals in Fig. 18A have no more amplitude than those shown in Fig. 18B, although the video signal of Fig. 18A is far brighter than that of Fig. 18B.

Now let us see how signals such as those shown in Fig. 18 affect tube spot brightness when the pedestals are lined up with each other. Remember that the electron beam is focused to a small spot on the screen and that the negative voltage applied to the control grid of the tube determines the brilliance of the spot.

The control that this grid has upon the spot brilliancy is fairly linear with respect to the applied grid voltage, except that complete cut-off or darkening of the spot occurs at a definite high negative bias voltage.

This is clearly illustrated in the curve shown in Fig. 19. Note that as

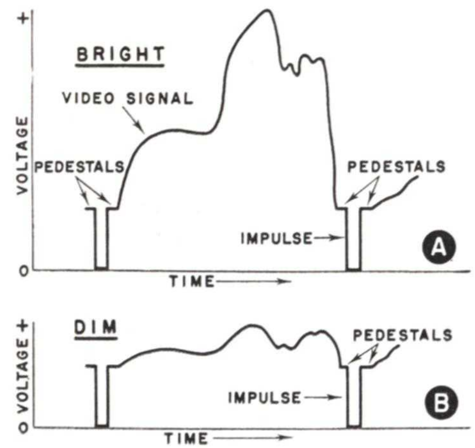


FIG. 18. The television signal which is applied between the grid and the cathode of a cathode-ray tube must have a constant pedestal voltage for scenes with all degrees of brightness, and must have a positive picture phase as shown here, so that the video signal will be positive with respect to the pedestal voltage, and the impulse signals will all be more negative than the pedestal voltage.

the video signal drives the grid of the picture tube in a positive direction the spot brilliancy will increase. Points 2, 3, 4, and 5 are increasingly brilliant and correspond to increasingly positive control grid voltages. This grid-voltage brilliancy-characteristic curve shown in Fig. 19 is quite similar to the grid-voltage—plate-cur-

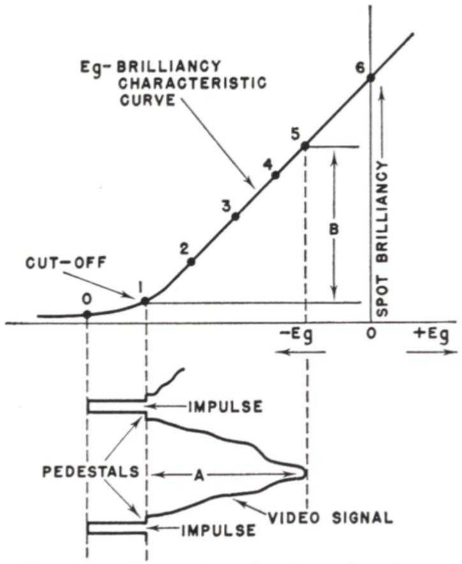


FIG. 19. Typical grid-voltage-brightness characteristic curve for a cathode-ray tube in a television receiver. Point 1 is considered the brilliancy cut-off point for the tube, as it corresponds to a spot brilliance weak enough to be indistinguishable to the human eye.

rent (Eg-Ip) characteristic curve of the average vacuum tube.

The negative bias on the grid of the picture tube must be chosen so that the pedestals in the applied television signal will be at the brilliancy cut-off point (point 1 in Fig. 19) on the characteristic curve of the tube.

With the picture tube bias properly adjusted, the video or picture signal will swing the grid more positive than cut-off, giving various degrees of brightness, and the sync pulse signals will drive the grid more negative than cut-off, so that the spot is darkened to the point where it cannot be seen. This is known as the blacker-than-black region of the characteristic curve.

When the video portion of the signal shown in Fig. 19 is acting on the grid-cathode of the picture tube the instantaneous control-grid voltage will vary between points 1 and 5 on the curve, and spot brilliancy will vary over the region indicated as B. The sync pulses associated with this signal will swing the grid beyond visual cut-off at point 1, and hence cannot produce a spot on the screen. As long as the pedestals line up with the cut-off point, the impulses cannot produce a visible spot even with a weak video signal, and a weak video signal, corresponding to a dim line or a dark scene, will cause the brilliancy to vary in the desired manner over the lower portion of the characteristic curve, such as between points 1 and 2.

However, suppose that the television signal in Fig. 19 were applied in such a way that the pedestals lined up with point 2. The video signal would swing the grid voltage positive from point 2 up along the curve to point 6, which is perfectly all right since the various shades of brightness would appear, but the sync pulses would only swing a small amount below cut-off and would not darken the spot completely. As a result vertical retraces would be clearly visible at the beginning and end of each frame as shown in Fig. 20. Such a condition would not give a picture that is satisfactory. Horizontal retraces are not seen as lines

because their time duration is too short to result in a trace visible to the eye.

Another undesirable condition occurs when the pedestals are beyond cut-off and line up with point 0 on the characteristic curve in Fig. 19. Under this condition, portions of the

Courtesy Philco Corp.

FIG. 20. A zigzag line rather than a single diagonal line appears because the horizontal sweep moves the beam from left to right several times before the vertical fly-back is completed.

video signal will swing into the dark region beyond cut-off, causing dimly lighted portions of the scene to appear black instead of gray as shown in Fig. 21. This condition is just as undesirable as that illustrated in Fig. 20.

The operating point on the Eg-brilliancy characteristic curve of a picture tube may be shifted in two different ways in order to make the pedestals line up with the black level (cut-off point) of the tube. One method involves adjusting the fixed C bias of the picture tube; the control in a television receiver that changes this bias is called the brilliancy control because its most noticeable effect is a change in the brilliancy of the reproduced image.

It is also possible to shift the pedestals in one direction or the other to make them line up with the cut-off point by changing the amplitude of the picture signal that is applied to the picture tube. The amount of signal that reaches the grid of the picture tube depends upon the amplification of the receiver, and by changing the gain of one or more stages through which the television signal passes we can vary the amount of signal that will reach the picture-tube input. The receiver control that changes the gain is called the contrast control, because its most noticeable effect is a change in the amount of contrast between bright and dark areas of the reproduced image.

If the picture appears as shown in Fig. 21, we can reduce the contrast control to restore the proper relationship between the bright and dark areas. On the other hand, if the receiver amplification is too low, giving us a flat gray picture with insufficient contrast, the amplification may be increased until the desired light and dark relationship is obtained.

Courtesy Philco Corp.

FIG. 21. The grid bias in this case is adjusted so that gray portions of the test pattern appear black, and we say the picture has too much contrast.

One point should be mentioned here that will be gone into in greater detail later. If the contrast is adjusted too high on a strong local station, some of the pedestals may be clipped by overloading the amplifier stages in the receiver and it will then be impossible to obtain proper synchronization of the picture due to the loss of the sync pulses.

Another requirement for a clear image is that the electron beam be focused to a clearly defined spot of the correct size on the screen. Improper adjustment will result in a fuzzy picture in which the lines are not clearly defined. An adjustable control, called the focus control, is provided to correct for errors in focusing due to the natural aging of the picture tube or to changes in part values.

The main adjustable controls for the sight section of a television receiver are the brilliancy control, the contrast control, the focus control, and the tuning control. Additional controls are also used that will be described later, but they are generally not on the front panel as they do not often require adjustment.

The controls on the front panel mentioned above must be adjusted to give an image that has the proper brilliancy and the correct contrast between elements along the line, with no vertical retraces visible. In general, when the brilliancy control is adjusted, the contrast control will also require resetting since there is some interaction between these controls.

Television Signal Standards

In order for a television system to be successful, the receiver must be easy to adjust, the cost of the receiver must be relatively low, and the transmitter must have as much control as possible over the receiver. This last requirement means that the receiver and the transmitter must be interlocked and synchronized. Furthermore, the type of transmission employed must be standardized to a certain extent—otherwise radical changes in the method of transmission might make all existing television receivers obsolete. At the same time, it would not be advisable to set up standards in such a way that it would be impossible to make improvements in the transmitting and receiving circuits. Standards are essential for a successful television system, but these standards must be sufficiently broad to permit future improvements that might make interlock and synchronism more reliable, or increase the definition of the reproduced scene.

Present standards set by the FCC for television transmission are summarized below:

1. *Television Channel Width; Channel Allocations.* The present standards provide for essentially single side-band transmission and reception (partial suppression of one set of side frequencies results in *vestigial side-band transmission*), for with this method of operation, sufficient detail for a satisfactory image along with the accompanying sound can be transmitted in a definite channel width of 6 megacycles. Twelve 6-mc. wide channels have been allocated by the Federal Communications Commission for television transmitters, as follows: 54 to 60, 60 to 66, 66 to 72, 76 to 82, 82 to 88, and seven other channels from 174 to 216 mc. A number of very-high frequency and microwave channels have been allocated for television relay purposes, such as linking the television studio to the transmitter by radio, linking the remote pick-up point to the transmitter by radio, or linking together television stations in different cities and towns to form a network. There is a possibility that the u.h.f. spectrum, around 500 mc., may be opened up for low-power transmitters to serve small cities and towns. For present-day receivers to pick up such transmissions a converter would be required. If such an addition to present TV channels should be made, such converters will be manufactured for them.

2. *Video and Sound Carrier Spacing.* The audio and video signals that make up a television program cannot be modulated on the same r.f. carrier; each must have its own carrier. By agreement *the sound carrier must be exactly 4.5 megacycles higher in frequency than the picture carrier.* To prevent interference between adjacent television channels or between a television carrier signal and services operating on adjacent carrier frequencies, it has been further agreed that there must be a .25-megacycle wide guard band at the high-frequency end of each television channel. These facts are illustrated by the chart in Fig. 22, that shows a typical distribution of signals in one 6-megacycle wide television channel.

3. *Frequency Relation Between Video and Sound Carrier.* An example will best illustrate the frequency relationship existing in a television channel. Suppose that the 76- to 82-megacycle channel is assigned to a particular television station. To give the required .25-megacycle guard band at the high-frequency end, the audio signal carrier must be placed at 81.75 megacycles. According to the standards, the video carrier must be 4.5 megacycles lower, or at 77.25 megacycles. It is not practical to remove all of the side frequencies below the frequency of the video carrier, so a portion of the channel must be provided for those frequencies that cannot be removed. This portion is indicated by the cross-hatched lines in Fig. 22. With this arrangement of a 6-megacycle channel, the frequency range of television equipment can be improved up to a maximum of about 4.25 megacycles without making existing television equipment obsolete.

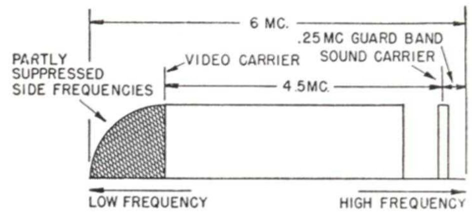


FIG. 22. Distribution of signals in a 6-megacycle-wide television channel.

4. *Type of Modulation; Black Level.* Negative modulation of the picture carrier signal is standard for the United States. As we have already pointed out, negative modulation means that *bright elements of a pic-*

ture are transmitted at low carrier levels, and *dark elements at high carrier levels.* The standards further specify that the black level or pedestal level at the transmitter shall be at a definite carrier level that remains fixed regardless of variations in sync pulse signals or in video signals. The black level at any one point in a television system is the

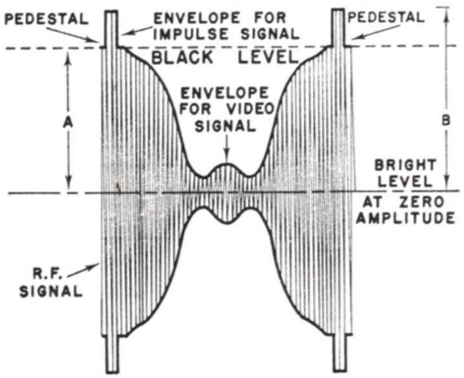


FIG. 23. Modulated r.f. carrier signal, with the amplitudes varying in accordance with a television signal. A is the unmodulated, and B the peak carrier level. This entire figure represents the transmitted side band. The vestigial side band (not shown) is much smaller in amplitude and would be somewhat distorted.

voltage that must exist at that point to give a just barely visible spot on the screen of a properly adjusted receiver.

5. *Sync-Pulse Amplitude.* Both horizontal and vertical sync pulses must be transmitted as carrier values higher than unmodulated carrier level (black level). These pulses extend from 75% (black level) to 100% of the peak carrier amplitude. The video signals may vary in amplitude from the black level down to 15% of the carrier level or lower. The general appearance of a typical modulated video carrier signal as it is fed into the television transmitting antenna is shown in Fig. 23. When there is no modulation, the r.f. carrier will have amplitude A, corresponding to the black level. Any increases in carrier amplitude must be for the synchronizing impulses; and decreases in carrier amplitude must be for the video signals.

6. *Horizontal, Vertical, and Frame Frequencies.* The establishment of standard values for these three frequencies was based upon the need for high-image definition with a minimum of flicker. The vertical scanning frequency (field frequency) is 60 times per second, for this value minimizes any trouble due to 60-cycle power ripple. (In England, where 50-cycle power lines are used, the field frequency has been standardized at 50 vertical scannings per second.) Since double interlaced scanning is used in the United States, two field sweeps are required to analyze all of the details once in a particular scene; these two vertical or field sweeps constitute a frame (one complete transmission of the picture), and consequently the standard for the frame frequency is 30 frames per second. As we have already seen, there are 525 lines per frame; this means that there are 262½ lines per field. With a 525-line picture being sent 30 times each second, the horizontal frequency becomes 525 times 30, or a total of 15,750 lines per second.

7. *Aspect Ratio.* This ratio has been standardized at 4/3, corresponding to existing motion picture standards and giving a width-to-height ratio of 4 to 3.

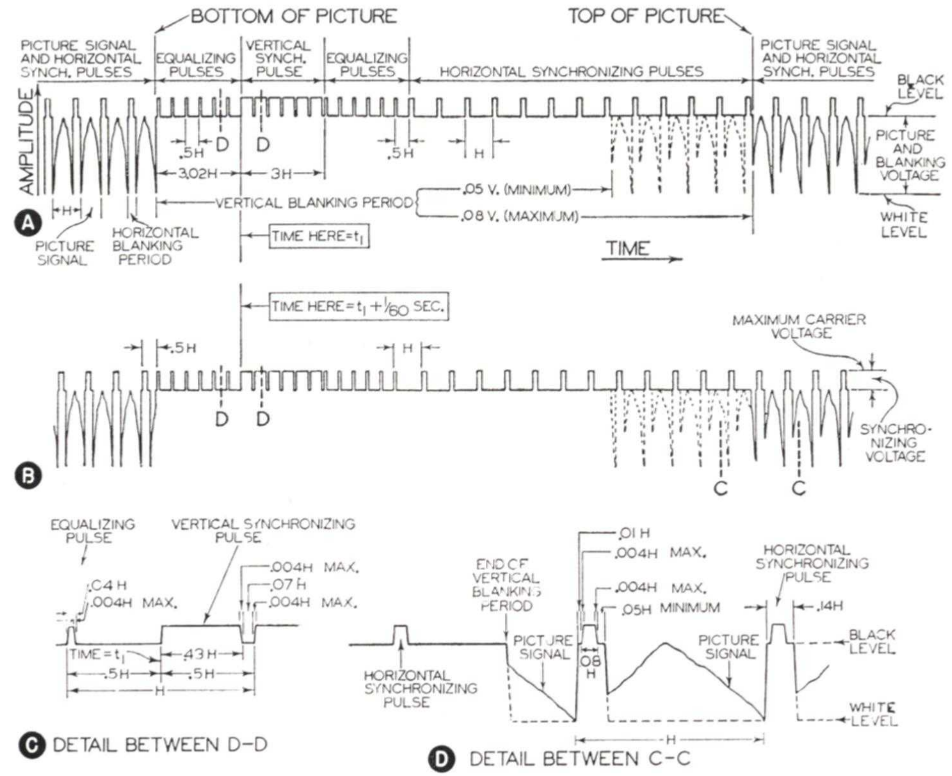


FIG. 24. Specifications for the standard television signal for 525-line pictures transmitted at the rate of 30 frames per second with double interlaced scanning, giving 60 fields per second. In these diagrams H is the time from the start of one line to the start of the next line, and is equal to 1/15,750 second. The time from the start of one field to the start of the next field is 1/60 second.

Diagrams A and B show blanking and synchronizing signals in regions of successive vertical blanking pulses. The black level is about .75 of the synchronizing pulse amplitude.

Horizontal dimensions in these diagrams are not drawn to scale. The receiver vertical retrace will be complete at the end of about .07 V during the vertical blanking period. The length of the vertical blanking period produced by the transmitter may vary between .05 V and .08 V. The leading and trailing edges of both the horizontal and the vertical blanking pulses have slopes (not indicated in A and B), which should be kept as steep as possible.

Diagram C is an enlarged detail view, drawn accurately to scale, of the signal between points D-D in diagrams A and B.

Diagram D is an enlarged detail view, drawn accurately to scale, of the signal between points C-C in diagram B.

8. *Synchronizing and Equalizing Impulses; Blanking.* The ability of a television transmitter to control the reproduced picture at the receiver depends entirely upon the synchronizing impulses. Many years of research have been spent on this problem, and many different forms of impulse signals have been tried. The standard synchronizing impulses shown in Fig. 24 have been found best suited to present and future requirements of television in this country. Pattern A shows, among other things, the sync

pulses recommended for the end of a frame; these will move the spot up to the top of the picture along the retrace path for the beginning of a new frame. Pattern B shows the impulse signal sequence recommended for the end of the first half-frame (the end of the first field); this moves the spot from the bottom to the top of the picture for the beginning of the second interlaced field scanning. A careful study of the diagrams in Fig. 24 will reveal five outstanding characteristics of a television signal:

I. The horizontal sync pulse that is transmitted at the end of each line is not exactly rectangular. The enlarged diagram in Fig. 24D shows the exact shape of this synchronizing signal.

II. The video signal is blanked out for a short interval before and after transmission of the horizontal sync pulse at the end of a line, in order to insure blanking during the horizontal retrace. The total time for this horizontal blanking shall be about 14% of the time from the start of one line to the start of the next line (this is designated as .14H at the right in Fig. 24D, H being the time from the start of one line to the start of the next line). Note that the horizontal pulse occupies about half of this blanking time, and that the front (leading) edge of the pulse is near the start of the horizontal blanking. The two portions of this blanking signal that are on each side of the horizontal sync pulse are known as *pedestals*, and are originally at the black level.

III. The vertical sync pulse exists for an interval of three lines, but this pulse is divided into six small pulses, each acting for half a line. This serrated pulse is shown in Fig. 24A. Each vertical pulse is divided into six small pulses or serrations in order to maintain horizontal sync pulses at all times. These serrations will be explained in detail later.

IV. Six equalizing pulses precede and six follow each vertical pulse period. The purpose of these will also be covered later.

V. The vertical blanking period starts slightly ahead of the first equalizing pulse and extends considerably beyond the last equalizing pulse; this vertical blanking period should take between 5% and 8% of the time for one vertical sweep. Note that horizontal sync pulses are transmitted during the latter portion of the vertical blanking period.

Explanation of Standards. As long as we have 60 vertical sweeps per second, interlaced scanning will continue automatically throughout a transmission. The vertical fly-backs or retraces will be 1/60 of a second apart; they may occur either near the beginning or near the end of the vertical sync pulse interval, but must occur at the same point in each pulse (this point is controlled by the design of the receiver).

Although the leading (left-hand) edge of the vertical sync pulse in Fig. 24A is directly above the leading edge of the vertical sync pulse in Fig. 24B, these actually occur 1/60 of a second apart due to interlacing. For this reason, the horizontal pulses at A and B in Fig. 24 are not in line.

Experience has shown that no matter what happens, the horizontal sync pulses must not stop even for a single line. If the vertical sync pulse were

made three lines long without breaking it up, no horizontal pulses would exist for this period. To avoid the situation, the vertical pulse is serrated or separated into six smaller pulses.

To visualize why the vertical sync pulse must be broken up, let us first assume that it is broken up into three pulses as shown in Fig. 25, and see what occurs under this condition. For the moment we will forget about the equalizing pulses. Pattern A in Fig. 24 shows the last horizontal sync pulse (just before the bottom of the picture) as being one whole line ahead of the start of the vertical blanking period, and pattern B shows this last horizontal pulse as only half a line ahead of the vertical blanking period; these are actual conditions for successive field sweeps, so we must consider them in Fig. 25. Horizontal sync pulses must exist for the entire vertical blanking period; this means that there should be horizontal sync pulses at points 2, 3, 4, and 5 in Fig. 25A. At each of these points there is a break or serration in the vertical pulse; since the leading edge of a pulse or serration is sufficient to control the horizontal sweep in the receiver, this will give adequate control of the horizontal sweep.

When we turn to pattern B in Fig. 25, however, we find that horizontal sync pulses should occur at points 2, 3, and 4. There are no steep leading edges at these points to control the line sweep, and consequently three serrations in the vertical impulse are not adequate for pattern B, which occurs for every other scanning of the picture. If the vertical impulse is divided into six parts as shown in Figs. 24A and 24B, we secure the desired steep front at points 2, 3, and 4 in pattern B in Fig. 25.

The vertical synchronizing pulse is chopped into segments by the application of a special signal having a rate twice that of the horizontal synchronizing signal. Because of the difficulty of synchronizing this signal exactly with the vertical pulse, this twice-normal signal exists somewhat before

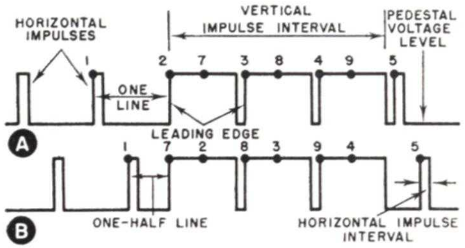


FIG. 25. These diagrams tell why the vertical synchronizing impulse signal must be broken up into six smaller impulses.

and after the vertical pulse as a series of horizontal synchronizing pulses at half-line intervals. Then, it is sure to cut up the vertical pulse properly. In Fig. 24A, these additional pulses are labeled "equalizing pulses." A pulse one-half a line from the proper one is ignored at the receiver; the sweep oscillator responds only to the pulse that occurs at the proper time to maintain the horizontal synchronization.

The value of this information will become apparent when you study sync circuits and methods of observing wave shapes with an oscilloscope. At that time you will find a review of this information helpful.

Fundamentals of TV Receiver Operation

Let us imagine that a TV transmitter that is operating on channel 2 is sending out signals having a frequency distribution as shown in Fig. 22, and let us consider just how this would be received and converted into an image by a typical television receiver having the sections shown in Fig. 26.

The superheterodyne circuit shown in Fig. 26 has the usual r.f. amplifier, mixer-first detector and local oscillator. In television, these sections are generally built together as a unit on a separate chassis. Where serious difficulty is experienced in this unit (called the "front end") the entire unit is removed and another one substituted. The front end is generally returned to the factory for any major repairs.

Referring to Fig. 22 again, you will see that two carriers are picked up by the antenna—the video carrier and the sound carrier. The r.f. amplifier response is sufficiently broad to pass both carriers without appreciable attenuation, and they are fed into the mixer input. In the early television receivers, the r.f. amplifier had an untuned input, double tuning of the band-pass variety being used between the r.f. amplifier and the mixer-first detector. In later models, the input of the r.f. amplifier is tuned, thus giving a much better signal-to-noise ratio and improving the over-all sensitivity of the receiver.

The two carriers are amplified by the r.f. amplifier and injected into the mixer, where they beat with the local oscillator signal and two separate i.f. signals are produced. The i.f. that is to be employed depends upon the design of the receiver. Generally the i.f. will be somewhere between 21 megacycles and 45 megacycles. The tendency is to go toward higher i.f. values to reduce image interference.

In this particular case we will assume that the local oscillator is operating at 81 megacycles. Since our station is assigned to channel 2 (54 to 60 megacycles), the picture carrier will be 55.25 megacycles and the sound carrier 59.75 megacycles. When these carriers beat with the 81-mc. signal of the local oscillator, a sound i.f. of 21.25 mc. and a picture i.f. of 25.75 mc. will be produced.

Sound Channel. In many receivers, separation of the two i.f. carriers is made at the output of the mixer as shown in Fig. 26. The sound i.f. signal then is fed through the sound amplifier, the limiter stage, a sound discriminator (which removes the audio modulation from the f.m. signal), through the first a.f. amplifier, to the power amplifier and to the loudspeaker.

As shown by the dotted lines, the sound i.f. signal may be taken off from the output of the first or the second video i.f. amplifier. In this case these amplifiers must have a wide enough response to pass both the video and the sound i.f. carriers. The object of taking the signal from the output of one of the video i.f.'s rather than from the mixer is to obtain a stronger sound i.f. signal, thus reducing the amount of amplification necessary in the sound i.f. amplifier.

As will be described in another Lesson in detail, the sound is sometimes taken from the output of the video amplifier. In this case the video i.f. amplifier must pass both the sound and the picture carriers. Since they are always separated by 4.5 megacycles, they will beat together in the video detector, producing a 4.5-megacycle signal modulated at an f.m. rate by the audio signal. The video amplifier will amplify this 4.5-megacycle signal and it may be removed from the output of the video amplifier and fed through a sound i.f. amplifier tuned to 4.5 megacycles. This signal is then fed through the sound discriminator, and the rest of the audio section in the usual manner. This is known as the intercarrier sound system and is employed in many of the lower-priced TV receivers.

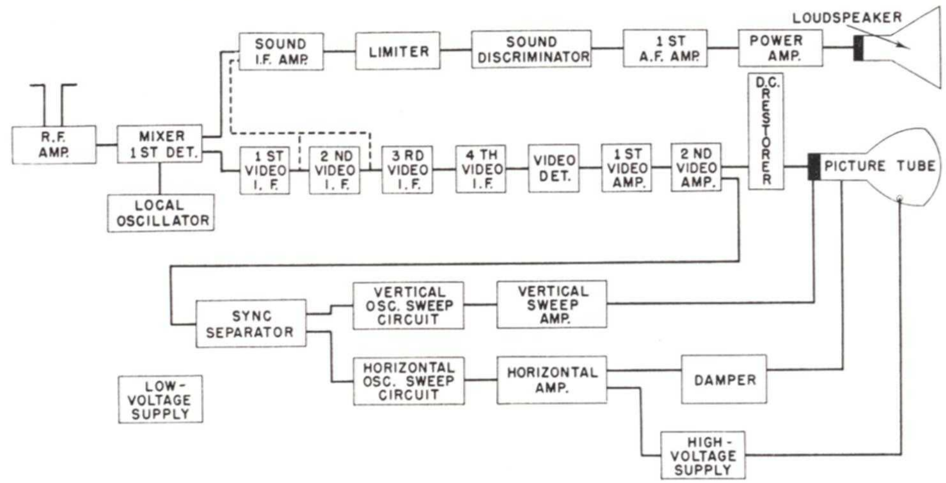


FIG. 26. Block diagram of modern TV Receiver.

Video Channel. At the mixer output we also have the video i.f. carrier that contains the picture signal and the sync pulses. You will note that four video i.f. stages are used in this particular circuit. Some less expensive receivers use three video i.f. amplifiers. In general the i.f. amplifiers are stagger-tuned, each i.f. stage being tuned to a different frequency. This enables us to obtain the necessary band width with a reasonably flat-topped response.* The amplified video i.f. carrier signal with its modulation is fed into the video detector, which is generally a half-wave diode. Here the modulation envelope is stripped from the carrier, giving us a signal similar to that shown in Fig. 18. This signal is then amplified by the first and second video amplifiers which correspond to audio amplifiers in a sound receiver. If direct coupling is used between the amplifiers and

* Some receivers use double-tuned video i.f. transformers that are overcoupled to give the necessary band width.

between them and the picture tube, the d.c. restorer shown in Fig. 26 is not needed.

If the video amplifier passes only the a.c. component of the television signal, a d.c. restoring circuit should be used just ahead of the television picture tube to restore the d.c. component, as you will learn in another Lesson. This d.c. potential must be restored in such a way that the pedestals will all line up with each other again, for they may be thrown considerably out of line by the video amplifier stages. All the components in the television signal, including the video signal itself, the horizontal and vertical sync pulses, and the equalizing pulses and pedestals are applied to the control grid of the picture tube.

Automatic gain control (a.g.c.) is a very desirable additional circuit in any TV set. Like automatic volume control in an ordinary sound receiver, a.g.c. compensates for fading and it also serves to supply the demodulator with an essentially constant signal. Of course, normal fading due to interaction between ground and sky waves is not apparent in a TV system, but it is perfectly possible for an effect like fading to occur due to swaying of the receiving antenna or the transmission line in the wind, or reflection of radio waves from moving objects such as automobiles or airplanes. If there are two or more television stations in a given locality, one may provide a stronger signal than the other at a given receiving point, causing different signal levels at the second video detector. Automatic gain control can compensate for all these effects.

In some receivers the a.v.c. system is actuated by the average carrier levels; in a television system, however, the average carrier level varies with the nature of the video signal being transmitted. The one fixed characteristic of a television signal is the black level; for a given station, this is fixed and corresponds to a definite carrier level. The sync pulses that are transmitted at amplitudes above the black level are likewise fixed, so by feeding the TV signal from some point in the receiver where the pedestals line up with each other (such as the output of the video second detector) and using an ordinary R-C filter that makes the output follow the peaks of the sync pulses, we can secure for the a.g.c. system a d.c. voltage whose value varies with the true carrier level of the TV signal.

Sweep Circuits. So far our study of the block diagram in Fig. 26 has been chiefly a review of an ordinary superheterodyne circuit. The remainder of the TV receiver, constituting the sweep circuits, is the only new thing.

In order to make the electron beam in the picture tube sweep both horizontally and vertically we need two sweep oscillators. These must be so designed that they can be controlled by the horizontal and vertical sync pulses in the TV signal. The sync pulses must be separated from the video signal before they can be applied to the sweep circuits. This separation is accomplished in the stage known as the sync separator.

The TV signal that is fed into the sync separator must be taken off from some point after the video detector.

A sync separator may consist of a diode tube or a negatively biased triode tube that will clip off the video signals, leaving only the sync pulses.

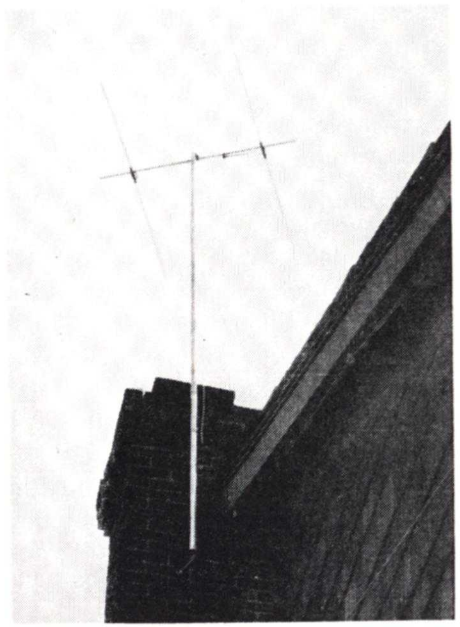
After the pulses have been separated from the video signal there will remain the problem of separating the horizontal sync pulses from the vertical sync pulses. The circuits that accomplish this are built into the inputs of the vertical and horizontal sweep circuits. Generally they consist of ordinary R-C filters; a low-pass filter is used for the vertical sweep input, and a high-pass filter that will accept the 15,750-kc. horizontal pulse is used at the input of the horizontal sweep circuit.

The outputs of the sweeps are fed through amplifiers and into the picture control circuits that will be either deflection plates in the case of the electrostatic picture tube or deflection coils in the case of the electromagnetic type picture tube.

The damper shown in Fig. 26 is used with electromagnetic picture tubes and damps out any tendency toward oscillation in the horizontal deflection coils. Due to the relatively high frequency employed here and the inductance in the coils, oscillation might take place if it were not for this damper circuit. This circuit will be studied in detail in other Lessons. The damper is not required where electrostatic deflection is employed.

Power Supplies. Power supplies are an essential part of a television receiver since the various tubes will require both a.c. and d.c. operating voltages. The low-voltage supply is similar to those used in sound receivers, although due to the large number of tubes in a TV set a pair of rectifiers in parallel may be used instead of a single rectifier. The power transformer will be much larger than that found in a broadcast set.

In many of the inexpensive television receivers the tube filaments are wired in series as in an a.c.-d.c. set. Due to the number of tubes encountered, more than one filament string is generally necessary. Selenium rectifiers are also widely used in voltage-doubler, and in some cases voltage-tripler, circuits. This eliminates the expensive power transformer.



Courtesy Philco Corp.

A typical TV antenna installation.

In addition, high voltage must be supplied for the second anode of the picture tube. This is obtained from a separate supply source. In the electromagnetic type receiver that is illustrated in Fig. 26, the high voltage is obtained from a part of the horizontal amplifier circuit. In other cases the high voltage may be independent of this circuit. The great advantage of having the high voltage tied to the horizontal amplifier circuit is in case the horizontal sweep chain fails, the high voltage will go out so that the picture tube will be protected. All types of high-voltage supplies will be described in greater detail later on.

CONTROLS

Adjustments must be provided in the receiver for controlling the action in the various circuits.

There will be a channel selector that corresponds to the tuning control in a broadcast set, a picture contrast control that corresponds to the volume control, a brilliancy control to vary the bias of the picture tube, and in addition to this there will be the usual audio type volume control and on-off switch in the sound system.

Additional controls will be found in the sweep- and picture-tube circuits. We must have controls that will vary the size of the picture horizontally and vertically, also controls that will make the vertical and horizontal oscillators lock in with the sync pulses. In any TV set you will find some means of centering the picture in the middle of the screen since in the manufacturing of tubes it is almost impossible to line up the electrodes perfectly.

The controls that are associated with the sweep circuits are generally on the back of the receiver since they seldom need to be adjusted. In some sets a few other special controls that need not be considered here will be encountered.

LOOKING FORWARD

In this first introductory Lesson on television we have surveyed the important needs of a television system. In some cases, brief explanations of these needs have been given and in other cases we have simply made statements because the explanations would be lengthy and not essential to clearness in this "bird's-eye view" of the entire television setup. The various methods for producing saw-tooth sweep signals, for providing interlocks, and for separating sync-pulse signals will all be taken up in later Lessons along with the typical circuits for the various other sections described in this Lesson.

Lesson Questions

Be sure to number your Answer Sheet 49RH-4.

Place your Student Number on *every* Answer Sheet.

***Send in your set of answers for this Lesson immediately after you finish them,* as instructed in the Study Schedule. This will give you the greatest possible benefit from our speedy personal grading service.**

1. Why is it that a TV picture signal does not require a channel band width equal to twice the modulating frequency?
2. What converts a scene into a succession of signal intensities?
3. What characteristic of the eye makes it possible to send a picture signal a portion at a time, and yet have the resulting picture appear as a complete scene?
4. What is the purpose of the sync pulses sent out by the transmitter?
5. Are the line sync pulses sent: 1, *at the beginning;* or 2, *at the end* of each line?
6. What is the advantage of using negative modulation of the picture carrier signal?
7. In an electrostatic picture tube, the voltage on which element is varied to focus the beam?
8. What effect on the picture is seen when the gain of a TV receiver is varied?
9. What is the frequency of (A) the vertical scanning, and (B) the horizontal scanning?
10. If both the sound and picture carriers are allowed to reach the second video detector, what will be the resulting beat frequency?

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

SELF-EDUCATION

"The best culture is not obtained from teachers when at school or college—but by our own diligent *self-education* when we have become men."

This quotation has been proved true many, many times. Let's take a few outstanding examples. President Ulysses Grant was often called "Useless" by his mother because he showed so little promise as a young man. General Stonewall Jackson was noted for his slowness while a pupil at West Point. Watt—who invented the steam engine—was notoriously dull in school. Sir Walter Scott was outstanding in school *only* for his readiness to pick a fight—and was not known as an author until he was over forty.

To again quote, Gibbon said, "Every person has two educations. One which he receives from others —and one, more important, which he gives to himself."

You are now busy *giving yourself* education in Radio and Television which can and should be the most important education of your entire career.

J. E. Smith