Introduction to Modern Cathode-Ray Television Reception

Fundamentals of Scanning and the Make-Up of the Television Signal

By Marshall P. Wilder,* W2KJL

IT IS timely that we take a serious interest in modern television as a certain future activity in amateur radio. In this, the first of a series of technical articles on practical television, the general background will be presented.

The purpose of this series is not just to present purely theoretical television receiver design. On the contrary, straightforward practical data will be given, dope that can be used not only to give an understanding of the principles but also to make possible the construction and adjustment of a cathode-ray television receiver that works. But before tackling the working circuits it is necessary that a great deal concerning the make-up of the television signal and what goes on in television reception must be thoroughly understood, so that when the images (or beginnings of images) appear on the screen, it will be possible, by looking at the tube, to tell what adjustments need be made and where further effort should be expended to improve the quality. Only by a thorough understanding of the fundamentals, coupled with actual experience with a working television receiver, will it be possible for the amateur to participate usefully in the development of this new art.

SCANNING

No picture or scene is properly intelligible to the human eye unless it can be perceived instantaneously as a complete whole. Unfortunately, no practical electrical communication system is capable of handling more than one element of information at any instant. The inability of electrical communication systems to transmit a picture as a whole makes it necessary to dissect the picture into a large number of small elemental areas—to transmit them one by one, and to reassemble them in their appropriate positions at the receiver, in order that the observer may view the scene as a whole. If this process of dissection and reconstruction is performed a sufficient number of times per second, the eye receives the impression of a complete picture as a result of the phenomenon of "persistence of vision." This dissection of the picture into small elemental areas is known as *scanning.*

Although scanning may be performed in several ways, it is usual to scan the picture in lines from left to right and to proceed line by line from top to bottom, in much the same way as one's eye scans in reading the pages of this magazine. This system, with a modification known as *interlacing,* has been adopted in modern practice.

Interlaced scanning requires that one line of the subject be scanned, then a line skipped, then another line scanned, and so on, until the whole scene has been covered, in alternate lines, from top to bottom. Then the scene is scanned again, getting those intervening lines that were not scanned previously. Interlaced scanning has the distinct advantage that the number of views per second presented to the eye is double the number with straight scanning; and, although the number of picture elements transmitted is no greater than in straight scanning, the rate at which flicker occurs is twice as fast and above the rate at which flicker is annoying to the eye.

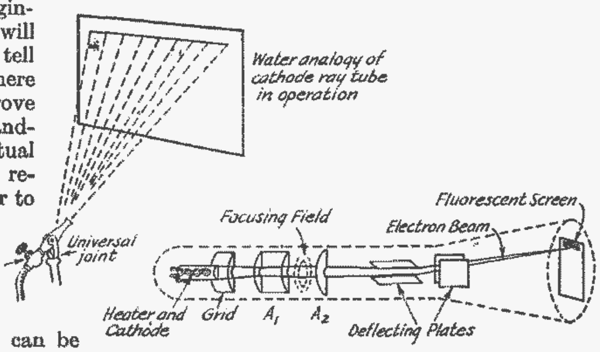

FIG. 1—ILLUSTRATING THE PICTURE-REPRODUCING ACTION OF THE CATHODE-RAY TUBE

Television to-day is received on a cathode-ray tube. Referring to Fig. 1, we have a tube consisting of a source from which a beam of electrons is projected onto a screen, a means of deflecting this beam so it will terminate at any desired spot on the screen, and a means of controlling the number of electrons in the beam. Let us study each part separately, and thereby properly understand the action of the whole.

A simple analogy of the cathode-ray tube is difficult to find, but if we consider a fine jet of water as a stream coming from a nozzle, which can be moved backward and forward, or up and down, we can more easily understand the action

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taking place. If, as in Fig. 1, a nozzle were set up before a screen and then moved from left to right it would draw a line of a width equal to the diameter of the stream. If we jerk this stream back to the left very many times faster than we moved it over from left to right, only a comparatively few drops of water will strike the screen during the return trip; and if we return from right to left in a slightly downward direction, the jet

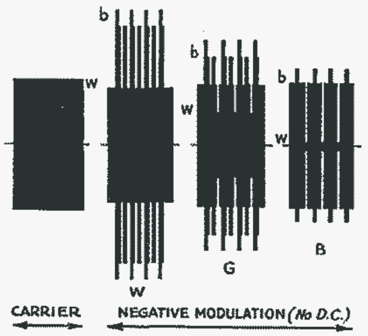


FIG 2

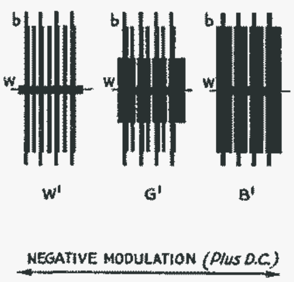


FIG 3

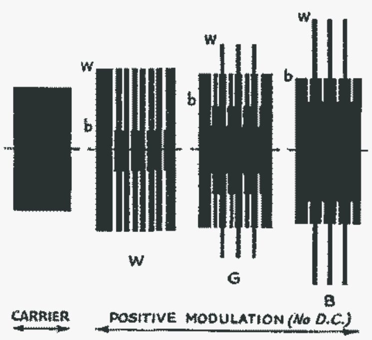


FIG 4

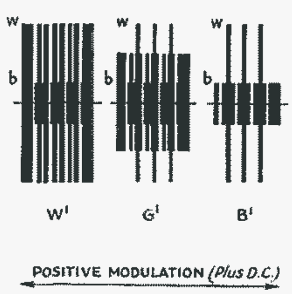


FIG. 5

FIGS. 2, 3, 4 AND 5—FOUR TYPES OF TELEVISION SIGNAL R.F. WAVES REPRESENTING SCANNING OF SIMPLE IMAGES

In each figure, W and W' correspond to a black vertical bar on a white background, G and G' to a white vertical bar and a black vertical bar on a gray background, B and B' to a white vertical bar on a black background. The small letters b and w on the diagrams indicate the voltage corresponding to black and white, respectively. The average amplitude and the voltage difference between b and w are intended to be the same for each condition. The synchronizing signals are the maximum parts of the wave amplitude with negative modulation, and the minimum parts with positive modulation. Without d.c. modulation, the carrier amplitude is constant and the peak amplitude varies in accordance with pedestal height. With d.c. modulation the carrier amplitude varies but the peak amplitude remains constant.

will be ready to start again from left to right and draw a second line, and so on to the bottom of the screen, where a quick jerk up to the top would set the process to begin again. To carry the analogy further, we might control the density of this stream by manipulating a valve. If we vary the amount of water projected, the result will be some sort of an image consisting of varying values of wetness; and if the valve were controlled in some proper sequence, a picture might be produced.

Of course it would not be possible to make such a piece of apparatus work as a television receiver because of the inertia of its moving parts. But, in a cathode-ray tube the stream is an inertialess electron beam. Since electrons are invisible, only the effect of their impact on the screen can be seen. This impact is visible when electrons strike certain salts, notably zinc and cadmium sulphide or their silicates. A coating of one of these materials is applied to the inside of the bulb in a thin, even layer so that the beam striking any part will show up at the point where it impinges as a more or less bright spot of light.

The intensity of this light can be controlled by varying the density of the electron beam. This control action is similar to that employed in an amplifying vacuum tube, the flow of electrons from the cathode being controlled or modulated by varying the voltage on a grid in familiar fashion. After this control or modulation, the emitted electrons getting past the grid are assembled by a focussing field which bundles them into a narrow beam and urges them in a forward direction between two deflecting fields, one horizontal and the other vertical. The two fields may be either electro-static or electro-magnetic.

The strength of these crossed fields is varied in the proper sequence by local oscillators controlled by synchronizing impulses derived from the received television signal. Thus the modulated beam is made to move across the fluorescent screen horizontally in practically straight lines, and vertically from line to line, in a manner similar to that outlined in the water analogy, so that a picture of varying light intensity can be obtained.

Before considering further the actual details of how a television picture is produced in a modern cathode-ray receiver, it is well to summarize the six essential requirements which must be satisfied.

First, a beam of electrons of very small cross-section must be produced and made to strike a screen of special material which will reveal the beam's incidence at the point of contact as a spot of light.

Second, the beam must be made to scan a given area in a proper sequence.

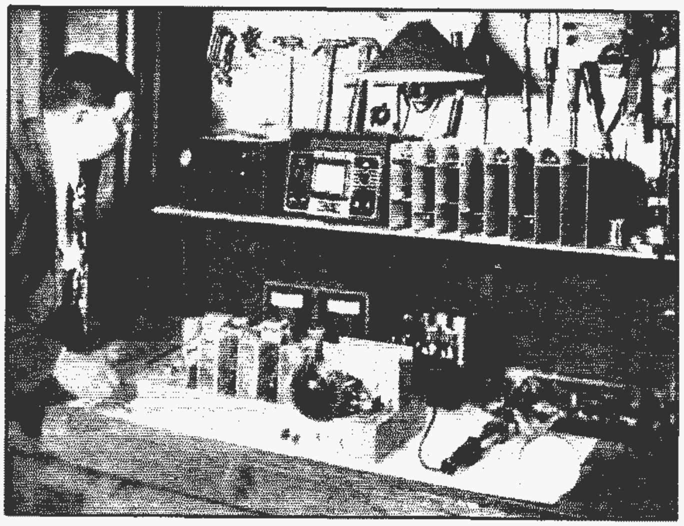
Third, the density of the beam must be capable of variation by the received impulses from the television transmitter.

Fourth, the speed of travel of the beam on the receiving tube screen must be the same as that of the scanning beam at the transmitter. This is accomplished by setting the oscillator which generates the deflecting field to run at approximately the correct rate and then applying correcting impulses at the completion of each line and at the completion of each half-frame or field. These correcting impulses are extracted from the signal received from the transmitter and are known as *synchronizing impulses*.

Fifth, *blanking impulses*, also from the transmitter, must be extracted from the received signal and applied to the beam during the retrace of each line and during the fly-back to the top of each half-frame so the beam will not have sufficient intensity to show up as light during the return trace.

Sixth, and finally, the average brightness of the picture must be transcribed from the incoming signal. Since the average brightness is of a relatively fixed nature, only varying occasionally as when the scene shifts from a dimly lighted room into a bright one, the average brightness variation must be considered as of very low frequency —or practically d.c.

There is now nearly general agreement on the technicalities for meeting these six requirements in practice— except on the method of transmitting the average brightness level and on the polarity of modulation which should be employed. With regard to transmission of information giving the average brightness or background, two methods are being used experimentally at the present time. One method employs modulation of the transmitted r.f. signal by d.c. which varies in accordance with the average brightness of the scene televised. The other method utilizes the variation in the amplitude of what is known as the *pedestal* component of the complete signal to control the average brightness of the received picture, as will be described later. The second unsettled point is whether the polarity of modulation should be negative or positive. With modulation of negative polarity, maximum amplitude of the modulated wave corresponds to black and minimum amplitude to white; while with positive modulation, maximum amplitude of the wave corresponds to white and minimum amplitude to black. The differences between television waves of positive and negative polarity, with and without d.c. modulation, are illustrated [1] in Figs. 2, 3, 4 and 5, which will be discussed later.



THE AUTHOR TESTING AN EXPERIMENTAL SUPERHETERODYNE TYPE TELEVISION RECEIVER, ONE OF THE MODELS DEVELOPED BY HIM IN PREPARATION FOR THE SERIES OF ARTICLES OF WHICH THIS IS THE FIRST

While these two technicalities affect the design of the television receiver, an experimental receiver employing electronic scanning can be readily adapted to receive any one of the types of transmission now in use.

The current American system employs 441 lines. These 441 lines are broken up into two half-frames of 220½ lines each. Approximately 20½ lines of each half-frame are employed for transmitting the field-frequency synchronizing impulse, as well as for blocking out the frame return trace. At the end of each line is a synchronizing impulse consisting of a pulse riding on a pedestal. The pedestal voltage is rectified and the resulting d.c. voltage determines the average brightness of the received image in accordance with that of the scene transmitted. These pedestals are used also to block the grid of the cathode ray tube to remove the return trace during the fly-back of the spot at the end of each line. To do this, the pedestal component is separated from the signal and rectified. The resulting d.c. voltage is automatically applied to bias the grid of the cathode-ray tube during each line, the video-frequency voltage being superimposed on this bias.

Meanwhile, the grid, under control of the *video*

[1] Reproduced by permission of the author and publishers from the article, "Standards in Television," by H. M. Lewis (Hazeltine Service Corp.), *Electronics*, July, 1937.

(picture element) modulation portion of the signal, determines the instantaneous brightness of the spot. In other words, the pedestal at the end of each line sets the d.c. grid bias and the video signal in between pedestals changes the intensity along each line. This is continued line by line to make up one half-frame. There are two half-frames interlaced to form one frame or picture. Thirty such completed pictures are transmitted in one second; that is, the frame or picture frequency is 30 per second, and the half-frame or *field* frequency is 60 per second.

In Fig. 2, a typical signal with negative modulation is represented. With the signal of Fig. 2-W a black bar on a white background would appear. The second picture, Fig. 2-G, corresponds to a white bar and a black vertical bar on a gray background, and Fig. 2-B to a white vertical bar on a black background. Figs. 3, 4 and 5 are for the same patterns with other types of modulation, which will be discussed later.

ANALYZING A TELEVISION SIGNAL

Fig. 6 represents a part of two half-frames with their line- and frame-synchronizing pulses, for a television signal wave with negative modulation. The pulses appear on the leading edge at the top of a pedestal. The width of the pedestal is equal to 1/10th of a line length. The pedestal voltage is used to bias the grid of the cathode-ray tube beyond cut-off during the retrace of the spot and to transmit the background brightness component, as previously explained. The drawing shows where the video signal stops and the synchronizing and blanking signal begins. Note that the video signal amplitude extends only part way up to the maximum amplitude of the complex signal. All signals in the region above this limit will automatically bias the grid of the picture receiving tube black. This region is therefore known as the "blacker-than-black" region, and in it all synchronizing impulses can be transmitted without appearing in the pattern of the received picture.

With negative polarity and no d.c. modulation, the average voltage of the video modulation is constant, but the height of the pedestal varies. As previously discussed, this changing pedestal amplitude conveys the average picture brightness. In Fig. 2-W the height of the pedestal is a maximum, and the picture background is white. In Fig. 2-G the pedestal is one-half the height it was in Fig. 2-W and, in this case, the background is gray; that is, half-way between black and white. In Fig. 2-B, where the pedestal height is zero, the background is black. Thus, we find our transmitted signal consisting of three major parts—

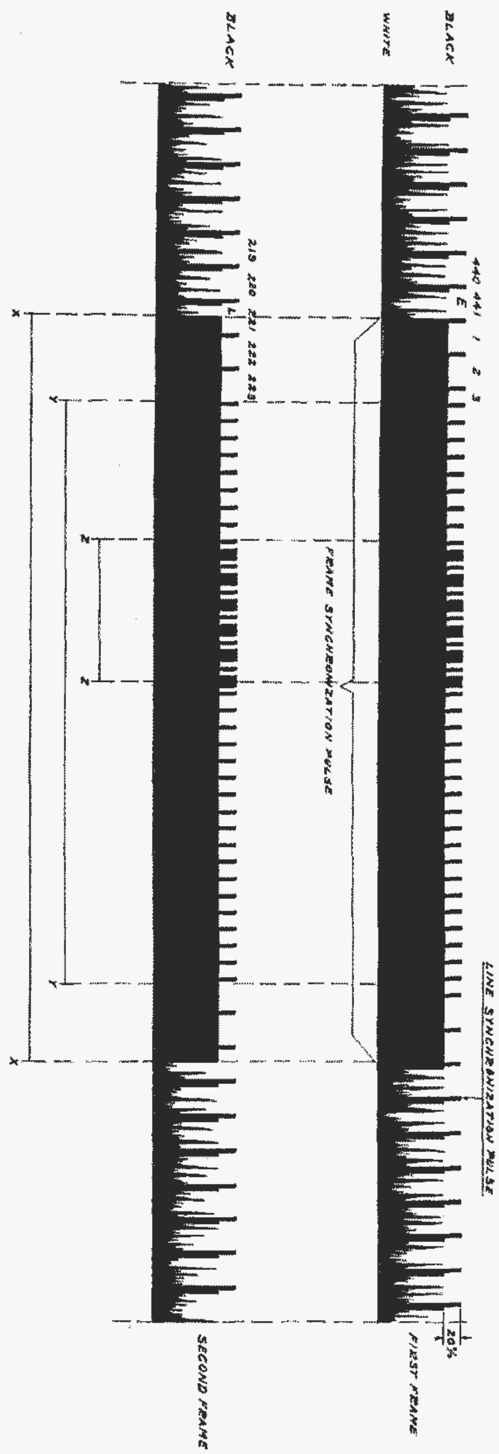


FIG. 6—CORRESPONDING SECTIONS OF TWO INTERLACED HALF-FRAMES OF A TELEVISION SIGNAL, SHOWING THE RELATION BETWEEN LINE-FREQUENCY AND FRAME-FREQUENCY SYNCHRONIZING PULSES

video signal, synchronizing pulse and pedestal.

If we return now to Fig. 6, and study the line and frame synchronizing pulses, we see the line pulse occurring in proper phase relation at the end of each line. A frame-frequency pulse occurs during a 20½-line interval every sixtieth of a second and consists of a group of serrations, from "X" to "X" on the diagram. Now it might appear simpler to transmit one long 60-cycle impulse for frame synchronization; but during such a long pulse, the line-frequency sweep generator would get out of synchronization. Therefore, it is necessary to transmit the line impulses *during* the frame impulse to keep the line-sweep generator constantly in step.

In the section called the frame or vertical synchronizing impulse region, extra impulses of a frequency which is a multiple of the line pulse frequency are inserted. These pulses will not disturb the line synchronization but will make the synchronizing impulses identical in phase and number in the region "Y-Y." Hence, integration of the frame impulse "Z-Z" can be accomplished in an *RC* circuit with less critical adjustment of the line- and frame-impulse separation circuit, allowing the low-frequency sweep generator to return the spot to the top of the screen ready to start the second half-frame without interrupting the line synchronization.

Interlacing of the lines of each frame is controlled by the phasing of the line-synchronizing impulse. These impulses are evenly spaced during the half-frame. They begin one-half line earlier on the first half-frame, as at "E" in Fig. 6. They begin a little later on the second half-frame, as at "L" in Fig. 6. Each time a half-frame of 220½ lines is drawn, the line placement will shift (up or down) a line-width on the cathode-ray tube screen. During the second half-frame, for instance, as the first impulse "L" is purposely delayed a half-line, the top line will be just one line-width lower down. This second half-frame of lines will fill in between the lines drawn during the first half-frame to complete one complete frame or picture.

The system which has been described in detail is that employing negative polarity without d.c. modulation to correspond with changes in average brightness. Although this system has been principally used for experimental transmission in this country up to the present time, it must be emphasized that there is no definite assurance that it will be the one used ultimately by the broadcasting stations. As previously mentioned, at least three other combinations are possible. That represented by the wave diagrams of Fig. 5, employing positive polarity with d.c. modulation, is preferred by a considerable number of engineers, for instance.[1,2] This is the type of signal transmitted by England's television station. Both systems have certain desirable characteristics for the particular service in which they are employed.

All four systems can be received on the same experimental television receiver, provided a suitable circuit is incorporated to restore the d.c. component and provision is made for reception of signals with either positive or negative modulation. A special circuit will restore the d.c. regardless of the manner in which it is transmitted, while a simple switching arrangement can be used to change the detected signal polarity to accommodate either position or negative modulation.

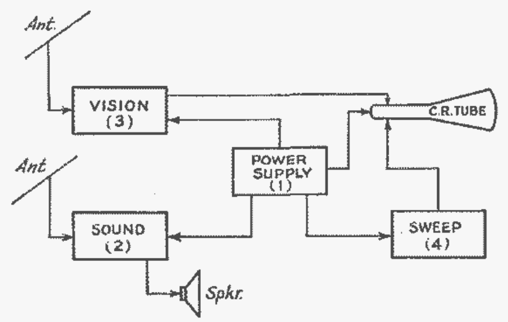


FIG. 7—BLOCK DIAGRAM OF THE UNITS OF A TELEVISION RECEIVER

It has been decided recently that a series of tests will be run by television broadcasters to determine which of these methods will be the most acceptable under actual operating conditions and will make the manufacture of television receivers the easiest. A receiver designed to be instantly adaptable to any one of the four types of signals will place the amateur in an especially effective position, since he will then be able to coöperate in the tests and furnish valuable information as to which method gives the best signal-to-noise ratio, which method causes the least difficulty in synchronization, and produces the best picture.

The receiver which will be described in subsequent issues of *QST* has been designed to have this desirable adaptability.

A WORD ABOUT STANDARDS

The tentative standards which are in use by the experimental transmitters on the air at the time of this writing, are as follows:

1. Frequency allocation, 42 megacycles to 90 megacycles, excepting the amateur 56- to 60-Mc. band; also an experimental band starting at 120 megacycles.[3]

(Continued on page 68)

[2] H. M. Lewis and A. V. Loughren, "Television in Great Britain," *Electronics*, Oct., 1937.

[3] New orders of the Federal Communications Commission change this allocation set-up, establishing the following channels for television: 44–50 Mc., 50–56 Mc., 66–72 Mc., 78–84 Mc., 84–90 Mc., 96–102 Mc., 102–108 Mc., and 12 additional channels above 156 Mc. This allocation does not become finally effective until Oct., 1938, however, and modification is possible before that time. See "The Editor's Mill," elsewhere in this issue.—EDITOR.

Introduction to Modern Television

(Continued from page 16)

2. Channel width, 6 megacycles.

3. Spacing between television and sound carriers, approximately 3.25 megacycles.

4. Television carrier higher in frequency than sound carrier.

5. Polarity of modulation, negative or positive.

6. Number of lines per picture, 441 (interlaced).

7. Picture or frame frequency, 30 per second; half-frame or field frequency, 60 per second.

8. Aspect ratio (width to height of picture), 4-to-3.

9. Percentage of television signal amplitude devoted to synchronizing signal, not less than 20%.

10. Duration of horizontal impulse, approximately 1/10 of the time to scan one line; duration of blanking impulse, 1/10 of the time to scan one half-frame; position of synchronizing impulse, approximately at leading edge of blanking signal impulse. (Average brightness of the picture transmitted by either varying the pedestal height or by d.c. modulation of the output of the transmitter.)

A simple formula gives the minimum bandwidth necessary in the receiver to obtain satisfactory pictures. This formula is

$$F = 0.64 \frac{A \times N \times n^2}{2}$$

where F = the maximum modulation frequency transmitted, A = the aspect ratio, N = the number of complete pictures scanned per second, n = the number of lines, and 0.64 is a correcting factor to give equal vertical and horizontal detail.[4]

It will be seen from this formula that it is necessary to transmit a sideband approximately 2½ megacycles wide. This means that intermediate frequency stages must pass at least 2½ megacycles with the signal tuned in so that single-sideband reception is approached.

UNITS OF THE TELEVISION RECEIVER

In the block diagram Fig. 7 are outlined the components of a modern television receiver. It consists of four different units. The first contains two power supplies, one for the tuners and sweep circuits, the other to generate high-voltage d.c. to accelerate and focus the cathode-ray beam. The second unit contains a sound receiver which may be a simple ultra-high frequency type. The third unit is the vision receiver, which may be either a tuned r.f. job, if one is comparatively near a transmitter, or a superheterodyne for more effec-

[4] Kell, Bedford and Trainor, *Television* (RCA Technical Press.)