"HOW IT WORKS"

Special Section of Volume X

by

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HOW IT WORKS

Special Section of Volume X

RIDER'S MANUAL

CONTENTS

	PAGE
TELEVISION—HOW IT WORKS	3
Comparison with Sound Broadcasting	3
Scanning	4
The Picture Tube	8
The Camera Tube	11
Scanning and Synchronization	13
Flicker and Hum on the Raster	14
Scanning Waveform	14
Overall View of a Television System	15
The Television Signal	16
Signal and Sync Pulses	18
RMA Standard Television Signal	19
Range of Frequencies in Video Signal	20
The Modulated Wave	22
Channel Make-up	23
Television Receiver Circuits	24
R-F and Oscillator Circuits	26
High-Frequency Section of Belmont X-466	27
High-Frequency Section of DuMont 180-183	28
I-F Circuits	28
Video I-F Circuits	30
Video I-F Circuit in Andrea 1F5	31
Video I-F Circuit in RCA TRK-12	32
Video Second Detector Circuits	34
Video Second Detector in DuMont 180-183	34
Video Second Detector in RCA TRK-12	34
Video AVC Circuits	35
Video AVC in RCA TRK-12	36
Video Amplifiers	37
Average Brightness and D-C Restorer Circuits	38
D-C Restorer Circuits	39
Brightness Control	41
Grid Leak-Condenser Restorer	41
The Contrast Control	42
Synchronizing Circuits	42
Sync Separator Circuit	43
Horizontal and Vertical Sync Selectors	44
Deflection Circuits	45
Electromagnetic Circuits	45
Blocking Oscillator	46
Width and Height Controls	47
Damping Tube	47
Electrostatic Deflection	48
Power Supplies	48
Antennas and Installation	50
FREQUENCY MODULATION	52
Advantages	52
How Noise is Reduced	52
What the Limiter Does	53
Special Detector Used	53
How the Discriminator Detects	54
The G.E. GM-125 Receiver	54
Alignment	55
WIRELESS RECORD PLAYERS	55
General Service Notes	56
FACSIMILE RECEIVERS	57
SERVICING BY SIGNAL TRACING	58

PREFACE

1939 witnessed the start of commercial exploitation of modern television. With two stations in operation, one at each end of the continent and other stations under construction in a number of the larger centers of population, television received a very definite stimulus. As a matter of fact, a number of different makes of television receivers are being demonstrated here in New York, with the NBC station W2XBS as the source of signals.

It therefore is only natural that television receivers be included in Rider's Manual Volume X and concurrently with the appearance of these service notes, we feel that an explanation of the subject of television transmission and reception should be a part of this "How It Works" section.

In this discussion you will find not only an explanation of the "how" of television but also a breakdown of some of the circuits to be found in the commercial television receivers contained in Rider's Volume X. Inasmuch as a certain amount of standardization in television transmission has been accomplished, the facts given herein will be found of interest at least for several years to come.

The presentation of facts is by no means complete. To cover the subject fully would take volumes. However, we feel that what is here presented is the actual "meat" and will be sufficient to give an insight to the *modus operandi* of television.

You also will find some facts pertaining to another development in transmission, one with myriad possibilities, namely frequency modulation. At present only a few receivers suitable for the reception of such signals are in use, but if what the originators say is true, we can look forward in the years to come to a general transition from the present amplitude-modulated form of transmission to the frequency-modulated form of transmission, with a corresponding radical change in receivers.

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TELEVISION—HOW IT WORKS

No COMMENTS can be made on advances in the radio art during the past year without recognizing that after many years of development, television has finally reached the stage where servicemen can no longer afford to ignore its existence. In some parts of the country television is already an accomplished fact; hundreds of receivers have been installed and sold, and all signs point toward the gradual expansion of television facilities into sections which do not have coverage at the present time.

Recognizing, then, that the radio serviceman's job is being extended to include not only radio servicing as we know it today, but also the servicing of television receivers, this section explaining the fundamentals of television is being offered in the belief that it will be of help to many of you in dealing with the problems introduced by television. Throughout you will find that it is written from the viewpoint of the man who is called upon to install and service television receivers; and yet, although there is this emphasis on the practical aspects of television, you will find that an essential amount of theory is included. Lest any of you feel that this inclusion of what might be called "theoretical" material is unnecessary, it should be pointed out that television is an extremely complicated subject, much more so in fact than is radio, and that television receivers cannot be serviced efficiently by any one who does not understand the principles underlying the operation of the system. The different situations which can arise are so numerous that it is indeed impossible to list them, to explain the reasons for each, and in the case of faulty operation to locate the source of the trouble. As in radio servicing, so it is in television servicing: a thorough understanding of the fundamental principles of operation is invaluable.

Fortunately for the radio serviceman, the advent of television does not mean that an entirely new field must be learned. The more you study television, the more you will come to realize that television embodies every principle that has ever been used in radio—and more besides. You will marvel at the ingenuity of television engineers in using the same old time-proved principles of radio, in adapting these to the needs of television, and in discovering new principles and new techniques wherever the available ones were inadequate. Thus, for example, you will find the simple diode rectifier being used in clipping circuits, in d-c restoring circuits, in video detector circuits, and in many other applications. If you understand how the diode rectifier operates, then you will recognize in each one of these "new" circuits an old friend. True, it will take some time before you become familiar with the need for these circuits and the specific modifications to achieve certain results, still you will be amply repaid for the effort in the new opportunities which television offers to the trained serviceman and technician.

Comparison with Sound Broadcasting

Just as it is the problem of radio broadcasting to recreate sound at places distant from the actual sound, so it is the problem of television to recreate a scene at

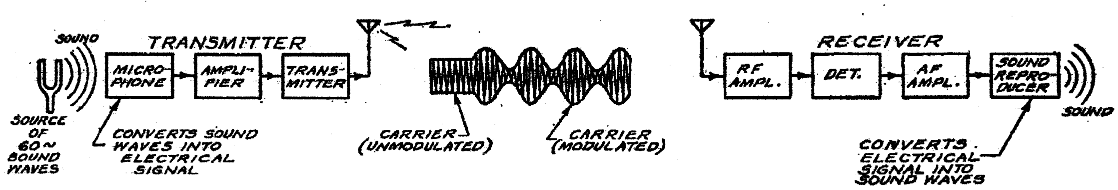


FIG. 1A - SOUND TRANSMISSION SYSTEM

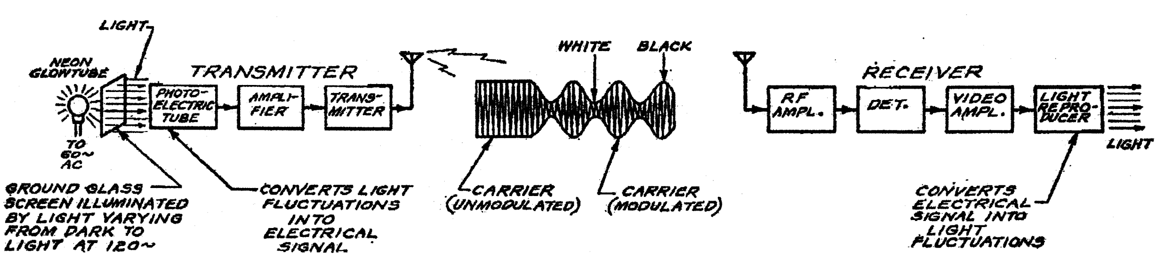


FIG. 1B - TELEVISION TRANSMISSION SYSTEM

FIGS. 1A, 1B.—A television system uses an arrangement similar to that employed in sound broadcasting. Note that in the television system the photoelectric tube replaces the microphone and the light reproducer replaces the speaker.

places distant from the original scene. In the case of sound broadcasting, as Fig. 1A shows, sound vibrations produced by, let us say, a tuning fork are picked up by a *microphone* which converts these vibrations into corresponding electrical vibrations. This electrical signal, which now carries an electrical image of the sound vibrations, is amplified, used to modulate the carrier, the radio wave is radiated, picked up by the receiver, amplified, detected and finally, as you know, the electrical impulses (similar in shape to those which were originally produced by the microphone) are used to actuate the speaker which in turn recreates the original sound.

Fig. 1B shows that a system very similar to this is used in television and that in general a very close resemblance exists between sound broadcasting and television. To simplify the explanation at the present time, we assume that only a very small part or element of a scene is being televised. For example, we might allow the light from a neon tube operated from the 60-cycle power line to fall on a small piece of ground glass. The illumination on the ground glass would then change from dark through various shades of brightness and back again to dark, and repeat this cycle 120 times per second. (Note that the rate is 120 cycles because both positive and negative cycles cause the neon tube to illuminate the screen.) In the same way that sound broadcasting uses a *microphone* to convert the sound pressure variations into electrical variations, so the heart of any television broadcasting system is the *"television camera"* which converts the time-variations in illumination of the scene into corresponding electrical variations. In the simple illustrations we have chosen, because only a single small area is being televised, an ordinary photoelectric cell can serve as the television camera.

Once the varying light values have been changed into corresponding electrical values by the television camera, the process of transmitting the information follows exactly the same procedure as in the case of sound broadcasting. Note that the carrier is modulated in the same way, and that it remains stationary in amplitude during the period before the screen is illuminated. Once the neon tube is turned on and illuminates the screen, the amplitude of the carrier varies in proportion to the amount of illumination. Note that the maximum amplitude of the carrier corresponds to a black image, and that the image gets progressively lighter as the amplitude of the carrier is decreased. In passing we might say that this is called negative modulation about which we shall have a great deal more to say later on.

For the present, the important thing to note is the similarity between the two systems, the one for transmitting information on light values, and the other for transmitting information on sound values. At the output of the television receiver, we of course have an important change. Whereas the output of the sound receiver is a speaker which converts the electrical impulses into corresponding sound impulses, the output of the television receiver is a *"picture tube"* or other device which converts the electrical impulses into corresponding light values.

We see then, that the sound system and the television system are identical with the exception that the television camera is substituted for the microphone and the picture tube for the loudspeaker. We might also mention here that in the RCA television system, the trade-mark name "Iconoscope" is used for the television camera tube and the trade-mark name "Kinescope" is used for the picture tube. As will be explained in detail later on, the Iconoscope consists of a very large number of minute photoelectric cells which create an *electrical* picture of the scene being televised, while the Kinescope consists of a cathode-ray tube on the screen of which is built up a visible image.

SCANNING

No doubt you have noticed by this time that in comparing television with sound broadcasting we limited ourselves to televising the simplest type of object, one which was uniformly illuminated over its entire area. We then showed that the two systems are identical provided that the television camera replaces the microphone and the picture tube replaces the loudspeaker. Unfortunately, however, television is not as simple as this or television would have "arrived" many years ago. In television, we are confronted with the problem of conveying information on the light value not at one point but at every point over the complete area of the scene being televised. Thus, the scene must be broken up into a great many elements or elemental areas and information on the light values over each one of these elements must be conveyed to the receiver and finally to the picture tube. And not only must this information be conveyed, but it must be reassembled in the correct order at the receiver and the corresponding light value reproduced for every one of the many elements into which the image has been broken down.

As a matter of fact, this process of breaking down a picture into a great number of elements is nothing new but is as old and as fundamental as the process of seeing itself. For, in viewing a scene, the image is carried to the brain by the eye over a huge network of transmission lines which tells the brain the intensity and the color of the light at every point in the field of vision. Because the number of elements into which the retina of the eye breaks down the scene is so great, we are not conscious that the picture is made up in this way but receive the impression that the picture is perfectly blended or continuous.

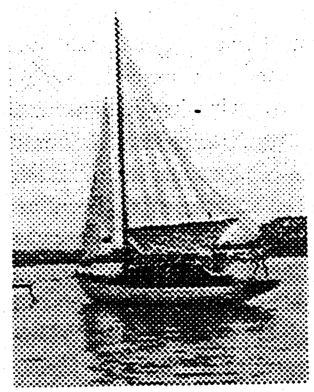
Some of you will be surprised to know that even photographs are made up of elementary particles even though they too appear to be continuous upon casual inspection. Actually the light and dark parts of a photograph are the result of the presence of black particles of silver which vary in number over the area of the picture. Where the picture is dark, these particles of silver are more numerous than where the picture is light. Because these particles are so small, they are not ordinarily visible. We might note in passing that where photographs are to be enlarged appreciably so-called fine-grain film and special developers are used so that the individual grains or particles will not become visible.

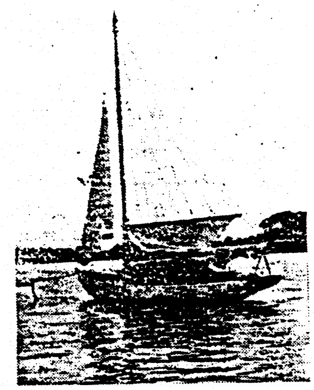
Number of Elements Required

It is important for an understanding of television to appreciate how the number of particles or areas into which a picture is broken up affects the type and quality of the reproduction which is obtained. As we should expect from the preceding discussion the quality of the picture will be improved as the number of elements is increased. In order to compare the effect of breaking up a picture into a varying number of elements, let us consider the two reproductions shown in Fig. 2a and Fig. 2b. These are reproductions of the same photograph, the only difference being the number of elements into which the picture is divided. If you examine these figures closely, you will see that they are composed of a large number of black dots of different sizes, and that Fig. 2b contains a larger number of dots than Fig. 2a. As a matter of fact, in printing as well as in the processes of seeing and photography, it is necessary for the picture to be broken down into a series of small areas before it can be printed. The engraver in making his halftone, places a fine mesh screen in front of his camera so that the image is broken down into a series of dots, the actual size of any one dot depending upon the amount of light on the area which the dot represents. Where the picture is dark, the size of the corresponding dot is large, and where the image is light the size of the black dot is correspondingly small. The number of dots into which Fig. 2a is broken down is 50 per inch, while Fig. 2b is broken down into 100 per inch.

The great improvement effected by breaking down the picture into a larger number of dots or elements is clearly apparent in the superiority of Fig. 2b over Fig. 2a. Because of the larger number of elements, the former presents more detail, appears finer, more blended and more continuous than the picture with the fewer number of elements.

The actual number of elements into which a picture





FIGS. 2a, 2b.—Fig. 2a is a halftone reproduction of a photograph using a 50 screen; in Fig. 2b greater detail is obtained by using a 100 screen.

FIG. 3.—Fig. 2b enlarged to twice its original size. Note that this illustration can be viewed from twice the distance and still the same detail will be seen as in Fig. 2b.

must be divided depends upon several factors: the fineness of detail which it is desired to reproduce, the distance from which the picture is viewed and the size of the picture. Fineness of detail, as we have seen, requires a large number of elements for a given portion of a scene. In addition, the more closely the picture is viewed, the smaller must be the individual elements. This is necessary so that the individual elements will appear to the eye to merge into smooth lines and shades. If a picture of a given scene is enlarged, either the total number of elements must be increased, or the picture must be viewed from a greater distance. Figs. 2a and 2b illustrate the first two factors, fineness of detail and viewing distance. Fig. 3, which shows Fig. 2b *enlarged* to twice its original size, illustrates the third factor. Fig. 2b contains 100 dots per inch; Fig. 3 contains only 50 dots per inch. Each contains the same *total* number of elements, therefore the *fineness of detail* is the same in each. Because Fig. 3 has *larger* dots, it must be viewed from a greater distance. This consideration is important in television, since the total number of lines into which the scene is divided is the same at all times. Therefore, large pictures should be viewed from a greater distance than small ones to get the same effect.

An idea of the number of elements needed to reproduce fine details can be obtained from Fig. 2b. This has 100 dots or "elements" per inch in an area 1.5 by 2 inches, giving $150 \times 200 = 30{,}000$ total elements, or 10,000 elements per square inch. Television pictures may be considered to contain about 224,000 elements, regardless of picture size. Although this does not work out to be so great a number per square inch on large picture-tube screens, the fact that the scene is usually in motion compensates for some loss of detail. A point to remember about television is that increasing the number of elements increases the frequency bandwidth which must be transmitted. Thus there are technical and economic limitations to the degree of detail that may be provided.

We can now begin to appreciate the complexity of the problem with which television is confronted. For not only must information on the light value of each one of many thousands of elements be transmitted to the receiver, but also information as to the order or sequence in which these light values must be assembled to form the picture. To make the problem even more complex, all this information must be transmitted in approximately 1/30th of a second in order to prevent blurring due to movement in the scene and in order to make way for the next picture impression or "frame." In this respect the problem of television is more difficult than that of facsimile, since in the latter a still picture is transmitted and the time consumed may be ten minutes or more instead of 1/30th second.

Need for Scanning

By this time we have seen that to make television possible, the picture must be broken down into a large number of elements and information transmitted on the light value at each one of the elements. At the receiver this information is reassembled in the proper space relationship to form the original picture. How to transmit this information is the next problem.

Previously we saw that using a conventional system of radio we could transmit information on the light value at any *one* element of a scene by using a photoelectric cell pickup to convert the light value to an electrical value, and that this process was essentially the same as that of sound broadcasting and involved essentially the same transmitting and receiving equipment. This was shown and explained in Fig. 1. The first thought that arises is this: Why not use individual channels of the type shown in Fig. 1b to transmit information on the light values at each one of the points into which the picture is divided? But then, this would require some 100,000 individual pickups and transmission systems each of which would be similar to the system of Fig. 1b. Quite obviously such a system would be far too complex and expensive to be practicable, even if other problems of great difficulty at the receiving end did not exist.

Another more promising solution, which is the one that is used in all television systems today, works on the basic idea of transmitting information on the light value of one element at a time. In this way the picture is covered or "scanned" in a systematic way until finally the image is said to be completely scanned when information on the light values at every point in the picture has been obtained. In this way the need for more than one channel is avoided. However, the information must still be reassembled in the proper order at the receiving end before the picture can be obtained.

Scanning a scene is sometimes compared with the manner in which we read a printed page. For instance as you read this page your eyes start at the upper left-hand corner of the page and successively sweep to the right-hand side while examining every letter on the line; when the first line has been completed the eye snaps over rapidly to the left hand side, jumps down one line, and in the same way, examines every letter on the second line as it progresses at a uniform rate toward the right. This procedure continues until finally the eye reaches the last letter on the lower right-hand side of the page, at which time we can consider that the whole page has been scanned.

This same procedure is used when a television camera scans a scene which is to be televised. The only difference is that the television camera breaks down the scene into finer elements than the letters of a page and that the camera produces electrical impulses which vary in proportion to the amount of light on each element of the scene being scanned.

The following simple example will help to clarify the fundamental principles and requirements involved in scanning. Suppose we wish to reproduce by television the pattern shown at the left of Fig. 4. Let us assume in this example that a television camera (consisting essentially of a photoelectric cell with the proper lens equipment) is available which can be focused so as to pick off the light values on any one of the squares into which the picture has been divided. Let us also assume that we have a mechanical arrangement for moving the camera both horizontally and vertically so that it will scan the object. That is, it is possible to start with the camera focused on element 1 and to move it at a uniform rate across the screen until it reaches element 6. At this point the camera snaps back rapidly to element 7 at the beginning of the second line and moves at a uniform rate along the second line until it reaches element 12. The camera then returns very rapidly to the left and starting at element 13 on line 3 it scans the third line. In this manner the procedure continues until the entire pattern is scanned. Note that at any one instant the camera receives light only from the particular element at which it is aimed and focused and produces an electrical impulse which is proportional to the amount of light reflected by this element.

So much for the scanning at the transmitting end where the picture is being televised. At the receiving end let us assume that we have a projector which projects a narrow pencil of light on the screen equal in area to one of the square elements. This projector like the camera can be moved horizontally and vertically so that the light can be focused on any part of the screen. Suppose further that the electrical impulses from the television camera are fed to the projector and arranged to control the intensity of the light emitted by the projector in accordance with the amount of light registered by the camera at any particular instant.

Under these conditions before a picture can be obtained at the receiver, the motion of the camera at the scene being televised and the motion of the projector at the receiver must be properly coordinated or "synchronized." This means that the television camera and the projector must go through the same movements together, that the projector must at all times be focused on exactly the same element in the picture as that on which the camera is focused. In the figure we have assumed a sort of mechanical linkage between the camera and the projector to accomplish this; actually no such mechanical linkage is possible in television and we shall see later that electrical *synchronizing pulses* are used to control the camera at the transmitting end and the projector (or picture tube) at the receiver, so that both the scene being televised and the image which is being reproduced at the receiver are scanned in unison—so that the scanning is *synchronized.*

In the picture shown the image has been scanned only as far as element 13; element 14 is about to be scanned. As a result the image at the receiver is totally dark beyond this point since the lower elements have not yet been scanned and hence have not yet been illuminated. We shall explain later on that the observer sees the complete image at one time even

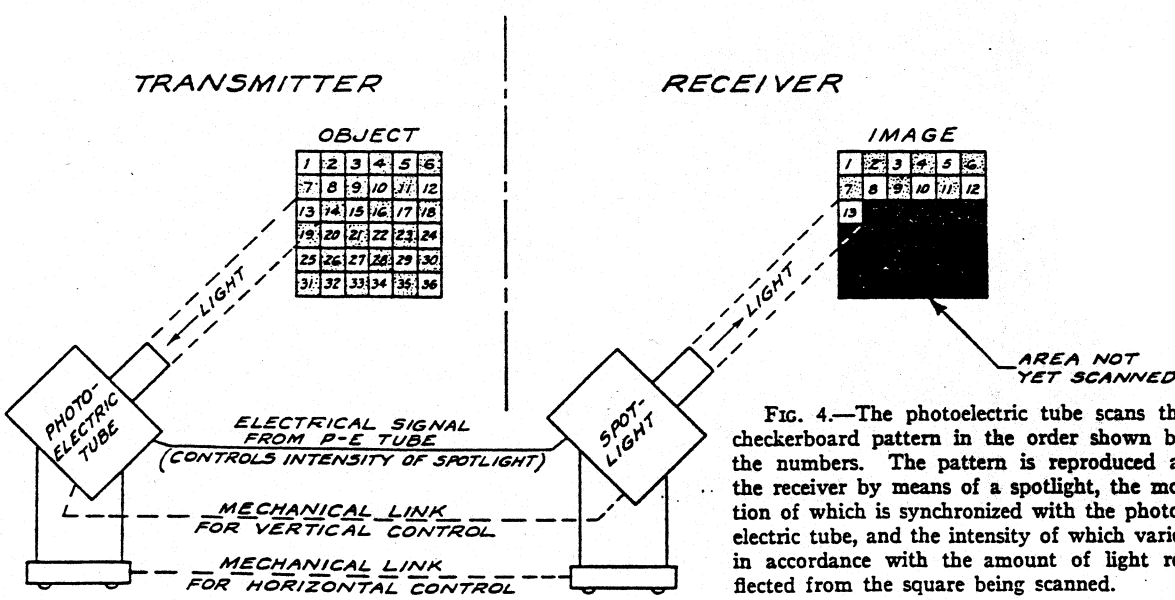


FIG. 4.—The photoelectric tube scans the checkerboard pattern in the order shown by the numbers. The pattern is reproduced at the receiver by means of a spotlight, the motion of which is synchronized with the photoelectric tube, and the intensity of which varies in accordance with the amount of light reflected from the square being scanned.

though only one element of it is receiving light at any particular instant. This is because the entire scanning process is repeated some thirty or more times a second, and the eye tends to see the image after it is no longer illuminated.

We can now summarize the requirements which must be met before a scene can be transmitted by television:

1. The scene must be systematically scanned by the television camera which interprets the light values at every element of the scene in terms of corresponding electrical values.

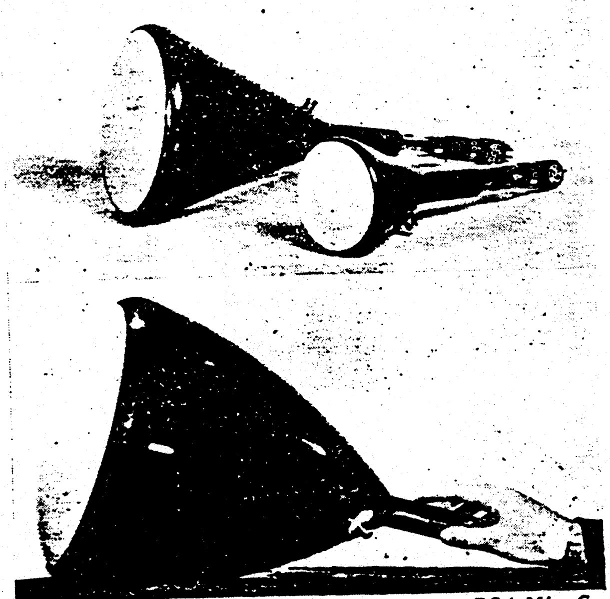
2. The image must be scanned at the receiving end according to the same systematic plan used by the television camera and the intensity of the light emitted by the light source in tracing the image must vary at every instant in accordance with the amount of light which the camera is receiving at that instant.

3. At every instant the camera and the light tracing the image must be synchronized so that the identical portion of the image is being traced out which corresponds to the element of area being scanned by the camera.

4. This scanning procedure or process must be completed over and over again at a rate of at least 30 times per second so that as far as can be determined by the eye a continuous image of the scene is formed.

THE CAMERA TUBE AND THE PICTURE TUBE

We have already seen that a complete television system, like a complete broadcasting system, requires a pickup at the transmitter and a reproducer at the receiver, and that the pickup is a photoelectric tube and the reproducer is a cathode-ray tube similar to those used in oscillographs. To avoid confusion of trade names let us call the pickup a "camera tube" (it "takes" the television picture) and the reproducer a "picture tube" (it reproduces the picture). Since we want to get a good general idea of how a television system works, we shall consider both these tubes here, although the serviceman in the field will naturally come in contact with only the picture tube.



Courtesy RCA Mfg. Co.

Fig. 5.—The left-hand Kinescope shown above has a 9-inch screen and the smaller has a 5-inch screen. Below is a 12-inch Kinescope.

The Picture Tube

Essentially the television picture tube is similar to the familiar cathode-ray oscillograph tube, so that those who have read Rider's "The Cathode-Ray Tube at Work" will have a good basis for understanding television picture tubes. For those who have not we will review the subject here.

Let us assume that television (video) signals are coming into a receiver; as we have said before, the amplitude of these signals is proportional to the light reflected by the object being televised. We want to use these signals to produce a picture. In sound work we know that the signals can be made to move the diaphragm of a loudspeaker, thus producing sound waves similar to the original. The picture tube, then, must be capable of converting the electrical video signals into *light* to produce a picture. It is a property of certain substances called fluorescent materials that they will glow when they are struck by a beam of electrons, and that the more electrons striking such a substance at a given instant, the brighter will be the glow. A picture tube, then, can be made if we have a source of electrons, means for controlling their motion and their quantity, and a fluorescent screen.

The external appearance of some typical picture tubes is shown by the photograph, Fig. 5. These are glass vacuum tubes specially shaped to withstand the high pressure exerted by the surrounding air, due to the high vacuum within the glass envelope. Servicemen should remember this, and handle picture tubes with great care. Even scratching the glass or careless handling may cause them to *collapse* as violently as if they exploded! The white appearance of the large end of these tubes is caused by the film of fluorescent

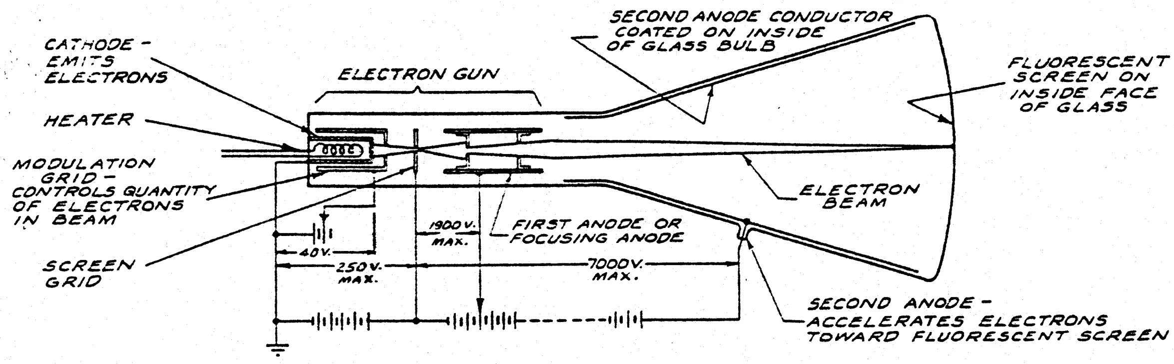
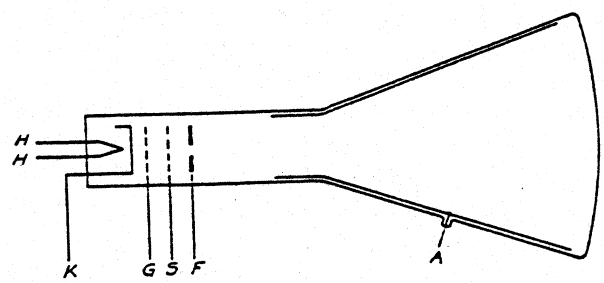


FIG. 6a.—The different elements of a picture tube are designated in the above sketch with typical voltages shown. Fig. 6b on the right shows a common schematic representation; where K is the cathode; G, the modulation grid; S, the screen grid; F, the focusing anode, and A. the second anode.



material deposited on the inside surface; this, of course, is where the television pictures are built up.

A cross-sectional view of a picture tube is shown in Fig. 6. As in the usual radio tube, the heater causes the cathode to emit electrons and the second anode (like the plate of the ordinary tube) strongly attracts them, giving them a high velocity. The modulation or control grid regulates the number of electrons which pass through it in a given time. In the picture tube are some additional elements such as a focusing anode, which forms the electrons into a narrow beam so that they will strike the fluorescent screen in a small round spot; in some tubes a screen grid is inserted between the modulation grid and the focusing anode to prevent the focusing action from affecting the modulating action. Fig. 6a shows the general arrangement of parts inside the tube, and Fig. 6b shows a common way of representing these in schematic form.

With the parts so far mentioned, the tube can produce a beam of electrons which will hit the center of the fluorescent coating on the inside of the picture tube and produce a small spot of light which can be seen through the glass end. We can focus this spot by varying the potential on the first (focusing) anode, and we can vary its brightness by applying a suitable potential to the modulation grid. The more negative the modulation grid becomes relative to the cathode, the dimmer the spot becomes; the less negative the grid, the brighter the spot. It now remains to provide some means for moving this spot rapidly enough over the fluorescent screen to give us a complete picture . . . in other words to provide scanning.

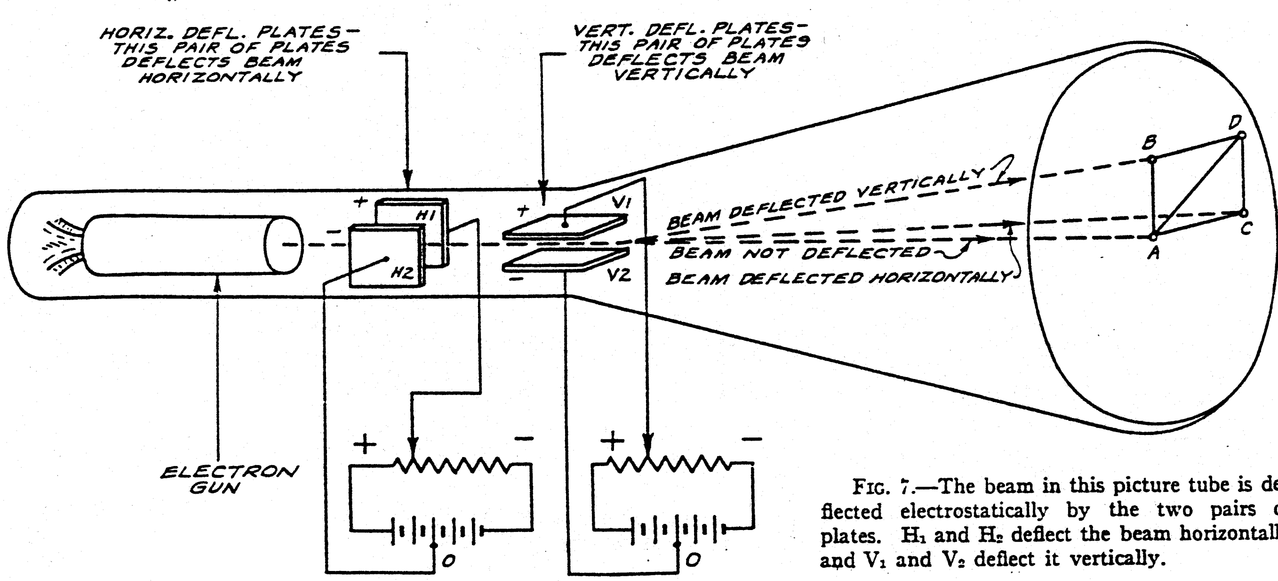


FIG. 7.—The beam in this picture tube is deflected electrostatically by the two pairs of plates. H_1 and H_2 deflect the beam horizontally and V_1 and V_2 deflect it vertically.

Two methods of deflecting the electron beam are now commonly used: *electrostatic* deflection and *electromagnetic* deflection. The first of these methods, which is probably the simplest to understand, takes advantage of the familiar fact that particles of matter having like charges of electricity repel each other, while particles having unlike charges attract each other. Since the electron beam consists of negative charges, we see immediately that the beam can be deflected by means of suitably shaped electrodes which are charged either positively or negatively as the case may require. In picture tubes, as in oscillograph tubes, this is done by building into the tube two pairs of metallic plates, arranged approximately as shown in Fig. 7.

The figure shows that plates H_1 and H_2 are parallel to each other but in a plane at right angles to plates V_1 and V_2. If no potential is applied to any of these plates, the electron beam will pass straight along the axis of the tube and cause a spot to appear on the screen at A. Now if we leave plates H_1 and H_2 alone, but make plate V_1 positive with respect to plate V_2, plate V_1 will tend to attract the negative electrons which make up the beam, thus causing the beam to bend, so that it strikes the screen at a new point, say at point B. We have thus deflected the beam upward in a vertical direction a distance AB. Similarly, if we leave V_1 and V_2 alone, but make H_1 positive with respect to H_2, H_1 will deflect the beam horizontally to the right until we get a spot at a point such as C.

If we combine these effects, by making both V_1 and H_1 positive at the same time, the beam will bend sidewise and upwards, causing the spot to appear at D. If the potentials of V_1 and H_1 have been the same as used in the first two tests, D will be located so that the distance AD is the hypotenuse of a right triangle whose sides are equal to AB and AC. Naturally, if V_2 is made positive with respect to V_1, the beam will be deflected vertically downward, and if H_2 is made positive with respect to H_1, the beam will be deflected horizontally to the left. The whole process of electrostatic scanning is simply a matter of varying the potentials on the deflecting plates in the picture tube so that the spot on the screen traces out the desired picture according to a regular plan. In a later section, we shall study the details of the plan actually used.

The second method of deflecting the electron beam is called *electromagnetic deflection,* because coils of wire carrying current act on the beam the way a magnet would. See Fig. 8a: The magnetic lines of flux from a permanent magnet pass from the north pole (N) to the south pole (S); the electron beam passes between the poles. If the magnet were not present, the beam would produce a spot at point A on the screen. When the magnetic field acts on the beam as in Fig. 8a, however, the beam is deflected vertically upward to produce a spot at point B. Compare this effect with that produced by the electrostatic field in Fig. 7, and you will notice that in Fig. 7 the electron beam was deflected *in the direction of the lines of elec-*

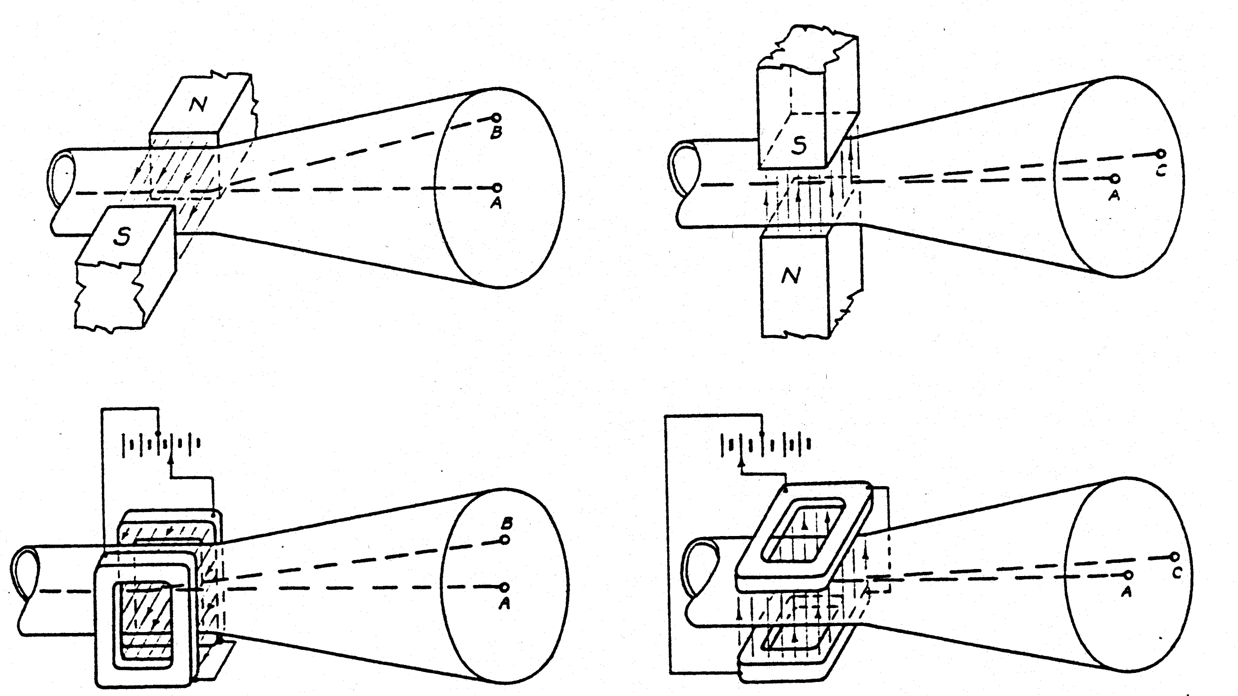
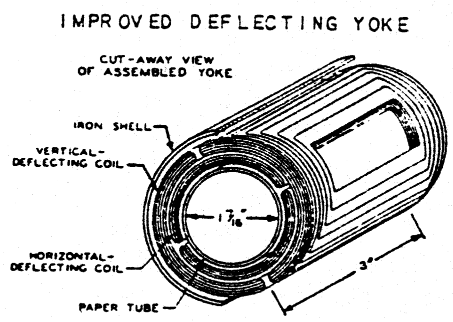


FIG. 8.—The magnetic deflection coils in Figs. 8c and 8d provide a magnetic field similar to that of the permanent magnets in Figs. 8a and 8b above. Note that the beam is deflected at right angles to the lines of force.

trostatic flux existing between plates V_1 and V_2, whereas in the case of magnetic deflection, the beam is deflected *at right angles to the lines of magnetic flux.* Thus in Fig. 8b the beam is deflected horizontally to the right, when another magnet is introduced whose influence is at right angles to the one shown in Fig. 8a.



Courtesy RCA Mfg. Co.

Fig. 9.—The magnetic deflecting yoke contains the horizontal and vertical deflection coils which are designated in the above sketch.

Of course, a permanent magnet gives a steady field and would therefore produce a constant deflection, whereas in television we must be able to vary the extent of the deflection from zero to maximum in various directions. Since we can also produce a magnetic field by passing a current through a coil, and in addition, can vary the strength of the field by varying the current, we use coils for electromagnetic deflection, as shown in Figs. 8c and 8d. Two pairs of coils are used, and these are often combined in a single compact cylindrical unit called a "deflecting yoke." Fig. 9 shows a partial cutaway view of an RCA deflecting yoke.

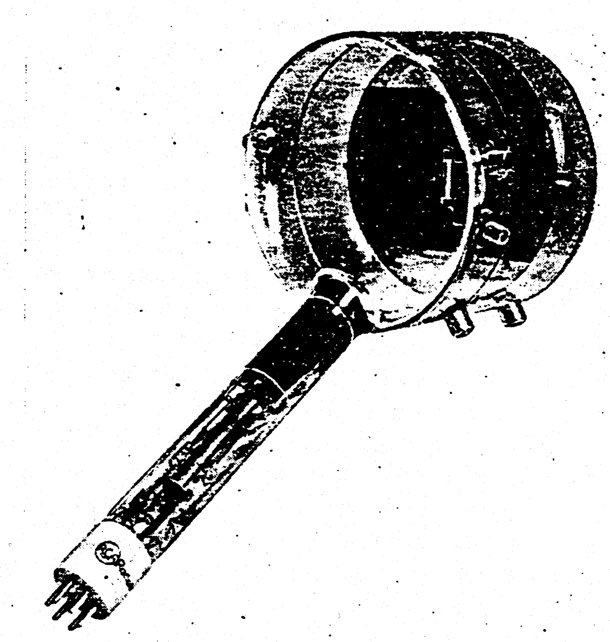
A point to remember about deflection systems is that when one tube has *electrostatic* deflection, a change of voltage on the deflecting plates is required to move the beam, whereas in *electromagnetic* deflection, a change of current through the deflecting coils is required.

The Camera Tube

Whereas the picture tube contains a fluorescent screen to convert an electric current into light, the camera tube contains a photosensitive screen to convert light into an electric current. The RCA type of camera tube, called the Iconoscope, the type in general use in this country at the present time, is illustrated in Fig. 10. The essential parts of this tube are shown in the cross-sectional view in Fig. 11: these are the mosaic, the signal plate, the collector and the electron gun. The important accessories external to the tube are the lens, the deflecting yoke, and the load resistor.

The mosaic consists of millions of individual photosensitive globules like metallic droplets deposited on one side of a thin sheet of mica. Each globule is like a minute island on the mica, so that the globules are insulated from each other. On the other side of the mica there is a layer of conducting material . . . the signal plate. Because the globules are separated from the signal plate by the mica, the mosaic consists of a myriad of mica-dielectric condensers, all having one plate in common. Fig. 12 shows in a general way what the mosaic looks like when viewed from the edge and enormously magnified. The collector ring is a metallic coating applied in the form of a ring around the inside of the tube and also extended down the neck of the tube near the electron gun.

Briefly the action of the Iconoscope is as follows: An optical image of the scene to be televised is focused on the mosaic by the lens. The electron gun projects



Courtesy RCA Mfg. Co.

Fig. 10.—Light images formed on the plate of the Iconoscope, the camera tube, are transformed into electrical energy by a scanning electron beam.

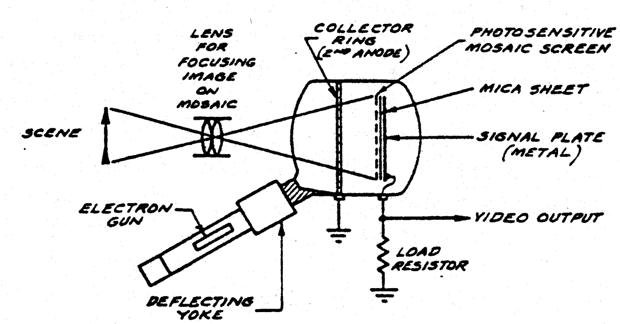


Fig. 11.—The elements of the Iconoscope can be identified in this sketch.

a stream of electrons over the mosaic, scanning it under control of the deflecting yoke, as already described in connection with the picture tube. The electron beam in traversing the mosaic causes a succession of voltages to appear on the signal plate which are proportional to the distribution of light in the image of the scene. The resultant current which flows in the load resistor causes a voltage drop. This constitutes the *video signal.* This signal is then amplified and used to modulate the television transmitter.

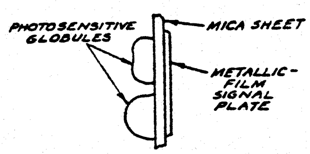


FIG. 12.—An enlarged view of how the photosensitive mosaic is arranged with respect to the signal plate of a picture tube.

The following more detailed description of the action of the Iconoscope is presented for those interested. When a scene is focused on the mosaic, each photosensitive globule emits electrons in proportion to the amount of light falling upon it; the more light that falls on a given area the more electrons are emitted from that area. This process is called "photoemission." Since a loss of electrons means a more positive charge, photoemission sets up a variety of different charges over the surface of the mosaic in accordance with the distribution of the light it is receiving. So far no video signal has been produced because the globules are insulated from the signal plate.

Since the path from the mosaic to the signal plate is through a condenser, the only way to get a signal across is to produce a sudden *change* of potential. In the Iconoscope type of camera tube, this change of potential is produced by the action of the electron beam from the gun. (The necessary orderly scanning action from left to right and top to bottom is provided by suitable currents through the deflecting yoke, as in the case of a magnetically deflected picture tube.) In order to understand the effects produced by this scanning beam, let us first consider three possible conditions on the surface of the mosaic *before* scanning. It has been found that the ordinary Iconoscope mosaic in *total darkness* (black scene) assumes a potential of —1.5 volts relative to the collector ring. When strong light (white scene) falls on a portion of the mosaic, a considerable number of electrons are lost by photoemission, and the potential is changed from, say, —1.5 volts to 0 volts. Illumination of medium intensity (gray scene) may cause the potential to change from —1.5 volts to —0.8 volt. These potentials of the mosaic, then, may be approximately as follows for these portions of the mosaic: black area, —1.5 volts; gray area, —0.8 volt; white area, 0 volts.

The electrons in the scanning beam travel so rapidly that when they strike a surface such as the Iconoscope mosaic, they knock off a great many electrons, more, in fact, than even bright light does. This kind of action is called "secondary emission." So many electrons are thus lost by secondary emission, that the portion of the mosaic directly under the action of the scanning beam is driven to a *positive* potential of +3 volts. Each portion of the mosaic is driven to +3 volts *during the instant the scanning beam acts upon it* and this +3-volt potential is reached *regardless of the light conditions prevailing* . . . a black area goes to +3 volts as well as a white or gray area. Although the *peak* potential reached by every area as the scanning beam passes over it is the same, the *change in potential* which this area undergoes at this time *will depend on the illumination* it has received. Thus the black area will change from —1.5 to +3 volts, a change of 4.5 volts; the gray area will change from —0.8 to +3 volts, a change of 3.8 volts; the white area will change from 0 to 3 volts, a change of 3 volts. It is this sudden *change of potential* which is induced on the signal plate that causes the video signal current to flow through the load resistor. The *difference between the changes* for black, gray and white areas is what indicates the difference in the illumination over the mosaic surface as it is scanned, and this difference is proportional to the distribution of light over the mosaic.

The important things to notice here are: (1) that we get a video signal across the load resistor (Fig. 11) only when a *change of potential* is produced on the mosaic, and that this is accomplished by the scanning beam; and (2) that the resultant *video signal is proportional to the light coming from the scene being televised,* the signal being of *maximum* amplitude for *black* portions of the scene, *minimum* amplitude for *white* portions.

The collector ring (2nd anode) serves to accelerate the electrons in the scanning beam, and also to collect some of the electrons emitted from the mosaic. In Fig. 11 you will notice that this element is grounded; it is, however, 500 to 1000 volts *positive* with respect to the cathode of the electron gun, because the gun is at a corresponding potential *negative* with respect to ground. This will not be the last time that you will find television tubes with elements at very high negative potentials, and the possibility of such circuits existing must always be borne in mind as a safety measure.

SCANNING AND SYNCHRONIZATION

In previous sections we discussed (1) the necessity for scanning both the camera tube and the picture tube, (2) the essential requirement that these operations must be synchronized, and (3) the devices which make it possible to control the motion of the electron beam in these tubes. In this section we shall describe the details of the path of the scanning beam on the tube screen, the waveshapes necessary to produce this path and some of the problems which arise in connection with scanning.

The Scanning Pattern

As we have already mentioned, the usual scan is from left to right and from top to bottom. In certain cases this order must be reversed, but the principle is the same. In Fig. 13 is shown a simplified diagram of a scanning pattern; this is often called a "raster." The rectangular diagram formed by the light lines connecting points A, B, C and D represents what we may call the "picture space." The width of this rectangle (AB) is drawn so as to be 4/3 times the height (AC); this is the proportion used in motion pictures. The ratio of width to height is called the "picture aspect ratio" and its value of 4/3 is one of the proposed RMA television standards. On a picture tube, the heavy lines ab, cd, etc., are caused by the fluorescent glow which occurs as the electron beam moves from point a to point b (in the direction of the arrow on line ab). You will notice that points a and A coincide, while point b is slightly *below* point B. In fact, *all* the lines in Fig. 13 slant downward. This slant is necessary to provide the *vertical* (top-to-bottom) part of the scanning process. In fact, the left-to-right component of scanning is called "horizontal scanning" or "line scanning"; the top-to-bottom component is called "vertical scanning" (also called "frame scanning" or "field scanning," for reasons which will be clear later on). This slant-line system of scanning is used because the characteristics of the electrical circuits which provide scanning make it impossible to scan in a series of truly horizontal lines, with an abrupt vertical drop at the end of each line.

After the beam reaches point b it is deflected back along the dotted line bc to start a new line, cd. On the picture tube the line bc would be much fainter than line ab because the *time* allowed for the beam to move from b to c is only about one-tenth the time allowed for it to travel from a to b. Lines like ab, cd, etc. are called "line traces"; lines like bc, de, etc. are called "line retraces" or "line flybacks."

Here some questions may arise: Why does the motion of the spot across the screen appear as a line? Why is the flyback dimmer than the trace? The eye is responsible for these effects. Any one who has ever swung a flashlight or a "sparkler" in a circle must have noticed that as the speed of the swinging is increased, the individual spot of light merges into an apparently continuous circle of light. The velocity of the scanning spot across the picture tube screen is so rapid (several thousand miles per hour) that the eye cannot distinguish the spot from a continuous streak. This property of the eye is called "persistence of vision."

The difference in brilliance between the trace and the flyback is due to the fact that the brilliance of the fluorescence produced on the picture-tube screen depends on the *time* during which the electron beam acts upon it. Although in both cases the actual time is very short, the *difference* in time (about 10 to 1) does result in a very marked difference in brilliance.

A complete set of lines such as shown in Fig. 13 is called a "frame." This particular frame is completed when the spot reaches point l; it then returns to point a to start a new frame. A frame like that shown in Fig. 13 is said to be built up by "progressive scanning" (the lines follow each other in a continuous chain). Six complete lines (retraces are not counted) are shown in this figure; a complete technical description of this figure would be: "A six-line frame (or raster) produced by progressive linear scanning." Of course, so few lines as we have shown would be insufficient to give a good picture, and a very great many more are actually used. In order to give the eye the illusion of motion, many complete frames must be

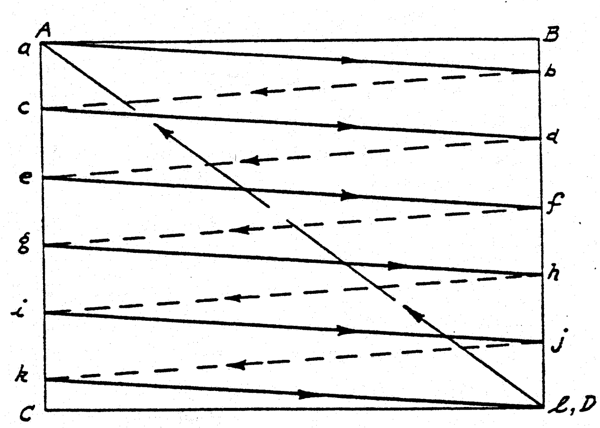


FIG. 13.—A simple progressive scanning pattern in which the picture is scanned in a series of lines which start at the upper left and slope down to the right.

traced out every second. The standard American procedure is to trace 30 complete frames every second; each frame consists of 441 lines.

Flicker and Hum on the Raster

It has been found that if the raster is bright a *flicker* will be observed when the number of frames per second (frame frequency) is less than a certain critical value. Although a satisfactory illusion of motion might be produced by about 12 frames per second, as many as 48 frames per second may be required to remove objectionable flicker. The more frames per second a television transmitter sends out, each having a large number of lines, the higher the modulation bandwidth required. One way to keep the bandwidth down is to send twice as many frames per second, each frame having half the number of lines. But a large number of lines is necessary for detail in the picture. It was therefore decided to divide the total number of lines in each frame between two rasters (called "fields"), each containing half the total number of lines required to make up a frame. These fields, transmitted at the rate of 60 per second, get rid of the flicker effect. The required number of lines per frame is supplied by sending the odd-numbered lines along with one field and the even-numbered lines along with the following field. The fields are transmitted so rapidly that as far as the eye can see, all the necessary lines appear in their proper positions on the raster simultaneously.

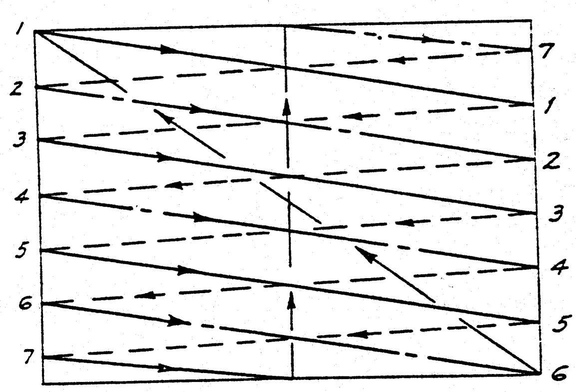


Fig. 14.—An interlaced scanning pattern in which the odd and even lines are scanned on successive fields.

The method of scanning just described is called "interlaced scanning," and is the system now in use. A simplified pattern of a frame produced by interlaced scanning is shown in Fig. 14. The general principles are the same as for progressive scanning; in fact, each *field* is itself progressively scanned. The lines transmitted during the first field scan, referring to Fig. 14, are lines 1, 3, 5 and the first half of line 7. The beam is then deflected to the top of the picture space to begin the second field. During the second field, line 7 is completed and lines 2, 4 and 6 are traced, thus completing the entire seven-line frame in two steps. (As in Fig. 13, the arrows show the direction of travel of the beam spot.) The use of an odd number of lines has been found advantageous in interlaced scanning; this method is called "odd-line interlacing." American practice calls for 220.5 lines in each field, making 441 total lines per frame. Sixty fields are transmitted each second, giving a field frequency of 60 per second.

The frame frequency chosen depends upon the a-c power-line frequency; it must be an even multiple or submultiple thereof. The reason for this is that if there is some hum present in the deflecting circuits, a certain amount of distortion will appear in the picture. If this distortion appears to be stationary, and is not excessive, it can probably be tolerated. On the other hand if the distortion moves so that the picture appears to have moving ripples in it, even slight distortion is most objectionable. By making the frame frequency an even submultiple of the power-line frequency, this type of hum pattern can be rendered stationary. Since most American power lines use 60-cycle a.c., the frame frequency chosen was 30 per second. (In England, with 50-cycle a.c., the frame frequency is 25.)

Scanning Waveform

In describing the picture tube, we showed that the beam can be deflected by applying suitable potentials to the deflecting plates or suitable currents through the deflecting coils. The nature of these voltages and currents depends on the kind of deflection to be produced. In Fig. 14 is shown the kind of deflection required in television scanning. The trace deflection required is a steady motion from left to right along a line slanting slightly downward to the right; the retrace travels from right to left along a line slanting downward to the left. We found out that such a motion will occur when both sets of deflecting plates or coils are in operation simultaneously. Thus in scanning, two deflection circuits are acting at once, one moving the beam horizontally (horizontal deflection circuit), the other moving it vertically (vertical deflection circuit).

The shape of the voltage (or current) wave which has to be applied to the deflecting plates (or coils) to produce the desired scan is shown in Fig. 15. At (a) is shown the waveform for horizontal or line scanning; at (b) the waveform for vertical or field scanning. Notice that the time of the line wave is equal to the time of the field wave divided by the number of lines per field (1/60 second divided by

220.5 = 1/13230 second). Also notice that the line retrace is allowed only about 1/6 the time allowed to the line trace; the field retrace is allowed 1/13 the time of the field trace. The total time-intervals allowed for these waves indicate that the line-scan frequency is 13,230 cycles and the field-scan frequency is 60 cycles. These waveforms are called sawtooth waves; circuits for generating them are described in a later section.

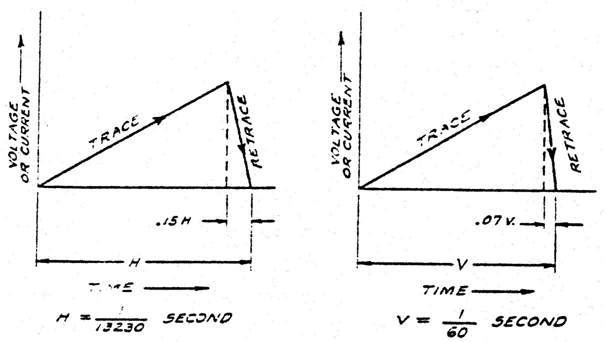


FIG. 15.—At the left is shown the sawtooth waveform required for horizontal scanning. A similar waveform, but of much lower frequency, is required for vertical deflection; it is shown at the right.

Overall View of a Television System

We are now in a position to obtain a bird's eye view of a complete television system. Such a step is advisable at this time because of the complexity of the system and the desirability of not losing sight of the function of the principal parts in the maze of detail associated with all the individual elements of the system.

Fig. 16 shows the general role played by each of the major units of a television system in causing the picture of the televised scene to appear on the screen of the picture tube. Referring to this illustration, you will note that the camera tube is focused on the scene to be televised with the result that an image of the scene is formed on the photoelectric mosaic of the camera tube. In this way each point of the mosaic takes on a voltage which is proportional to the light value associated with this point of the image. In order to transmit this information, the electron beam of the camera tube completely scans the image on the photoelectric surface 30 times in each second. As a result of this the video portion of the television signal is produced in which the electrical variations correspond with the light variations on the screen of the camera tube.

In order to fulfill the requirements of synchronization, the need for which has already been explained, a synchronizing signal (abbreviated "sync" signal) is applied to the camera tube deflecting circuits so that the scanning of the electron beam is at all times under the timing control of this sync signal.

At the same time this sync signal must also form a part of the television signal which is broadcast in order that the scanning at the picture tube in the receiver can be kept in synchronism (in step) with the scanning at the camera tube. For this reason you will note that the sync circuit also feeds the same sync signal to the video amplifier, and as a result the complete signal contains information not only on the light values but also the necessary control signals to synchronize the scanning at the picture tube with that at the camera tube.

The complete television signal is amplified by the video amplifier circuits in the transmitter and fed to the modulating circuits of the transmitter where it modulates the high-frequency radio wave which serves as the carrier. According to the present frequency allocations assigned by the Federal Communications Commission, the carrier frequencies used lie within the range between 44 and 108 megacycles, with the lower values being in greater use. The reasons for the use of carrier frequencies in the ultra-high frequency range and the actual make-up of the signal will be discussed later in detail.

The signal which is radiated by the transmitting antenna is picked up by the receiving antenna and fed to the television receiver. The television signal is

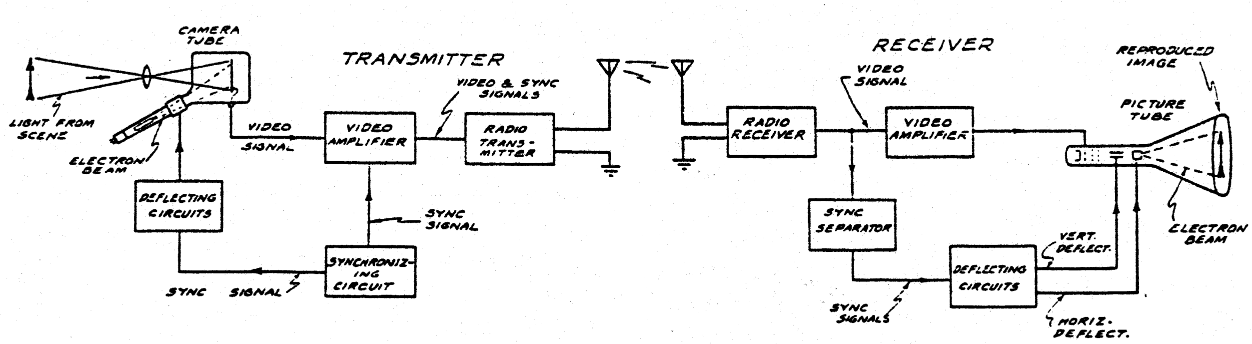


FIG. 16.—The principal elements of a complete television system. Note the provision made for synchronizing the scanning at the picture tube with that at the camera tube.

amplified in this receiver which incidentally is almost invariably of the superheterodyne type. After sufficient amplification the signal is demodulated in the second detector of the receiver and the video and sync signals are recovered. The video amplifier following the detector further amplifies the signal which is finally impressed on the control grid of the picture tube. The fluctuations of voltage on the control grid of the picture tube cause the intensity or brightness of the scanning spot to vary in accordance with the amount of light on that element in the scene which at that particular instant is being scanned by the electron beam of the camera tube.

The receiver contains separate circuits for deflecting the beam of electrons horizontally and vertically so as to accomplish the scanning of the image at the picture tube. In general these circuits are similar to those used to deflect the electron beam at the camera tube. To insure absolute synchronization between the scanning at the picture tube and that at the camera tube, the receiver contains circuits (called sync separator circuits) for separating the synchronizing pulses from the complete television signal. As is noted in the figure, these impulses are applied to the deflection circuits in the receiver and keep the two scanning beams—the one in the camera tube at the transmitting end and the other in the picture tube at the receiving end—in perfect synchronism. In this way the image of the scene is traced out by the moving spot of light on the screen of the picture tube.

In the above description we have omitted a consideration of the sound broadcasting which almost invariably is a part of the television broadcast. For the present, it will be sufficient to understand that the sound is transmitted and received in the same way as a conventional sound broadcast even to the extent that an entirely separate carrier is used to carry the modulation of the sound accompanying the television broadcast.

THE TELEVISION SIGNAL

One of the most important factors delaying the commercial introduction of television in this country was the necessity for establishing definite standards. You can appreciate that standards are of tremendous importance in television—and in this respect television is unlike radio—because of the close relationship which exists between the design of the receiver and conditions at the transmitting end. Thus the manner in which the image is scanned and the manner in which the synchronizing information is conveyed influence both the design and operation of the receiver.

To avoid the danger of establishing transmitting standards which would tend to prevent progress in television, the entire problem in all its aspects was investigated by the television committee of the Radio Manufacturers Association—the RMA. After several years of careful study, the standards were arrived at which are the basis of television in the United States today. It is believed that these standards have been made flexible enough to permit gradual improvements without requiring radical changes in receivers now being distributed and sold. Thus improvements which will be made will probably be improvements in the present basic system rather than radical changes in the system itself. The primary contribution of the present RMA standards is that they have started television out along the path which appears to hold the greatest promise for the future.

The Video Signal

We are now in a position to consider more fully the nature of the signal which is used to transmit the television image. Up to this point we have explained in a general way that this signal contains the electrical image of the scene being televised and in addition contains the information required to synchronize the scanning at the camera tube with that at the picture tube. We will now go into greater detail as to the structure of this signal because of the bearing which it has on the operation and servicing of television receivers.

It will be helpful in understanding the nature of the television signal to review briefly the audio signal used in sound broadcasting and later to compare the two. In Fig. 17a is shown a typical sound or audio signal. As you know, the amplitude of this audio signal represents the intensity (loudness) of the sound, and the number of cycles per second represents the frequency (pitch) of the sound. During periods when the sound intensity is zero, the amplitude of the sound wave is of course zero; on the other hand, during periods when the sound intensity is high, this is represented by a proportionate increase in the amplitude of the signal. An important characteristic which you should note is that in a sound wave, the amplitude of the wave has both positive and negative peaks and extends equally in both directions from the zero axis.

A typical video or picture signal, that is, the electrical signal which represents the variations in brightness over the elements of a scene, is shown in Fig. 17b. The horizontal line in the left-hand portion of the signal shown represents the signal voltage produced by an *unilluminated* or *black* portion of the scene, which is called the "black level." In discussing video signals this black level is used as a reference from which the light values corresponding to all other signal voltages are measured. The reason for this is apparent from inspection of the rest of Fig. 17b, which represents various signal voltages corresponding to parts of the scene reflecting varying degrees of brightness. Note that as the brightness of the scene increases from black, the voltage of the video signal decreases, and that in any case the picture brightness never results in a signal voltage greater than the black level. The black level is therefore a suitable reference, because its voltage is fixed and easily reproduced. "White" would not be a suitable reference because the signal voltage corresponding to "whitest white" depends upon the maximum intensity of illumination available.

A video signal in which the signal voltage decreases (from the black level) as the picture brightness increases toward white is said to have a "negative picture polarity." The signal of Fig. 17b, as we have seen, is of this type. If we call the black-level voltage zero volts in Fig. 17b, all other shades of brightness will produce negative voltages, the whitest part of the scene having the greatest negative voltage. A signal having negative picture polarity is used to modulate the television carrier in present-day American television. Of course it is perfectly possible to have a video signal in which the signal voltage increases as the picture brightness increases; in this case the signal is said to have a "positive picture polarity." In fact we shall see later on, in considering receiver circuits, that the signal undergoes a reversal of polarity in passing through each stage of the video amplifier.

The important difference between the audio signal and the video signal is that the *video signal is always located on only one side of the black reference level,* whereas the audio signal contains variations on both sides of the zero-signal level. The video signal is therefore a pulsating voltage with a d-c component, not an a-c wave like the audio signal.

Let us now consider the video signal in greater detail. Fig. 18a shows the output of the camera tube for two successive lines of the image. At the same time Fig. 18b shows these two lines as they appear on the scanning pattern or raster. Starting at a, the beginning of the field, the beam traces the first line a-c; referring to the signal (Fig. 18a) it can be seen that the image is black at a, changes gradually to a brilliant white at b, and finally changes gradually to black at the end of the line c.

During the retrace time c-d, the signal level is maintained at a uniform black level as shown by c-d on Fig. 18a. This "black" interval during which the retrace is carried out is called the "horizontal blanking period," and the pulse c-d is called the "horizontal blanking pulse," or the "horizontal blanking pedestal."

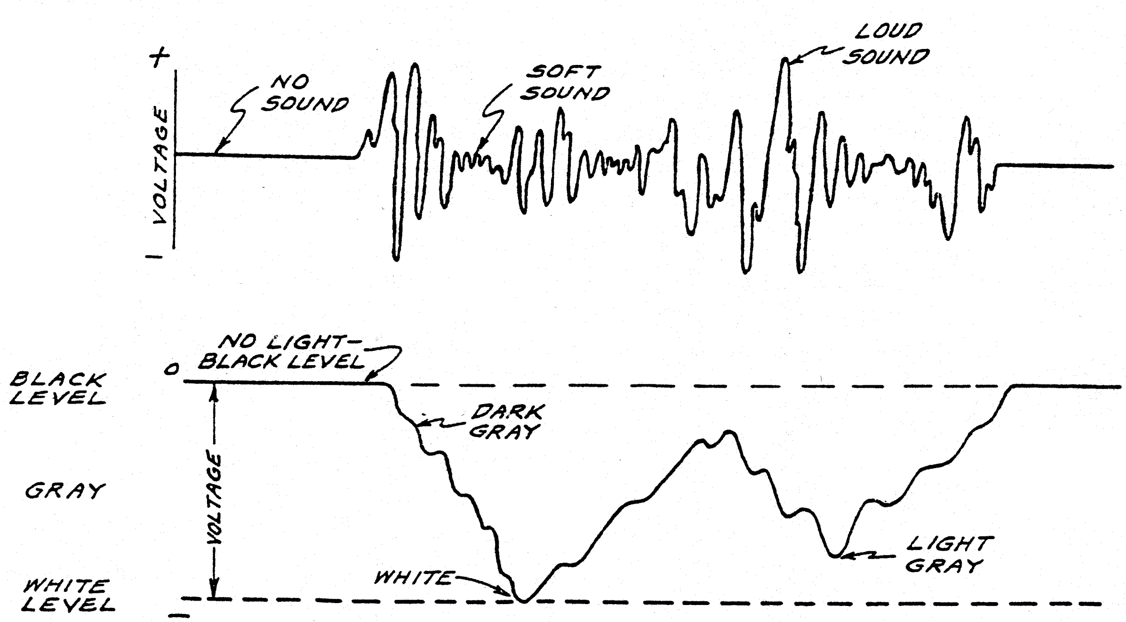


FIG. 17a, 17b.—Comparison between a sound and video signal. In the video signal black is represented by a fixed level, and various shades of brightness by voltages which are displaced proportionately from the black reference level.

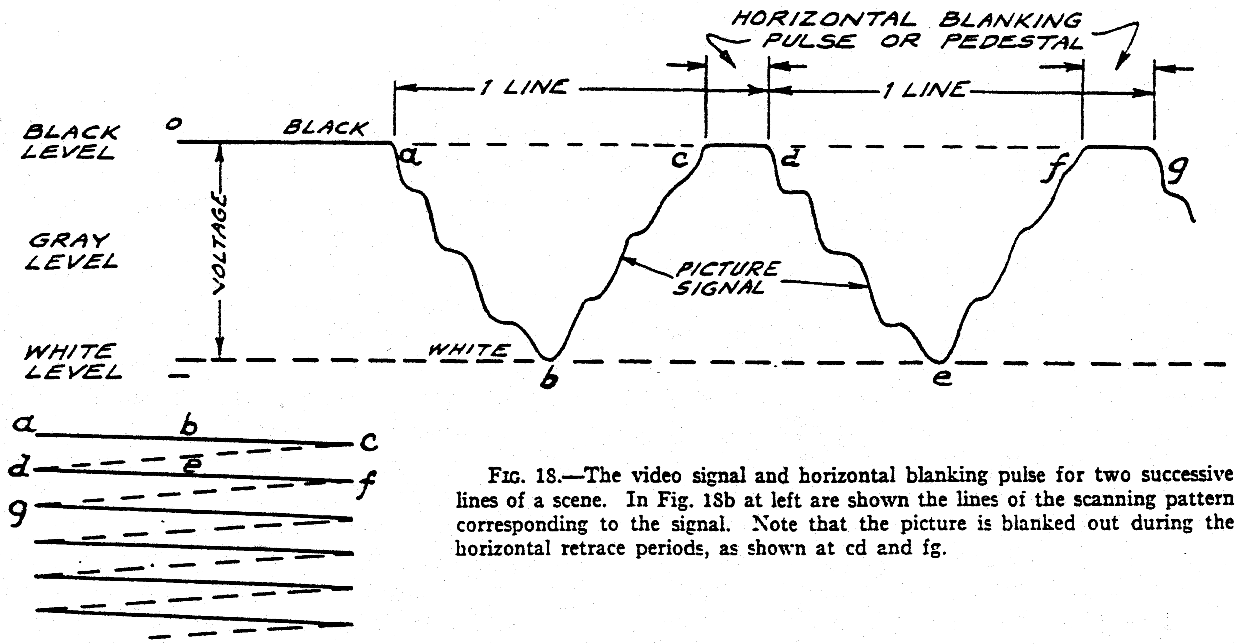


Fig. 18.—The video signal and horizontal blanking pulse for two successive lines of a scene. In Fig. 18b at left are shown the lines of the scanning pattern corresponding to the signal. Note that the picture is blanked out during the horizontal retrace periods, as shown at cd and fg.

As we shall see later in more detail, the pedestal performs two functions: (1) It blacks out the return trace so that it will not appear on the screen of the picture tube and (2) it provides a platform on which the horizontal synchronizing pulse is erected. Note that the second scanning line d-e-f is essentially the same as the first line and again the line is terminated on the signal wave by a blanking pulse f-g. In this way the entire field is scanned and the picture signal corresponding to the light and dark variations of the field is produced.

Signal and Sync Pulses

In the previous section we showed the video signal without discussing the modifications which must be made in the signal in order to provide the necessary synchronization. We shall now describe how this synchronizing information is added to the signal.

Consider the video wave shown in Fig. 19. This shows the wave for the last two lines of the field, just preceding the vertical retrace period during which the beam returns to the upper portion of the field. Starting at the left of the figure, the first thing you will note is the addition of a pulse which is erected on top of the horizontal blanking pulse; this is called the "horizontal sync pulse." As we shall see later in the discussion of receiver sync circuits, this small rectangular pulse provides the means which keeps the horizontal line or scanning oscillator in the receiver in synchronism with the scanning at the camera tube. An important thing to note is that this sync pulse is located in the "blacker-than-black" region so that the screen of the picture tube is kept dark during the period of the horizontal retrace. Thus the portion of the signal more positive than black is used for synchronizing information, whereas the voltage more neg-

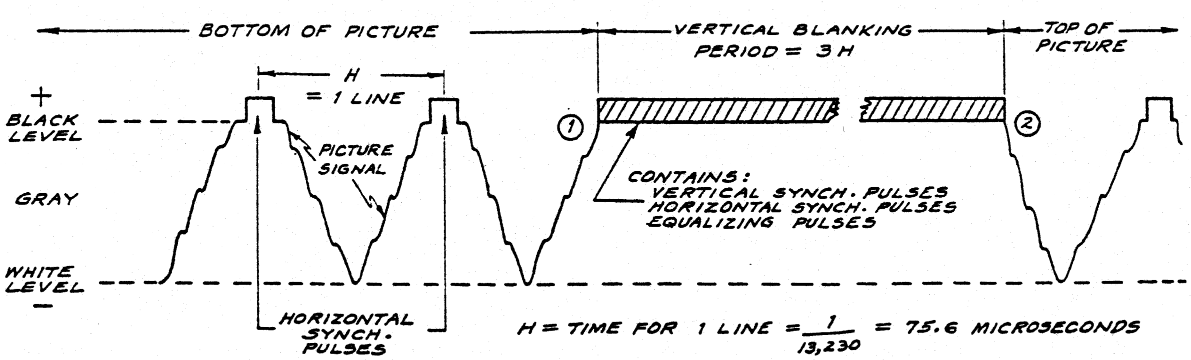


Fig. 19.—The video signal, showing the last two lines of a field followed by a vertical blanking period. Horizontal sync pulses have been erected on the horizontal pedestals and during the vertical blanking period the vertical sync pulse is transmitted.

ative than the black level is used for the picture information. It is also important to observe that this line-synchronizing pulse appears at the end of each line so that constant synchronization of the line oscillator is maintained.

At the end of the last line at the bottom of the field represented by point 1 in Fig. 19, the beam is ready to return to the upper edge of the field. As in the case of horizontal scanning, a sync pulse is required to return the beam to the top at the proper instant. All the information associated with the end of the field, required to return the beam to the top of the field in preparation for the one to follow, is contained in the interval designated as the "vertical blanking period." Essentially the following three functions are performed during the vertical blanking period: (1) A field synchronizing pulse is provided (the exact nature of this pulse is described later) so that the beam will be returned to the start of the frame at the proper instant. (2) The entire signal is blacked out so that the field retrace and lines scanned during this interval will not be apparent to the observer. (Actually, of course, the line-scanning circuits continue to function, but the beam does not exist because of the negative voltage on the control grid of the picture tube during this interval.) (3) The line synchronizing pulses are maintained during the vertical blanking period, which lasts for about 15 lines, so that the horizontal deflecting circuit in the receiver will not slip out of synchronism during this period. In addition to the vertical and horizontal sync pulses, two groups of so-called "equalizing pulses" are transmitted during the vertical blanking period; these are required for reasons which will be explained later.

RMA Standard Television Signal

It is desirable at this point to show the complete signal which has been recommended by the RMA to be used as the standard for this country. To illustrate the makeup of this signal, Fig. 20 shows the signal for two successive fields in the neighborhood of the vertical blanking pulse. Accordingly the left-hand portion of A shows the last four lines of any one field. This is followed by the vertical blanking period which contains equalizing pulses both preceding and following the vertical sync-pulse interval. After the last equalizing pulse the horizontal sync pulses are resumed; by this time the beam has been returned to the upper portion of the screen so that shortly thereafter the normal video signal is resumed. To summarize, the first line, A, shows the complete signal as it exists for any one field both before and after the transmission of the vertical blanking period.

Part B of this figure describes the signal as it exists 1/60 second later for the following field. Since the scanning is interlaced, note that the line-sync pulses in B appear *between* the line-sync pulses in A, thus providing the timing which is essential for interlacing. Again the last line in this field is followed by a vertical blanking period at the end of which the video signal is resumed. Note that for both parts of the figure, the reference point from which time is reckoned is the beginning of the vertical sync pulse, which is designated as taking place at any time represented by $t = t_1$. Using this time reference, it of course follows that the vertical sync pulse for the next field must begin 1/60 second later (since there are 60 fields per second); this is shown by part B of the figure so that the two vertical sync pulses are directly below each other but 1/60 second apart in time.

The description which follows shows in greater detail those parts of the complete video signal which have already been described. The specifications throughout are those of the RMA.

Horizontal Blanking and Synchronization

As shown in Fig. 20, the horizontal sync signal is transmitted at the end of each line and consists of an essentially rectangular pulse erected on the horizontal blanking pedestal. The amount of time allowed for the blanking pedestal is specified as 15% of the total time from the beginning of one line to the beginning of the next line. Since the time for each line (including the retrace) is 75.6 microseconds (1/13230 second), the time devoted to horizontal blanking is about 11 microseconds. This interval of 11 microseconds has been found to be just large enough to allow for the retrace time, to allow the spot to assume normal scanning speed at the left edge of the picture and to maintain reliable synchronization.

The whole of the horizontal blanking interval is not utilized for the synchronizing pulse as can be seen by examining the enlarged view of the wave between C-C (Part A) shown in the detail view, Part C of the figure. Actually only about half the total blanking time is used, and the front or leading edge of the sync signal is placed as close as possible to the beginning of the blanking pulse. The small allowance which is made takes care of some variation in timing and insures that the sync pulse will not run into the video portion of the signal and thus upset the line timing.

Vertical Blanking and Synchronization

The vertical blanking interval follows the last line of each field and consists of the following four parts which will be considered separately.

(1) *Equalizing-Pulse Interval*: Six equalizing pulses one-half line apart precede the sync pulse and accomplish (a) the maintenance of horizontal or line synchronization and (b) the "equalization" of the intervals preceding the vertical sync pulse so that *conditions preceding the vertical sync pulse are identical for alternate fields.* The need for these equalizing pulses arises because of the interlacing of alternate fields. As you can see from Fig. 20, the lines in the second field (B) are interlaced between those of the preceding field (A). If the equalizing pulses were eliminated and the vertical sync pulses were inserted in A at the end of the last line, then the vertical sync pulse would have to appear in the next field B at the middle of the line; the reason for this is that 1/60 second later the beam is in the middle of the line because of the interlacing. Thus *without the equalizing pulses,* the conditions preceding the vertical sync pulse would be different for each of the two fields. This would tend to produce a different type of vertical sync pulse for alternate fields, upset the synchronization and give rise to the distortion known as "pairing of the interlace." In a paired interlace, the even-scanned lines do not lie midway between the odd-scanned lines, because of the difference in timing on alternate fields.

In connection with the maintenance of line synchronization during the vertical blanking interval, note that the leading edges of the equalizing pulses function to maintain synchronization. Not all the pulses are used for each field, however. Thus note that because of the interlacing, the first, third and fifth equalizing pulses are used on the first field (A), and the second, fourth and sixth pulses are used on the succeeding field (B). This explains why six pulses are used, each spaced one-half line apart, rather than three pulses spaced one line apart. It would, of course, be possible to use three different pulses in each field, but if this were done the signal preceding the vertical sync pulse would be different for succeeding fields and there would be a resulting absence of equalization.

(2) *Vertical Sync Pulse*: The vertical sync pulse follows directly after the equalizing pulse interval and consists of six broad pulses in which the edges are serrated or cut at one-half line intervals. The function of the vertical sync pulse is to provide the control signal which tells the vertical oscillator that it is time to begin the retrace and thus to return the beam to the top for the beginning of the next field. The pulses in the vertical sync-pulse interval are considerably broader than the line pulses so that the sync separator circuit will be able to distinguish between the two types of pulses and thus be able to separate the vertical sync pulses from the horizontal sync pulses. At the same time the edges of the serrations at half-line intervals provide the necessary control for maintenance of horizontal synchronization. The serrations are required at half-line intervals because of the interlacing; the reasoning used in connection with the equalizing pulses also applies here.

(3) *Lagging Equalizing Pulses*: It was explained previously that in order to provide identical conditions for the two successive fields preceding the vertical sync pulses, six equalizing pulses were inserted in front of the vertical sync pulse in each field. It is just as necessary to keep the conditions following the vertical sync-pulse interval the same for the two successive fields A and B; for this reason six lagging equalizing pulses appear in both A and B after the vertical sync pulse. If you examine the vertical sync-pulse interval in both A and B you will see that, although the lines in the two fields are displaced by one-half line because of the interlacing, nevertheless the conditions in the neighborhood of the vertical sync-pulse interval are the same for both fields. Note that the lagging equalizing pulses are also one-half line apart so that line synchronization is maintained for both the "odd" and "even" fields.

(4) *Normal Horizontal Sync Pulses*: The lagging equalizing pulse interval is terminated before the end of the vertical blanking period so as to prepare the line oscillator for the normal horizontal sync pulses which are to follow. In practice, the video signal is blanked out for a period of from 7 to 12 lines following the last equalizing pulse so that the line oscillator (which may have been operating at double line frequency during the preceding period) has a chance to settle down to being under control of the normal type of sync signal. At the end of the vertical blanking interval, the blanking is of course removed and the video portion of the signal again controls the intensity of the beam in the picture tube.

Range of Frequencies in Video Signal

Unlike audio signals which contain frequency components ranging from a low value of about 20 cycles per second to a high value of about 12,000 cycles per second, video signals include a range from practically zero frequency (produced over areas where there is little variation in light intensity) to as high as 4 or more megacycles (produced over areas where there is a very rapid variation in light intensity).

It is interesting to examine the manner in which the maximum frequency required in the video signal is related to the amount of detail which is reproduced. This can be arrived at from the following considerations: Let us assume that we wish to transmit a picture in which the same resolution or detail is desired in the horizontal direction as in the vertical direction.

Now in the vertical direction we have a total of 441 lines or 441 elements. Since a horizontal line is 4/3 times as long as a vertical line (the picture is 4/3 times as wide as it is long), it follows that there are 4/3 as many elements in a horizontal line as there are in a vertical line. This makes a total of 441 x 441 x 4/3 or 260,000 elements in the complete picture.

Since we wish to calculate the maximum frequency which is required to reproduce the light and dark variations over each one of these 260,000 elements, let us assume that alternate elements in the picture are black and white so that the image resembles a checkerboard pattern. This type of scene requires the highest possible frequency for faithful reproduction because of the rapid variation in light intensity as the beam goes from one element to the next. The exact opposite of this type of scene would be one which was uniform over its entire area, for in this case it would be necessary for the system to transmit only very low frequencies. For the checkerboard pattern under discussion, the variation from black to white in scanning two adjacent elements requires a certain amount of time. This amount of time represents the duration of one complete cycle and 1 divided by this number represents the highest frequency which must be transmitted.

Let us calculate this time interval required for the beam to scan two adjacent black and white elements. Since there are 260,000 elements in a complete picture and it requires 1/30 second to transmit this picture, the time alloted to the transmission of information on two elements (1 cycle) is equal to

$$\frac{2}{260{,}000} \times \frac{1}{30}\ \frac{\text{second}}{\text{cycle}} = \frac{1}{3{,}900{,}000}\ \frac{\text{second}}{\text{cycle.}}$$

The frequency generated when the scanning beam passes over these two elements is thus equal to 3,900,000 cycles per second, or 3.9 megacycles.

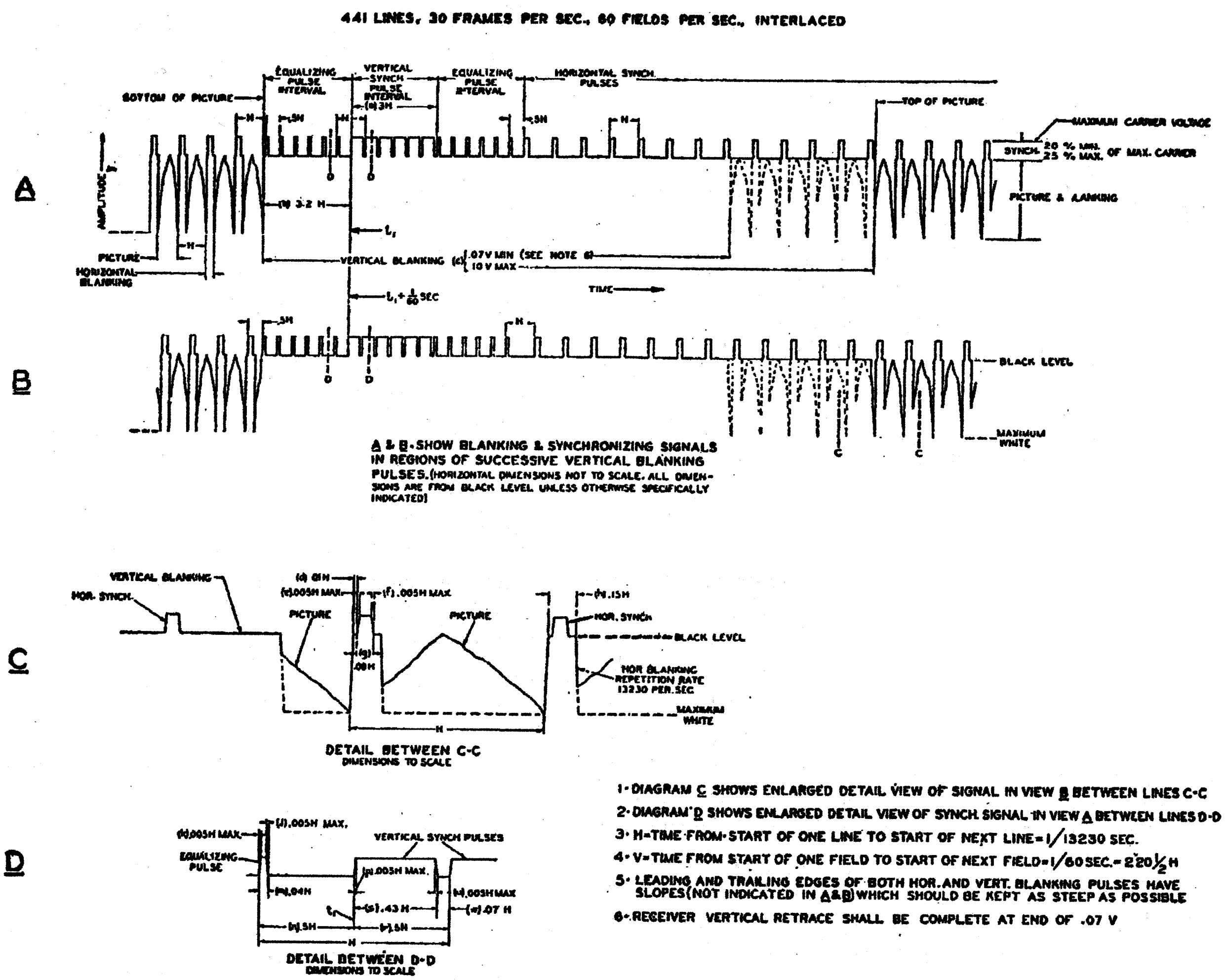


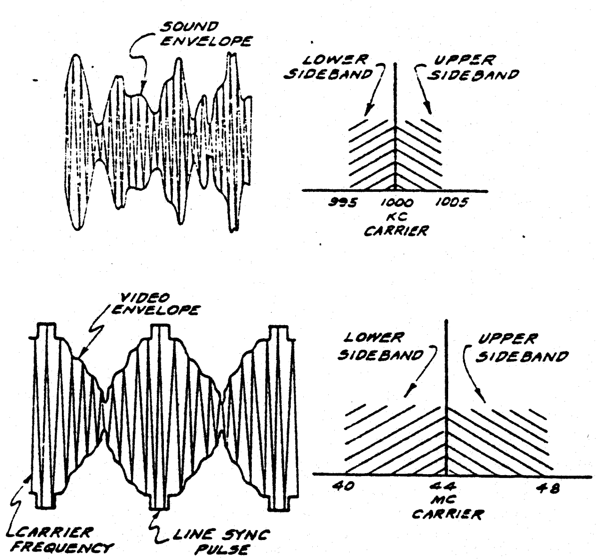
FIG. 20.—The standard RMA television signal. Diagram A shows the signal at the bottom of any one field; diagram B shows the signal at the bottom of the next field, 1/60 second later. Note the interlacing of the lines in the two successive fields shown by A and B.

As we have previously seen, the maximum frequency which is present in the video signal is related directly to the amount of detail required in the image. It has been found that for the smaller picture tubes satisfactory detail is obtained when frequency variations up to 2.5 megacycles are transmitted and that little is gained by transmitting the high frequency components produced in the scanning at the camera tube. However, where a comparatively large picture tube is used, additional detail and a finer image can be produced by transmitting frequency components ranging up to about 4 megacycles.

The Modulated Wave

In previous sections we have described the video wave produced when a scene is scanned and the modifications which are made in this wave in order to provide for both line and field synchronization. We now need to consider the make-up of the modulated wave which is produced when this video wave is arranged to modulate a high-frequency carrier.

First let us review the result of modulating a carrier with a conventional audio signal. As Fig. 21a shows, if we modulate a 1000-kc carrier with an audio signal which contains frequency components ranging up to 5 kc, then the resulting modulated wave contains, in addition to the carrier frequency, new frequencies which extend to the limits of 5 kc below the carrier frequency and 5 kc above it. In other words, the process of modulating the carrier results in the introduction of two sets of *sidebands* which extend outward from the carrier to a value equal to the highest frequency in the modulating wave. The sideband which contains frequencies lower than the carrier frequency is called the "lower sideband," and that which contains the frequencies higher than the carrier is called the "upper sideband."



Figs. 21a, 21b.—The sidebands in a sound signal occupy a bandwidth of only about 10 kc whereas the sidebands in a television signal require a bandwidth of about 8 mc or 8000 kc.

It would be impossible to use a broadcast-band carrier for television work. This can be seen from the fact that unlike sound, the video modulating frequencies would themselves be higher than the carrier frequency. In order to make the modulation process work, it is necessary that the carrier frequency be at least several times the highest frequency of modulation. For this reason the carrier frequency in television must be several times as high as the maximum video frequency, or several times 4 mc. Actually the carrier frequencies which have been chosen for television are at least ten times the highest video frequency since the lowest carrier frequency which is being used for 441-line television is 44 mc.

Some of you may recall that a few years ago, carrier frequencies only a little higher than the broadcast-band were assigned to experimental television. This merely illustrates our point, however, since those early low-definition pictures contained comparatively few elements and consequently had maximum video frequencies far below those found in present-day high-definition work (for example, 100-line picture has a top video frequency only 1/16 as high as that of a 400-line picture).

Returning to the comparison between a broadcast-band carrier modulated by a sound wave and a modulated television carrier, we show in Fig. 21b the wave which results when a 44-mc carrier is modulated with a video signal. As in the case of the 1000-kc carrier, the process of modulation introduces two sets of sidebands, and for the example shown the two sidebands extend to 4 mc below and 4 mc above the 44-mc carrier.

It is interesting to compare the bandwidth required for the transmission of a scene by television with the bandwidth required in sound broadcasting. As Fig. 21 shows, a sound broadcast requires only a 10-kc channel whereas the television channel (arranged for double-sideband modulation) requires 8000 kc or 800 times as much space as the sound channel. Although it is possible to locate approximately 100 sound channels in the broadcast band it would require more than 8 times the space provided by the entire broadcast band for the transmission of a single television channel with double-sideband modulation. The large amount of the radio spectrum required for television is one of the reasons for the choice of the ultra-high frequency range for television.

Positive and Negative Modulation

In discussing video signals we pointed out that the video signal is said to have a positive or negative picture polarity depending upon whether the changes from the black level take place in a positive or a negative direction, respectively. In modulation we run into somewhat similar terms—positive and negative modulation—which are related not to the polarity of the video signal but to the modulated wave itself. A television carrier is said to have positive modulation when an increase in carrier amplitude corresponds to a brighter area in the scene being scanned. Thus for a wave with *positive* modulation, the *lowest* carrier amplitude corresponds to *black* while the maximum carrier amplitude corresponds to the brightest part of the image. On the other hand, for negative modulation, a decrease in carrier amplitude corresponds to an increase in the brightness of the image. Thus for a wave with *negative* modulation, the lowest carrier amplitude corresponds to maximum white in the image and the *highest* carrier amplitude corresponds to *black*.

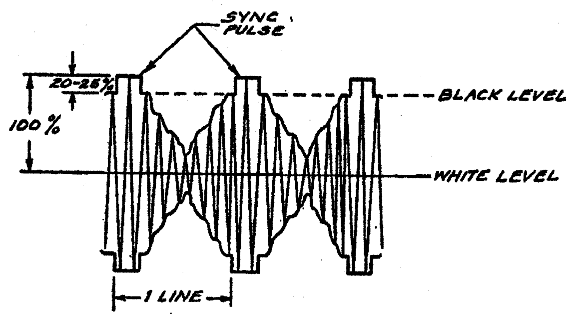


Fig. 22.—A modulated video wave. The sync pulses are located in the blacker-than-black region and occupy from 20 to 25% of the maximum carrier amplitude.

Because negative modulation offers certain advantages in improved performance and simplified receiver design, it has been recommended by the RMA as standard for this country. All television transmissions in this country therefore use negative modulation, although in England positive modulation is being used. As shown in Fig. 22, the maximum amplitude of the carrier is used for the synchronizing pulses and lies in the blacker-than-black region. The term "blacker-than-black" merely means that the sync signals have higher amplitude than black picture signals. It has been found that reliable synchronization can be secured so long as the amplitude of the synchronizing pulses is from 20 to 25 percent of the maximum carrier amplitude; this recommendation is also part of the RMA standards. Actually, then, not more than 80% of the total carrier amplitude is available for transmitting information on the light values in the scene, the rest of the wave being used for synchronization.

Channel Make-up

The standard RMA television channel is laid out so that the complete video signal and its accompanying sound signal can be transmitted as close together as possible, thus making for a compact channel which takes up a minimum amount of space in the radio spectrum. As shown in Fig. 23, the complete channel is 6 mc wide and the video carrier is placed 1.25 mc from the low-frequency end of the channel. The sound is transmitted on a separate carrier which is located 4.5 mc higher than the video carrier or 0.25 mc from the upper end of the band.

In order to use the minimum possible channel width, the major part of the lower sideband is *suppressed* and only the portion shown is transmitted. In this type of transmission, which is known as "vestigial sideband transmission," the transmission is essentially double-sideband for the *low* modulating frequencies (up to approximately 1.25 mc) and then becomes single-sideband for the higher modulating frequencies (above approximately 1.25 mc). This tends of course to overemphasize the *lower* frequencies (since they receive contributions from both the partially suppressed lower sideband and the upper sideband). Such overemphasis is avoided by designing the selectivity of the receiver to attenuate the carrier and the lower (double-sideband) frequencies. The difference between the transmitter selectivity curve and the receiver selectivity curve is shown by the dotted line in Fig. 23.

The advantage of this type of transmission is that it reduces the channel width required for a given maximum amount of detail in the image. We might mention here that earlier RMA proposed standards called for a double-sideband transmission which—although using the same 6-mc channel—made it possible to transmit video frequencies up to only 2.5 mc because both sidebands (occupying a 5-mc total bandwidth) were transmitted.

It is interesting to note the relatively small part of

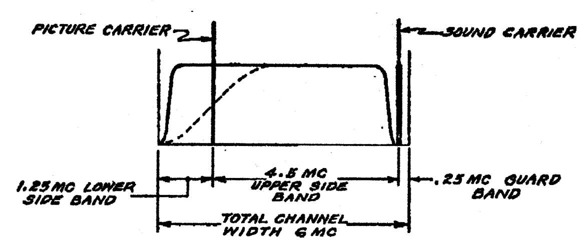


Fig. 23.—Make-up of the standard RMA television channel, showing the position of the picture and sound channels. The dotted line shows the receiver selectivity characteristic.

the total channel width occupied by the sound carrier. Even assuming that radio frequencies up to a maximum of 10 kilocycles are transmitted, this would make the total bandwidth (including both upper and lower sidebands) equal to 20 kc or 0.02 mc. It is thus apparent that the guard band of 0.25 mc is more than enough to prevent the sound modulation from spreading into the next channel. In practice, to take care of oscillator drift, the sound-carrier bandwidth is often about 100 kc.

Frequencies Assigned to Television

The Federal Communications Commission has assigned a total of nineteen channels for television transmissions, each of these channels being 6 mc wide in accordance with the description in the preceding sections. The distribution of these channels is noted in Fig. 24; seven of the channels are located between 44 mc and 108 mc; the remaining 12 lie between 156 and 294 mc. At present, only the lower-frequency channels are in use, but it is expected that the higher-frequency channels will be employed as television services expand.

FIG. 24

Channels Assigned to Television

44–50 MC	156–162 MC	234–240 MC
50–56	162–168	240–246
66–72	180–186	258–264
78–84	186–192	264–270
84–90	204–210	282–288
96–102	210–216	288–294
102–108		

For a number of reasons the ultra-high frequency bands are the most logical choice for television. In the first place, a relatively high-frequency carrier is required to accommodate the wide sidebands. Even if this requirement did not prevent the use of lower frequencies it would still not be feasible to use the lower radio frequencies because these are practically all in use already for other services. The ultra-short waves used for television have the advantage that the waves are not usually reflected by the ionosphere so that multiple signals and fading from this source are eliminated. This is desirable because the time difference in the reception of the direct image and each of the multiple reflected images causes a displaced "ghost" pattern to appear on the screen of the picture tube. The absence of *natural* static is another important feature in making the frequencies above 40 megacycles suitable for television work.

The fact that ultra-short waves travel essentially in straight lines and so do not follow the curvature of the earth limits the effective radius of a television station to a "horizon" which depends upon the height of the transmitting and receiving antennas. In the case of the transmitter atop the Empire State Building in New York City (about 1250 feet above street level) the expected range for reliable reception is about 40-45 miles. Although this is a disadvantage in that the coverage of any one station is limited, there is the slight compensating advantage that the same frequencies can be reassigned in various sections of the country which have a reasonable geographical separation.

RECEIVER CIRCUITS: GENERAL

Having examined the fundamental principles of television, let us now investigate the operation of receiver circuits. These circuits are especially important because primarily the work of servicemen in the field deals with the installation and maintenance of receivers. In order to show the interrelationship between the many components that make up a receiver, we shall first break down the receiver into its major sections and later consider the functioning of these in more detail.

Fig. 25 shows a block diagram of a typical television receiver, this being arranged to show the general character of the signal and the function performed by each section. For convenience we shall assume that the receiver is tuned to the 44-50 mc channel. In accordance with the preceding description, this means that the frequency of the video carrier is 45.25 mc (1.25 mc above the low-frequency end of the channel) whereas the frequency of the audio carrier is 49.75 mc (0.25 mc below the high-frequency end of the channel).

Both these signals, together with their sidebands, are picked up by the antenna and fed through a transmission line to the input of the r-f amplifier. Essentially the function of the r-f amplifier is the same as that of the r-f amplifier in any superheterodyne receiver—to amplify the signal and to reject unwanted signals in adjacent and other channels. In this case, the r-f amplifier is broadly tuned so that both the video and sound carriers, which are separated by 4.5 mc, are amplified equally.

After being amplified in the r-f amplifier, both signals are fed to the *first detector* circuit where the conversion of the signals to the intermediate frequencies takes place. Since there are two radio frequencies, it of course follows that two separate intermediate frequencies are produced.

In accordance with a proposed RMA standard, and general present practice, the oscillator operates at a frequency *12.75 mc above the video carrier frequency.* For the channel being received, the frequency of the oscillator in the receiver is thus equal to 45.25 mc + 12.75 mc, or 58 mc. Since the oscillator frequency is 12.75 mc above the video carrier frequency, it follows at once that the video intermediate frequency produced is equal to 12.75 mc. In the same way, the intermediate frequency of the sound signal is equal to the difference between the oscillator frequency and the sound carrier frequency, 58 mc — 49.75 mc, or 8.25 mc.

Following the first detector, the sound channel is entirely independent of the rest of the receiver and in practically every detail is similar to a conventional broadcast receiver. Thus the 8.25-mc sound i-f signal passes through the sound i-f amplifier (the selectivity of which is broader than usual to minimize the effects of oscillator drift, as mentioned above) and is demodulated at the sound second detector. The avc voltage is supplied in the usual manner to control the gain of the stages in the sound i-f amplifier. The design of the audio amplifier and the reproducer is also conventional so that no further comment is required.

Returning to the video signal, we have seen that a 12.75-mc i-f signal is produced by the first detector and that this signal carries the video modulation. As the diagram shows, this signal is amplified in the *video i-f amplifier,* which usually consists of several stages, and finally reaches the *video second detector* where the signal is demodulated. The video signal recovered at this point is essentially the same as the output of the camera tube so that it contains all the information required to reproduce the picture, and in addition, includes the blanking and sync pulses. The video second detector is followed by the *video amplifier* which in terms of a sound receiver, corresponds to the audio amplifier. The function of the video amplifier is to amplify the video signal so that its amplitude will be great enough to "swing" the modulation grid of the picture tube. For the average picture tube this requires approximately 25 volts, peak-to-peak.

Note in the diagram that the polarity of the video signal is reversed 180 degrees for a single stage of video amplification and that the receiver is arranged so that the signal which reaches the control grid of the picture tube has a positive polarity. As a result the synchronizing impulses appear in the blacker-than-black (highly negative grid-bias) part of the picture-tube characteristic so that the beam is blocked during the retrace part of the line and field sweeps.

In addition to supplying the video signal and the signal which actuates the avc system, the second detector supplies the video signal to the *synchronizing separator.* The purpose of this separator is to remove the picture component from the complete video signal, and then to separate the horizontal sync pulses from the vertical sync pulses. As is shown, the horizontal sync pulses are arranged to control the timing of the horizontal deflection circuit, while the vertical sync pulses are arranged to control the timing of the vertical deflection circuit.

The power supply is not shown in the block diagram. As a general rule, a single low-voltage power supply is used to take care of all voltage requirements throughout the receiver with the exception of the high-

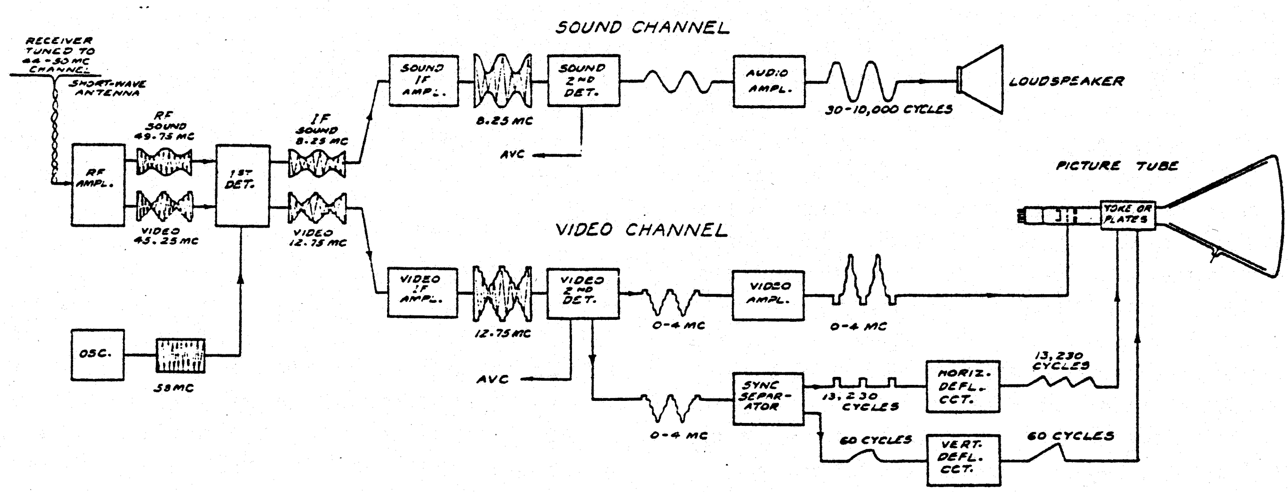


FIG. 25.—A block diagram of a typical television receiver showing the principal sections of which it is composed. Note the changes in the signal as it passes through the receiver.

voltage requirements for the picture tube. The latter, which may include voltages as high as 9000 volts, is supplied by a separate high-voltage power supply which has its own transformer, rectifier and filter.

RECEIVER CIRCUITS: DETAILS

The serviceman who examines a television receiver schematic for the first time is likely to be discouraged. Considering the size of the schematic, the large number of components, and the newness of many of the circuits, this is not at all surprising. Even the man who understands the basic ideas associated with television may find himself unable to understand immediately the operation of some of the circuits. Fortunately, however, the circuits are not actually as complicated as they appear on first sight. What is really required is an explanation of how the basic principles of radio have been applied in television receivers. With this explanation as a guide and with the aid of experience, the serviceman will find that the apparently complex television receiver schematic will begin to look more like an old friend.

We can best explain the circuits being used in television receivers by breaking down the complete receiver circuit into separate sections and considering the function and operation of each section separately. By this means we can for the time being eliminate the complications introduced by the related parts of the circuits and also eliminate unessential detail which tends to obscure the operation of the circuit. Since without exception all television receivers in this country are of the superheterodyne type, the divisions which will be followed are those characteristic of superheterodyne receivers.

R-F Circuits

The action in a receiver circuit can well be considered as beginning at the antenna, for it is at this point that the signal enters the receiver. Since we shall consider antennas in more detail under the head of "Antennas and Installation," for the present it is sufficient to note that the function of the antenna is to provide the maximum signal pickup with a minimum of noise. To do this, the antenna must be located as high and as far away from sources of man-made noise as possible and placed for maximum pickup. The signal is fed from the antenna to the receiver input by means of a transmission line.

Since the complete television signal consists of a band of frequencies extending over a 6-mc channel, it is clear that the antenna and transmission line must be broad enough to pass the 6-mc band. A sharply tuned antenna system is undesirable because it discriminates against the different frequencies present in the signal and as a result produces distortion.

The characteristics of the r-f circuits in television receivers are the same as for ordinary broadcast receivers. As in any superheterodyne receiver, the function of the r-f circuits is to select and amplify the wanted signals and to reject all other signals. As a general rule, most television receivers do not use an r-f stage but rely on the selectivity of the tuned circuit which feeds the signal from the transmission line to the mixer input to provide the required selectivity and image rejection. In some receivers, however, an r-f stage is provided so that additional gain, selectivity and a higher signal-to-noise ratio are obtained.

In most cases you will observe that the r-f tuned circuits as well as tuned circuits in the i-f amplifier are shunted by resistors of comparatively low value. The function of these resistors is to damp the circuits so that sideband cutting will not take place and so that the complete television signal will be passed. Although these resistors lower the gain, this reduction in gain must be tolerated in order to broaden the circuits sufficiently.

Without exception all commercial receivers use push-button or switch-controlled tuning rather than conventional continuous tuning with a large variable condenser. This is feasible because the short-wave channels which have been assigned for television are limited in number and do not require continuous coverage as is the case, for instance, in the broadcast band. At the present time the lower channels are most in use and will probably be the only ones in use for some time.

As a general rule, a small vernier condenser is provided to permit a fine adjustment of the tuning. This condenser is placed across the oscillator tuned circuit and compensates for drift in the trimmers and other effects which tend to change the oscillator frequency. No external tuning adjustments are required for the r-f circuits since these are not critical of adjustment.

Oscillator Circuits

As has been previously pointed out, the oscillator in a television receiver beats with both the sound and video carriers of the signal to form two separate intermediate-frequency signals: the video i.f. and the sound i.f. According to present standards, the oscillator frequency for any given channel is 14 mc above the low-frequency end of the channel, which in turn makes it 12.75 mc above the video carrier and 8.25 mc above the audio carrier. As a result, the frequency of the signals produced by heterodyning with the oscillator signal is 12.75 mc for the video i.f. and 8.25 mc for the sound i.f.

Combination oscillator and mixer tubes are not satisfactory for the comparatively high frequencies at which the oscillator must operate, because of low conversion gain and because these tubes do not oscillate readily at the high frequencies required. For these reasons a separate tube is generally used for the oscillator circuit. The type 6J5 tube is more widely used than any other tube because of its high mutual conductance, low capacitance, and because it oscillates readily at frequencies up to 120 megacycles.

In the design of oscillator circuits much attention is given to the problem of minimizing frequency drift. Because of the high frequencies at which the oscillator operates, a comparatively small percentage change in the oscillator frequency, such as might be caused by drift, has the effect of spoiling the picture and causing the sound i.f. to drift out of the range of the sound i-f channel. Although the effect of oscillator drift is minimized because of the comparatively high intermediate frequencies, the problem of oscillator stability and freedom from drift is an important one. In commercial receivers, drift is minimized through proper circuit design and by the use of coils and condensers which are independent of changes in temperature and humidity.

Mixer

As has previously been pointed out, combination oscillator-mixer tubes such as are satisfactory at lower frequencies are not satisfactory at frequencies above 40 mc. It is general practice to use one of the new high mutual conductance tubes in the mixer circuit, such as the type 1852. The 1852 is especially adapted for frequency conversion and provides high conversion efficiency. For proper mixer operation, it is essential that the output of the separate heterodyning oscillator be coupled to the mixer tube and that the mixer receive approximately the same value of voltage from the oscillator on all bands.

Typical R-F, Oscillator, and Mixer Circuits

Belmont Model X-466

The circuit shown in Fig. 26 is that of the high-frequency section of the Belmont Model X-466 receiver. This receiver does not use an r-f stage but the signal is coupled directly to the grid of the 1851 mixer tube through a double-tuned closely coupled band-pass circuit. This bandpass circuit provides the required selectivity without sacrifice in gain. Five of the assigned television channels are covered, beginning with the 44-50 mc channel, the highest channel being the 84-90 mc channel. The three highest-frequency channels are shunted by resistors having a value between 1000 and 2000 ohms in order to obtain the required pass band. These resistors do not have the loading effect that might be expected offhand, since the loading of the input resistance of the tube is itself of the order of 1000 ohms. In addition to improving the gain and selectivity of the input circuits, the tuned primary windings of the input transformers aid in proper matching of the transmission line and in eliminating reflections. These reflections are undesirable because they tend to produce more than one image on the screen of the picture tube.

The oscillator circuit, which uses a 6J5 tube, is conventional in design, with the tank circuit located in the grid circuit. Note the comparatively small value of grid condenser-25 mmf. The major portion of the total capacitance in the tank circuit of the oscillator is selected by means of the 5-position switch which is of course ganged with the r-f selector switch. A small vernier tuning condenser across the grid coil provides an adjustment which compensates for small variations due to oscillator drift. This control appears on the panel and its designated as the tuning control.

A type 1851 tube is used as the mixer tube. This is a pentode having a high mutual conductance, and is similar to the 1852 but has the grid cap on the top. It is used in preference to a 6J7 because it provides higher gain and a higher signal-to-noise ratio.

There is no direct coupling connection between the oscillator circuit and the mixer; the required coupling is provided inductively by placing the oscillator coil close to the mixer input coil.

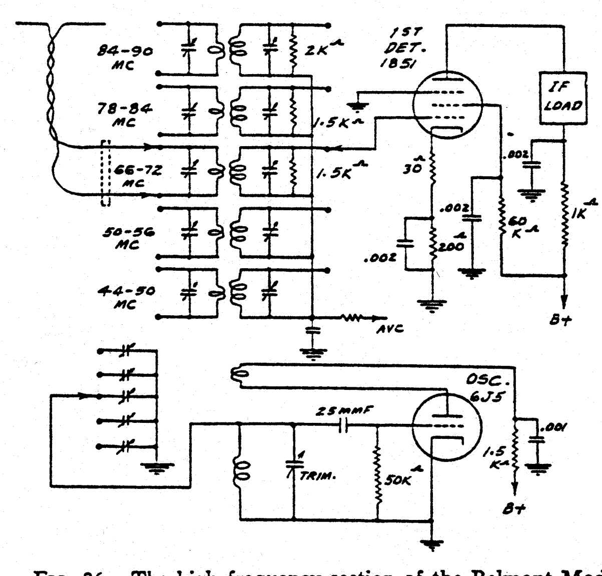


FIG. 26.—The high-frequency section of the Belmont Model X-466 receiver. The signal from the oscillator coil is inductively coupled to the mixer input coil.

DuMont Models 180-183

The DuMont Models 180-183 use a tuned r-f stage preceding the mixer stage, as shown in Fig. 27. In this receiver the transmission line feeds directly into an untuned primary winding which is the same for all four channels. The secondary winding is tuned by one of the four trimmers, depending upon the channel selected. The secondary winding is loaded on all bands by the 3000-ohm shunt resistor which is required to obtain the necessary 6-mc pass band; on one of the bands, an additional shunt resistor of 10,000 ohms is provided.

The signal voltage developed across the secondary tuned circuit is fed to the grid of the 1853 tube used as the r-f tube. Note the small values of capacity—600 mmf—used for the cathode and screen bypasses. These condensers although they seem small in capacitance provide the same relative bypassing action at 50 mc as would be provided by a .06-mf condenser at 500 kc. The tuned circuit used in the grid of the mixer tube is similar to that used in the input circuit of the r-f tube. The r-f tube receives its plate voltage through the 3000-ohm resistor. This resistor, as far as r.f. is concerned, is effectively shunted across the coil in the mixer tube grid circuit, and thus provides the damping necessary to broaden the selectivity. Note that this type of circuit is not used at lower frequencies, such as the broadcast band, because the values of tuned-circuit impedance are much larger at the lower frequencies, and to attempt to use a high value of resistance would introduce a large voltage drop. For this reason, transformers are generally used at the lower radio frequencies rather than the resistive-tuned circuit coupling arrangement shown in Fig. 27.

The oscillator circuit used here is a conventional Hartley oscillator with the feedback obtained by returning the cathode to a tap on the coil. Vernier tuning for each one of the four channels is provided by the small condenser C which appears on the panel as the tuning control. The oscillator coil and the mixer input coil are close to each other so that the oscillator voltage is coupled to the mixer magnetically.

I-F Circuits

As a result of the action in the mixer circuit, we have seen that two intermediate frequencies are produced and that one of these—the video i.f.—carries the picture signal, while the other one—the sound i.f.—carries the sound signal. As in the conventional superheterodyne receiver, it is necessary to amplify both of these i-f signals before they are finally demodulated in the second detectors. These functions are performed by the video i-f and the sound i-f amplifiers. In this section we shall discuss the design of i-f circuits for television receivers and illustrate the principles with circuits taken from typical receivers on the market at the present time.

Signal Output of Mixer

The frequencies which must be handled by the two i-f amplifiers are illustrated in Fig. 28. Let us assume that a signal in the 44-50 mc channel is being received. In this channel, the video carrier is at 45.25 mc and the sound carrier is at 49.75 mc; the local oscillator frequency, which is 14 mc above the low-frequency end of the channel, is therefore at 58 mc (44 + 14). As a result of beating with the oscillator, the video i-f signal at 12.75 mc (58 — 45.25) and the sound i-f signal at 8.25 mc (58 — 49.75) are produced. It is important to note, as the figure shows, that whereas the video r-f carrier is lower in frequency than the sound r-f carrier,

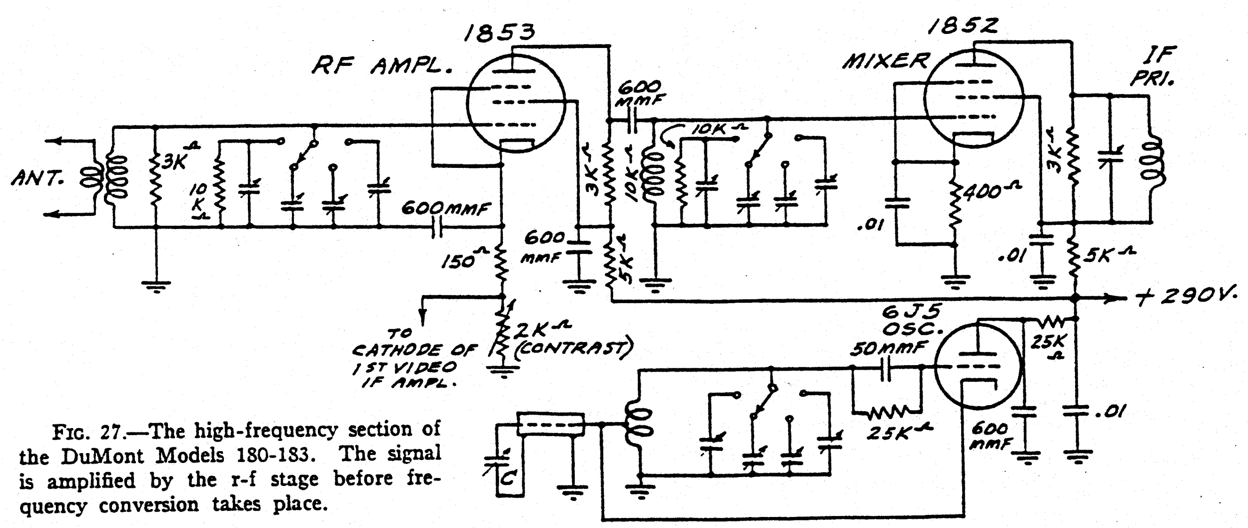


FIG. 27.—The high-frequency section of the DuMont Models 180-183. The signal is amplified by the r-f stage before frequency conversion takes place.

the video i.f. is higher in frequency than the sound i.f. However, the relative placement of the various components of the complete signal is the same in the i-f signal as in the r-f signal. Thus the frequency separation between the two carriers is constant at 4.5 mc in both cases as is also the separation from the two ends of the channel.

The intermediate frequencies used in television receivers have a number of desirable qualities which are the result of careful planning by television engineers.

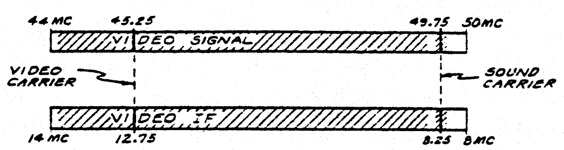


FIG. 28.—The upper part of this figure shows the make-up of a video signal in the 44-50 mc band. The lower part shows that the same frequency separation of the components of the signal is maintained in the i-f signal as in the r-f signal.

Thus the frequencies are high enough to give good image rejection; this is especially important because many receivers do not use an r-f stage. At the same time, the video i.f. is high enough so that there is sufficient space for the sidebands and the sound i.f. is high enough so that the sound selectivity is not too sharp. The effect of too sharp selectivity in the sound i-f amplifier is to make tuning critical, to exaggerate the effect of the slightest drift in the oscillator frequency and to prevent adjustment for the best picture detail without losing the sound signal.

Like any other superheterodyne, television receivers are subject to interference due to pickup by the antenna of frequencies within the range of the i-f amplifier. In the case of broadcast receivers, such interference shows itself in the form of squeals, code signals, and general distortion. Similarly, in the case of television receivers such pickup may distort either the picture, the sound, or both, depending upon the frequency of the interference. The range of intermediate frequencies between 8 and 14 mc has been especially chosen to minimize i-f interference; the fact that the amateur bands lie outside of this range is of considerable assistance in this respect.

Sound I-F Channel

It is the function of the sound i-f amplifier to separate the sound component of the i-f signal from the video component and to amplify this signal before it is demodulated at the sound second detector. Because of the comparatively high frequencies involved, however, the design of a television sound i-f amplifier is somewhat more difficult than that of the conventional i-f amplifier in a radio receiver. Thus there is a greater tendency toward regeneration and more attention must be paid to stray wiring and tube capacitance.

The bandwidth which must be passed is comparatively small and does not present the same problem as does the video i-f amplifier. Actually, of course, a bandwidth of from 10 to 20 kc is sufficient to transmit all the frequencies present in the audio signal. However, in practice, the bandwidth of the sound i-f amplifier is made approximately 100 kc. Primarily this larger bandwidth is necessary to allow for normal drift in the frequency of the oscillator. The significance of this is that if the bandwidth of the sound i-f amplifier were held to 10 kc, then a change of 10 kc in the oscillator frequency would cause the sound signal to drift completely out of the range of the sound i-f amplifier. However, a change of 10 kc, in an oscillator operating at a frequency of the order of 60,000 kc and up, represents a frequency drift in the oscillator of only one part in 6000, whereas in practice it is not possible to design receiver oscillators which will have a reliable frequency stability of better than one part in 1000. Therefore, instead of resorting to voltage regulation and expensive design to prevent oscillator drift, the bandwidth of the sound i-f amplifier is intentionally made about ten times as great as that required for the sound modulation, thus allowing for reasonable drift in the oscillator. Assuming that the receiver is initially tuned to the center of the sound i-f amplifier, a drift in the oscillator frequency as high as 25 kc will not cause any appreciable change in the quality of the audio signal. This is illustrated in Fig. 29, which shows that the effect of a change in the frequency of the oscillator is merely to shift the location of the sound signal within the band passed by the sound i-f amplifier.

Although the bandwidth of approximately 100 kc is sufficiently great to compensate for normal oscillator drift, this bandwidth is still small enough so that the receiver can be tuned by listening to the sound accompanying the picture. At the same time there is enough latitude so that the tuning can be varied slightly in

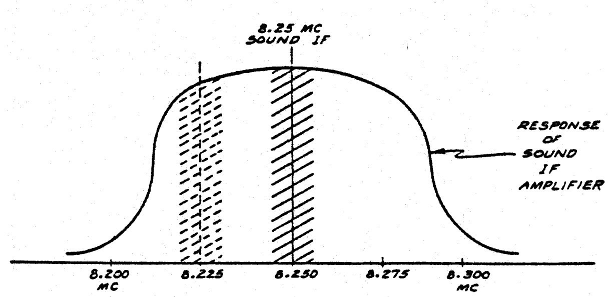


FIG. 29.—The frequency response of a typical sound i-f amplifier. The dotted signal shows that the sound signal can be detuned appreciably without falling outside the pass band of the amplifier.

order to improve the detail of the picture without losing the accompanying sound signal. Although we shall see later that a special type of AVC circuit is required in the video i-f amplifier, the AVC circuits used in the sound i-f amplifier are conventional.

Sound I-F Amplifiers in RCA and Westinghouse Receivers

The circuit of the sound i-f amplifier used in the RCA Models TRK-9 and TRK-12 is shown in Fig. 30; these receivers are also used in the Westinghouse Models WRT-702 and WRT-703. The tuned circuit L18-C19 is part of the load circuit of the mixer tube and is tuned to 8.25 mc so that the sound i-f signal is developed across this tuned circuit. This signal is fed to the grid of the first sound i-f tube, a 6SK7, which is similar to the 6K7 with the exception that the control grid is terminated at one of the base pins so there is no top cap. A double-tuned interstage transformer is used to feed the second sound i-f stage, which employs an 1853 tube. Because the gain obtainable with this tube is approximately twice that which can be obtained with an ordinary r-f pentode, no further amplification is required and the output of the 1853 feeds directly into the 6H6 second detector. The circuit beyond the second detector is not shown but this is a conventional high-quality audio system and requires no comment.

The i-f transformers in this circuit are especially designed so as to provide an overall selectivity of approximately 100 kc. The 68,000-ohm resistor shunting the primary winding of the last i-f transformer loads this circuit so as to aid in obtaining the proper response.

The AVC circuit is similar to one which has been extensively used in other RCA receivers. This circuit has been described in detail in the book "An Hour a Day with Rider on AVC." Briefly, one of the diodes is used as the second detector and AVC tube, while the second diode of the 6H6 provides a delayed AVC action and permits the minimum bias of approximately —2 volts to be fed to the grids through the AVC bus. Both i-f tubes are controlled by the AVC circuit.

Because of the high frequencies being amplified and the low shunt capacitances across the tuned circuits, it is important that there be no change in the effective tube capacitances to cause detuning to take place as the AVC bias changes in accordance with the strength of the incoming signal. This effect, ordinarily not important in broadcast receivers, is avoided in this receiver by using *unbypassed* cathode resistors. The negative feedback introduced by these resistors tends to keep the tube input capacitance constant and independent of the voltage on the control grid.

Video I-F Circuits

The design of the video i-f amplifier is more complicated than that of the sound i-f amplifier because of the wide band of frequencies which the video i-f amplifier must pass. Thus the video i-f amplifier often must handle frequencies extending from approximately 8.7 mc to 14.0 mc, a range of over 5 mc. Not only must the amplifier have an almost flat response over this range, but at the same time it must reject interfering signals close to the edges of the pass band.

The use of the so-called vestigial sideband transmission, in which all of one sideband and a small portion of the other sideband are transmitted, makes it necessary for the selectivity of the i-f amplifier to depart from the uniform selectivity which might at first be expected. To avoid overemphasis of the lower video frequencies, which receive contributions from both the upper and lower sidebands, the selectivity of the i-f

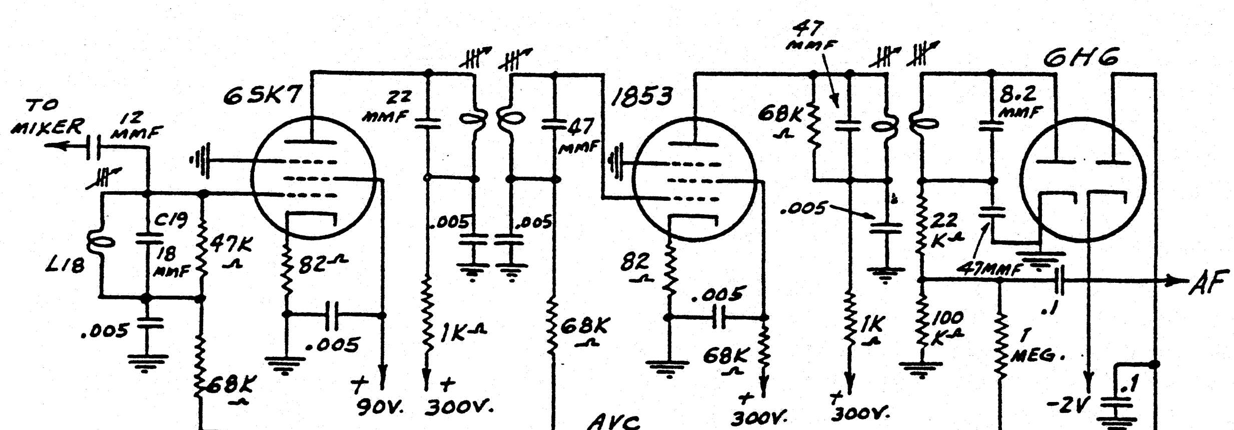


FIG. 30.—The sound i-f amplifier used in the RCA Models TRK-9 and TRK-12. The transformers are designed so that the overall bandwidth of the amplifier is approximately 100 kc.

amplifier is designed to have a sloping characteristic in the neighborhood of the video i-f carrier at 12.75 mc. This is illustrated in Fig. 31 which shows a typical *overall* selectivity curve for a video i-f amplifier.

The amplification which the i-f carrier receives is only 50% of the maximum amplification received by the upper sidebands and the lower sidebands, which are only partially transmitted, also do not receive the full amplification. In this way overemphasis of the lower video frequencies is avoided by shaping the overall selectivity so that the contribution of the lower sideband plus the contribution of the upper sideband is equal to the gain for the higher video frequencies. Since the upper video frequencies receive contributions only from the one sideband, the selectivity, as Fig. 31 shows, is such that the full gain is received by these frequencies.

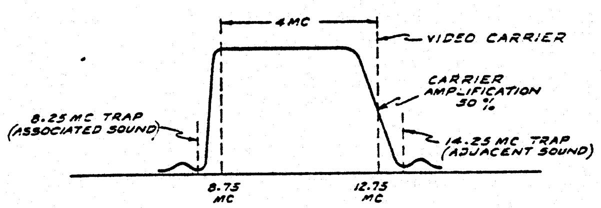


FIG. 31.—The overall frequency response of a typical video i-f amplifier. Note that the carrier receives only 50% of the maximum amplification.

If video frequencies up to a maximum of 4 megacycles are to be received, which is usual for the higher-priced sets using large picture tubes, then the i-f amplifier should cut off at about 8.75 mc (12.75 — 4.0). Since the sound i-f carrier is located close by, at 8.25 mc, it is necessary that this cutoff be sharp in order to prevent the sound carrier and its sidebands from causing interference with the video signal. In practice this rejection of the sound carrier is secured by the use of rejection or trap circuits which generally are part of the video i-f coupling transformers.

In addition to rejecting the sound i-f carrier of the *associated* channel at 8.25 mc, it is desirable that the i-f amplifier have a sharp cutoff at the high-frequency end of the band. This is required in order to prevent the sound signal on the *lower adjacent* television channel from getting through the video amplifier. Because of the reversal of high and low frequencies which takes place in the mixer, the sound carrier of the lower adjacent channel will beat with the oscillator and cause an interfering signal which is located 0.25 mc above the edge of the channel, at 14.25 mc. These frequency relationships just described are shown in Fig. 32. A trap of the same general type as that used to reject the 8.25 mc carrier is used to reject possible interference from the adjacent sound carrier at 14.25 mc.

The maximum gain which can be obtained in a video i-f stage is considerably lower than that in an ordinary broadcast i-f stage because of the wide band of frequencies which must be passed and because of the high carrier frequency. This is true even where high mutual conductance tubes of the 1851 series are used, so that it is not unusual for as many as five separate stages to be used in the video i-f amplifier.

The transformer design is especially complicated in video i-f amplifiers because of the wide pass band of from 2.5 to 4.0 mc which must be obtained. To obtain close coupling so as to increase the pass band, direct coupling of the primary and secondary windings by means of a common inductance is often used. Loading of the tuned circuits with resistors so as to broaden the circuits is very common and will be found in practically all the circuits. Video i-f transformers are further complicated because the rejector circuits for the associated and adjacent sound channels are often an integral part of the interstage coupling transformers. Because of the comparatively high frequencies, the only capacitance used to tune the circuits is often that of the wiring and tube capacitance so that no condenser as such appears on the schematic. Nevertheless this capacitance forms a resonant circuit with the related windings of the transformer and should be taken into consideration. Since the wiring capacitance is an important part of the total circuit capitance, it is important that no changes be made in the wiring when servicing is required.

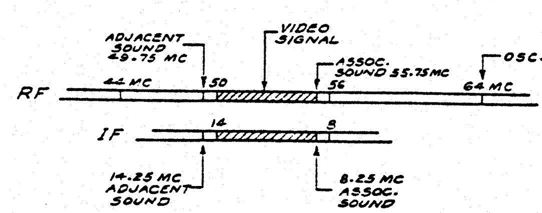


FIG. 32.—The sound signal of the associated channel at 8.25 mc and the sound signal of the adjacent channel at 14.25 mc are both close to the edges of the video band. Traps are provided to prevent interference from these signals.

AVC is often used in video i-f amplifiers, but as will be explained later under "AVC Circuits," the manner in which the AVC voltage is produced differs from that in radio receivers and in the sound i-f amplifier.

Video I-F in Andrea Model 1F5

In the Andrea Model 1F5 receiver, shown in Fig. 33, the video i-f amplifier employs two stages of amplification both of which use type 1852 tubes. In order to separate the sound i-f part of the signal from the video part, a separate secondary circuit L2-C2 is tuned to 8.25 mc so that the sound i-f signal appears across this circuit. The sound i-f signal is fed directly to

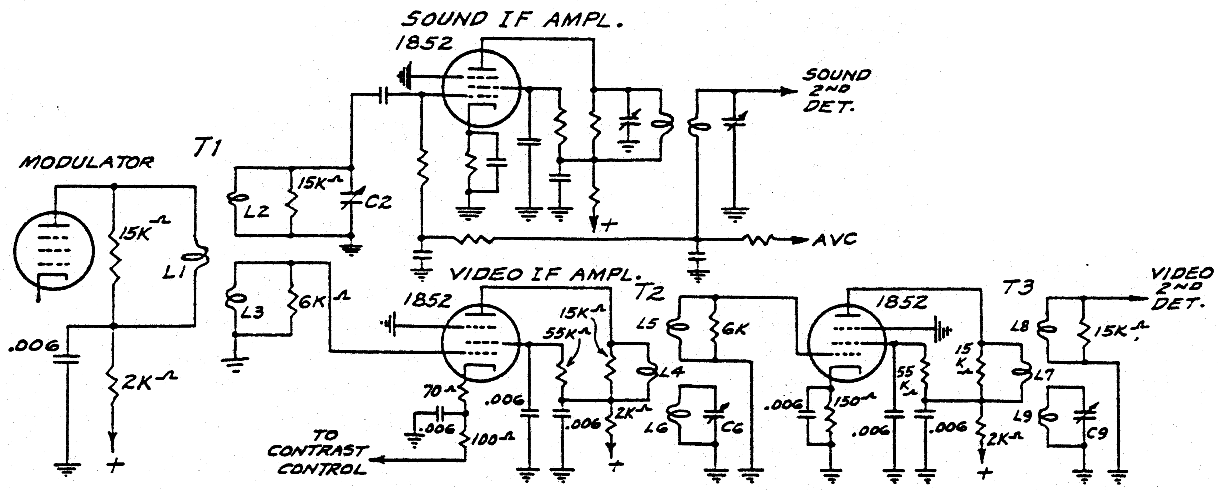


FIG. 33.—The video and sound i-f amplifiers in the Andrea Model 1F5 receiver.

the sound i-f channel which is conventional and requires no further comment.

The video component of the i-f signal is developed across L3. No trimmer condenser is used on this winding and the circuit is heavily loaded by the 6000-ohm resistor in order to pass the required band of frequencies. The video signal is applied directly to the grid of the type 1852 tube used in the first i-f stage. To obtain negative feedback and the increased stability which it makes possible, an unbypassed 70-ohm resistor is placed in the cathode circuit. The other end of this resistor is connected to a variable resistor—the "contrast control"—by means of which the gain of the i-f stage is controlled. Since no AVC is used, the control grid is returned directly to ground. The band of frequencies passed by this amplifier is approximately 2.5 mc; this pass band is generally considered to provide sufficient detail for the small picture tube used with this receiver.

The signal is coupled to the grid of the second i-f tube by means of the transformer T2. The windings L4 and L5 of this transformer function as the primary and secondary windings of the interstage transformer and are loaded by means of the 15,000-ohm resistor across the primary and the 6000-ohm resistor across the secondary. The only capitance used to tune these windings is the tube and circuit capacitance.

The third winding L6 is tuned to 14.25 mc by means of the trimmer C6 and eliminates possible interference from the sound carrier of the lower adjacent television channel, as was previously shown in Fig. 32. This circuit acts as a trap by absorbing all the energy in the neighborhood of 14.25 mc so that it is not passed on to the grid of the following tube.

The second i-f stage feeds directly into the video i-f second detector through the transformer T3 which is similar to T2. The circuit L9-C9 is likewise tuned to 14.25 mc so that it acts as a trap circuit for this frequency.

No AVC is used in the video i-f amplifier in this receiver and accordingly the grids of the two i-f tubes are returned directly to ground. The gain is controlled by means of the "contrast control" which varies the bias of both the first i-f stage and the first detector stage.

Video I-F Amplifier in the RCA Model TRK-12

The partial schematic in Fig. 34 shows the video i-f amplifier used in the RCA Model TRK-12 receiver, which is also used in the Westinghouse Model WRT-703. In contrast to the video i-f amplifier described above, this amplifier is designed so as to obtain a pass band of approximately 4 mc. As a result of the higher modulating frequencies which are passed, the detail in the image is increased correspondingly. A large 12-inch picture tube is used with this receiver; this permits finer detail, so that it utilizes the aditional detail which the wide response of this more elaborate amplifier provides.

Unfortunately it is not possible to increase the pass band of the i-f amplifier without decreasing the gain obtained in each stage. As a consequence of this it is necessary to use a larger number of stages in the i-f amplifier; five stages are used in the receiver being described. In addition to the large number of stages required, the complexity of the coupling transformers is increased both as a consequence of the larger bandwidth and the fact that the trap circuits must be more effective. Thus the frequencies accepted by the i-f amplifier are very close to the sound carrier so that the rejection must be more nearly perfect than in the case of a video i-f amplifier which passes a smaller band.

The transformers used in this receiver can be broken down into three basic elements which are shown in Fig. 35: the primary winding L1, the coupling winding L3 and the secondary winding L2. Inductive coupling between the primary and secondary is not used, but instead the primary and secondary are coupled directly by means of the inductance L3 which is common to both circuits. The primary circuit is resonated by C1 near one end of the pass band, whereas the secondary circuit is resonated by C2 near the opposite end of the band. R1 and R2 are loading resistors used to broaden the response.

Although the i-f transformers in the RCA TRK-12 use the relatively simple basic design shown above, the circuits are further complicated because of the blocking condenser required to keep the plate voltage off the grid and because of the presence of the trap circuit. The condensers C1 and C2 do not appear as such in the schematic because they are represented by the plate-to-ground and grid-to-ground capacitances, which include the stray wiring capacitances in addition to the tube capacitances.

Referring again to Fig. 34, let us consider the several transformers separately. The first-detector transformer assembly is more complicated than the others because the sound i-f signal is present at this point, and must be separated from the video i-f signal. This separation is accomplished by means of the circuit L18-C19 which is resonated to 8.25 mc, the sound i-f. The sound i-f signal is coupled to this circuit by means of the 12-mmf condenser C24; the resistor R10 is used to broaden the selectivity of the sound i-f channel.

With respect to the video section of this transformer, L17 and L20 are the primary and secondary windings which are tuned by the plate and grid capacitances as explained in connection with Fig. 35. These circuits are coupled to each other by the common coupling condenser C23. A trap circuit is made an integral part of the transformer assembly. This circuit is tuned by L19 to 14.25 mc and prevents frequencies close to this value from getting into the video i-f amplifier. There are thus four adjustments required for proper operation of this transformer which can be summarized as follows: L17 and L20 control the primary and secondary tuning and are resonated at opposite ends of the pass band of 4 mc; L18 tunes the sound pickup circuit and is resonated at 8.25 mc; L19 tunes the trap circuit so as to reject interference in the neighborhood of 14.25 mc.

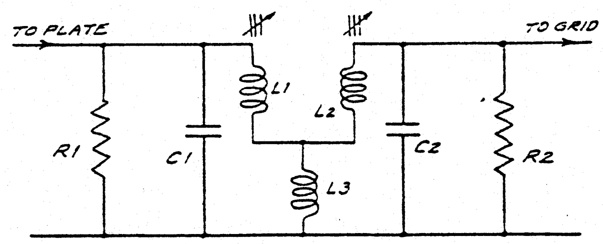


FIG. 35.—A simplified diagram of the video i-f transformers used in RCA television receivers. Direct coupling is provided by the inductance L3 which is common to both primary and secondary circuits.

The first and second i-f transformer assemblies are practically identical, and are somewhat similar to the first detector unit. In the first i-f assembly, L21 and L25 are the primary and secondary inductances which are again resonated at opposite ends of the pass band. L24 provides the direct coupling between the primary and secondary as shown in the simplified drawing of Fig. 35. L23 is part of a trap circuit which is tuned to 8.25 mc, so that, in all, two sharply tuned trap circuits are provided at this frequency. These are required because the wide pass band necessitates passing video frequencies which are close to the sound carrier frequency; at the same time this sound carrier and its sidebands must be rejected and this is effected by means of the tuned circuits associated with L23 and L28.

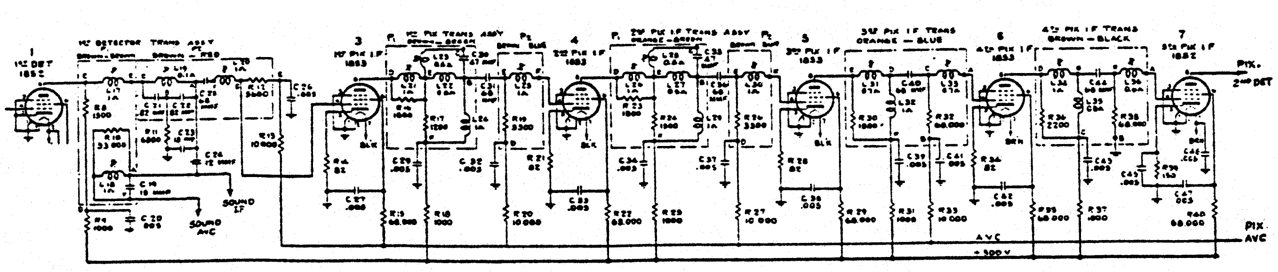


FIG. 34.—The video i-f amplifier in the RCA Model TRK-12. Five i-f stages are used to obtain a pass band of 4 mc. Traps are provided at 8.25 mc and 14.25 mc to prevent interference from the associated and adjacent sound channels.

The third and fourth transformer assemblies do not incorporate any trap circuits and are similar to the transformer shown in Fig. 35. The condensers C40 and C44 are blocking condensers which prevent the plate voltage from being applied to the control grid of the following tube. The plate of the fifth i-f tube feeds through a special coupling transformer to the video second detector; this transformer is not shown in the figure but will be discussed later in connection with video second detector circuits.

As the schematic of Fig. 34 shows, the first, second, third and fourth video i-f tubes are controlled by the video AVC circuit; the grids of these tubes are each returned to the common AVC bus through a filter combination consisting of a 10,000-ohm resistor and a .005-mf condenser. In addition, the gain of the first detector tube is controlled by the same AVC voltage, so that effectively there are five stages under control. This makes for a very effective AVC action which keeps the signal applied to the video second detector and sync separating circuits essentially constant.

Video Second Detector Circuits

In a radio receiver the second detector rectifies the i-f signal and as a result the audio signal corresponding to the variations in the carrier is recovered. In the same way, the video second detector in a television receiver rectifies the video i-f signal and as a result the video signal corresponding to the variations in the amplitude of the carrier is recovered. This video signal is of course that produced by the camera tube and contains in addition the pulses required for synchronization; it is similar to the standard RMA signal shown in Fig. 20.

Generally speaking, video second detectors are similar to the second detectors of the diode rectifier type used in radio receivers. However, because modulating frequencies as high as 4 mc (in the larger receivers) must be passed, a lower value of load resistance is used in order to prevent the attenuation of the higher video frequencies. The value of load resistance generally used is of the order of 2500 ohms; on the other hand, the values used in radio receivers are of the order of 250,000, or approximately 100 times as great. Because of the low value of diode load resistance, receivers are generally designed so that the signal level at the second detector is approximately 5 volts or more. This minimizes distortion due to the curvature of the diode characteristic, which is more pronounced when low values of diode load resistance are used.

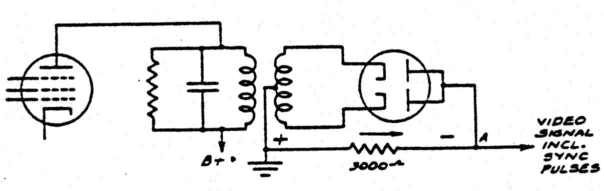


FIG. 36.—The video second detector circuit in the DuMont Models 180-183. A full-wave rectifier circuit is used.

Video Second Detector in DuMont Models 180-183

The video second detector circuit used in the DuMont Models 180-183 receivers is shown in Fig. 36. A full-wave rectifier circuit is used so that both halves of the signal are rectified. Since the cathodes are connected to the ends of the centertapped secondary, each diode will draw current when its cathode is negative with respect to ground (the diode plates both return to ground through the 3000-ohm load resistor). As a result the current flow through the load resistor will be in the direction shown. Thus when a video signal is applied to the primary of the transformer, the plate end of the load resistor will become negative in proportion to the amplitude of the carrier. When the carrier amplitude is greatest, as it is for the sync pulses, the greatest negative voltage will be produced at A. The various shades of white and gray in the signal will produce lesser values of voltage at A, zero voltage of course corresponding to whitest white. In accordance with the definition of signal polarity previously given, the video signal produced at A is said to have *positive polarity.*

It is worth while noting that if the diode plates, instead of the cathodes, had been connected to the ends of the coil, then the polarity of the video signal would have been reversed. As we shall see in the discussion of video amplifiers, whether or not the diodes are connected to give a signal of positive or negative polarity depends upon the number of stages in the video amplifier. The controlling factor is that the amplified signal which is finally applied to the grid of the picture tube must of course have a positive polarity since a more positive voltage on the grid produces a brighter spot on the screen of the tube.

Video Second Detector in RCA Model TRK-12

The video second detector in the RCA Model TRK-12 (also used in the Westinghouse Model WRT-703) is shown in Fig. 37. The signal is coupled through an autotransformer arrangement from the plate of the last video i-f tube into the full-wave diode rectifier circuit. Thus the signal voltage between A and the centertap C is stepped up so that the voltages across each half of the coil L38 are equal. The secondary winding is loaded to broaden the frequency response. By means of the bypassing action of the .005-mf condenser C48, the centertap of L38 is maintained at ground i-f potential; in other words, there is no signal voltage at point C.

Unlike the previous circuit, the video signal produced across the 4000-ohm load resistor R45 has a negative polarity. This can be seen from the fact that a large carrier amplitude, which corresponds to black in the picture, produces a more positive voltage at B. R45 is a potentiometer and serves to regulate the magnitude of the video signal fed into the video amplifier. Since it controls the maximum voltage swing of the video signal on the grid of the picture tube between black and white, it is called the "contrast control."

An important advantage which results from the use of a full-wave rectifier circuit in video second detectors is that the filtering of the i-f components from the video signal is more easily accomplished. Because of the balanced nature of the circuit, the lowest frequency which is present across the output load R45 is the second harmonic of the video i.f. and this is more readily prevented from getting into the video amplifier. On the other hand, in the case of a single-ended circuit using only one diode, the fundamental video i.f. is present across R45 and is more difficult to filter out.

Video AVC Circuits

Although the ultra-high frequencies used for television are not subject to fading of the same type as that found in the high and medium radio frequencies, the signal strength may still vary because of swinging of the antenna or the presence of automobiles and other moving objects. Since these variations will cause a change in the contrast of the picture being received, they are undesirable and can be avoided if the receiver is equipped with AVC. The use of AVC also simplifies the design of both the video gain control circuit and the sync separating circuits because it assures the maintenance of a constant signal voltage at the video second detector.

In the conventional AVC circuits used in radio receivers, the control voltage is produced by rectifying the carrier and as a result the control voltage is proportional to the *average* value of the carrier. Because the average value of the carrier in ordinary broadcasting does not change during modulation, it is a measure of the signal strength and hence can be used to control the gain of the receiver.

In television this same system cannot be used because the average value of the video carrier is dependent upon the average illumination of the scene being televised. Thus if the average background of the scene is white, then the average carrier amplitude will be small; on the other hand, if the average background is dark, then the average carrier amplitude will be large. (The above conditions are of course only true for negative modulation which is standard for this country.) Obviously, then, we cannot use the average amplitude of a video signal to obtain the necessary d-c control voltage, because such a control action would vary the gain of the amplifier in accordance with the average background illumination and as a result produce distortion.

However, although the average value of a video signal does not remain constant, the *peak* value always has the same fixed value regardless of the percentage of modulation or the average illumination of the scene. For this reason the peak value of the carrier serves as a convenient reference to establish the strength of the carrier and is the basis of operation of video AVC circuits. As we have seen, this peak value is transmitted at the end of each line, that is, 13,230 times in every second, and thus it is available at regular intervals which are frequent enough to make possible the production of an automatic control voltage.

It is of interest to note here that one of the important reasons for the use of negative rather than positive modulation is that only in negative modulation is this regular succession of peak pulses available for AVC purposes. The design of AVC circuits where positive modulation is used, is considerably more complicated; for positive modulation the peak values of the signal are not fixed but depend upon the brilliance of the scene being televised.

Satisfactory operation in the smaller and less expensive receivers is often secured without the use of a separate AVC system in the video channel. In these receivers, relatively few video i-f stages are used so that the problem of manual gain control is not so difficult. In addition, the first detector is often controlled by the AVC voltage produced in the sound channel, so that some degree of automatic control is provided. Since the video and sound carriers are close to each other, they undergo approximately the same varia-

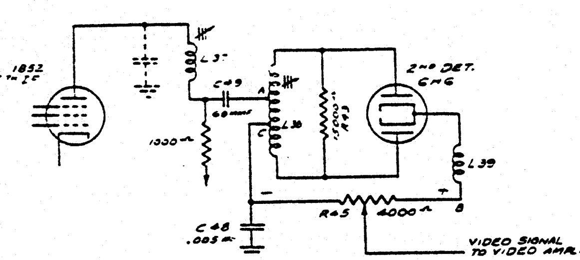


FIG. 37.—The video second detector circuit in the RCA Model TRK-12.

tions in transmission from the transmitting antenna to the receiving antenna, but in general these variations are not sufficiently alike to permit the use of sound AVC voltages on all the video stages.

Video AVC Circuit in the RCA Model TRK-12

The video second detector and AVC circuit used in the RCA Model TRK-12 is shown in Fig. 38. Although the second detector has been described previously, it is shown here because the action of the AVC circuit is connected with the detector. When a signal is being received, full-wave rectification takes place in the 6H6 and as a result the demodulated video signal is produced across the 4000-ohm load R45 in series with the peaking coil L39. The polarity of this signal is indicated by the insert wave which shows that point B of the load is positive with respect to point A; B can be considered as being at a fixed reference voltage since it is tied down to —33 volts through the filter resistor R47.

The circuit used to obtain the AVC voltage from the signal across AB is essentially a peak voltmeter using one section of the 6F8-G tube as a diode. As the circuit shows, the grid is used as the diode plate and is connected directly to B; the cathode is bypassed to ground by a 1-mf condenser C54 and is returned to A through a 470,000-ohm resistor, R46.

During the sync intervals, the grid of the diode is highly positive with respect to its cathode so that a current flow takes place through R46 and a positive change is stored in C54. Because the sync pulses are repeated rapidly, 13,230 times per second, this charge is continually replenished and C54 remains charged to the peak value of the video signal. If, for example, we assume a 10-volt peak signal, then C would charge up to a potential 10 volts greater than that at A or —23 volts (—33 + 10).

Since the voltage produced in this way is proportional to the peak value of the carrier, it is a suitable measure of the signal level at the second detector. However, its polarity must be reversed in order that an increase in signal input will produce a more *negative* rather than a more positive control voltage. This reversal of polarity is effected by means of the second section of the 6F8-G which is used as a d-c amplifier.

This tube receives its plate voltage through a 680,000-ohm load resistor R50 which is 2 volts negative with respect to ground. Since the cathode is returned to —23 volts on the bleeder, the net plate voltage with no input signal is equal to 21 volts (—2 + 23). The grid bias is equal to the voltage at the grid minus that at the cathode or —10 volts (—33 + 23). When no signal is present this value of bias is so great that the cathode current is completely cut off and as a result the voltage at D is equal to —2 volts. This is the minimum bias with no signal and in combination with the drop of 0.7 volt across the 82-ohm cathode resistor of each of the controlled tubes, provides a net bias of 2.7 volts for each of the video i-f tubes.

On the other hand, when a signal is being received, C54 charges up positively to the peak value of the signal and this positive voltage is applied to the grid of the AVC triode amplifier. If the signal is strong enough, the plate current will increase, the voltage drop across R50 will increase, and D will become more

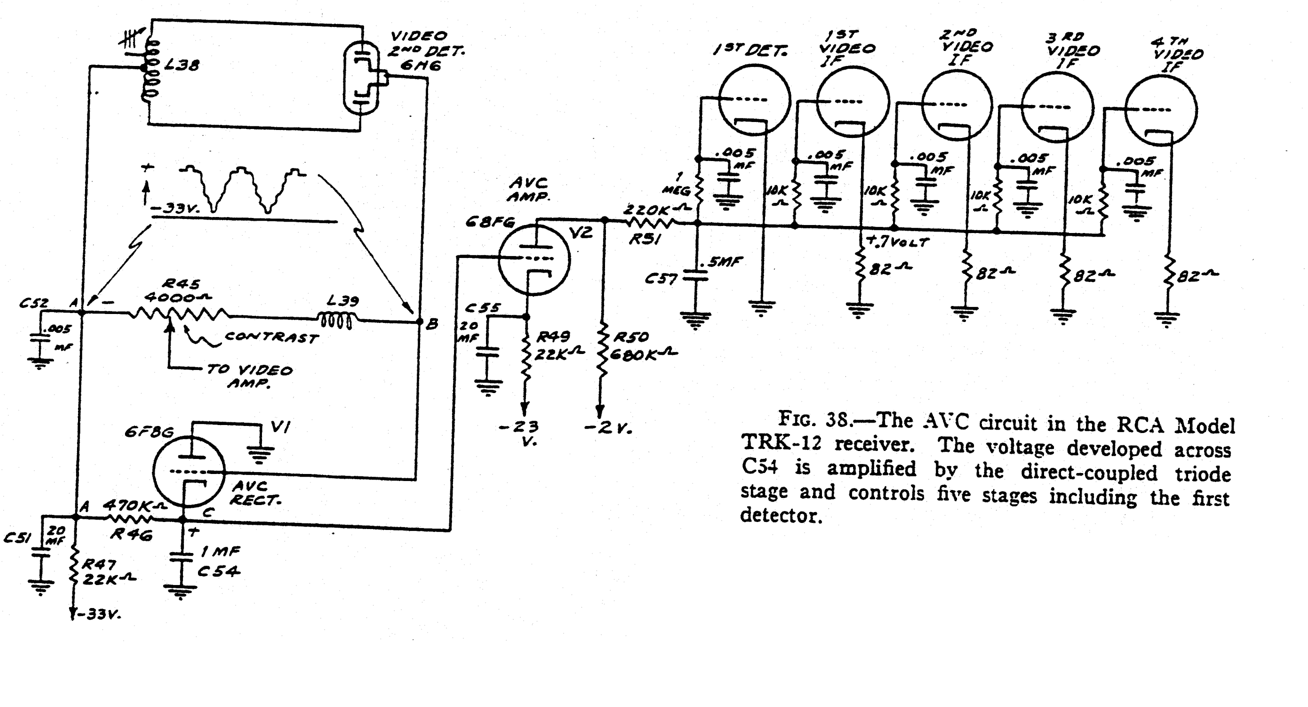


FIG. 38.—The AVC circuit in the RCA Model TRK-12 receiver. The voltage developed across C54 is amplified by the direct-coupled triode stage and controls five stages including the first detector.

negative than —2 volts. The amount of negative voltage produced at D is proportional to the strength of the signal and hence the voltage is available for AVC.

A delayed AVC action is secured because the negative bias of 10 volts, which exists with no signal, drives the grid of the AVC amplifier tube considerably beyond cutoff. Thus the signal level must reach a certain minimum value before the plate current will flow and the AVC voltage be produced.

In addition to the delay action, the fact that five stages are controlled results in a very effective AVC action which maintains the signal level at the second detector essentially constant.

Video Amplifiers

In the same way that the audio signal in a radio receiver requires amplification before it has sufficient power to drive the speaker, so the video signal in a television receiver requires additional amplification following the video second detector before it has sufficient amplitude to swing the grid of the picture tube. This amplification is supplied by the video amplifier which works between the video second detector and the grid of the picture tube.

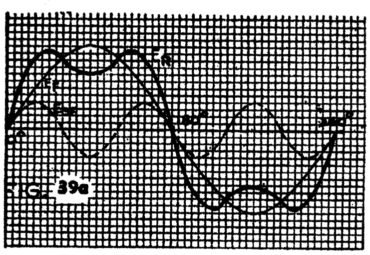


FIG. 39a, on the left, shows the resultant wave (E_R) when a 1000-cycle sine wave (E_F) and a 3000-cycle sine wave (E_{3F}) are added in phase.

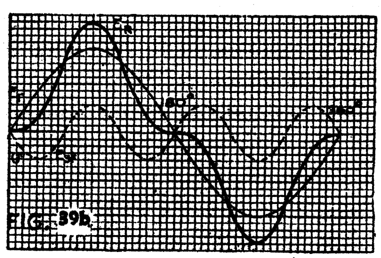


FIG. 39b, on the right, shows how the resultant wave (E_R) is distorted when the 3000-cycle sine wave (E_{3F}) is retarded half a cycle.

The problems associated with the video amplifier, like most television problems, are considerably more difficult than the corresponding problems for a radio receiver. Thus the video amplifier must amplify uniformly frequencies ranging from a few cycles to frequencies as high as 2 to 4 mc. Whereas phase shift is not important in an audio amplifier, in a video amplifier all the frequencies in the signal must take the same time to pass through the amplifier from input to output. This is important because distortion of the waveform and hence of the picture, is produced when the different video frequencies do not all take the same time to pass through the amplifier. This type of distortion is illustrated in Fig. 39 which shows the difference in waveform produced when a 3000-cycle wave is retarded half a cycle in passing through the amplifier. That the uniformity of time delay plays an important part can be seen from the fact that it takes only approximately seven one-millionths of a second for the cathode-ray beam to move one inch across the screen of the picture tube. Thus even a small non-uniformity in time delay can cause serious distortion of the image.

The video amplifiers being used in television receivers now on the market have successfully met the problems outlined above. By using low values of load resistance, the shunting effect of tube and circuit capacitances has been minimized and the upper frequency limit extended. Fig. 40 shows how the use of a low value of plate load resistance, although it lowers the maximum amplification obtainable, makes possible a more uniform gain over a wide range of frequencies. The sacrifice in gain accompanying the use of low values of load resistance has been partially compensated for by the use of the new high mutual conductance tubes which provide approximately three times as much amplification for a given value of load resistance, as was previously possible with the older tubes.

The most common method for obtaining uniform gain is to use so-called "peaking coils" in series with the plate load resistor. These are small inductances of the order of 100 microhenries, which are resonated with the tube and wiring capacitance near the high-frequency limit of the video amplifier. Peaking coils permit higher values of plate load resistor for a given uniformity of amplification, and consequently make possible reasonably high gains per stage.

In most video amplifiers, filter resistors and condensers are used in the plate and screen leads to provide low-frequency compensation for both gain and time-delay. These filter resistors and condensers are

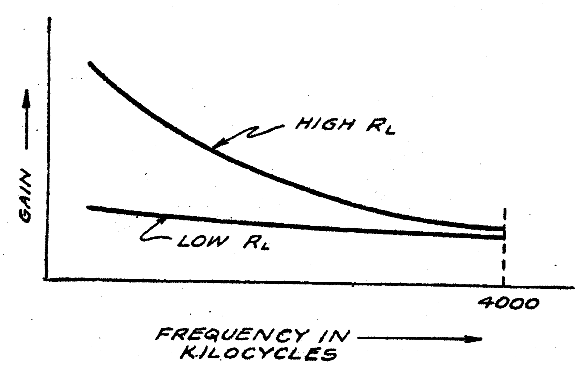


FIG. 40.—The use of a small value of load resistance provides a more uniform gain over a wide range of frequencies, although the maximum gain is decreased.

more critical in value than they are in a radio receiver where the primary purpose is to reduce hum and prevent circuit interaction through the common power supply. For this reason, whenever replacement becomes necessary, the resistors and condensers should be replaced with the correct value. Although a larger plate filter condenser, for example, will cause no harm and may even do some good in reducing hum in a radio receiver, the same procedure followed in a video amplifier may cause serious distortion of the picture.

Average Brightness and D-C Restorer Circuits

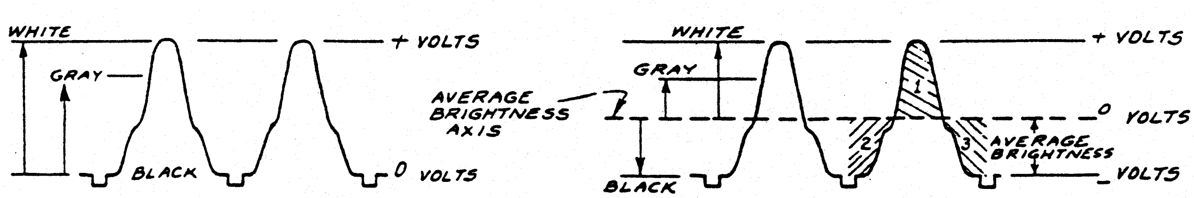
In our previous discussion of the video signal, we looked upon this signal as containing a series of voltage values each of which corresponded to a particular value of light intensity in the televised image. We considered that in the same way that light values can be reckoned from black as a reference level, so a particular voltage value can be assigned to black and then each light value represented electrically by assigning a higher (or lower) voltage to the signal, depending upon the brightness of the light value at the scanned area. This method of looking upon a video signal is shown in Fig. 41 (a), in which it is clear that all light values are with reference to the black level—which is taken as the zero-voltage axis.

Insofar as video amplifier operation is concerned, the important thing about Fig. 41 (a) is that it shows that a video signal is inherently a pulsating d-c voltage. In other words (as in the case of a rectified a-c voltage which is also a pulsating voltage) all the light values are represented by electrical values on one side of the zero-voltage axis. The video signal must therefore contain both a d-c and an a-c component in the same way that a rectified a-c voltage representing the output of a power supply contains a d-c component—the d-c voltage of the power supply, and an a-c component—the hum ripple of the power supply.

Physically what does it mean to say that a video signal contains a d-c as well as an a-c component? Actually it is only another way of looking at the signal, as Fig. 41 (b) clearly shows. In this figure we describe the signal by saying that the light values are represented by fluctuations in both directions from an average level which we can call the "average brightness," or the "picture background." Thus instead of describing the light value at any point in the scene by stating how much brighter it is than black, as in (a), in (b) we accomplish exactly the same thing by stating how much brighter or blacker is the particular light value than the *average brightness*. In (a) we use the black level as the reference level whereas in (b) we use the average brightness as the reference level.

Electrically speaking, the average brightness level represents the average value of the video signal or in other words the d-c component of the signal. On the other hand, the fluctuations in the signal on either side of the average brightness level, which is electrically the a-c axis of the signal, represent the a-c component of the signal. An important characteristic of the average brightness or a-c axis is that the area between the positive part of the cycle and the a-c axis is equal to the area included between the negative part of the cycle and the same a-c axis. This is shown in Fig. 41 (b), where it can be seen that area 1 is equal to area 2 + area 3.

From the preceding it will be clear to you that proper operation of the picture tube requires that both the d-c and a-c components of the video signal be passed by the video amplifier. For if only the a-c component reaches the grid of the picture tube, then the picture tube will have information only on the fluctuations in light values *with reference to the average brightness level* but it will have no information whatsoever on the value of this average brightness level. Thus the picture cannot be reproduced accurately since the same variations (represented by the a-c component) might be superimposed on say either a dark or light background of any shade. The average brightness, or the d-c component of the video signal, must be present before the picture can be reproduced.



FIGS. 41a, 41b.—The light values in a video signal can be reckoned in two ways: In (a) the various light values are described with reference to the black level, whereas in (b) the same light values are described with reference to the average brightness of the signal.

D-C Restorer Circuits

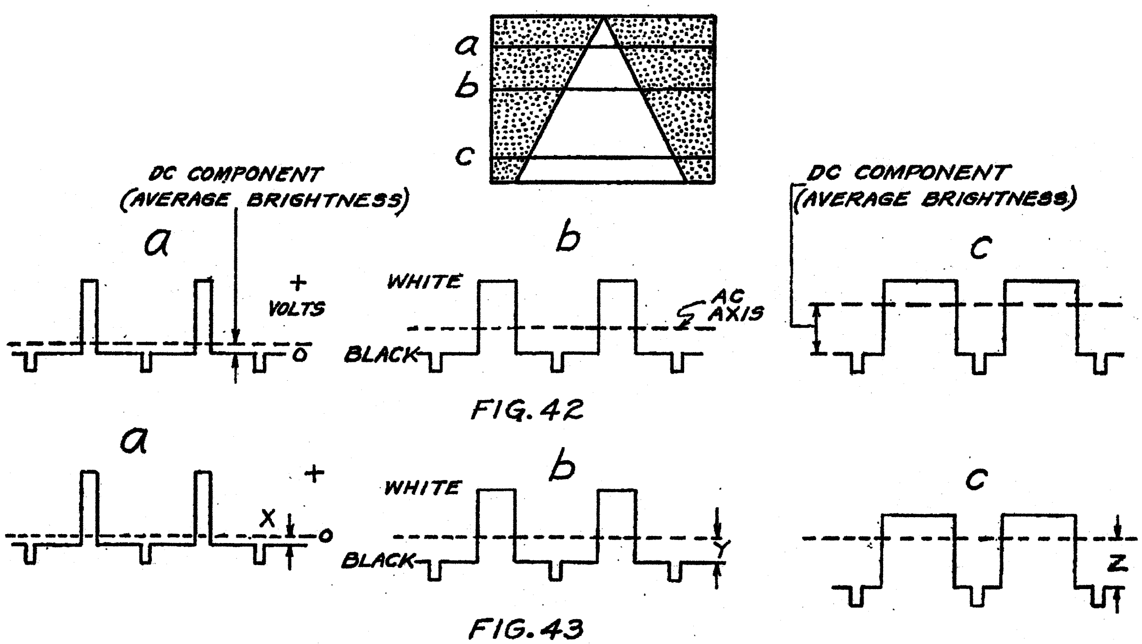
Unfortunately it is not possible to transmit the d-c component of any signal without using a direct-coupled amplifier. However, the use of direct-coupled amplifiers is not practical in television receivers because of their comparative instability and high cost. For this reason, television engineers have developed circuits which make possible the use of conventional a-c amplifiers with condenser coupling and at the same time provide for the restoration or *recreation* of the d-c component after the a-c component has been amplified by itself.

It will be helpful at this time to consider several video signals which have different values of average brightness and to describe the action which takes place when these signals pass through an amplifier which employs a blocking condenser as a coupling element between stages. It is because of the presence of the blocking condenser that only the a-c component is passed and that the d-c component is lost.

In Fig. 42, the picture being scanned is a white triangle on a black background, with the vertex of the triangle near the top. Part (a) shows two lines scanned near the top of the picture; part (b), near the middle of the picture; and part (c), near the bottom. Thus (a), (b) and (c) represent three sections of the picture where the average brightness is low, medium, and high respectively. Fig. 42 can be said to represent the signal as it is at the output of the camera tube or as it is recovered at the video second detector. Of special importance is the fact that all the blacks are lined up so that the d-c component of the signal is represented in all cases. Note that the d-c component, like the average brightness which it represents, is successively larger in (a), (b), and (c).

Now what happens to this signal when it is passed through an a-c amplifier which contains coupling condensers and therefore will not pass the d-c component? This is clearly illustrated in Fig. 43 which shows that the blacks are no longer lined up, but instead the separate average-brightness or a-c axes are all lined up. In other words, when the d-c component is lost, only the fluctuations on either side of the average brightness are transmitted and this axis must of necessity be the zero voltage axis in all instances because no d-c component can get through the amplifier.

Having investigated the video signal both with and without the d-c component, let us now examine the manner in which the picture tube is affected by the presence or absence of the d-c component. In Fig. 42, we see that black in every case corresponds to the same definite voltage value and that is also true for white and every intermediate shade between black and white. Thus when the voltage of Fig. 42 is applied to



FIGS. 42, 43.—FIG. 42 shows the video wave produced when two lines are scanned at a, b, and c of the white triangle on a black background. Since the black level is the same for all three cases, this signal contains the d-c component. FIG. 43 shows the same signal after it has passed through an a-c amplifier; note that the d-c component has been lost so that black in the signal no longer corresponds to a fixed voltage level as it does in FIG. 42.

the grid of the picture tube, the picture will be reproduced without any distortion.

This, however, is not true of the signal in Fig. 43, from which the d-c component has been removed. Black no longer corresponds to the same value in all instances, but instead the signal voltage associated with black takes on a value which is entirely dependent upon the average brightness of the strip being scanned. In the same way, this figure shows that white, and in fact every intermediate shade as well, has a different voltage value which is also dependent upon the average brightness of the strip being scanned. A little reflection will show you that this gives rise to serious distortion because the same light value in different parts of the picture does not correspond to the same voltage value in the signal. Thus, for example, the grid of the picture tube receives a *different voltage* for the *same shade* of gray in (a), (b) and (c) of Fig. 43 and as a result this shade is reproduced differently in the three instances.

In order to remove this source of distortion, it is apparent that the average brightness or the d-c component must be restored. At first glance this seems impossible, for how can the d-c component be restored after it has once been lost in the video amplifier? As a matter of fact, it is generally not possible to restore the d-c component of a pulsating wave after the d-c component has been lost in transmission, because no information relative to the d-c component is contained in the a-c component; the two are entirely independent of each other. Fortunately, however, the sync pulse is transmitted at the end of each line, *and the pedestal on which the sync pulse stands corresponds to a definite black reference level.* These facts make it possible to restore the lost d-c component. Thus to restore the d-c component to the signal of Fig. 43 it is only necessary to modify the signal so that all the synchronizing pulses are lined up. When this is done, the signal in Fig. 43 is exactly the same as that in Fig. 42 and the d-c component has been completely restored.

The solution of the problem depends upon finding this varying d-c voltage and adding it to the signal. This is accomplished in a very simple manner by using a diode to rectify the "black" half of the a-c video signal (which contains the sync signal) and in this way the required voltage is produced. Thus in Fig. 43, at (a) this rectification produces the voltage x; at (b) it produces the voltage y; and at (c) it produces the voltage z. In general, the addition of this varying d-c voltage lines up all the pedestals to produce the original signal (Fig. 42) with the d-c component restored.

Basic D-C Restorer Circuit

In Fig 44 we show a straightforward circuit which is used to restore the d-c component in the video signal before the signal is applied to the control grid of the picture tube. The video signal is developed across the 3000-ohm plate resistor R1 and fed to the control grid through a 0.1-mf coupling condenser C1. As the sketch shows, the signal has the required positive polarity both at the plate of the video amplifier and the grid of the picture tube. However, the d-c component is not present at the plate side of C1, whereas the diode circuit shown in heavy outline has restored the d-c component on the grid side.

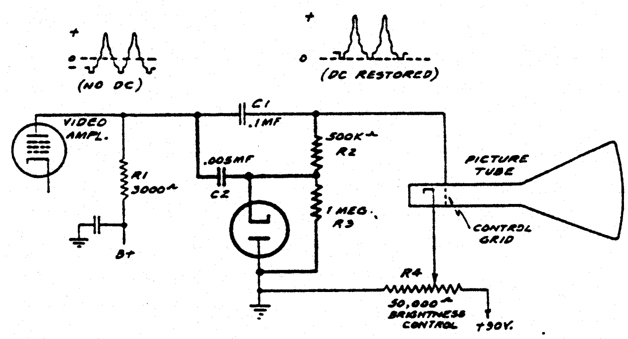


Fig. 44.—The heavy outline shows a typical d-c restorer circuit arranged to restore the d-c component to the video signal before it is applied to the control grid of the picture tube.

Let us see just how the diode circuit restores the d-c component. Considering the series circuit composed of the video voltage across R1, the .005-mf condenser C2, and the diode in shunt with a 1-meg resistor,—we can see that the following takes place: On the positive half of the cycle the cathode of the diode is swung positive with respect to its plate so that no current flows in the diode circuit. On the negative half of the cycle, however, the cathode is swung negative with respect to the diode plate, and current flows in the diode circuit through R3. It is this current flow which charges C2 and makes the cathode end of R3 positive, and as a result provides the d-c restoring bias.

Note that the d-c voltage across R3 satisfies all the conditions required to line up the sync pulses so as to restore the d-c component. Essentially the action in the diode circuit is such that the *negative* part of the video wave is rectified and that the diode current charges C2 positively to a value equal to the amount by which the sync pulses in (a) are depressed below the a-c axis. Since the grid of the picture tube is returned to this d-c voltage through the 50,000-ohm resistor R2, the d-c voltage is added to the video signal at (a) and "raises" the pedestal so that it lies along the zero-voltage axis, as shown at (b).

Now suppose, as in Fig. 43 (c), that the average brightness is higher than that shown at (a) in Fig. 44. This results in the pedestal being more negative with respect to the a-c axis, so that the diode produces a more positive voltage which again raises the pedestal to the same zero-voltage axis as at (b) in Fig. 44. Thus the action is entirely automatic so that all the pedestals are lined up at the grid of the picture tube, *regardless of the value of the average brightness.*

It is important to understand that the voltage produced at the cathode varies constantly throughout the scanning and that its value at any time depends upon the average brightness of the *portion* of the picture being scanned at that particular time. The time constant (RC) of the diode circuit is designed so that C2 will not discharge appreciably during the interval between successive sync impulses. At the same time, the time constant is sufficiently small so that when the average brightness changes, the condenser is able to change its charge rapidly enough to respond to the new conditions.

Insofar as the grid of the picture tube is concerned, it receives the a-c component of the video signal through C1, and *only* the d-c component through R2. Although the a-c component is also present at the cathode of the diode, R2 acts as a filter resistor to prevent that portion of the video signal present at the cathode from reaching the picture-tube grid through R2.

Brightness Control

We have just seen how the d-c restorer circuit automatically lines up all the sync pulses so they are at the same voltage level. For correct operation of the

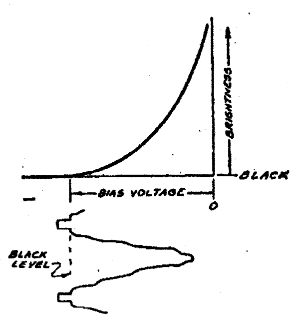


FIG. 45.—The effect of bias voltage on the brightness of the image. The brightness control (see FIG. 44) should be adjusted so that the black level on the signal occurs approximately at the cutoff of the picture tube characteristic.

picture tube, the bias on the picture tube must be so adjusted that these aligned pedestals occur at the cutoff or black level. The sync pulses will then lie in the blacker-than-black region and the various shades of gray and white will be reproduced correctly.

Fig. 45 shows the illumination characteristic of a picture tube and the manner in which the brightness of the scanning spot depends upon the bias voltage on the control grid. Referring again to Fig. 44, it will be observed that the cathode of the picture tube is returned to a potentiometer which makes it possible to vary the bias voltage from 0 to 90 volts.

When the bias is highly negative, the tube is cut off and the spot intensity is zero. As the bias becomes more positive, the intensity of the spot increases. For correct operation, the brightness control should be adjusted manually so that the pedestals occur at the black or cutoff points. Once the brightness control has been set, the d-c restorer circuit automatically keeps the pedestals in alignment so that no further adjustment is required.

Grid Leak—Condenser Restorer

Another type of d-c restorer circuit which is very widely used is shown in Fig. 46. In this circuit the

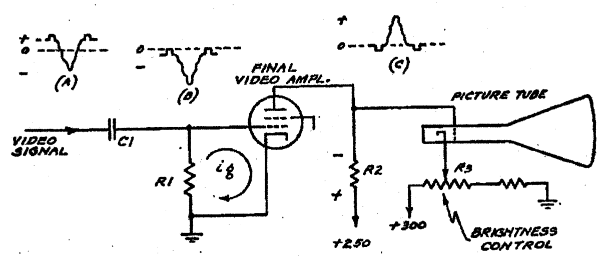


FIG. 46.—A widely used type of d-c restorer circuit in which the video amplifier output tube is operated at zero bias so that the grid-cathode elements function as a diode to reinsert the d-c component.

output video amplifier tube is operated at zero bias and the grid-cathode elements are used as a diode to insert the missing d-c component. To prevent the loss of the newly restored d-c component which would occur if condenser coupling were used in coupling the plate to the picture tube, the plate is coupled *directly* to the picture tube grid.

From the explanation already given of the process of d-c restoration, it is easy to understand how circuits of this type operate. The waveform of the video signal on the left side of C1 is shown at (a); at this point the signal has a negative polarity and of course the d-c component is missing. When this a-c signal is impressed on the grid of the output tube through C1, the positive parts of the video cycle (including the sync pulses) place the grid positive with respect to its cathode so that grid current flows through R1. The direction of this grid-current flow is such that the grid becomes negative with respect to ground.

When the average brightness of the signal is small, the a-c axis of the signal will be near the black level, the positive peaks will be small in amplitude, only a small value of grid current will flow, and consequently the grid will be displaced only slightly negative. On the other hand, when the average brightness is great, the a-c axis is away from the black side, the positive peaks will be large in amplitude, a relatively large flow of grid current will take place, and the grid will be made highly negative. *In each instance, the grid will be made more negative by an amount equal to the height of the sync pulses above the a-c axis of the wave.* As a result of this action all of the pedestals in the signal are depressed by an amount sufficient to align them to the same zero-voltage level at the grid. This is shown by the signal waveform at (b). Essentially the action here is the same as that previously described for the circuit using a separate diode. The condenser C1 performs the same function of storing the grid charge as in the previous method.

At the plate of the output tube, the polarity of the video signal is reversed and as (c) shows, the signal at this point has the required positive polarity. Since no blocking condensers are interposed between the plate and the grid of the picture tube, the sync pulses remain in alignment.

As in the previous circuit, provision must be made for initial adjustment of the bias of the picture tube so that the pedestals of the signal will occur at cutoff (black level) on the picture-tube characteristic. To accomplish this, the cathode of the picture tube is returned to a bleeder-potentiometer which makes it possible to place up to a maximum of +300 volts in the cathode. Since the grid can at most have a potential of +250 volts, this makes a bias of —50 volts available on the grid of the picture tube. Under actual operating conditions, the voltage drop across R2 makes the grid more negative; this is compensated for by making the cathode of the picture tube less positive by adjusting the brightness control R3.

When the receiver is first turned on, there is no voltage drop across the plate-load resistor R2 until the output video tube warms up and draws plate current. The final adjustment of the brightness control therefore should not be attempted until the receiver has been turned on for a few minutes. In particular the brightness control should be all the way to the left (with the rotor at +300) until the receiver has warmed up; this is done to avoid possible damage to the picture tube because of excessive beam current.

The Contrast Control

The "contrast control" is the gain control which determines the magnitude of the video signal applied to the grid of the picture tube. Its counterpart in a sound receiver is the volume control, and in the same way that the sound volume control determines the range of intensities between the loudest sound and the softest sound, so the video contrast control determines the range of light intensities between the highlights and the shadows of the picture. Referring to Fig. 45, the setting of the contrast control determines how much of the picture tube characteristic is used and how bright will be the brightest element of the scene. When the contrast control is not advanced far enough, the picture lacks brilliance and the highlights are comparatively dark; when the contrast control is advanced too far, the picture becomes blurred, there is a loss of detail in the highlights, and in general the intermediate shades are lost.

Synchronizing Circuits

The circuits devoted to synchronization in a television receiver are those which remove the sync information contained in the complete video signal and utilize it to control the timing of the horizontal and vertical deflection oscillators. To perform these functions, the sync part of the signal must first be separated from the picture part of the signal. In addition the vertical sync pulses must be separated from the horizontal sync pulses so that each can be applied to the respective deflection oscillator which it controls.

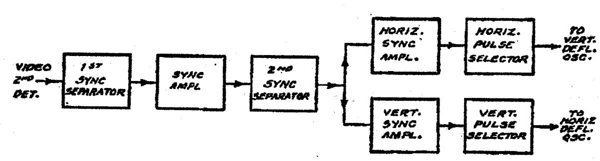


FIG. 47.—Block diagram of the sync circuits used in the RCA Model TRK-12 receiver.

The circuits used to separate the synchronizing pulses from the picture portion of the signal are called "sync separators" or "clippers." These circuits are designed so that they are responsive only to the sync pulses which lie above the pedestals; thus they reject the picture portion of the signal. The clipper or sync separator is generally followed by additional amplification and finally the sync signal is fed to a frequency-selecting circuit which separates the horizontal sync pulses from the vertical sync pulses. This separation is accomplished by circuits which depend for their action upon the difference in the time duration of the two types of pulses.

To illustrate the principles involved in sync circuits, we shall describe the circuits used in the RCA Model TRK-12 receiver. As the block diagram in Fig. 47 shows, the video signal is taken directly from the second detector and passes through the *first sync separator* which removes most of the video signal from the sync signal. The sync signal is then amplified in a *sync amplifier* stage and fed to a *second sync amplifier* stage which completes the separation of the sync signal. The output of the second clipper is fed to two separate stages, the horizontal sync amplifier and the vertical sync amplifier. The output of the horizontal sync amplifier feeds the sync pulses to a circuit—*the horizontal pulse selector*—which selects the vertical sync pulses; the output of the vertical sync amplifier also feeds the sync pulses to the *vertical pulse selector* which selects the vertical pulses.

On the whole, the block diagram presents quite an imposing array of circuits considering that it represents but a small part of all the circuits in the complete receiver. However, synchronization is so important in the operation of the television system that great care must be taken to make the synchronization positive in action.

Sync Separator Circuit

Referring to the partial schematic in Fig. 48, the video signal is fed from the second detector directly into the grid of the first sync separating tube. This stage uses one section of the 6N7 dual triode. The distinguishing features of this stage are that the tube is operated at the very low plate voltage of 15 volts and at zero bias (when no signal is present). When a signal is being received the grid leak-condenser combination R75-C77 provides a bias voltage as a result of the rectified grid current. As the waveform shows, the polarity of the video signal applied to the grid is negative so that the grid bias is supplied by the sync pulse part of the signal. As previously explained in connection with d-c restorer circuits, the bias at the grid varies in accordance with the average brightness and the result is that all the sync pulses are lined up with the zero-voltage axis at the grid of the first sync separator. This is illustrated in Fig. 49 which shows the plate current-grid voltage characteristic of the first sync separator stage.

Because of the low plate voltage of only 15 volts, plate-current cutoff is reached at a low value of negative grid voltage. Consequently the picture part of the signal lies beyond cutoff, and only the sync pulses are effective in causing the plate current to change. Thus the picture part of the signal is removed and so does not appear in the plate circuit of the first sync amplifier tube. An important part of the action in this circuit is the operation with grid leak bias so that all the sync pulses are lined up. As in the d-c restoring circuits, the time constant of the input circuit is sufficiently large so that the bias is maintained during the interval between sync pulses.

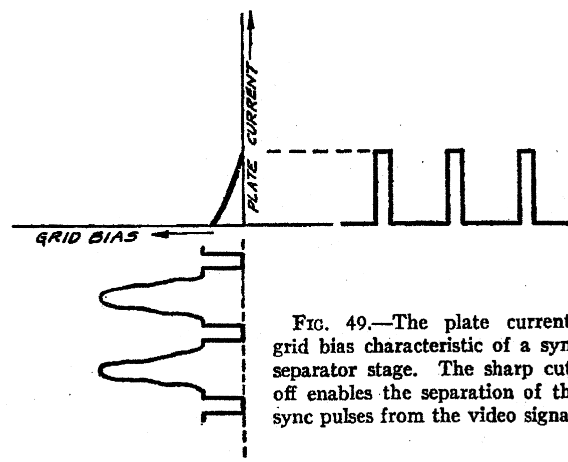


FIG. 49.—The plate current-grid bias characteristic of a sync separator stage. The sharp cut-off enables the separation of the sync pulses from the video signal.

The signal produced in the plate circuit of the first sync separator no longer contains the picture part of the signal but instead the latter has been removed because of the sharp cutoff of this stage. A term often used to describe the action of a circuit similar to the first sync separator is the term "clipper." This term is appropriate because the stage can be thought of as clipping the video portion of the signal and leaving only the sync pulses.

The clipped sync signal is next fed to the grid of the second triode of the 6N7 which is arranged to func-

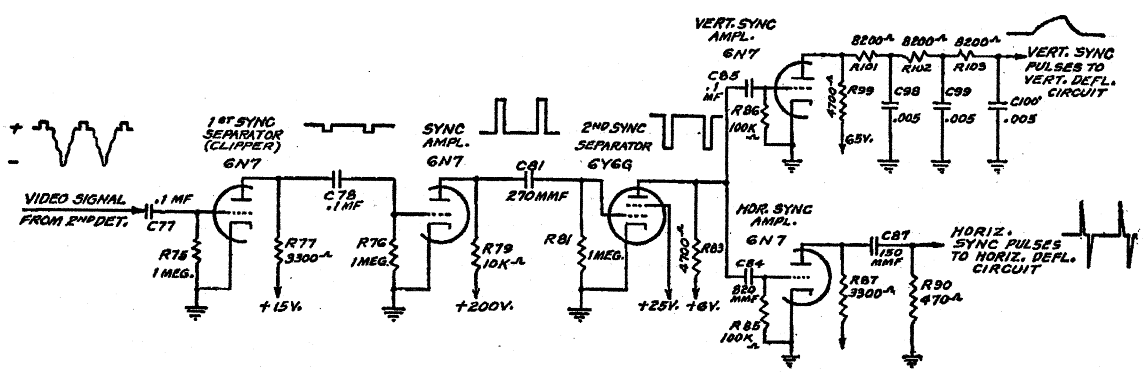


FIG. 48.—Schematic of the sync circuits used in the RCA Model TRK-12 receiver.

tion as an amplifier. For this reason a high value of plate voltage, 200 volts, is used. Note that the sync pulses have been reversed in polarity so that the grid of the amplifier tube goes negative on the peaks of the sync pulses. However, the operating characteristics of the amplifier stage are such that the sync pulse waveform in the plate circuit of the sync amplifier is simply an amplified version of the signal in the grid circuit. The polarity of the signal is of course reversed 180 degrees so that the sync signal in the grid circuit of the following clipper tube is negative in polarity.

The action in the second sync separator is similar to that in the first sync separator. A screen grid tube is used with the screen placed at a higher voltage than the plate and with both these voltages comparatively low. Thus the screen voltage is only 25 volts and the plate voltage about 6 volts. Under these conditions the stage has a very effective clipping action on both the positive and negative peaks of the sync pulse. In this way, if any video signal still remains it is clipped sharply by the plate-current cutoff; at the same time, the positive peaks of the sync pulses are again clipped as in the previous sync separator. As a result of this second clipping of the sync pulses, the waveform is made flat and any noise components that may have been added to the signal are removed. Thus noise is prevented from interfering with the synchronization.

The output of the second sync separator feeds the sync pulses to two separate amplifier stages, a vertical sync amplifier and a horizontal sync amplifier. These individual stages provide further amplification of the sync pulses and at the same time act as buffer stages to isolate the vertical sync circuits from the horizontal sync circuits. The circuits used in the output of these stages are frequency-selecting circuits which differentiate between the two types of sync pulses by making use of the fact that the duration of the vertical sync pulses is greater than that of the horizontal sync pulses.

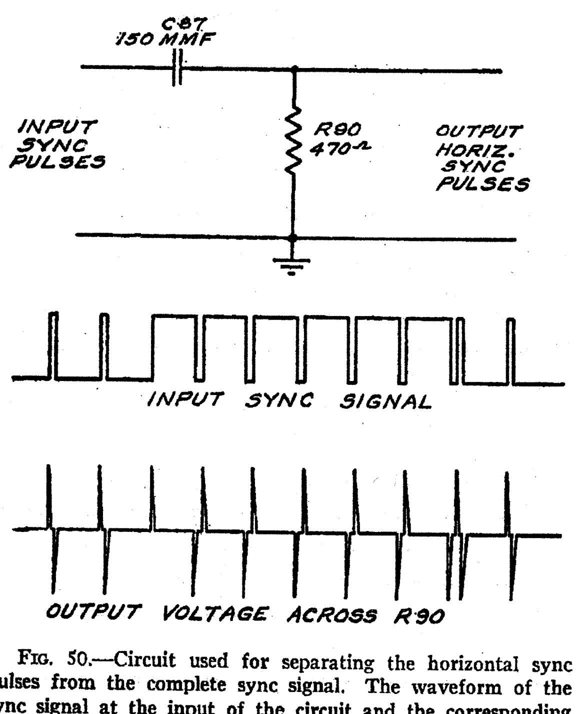


FIG. 50.—Circuit used for separating the horizontal sync pulses from the complete sync signal. The waveform of the sync signal at the input of the circuit and the corresponding waveform at the output are shown below the circuit.

Horizontal Sync Selector

The signal is coupled to the horizontal sync amplifier through the 820-mmf condenser C84. The amplified signal appears across R87 and is fed to the *selector circuit* consisting of C87 (150-mmf) and R90 (470 ohms). This circuit separates the horizontal sync pulses, which appear across R90.

The manner in which this selector circuit operates requires some explanation. Essentially the current which passes through R90 is limited by C87 because of the small value of capacitance and the low value of resistance. As a result the current through R90 is proportional to the rate of change of the sync pulse voltage and in this way sharp voltage pulses are produced across R90. This is clearly iluustrated in Fig. 50 which shows the input sync signal during the interval between successive fields. Note that at each edge of the sync signal where the waveform changes abruptly, this rapid change results in a pulse of current through C87 and R90, which produces the voltage drop across R90 shown in the figure. As explained later, only the positive pulses across R90 are effective in synchronizing the deflection circuit; those below the axis have no effect. As Fig. 50 shows, horizontal sync pulses are also produced during the vertical blanking period because the leading edge of each vertical sync pulse represents a rapid change of voltage and therefore produces a pulse through R90.

Vertical Sync Selector

The complete sync signal is also fed from the second sync separator into the grid of the vertical sync amplifier. The amplified sync signal appears across R99 and is fed to the selector circuit consisting of R101 and C98. Two additional sets of resistor-condenser combinations are used in series in order to increase the effectiveness of the vertical pulse selection.

The action of R101 and C98 in differentiating between the vertical and horizontal sync pulses is a direct result of the longer duration of the vertical pulses. Thus Fig. 51 shows that each one of the sync impulses, including the horizontal impulses, contributes a small amount of charge which is stored in the condenser. The greater the duration of the pulse, the greater the voltage across the condenser. During the

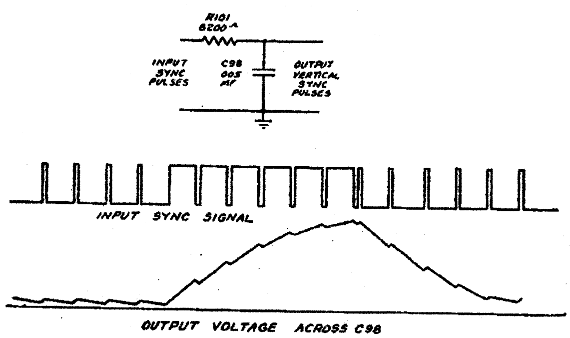


FIG. 51.—Circuit used for obtaining the vertical sync pulses required for field synchronization. The corresponding waveforms at the input and output are shown below the circuit.

transmission of the long vertical sync pulses, the accumulation of charge on the condenser is greater than during the transmission of the short line sync pulses. As a result, the voltage across the condenser C98 builds up to a peak once during each field or 60 times in each second. As the figure shows, the vertical pulse builds up to a maximum at the end of the last vertical sync pulse and then steadies down to an average value of voltage which remains constant until the beginning of the next field pulse.

To increase the circuit effectiveness, two more similar resistor-condenser combinations are used in series as shown in Fig. 48. These circuits accomplish a further selection of the two pulses so that a sharper pulse is produced once during each field. The peak of this pulse is used to synchronize the vertical deflection oscillator.

For exact interlacing it is important that the vertical pulses produced at the output of the vertical selector circuit be the same on alternate fields. The equalizing pulses, previously described, accomplish this by making the conditions exactly the same before and after the transmission of the actual broad vertical sync pulses. As a result, the condenser charges up to the same value of peak voltage on both the odd and even fields so that the vertical oscillator is maintained in perfect timing.

DEFLECTION CIRCUITS

In describing the picture tube we explained how the electron beam can be deflected by sawtooth waves applied to the deflecting elements of the picture tube. The previous sections have explained the necessity for synchronizing these waves and how the sync signals are selected at the receiver. The next problem is to generate the sawtooth waves, control them by the sync signals and to apply them to the deflecting system of the picture tube.

The block diagram of Fig. 52 shows the essential parts of a common type of deflection circuit for television. From the sync separator described in the previous section, horizontal sync pulses are applied to the horizontal deflection circuits and vertical sync pulses to the vertical deflection circuits. Both sets of deflection circuits contain the same type of elements, the principal difference being the operating frequencies.

The sawtooth waves shown in Fig. 15 are formed in the *discharge circuit*. This circuit includes a condenser which is slowly charged from the B supply and then rapidly discharged through a vacuum tube. The voltage across this condenser varies in such a way as to form a sawtooth voltage wave similar to that shown in Fig. 15. The exact moment at which the discharge tube operates is determined by the *blocking oscillator* which provides pulses to the grid of the discharge tube of sufficient amplitude to "trip" it. The frequency of the blocking action is itself synchronized with the incoming signal by pulses from the *sync separator*. The sawtooth voltage wave formed in the discharge circuit

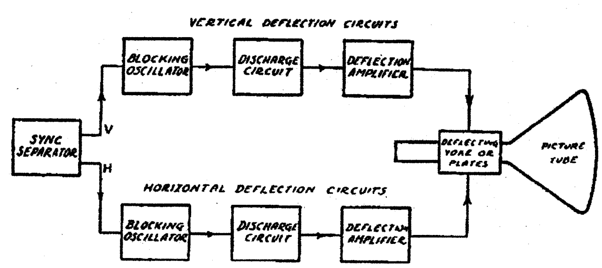


FIG. 52.—Block diagram of the essential parts of a widely-used type of deflection circuit.

is amplified in the *deflection amplifier* and then applied to the deflecting yoke or plates which cause the scanning action of the beam in the *picture tube.*

Circuits for Electromagnetic Deflection

The schematic, Fig. 53, shows the deflection circuits used in the RCA Model TRK-12 and Westinghouse Model WRT-703 receivers. These are examples representative of circuits for use with a picture tube deflected by the electromagnetic method.

To describe the formation of the sawtooth wave, let us assume that the grids of the 6N7 tube (in the horizontal circuit) are biased to cutoff so that the tube is non-conducting. The plate voltage starts to charge the .001-mf condenser C90 through resistors R93, R94 and R95 in series. The voltage across C90 (from D to ground) rises as shown by the line designated "trace" in Fig. 15a. About 65 microseconds later, a positive pulse of voltage is applied to the grids of the 6N7 and the tube "trips" or starts conducting. The triode section, whose plate is connected to D, then acts as a short to ground and discharges C90 in about 11 microseconds. The voltage across C90 falls as shown by the line designated "retrace" in Fig. 15a. The discharge is stopped after 11 microseconds by a sudden blocking of the grids, and the charging cycle starts again. The relatively short time allowed for the charge and discharge of condensers C90 (horizontal) and C103 (vertical) assures that the sawtooth wave will be essentially linear.

Blocking Oscillator

The periodic blocking and tripping of the 6N7, which has just been mentioned, is accomplished by the blocking oscillator. In connection with the latter, the question naturally arises as to why the sync pulses could not be used directly to trip the discharge tube. Actually, the sync pulses could be used directly, but it has been found more satisfactory to use the blocking oscillator circuit being described. The blocking oscillator provides a steep pulse of high amplitude which is more readily adapted to the control of the discharge tube than is the sync pulse itself. The necessary timing of the blocking oscillator is of course obtained from the sync pulses.

As the name implies, the blocking oscillator is a regenerative oscillator in which the feedback is so large that the oscillator is blocked on the first cycle of oscillation. Thus when oscillation starts, the amplitude is so great that the negative charge which accumulates on the grid condenser drives the tube to cutoff. Before the oscillations can start up again, the charge on the grid condenser must leak off. The rate at which this charge leaks off determines the rate at which the steep pulses are produced by the blocking oscillator. Because the circuit constants are such that the natural frequency at which the oscillator attempts to work is higher than the frequency of blocking, the pulse produced when oscillations start has a very steep waveform which is advantageous in controlling the discharge tube.

The rate of blocking, and hence also the rate at which the pulses for the discharge tube are produced, is controlled by R91 and R92. The lower the value of this grid resistance, the more rapidly the charge leaks off so that the oscillations can begin again and produce another pulse. The "free-running" frequency of

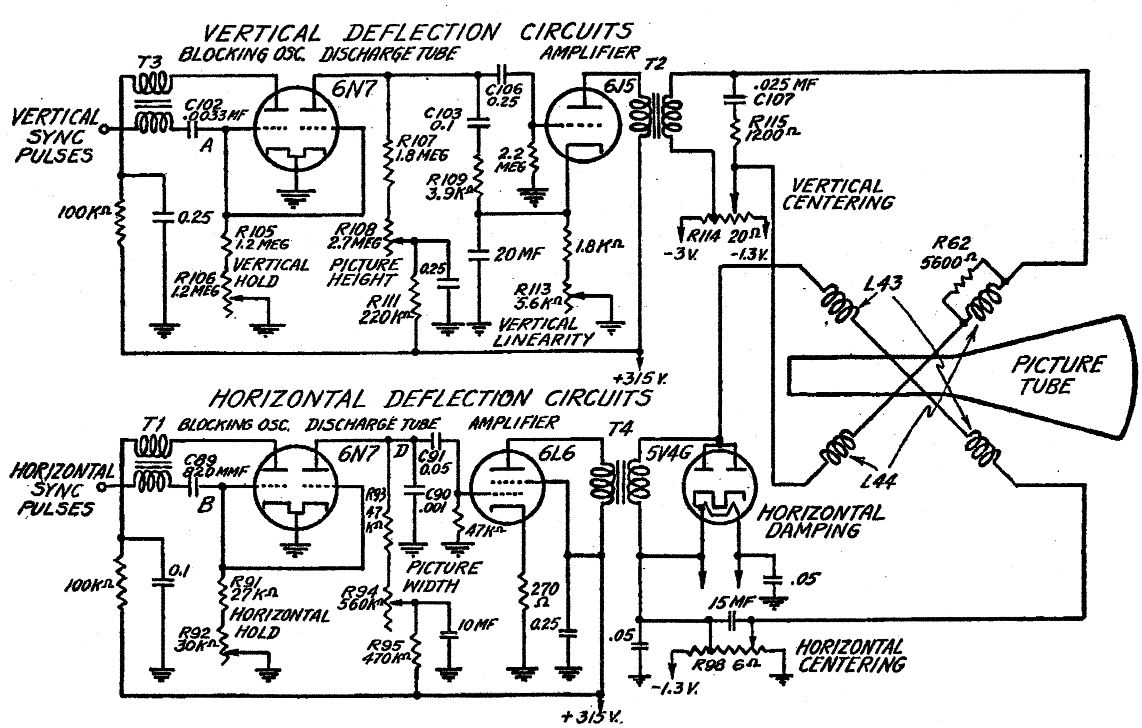


FIG. 53.—Deflection circuits used in the RCA Model TRK-12 receiver. Compare with the block diagram shown in FIG. 52.

the blocking oscillator is thus controlled by the value of C89, which determines the amount of charge stored in the grid circuit, and R91 and R92 which determine the rate at which this charge leaks off.

In practice, the free-running frequency is adjusted by means of the *horizontal hold control* R92 so that it is lower than the line frequency of 13,230 cycles. The application of the horizontal sync pulse to the grid circuit, as shown, will then introduce a positive pulse into the grid circuit and cause the blocking oscillator to start operating slightly before the instant when it would normally resume operation. In this way the sync pulse keeps the blocking oscillator exactly in synchronism with the frequency of the scanning at the camera tube.

The circuit for the vertical deflection operates in the same manner. In this case R106, the *vertical hold control*, is adjusted so that the free-running frequency of the vertical oscillator is slightly less than 60 cycles. The introduction of the vertical sync pulse trips the oscillator just before it would otherwise resume oscillation so that the frequency is kept in synchronism with the vertical sync pulses.

Width and Height Controls

The peak value of the sawtooth voltage which is developed across C90 depends on the setting of R94. Since the peak value of the voltage across C90 determines the magnitude of the horizontal scan and therefore the picture width, R94 is called the *picture width control.* Similarly R108 controls the vertical sawtooth amplitude and therefore is called the *picture height control.*

The *vertical linearity control* R113, which is in series with the vertical wave-forming condenser C103, corrects the waveshape so that a sawtooth wave of current will be obtained through the deflecting coils.

Centering

As a result of the circuits described, accurately timed sawtooth voltages are available at points C and D. These waves are amplified and coupled to the deflecting coils L44 and L43 by transformers T2 and T4 respectively. The picture is centered on the picture-tube screen by sending a small direct current through the deflecting coils. Potentiometers are provided for making the vertical and horizontal centering adjustments.

Damping Tube

The 5V4G diode shunted across the secondary of T4 is provided so as to prevent transient voltages being set up when the scanning current changes abruptly. This diode acts as an automatic switch so that the transformer is loaded only during the trace period, and the load removed during the retrace period. It is not possible to use a permanently-connected resistor load in place of the diode switch because this continuous loading would tend to prolong the retrace period by an excessive amount.

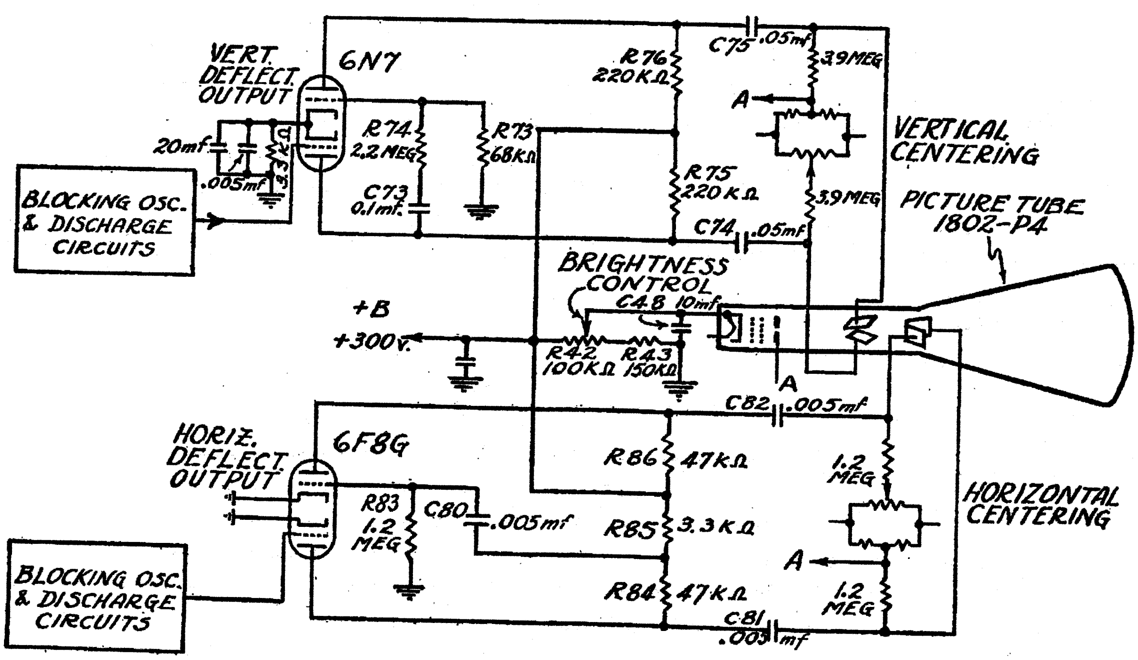


FIG. 54.—Circuits used for electrostatic deflection in the RCA TRK-5 receiver. Note the push-pull output in both the horizontal and vertical channels.

Electrostatic Deflection

In electrostatic deflection systems for television, it is usual to use the same type of sawtooth-wave generator as is used for electromagnetic deflection. The output systems, however, are quite different. To avoid distortion of the raster and defocusing of the spot, the sawtooth waves on each plate of any pair must be alike but 180 degrees out of phase. A balanced amplifier using a phase inverter is used to furnish these deflecting voltages. The force acting on the electron beam is thus due to the difference between the potentials of the two plates, since at any one instant the positive voltage on the one plate attracts the electron beam at the same time that the corresponding negative voltage on the other plate repels the electron beam. Thus, if at any instant the deflecting voltage on one plate is +50 volts, then the voltage on the other plate is —50 volts and the effective deflecting voltage is the sum or 100 volts.

Electrostatic Deflection Circuits

Fig. 54 shows the output circuits of the electrostatic deflection circuits used in the RCA TRK-5 and Westinghouse WRT-701 receivers. The blocking oscillator and discharge circuits are shown in block form because they are similar to those shown in Fig. 53. In the vertical circuit the signal across R75 is fed to one of the vertical deflecting plates through condenser C74. This same signal is also fed to the grid of the phase inverter section of the 6N7 tube through condenser C73 and a voltage divider consisting of R74 and R73. The signal across the phase inverter load R76, which is 180 degrees out of phase with the signal across R75, is fed through condenser C75 to the other vertical deflecting plate. The voltage divider R74, R73 is used to compensate for the gain of the phase inverter section of the 6N7 so that the signal amplitude applied to each deflecting plate is the same except for the phase reversal. In the case of the horizontal deflecting circuit, the action is similar; here the voltage divider consists of R84 and R85.

Centering Control

Fig. 54 also shows the type of centering circuit used with electrostatic deflection. One plate of each pair is returned to the second anode through a high resistance. The second plate is returned through a high resistance to the potentiometer which permits a d-c voltage, either zero, plus or minus with respect to the first plate, to be applied to the second plate in order to center the raster on the screen of the picture tube. These potentiometers, called *centering controls,* are usually adjusted during installation and seldom need readjustment. The details of this type of circuit are shown in Fig. 55 in the following section on power supplies.

POWER SUPPLIES

As a general rule, two separate rectifiers are used to supply the d-c voltages for television receivers. A low-voltage supply provides approximately 300 volts for the tubes associated with the amplifier, deflection, and sync circuits of the receiver. A separate high-voltage power supply provides the high voltages—from approximately 2000 to 10000 volts—required for the picture tube.

Since the low-voltage power supplies are very similar to those used in radio receivers, a separate low-voltage schematic is not shown here. The regulation in a television low-voltage power supply is generally better than that in a radio receiver because of the importance of preventing variations in the numerous circuits from interfering with each other and with the picture. The hum level is also kept down to a lower value because of the large number of circuits and stages, and because hum which would be inaudible in a sound receiver may cause appreciable distortion of the picture.

Unlike the low-voltage power supply, a half-wave rectifier is invariably used in the high-voltage supply. The advantages of the half-wave rectifier are that the transformer does not have to be as large and that the peak voltage is reduced to about one-half the value required for full-wave rectification. Ordinarily the half-wave rectifier is not used in radio receiver power supplies because its output is harder to filter and because it cannot supply as much current to the load as the full-wave rectifier. However, these characteristics are not disadvantages in television receivers because only a very small current is drawn and a resistor-condenser filter can be used.

High-Voltage Power Supply in RCA TRK-5, Westinghouse WRT-701

The high-voltage power supply used in the RCA Model TRK-5 and Westinghouse WRT-701 receivers is shown in Fig. 55. A type 879 high-voltage half-wave rectifier is used, the complete path of the rectified current being from the low-voltage end of the secondary, through the secondary winding, the 879 rectifier tube, the first filter resistor R91, the second filter resistor R92, and the bleeder resistors from R93 to R98, inclusive, and back to the low-voltage side of the secondary.

R91 acts as a filter resistor and also limits the voltage and current through the first filter condenser C86. Good filtering is secured by using a high value of filter resistance; R92 is 470,000 ohms, and in combination with the two .05-mf condensers provides adequate filtering. Note that large values of filter resistance rather than large values of capacitance are used to obtain the required filtering. The advantage of this is the reduced cost and size of the condensers; in addition, the smaller the size of the filter condenser, the less is the danger of fatal shock if one accidently comes in contact with a charged or partly-discharged condenser. Nevertheless, the high-voltage filter condensers should always be discharged before any measurements are made so as to guard against the possibility of an open bleeder circuit.

In the circuit being described the cathode of the picture tube is near ground potential while the second anode is 2000 volts positive with respect to the cathode. The focusing anode is returned to the focusing control which places approximately 500 volts on this electrode. Centering of the beam horizontally and vertically is accomplished by returning one plate of each of the pairs to point M which is at a voltage slightly lower than the maximum output of the power supply. The remaining plates are then returned to the sliding taps on the horizontal and vertical centering potentiometers so that the voltages can be varied either positively or negatively with respect to the other plates. These circuits should not be tested while the power is on since the maximum high voltage is present on all the deflection plates and centering adjustments. The deflecting plates are capacitively coupled to the horizontal and vertical deflection output tubes through .05-mf and .005-mf condensers as shown in Fig. 54; these condensers are of course rated to withstand the full high-voltage output.

The high-voltage supply is not entirely independent of the low-voltage power supply in the sense that the entire high-voltage power supply is returned to ground through the brightness control in the low-voltage power supply. If the connection to the brightness control at R42 were broken, then the entire high-voltage power supply would "float." In actual operation, the potential at the cathode is approximately 200 volts above ground potential, depending upon the setting of the brightness control; as a result the low end of the high-voltage rectifier circuit, including the cathode of the picture tube, is above ground potential by this same amount. The control grid of the picture tube, which is tied to the plate of the 6V6 video output tube, is approximately 175 volts above ground potential so that the proper average brightness can be secured by means of the setting of R42.

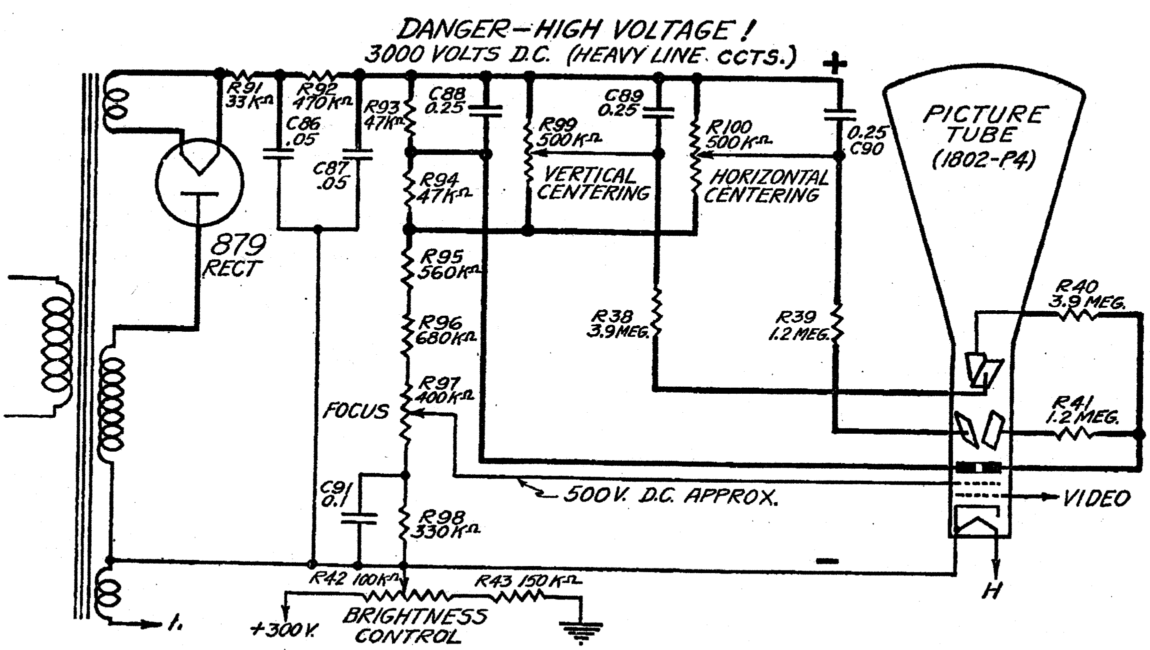


FIG. 55.—High-voltage power supply used in the RCA Model TRK-5 receiver. The heavy black lines represent the high-voltage circuits. Extreme caution should be observed to avoid coming in contact with high-voltage points.

Grounding of High-Voltage Power Supply

The high voltage difference required between the cathode and second anode of the picture tube can be obtained with either the positive or negative side of the high-voltage power supply near ground potential. In receivers using the electromagnetic method of deflection, it is usual for the negative side of the power supply to be grounded since this enables coupling the video output tube to the modulation grid without the use of a high-voltage condenser. This same system is also used in some receivers which use electrostatic deflection, as for example in the RCA Model TRK-5 receiver. Where electrostatic deflection is used, however, high-voltage blocking condensers are required in the circuits which couple the deflection output tubes to the horizontal and vertical deflection plates.

To avoid the use of high-voltage blocking condensers in the deflection plate circuits and at the same time maintain the deflection plates at the same potential as the second anode (which is necessary to avoid distortion in the picture tube), the positive side of the high-voltage power supply is sometimes grounded and the cathode is then several thousand volts negative with respect to ground. The DuMont Models 180-183 are examples of receivers using this type of circuit. Although high-voltage condensers are not required in the deflection circuits, a high-voltage blocking condenser must be used between the plate of the video output tube and the modulation grid.

Regardless of whether the positive or negative side of the power supply is grounded, the usual precautions against electrical shock must be observed.

ANTENNAS AND INSTALLATION

The proper operation of a television receiver depends to a very great extent upon the care with which the installation is made. No matter how well designed the receiver may be, its performance will be poor unless proper attention is given to the type of antenna, its location, and the installation of the receiver itself.

The receiver should be placed where no direct light will fall on the cathode-ray tube viewing screen. Although television pictures can be seen satisfactorily without total darkness, the vicinity of the receiver should be capable of being darkened readily. The location chosen should permit adequate ventilation and be close enough to a power outlet to avoid the use of extensions to the power cord. A good ground connection is also important. If the receiver is of the type intended to be used with a broadcast receiver, it should be placed in such a way that the sound appears to come from the picture, and the connections between the receivers should be as short as possible. The relation between the receiver location and the length of the antenna lead-in should also be considered, since the antenna location itself is usually determined by external conditions which cannot readily be changed.

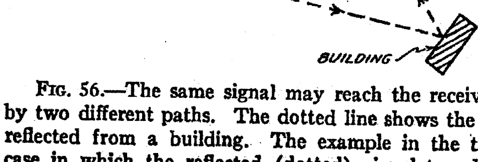


FIG. 56.—The same signal may reach the receiving antenna by two different paths. The dotted line shows the signal being reflected from a building. The example in the text is for a case in which the reflected (dotted) signal travels two miles farther than the direct signal.

The most important problem is the choice and installation of the antenna. The various manufacturers offer different types of antennas, some types being recommended for suburban areas, others for city use. All are of special design suitable for the ultra-short waves used in television, an ordinary broadcast antenna not being suitable for television use.

The necessity for special antennas for television is more apparent when we consider some of the differences between the short waves used in television and the comparatively long waves used in ordinary broadcasting. The shorter the wavelength of a radio wave, the more it behaves like light. For example, we know that light travels in straight lines through space. For this reason we cannot see objects far enough away to be "below the horizon." Clearly a taller object can be seen from a greater distance than one closer to the surface of the earth since it projects above the horizon. In the same way, the "coverage" of a television transmitter depends upon the height of both the transmitting antenna and the receiving antenna. In addition to increasing the range of reception, placing the receiving antenna as high as possible has the important advantage of increasing the signal pickup and decreasing the noise pickup. It is interesting to note that the television transmitter of the National Broadcasting Company in New York, which is located atop the Empire State Building (1250 feet high), covers a radius of about 40 miles or an area of about 5000 square miles.

In ultra-short wave transmissions as in light, buildings, mountains and other opaque objects cast "shadows" which result in no signal or very weak signal within the shadow area. In addition such objects can cause reflections which may result in distorted pictures because of the small but appreciable difference in the time of arrival of the direct wave and reflected wave. Fig. 56 shows how this reflection may occur. The transmitter sends out waves in all directions, one of which may be considered as going directly to the receiver. Another wave reaches the receiver indirectly by going first to a building or other reflector and then to the receiver. The important point here is the difference in the total length of the path which the reflected wave has to travel as compared with the path of the direct wave. Here the difference is 2 miles. Since both waves travel at the same velocity of 186,000 miles per second, the reflected wave will arrive $\frac{2}{186,000}$ second, or approximately $\frac{1}{100,000}$ second later than the direct wave. The time required for the electron beam to travel 1 inch horizontally across the picture tube is also about $\frac{1}{100,000}$ second. Therefore the reflected wave will cause a second image which is displaced about 1 inch horizontally to the right of the image due to the direct wave. Smaller time differences may produce only lack of sharpness in the picture, but in any case, when installing the antenna the serviceman should try to avoid multiple images due to reflections. This effect can often be reduced or eliminated by slight changes in the position of the antenna, or by the use of a special antenna.

In general, since American television transmitting antennas will be mounted horizontally, the receiving antenna should also be approximately horizontal, and placed broadside to the direction of the transmitter. During installation, however, the best procedure is to watch an actual picture on the receiver, comparing different locations and positions of the antenna on the basis of the results obtained at the receiver. An intercommunication set between the man working on the antenna and another observing the received picture is obviously a useful accessory for antenna installation.

Automobile ignition systems and diathermy apparatus emit short-wave signals covering at least part of the television spectrum. Antennas should therefore be erected as far as possible away from these sources of interference.

The antenna should be erected at as high a point as conditions permit, since, other things being equal, the signal strength increases when the elevation of the antenna is increased. A high antenna is also likely to reduce local interference. Both these effects of course, tend to improve the signal-to-noise ratio.

Most television antennas consist of two rods or tubes of conducting material placed in a straight line end to end, but with some separation between them. Each section is about ¼ wavelength (roughly 5 feet) long, making the total length about ½ wavelength. Such an antenna, shown in Fig. 57, is called a simple *half-*

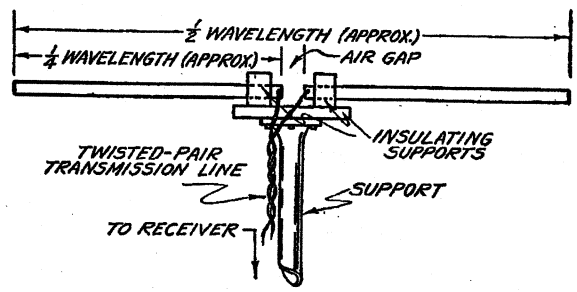


FIG. 57.—A half-wave dipole antenna—a type very widely used for television reception.

wave dipole. The lead-in or transmission line is usually a twisted pair of wires specially insulated against weathering; one wire of the pair is connected to each rod near the air gap. Some manufacturers have different kinds of transmission line for special purposes. The simple dipole is generally satisfactory, but improved performance can often be obtained from two such dipoles connected in parallel. Such double dipoles are mounted one above the other like the cross arms on a telephone pole.

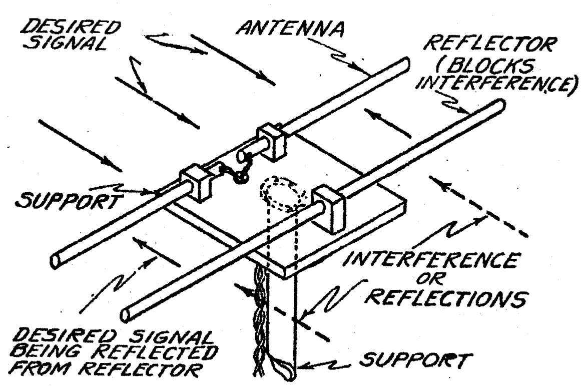


FIG. 58.—A half-wave dipole antenna with a reflector for increasing the signal pickup and reducing interference from reflections.

Where trouble is encountered from reflections or low signal strength, or both, a reflector element may be added to the antenna system. As shown in Fig. 58, the reflector is a continuous rod somewhat longer than the antenna and placed *behind* it; that is, the reflector is at the same elevation as the antenna and is parallel to it, but placed on the side of the antenna *away from* the transmitting station whose signal it is desired to receive. The reflector serves two desirable purposes:

it blocks interference or reflections coming from "behind" the dipole, and it strengthens the desired signal by reflecting it back to the dipole. The spacing between antenna and reflector is determined from the manufacturer's instructions or by experiment. The double dipole described previously may be provided with a double reflector.

No dipole of fixed dimensions can be equally efficient for all the television channels. The reason for this is that maximum efficiency requires that the length of the dipole (and also the reflector, if used) should have a fairly definite relation to the wavelength of the desired signal. We have mentioned, for example, that it should be about ½ wavelength long overall. For the first two television channels (44 to 56 mc) the middle frequency is 50 mc and the corresponding wavelength is 6 meters, or almost 20 feet. A 10-foot half-wave dipole is therefore quite efficient for these two channels. It is not so efficient, however, for the 66-72 mc and 78-90 mc channels, since the mid-channel wavelengths for these are respectively about 14.3 and 11.7 feet. If all these channels are to be received on one antenna, they will not be received with equal efficiency. Depending upon the local conditions, it is possible to choose the antenna length suitable for either (1) the mid-point of the whole band, (2) the mid-point of the most popular station or stations, or (3) to provide an antenna of adjustable length.

FREQUENCY MODULATION

Up to the present time all broadcast stations have used amplitude modulation for program transmission. In this method of transmitter operation the frequency of the carrier is maintained constant, usually by crystal control, while the amplitude of the carrier is varied by the audio modulation impressed upon it. A new system of broadcast transmission by frequency modulation is now being introduced by a few stations in the East. This system was devised by Major E. H. Armstrong and differs from amplitude modulation in that the carrier *frequency* is varied by the impressed audio modulation, while the carrier amplitude is held constant.

Advantages of Frequency Modulation

The principal advantages of frequency modulation over amplitude modulation are an improved signal-to-noise ratio, particularly in poor reception areas where the signal strength of the transmitter is weak, and a reduction in interference when two frequency modulated transmitters are geographically separated but operating on the same frequency. In receiving, better fidelity is usually more easily obtained from frequency-modulated transmissions.

Since the carrier frequency in frequency-modulated broadcasting is varied over a wide band, wide channels are necessary for transmission. Present channels are 200-kc wide and have been allocated in ultra-high frequency bands to avoid interference with other services which would result if channels of such width were assigned within the standard broadcast band. The actual carrier frequency variation is limited to one-half the channel width, as with amplitude modulation, since the frequency of the carrier varies above and below the nominal assigned value when audio modulation is applied. In present frequency-modulated broadcast transmissions, the maximum frequency deviation is held to approximately plus or minus 75 kc during audio modulation.

How Noise is Reduced

The manner in which frequency modulation reduces noise may be understood by remembering that most electrical noises change the amplitude of the signal but not its frequency. Now, in the amplitude modulation method of broadcasting, both noise and audio modulation act to vary the carrier signal voltage so that the two are combined in the signal detected by the receiver. In frequency modulation, however, the audio modulation varies only the frequency of the carrier signal and not its amplitude. Noise, on the other hand, will cause no change in the carrier frequency, though it will affect its amplitude. If, then, the receiver is designed to detect only variations in signal frequency and not variations in amplitude, noise resulting from amplitude modulation is eliminated. Frequency modulation is not perfect, but a very great reduction in noise is secured by this method.

Special Receivers Necessary

Conventional broadcast receivers are designed only for the reception of amplitude-modulated transmissions and therefore are not suitable for receiving frequency-modulated broadcast signals. The principal differences in the latter are in the design of the detector and in the limiter stage which precedes the detector.

A typical stage-by-stage lineup for a frequency modulation receiver is shown in Fig. 1. This shows an r-f amplifier, converter, 3-stage i-f amplifier, limiter, detector and a-f amplifier.

Since the transmitted frequency varies about 75 kc above and below the point to which the receiver is tuned and flat amplification is necessary for high-quality reproduction, the carrier-amplifying stages and the converter must be designed to pass a 150-kc band without frequency discrimination. Ordinary tuned circuits are usually far too sharp for this purpose, particularly in i-f circuits, so we find in the frequency modulation receiver that low-Q circuits are necessarily employed to achieve broad tuning.

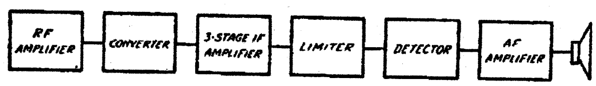


FIG. 1.—Block diagram of a receiver designed for the reception of frequency-modulated signals. With the exception of the limiter stage, the lineup is similar to that of a conventional superheterodyne receiver.

In the i-f stages, broad-band reception is secured by using a high intermediate frequency, usually of the order of 3 megacycles, and by broadening the i-f transformer response by resistance shunted across one or more windings.

What the Limiter Does

The limiter stage requires detailed consideration. Its purpose is to smooth out any variations in carrier amplitude so that it may pass on to the detector circuit a signal which is constant in voltage but varies in frequency. This is done by designing the circuit and operating the tube so that it overloads even when a weak signal is being received. Then any increase in signal voltage will not cause an increase in the carrier signal voltage which appears across the tuned circuit forming the limiter stage plate load. The high gain in the r-f, converter and i-f stages provides sufficient amplification for even weak signals so that the actual signal voltage at the limiter grid during reception will always be several volts. Any applied signal voltage greater than the overload point causes rectification in the grid circuit. A resistor in series with the grid return of the limiter input circuit is installed so that the grid current resulting from rectification in this circuit causes a voltage drop across the resistor which can be utilized to provide AVC action. This AVC voltage is applied, through appropriate filters, to preceding i-f, converter and r-f stages.

Special Detector Used

Since, in frequency modulation, the a-f modulation causes a variation in carrier frequency, we need a type of detector which will convert these frequency variations into the a-f signal voltages which originally produced these carrier frequency variations, and in this way restore the original modulation. Ordinary detector circuits are not suitable, since they give an output voltage which is proportional to the amplitude of the carrier modulation and not to the carrier frequency. Since the voltage output of the discriminator circuits employed in AFC designs varies with the frequency shift of the applied carrier signal, it serves as an ideal device for the detection of frequency-modulated signals.

A typical AFC discriminator circuit is shown in Fig. 2. The primary coil, L1, of the discriminator transformer is connected in the plate circuit of the limiter tube and is closely coupled to the center-tapped secondary L2, L3. When the transformer secondary circuit is tuned to resonance with the alignment frequency of the i-f system, the voltages E2 and E3 are equal but opposite in phase. Since the d-c voltage across the discriminator load resistors, R1 and R2, occurs as the result of rectification of E2 + E1 and E3 + E1, then, at resonance, the d-c voltage from point B to ground is equal to that from point B to A, as both R1 and R2 are similar resistors. However, because of the manner in which the diodes are connected, the resulting d-c voltages will be opposite in polarity. Therefore, the voltage across R1 will cancel that across R2 and a measurement from point A to ground will show zero voltage between these two points when the circuit is tuned to resonance with the alignment frequency. This is the normal condition for perfect alignment of an AFC circuit.

When the signal voltage applied to the discriminator transformer is higher or lower in frequency than that to which it is tuned, the voltages E2 and E3 will remain equal but their phase relationship with respect to E1 will change. As a result, E2 plus E1 will no longer equal E3 plus E1. Since this becomes the case, the resulting d-c voltages across R1 and R2 will no longer be equal and opposite in polarity and a voltage with respect to ground will accordingly appear at Point A. As the frequency of the carrier signal becomes higher or lower than that to which the discriminator is tuned, the voltages developed across R1

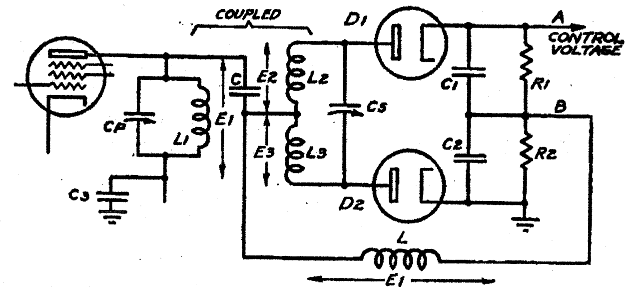


FIG. 2.—The second detector of a receiver for frequency-modulated signals is similar to the discriminator circuit shown.

and R2 add or subtract. Since point A is at zero voltage at resonance, this signal frequency variation causes point A to assume a potential with respect to ground which varies in a positive or negative direction in accordance with these frequency variations. The change in voltage of point A with respect to ground as a result of this shifting frequency is represented in the diagram, Fig. 3.

How the Discriminator Detects

Now let us see how this characteristic of the AFC circuit serves to supply an audio signal to actuate the a-f amplifier of the receiver. We have seen, in frequency-modulated transmissions, that the carrier frequency changes at a rate which is in accordance with the audio modulation impressed upon the carrier. Let us assume that a 400-cycle audio note is being broadcast and the nominal frequency of the transmitter is 42 mc. On the positive half of the 400-cycle modulation, the carrier frequency may be increased while on the negative half it may decrease. If the modulating voltage is sufficient, this may cause a maximum increase of carrier frequency of 75 kc so that the maximum frequency at the peak of the positive half of the wave becomes 42 mc + 75 kc and, at the peak of the negative half of the cycle, to 42 mc — 75 kc. Now, referring again to Fig. 3, we see that a carrier frequency shift in a negative direction will cause the output voltage of the discriminator to become positive whereas an increase in carrier frequency will cause this output voltage to become negative. Since a 400-cycle note is being broadcast, the carrier frequency increases and decreases and the output voltage of the discriminator becomes positive and negative at the

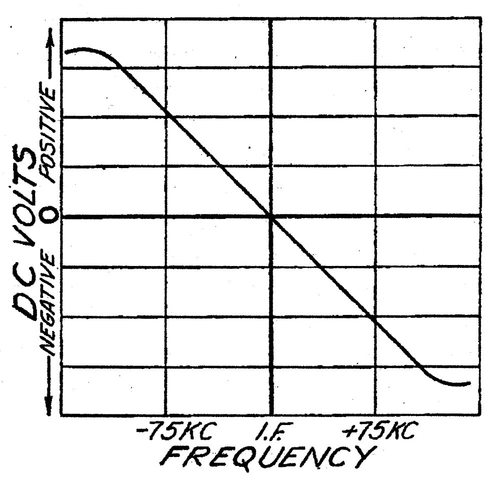


FIG. 3.—The output voltage of the frequency demodulator or second detector varies in accordance with the amount by which the signal frequency differs from the intermediate frequency.

same rate, 400 cycles per second, as that of the original broadcast note. Now, if we apply this rapidly-varying voltage to the grid of an amplifying tube, the voltage across its output load will vary at the same rate. Since this is precisely what occurs when an a-c signal is applied to a grid, we see that in this manner detection of frequency-modulated signals is effected.

Once the frequency-modulated signal is converted into audio frequencies, any type of conventional audio amplifier is suitable. Since the fidelity of reproduction in a carefully-designed receiver is exceptional, high-grade a-f amplifiers and speakers are usually employed.

The G-E Model GM125 Receiver

The schematic (see page 10-35) shows the circuit of the G-E model GM125 receiver, which is designed for frequency-modulation reception. This is a 12-tube, single-band receiver which covers a frequency range of from 37 to 44 megacycles. A single r-f stage feeds the 6K8 converter; four i-f stages are employed, the fourth stage acting as the "limiter." The detector is similar to the AFC discriminator previously described. The triode section of a 6Q7G is employed as the first a-f amplifier and feeds a 6J5G phase inverter which drives the push-pull 6L6G output tubes.

The r-f and converter stages are similar to those which could be employed in conventional designs for the same frequency band, except that no effort has been made to acquire selectivity in the tuned stages since this would be undesirable in a receiver which is required to pass a wide frequency band without frequency discrimination.

The i-f stages are designed to give a band width of 300 kc. This is done by using a high intermediate frequency (3000 kc) and by shunting each i-f transformer primary winding with a 15,000-ohm resistor.

The last i-f stage operates as a limiter. The limiting effect is secured by using a 6SJ7 tube in this stage and operating it with zero control grid bias and only 65 volts on the plate and screen. Under these operating conditions, the tube overloads with a relatively small applied signal. The high overall gain of the stages preceding the limiter tube provides sufficient amplification so that even a weak signal in the antenna circuit is built up to a voltage sufficient to overload the limiter.

When the signal strength is sufficient to overload the limiter stage, grid current flows through the 330,000-ohm resistor, R15, in the grid return circuit of the 6SJ7. The resulting voltage drop across R15 is used to provide AVC action and thus prevent overloading of preceding stages. By incorporating AVC in this stage, there can be no AVC action until the limiter is overloaded, which is its required operating condition. When such is the case, an increase in signal voltage applied to the limiter grid will cause no increase in the output signal voltage across its plate load but the grid current will increase, thereby assuring an increasing AVC voltage.

The discriminator-type detector is similar in action to that reproduced in Fig. 2. It converts the frequency variations of the i-f signal output to a voltage which varies in amplitude at the audio frequency rate. The essential difference between this type of discriminator and one used solely for AFC purposes is that the audio component is not filtered out. This must be done when such circuits are used for AFC applications to avoid modulating the oscillator at the audio frequency. The discriminator load by-pass condensers, C18, C19, are accordingly only 22 mmfd each in this circuit, so there is no by-passing of the higher audio frequencies.

The output of the frequency-demodulator is coupled to a tone control network composed of R11, R20, R40 and the shunt and series condensers C39 and C17. Operation of R40 provides attenuation of either high or low frequencies, as desired. The output of this network connects to the volume control, R21, which returns to ground through an inverse-feedback network composed of R37 shunted by C16 in series with R22. The balance of the audio system is conventional.

Alignment Procedure

To align the i-f amplifier, connect an electronic voltmeter (or any other d-c voltmeter which has a high input resistance) across R15. Feed a 3-mc signal to the grid of the third i-f tube. Temporarily shunt the secondary winding of T7 with a 10,000 or 15,000-ohm resistor and adjust C48 until the voltmeter reading is a maximum. Then remove the secondary shunting resistor and adjust C49 for maximum reading on the voltmeter. Then connect the shunting resistor across T6 secondary, feed the 3-mc signal to the second i-f grid and peak the trimmers of T6 in the same manner. Repeat this process for each of the i-f transformers in turn until all are aligned.

The frequency demodulator circuit may also be aligned with the voltmeter and signal generator. Feed a 3-mc signal to the input of the i-f amplifier and connect the voltmeter from the cathode connection of R18 to ground. A small voltage reading usually will be indicated if the circuit is slightly out of adjustment. If not, adjust C51 until a reading is secured. Then adjust C50 until the voltage reading is a maximum. After this is done, adjust C51 until the voltmeter reads zero. The discriminator alignment is then complete.

The r-f and oscillator stages are aligned by feeding a 42.8 mc signal to the antenna terminals and, with the receiver tuned to this point on the dial scale, adjusting the oscillator trimmer C4 for maximum reading on the voltmeter, which should be connected across R15. Then peak the antenna and r-f trimmers (C2 and C3) in the same manner.

The receiver may also be aligned with a frequency-modulated signal generator as described in the service notes given in Volume X of Rider's Manual.

WIRELESS RECORD PLAYERS

A number of different wireless record players are described in Volume X. These were first announced about the middle of 1938, although phonograph oscillators were available commercially as far back as 1935. Contributing to the present popularity of these record players is that fact that no direct connection is required between the record player and the receiver, as well as the element of mystery which is introduced because of the absence of any wire connection to the radio. Although specific service data are shown in Volume X for the models listed in the index, there are certain general considerations which apply to all wireless record players.

Essentially a wireless record player is a low-powered transmitter which provides a signal much in the same way as an ordinary broadcast transmitter. However, instead of the modulation being obtained from a studio microphone, the phonograph pickup converts the vibrations on the record into an audio signal and this voltage is used to modulate the oscillator contained in the wireless record player. The modulated signal is radiated to the receiver which is tuned to the signal and as a result the record is reproduced by the receiver in the conventional manner. Note that the entire receiver is used rather than just the audio section. Unlike the phonograph oscillators which preceded wireless record players, there is no direct connection to the receiver and hence the name "wireless" record player.

In general, the design of the radiating system in these record players is such that the effective range of pickup is approximately fifty feet. Since excessive radiation will cause interference in other radio receivers, the Federal Communications Commission has limited the amount of radiation to a value which is high enough to permit satisfactory operation of the record player in a typical installation, and which at the same time is not so high as to cause interference in neighboring receivers. In general a long antenna should not be attached to the record player to supplement the built-in antenna, but where the signal input to the receiver is too small the coupling between the record player and the receiver should be increased. This can be accomplished by running the antenna of the record player closer to the antenna lead-in of the receiver.

Most wireless record players use two tubes, one tube as a combination oscillator and modulator, and the other tube as the rectifier tube. The 6A7 and the 25Z5 (or their newer equivalents) are commonly used to perform these functions. In some cases a single combination tube, such as the 12A7, is used both as an oscillator-modulator and as a rectifier.

The power supply design for the most part follows conventional practice and is not unlike the power supplies used in midget receivers. In some cases a small power transformer is used, but in general the d-c voltage for the oscillator-modulator tube is obtained by means of half-wave rectification of the line voltage. In the latter case, the voltage for the heaters and the pilot bulb are obtained through a line cord or ballast tube, although in some instances the heaters are in series with the motor windings so that no ballast resistor is required.

Where the 6A7 tube is used as the oscillator-modulator, the first two grids are not used to form the oscillating circuit, as is the case in the pentagrid converter. Instead, the tuned circuit of the oscillator is connected to the signal grid (the #4 grid) and the feedback circuit is through the plate of the tube, which carries the feedback or tickler winding. Essentially, then, as far as the action of the tube as an oscillator is concerned, the tube may be considered as an ordinary regenerative triode oscillator, in which the signal grid acts as the control grid and in which the feedback is supplied through the plate.

The unmodulated signal produced by this oscillator is modulated by means of the audio signal from the phonograph pickup. The action which takes place here is similar to that which takes place in the pentagrid converter. In the pentagrid converter, the local oscillator signal is produced by the first two grids of the tube, and the incoming signal (applied to #4 grid) is modulated by means of this local oscillator signal so as to produce the intermediate frequency. In wireless record players, however, the signal to be modulated is the oscillator signal (produced as explained above by connecting a tuned circuit to the #4 grid) and the modulation is accomplished by feeding the audio signal to the #1 grid. Both grids #2 and the screen grid (#3 and #5) are connected to B+.

As a general rule a crystal pickup is used in wireless record players and, where the type 6A7 tube is used, the pickup is connected to the #1 grid. The output of these pickups is of the order of 1 volt or more, so that with average circuit conditions the percentage of modulation is fairly low. In order to prevent distortion as a result of non-linearity of the modulation, some designs do not apply the full value of the pickup output to the grid, but use a high value of series resistance to form a voltage divider. Where a volume control is used in the record player, this control appears in the input circuit so that it is possible to control the level of the audio signal which is fed to the modulator grid.

General Service Notes

The servicing of wireless record players is similar to that of radio receivers so that no special instructions are required. However, the following notes will be found helpful in dealing with the specific conditions which are enumerated below and which are peculiar to these record players.

1. *High Noise Level*: A condition wherein the noise level is excessively high can generally be eliminated by coupling the record player more closely to the receiver. As a result of the closer coupling, the signal input from the record player to the receiver is increased, so that the noise level is correspondingly decreased. It is preferable, in coupling more closely to the receiver, to bring the antenna wire of the record player in close proximity to the lead-in of the receiver, rather than to extend the antenna of the record player in a random direction. In places where the noise level is especially high and it is difficult to find a clear channel, it will be found helpful to wind several turns of the antenna wire around the lead-in of the receiver. In no case should a direct connection be made to the antenna post of the receiver.

An alternative method of increasing the signal input to the receiver is to couple a wire to the tuned circuit of the record player through a 20-mmf condenser and to wrap several turns of this wire around the antenna lead in.

In some cases it will be helpful to tune the receiver over the range of the record player as it may turn out that a more quiet channel is clear which can be used advantageously. The record player should be off while this check is made. If a more quiet channel is found, then the record player should be tuned to this frequency.

Hum: Reversing the line cord plug has been found of help in reducing hum and in some instances a further reduction of hum can be effected by using the same receptacle for both the record player and the receiver. Aside from the usual causes of hum such as defective filtering in the power supply, excessive hum may be caused by proximity of the pickup leads (or the leads in the tuned circuit) to the line cord or rectifier leads.

Distortion: Where distorted operation is encountered, a check should be made to determine whether the distortion is being introduced by the record player or by the receiver. It should be remembered that in the last analysis the quality of reproduction can, at best, be equal to that of the receiver when it is operating on ordinary broadcast signals. This follows inasmuch as the entire receiver, and not just the audio section, is used to reproduce the signal.

If the operation of the receiver is good on broadcast signals but the output is distorted when the record player is used, then the distortion is most likely in the record player. A probable cause of distortion is a defective oscillator-modulator tube and this should be replaced to see whether another tube makes any difference. Other possible causes of distortion are a worn needle, defective crystal cartridge, or improper operating conditions. The actual cause of the distortion can be localized by following usual service procedure. It should be noted that in some cases placing the record player too close to the radio may cause microphonic action to take place with resulting distortion. On records which are deeply cut, distortion may sometimes be encountered as a result of amplitude distortion. This can be eliminated by changing to a softer needle or by reducing the setting of the volume control in order to feed a weaker signal to the modulating grid of the record player. The resulting decrease in volume which results can be compensated for by advancing the volume control setting in the radio receiver and, if necessary, by increasing the coupling between the wireless record player and the receiver in the manner previously described. In general, the volume control in the receiver should be adjusted for the highest volume that will be required and the volume control in the record player should only be used for further control of volume. The quality of reproduction will generally be better when the volume control in the record player is not fully advanced.

FACSIMILE RECEIVERS

On Crosley pages 10-41 to 10-44 of Rider's Manual Volume X there are included service notes on the Crosley Models 118, 119 facsimile receivers. Although these service notes are complete in themselves, they assume that the reader understands the theory and operation of the vasic system. For this reason the following description of facsimile as used in the Crosley-Finch system will be of interest.

As the name implies, facsimile transmission is the transmission of an exact copy of original material which may be composed of black and white characters of various shades of gray. This, of course, includes all printed material, line drawings, sketches, or photographs.

It is, therefore, necessary to prepare the copy which you desire to send by facsimile transmission. In the Crosley-Finch system, this represents the printing of copy on a sheet of plain white paper of the same size as is used in the Reado printer. Sketches or drawings are also made directly on this piece of paper, or may be pasted on as half-tone photographs usually are handled. It is essential that all characters of this copy be sharply defined, if best results are to be obtained.

This copy is then fed through the scanning mechanism by means of a paper feed system practically identical to the one used in the Reado Receiver. As the paper is fed through the machine at the rate of 1/100 of an inch per second, it is scanned from left to right by a small, intensely bright point of light 1/100 of an inch in diameter. This light strikes either the characters which are black or some shade of gray, or the white spaces between the characters, and reflects back off the copy on the plate of a photoelectric cell. Optical lenses are used to obtain the small point of light from the 50 candle power 6 volt automobile headlamp, and a lens is also used to gather the reflected light from the copy and focus it on the plate of the photoelectric cell. The photoelectric cell emits electrons when light falls upon its plate, and these electrons form a small current which, as it flows through a very high value resistor, produces a voltage which regulates the amount of signal from a 2000-cycle oscillator that will pass through the 1851 modulator tube. When the tiny point of light falls on black characters, most of the light is absorbed and very little is reflected; but when the light falls on white paper, most of the light is reflected, and in this way the photoelectric cell may differentiate between black and white. Shades of gray reflect light according to their degree of whiteness, and so they are also detected by the photoelectric cell. We, therefore, have obtained from the black and white characters on the paper small pulses of electrical waves

(2000 cycles) which are proportional in intensity to the blackness of the characters and proportional in time duration to the length of the particular black character scanned by the small spot of light on its journey from left to right on its narrow path of 1/100″ across the paper.

Synchronizing

Since even such small type as 6 or 8 point is from .040 to .060″ in height, it is readily apparent that the small light spot from the scanner will have to make from four to six journeys from left to right to complete one line of type. In a like manner in the Reado printer the small stylus which travels from left to right across the recording paper is only 1/100″ in diameter, and therefore must make the same number of journeys from left to right to print the same line of type. It is apparent, therefore, that both the spot of light and the recording stylus must move across the paper in perfect synchronism, if the characters are to be built up as they appear in the original copy.

Various systems of synchronism have been used in facsimile. One of the simplest systems makes use of the fact that two synchronous motors running on the same power line will run exactly at the same speed, and therefore if both are started at the same instant, will remain together. However, if the scanner and printer are on separate power lines, serious distortion occurs since one or the other may be going faster or slower. In the Reado system, the printer is geared to run 2% faster than the scanner. It will, therefore, complete one journey from left to right and back from right to left in a shorter time than will the scanner. The stylus arm is then held over at the left side of the copy by slipping a clutch between the motor and the stylus arm. This clutch is released by a small pulse of 500 cycles which is set up by the scanner just before it starts on the journey from left to right across the copy, thereby insuring that both the small spot of light and the stylus needle start on their journey in perfect synchronism. It is perfectly true since the recording stylus travels 2% faster than the small spot of light, it will arrive at the right side of the copy sooner than the spot of light, but this difference in speed is constant and so slight that no distortion is noticed.

This, of course, means that the Reado printer will receive perfect transmission regardless of its power source and makes possible the transmission of facsimile from a phonograph record, as the records have not only the small electrical impulses represented by the black and white characters but also the small pulse of 500 cycles which releases the clutch in the receiver impressed upon them.

The simplicity of the Crosley Reado printer is due primarily to the ability of the Reado paper to turn black or some shade of gray as the small current emanating from the stylus point passes through this paper. This does away with expensive types of ink, chemically treated paper which must be used in a slightly moist condition, or carbon paper pressure recording systems. This white-coated electro-sensitive paper is a development of the Crosley laboratories. It is capable of reproducing some five or six shades of half-tone as well as sharp definite characters which, of course, is necessary in handling small type size.

The paper feeds through the machine at the rate of 1/100 inch per second, which means that three feet of copy should be received during an hour broadcast from stations using the Finch system of facsimile.

Two small coils are mounted on the left side of the printer which actuate the small pawl to release the clutch, which makes possible the synchronization of the printer and scanner at the beginning of each stroke.

SERVICING BY SIGNAL TRACING

This business of radio servicing has been in existence now for a good many years and the one subject that is of primary importance to every man actively connected with it is how a defective receiver should be tested or inspected in order that the fault may be found accurately, quickly, and easily, because unless the test be conducted so that these conditions are met, the chances are good that the serviceman will not show a reasonable profit on any one particular job.

Ream after ream of paper has been covered describing all manner of test procedures—some good—some fair—and others decidedly not so good. There have been advocates of one system or another and they apparently find one suited to their needs for they have built up a successful business. Yet when each and every one of these systems of testing be analyzed—taken apart to see upon what it is based, it will be found that there are almost as many bases as there are systems. Now to our way of thinking—and we feel sure that you will agree with our premise—there is just one way to test any machine or system—no matter what its variations may be—and that is to decide what is the essential factor that is responsible for the functioning of the system; then when that has been determined, to investigate its behavior as it progresses through the system and performs useful work. All too often this thought of the power itself is sidetracked and because of some reason, a multitude of minor procedures come into practice that check the *parts* of the system but not the fundamental or driving force itself.

For example, when a steam generating plant is tested, upon what are the observations made? The live steam itself—the moving force that performs work. If you were to look in at such a test, you would find the engineers reading gauges and thermometers, watching flow meters—inspecting the condition of the steam as it progresses through the system . . . watching the force itself, as it were. True, you would find men taking the temperature of the fire with a pyrometer—checks being made on the gases going up the flue with a CO_2 analyzer—records made of the amounts of the coal and water being consumed—but these are only to calculate the overall efficiency of the installation—it is the steam itself that is the important factor.

Now apply this same line of reasoning to the testing of a radio receiver—*any* receiver, mind you—old or new or yet to be designed—a-c or d-c operated—trf or superhet. . . . Just what is the one essential factor upon which the functioning of every radio receiver ever built or ever to be built, is based? What is this common denominator of all receiving systems—the fundamental—the elemental? It is the signal itself.

What is it that is superimposed upon the carrier wave? The signal. What is it that every condenser, resistor, transformer, tube or any other part in a receiver works on? The signal. When you are called into a customer's home, you are wanted because the receiver is not functioning as it should and the *signal* has been affected in some way or other. Perhaps it has become distorted—perhaps hum is superimposed upon it—maybe there is a reduction in the sensitivity or a loss of control or maybe no signal at all. . . . Any way you approach it, the signal, and the signal alone, is the all-important factor. And this is what you as a serviceman must restore to its normal state. . . . No matter *how* you do it, it is your job to fix the trouble as easily and as quickly as you can.

Diagnosis All-Important

But before the signal can be brought back to normality, the condition or conditions causing the trouble—and they may be external as well as in the set itself, although the chances are that they will be the latter—must be discovered. And that brings us back to our starting point: the testing of the receiver—the diagnosis of the condition that is affecting the signal. You know as well as we do that it is the ability of a serviceman to diagnose trouble that makes him valuable to his business. . . . The locating of the fault is 90% of the whole job of bringing back the signal and if the time to do this great percentage can be reduced, even a few minutes, then that will automatically make for increased profits.

And that is what we have been striving to do and it is our belief that we have found a way that you can localize the faulty condition in a receiver more quickly and more efficiently than it has been possible to do heretofore.

First of all, if one method of finding out what is causing the signal's abnormality could be equally well applied to *any* type of receiver, matters would be simplified enormously. Furthermore, if this method could be applied to any *new* receiver as well as those now on the market, then it would be unnecessary to clutter up your mind with a thousand and one details. Now taking the premise that in every radio receiver essentially the identical things happen to the signal, a good start towards universality has been made.

In general terms the signal in every receiver is detected, amplified at audio frequencies, and then the electrical energy is delivered to the actuating mechanism of a loud speaker. If the signal be amplified at radio frequencies before detection that still does not spoil the picture . . . it is just an additional step—just as the introduction of avc or afc would be. . . . Also if a locally generated current be mixed with the signal before it is detected that is just one more step that does not detract from the main idea. Think in generalities and you will find nothing complicated. If you will look into the future a bit, you will see that unless the whole system of broadcasting be entirely changed—and there is little chance of that coming to pass—receivers of the future will have exactly the same features as those of today . . . perhaps a few refinements and embellishments, but nothing to affect the main idea. It is just like the automobile industry: new models are introduced annually with knee action, improved brakes, balloon tires and what have you, but still the same old fundamentals are there—you have a motor in which the expanding gases push a piston down and that mechanical energy makes the rear wheels revolve.

Signal Tracing

Granting that all receivers are alike fundamentally in their action on the signal, some way had to be found whereby the signal could be inspected from the instant it enters the receiver at the antenna until it arrives at the output. Moreover if some practical way of doing this existed, it would make possible the locating of the point at which the signal departed from normal . . . where it became distorted . . . where it weakened or where something else happened to it. Yet no matter how desirable such a procedure might prove to be, with the equipment available to the serviceman such a method was out of the question. Therefore, in order to employ this signal-checking procedure, which we consider to be universally practical, it was first necessary to develop some apparatus that would give the information required under actual operating conditions and without influencing the signal in its passage through the receiver. Moreover, theoretical analysis of the problem showed that if such apparatus could be developed, it would not only localize the fault in some particular circuit, but it would also go a long way in tracking down the part that caused the signal to depart from its normal condition.

Accessibility of Parts

We then turned our attention to the physical side of the receivers themselves. Granting the signal-tracing system of testing to be the best, would it be possible to get at the different points in the sets where connections would have to be made and what effect would such connections have not only on the readings but on the operation of the receiver? Schematics of all kinds were examined as well as the chassis of a large number of existing receivers. . . . Design engineers were consulted concerning the electrical and physical trends in the sets to come; what would be the result if the ideas of today were incorporated in the sets of tomorrow? All our findings were encouraging; the further we went, the firmer were our convictions that we were on the right track. As far as we were able to discover the parts in the new receivers were to be as accessible as possible in order to assure simple and economical maintenance. And it goes without saying that if the parts are easily reached, then the paths along which the signal flows will also be accessible. Furthermore, as our method offered no interference with the receiver's operation, the complex interlocked circuits would not offer any problem in respect to its application.

The problem was also considered from the point of view of the servicemen's technical capabilities in relation to the new design of receivers. It was clear that a new attack—a new method of approach was in order so that the trouble in a receiver could be diagnosed systematically, efficiently, and quickly. As our readers will admit, although receiver design has advanced with gigantic strides in the last few years, the serviceman's methods of trouble localization might well be described as belonging to the Stone Age. It has been conceded that some new method must be devised if the service industry is going to survive by mastering the problems presented by the new receivers. We wish that you would think back over the last few months' work and remember the number of conditions that you were unable to check in late receivers or the number of things you had to assume—mainly because it was impossible for one reason or another to check them.

Three Essentials

With all these facts marshalled before us, we arrived at the conclusion that this signal-tracing method of testing required three major items in order to be effective; it must have universal application, positive identification, and speedy operation. In no one of the methods in use up to the present time are these three factors incorporated and you can readily see that they are necessary for rapid and accurate work. Although the signal is really the basis of the system, yet its tracing through the receiver is the primary, but not the only test. It is supplemented by a voltage test which although secondary, plays an important part. The primary test locates the trouble in some certain portion of the receiver—sometimes the exact defective part. The supplementary test identifies the defective part in many cases—but in every case furnishes the required information.

Now what must we be able to do in finding the portion of the receiver that is not functioning correctly and locating the faulty component? First we must be able to trace the passage of a signal entering the receiver through the antenna post throughout the various signal-current-carrying circuits, no matter if it be at radio frequency, intermediate frequency or audio frequency. Then the signal must be traced throughout the receiver without altering the constants of the circuits and as a consequence, impairing the operation of the receiver and so nullifying the observations. Simultaneously, the operation of the receiver oscillator also is checked. The voltage tests must be of such a kind that they will take care of the operating voltages and also the control voltages that are developed by the signal. These voltage measurements can be made simultaneously with the observation of the signal and at points common to both the signal and the voltage. The measurement of the d-c voltages must be made with reasonable accuracy with respect to the true voltage present at the point under test without changing the constants of the circuit.

It is our belief that you will agree that the different points outlined above would go far towards helping servicemen over many difficult spots, if it were possible to perform the signal-tracing tests and make the various voltage measurements. And all this *is* possible.