TELEVISION
Simplified

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PREFACE

Those of us who have followed the progress of radio have always looked to television as the logical successor to present-day "blind" or sound broadcasting. The combination of sight and sound, it was felt, contained an appeal that far surpassed anything that sound alone could offer. The enthusiastic manner in which the public has accepted television has vindicated that belief. Paralleling the demand for television is an intensified program of research, a program aimed at developing more compact, more economical sets, possessing larger viewing screens. In the brief span of four years, since the appearance of the first edition, sufficient advances have been made to necessitate *two* complete revisions.

The presentation in this third edition follows exactly the pattern established in the two previous editions. Little is assumed beyond an elementary knowledge of the operation of home sound receivers and upon this is built an understanding of the modern television set with its highly integrated synchronizing circuits. Chapter 1 presents an outline of the various units that combine to make a television system. It attempts to answer those pertinent questions which always arise when any subject is first investigated and which, if left unanswered, soon begin to interfere with the smooth accumulation of subsequent information. With each succeeding chapter, a different section of the television receiver is discussed, starting at the input end of the set and traveling along the same path as the incoming signal. The function of every part, both within its stage and within the receiver as a whole, is carefully noted.

An entire chapter (No. 12) is devoted to an explanation of frequency modulation since the audio portion of the television signal employs this type of transmission. Sufficient basic data

are given so that anyone not familiar with the subject can follow the discussions readily. A new chapter (No. 13) discusses the principles of the recently devised Intercarrier Sound Television system. The color television chapter (No. 15) has been brought up to date and covers the new CBS, RCA, and CTI systems.

The genuine test of how well knowledge has been acquired is its application to everyday problems. Chapter 14 on servicing has as one of its aims the co-ordination and application of all the facts contained in the preceding chapters. The television receiver is divided into several major sections and, from the facts previously presented, the repairing of the majority of troubles is systematically analyzed.

A set of questions is included at the end of this text for those who want to gauge their progress through the book. The questions are straightforward and are drawn wholly from the text material. They are arranged by chapter in order to permit each chapter to be utilized as a unit and to facilitate their use in schools.

No book represents the sole efforts of one person, and this volume is no exception. Grateful acknowledgment is due to the Radio Corporation of America, the Allen B. DuMont Laboratories, Inc., the Rauland Manufacturing Company, the General Electric Company, the Tele Tone Radio Corporation and the Essex Electronics Corporation, for their generous aid in furnishing illustrations and data that were essential in the preparation of the book. The author is also indebted to Melville Byron, who proofread the manuscript and offered suggestions on methods of presentation, and to George Kearse for his permission to use the antenna chart appearing in Chapter 2. Finally, there is the ever-present aid and encouragement of the author's wife, Ruth Ann, who had to forego many pleasures in order that this book might be written.

<div align="right">M. S. KIVER</div>

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CHAPTER 1

THE TELEVISION FIELD

Introduction. Television radio, the science of transmitting rapidly changing images from one place to another by means of electromagnetic waves, is rapidly becoming as important a factor in the radio industry as the present amplitude-modulated (A-M) sound receivers. The introduction of television home sets requires that the present radio serviceman must possess a good knowledge of television operating principles before any competent repair work on these receivers can be undertaken. It also requires of other technicians, men and women, associated with the construction, operation and alignment of this type of set, to become familiar with the basic operation of television sets, the amount of knowledge required dependent upon the complexity of the job at hand. Present-day television receivers are intricate, critical mechanisms, and the person with insufficient technical knowledge will rapidly find the situation hopeless.

Television receivers are housed in either large console cabinets or in the smaller table enclosures. A television receiver is shown in Fig. 1.1 which is representative of the outward appearance of commercially manufactured sets. The number of tubes vary with the elaborateness of the layout, with as few as 15 tubes or as many as 30 or more. However, although this increase in tubes may be appreciable compared to A-M sets, the number of *additional* tuning controls at the front of the receiver is kept as low as possible. One control regulates the background brightness, another permits the proper station to be obtained, while the third control adjusts the intensity of the various objects in the image itself. The latter is known as the contrast control.

In addition to the three television controls just mentioned,

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FIG. 1.1. A combination A-M, F-M, and television table model receiver.

others will be found. One is labeled "Fine Tuning." This is actually a correction control. The main tuning circuits used in television receivers are relatively fixed and the desired station is obtained either by push buttons or a selector switch. In addition to these main resonant circuits, the proper oscillator coil and condenser are likewise selected at the same time. If any change should occur in the resonant properties of these circuits and no adjustment were provided, it may readily be seen that distorted sound and optical images would be obtained at the output of the receiver. To prevent such a situation, a fine tuning control is placed on the front panel. Within limits, this permits the observer to center the entering signal so that the proper frequencies are obtained at the video and audio I.F. amplifiers. Thus, we may consider this knob as a vernier adjustment.

Among the other controls on the front panel, we find volume and sometimes tone controls. These are associated with the sound portion of the television receiver and their function is the same as in the more common A-M receiver. Thus, while the mechanism of the television radio set may be quite complex, the necessary controls are few and readily learned, even by those entirely unfamiliar with the technical aspects of radio. It will be readily appreciated that this must be so, if television is to become popular.

In the following paragraphs of this chapter, the overall operation of the present-day television system is explained, with particular emphasis on the methods used to transform light rays into equivalent electrical impulses. After that, chapter by chapter, and section by section, the receiver operating principles are presented, assuming only a rudimentary knowledge of the operation of present superheterodyne A-M receivers.

Desirable Image Characteristics. Since the image is the final product of the television system, and because everything centers about the production of this image, here is the most logical place to begin. In order for the picture to be satisfactory from the observer's point of view, the following minimum requirements should be obtainable.

1. The composition of the image should be such that none of the elements that go into its make-up is visible from ordinary viewing distances. This requires that the image have the same fine, smooth appearance that we obtain with good photographs.

2. Flicker must be totally absent. To accomplish this, it is necessary for the cathode-ray beam to sweep across the fluorescent screen in time to cause light to be emitted before the previous image has lost its effect in the observer's mind. Then the scenes follow each other in rapid succession and the action appears continuous.

3. The size of the picture should be large enough to permit comfortable viewing by several people at distances of 10 feet or more from the screen.

4. To meet the changing requirements for viewing the screen either by day or by night, an adequate amount of light must be available from the cathode-ray screen. Naturally, less would be necessary when the room illumination is low than when it is high.

5. The final consideration, contrast, is less important than any of the previous conditions, but effective range is still desirable. Contrast refers to the ratio between points of maximum to minimum brightness on the same screen. In broad daylight, for example, the contrast ratio between places in bright sunlight to shaded areas may run as high as 10,000 to 1. On fluorescent screens, however, the amount of light that can be emitted is definitely limited, and only contrast ratios of from 50 to 100 to 1 are obtainable ordinarily. These, however, prove quite satisfactory.

The foregoing requirements have been listed with only a slight explanation advanced for each. There are limitations which affect these conditions, but before any extensive discussion is undertaken, it is necessary to gain a more detailed knowledge of the overall operation of present-day television systems.

Outline of Stages of Television Transmitters and Receivers. An outline of the various stages of a television transmitter is shown in Fig. 1.2. The scene to be televised is focused onto the photosensitive plate of the camera tube by means of a lens.

At the tube, the light rays are transformed into equivalent electrical impulses. Thereafter, amplifiers and the regular amplitude-modulating sequences take place, the final television signal is formed and transmitted into the ether. To synchronize the position of the electron beam at the receiver-viewing tube
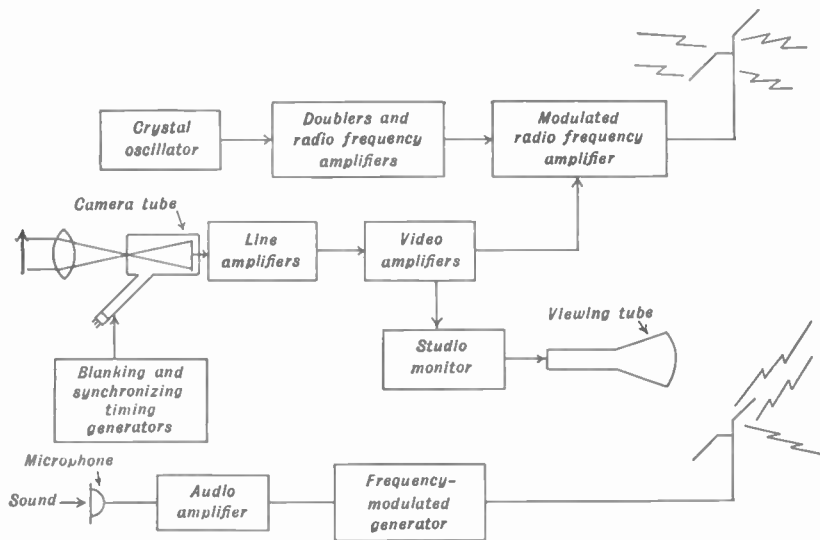

Fig. 1.2. An outline of a modern television transmitter.

with the beam in the camera tube, synchronizing pulses are inserted into the television signal as well.

We may pause for a moment and observe that, aside from the synchronizing pulses, the action in a television transmitter is entirely analogous to the corresponding action in a sound transmitter. In one, the object is to transform audio vibrations in the surrounding air to equivalent electrical variations. A microphone accomplishes this simply. In the other, light rays are changed into equivalent electrical variations and a camera tube is employed. In either case, once the currents have been formed, essentially the same procedure is followed to form the final amplitude-modulated R.F. signal. It is well to keep the correspondence between the purpose of the microphone and the

camera tube in mind, for this will aid in visualizing the overall
operation of television transmitters.

The sound that is spoken by the actors in the scene being tele-
vised is kept separate from the video electrical currents. The
sound is frequency modulated and sent out by another trans-
mitter at a frequency that lies close to the edge of the band of
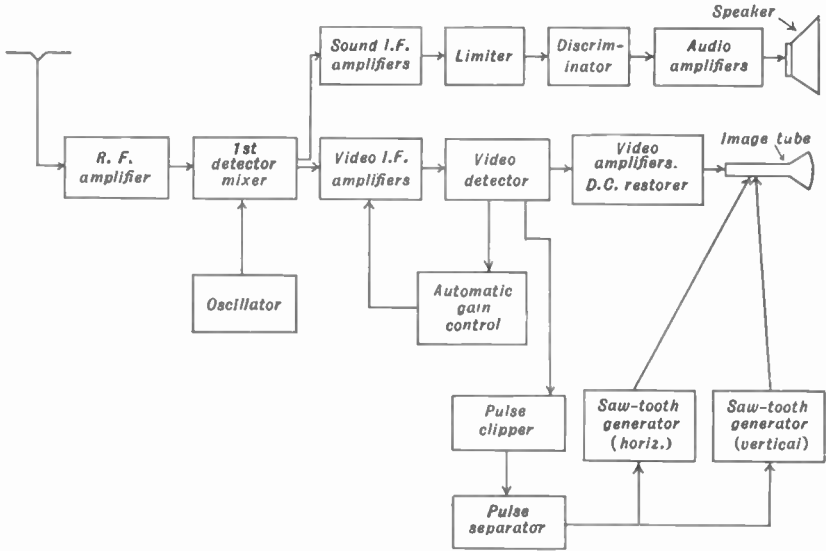
Fig. 1.3. A block diagram of the components of commercial television receivers.

frequencies utilized by the image signals. So far as the trans-
mitters are concerned, two separate units are necessary; one for
the sound, the other for the image signals.

At the receiver, shown in block form in Fig. 1.3, the video and
audio carriers are received simultaneously by wide-band ampli-
fiers. After amplification by an R.F. stage (if used), the com-
posite signal is applied to the mixer tube where it is acted on by
the high-frequency oscillator voltage. The desired I.F. values
are produced by this action and, at the output of the mixer
stage, the video and sound signals are separated and fed to their
respective I.F. amplifiers.

The audio signal is frequency modulated and, although the I.F. amplifier stages found in F-M receivers do not differ radically in construction from the corresponding amplifiers in A-M sound superheterodyne receivers (except for frequency), the detector is entirely new. In the F-M set, a discriminator is necessary in order to convert the F-M signal into the equivalent audio variations. A brief description of the operation of F-M receivers will be given in Chapter 12. Once past the discriminator, the ordinary audio stages amplify the signal until it is suitable for application to a loudspeaker.

Returning to the video signal, we find that, after separation from the audio voltage, it passes through several I.F. amplifiers (the number ranging from three to five), before the diode detector is reached. Either half-wave or full-wave rectification is employed at the detector. At some point beyond the detector, a portion of the signal is applied to the synchronizing section of the receiver. Here, the synchronizing pulses are separated from the picture detail and used to actuate oscillators that directly control the position of the electron beam in the cathode-ray tube. In this manner, the exact point where the electron beam impinges on the fluorescent screen is kept related to the electron beam in the studio camera tube. Only vertical and horizontal synchronizing pulses are required for black and white images.

The remainder of the video signal, where the detail information is contained, is amplified by the video amplifiers and then applied to the control grid of the viewing tube. The amplitude of the input voltage varies the intensity of the electron beam while the deflecting plates (or coils) are swiftly moving the beam from one side of the screen to the other. The result is an image on the screen, produced by approximately 500 distinct lines. The eye of the observer integrates these lines so that they blend into each other, and the image assumes the appearance of a photographic picture.

After the scanning beam forms an image in this manner, a second picture, a third picture and so on are formed in such rapid succession that the blending of each into the next be-

comes even and continuous, as in the movies. When the system is operating properly the viewer is not aware of each individual picture.

Television Camera Tubes. The preceding explanation is an outline of present-day television systems. With this in mind,
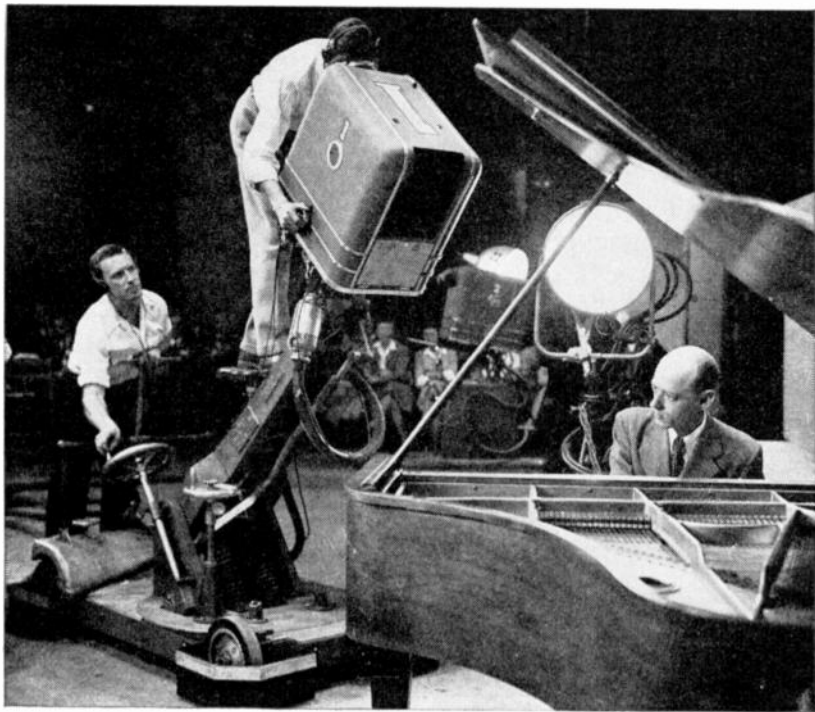
Fig. 1.4. A television studio scene developed from an ordinary negative.

let us investigate the important operation of the studio camera tube in greater detail, for it is what this tube "sees" and converts into equivalent electrical impulses that will determine the form of the final reproduced image at the receiver. Faithful reproduction of the scene being televised is essential for high quality images at the receiver.

Consider an ordinary photograph, such as shown in Fig. 1.4. This was obtained from a negative that contained a large num-

ber of grains originally sensitive to light. So long as the picture
or positive obtainable from the negative is not greatly enlarged
or examined too closely, the granular structure of the photograph
is not evident and the photograph appears smooth and con-
tinuous. However, if the picture is further and further en-
larged, a point is soon reached where the granular structure of
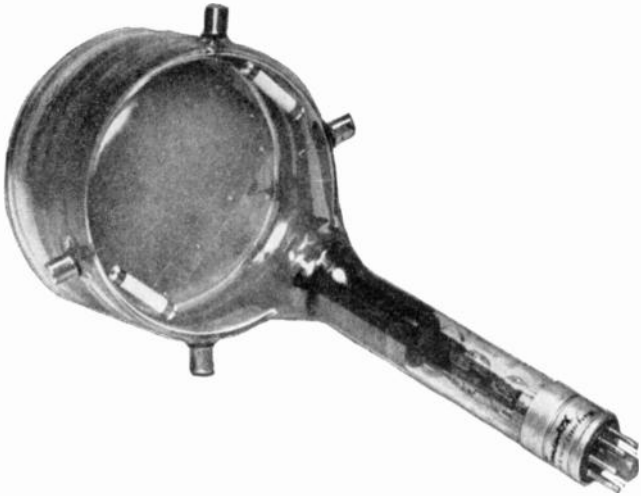
Courtesy Farnsworth

Fig. 1.5. An Iconoscope camera tube.

the picture does become visible. These grains, then, are the ele-
ments that combine to form the picture.

A fine grain photograph, in which there are many grains per
unit area, is capable of greater enlargement than a coarse grain
picture, before these elements become discernible. With tele-
vision images, much the same sort of situation prevails. In the
receiver, each picture element is just as large as the area of the
circular beam impinging on the fluorescent screen of the cathode-
ray tube. The light that is seen when observing a cathode-ray
tube screen is derived from the energy given off by the imping-
ing beam to the particles of the fluorescent coating on the inner
face of the tube. If the points of light are closely spaced, the ob-

server will integrate them and their separate character will disappear. Hence, one of the first considerations for a television picture that is to reproduce any amount of fine detail is an electron beam of small diameter. This requirement is just as important at the receiver screen as it is at the camera tube.
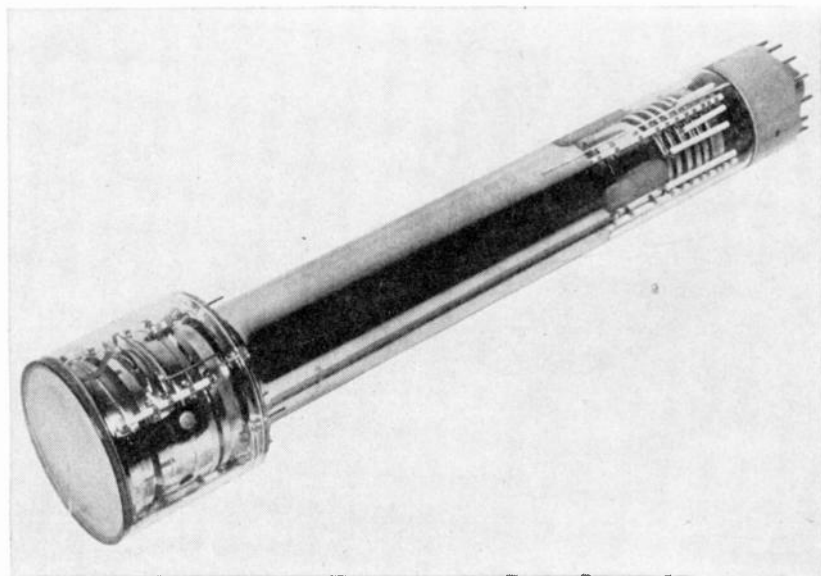
Courtesy RCA

Fig. 1.6. An Image-Orthicon Camera tube.

At present there are three types of camera tubes that are widely used in this country. They are known by the patented names of Iconoscope, Image Orthicon and Image Dissector tubes. A photograph of each is given in Figs. 1.5, 1.6, and 1.7. These tubes are commercially employed now; but, like the microphone, they are continuously being modified and revised as better and more efficient methods are evolved that permit the same scenes to be televised under poorer conditions with better results.

The Iconoscope has the internal construction shown in Fig. 1.8. Within the tube is a relatively large rectangular plate upon which all the light from the scene is focused. The plate con-

sists of a thin sheet of mica (an insulator) upon the front of which has been deposited many microscopic globules of a sensitized caesium-silver compound. Due to the manner in which the globules have been placed on the mica plate, they do not come in actual contact with each other, each tending to form its own little island. Between these separate globules, of course, is the surface of the mica. On the reverse side of the plate, a continuous layer of some conducting substance is deposited and
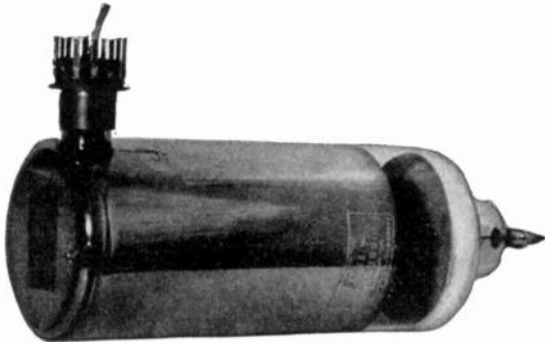
Fig. 1.7. Farnsworth Image Dissector tube.

an electrical connection is brought from here to the external circuit.

It will be recognized that actually a condenser combination is formed by the foregoing method of construction. Each globule forms one separate plate, with the back side of the mica acting as the common second plate for all the globules. The dielectric is the mica.

The object is focused on the front face of the plate (commonly called the mosaic). Due to their silver-caesium composition, the globules emit electrons in proportion to the light intensity reaching that particular point. Thus each globule assumes a different positive charge due to this loss of negative electrons, with each element retaining this charge since it is insulated from all the other elements. The mica likewise prevents the charge from leaking off to the conducting layer on its other side. Es-

Fig. 1.8. The internal construction of an Iconoscope. The neck of the tube has been purposely enlarged out of proportion to the rest of the drawing to illustrate the construction of the elements of the electron gun.

sentially, we now have a charged condenser, but the charge varies from globule to globule because of the difference in light intensity that fell on these various points.
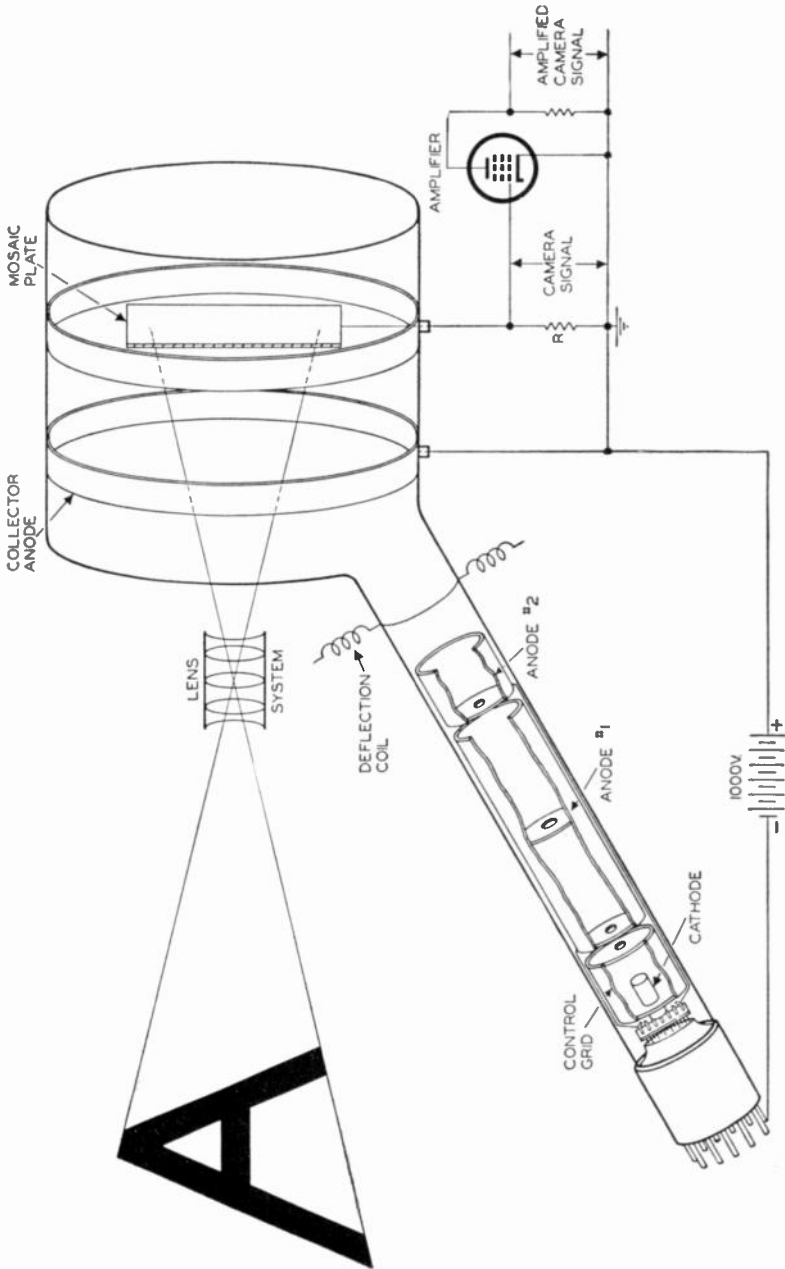
By having the amount of charge on each globule vary in proportion to the light at that globule, we have succeeded in accomplishing the first step of our process, namely, conversion of light rays into equivalent electrical charges. It remains for us to convert these charges into electrical currents.

The similarity between the above action and the corresponding photographic process of taking a picture is noteworthy. With more globules deposited on the mosaic, it should be possible to obtain a finer structure for the final reproduced image. This possibility will depend on the size of the electron beam and the scanning process used. The latter is associated with the method employed to convert the various differences in globule charge into corresponding electrical impulses. For the reproduction of fine detail, a fine grain structure is necessary, in photographic films. For the iconoscope mosaic, caesium-sensitized globules correspond to the grains on a film negative. The more globules that are deposited on the mosaic, the smaller the detail that may be distinguished. However, the number of globules, in itself, is not the only deciding factor. Important, too, is the diameter of the scanning electron beam. A large round beam covers many globules at one time, and an average current, determined by the average of the charges on all these globules, results. Any detail that is too fine will blend with the surrounding objects and become obscured. On the other hand, with a small beam it is possible to contact smaller groups of globules and cause separate electrical currents to flow for each. The finer detail will be more evident now.

Electron Beam Scanning. In order to transmit a picture, it is possible to send all the elements that compose this picture at one time, or to send each element separately in some orderly sequence. Due to the complexity of the system that would be required if an attempt is made to transmit all the elements simultaneously, the second method (sending each element

separately) has been universally adopted. Even with these alternatives, there is still a choice of scanning sequence. For example, it is possible to divide the image into a series of narrow horizontal strips and transmit each after the other, starting at
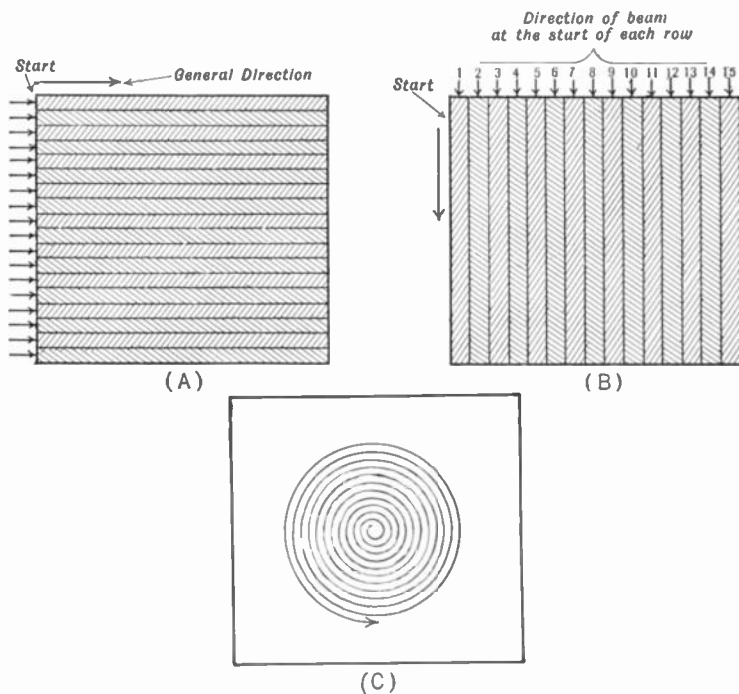
Fig. 1.9. Three possible methods of scanning an image: Horizontal scanning at (A), vertical scanning at (B) and spiral scanning at (C).

the left-hand side of the uppermost strip. Another method might dissect the image into vertical strips and transmit these in order, while a third means could employ spiral scanning. Each is illustrated in Fig. 1.9. Of practical interest, however, is horizontal scanning, since this is closest to the process currently employed in all American receivers.

At the start of the horizontal scanning process in the Iconoscope, an electron beam is formed, focused in the neck of the tube, and accelerated toward the upper left-hand corner of the

mosaic plate, point A in Fig. 1.10. There, under the influence of varying voltages applied to the Iconoscope's deflecting coils (contained on the neck of the tube), the electron beam moves to the right, passing over the charged globules that are located across the top of the image and which have been exposed to the focused rays of light from the televised scene. As each globule, or group of globules, is reached, enough electrons are supplied by the electron beam to restore the globule to its previously neutral potential.

This action automatically releases any charge on the opposite conducting surface of the mosaic that was held there by the positive globules. With the release of this charge, a small pulse of current passes through resistor R of Fig. 1.8. The strength of this current is proportional to the amount of positive globule charge neutralized, which in turn was proportional to

Fig. 1.10. The motion of the electron beam in one form of horizontal scanning.

the intensity of the light striking this point of the mosaic plate. Thus the second phase of our task has been accomplished and we have transformed light rays into equivalent electric currents. The voltage developed across R will be proportional to the varying pulses of current passing through it. Tube T will then amplify the fluctuating voltage and forward it to the stages that follow.

Returning to the scanning process, the beam will continue along the first line until the end, point B, is reached. Here a generator connected to the camera tube will cut off or blank out the beam while the deflecting coils bring it rapidly back to point C at the left-hand side of the mosaic again. This point is slightly below the first line. The blanking voltage is removed now, and again the cathode-ray beam moves toward the right, neutralizing the positively charged globules along this horizontal line and causing electrical impulses to pass through R.
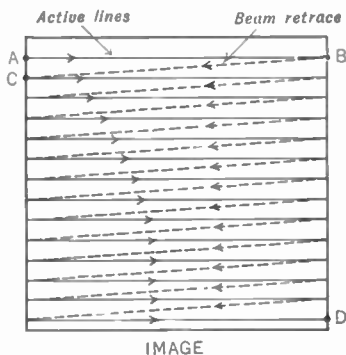
The sequence recurs until the end of the lowermost line is reached, at point D. The beam is blanked out and returned to the starting point A. The entire process is now ready for repetition. It should be noticed that each globule has been storing up a charge (or giving off electrons) during the time the electron beam is busy passing over other globules. Thus, if it takes the beam one minute to scan the entire image, during all of this time the globules are exposed to the focused light rays. The resultant emission of electrons causes the positive charge to increase. With the arrival of the beam, a neutralization takes place; but, at the next second, with the passage of the beam, the storage process begins anew. While one minute is mentioned as an arbitrary period, in practice the beam passes over each globule every $\frac{1}{30}$ of a second. Hence 30 complete pictures are sent every second.

In actual equipment, the motion of the scanning electron beam, as described above, must be modified somewhat for two reasons. First, it is extremely difficult to generate a voltage that will cause the beam to drop suddenly from the end of one line to the level of the next one directly beneath it. It is simpler to have the beam move down to the level of the second line gradually, as illustrated in Fig. 1.11.

To obtain this type of motion for the electron beam, both horizontal and vertical deflection coils in the Iconoscope tube are utilized. Without going into any extensive discussion at this time of the operation of the electron gun located in the neck of the Iconoscope, let us state simply that the horizontal deflection coils can move the electron beams horizontally across the screen from left to right and back again. The vertical deflection coils can cause the beam to move vertically. Between them, and with different amounts of currents through each set of coils, it is possible to move the electron beam across the screen to reach any desired point.

In the foregoing type of motion, with the beam moving across the screen slantwise, we have the equivalent of a fast-acting voltage on the horizontal plates quickly forcing the beam

straight across, while a slow-acting voltage at the vertical plates is forcing the beam down. The result is pictured in Fig. 1.11. When the beam reaches the end of a line, it is quickly brought
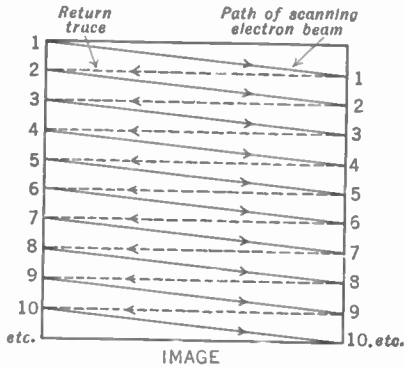

Fig. 1.11. In actual equipment, it is easier to have the electron beam travel in the manner indicated above, rather than as shown in Fig. 1.10.

almost straight across (with the blanking signals on) and thus finds itself in correct position to start scanning line 2 when the blanking voltage is removed. The remainder of the lines follow in similar fashion. At the bottom of the picture, after the last line has been scanned, a longer blanking signal is applied while the beam is returned to the top of the picture. The purpose of the blanking voltages is simply to prevent the beam from impinging on the screen when

there is nothing to impart, but is merely moving into position for the next scanning run.

Many readers will probably note at this point that possible currents that could be used for the horizontal and vertical deflecting coils are of the familiar saw-tooth form illustrated in Fig. 1.12. These rise gradually to a fixed level and then suddenly drop (almost vertically) to zero to begin the process all over again. More will be mentioned about

Fig. 1.12. A saw-tooth current, as illustrated here, when sent through a set of deflecting coils, will cause the electron beam to move slowly from left to right and then retrace rapidly from right to left.

saw-tooth wave generators when the television receiver is discussed.

It was stated that there are two reasons why the horizontal scanning process as first explained had to be modified. The first reason has already been given. For the second reason, we must

examine more closely the human eye and its action when observing motion on a screen.

Flicker. If a set of related still films follow each other fairly rapidly on a screen, the human eye is able to correlate them, and the motion appears continuous. The eye can do this because of the well-known phenomenon called persistence of vision. Due to this property of the eye, visual images do not disappear as soon as their stimulus is removed. Rather, the light appears to diminish gradually taking, on the average, about $\frac{1}{30}$ of a second before it disappears entirely. In motion pictures, this is very fortunate, for otherwise this method of entertainment would be impossible.

It has been found that when the theater films are presented at a rate of 15 stills per second, the action appears continuous. However, at this speed, a flicker is still detectable and detracts from the complete enjoyment of the film. The flicker is due to the sensation in the observer's mind reaching too low a value before the next film is presented on the screen. Increasing the rate at which the stills are presented will gradually cause the flicker to disappear. At 50 frames per second there is no trace of flicker, even under adverse conditions. The rate is not absolute, however, but depends greatly upon the brightness of the picture. With average illumination, lower frame rates prove satisfactory.

In the motion picture theater, 24 individual still films (or frames) are flashed onto the screen each second. Since at this rate, flicker is somewhat noticeable, a shutter in the projection camera breaks up the presentation of each frame into two equal periods. This is accomplished by having the shutter move across the film while it is being projected onto the screen. Thus we are actually seeing each picture twice; the fundamental rate has now been increased to an effective rate of 48 frames per second. By this ingenious method, all traces of flicker are eliminated.

In television, a fundamental rate of 30 images (or frames) per second was chosen because this frequency and the effective rate

are related to the frequency of the alternating current power lines. Practically, this choice of frame sequence rate results in less filtering in order to eliminate a-c ripple, which is called hum in audio systems. With 24 frames per second, for example, any ripple that was not eliminated by filtering would produce a weaving motion in the reproduced image. Less difficulty is encountered from a-c ripple when 30 frames per second are employed.

To eliminate all traces of flicker, an *effective* rate of 60 frames per second is employed. This is accomplished by increasing the downward travel rate of the scanning electron beam so that not every successive line, but every *other* line is sent. Then, when the bottom of the image is reached, the beam is brought back to the top of the image, and those lines that were missed in the previous scanning are now sent. Both of these operations, the odd and even line scanning, take $\frac{1}{30}$ of a second and so 30 frames is still the fundamental rate. However, all the even lines are transmitted in $\frac{1}{60}$ of a second and the same is true of the odd lines. Both add up, of course, to $\frac{1}{30}$ of a second. Hence, to the eye, which cannot separate the two, the *effective* rate is now 60 frames per second and no flicker is noticeable.

To differentiate between the actual fundamental rate and the effective rate, we say that the frame frequency is 30 cycles per second, whereas the effective rate (called the field frequency) is 60. This method of sending television images (see Fig. 1.13) is known as interlaced scanning.

Thus, as the standards for television images now stand, each complete scene is sent at a rate of 30 frames per second. In order to obtain the desired amount of detail in a scene, the picture is divided into a total of 525 horizontal lines. The technical reasons behind the choice of 525 lines are related to:

1. The frequency band width available for the transmission of the television signals. As will be shown later, the required band width increases with the number of lines.

2. The amount of detail required for a well-reproduced image.

3. The ease with which the synchronizing (and blanking) signals can be generated for the horizontal and vertical deflection plates.

With each frame divided into two parts (because of interlaced scanning), each field will have one-half of 525 lines or 262½ lines from its beginning to the start of the next field. (As a matter of definition, a complete picture is called a frame.) With interlaced
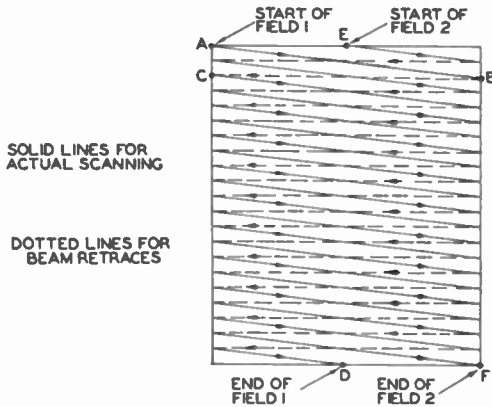
FIG. 1.13. The path of the electron beam in interlaced scanning.

scanning, each frame is broken up into an even-line field and an odd-line field. Each field contains 262½ lines whereas a frame has the full amount, or 525.

The Complete Scanning Process. From the foregoing discussion it becomes possible to reconstruct the entire scanning process. Although only the movement of the electron beam at the Iconoscope will be considered, an identical motion exists at the receiver screen.

At the start of the scanning motion at the camera tube mosaic, the electron beam is at the upper left-hand corner, point *A* of Fig. 1.13. Then, under the combined influence of the two sets of deflecting coils, the beam moves at some small angle downward to the right. When point *B* is reached, the blanking signal acts while the beam is rapidly being brought back to point *C*,

the third line as required for interlaced scanning. The blanking signal then relinquishes control and the electron beam once again begins its left-to-right motion. In this manner every odd line is scanned.

When the end of the bottom odd line has been reached (point D), the blanking signals are applied while the beam is brought up to point E. Point E is above the first odd line of field 1 by a distance equal to the thickness of one line. The beam is brought here as a result of the odd number of total lines used, namely, 525. Each field has 262½ lines from its beginning to the start of the next field and, when the beam reaches point E, it has moved through the necessary 262½ lines from its starting point A. From here the beam again starts its left-to-right motion, moving in between the previously scanned lines, as shown in Fig. 1.13. The beam continues until it reaches point F and from here is brought to point A. From point A the entire sequence repeats itself.

Thus, as matters stand, the electron beam moves back and forth across the width of the mosaic 262½ times in going from point A to point D to point E. The remaining 262½ lines needed to form the total of 525 is obtained when the beam moves from point E to point F back to point A. The process may seem complicated but actually it is carried out quite readily and accurately at the transmitter (and receiver). A more detailed analysis, including the number of horizontal lines which are lost when the vertical synchronizing pulse is active, will be given in Chapter 9.

The Image Orthicon. Of the three camera tubes mentioned previously, the Iconoscope has already been described in some detail. It is not without defects, the two most serious being its poor efficiency and its tendency to produce background shading that is not found in the original scene. The latter defect arises from the fact that the impinging scanning beam has sufficient force to dislodge secondary electrons from the surface of the globules over which it may be passing. Some of these electrons, once freed from their globules, may be attracted either to the

positive collector ring or fall back on the mosaic plate. In either case, the charge distribution of the mosaic plate has been altered from its true, original form. This distortion, for that is what it is, appears on the screen, generally, as a darkened background. Correction voltages from a so-called shading generator are inserted into the signal in an effort to eliminate the distortion. In essence, the voltages from the shading generator are 180° out of phase with the distortion voltages, and their elimination is thus effected. It may appear to the reader that almost an infinite number of shading signals would be required. Fortunately this is not so. Experience with Iconoscopes reveals that relatively simple correcting voltages are required and these are readily generated and injected into the voltage wave.

A camera tube which is claimed to be one hundred times more sensitive than the Iconoscope and the Image Dissector was recently developed by RCA engineers. The tube, shown in Fig. 1.6, is known as the Image Orthicon. The greater sensitivity of this tube gives it the following advantages:

1. The ability to televise scenes too dark to establish an acceptable image with other camera tubes.

2. A greater depth of field, permitting the inclusion of background that otherwise appears blurred or obscured on the receiver screen.

Physically, the tube looks like an elongated image projection tube, being approximately 15 inches long and 3 inches in diameter at the head. Electrically, the tube is divided into three parts: the image section, where the equivalent distribution of charge over a photosensitive surface is formed; a scanning section, consisting of the electron gun, the scanning beam and deflecting coils; and, finally, a multiplier section where, through a process of secondary emission, more current is generated than is contained in the returning beam. This action is closely akin to the electron multiplier contained in the Farnsworth Image Dissector. Fig. 1.14 illustrates these three sections of the Image Orthicon.

In operation, light rays from the scene to be televised are

focused by an optical lens system onto a transparent photo-
sensitive plate. At the inner surface of this plate, electrons are
emitted from each point in proportion to the incident light in-
tensity. Note that the light rays must penetrate the transparent
plate to reach the photosensitive inner surface.

The emitted electron image (in which at each point, the den-
sity of the electrons corresponds to the light at that point) is
drawn to the target by a positive wall coating. At the target,
the arriving electrons produce secondary emission and thus de-
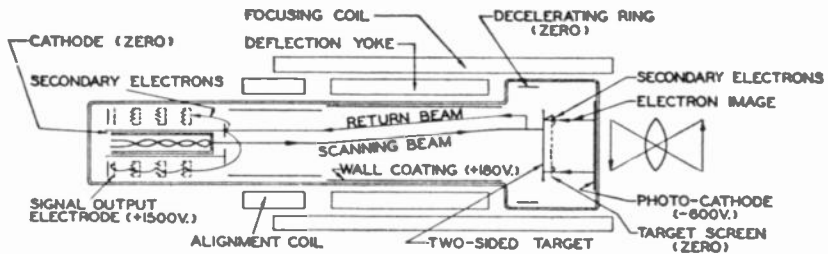
Fig. 1.14. The internal construction of the Image Orthicon.

velop a pattern of positive charges directly proportional to the
distribution of energy in the arriving electron image. The target
is not photosensitive, but is capable of emitting secondary elec-
trons.

Note that by this method of forming a charge distribution on
the target plate, we obtain a more intense degree of positive
charge distribution than if the light rays themselves had been
the activating agent, as in the Iconoscope.

The back of the target plate is scanned by a low-velocity elec-
tron beam. This beam is slowed down just short of the plate,
and at each point gives up sufficient electrons to neutralize the
positive charge at that point. The remainder of the electrons in
the beam then return to an electron multiplier arrangement
where several electrons are produced for each impinging electron.
The result—at the output—is a current amplified many times
over the current in the return beam.

It is evident that the most positive points on the plate return

the least number of electrons from the original scanning beam. Hence, the voltage developed across the output load resistor is inversely proportional to the positive charge intensity on the target. As we shall see presently, this corresponds to negative phase polarity in the signal.

In order to function effectively, the two-sided target must be able to conduct electrons between its two surfaces but not along either surface. The logic of this is evident. Whatever charge appears on the one side of the target due to the focused image must likewise appear on the other side. It is this second side which is scanned and it is from here that the video signal is obtained. Hence, a conducting path must exist between the front and back sides. On the other hand, nothing must disturb the relative potential that exists throughout the charge pattern, as deposited on the front side of the target. Hence, no conduction is permissible between the various elements of any one side of the target plate. Where this occurs, the charge differences between the various points on the image disappear.

The two-sided target used in the Image Orthicon consists of a thin sheet of low-resisting glass. The resistivity between the front and back sides is sufficiently low so that if we were to place opposite charges on the sides, complete neutralization (by conduction) would occur in less than $\frac{1}{30}$ of a second. In this way, we prevent one frame from affecting the next frame, an effect which is known as "hangover."

The thin sheet of glass is about $1\frac{1}{2}$ inches in diameter. It is placed about two thousandths of an inch from a flat fine-mesh screen. The purpose of this fine-mesh screen is to collect secondary electrons that are knocked off the target when the photoelectrons impinge upon it. In order not to interfere with the oncoming photoelectrons, the mesh contains 500 to 1,000 meshes per linear inch, an open area of 50 to 75 per cent and a considerable accuracy of spacing.

The Image Dissector Camera Tube. The Iconoscope and Image Orthicon come under the heading of storage type camera tubes because the globules of the mosaic have the property of

increasing their charge during the time that the electron scanning beam is acting elsewhere on the plate. In this way, each picture element, by the time it is scanned, possesses a greater charge than if it did not have the property of storage.

P. T. Farnsworth developed a camera tube that may be considered as an instantaneous scanner because storage of energy is not involved. The tube, shown in Fig. 1.7, consists of a flat
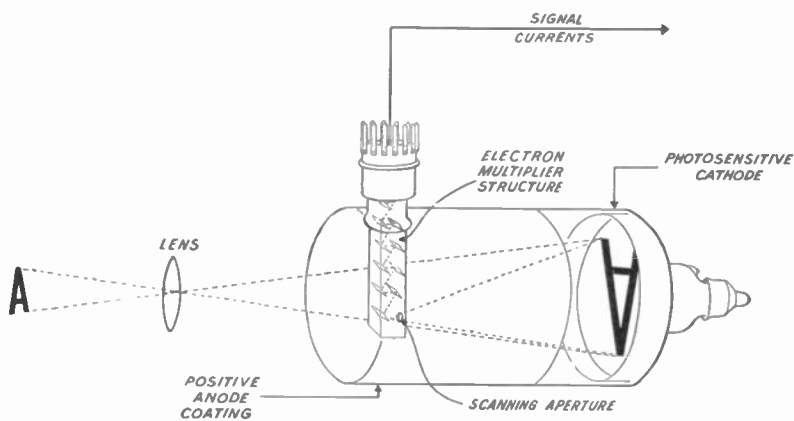
Courtesy Farnsworth Radio

FIG. 1.15. An internal view of an Image Dissector tube.

photosensitive cathode located at one end of the tube. The scene to be televised is focused on this cathode by means of a lens system located outside the opposite end of the tube. When the light reaches the cathode, electrons are omitted in proportion to the amount of light striking any one point. Thus the electron distribution leaving the cathode is equivalent to the distribution of light focused by the lens.

The electron cloud is forced to move down the tube by high positive voltages applied to attracting electrodes situated at the other end of the tube. A scanning aperture (see Fig. 1.15) is also located at the other end of the tube, but its position is fixed. Here, deflecting coils move the electron cloud past the aperture and each electron, as it is swung in front of the opening, enters

because of its forward motion. Notice that in this tube, the electron cloud or electron image is moved while the scanning device is stationary. In the Iconoscope, the opposite was true. As in the Iconoscope, however, the image is scanned by horizontal lines, 525 in all.

After the electrons enter the scanning aperture in turn, they hit specially constructed plates that have the property of emitting a number of electrons for each one that impinges on them from the electron cloud. These extra, or secondary, electrons thus emitted are accelerated to another plate which also gives off more electrons than strike it. The process is repeated approximately eleven times and a fairly large current is obtained at the output. A structure of this type is known as an electron multiplier; some idea of its internal structure may be gained from Fig. 1.15.

If the reader is puzzled as to what happens to the electrons in the electron cloud or image that are not, at any particular moment, being scanned, it may be stated that they are attracted to the anode coating located on the side walls. The image is not destroyed because electrons in a steady stream are continually being given off by the photocathode. Thus there is always an electron image present and the scanning aperture always has electrons surging in. The electrons all eventually get back to the photocathode by either of two routes. One is from the anode coating on the side walls; the other is through the scanning aperture, down the electron multiplier structure, through the load resistor and back to the cathode.

To move the electron cloud past the scanning aperture, horizontal and vertical deflecting coils are employed. Currents from timing generators control the fields set up by these deflecting coils and the entire electron image is moved back and forth and scanned. With sufficient light from the scene being televised, pictures of good quality are obtainable. The Image Dissector is employed extensively in equipment manufactured by the Farnsworth Corporation.

All camera tubes are housed in large rectangular cases, then

placed on dollies to allow the entire assembly to be moved from
one position to another quickly and quietly. The necessity for
employing the relatively large cases is due to the extremely small
video currents generated in the camera tubes, even under the
most favorable conditions. If these tiny currents were sent into
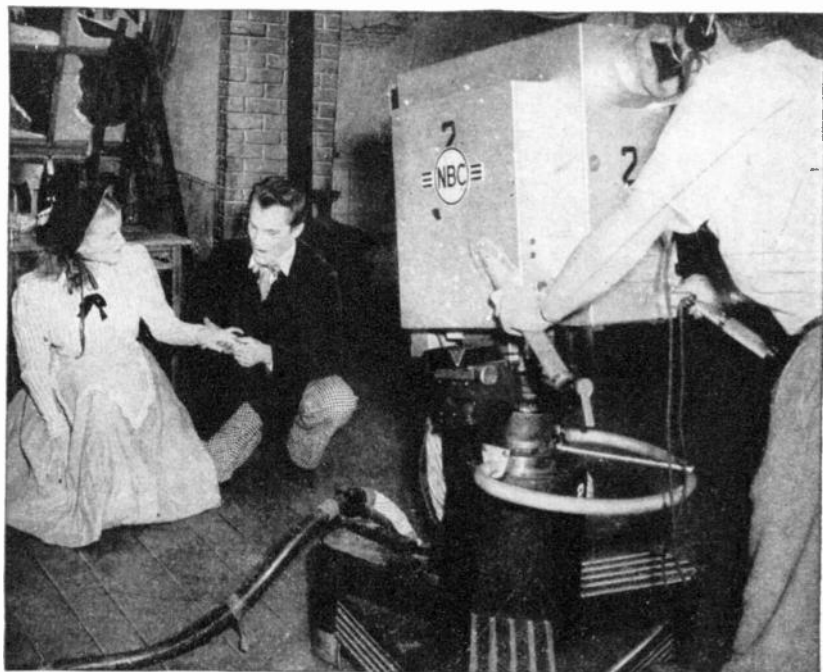
Courtesy NBC

Fig. 1.16   A television studio camera in action.

the long connecting coaxial cables, they would be too small to
override the inherent noise in the system by the time the trans-
mitter was reached. To overcome this, several amplifiers are
built into the camera assembly along with the camera tube.
Consequently, the small video currents are amplified immedi-
ately and then sent into the connecting transmission line.

Figs. 1.16 and 1.17 illustrate two examples of present-day tele-
vision cameras. The first camera is for regular studio use; the
second is designed for outdoor, on-the-spot programs.

Blanking and Synchronizing Signals. The cathode-ray beam at the receiver must follow the transmitter action at every point.
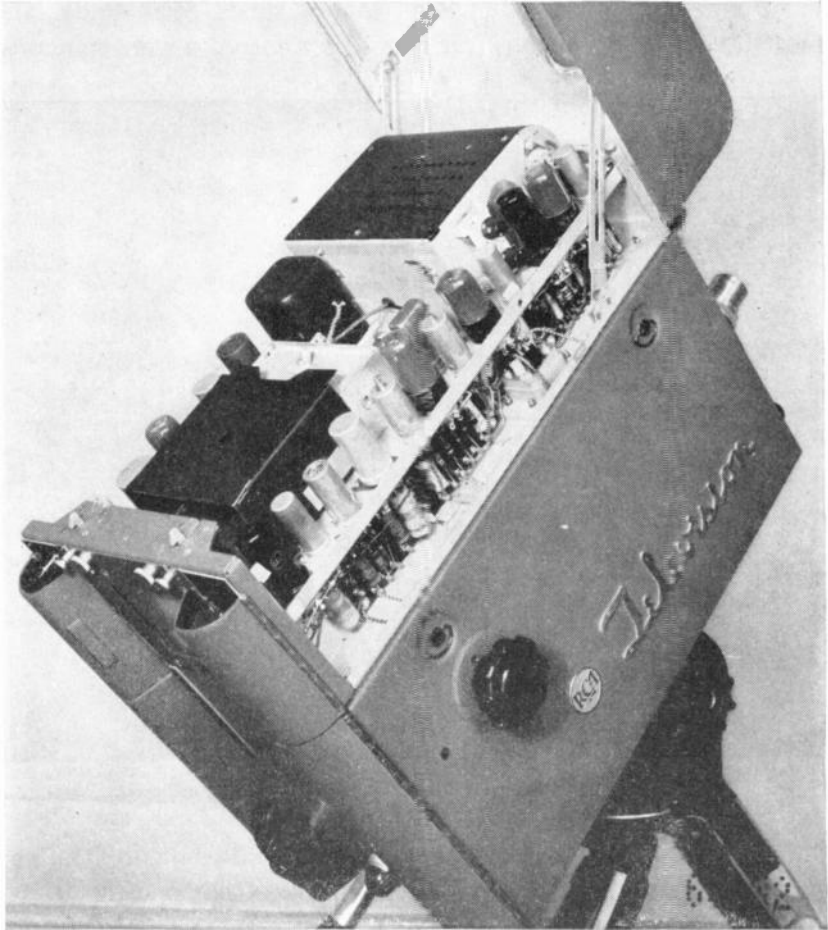
Fig. 1.17. Inside view of a Portable Image Orthicon Camera.

For example, each time the camera-tube beam is blanked out, the same process must occur at the receiver and in the proper place. It is for this purpose that blanking signals are sent along with the video signals, those that contain the image details.

These blanking pulses, when applied to the control grid of a cathode-ray tube, bias it to a large negative value, sufficient to prevent any electrons from passing through the grid and on to the fluorescent screen.

Blanking voltages, while preventing the electron beam from impinging on the fluorescent screen during retrace periods, do not cause the movement of the beam from the right- to the left-hand side of the screen, or from bottom to top. For this,
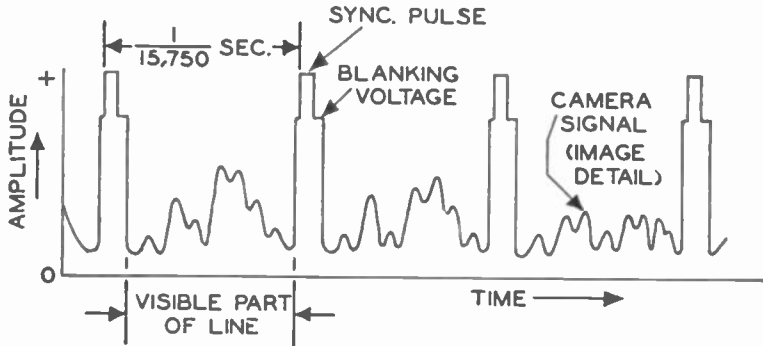
Fig. 1.18. The complete video signal for three scanned lines.

another set of pulses, superimposed over the blanking signals, control oscillators at the receiver and these, in turn, control the position of the beam. The pulses are called synchronizing pulses. A horizontal pulse at the end of each line causes the beam to be brought back to the left-hand side, in position for the next line. Vertical pulses, at the end of each field, are responsible for bringing the beam back to the top of the image.

The Video Signal. In order to see how the picture detail, blanking signals and synchronizing impulses are all combined to form the complete video signal, refer to Fig. 1.18. Here three complete lines have been scanned. At the end of each line the blanking signal is imposed on the beam and automatically prevents the electron beam from reaching the mosaic at the Iconoscope or fluorescent screen at the receiver. With the blanking signal on, a synchronizing impulse is sent to cause (in this in-

stance) the horizontal deflection plates to move the position of
the electron beam from the right side of the picture to the left.
This accomplished, the synchronizing impulse's job is completed
and a fraction of a second later the blanking control releases its
negative bias on the control grid of the cathode-ray tube and
the electron beam starts scanning again.   The process continues
until all the lines (odd or even) in one field have been scanned.
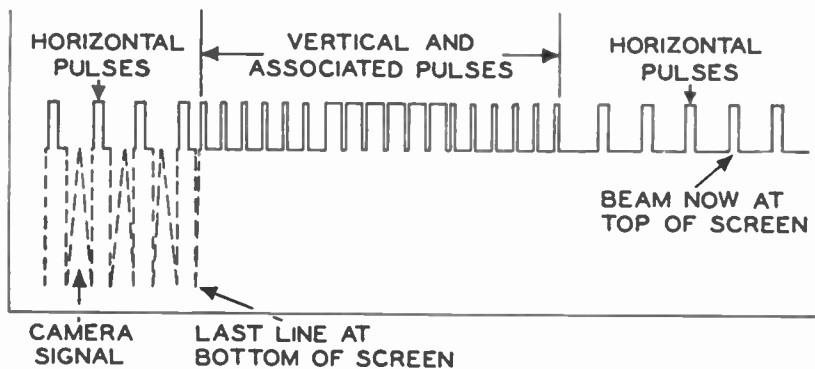
FIG. 1.19. The form of the vertical synchronizing pulses.

The vertical motion ceases at the bottom of the field and it is
necessary to bring the beam quickly to the top of the image so
that the next field may be traced.   Since the vertical triggering
pulse and retrace require a longer period of time than the hori-
zontal triggering and retrace, a longer blanking signal is inserted.
As soon as the blanking signal takes hold, the vertical synchro-
nizing pulse is sent.   The form that this takes is given in Fig.
1.19.   Because the horizontal synchronizing pulses must not be
interrupted, even while the vertical deflecting plates are bringing
the electron beam to the top of the field, the long vertical pulse
is broken into appropriate intervals.   In this manner it is pos-
sible to send both horizontal and vertical pulses at the same
time, each being accurately separated at the receiver and trans-
ferred to the proper deflection plates.   Greater detail is given
on this point in Chapter 9.   The term used for the series of

synchronizing pulses that combine to make up the total vertical signal is "serrated vertical impulses." This type of wave form has been established as standard in the United States.

Under the action of the vertical deflecting plates the beam is brought to either point A or E (refer to Fig. 1.13) and then the usual camera action starts anew.

Negative and Positive Video Polarity. A closer inspection of a video signal, Fig. 1.20, reveals that of the total (100%) am-
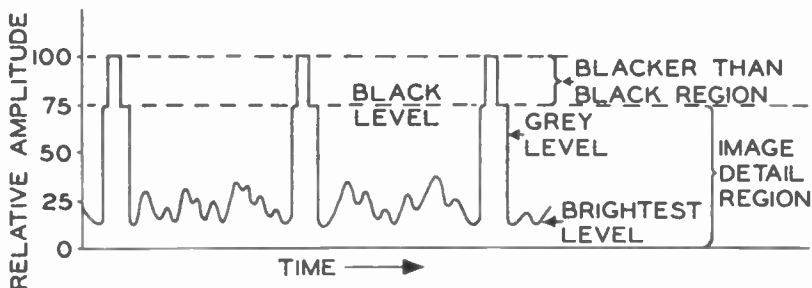
FIG. 1.20. The various proportions of a video signal.

plitude available, 75 to 80 per cent is set aside for the camera signal variations. At the level where the camera signal ceases, the blanking voltage is inserted. The remaining 20 to 25 per cent of the amplitude is reserved for the horizontal or vertical synchronizing pulses. It will be noticed that, no matter where the camera signal happens to end, the blanking level (and the synchronizing pulses) always reaches the same amplitude. This is done purposely at the transmitter, and several operations in the television receiver depend upon this fact. It must be remembered, however, that this does not necessarily have to be, but is specifically accomplished because of resulting simplicity at the receiver.

Fig. 1.20 illustrates the form of the video signal as it is used in the United States. From the relative polarity marked on the side (or vertical) scale, it is seen that the brightest portions of the camera signal cause the least amount of current to flow, or the voltage has the least amplitude. This is exactly opposite

to the action at the Iconoscope as explained previously in the chapter. The signal voltage (or current) values have been completely reversed. The blanking voltage, which should be more negative than any portion of the camera signal, is actually more positive. And the synchronizing pulses give the largest voltage and current of all.

Transmitting the signal in this form is known as negative picture transmission, and the picture is said to be in the negative
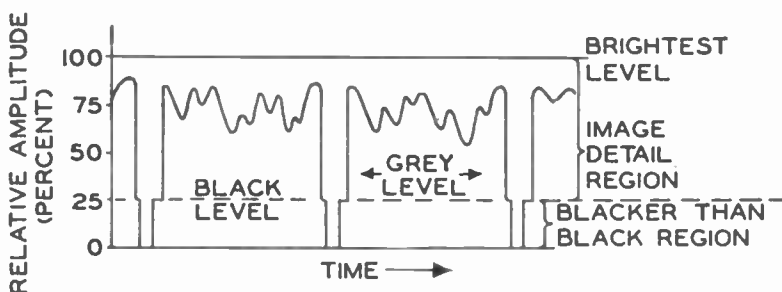
FIG. 1.21. The form of the video signal in positive transmission.

picture phase. If the video signal were reversed so that it assumed the form of Fig. 1.21, it would be called the positive picture phase and, if transmitted, would be known as positive transmission. In the United States, negative R.F. transmission is employed, although in England the other form is preferred. It is claimed here that less interference is visible on the viewing screen with negative transmission, and better all-around reception is obtained under adverse conditions. Be that as it may, one standard has been decided upon, and all receivers must be constructed to receive this signal. If a receiver designed for negative picture phase signals receives a positive picture phase signal, all the image light values are reversed on the viewing screen. The bright portions would appear dark and vice versa. The result would be similar to a photographic negative, in which the values are likewise reversed.

In the receiver, before the video signal is applied to the control grid of the cathode-ray tube, the signal must be transferred into

the proper or positive picture phase. The grid of the cathode-ray tube is then biased by enough negative voltage so that, whenever the blanking voltage section of the signal does act at the grid, the electron beam is automatically prevented from reaching the fluorescent screen. With the positive picture phase, the camera signal voltages are all more positive than the blanking pulse and, on these portions of the video signal, the electron beam is permitted to impinge on the screen with varying amounts of electrons. A bright spot in the received image causes the grid to become more positive than when the voltage of a darker spot is applied. More electrons in the beam mean more light emitted at the screen, and the various shades and light gradations of the image are formed by different voltages.

The purpose of the blanking voltage in the video signal is to prevent the electron beam from reaching the fluorescent screen. This is well known by now. The point in the video wave where the blanking signal is located occurs in the region where the currents corresponding to the very dark portions of the image are found. By the time the blanking voltage acts at the control grid of the viewing tube, the beam is entirely cut off and nothing appears on the screen. The blanking level could then properly be called the black region, because nothing darker appears on the fluorescent screen. By nothing darker, we mean no light at all.

Now, consider, the video signal of Fig. 1.21. With the blanking level we find the synchronizing pulses. When applied to the viewing tube control grid along with the rest of the wave, the pulses drive the grid to a negative voltage even greater than cut-off. The pulse region, for this reason, is labeled as blacker than black, because the position of the blanking signal has been called black. The unwanted synchronizing pulses that ride through the video amplifiers with the necessary video signal need not be removed because they do not interfere, in any way, with the action of the control grid at the cathode-ray tube. As will be shown presently the complete video wave is applied, after the detector, to the synchronizing and video amplifier circuits

simultaneously. The synchronizing clipper tube permits merely the pulses to pass through, whereas the video amplifiers allow the entire signal to pass.

Why Television Requires Wide Frequency Bands. In dealing with television receivers, it will be found that extensive use is made of wide-band amplifiers designed to receive signals extending over a band width of 6 megacycles (mc). The different forms these amplifiers may assume and their characteristics are discussed in later chapters; however, the reason for the extremely wide band width may be appreciated now.

In the foregoing paragraphs on television images, it was brought out that the more elements in a picture, the finer the detail that could be portrayed. The picture could also stand closer inspection before it lost its smooth, continuous appearance. Each thirtieth of a second, 525 lines are scanned, or a total of 15,750 lines in one complete second. If each horizontal line contains 700 separate elements, then $15,750 \times 700$ or 11,025,000 elements or electrical impulses are transmitted each second. In order to attain full advantage of the use of this number of elements, it is first necessary to determine what relationship exists between the two quantities, number of elements and band width.

Consider, for example, that the mosaic plate in the Iconoscope is broken up into a series of black and white dots, each dot representing one element. The resulting pattern is shown in Fig. 1.22A. As the scanning beam passes over each element in turn, a pulse of current flows every time a white dot is reached, for this element has a large deficiency of electrons. At the next element, the current drops to zero, for theoretically a black dot represents an element that has received no light at all and hence requires no additional replacement of electrons. In one complete horizontal line, the electric pulses of current would have the shape shown in Fig. 1.22B.

If we combine one maximum point in the wave with its succeeding minimum point, we obtain one complete cycle. The same situation prevails in any sine wave. (See Fig. 1.22C.)

Since each white dot represents a maximum point and each black dot a minimum point, then by taking the total number of white and black dots on a line, and dividing their sum by 2, we
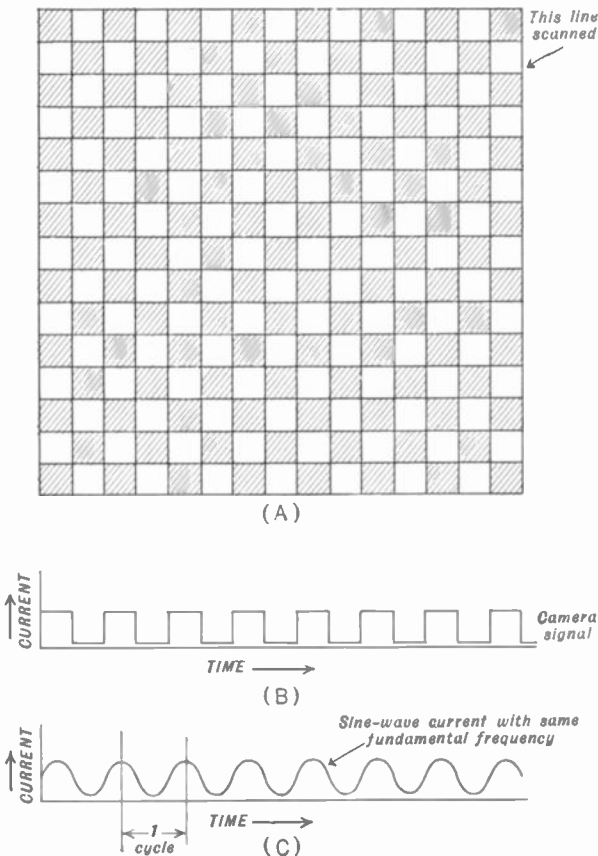

FIG. 1.22. The basic relationship between the number of elements in an image and the width of the frequency band required.

obtain the number of cycles the current goes through when one horizontal line is scanned. With 700 elements (dots, in this case) on a line, a fundamental frequency of 350 cycles is generated.

Under present standards, 525 lines are scanned in $\frac{1}{30}$ of a

second, or a total of 15,750 in one second. Employing 700 elements per line, 11,025,000 picture elements are sent each second. This, from our analysis, results in a frequency of $\dfrac{11,025,000}{2}$ cycles per second or 5.51 mc. In actual practice, a band width of 4 mc is allowed. Thus, for the video section alone, this extremely large band width must be passed by all the tuned circuits of the television receiver.

The above situation would seldom, if ever, be found in practice. However, the figures obtained by this reasoning yield results that have been found satisfactory and so the method, from this viewpoint, is justified.

While 4 mc are required to accommodate the video information alone, the band width set in practice is 6 mc. Of the extra 2 mc, the F-M audio carrier uses 50 kilocycles (kc). Apparently considerable band width is not utilized. The reason for the extra space is found in the process whereby the television video carrier is generated.

On ordinary broadcast frequencies, it is common knowledge that most stations occupy a 10-kc band width, or ± 5 kc about the carrier position. Thus, if a station is assigned to the frequency of 700 kc, it transmits a signal that occupies just as much frequency space on one side of 700 kc as on the other. Under existing F.C.C. regulations, the maximum deviation is 5 kc (or 5,000 cycles) on either side of the carrier position of 700 kc. In radio language, we say that these side frequencies are side bands and, for the present illustration, each side band may have a maximum deviation of 5 kc about the mean or carrier position. The information of the signal is contained in the side bands, since they are not generated until speech or music (or other sounds) are projected into the microphone. At the receiver, the variations in the side bands are transformed into audible sounds and heard by the radio listener.

It can be shown that those side bands that are generated having frequencies higher than the carrier frequency contain the

same information as the side bands with frequencies lower than the carrier. In other words, if we eliminated one set of side bands (either above or below the carrier), we could still obtain all the necessary information at our receiver. The only reason one side band is not eliminated is due to purely economical reasons. A transmitter naturally generates both side bands and it is cheaper to transmit both rather than try to eliminate one by expensive and complicated filters. But, if it were desired, it could be done.

Now, let us turn our attention to the video signal. It is generated by fundamentally the same type of apparatus that is employed at the sound broadcast frequencies. Since 4 mc are needed for the picture detail, a signal would be generated that extended for 8 mc, or ±4 mc about the carrier. And this does not include the sound. An 8-mc band is undesirable because of the ether space occupied and the difficulties inherent in transmitting a signal of this band width. Hence, the necessity arises for removing one side band, since only one is required.

The undesired side band is removed by filters that follow the last amplifier of the television transmitter. But filters are not easily constructed that will sharply cut off one side band completely and leave only the desired one. Furthermore, in the process of elimination, nothing must occur that would change the amplitude or phase of any of the components in the desired side band. As a compromise arrangement, most, but not all, of one side band is removed and in this way the remaining side band is least affected by the filtering. Thus part of the 2 mc (of the total 6-mc band width) is occupied by what may be called the remnants of the undesired side band. This method is known as "quasi-single-side band" or "vestigial-side band" operation.

In Fig. 1.23A is the television video signal as it appears with both side bands present, and Fig. 1.23B shows it as it appears after passage through filters that partially remove one side band. The carriers frequency is found 1.25 mc above the low-frequency edge of the television signal. Then for 4 mc above this, we have the television video signal with the desired picture information.

This is all indicated in Fig. 1.23. A 0.5-mc band width separates
the high-frequency edge of the video signal and the F-M carrier.
The space is left for the purpose of preventing undesirable inter-
action between the two, such as cross-modulation, which would
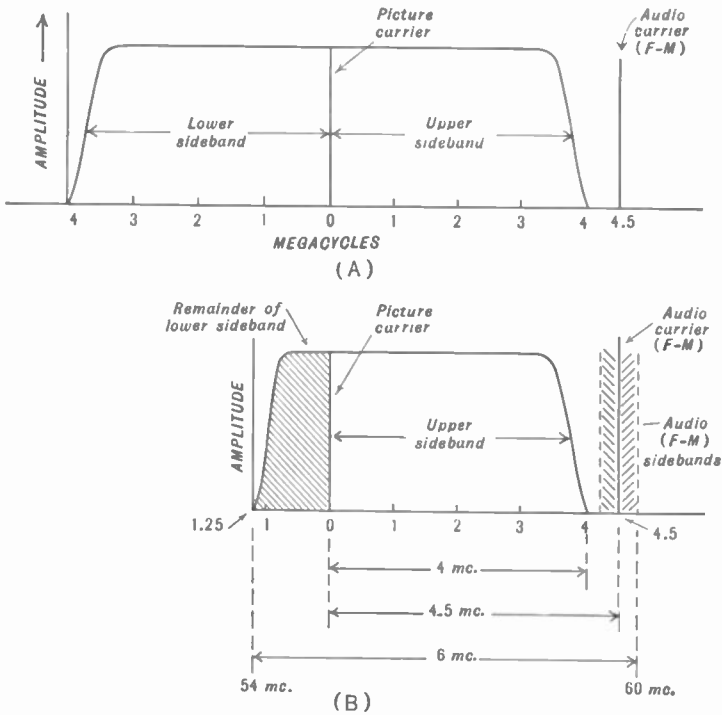
Fig. 1.23. Double-side band (A) and vestigial-side band (B) transmission of tele-
vision signals. Method B is standard in the United States and represents the signal
as sent.

lead to distortion of the video signal. In this manner the
allotted 6 mc are distributed.

Effect of Loss of Low and High Video Frequencies. While
uniform response over a 4-mc band may be required in the pic-
ture I.F. and video amplifiers, this is not easily attained in prac-
tice. Special circuit designs must be resorted to which are more
fully explained at their appropriate places in later chapters. For

the moment, it is only necessary to point out the effects of poor response at either the high- or low-frequency ends of the band.

In the preceding analysis we have seen that a greater number of elements required a greater band width if advantage was to be taken of the increase. Since detail is determined mainly by the number of very small elements, any decrease in the response at the higher frequencies will result in less fine detail available at the receiving cathode-ray screen. This fact is recognized commercially by designing circuits with smaller band widths for receivers that have small screens (5 inches or so). Fine detail is not easily visible and, even if placed on the screen, would be lost to most observers. Naturally, a saving in the cost of the receiver follows, as it is cheaper to construct circuits having narrower bandpass properties than those possessing greater uniform frequency response. For receivers with small screens, the frequency response curve is uniform for only 2.5 mc.

At the low-frequency end of the band, poor frequency response results in obliterating the slow changes that occur in background shading. However, it is possible partially to counteract bad effects caused by the poor response with the manually adjusted brightness control to be described later.

Frequency Allocations. With a maximum band width set at 6 mc, it becomes obvious that in order to operate even as few stations as five in any one area, a band 30 mc wide must be provided. With most of the lower frequencies already occupied by existing services, television was allotted space at the high frequencies, from 50 mc up. The advantage of using the higher frequencies lies in the vast amount of free ether space that is available. This permits extensive expansion, which is certain to occur when television sets become as numerous as the present A-M receivers. The disadvantages of using the higher frequencies result from the semi-optical behavior of radio waves in this range and the engineering difficulties in building stable high-powered equipment at short wavelengths.

The latter problem is fast dissolving in the many research

laboratories in this country and abroad. New tubes, more easily built components, better design and many other factors have combined to give good results with receivers and transmitters at the high and ultra-high frequencies.

The other problem involving the short range in which high-frequency radio waves can be received means that eventually numerous relay stations will have to be installed throughout the country for wide population coverage. Such work is now in full swing and consists of a combination of coaxial cable and micro-wave relays. A section of the transmission cable (Fig. 1.24) actually being used contains eight independent concentric cables —together with 49 paper insulated wires for testing and main-tenance purposes. A pair of the concentric cables, when fully terminated by the proper repeater stations, is capable of han-dling about 600 simultaneous telephone conversations, or one television program in each direction. Each of these copper tubes is about the diameter of a man's small finger. Running down the center of each tube is a copper wire about the size of a pencil lead, held in place by round insulating discs. Both the copper tube and the wire inside have the same axis, hence the name of concentric or coaxial.

Microwave systems, which may be used for long-distance tele-phone calls as well as television, make use of very short radio waves (in the neighborhood of 4,000 megacycles). These micro-waves are free from static and most man-made interference and shoot off into space instead of following the earth's curvature. Therefore, the waves are gathered into a beam and aimed at towers, usually located atop high buildings or hilltops. Micro-waves are focused in narrow beams from one point to another by huge horn-shaped antennas. Microwaves can be beamed over distances of 30 to 40 miles, just as long as there is no interference in its line-of-sight path. Typical of the microwave relay sta-tions on hilltops is the one shown in Fig. 1.25. This is located along the Bell System radio relay route between New York and Boston and is the one at Birch Hill, near Patterson, N. Y.
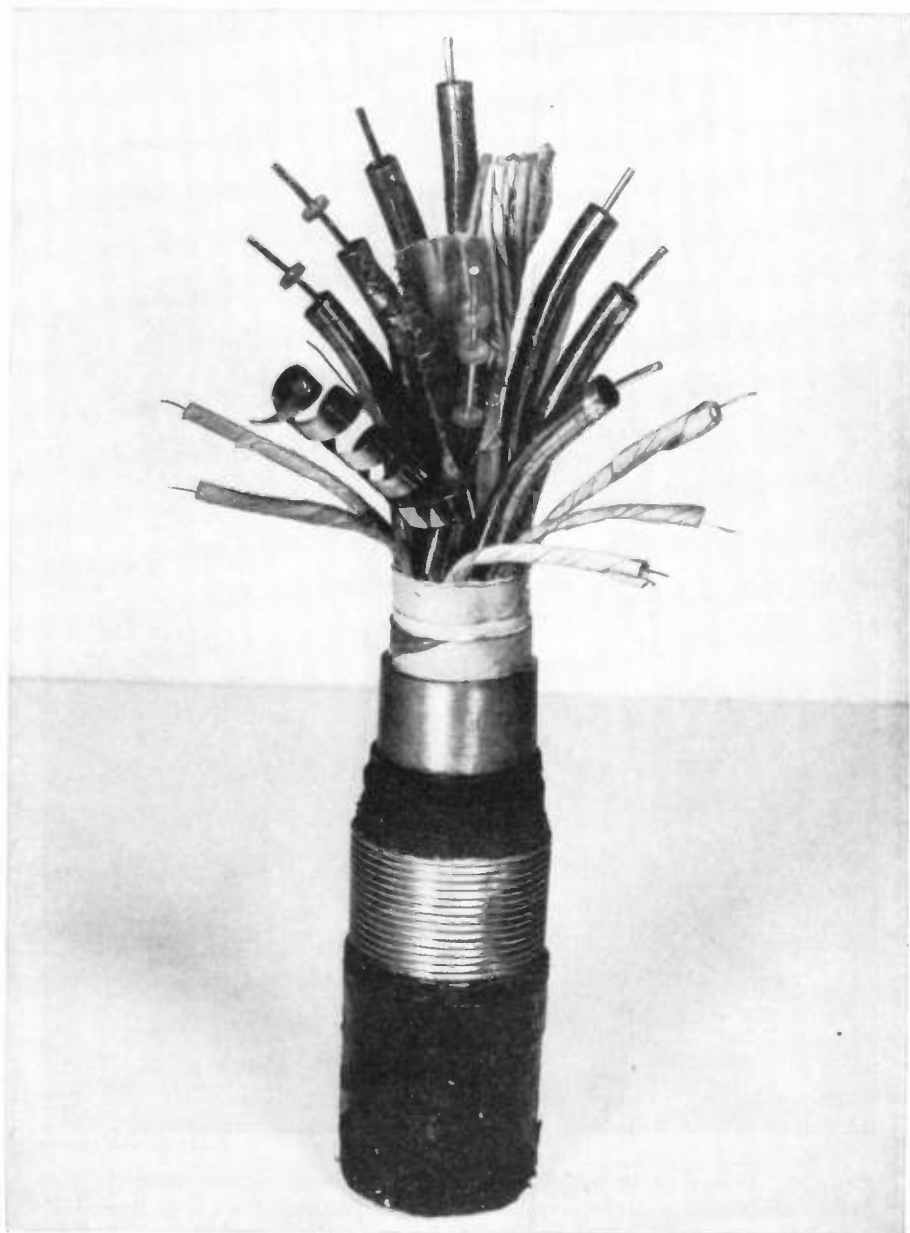
FIG. 1.24. A fanned-out section of an 8-tube transmission cable.

FIG. 1.25. Typical of the seven intermediate stations on hilltops along the Bell System radio relay route between New York and Boston is the one at Birch Hill, near Patterson, N. Y. Electro-magnetic lenses in the horns seen on the roof receive and beam long distance communication between the two cities.

Fig. 1.26 shows the Bell System's coaxial cable and radio relay system as it exists now and as it is expected to become in the next few years. While not shown separately, some portions of the routes use microwave relay and other sections use coaxial cable. Thus, for example, the link between Boston and New

Fig. 1.26. The Bell System coaxial cable microwave relay routes.

York consists entirely of microwave relay stations, while from New York, southward and westward, there is coaxial cable. In addition, one set of plans are being formulated for a microwave relay system between New York and Chicago to supplement the coaxial cable already existing between these two cities. Other systems besides the Bell System are in operation, but the latter is the most extensive.

The allocation of channels for television broadcasting, as it now stands, is as follows:

Channel	Megacycles	
2	54–60	
3	60–66	
4	66–72	lower band
5	76–82	
6	82–88	
7	174–180	
8	180–186	
9	186–192	
10	192–198	upper band
11	198–204	
12	204–210	
13	210–216	

In addition, the frequencies starting above 480 mc have also been assigned to television, although not on as definite a basis as those from 54 to 216 mc. These higher frequencies are to be used experimentally for the further development of black and white and color television. It is felt, however, that eventually most, if not all, of commercial television broadcasting will be located in this region.

When television allocations were first made following the war, thirteen channels were assigned to immediate television broadcasting. These included the 12 channels listed above, plus channel 1, at 44–50 mc. At the same time, non-government fixed and mobile radio services were permitted to share television channels 1 through 5 and 9 through 13. However, it didn't take long to demonstrate that this sharing was impractical because of serious interference to television reception. It was then decided to allot channel 1 entirely to non-government fixed and mobile services and to eliminate sharing of television channels 1 through 5 and 9 through 13. Channels 8 and 9 are shared with government fixed and mobile services, but since these latter services function infrequently, no serious interference is obtained.

F-M for Audio Transmission. When standards were established for commercial television broadcasting, it was directed that F-M was to be utilized for the audio portions of the television signal, and amplitude modulation for the video portion of

the signal. F-M for the audio offers noisefree reception and higher fidelity due to the possible use of audio frequencies up to 15,000 cycles. This type of modulation, however, has been found to give poorer results for the video signal, and amplitude modulation will be retained for two reasons.

Let us consider, for example, an antenna receiving two waves from the same transmitter. One ray traveled directly from transmitter to receiver, while the other ray (which we will call the reflected ray) arrived at the receiver by a longer, more indirect path. This could have occurred if the second ray was moving in some other direction, hit an obstacle in its path, and was reflected toward the receiving antenna. Because the reflected ray traveled a longer path to reach the receiving antenna, it arrived some small fraction of a second after the direct ray. During the interval between received rays, the electron beam has traveled a small distance across the fluorescent screen. The end result is two similar images, slightly displaced from each other. This condition is known as "ghosts" and occurs when A-M is used. The same situation with F-M also produces a ghost image, but the two contrasts are more prominent and prove more distracting than the ghost images of A-M.

Another advantage of A-M over F-M for the video signal is the better synchronizing action observed. When there are several paths that a signal may follow in reaching the receiving antenna, or when there are other types of interference, there is less tendency for the synchronizing pulses to become obliterated in the A-M signal. Loss of the synchronizing pulses means no control of the motion of the electron beam as it moves across the screen. The image, under this condition, would appear with streaks in it at points where the synchronizing action was lost.

The distance over which the signal can be transmitted directly is the same, whether F-M or A-M is employed. Frequency, and only frequency, is the determining factor. As explained in Chapter 2, the usable range at these high frequencies is governed by the height of the receiving and transmitting antennas above the ground.

ULTRA-HIGH FREQUENCY WAVES AND THE TELEVISION ANTENNA

The antenna for a television receiver requires much more attention and care, especially with regard to placement, than those used with the ordinary sound receiver. In order to obtain a clear, well-formed image on the cathode-ray tube screen, it is absolutely necessary that:

1. The maximum signal strength be developed at the antenna.

2. The signal be received from one source, not several.

3. The antenna be placed well away from man-made sources of interference.

In ordinary sound receivers, a certain amount of interference and distortion is permissible. If not excessive, reception of the broadcast is satisfactory. For television, however, the standards are more severe, and added precautions must be taken to guard against almost every type of interference and distortion. Hence, the need for more elaborate antenna receiving systems.

The position of the antenna must be chosen carefully, not only for additional signal strength, but also because of the appearance of so-called "ghosts" on the image screen which are due to the simultaneous reception of the same signal from two or more directions. For an explanation of this form of interference, refer to Fig. 2.1, in which a television dipole antenna is receiving one signal directly from the transmitting tower, while another ray strikes the same antenna after following a longer, indirect path. Reflection from a building or other large object could cause the indirect ray to reach the antenna.

Because of the longer distance the reflected ray travels, it will arrive at some small fraction of a second later than the

direct ray. In sound receivers, the ear does not detect the dif-
ference. On a television screen, the scanning beam has traveled
a small distance by the time the reflected ray arrives at the re-
ceiver. Hence, the image contained in the reflected ray appears
on the screen displaced some small distance from similar de-
tail contained in the direct ray. The result is shown in Fig.
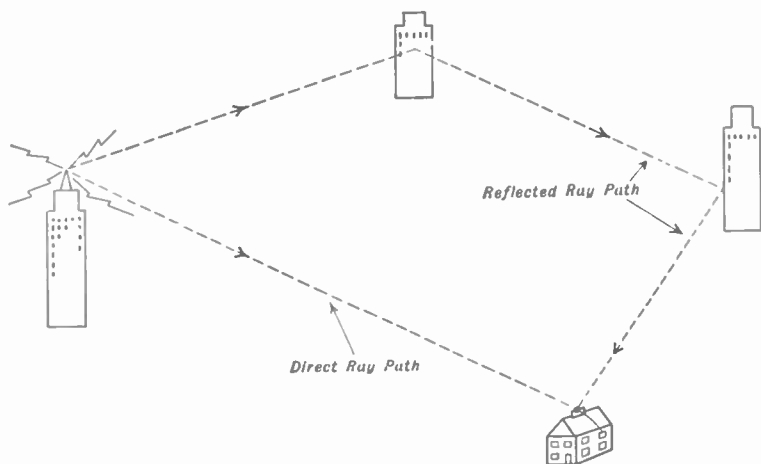
FIG. 2.1.   The reflected-ray, along with the direct ray, arrive at the receiving
antenna to form double images, called "ghosts."

2.2. When the effect is pronounced, a complete double image is
obtained and the picture appears blurred. To correct this con-
dition, it is necessary to change the position of the antenna until
only one ray is received. The antenna should not be turned
to favor the reflected signal unless it is impossible to obtain a
clear image with the direct ray. The properties of reflecting
surfaces change daily, and there is no certainty that a good sig-
nal will always be received.

The placement of the antenna is generally the most difficult
operation of a television installation. To obtain maximum re-
sults, it is necessary for the radio serviceman or other person
erecting the receiving antenna to have a good knowledge of the
behavior of radio waves at the high frequencies.

Radio Wave Propagation. Transmitted radio waves at all frequencies may travel in either of two general directions. One wave closely follows the surface of the earth, whereas the other travels upward at an angle which is dependent on the position of the transmitting radiator. The former is known as the ground wave, the latter as the sky wave. At the low frequencies, up to approximately 1,500 kc, the ground wave attenuation is low, and signals travel for long distances before they disappear. Above
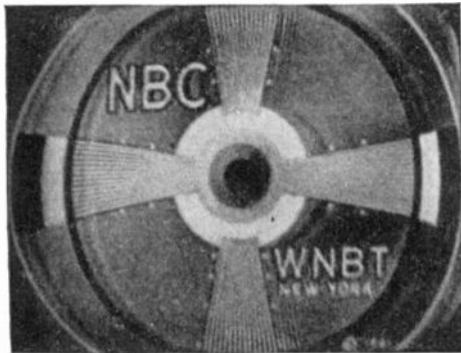
Fig. 2.2. A "ghost" image on a television viewing screen.

the broadcast band, the ground wave attenuation increases rapidly, and all extensive communication is carried on solely by means of the sky wave.

The sky wave leaves the earth at an angle that may have any value between 3° and 90° and travels in almost a straight line until the ionosphere is reached. This region begins at a distance of 70 miles above the surface of the earth and within this area are found large concentrations of charged gaseous ions, free electrons, and uncharged or neutral molecules. The ions and free electrons are acted on by all passing electromagnetic waves and tend to bend these waves back to earth. Whether the bending is complete (and the wave does return to the earth) or only partial depends on several factors:

1. The frequency of the radio wave.
2. The angle at which it enters the ionosphere.

3. The density of the charged particles (ions and electrons) in the ionosphere at that particular moment.

Extensive experiments indicate that, as the frequency of a wave increases, a smaller entering angle is necessary in order for complete bending to occur. As an illustration of this, consider the two high-frequency waves, *A* and *B*, shown in Fig. 2.3. Wave
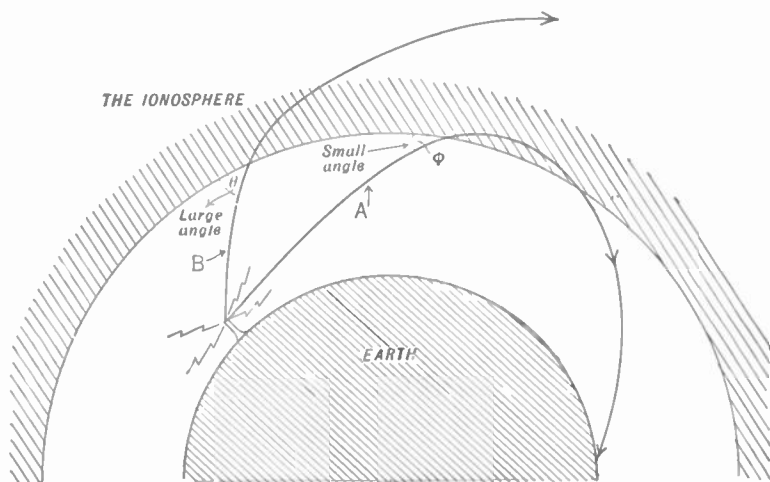
FIG. 2.3. At the higher frequencies, a radio wave must enter the ionosphere at small angles if it is to be returned to earth.

A enters the ionosphere at a small angle and, hence, little bending is required to return it to earth. Wave *B*, subject to the same amount of bending, is headed outward, however, because its initial entering angle was too great. Naturally, this latter wave would not be useful for any communication purposes.

By raising the frequency still higher, the maximum incident angle at the ionosphere becomes smaller, until finally a frequency is reached where it becomes impossible to bend the wave back to earth, no matter what angle is used. For ordinary ionospheric conditions, this occurs at about 35 to 40 mc. Above these frequencies, the sky wave is useless so far as radio communication is concerned. Only the direct ray is of any use. Television bands, starting above 40 mc, would fall into this

category. By direct ray (or rays), we mean the radio waves that travel in a straight line from transmitter to receiver. Ordinarily, at lower frequencies, the radio waves are sent to the ionosphere and, from there, to the receiver at some distant point. With high frequencies, the ionosphere is no longer useful, so the former sky waves must be concentrated into a path leading direct to the receiver. If not intercepted by the receiver, they finally hit the ionosphere and are lost. It is this restriction to
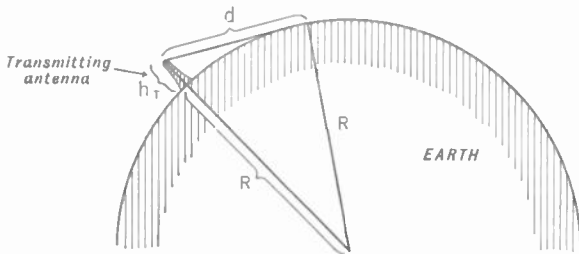
Fig. 2.4. Illustrating how to compute the line-of-sight distance for high-frequency radio waves.

the use of the direct ray that limits the distance in which high-frequency communication may take place.

There are, at times, unusual conditions present when the concentrations of charged particles in the ionosphere increase sharply. At these times, it is possible to bend radio waves of frequencies up to 60 mc. The exact time or place of these phenomena cannot be predicted and hence are of little value for commercial operation. They do explain to some extent the distant reception of high-frequency signals that may occur.

Line-of-Sight Distance. At the frequencies employed for television, reception is possible only when the receiver antenna directly intercepts the signals as they travel away from the transmitter. These electromagnetic waves travel in essentially straight lines, and the problem resolves itself into finding the maximum distance at which the receiver can be placed from the transmitter and still have its antenna intercept the rays. This distance may be computed as follows.

In Fig. 2.4, let the height of the transmitting antenna be called h_t, the radius of the earth R, and the distance from the top of the antenna to the horizon d. To simplify the derivation somewhat, it will be assumed that the earth, for that small section under consideration, is flat. This gives us a right triangle. From elementary geometry it is possible to write down the following equation

$$(R + h_t)^2 = R^2 + d^2 = R^2 + 2Rh_t + h_t^2$$

h_t is very small compared with the radius of the earth and the h_t^2 term may be neglected. This leaves

$$d^2 = 2Rh_t$$

The value of R is approximately 4,000 miles. Substituting this value in the above equation, and changing h_t from units of miles to feet, we obtain

$$d = 1.23\sqrt{h_t}$$

where d is in miles, h_t in feet. The relationship between d and h_t for various values of h_t have been put into graph form in Fig. 2.5.

The coverage for any transmitting antenna will increase with its height. The number of receivers capable of receiving the signals would likewise increase. This accounts for the placement of television antennas atop tall buildings (for example, the Empire State Building) and on high plateaus.

The signal range thus computed is from the top of the transmitting antenna to the horizon at ground level. By placing the receiving antenna at some distance in the air, it should be possible to cover a greater distance before the curvature of the earth again interferes with the direct ray. Such a situation is depicted in Fig. 2.6. By means of simple geometrical reasoning, the maximum distance between the two antennas now becomes

$$d = 1.23(\sqrt{h_t} + \sqrt{h_r})$$

where h_r is the receiving antenna height in feet.

Unwanted Signal Paths. While the foregoing computed distances apply to the direct ray, there are other paths that waves may follow from the transmitting to the receiving antennas. Each of these other rays is undesirable as they tend to distort and interfere with the direct-ray image on the screen. One
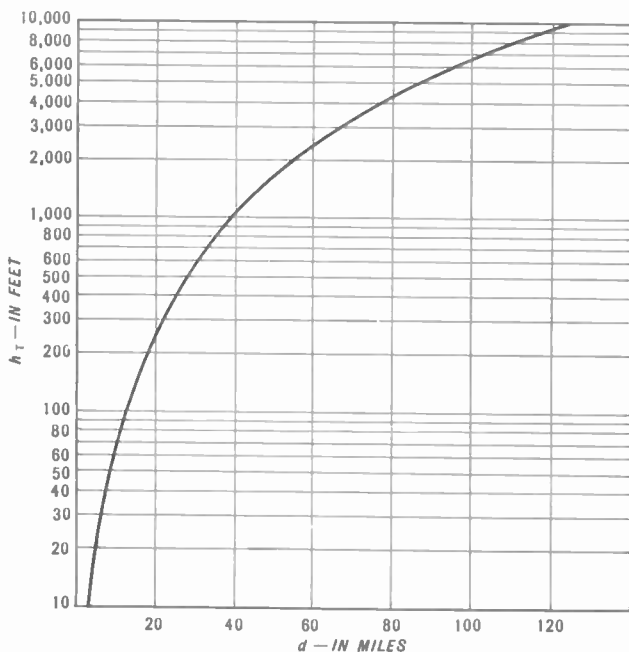
Fig. 2.5. The relationship between the height of the transmitting antenna (in feet) and the distance in miles from the antenna that the ray may be received.

method, by reflection from surrounding objects, has already been discussed. Another ray may arrive at the receiver by reflection from the surface of the earth. This path is shown in Fig. 2.7. At the point where the reflected ray impinges on the earth, phase reversals up to 180° have been found to occur. This phase shift thus places a wave at the receiving antenna which generally acts against the direct ray. The overall effect is a general lowering of the resultant signal level and the appearance of annoying ghost images.

However, there are compensating conditions acting against the decrease due to the ground reflected ray. One is the weakening of the wave strength by the absorption at the point where it grazed the earth. The other results from the added phase change (not that just mentioned) arising from the fact that the length of the path of the reflected ray is longer than the direct ray path. Thus there is a ground phase shift plus whatever

FIG. 2.6.   Increasing the line-of-sight distance from the receiving antenna to the transmitter by raising both structures as high as possible.

else may have been added because of the longer distance. All combine to lower the direct ray strength less than we would at first expect.

It has further been observed that the received signal strength increases with the height of either or both antennas. At the same time, a decrease in noise pick-up occurs. For television signals, this is most important. Placement of the antenna and
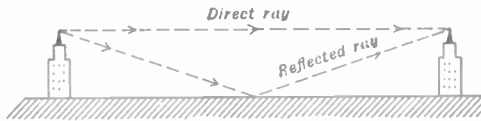
FIG. 2.7.   The reflected radio wave, arriving at the receiving antenna after reflection from the earth, may lower the strength of the direct ray considerably.

utilization of its directive properties will help in decreasing (and many times eliminating) all but the desired direct wave.

Wave Polarization. The height of the antenna is important, but the manner in which it is held, either vertically or horizontally, must also be considered. The position of the antenna is affected by the nature of the electromagnetic wave itself.

All electromagnetic waves have their energy divided equally

between an electric field and a magnetic field. In free space
these fields are at right angles to each other. Thus, if we were
to visualize these fields and represent them by their lines of
force, the wave front would appear as in Fig. 2.8. The fields
represent the wave, the arrows the direction in which the forces
are acting. The mode of travel of these waves in free space is
always at right angles to both fields. As an illustration, if the
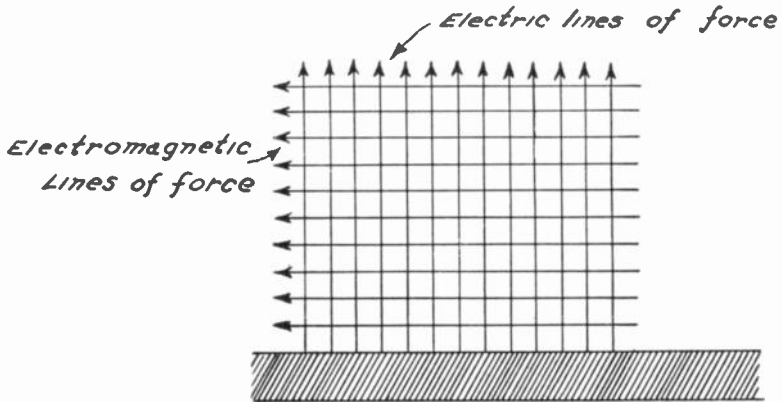
FIG. 2.8. The components of an electromagnetic wave. The wave travels at right
angles to these lines of force. In this illustration, direction of travel is forward,
out of the paper.

electric field lines are vertical and those of the magnetic field
are horizontal, the wave travels forward.

In radio, the sense of a radio wave has been taken to be the
same as the direction of the electric lines of force. Hence a
vertical antenna radiates a vertical electric field (the lines of
force are perpendicular to the ground), and the wave is said to
be vertically polarized. A horizontal antenna radiates a hori-
zontally polarized wave. Experience has revealed that the great-
est signal is induced in the receiving antenna if it has the same
polarization (is held in the same manner) as the transmitting
antenna.

Concerning the relative merits of horizontal versus vertical
polarization, Dr. George H. Brown has found that for antennas

located close to the earth, vertically polarized rays yield a better signal. On raising the receiving antenna about one wavelength above ground, this difference generally disappears and either type may be employed. Further increase in height, up to several wavelengths, has shown that the horizontally polarized waves give a more favorable signal-to-noise ratio and are to be desired. In television, the wavelengths are short and the antennas are placed several wavelengths in the air. Hence, horizontally polarized waves have been taken as standard. All television receiving antennas are mounted in the horizontal position.

Tuned Antennas. The need for good signal strength at the antenna has led to the general use of tuned antenna systems. A tuned antenna, which is a wire cut to the necessary length, is equivalent in its properties to any resonant circuit. The radio waves, passing by the antenna, will induce voltages along the wire. For equally powered radio waves, the maximum voltage is developed in the antenna when its resonant frequency is equal to that of the passing wave. A large signal at the antenna means a greater input to the receiver.

Half-Wave Antennas. An ungrounded wire, cut to one-half the wavelength of the signal to be received, represents the smallest length of wire that can be made to resonate at that frequency. The half-wavelength antenna is the most widely used since it represents the smallest antenna for its frequency and consequently requires the least amount of space. In troublesome areas it may be necessary to erect more elaborate arrays possessing greater gain and directivity than the simple half-wave antenna. They are, however, more costly and more difficult to install.

A simple half-wave antenna is erected and supported as indicated in Fig. 2.9. Metallic rods are used for the antenna itself, mounted on the supporting structure and placed in a horizontal position (parallel to the ground). Each of the rods is one-quarter of a wavelength long, the total equal to the necessary half wavelength. In this arrangement, which is also known as a dipole antenna, the transmission lead-in wire is connected to

the rods, one wire of the line to each rod. The line then extends
to the receiver. Care must be taken to tape the line at several
points to the supporting mast so that it does not interfere with
the operation of the antenna. Taping also prevents the line
from flapping back and forth in the wind. Any such motion
could weaken the connections made at the rods.
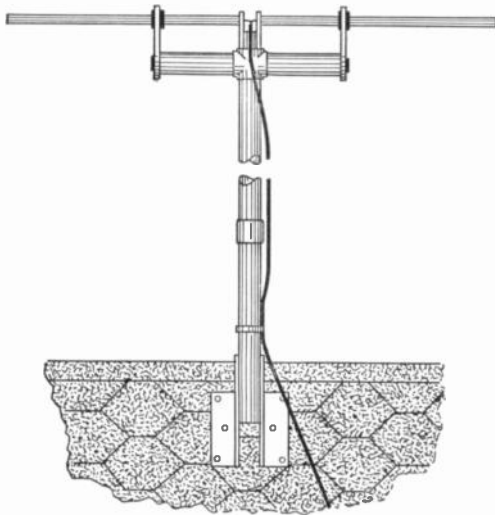
FIG. 2.9.   Dipole antenna assembly used extensively for television receivers.

When the properties of a dipole antenna are investigated, it is
found that signals are received with greatest intensity when the
rods are at right angles to the direction of the signal. This is
illustrated in Fig. 2.10A. On the other hand, signals approach-
ing the antenna from either end are very poorly received. To
show how waves at any angle are received, the graph of Fig.
2.10B is commonly drawn. It is an overall response curve for
a dipole antenna.

From the diagram, with the placement of the antenna as
shown, the strongest signal would be received from direction A.
As the angle made with this point is increased, the strength of
the received signal decreases, until at point B (90°) the received
signal voltage is at a minimum (or zero). The reader can de-
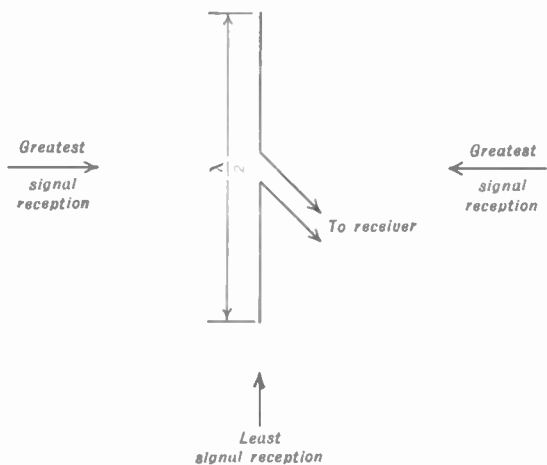
FIG. 2.10A. Dipole antennas, of the type shown, received signals best from the directions indicated.
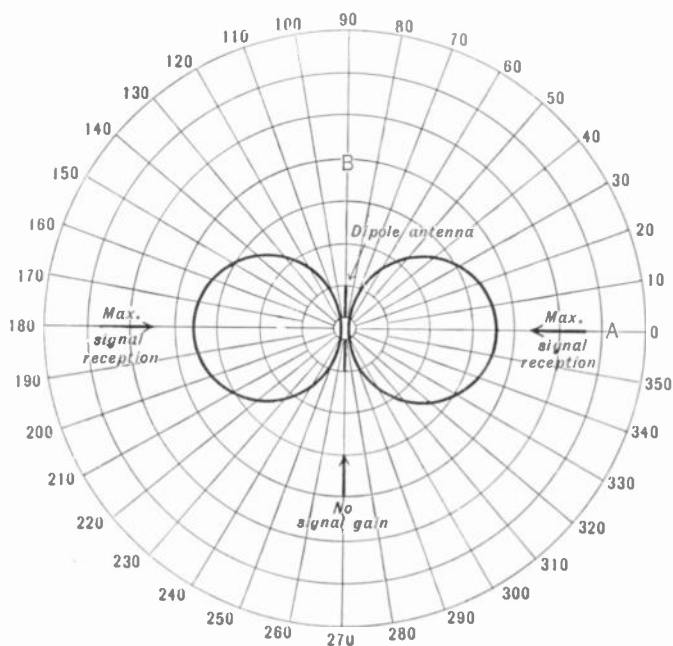
FIG. 2.10B. The directional response curve of a dipole antenna.

termine the reception for waves coming in at other angles by inspection of the graph. Notice that good signal strength is obtained from two directions and because of this, the dipole may be called bi-directional. Other systems can be devised that are uni-directional, non-directional or that have almost any desired properties. For each system, a response curve would quickly indicate its properties in any direction.

As stated, an antenna must be tuned in order to have the strongest signal develop along its length. Hence it becomes necessary to cut the wires (or rods) to a specific length. The length will vary with each different frequency, longer at the lower frequencies and shorter at the higher frequencies. It might be supposed then, that a television set, capable of receiving signals with frequencies ranging from 50 to 88 mc would need several antennas, one for every band. It is not necessary, however, to go to such extremes and, in practice, one antenna is sufficient, if tuned to a middle frequency.

Antenna Length Computations. With the foregoing range of frequencies, a middle value of 65 mc might be chosen. While an antenna cut to this frequency would not give optimum results at the other bands, the reception would still be quite satisfactory.

To compute the length needed for the 65-mc frequency half-wave antenna, the following formula is used:

$$L_{\text{ in feet}} = \frac{468}{f_{\text{mc}}}$$

With f set equal to 65 mc, the length would be equal to $\frac{468}{65}$ or

7.2 feet. Practically, 7 feet might be cut, with each half of the half-wave antenna 3.5 feet long. For a full-wavelength antenna, approximately 14 feet is needed. In congested areas, antenna length must be as short as possible, and only half-wave antenna systems are generally found. For the present, the indications are that most television stations will be found in large cities in order to reach the greatest number of sets. Emphasis, then, will be on short antennas, such as the half-wave type. If longer

lengths are desired, the equation should be modified by the proper factor. A full wavelength antenna requires a factor of 2; a wavelength and a half requires a factor of 3, etc.

Half-Wave Dipole with Reflector. The simple half-wave system provides satisfactory reception in most locations within reasonable distances of the transmitter. However, the signals reaching receivers situated in outlying areas are correspondingly weaker, and noise and interference have a greater distorting effect on the image. For these locations more elaborate arrays
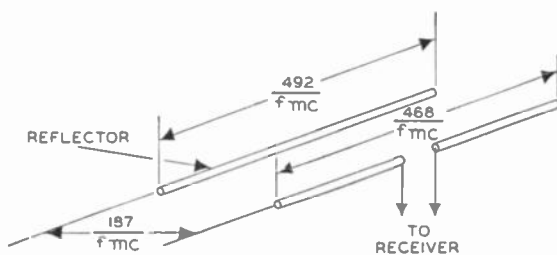
Fig. 2.11.   Dipole receiving antenna and reflector.

must be constructed—systems that have greater gain and directivity and provide better discrimination against interference.

A simple yet effective system is shown in Fig. 2.11. The two rods are mounted parallel to each other and spaced about .2λ–.25λ apart. The action of the second wire, which is not connected, is twofold. First, because of its position, it tends to concentrate signals reaching the front wire. Second, it shields the front antenna from waves coming from the rear. The gain of the array is generally 5 db greater than that obtainable from a single half-wave antenna.

Besides the additional gain that is observed with this two-wire system, the graph of Fig. 2.12 shows that the angle at which a strong signal may be received now is narrower. This is also advantageous in reducing the number of reflected rays that can affect the antenna. Finally, partial or complete discrimination is possible against interference, man-made or otherwise.

The method of erecting the antenna is similar to that of the

half-wave dipole, although the adjustment of the position of the wires is more critical. A small displacement, one way or another, alters the strength of the received signal appreciably. Many commercial antenna kits do not provide adjustment of the spacing distance between the two wires. However, if an adjust-
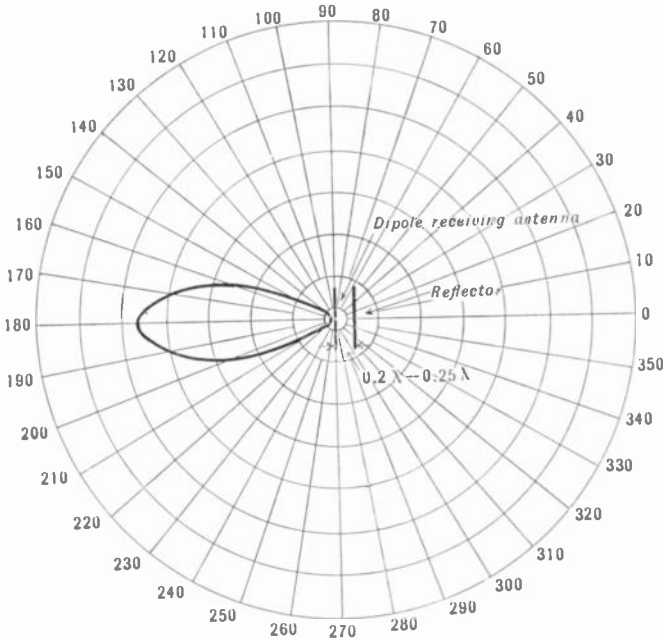
Fig. 2.12. The directional response curve for a half-wave antenna with a reflector.

ment is possible, the spacing may be altered if experimentation indicates that it would result in better reception.

Another antenna widely used by servicemen and recommended by television receiver manufacturers is the folded dipole shown in Fig. 2.13A. This antenna consists essentially of two dipole antennas connected in parallel with each other. The separation between the two sections is approximately 3 to 5 inches. The folded dipole has the same bi-directional pattern as the simple dipole and approximately the same gain. The input impedance is now 300 ohms (at the frequency for which it
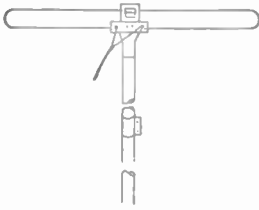
(A) Folded dipole
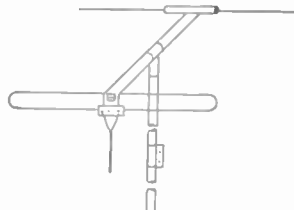
(B) Folded dipole with reflector
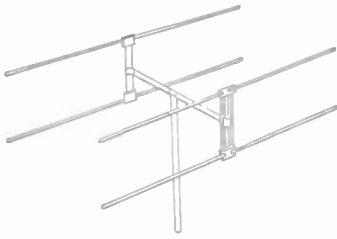
(C) Stacked dipoles, with reflector
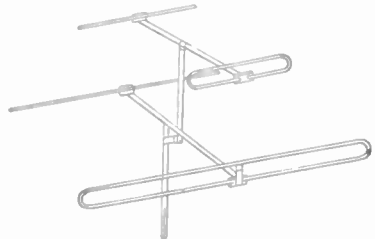
(D) Two folded dipoles cut for different frequencies
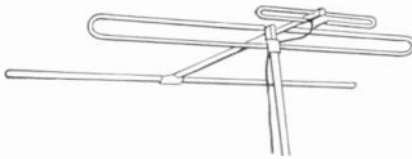
(E) Amphenol array combining low and high frequency folded dipoles
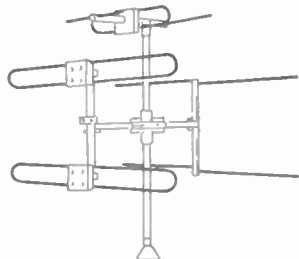
(F) Stacked array for low band; single dipole for high band
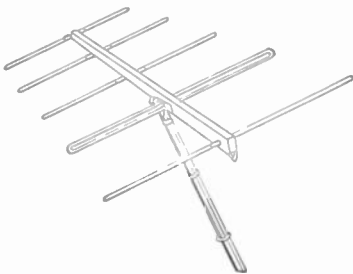
(G) Yagi array
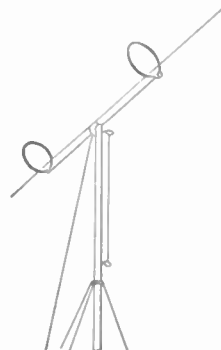
(H) Tricraft antenna

FIG. 2.13. Various types of popular television receiving antennas.

was cut) against 72 ohms for the simple dipole. However, the response of a folded dipole is more uniform over a band of frequencies than the simple dipole.

The directivity of the folded dipole can be increased by the addition of a reflector. (See Fig. 2.13B.) The unit now possesses the same directional pattern as the simple dipole with reflector. The length and spacing of the reflector can be determined by the same formulas previously given for the simple dipole and reflector.

In the remaining illustrations of Fig. 2.13, other popular types of television antennas are shown. Nearly all of these are elaborations of the basic dipole or folded dipole. In Fig. 2.13C, we have a stacked dipole array, with reflectors. (This antenna is sometimes referred to as a "Lazy H" because of its similarity to the letter H lying on its side.) Two half-wave dipoles are placed at the front of the assembly, one mounted above the other. The center terminals of each dipole are connected together by means of a parallel-wire transmission line. Each conductor of the lead-in line to the television receiver attaches to a conductor of this connecting transmission line at a point midway between the dipoles. A reflector is mounted behind each dipole.

In Fig. 2.13D, there are two folded dipoles, with reflectors, mounted one above the other. The upper dipole is cut for a resonant frequency approximately in the center of the upper television band (174–216 mc), and the longer folded dipole is resonated at the center frequency of the lower television band. A short length of 300-ohm transmission line connects the upper dipole to the lower. From the lower antenna, a 300-ohm line feeds the signals to the receiver. With this assembly, each antenna can be oriented independently for best reception from stations within its band, providing the receiver with good coverage on both bands. Fig. 2.13E is essentially the same arrangement as Fig. 2.13D, except that the longer folded dipole acts as the reflector for the shorter folded dipole. The two folded dipoles are connected in the same manner as the array in Fig. 2.13D. Independent orientation of each folded dipole is not

possible in the array of Fig. 2.13E. The unit in Fig. 2.13F is an elaboration of that shown in Fig. 2.13C.

The antenna of Fig. 2.13G contains a folded dipole with one reflector and three directors. It is known as a "Yagi" array and possesses sharp uni-directional directivity. Signals are received only from the direction broadside to the directors. The final array (Fig. 2.13H) is a special combination of two dipoles designed to receive signals in the two television bands and the F-M band (88–108 mc) from a fairly broad direction. In other words it is not very directional. Arrays C, F, and G are useful in weak signal areas where the added expense is more than compensated for by the additional signal made available to the receiver. In most locations within 20 miles of a transmitter, however, the simple dipole and folded dipole, each aided perhaps with a reflector, will prove completely satisfactory.

Table 2.1 reviews the properties of the basic television antennas, together with their dimensions.
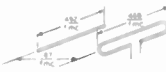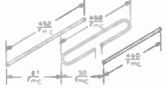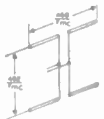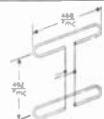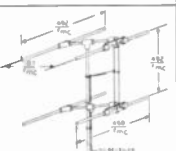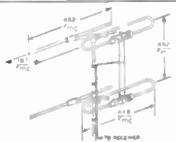
After the particular antenna has been chosen, the following points should be kept in mind before installing the antenna.

1. The higher the antenna, the stronger the signal received.

2. The antenna should be set-tested with an actual connection to its receiver before the supports are fixed in place permanently.

3. When more than one station is to be received, the final placement of the antenna must, of necessity, be a compromise. In extreme cases, it may be desirable or even necessary to erect several antennas.

Transmission Lines. With the antenna system in position, the next problem is the transmission line that conducts the signal from the antenna to the receiver. Although many differently constructed transmission lines have been designed, only four types find any extensive use in F-M and television installations. These are the two parallel-wire types, the concentric or coaxial cable, and the twisted pair.

From the standpoint of convenience and economy, one antenna should be capable of receiving all the television and F-M stations. It should have, therefore, a fairly uniform response

TABLE 2.1. Characteristics of the most common television antennas.

ANTENNA TYPE	APPROXIMATE CHARACTERISTIC IMPEDANCE (ohms)	DIRECTIVITY	DIMENSIONS (feet)	GAIN [COMPARED TO DIPOLE]	
				db	voltage
Plain dipole	72	Bi-directional; broadside to elements		-	Unity
Folded dipole	300	Bi-directional; broadside to elements		-	Unity
Dipole and reflector	50	Uni-directional, broadside to radiator		5	1.78
Folded dipole and reflector	250	Uni-directional; broadside to radiator		5	1.78
Dipole, reflector, and director	25	Uni-directional; broadside to radiator		7	2.24
Folded dipole, reflector and director	100	Uni-directional; broadside to radiator		7	2.24
Stacked dipoles	40	Bi-directional; broadside to elements		5	1.78
Folded stacked dipoles	150	Bi-directional; broadside to elements		5	1.78
Stacked dipoles and reflectors	25	Uni-directional; broadside to elements		10	3.16
Folded stacked dipoles and reflectors	100	Uni-directional; broadside to elements		10	3.16

over the entire band. A resonant dipole presents an impedance,
at its center, of 72 ohms. To obtain maximum transfer of power,
the connecting transmission line should match this value. How-
ever, when we attempt to use the same dipole for a band of
frequencies, we find that the 72-ohm value is no longer valid.
A dipole cut for 50 mc presents a 72-ohm impedance. At 100 mc,
the impedance has risen to 2,000 ohms. It is obvious that the
best transmission line impedance is no longer 72 ohms, but a

(A) Parallel-wire line (Unshielded)   (B) Parallel-wire line (Shielded)

(C) Twisted pair (Unshielded)   (D) Twisted pair (Shielded)

(E) Coaxial line
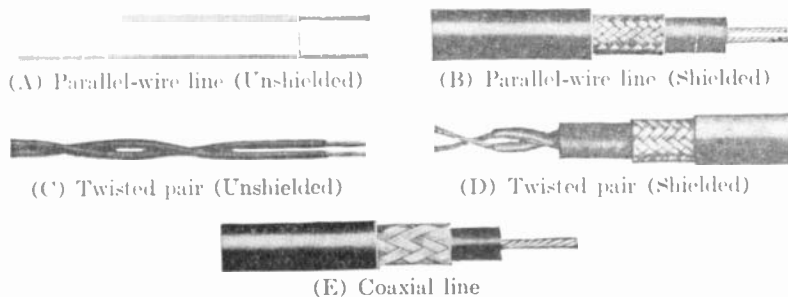
FIG. 2.14. Various types of popular transmission lines used for F-M and television
installations.

higher value which will serve as a compromise. It is desirable
to use as high an impedance value as possible, because line loss
is inversely proportional to characteristic impedance. On the
other hand, such factors as the size of the line and the wire gage
must also be considered, and it is current practice to design the
input circuit of the television receiver for a 300-ohm transmis-
sion line. It has been found that a 300-ohm line used with a
half-wave dipole produces a broad frequency response without
too great a loss due to mismatching. A folded dipole has an
impedance close to 300 ohms at its resonant frequency and a
much more uniform response is obtained with this antenna.

The parallel-wire transmission line (Fig. 2.14A) has recently
become popular because of its low-loss properties when encased
in a plastic ribbon of polyethylene. Polyethylene is a strong,
flexible material and is not affected by sunlight, water, cold,
acids, or alkalis. At 50 mc, the line loss is less than 0.8 db per

hundred feet of line. Its characteristic impedance ranges from 75 ohms to 300 ohms and will match a folded dipole antenna. The line is balanced, which means that both wires possess the same average potential with respect to ground. It is, however, unshielded and therefore not recommended for use in extremely noisy locations.

A parallel-wire transmission line that is completely shielded is shown in Fig. 2.14B. The two wires are enclosed in a dielectric, possibly polyethylene, and then the entire unit is shielded by a copper-braid covering. As a protection against the elements, an outer rubber covering is used. Grounding the copper braid converts it into a shield which prevents any stray interference from reaching either conductor. Furthermore, the line is balanced against ground. It is built with impedance values ranging from 50 to 100 ohms. The line loss is greater than the unshielded parallel pair, being on the order of 2.5 db per hundred feet at 50 mc.

The twisted pair transmission line (Fig. 2.14C) is made by twisting wires about each other in the same manner as twisted lamp cord. Of all the lines described, this is the most economical, but it has the greatest loss and becomes impractical for lengths beyond 50 feet. The characteristic impedance ranges from 50 ohms to 150 ohms; and, at 50 mc, the db loss is 4 for each hundred feet of line. Unless this line is specially constructed, it will deteriorate in time under the ravages of the atmosphere. A shielded twisted pair line is shown in Fig. 2.14D. This line has more desirable characteristics than the unshielded twisted pair, but its cost is greater.

The fourth transmission line is the coaxial or concentric cable, shown in Fig. 2.14E. It contains an insulated center wire enclosed by a concentric metallic covering which is generally flexible copper braid. The inner wire is kept in position by a solid dielectric which is chosen for its low-loss properties. The signal carried by the line is confined to the inner conductor, with the outer copper-braid conductor grounded so as to serve as a shield against stray magnetic fields. Due to this arrangement, the line
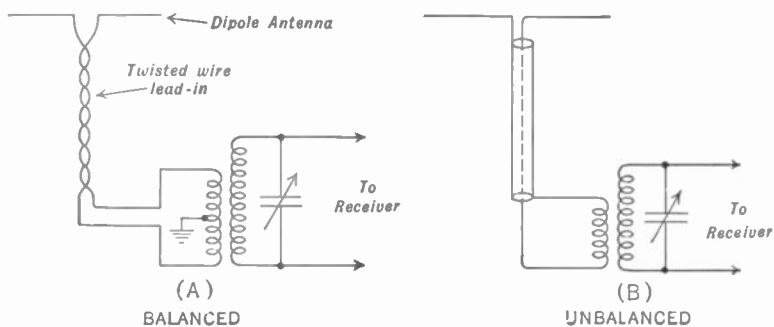
FIG. 2.15. Methods of connecting lead-in wires to the input coil of a receiver.
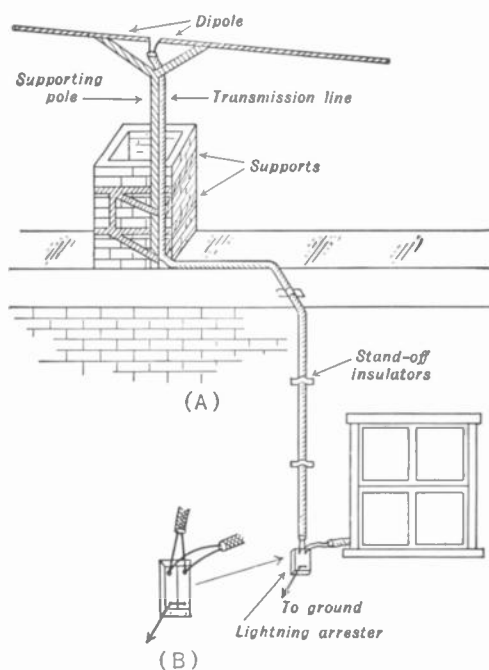
FIG. 2.16. An antenna installation for a television receiver. The ground from the lightning arrester should be as short and direct as possible.

is unbalanced and the input coil of the receiver must be connected accordingly. Coaxial cables are available in a range of impedances from 10 to 150 ohms.

At the receiver, the connections for balanced and unbalanced line differ, as shown in Fig. 2.15. For a balanced line, the input coil is center-tapped and grounded at this tap. Stray fields, cutting across both wires of a balanced line, induce equal voltages in each line. The similar currents that flow because of the induced voltages are in the same direction on the two conductors of the line and they neutralize each other.

Antenna Installation. A complete installation is illustrated in Fig. 2.16A. Stand-off insulators should be mounted on the side of the building to prevent the transmission line from rubbing against the wall. It is good practice, also, to install a lightning arrester at the point where the line enters the building (see Fig. 2.16B). The other ends of the arrester should be connected securely to an iron pipe sunk into the earth. From the lightning arresters, the transmission line is led into the building to the receiver.

CHAPTER 3

WIDE-BAND TUNING CIRCUITS—R.F. AMPLIFIERS

The Band Width Problem. The television signal occupies a 6-mc band width in the radio spectrum, a range far greater than anything we have had to receive with the ordinary sound set. The problem must be met at the television receiver in the R.F. and mixer stages, if both are used; otherwise, only at the mixer. The response of the tuned receiving circuit should be uniform throughout the 6-mc band and yet be selective enough to discriminate against unwanted image frequencies or stations on adjacent bands. Before the circuits of the R.F. and mixer stages are considered, it will be helpful to discuss wide-band tuning circuits.

FIG. 3.1A. A parallel tuning circuit is shown at (A). The response curve for this circuit is shown in Fig. 3.1B.

Ordinary Tuning Circuits. A single coil and condenser, connected as shown in Fig. 3.1A, form a parallel tuning circuit. At or near the resonant frequency, the variation of impedance which this combination presents is given by the graph of Fig. 3.1B. At frequencies below the resonant frequency, the parallel combination acts as an inductance with a lagging current; above resonance, the effect is capacitive with a leading current. At the resonant point, both capacitive and inductive reactances cancel each other, the impedence becoming high and wholly resistive.

While Fig. 3.1B shows the general shape of the resonant curve, more specific information is necessary. Hence, in Fig. 3.2, several resonant curves have been drawn, each for a circuit having

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a different value of Q. Q, which is the ratio of inductive react-
ance to coil resistance, may be taken to indicate two things:

1. The sharpness of the resonant curve in the region about the
resonant frequency.   This, of course, is the selectivity of the
tuning circuit

2. The amount of voltage that will be developed by the in-
coming signal across the resonant circuit at resonance.
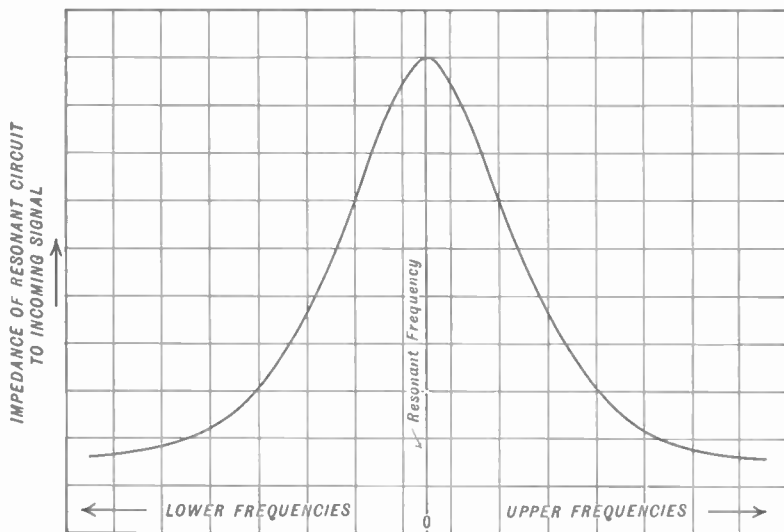
Fig. 3.1B.   The response curve for the tuning circuit shown in Fig. 3.1A.

For any given circuit, the greater its Q value. the more selec-
tive will be the response of the circuit and the greater the voltage
developed.   While these factors may be highly desirable, they
are only useful if they do not interfere with reception of radio
signals.   At the broadcast frequencies, each station occupies a
band width of 10 kc.   Within this region, uniform response is de-
sirable.   However, the sharply peaked curve of Fig. 3.1B does
not produce equal response at all points within this region.   The
portion of the signal exactly at the resonant frequency, for ex-
ample, would develop a greater voltage across the resonant cir-
cuit than those frequencies at the outer fringe, plus and minus

5 kc away. A coil and condenser combination having a lower Q would give a more uniform response and might be chosen over one with a higher value of Q. Less voltage results from this
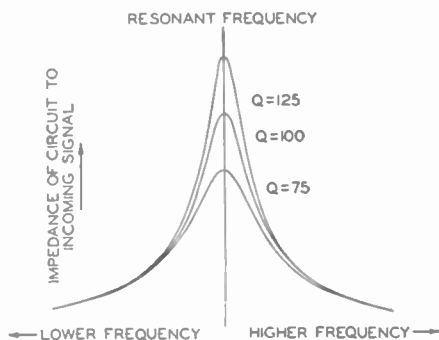
Fig. 3.2. The variation in the response curve with different values of Q.

change but, with the advent of high gain tubes, amplification is not too serious a problem. The emphasis now can be shifted to fidelity, which is especially necessary for the reproduction of images in television receivers.

Transformer Coupling. Whereas the simple circuit already described is sometimes used by itself for tuning, a more common combination is shown in Fig. 3.3. Here we have an untuned primary coil inductively coupled to a tuned secondary. With this form of coupling, additional gain may result by having more turns in the secondary than in the primary coil. The stepped-up voltage applied to the grid of the next stage is larger

Fig. 3.3. A common form of coupled tuning circuit used in radio receivers.

than that obtained with only the single coil and condenser by a figure dependent upon the design of the coils.

The shape of the response curve of the primary circuit depends to a great extent upon the degree of coupling between the coils. When the coefficient of coupling k is low (i.e., when the coils are

relatively far apart), the interaction between coils is small. The secondary response curve will retain the shape shown in Fig. 3.1B.

As the coefficient k is increased, the secondary circuit reflects a larger impedance into the primary. The primary current is affected more by variations in the tuning of the secondary condenser. This, in turn, changes the manner in which the flux lines cut across the secondary coil and the end result is a gradual broadening of both primary and secondary response curves. With very close coupling, the secondary response curve may continue to broaden and even develop a slight dip at the center. The dip, however, will never become too pronounced. It must be remembered that the discussion, so far, has dealt with coupled circuits where the primary is untuned. Hence, no matter how close a coupling is effected, the secondary will retain essentially the same curve shape given in Fig. 3.1.

On the other hand, with two *tuned* circuits coupled together, such as I.F. transformers, the effect of each circuit on the other becomes more pronounced. With close coupling, the familiar double-humped curve of Fig. 3.4 is obtained. The closer the coupling, the broader the curve and the greater the dip at the center.

For television reception, none of these preceding combinations provide the necessary uniform band width. Loose coupling gives a curve that is too sharp and which lacks uniformity over its range. Tight coupling tends to decrease the voltage of the frequencies near resonance because of the dip. Between these two extremes we may obtain some semblance of uniform response about the center point of the curve, but never for a 6-mc spread. However, if a low-valued resistor is shunted across the coil and condenser, we can artificially flatten the curve to receive the necessary 6 mc. The extent of the flat portion of the response curve will depend inversely on the value of the shunting resistor. The higher the resistor, the smaller the width of the uniform section of the curve. Hence, what we could not accomplish with

a coil and condenser alone, we can do with a combination of these two with resistance.

One of the undesirable results of increasing the width of a response curve by the resistor method is the lowered Q that is obtained. As the value of Q decreases, the voltage developed across the tuned circuit becomes smaller for the same input. An
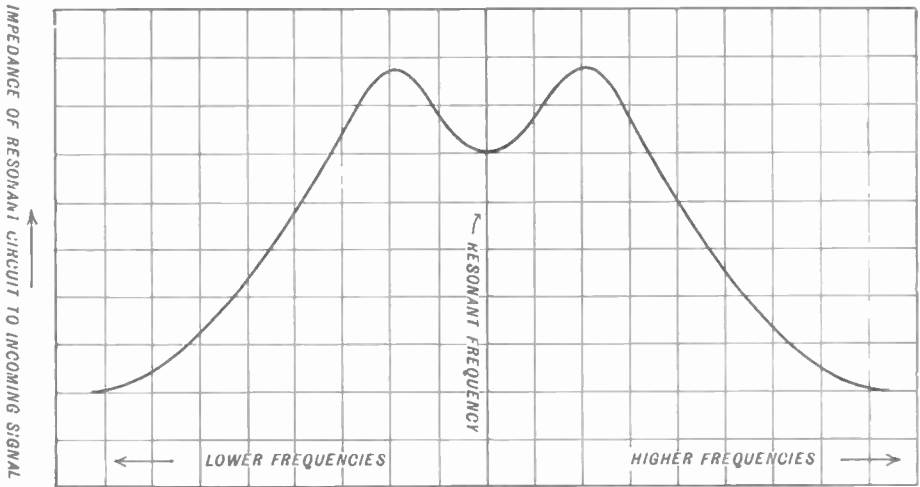
FIG. 3.4.   Close coupling between two tuning circuits produces this type of response curve.

inevitable reduction in output results. There are many ways of combining the tuned circuits and loading resistors to achieve the optimum gain and selectivity. Several of the more widely used circuits will be discussed in the section on R.F. amplifiers.

Special Tubes for Television. In commercial television circuits, resistors having values between 1,500 and 10,000 ohms are shunted across the tuning circuit to provide the necessary band width. To compensate for the signal reduction due to the shunting resistors, pentode tubes having large values of mutual conductance were especially designed for television. At present, the best gain obtainable is about 20 per stage. Compared to the amplification available with similar tubes at the broadcast

frequencies (several hundred or more), the need for a greater number of stages becomes evident.

The reason for the low gain at television frequencies is directly related to the low-valued shunting resistor that is placed across the tuning circuit. A tuning circuit, when connected in the output of a tube, is essentially in series with the plate resistance of the tube. This is illustrated in Fig. 3.5, in which the actual schematic and its electrical equivalent are shown. At resonance, the resistance of the tuning circuit itself may be high, but due
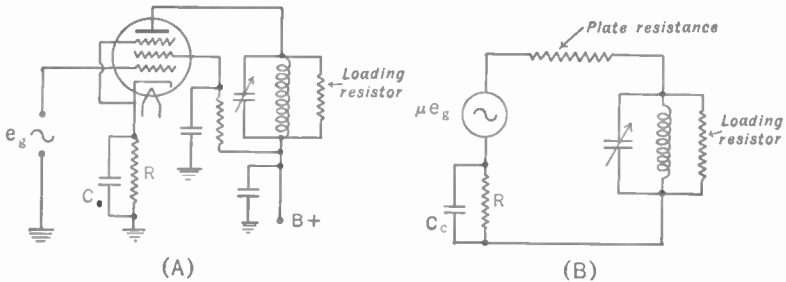
Fig. 3.5. An amplifier stage (A) and its equivalent circuit (B).

to the low shunting resistor, the total value of the combination becomes low. The plate resistance, on the other hand, is very high (in pentodes), and most of the output voltage is lost in the tube. Only a small portion of the total voltage appears across the tuning circuit to be transferred to the next stage.

Mathematically, the gain of the pentode stage can be expressed closely by the relation:

$$\text{Gain} = g_m \times Z_L$$

where g_m = mutual conductance of the tube (in mhos),
Z_L = load in output circuit (in ohms)

For a 6AG5 tube, g_m is 5,000 micromhos. With a plate load of 2,000 ohms, we obtain

$$\text{Gain} = \frac{5,000}{1,000,000} \times 2,000$$

$$= 10.$$

The 5,000 is divided by 1,000,000 to convert it from micromhos to mhos.

To obtain more amplification per stage, the mutual conductance of the tube must be increased. g_m, it will be recalled, represents the change in plate current caused by a change in grid voltage. To effect an increase in this ratio, radio engineers designed tubes in which the grid is given greater control over the space charge near the cathode. This was done by moving the grid closer to the cathode. Although this caused an increase in grid-to-cathode capacity, it increased the mutual conductance even more. This design is exemplified in tubes like the 1800 series (1852, 1853) and the miniature tubes, 6AG5, 6J6, 6AK5, and 6C4.

As an example, the 6AG5 has a mutual conductance of 5,000; the 6AK5 likewise has a g_m of 5,000, and the 6AC7 has a g_m of 9,000. Compare these values with ordinary R.F. and I.F. pentode voltage amplifiers, like the 6SK7, 6D6, 6S7, and the 6SJ7, which have mutual conductances of 2,000, 1,200, 1,750, and 1,600 micromhos, respectively. If the gain of the television stage is computed using these values of mutual conductance, a voltage amplification much less than 10 is obtained.

R.F. Amplifiers. The typical television R.F. stage, shown in Fig. 3.6, is very similar to the same stage in amplitude-modulated broadcast receivers. Its functions are threefold. First, it provides signal amplification in a portion of the set where the signal is at its lowest value. In outlying regions or noisy locations, this extra amplification may be the deciding factor in whether or not satisfactory reception is obtained. Second, it provides greater discrimination against signals lying in adjacent bands. This is especially applicable for image frequencies. A properly designed R.F. stage will help the signal override any small interferences that are produced in the tubes themselves. The latter boost applies only to the first tube or two (especially the mixer) where the signal may be comparable to the internal disturbance voltage. In audio systems, the internal tube disturbance is known as noise. In television receivers, these dis-

turbances are amplified along with the video signal and, if stronger than the received signal, will appear as small white spots on the image screen. (These spots are sometimes referred to as "snow," or masking voltages.) Finally, the R.F. amplifier also reduces oscillator re-radiation, which is quite offensive to neighboring receivers.

The tube employed in the R.F. stage, besides having a high mutual conductance factor, should also possess an extended cut-
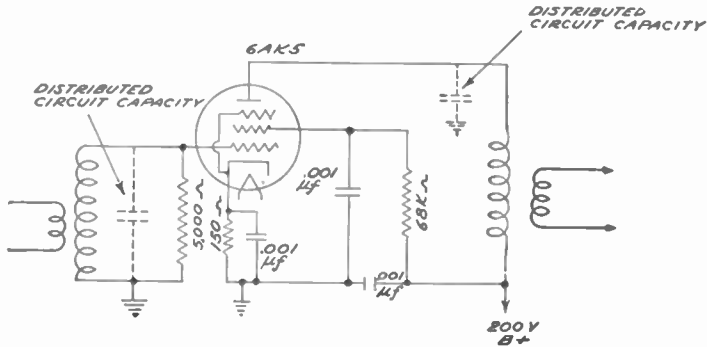
FIG. 3.6. A typical television R.F. amplifier.

off characteristic. With extended cut-off properties, the stage does not distort as readily when large input signals are received. Furthermore, automatic gain control * voltage may be applied to the tube, materially aiding the amplifier stability and tending to maintain a steady signal output.

Some of the forms that the R.F. stage may assume are shown in the accompanying diagrams. In Fig. 3.6, transformer coupling is used in the input and the output circuits of the R.F. amplifier. Each transformer is tuned to a slightly different frequency, the resultant overlapping response characteristic extending for 6 mc. Too great a separation between peaks will result in a considerable dip at the center of the response. By carefully choosing the values of the loading resistors, we can

* A.G.C. in a television receiver is similar to A.V.C. in a conventional radio receiver.

achieve a fairly uniform response without, at the same time, decreasing the circuit gain too much.
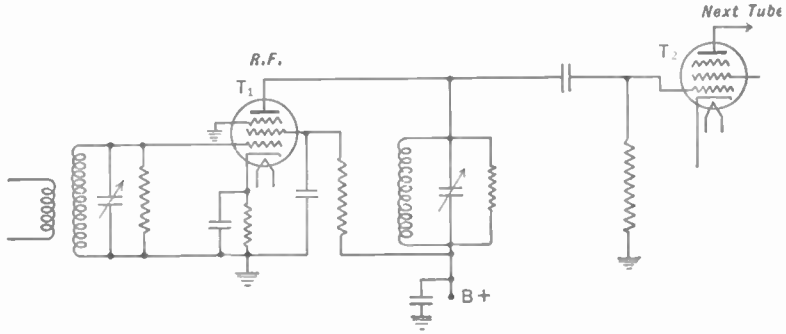
Fig. 3.7.   Another R.F. amplifier stage.   One tuned circuit is common to the plate of T_1 and the grid of T_2.

In Fig. 3.7 we have an arrangement in which a single tuned circuit, instead of a transformer, is used between the plate of the R.F. amplifier and the mixer tube.   The tuning capacity shown in each of these diagrams might either be a small variable trimmer condenser or the stray circuit wiring and tube capacity always present in the circuit.   In the latter instance, adjustment of the tuned circuit would not be accomplished by varying the capacitance (since the wiring and tube capacitances are not adjustable) but by using movable cores within the coil. Thereafter a selector switch, or some other tuning arrange-

Fig. 3.8.   A continuous permeability tuner.

ment, is used.   Although only one set of coils is shown in some of these diagrams, there would be similar arrangements for each of the channels.
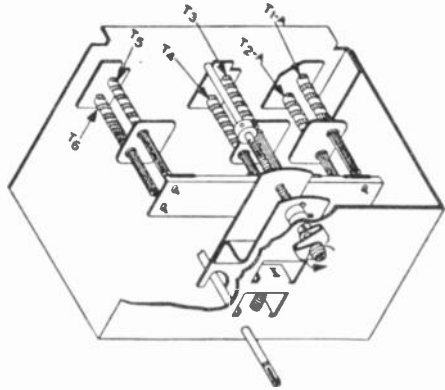
An example of a continuous permeability tuner is shown in Fig. 3.8. The movable slugs of each coil are mechanically ganged together and move in or out of the coils when the front panel
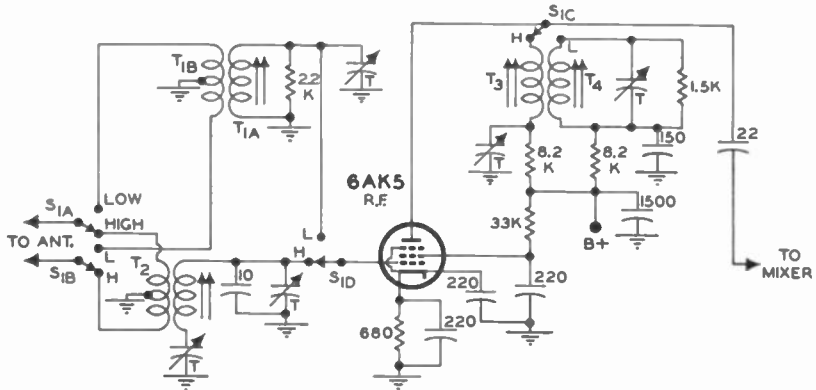
Fig. 3.9. The R.F. section of a television receiver using the permeability tuner shown in Fig. 3.8.

knob is rotated. In the circuit itself (Fig. 3.9) there are two sets of coils in the front-end stage, of which only one set is used at any one time. T_1 and T_4 operate only on the five lower tele-
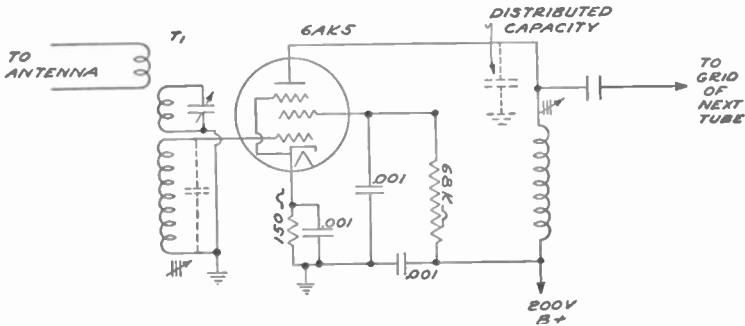
Fig. 3.10. An R.F. amplifier which combines the response characteristics of grid and plate tuned circuits to obtain a 6-mc overall spread.

vision channels. When the set is to receive any of the seven upper channels, a special switch on the front panel is placed in the high position. The active coils in the set now become T_2

and T_3. T_3 and T_4 represent the tuned circuits of the following mixer; the local oscillator would similarly have two coils (T_5 and T_6 in Fig. 3.8).

The R.F. amplifier uses a 6AK5 high-frequency pentode whose gain is controlled by an automatic gain control (A.G.C.) voltage (not shown in this diagram). Bandswitch S_{1A} and S_{1B} connects the antenna to coupling coil T_1 on the low band and to coil T_2 on the high band. A single tuned circuit couples the output of the R.F. amplifier to the converter.

A common practice of some manufacturers is to insert an over-coupled transformer in the input circuit and a single peaked circuit in the plate circuit of the stage. One such circuit is shown in Fig. 3.10. The primary winding of T_1 is untuned and matches the transmission line impedance. The grid winding is tuned by the grid input capacitance of the tube, plus whatever stray capacitance is inevitably present in the circuit. The third winding contains a small trimmer to permit adjustment, although in some instances it is nothing more than a one- or two-turn winding which functions as a

FIG. 3.11. The combination of two tuning circuits to produce a flat-topped overall response. (A) grid-circuit response; (B) plate circuit response; (C) overall response.

link coupling between the input and grid coils. The combination of these three coils results in a double-peaked response curve (see Fig. 3.11A). In the plate circuit of the stage, and serving as impedance coupling between circuits, is a single tuned coil. Its response is single-peaked, as illustrated in Fig. 3.11B. By properly adjusting the peaks of these circuits, we can readily achieve an overall flat response of 6 mc for the stage (see Fig. 3.11C).

Another method of coupling between stages in order to achieve a broad bandpass is shown in Fig. 3.12. Here, a small capacitor connects the primary and secondary windings. The value of this capacitance is low (10 to 20 $\mu\mu f$) and governs the extent of the bandwidth; increasing the capacitance increases the bandwidth.

In Fig. 3.13. mutual capacitive coupling between R.F. amplifier and the mixer is achieved in still another way. L_A and L_B
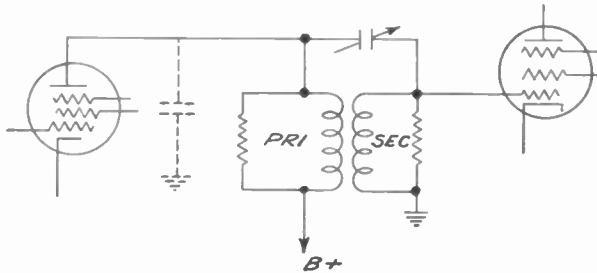
Fig. 3.12.   One method of increasing the coupling between two tuned circuits to achieve broad bandpass.

are two coils which are coupled to each other *only* through the common capacitance C_4. In other words, their magnetic fields do not interact. Each coil is pre-tuned to the same frequency by means of a brass slug. C_A represents the output capacitance of the 6AG5 R.F. amplifier plus other circuit capacitances; C_B is the input capacitance of the following 6J6 plus the distributed wiring capacitance.

In this type of tuned circuit, the bandwidth is determined by the degree of coupling and the Q's of L_A and L_B. The degree of coupling is controlled by the value of C_4. The smaller this capacitance, the greater the mutual impedance and the greater the bandwidth. The value of C_4 is chosen to provide a bandpass of approximately 6.0 mc. To maintain a constant bandwidth, C_4 has a value of 250 $\mu\mu f$ on the lower channels and a value of 140 $\mu\mu f$ on the higher channels. This compensates for the

change in coil Q's with frequency. For each channel a new pair
of coils is switched into the circuit.

Another feature of the circuit in Fig. 3.13, used in Motorola
television receivers, is the provision for either 75- or 300-ohm
input transmission lines. This is accomplished simply by using
the full primary winding of the input transformer for the 300-
ohm line and half of the winding for the 75-ohm coaxial line.
Inductance of a coil is proportional to the square of the number

Fig. 3.13. Mutual capacitive coupling, C_4, is used between L_A and L_B. (See text).

of turns. Doubling the number of turns produces four times
the inductance and, at the same frequency, four times the im-
pedance; 300 ohms is four times 75 ohms.

The complete schematic (Fig. 3.14A) indicates that separate
tuned circuits are switched in for each channel. The physical
appearance of the Motorola rotary switch tuner is shown in
Fig. 3.14B.

In place of the conventional coil and condenser components of
tuning circuits, RCA, in recent sets, has utilized a modified
quarter-wave transmission line. The circuit schematic is shown
in Fig. 3.15. The transmission line from the antenna is fed di-
rectly into the grids of a 6J6 push-pull triode amplifier. To
match the impedance of the line, two 150-ohm resistors are
connected in series to provide the total of 300 ohms. T_1 is a
center-tapped coil used to prevent low-frequency signals from

reaching the grids of the R.F. amplifier. C_1 and C_2 are antenna-isolating condensers.

In the plate circuit of the R.F. amplifier, starting with $L26$ and progressing down to $L1$, we have a series of inductances that
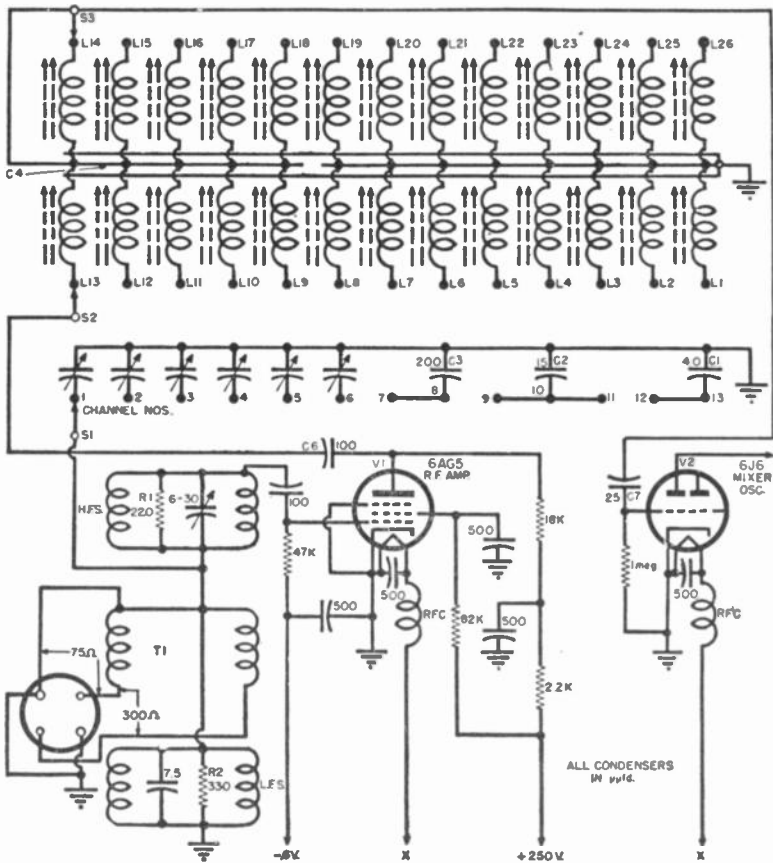
Fig. 3.14A.   The complete circuit of the diagram in Fig. 3.13 showing the tuning coils for all television channels.

may be considered as sections of a quarter-wave transmission line.   The switch, as it moves progressively to the left, brings in more inductances, thus decreasing the channel frequency.   In position 13, only $L25$ and $L26$ are in the circuit and the receiver

is set for the highest television channel. At position 1, the set will receive the 44–50 mc channel. At various points along the
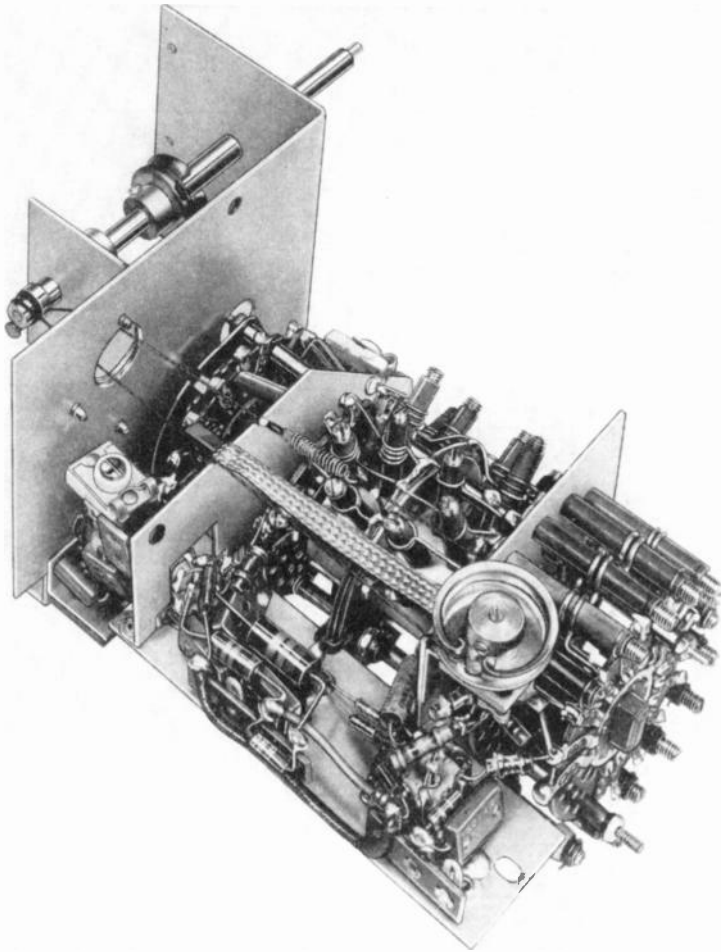
FIG. 3.11B. The Motorola rotary switch tuner.

line, adjustments may be made by changing the position of the tuning slugs. The physical construction of each of the small inductances, $L13$ to $L26$, is a small, fixed silver strap between the
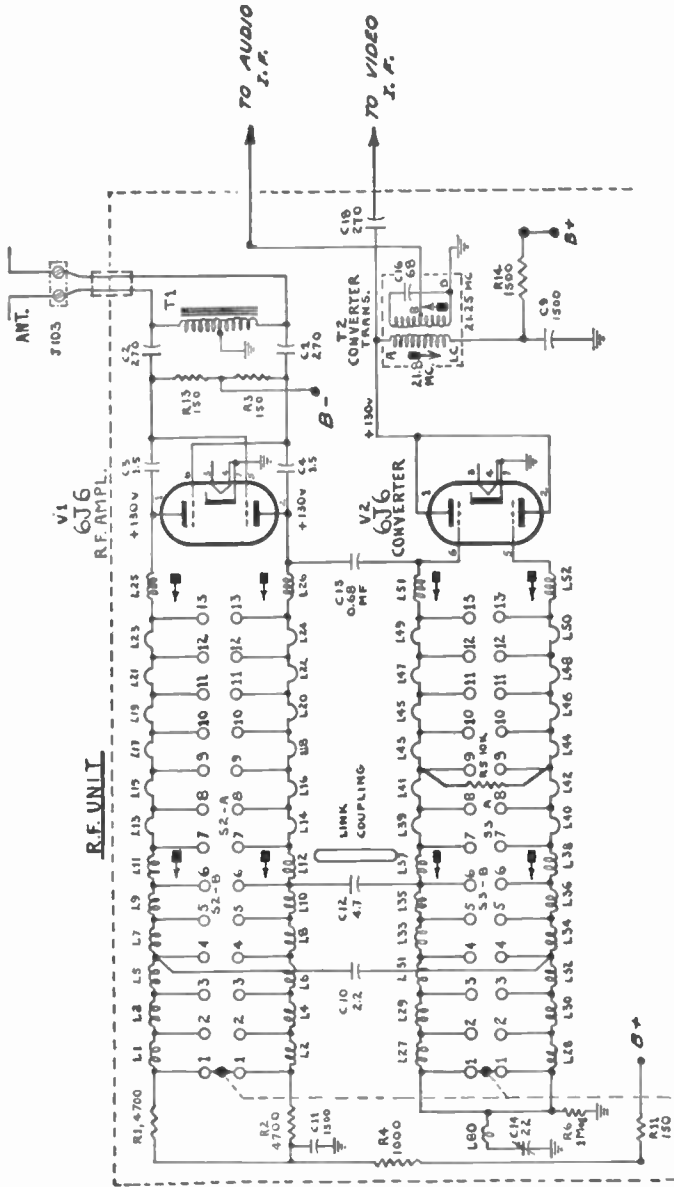
Fig. 3.15. A quarter-wave transmission line used for tuning the R.F. stages of a television receiver.

switch contacts. Each strap is cut long enough to introduce a 6-mc change in frequency. In order to make the transition from the lowest high-frequency channel, 174–180 mc, to the highest low-frequency channel, 82–88 mc, adjustable coils $L11$ and $L12$ are used. Coils $L1$ to $L10$ are more substantial in appearance than coils $L13$ to $L26$, being wound in figure-8 fashion on fingers protruding from the switch assembly.

Since each section of the 6J6 is a triode, neutralizing condensers are necessary to counteract the grid-to-plate capacitance. This is the function of C_3 and C_4.

Coupling between the quarter-wave line of the R.F. amplifier and a similar section in the grid circuit of the mixer tube is two-fold: by direct capacitance connection and by link coupling. The response characteristic of these R.F. circuits extends the full 6 mc. In addition, a 10,000-ohm resistor is connected across the quarter-wave line in the mixer grid circuit.

Pentodes rather than triodes have been used in the R.F. and I.F. stages of conventional sound receivers because of their ability to amplify more strongly weak signals. However, the wide channels used for television require low-valued shunting resistors. The equivalent circuit of a high-resistance pentode and a low-resistance load, shown in Fig. 3.5, indicates that most of the amplified signal voltage is lost in the tube. A triode, on the other hand, has a much lower internal resistance and absorbs less of the signal. Thus, the advantages of pentodes over triodes for television no longer exist. A properly constructed triode will give as much gain as a pentode and do it with considerably less noise. Noise originating in a tube varies directly with the number of grids within that tube. This is one reason why the trend has been toward the development of triodes for high-frequency amplifiers and diodes for mixers. The gain of a push-pull triode amplifier can be made at least equal to and generally greater than a single pentode.

Grounded-Grid Amplifiers. Recently, an arrangement known as the grounded-grid amplifier has permitted the use of triode R.F. amplifiers with good results. The grounded-grid amplifier

is contrasted with the conventional amplifier in Fig. 3.16. Note that the grid of the tube is at R.F. ground potential and that the signal is fed to the cathode. The tube still functions as an amplifier because the flow of the plate current is controlled by the grid-to-cathode potential. Instead of varying the grid potential and maintaining the cathode fixed, the grid is fixed and the cathode potential is varied. The net result is still the same. In
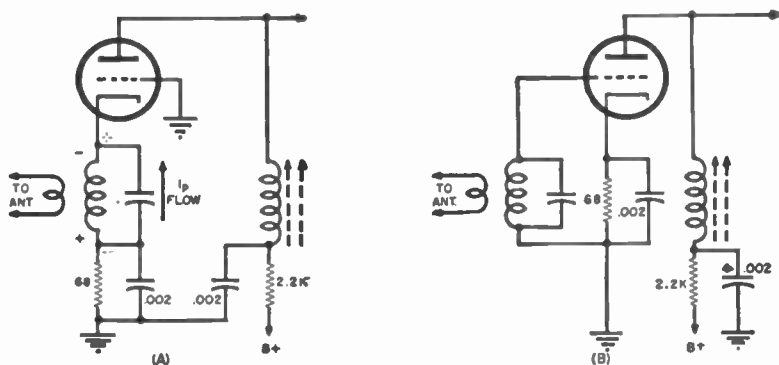
Fig. 3.16.   A comparison between the grounded-grid (A) and conventional R.F. amplifier (B).

addition, the grid, being grounded, acts as a shield between the input and output circuits, thereby preventing the feedback of energy which is so essential to the development of oscillations.

The grounded-grid amplifier also offers low input impedance, enabling the amplifier to match the antenna transmission line impedance. The low impedance provides a broader bandpass characteristic which is particularly desirable for 6-mc television signals.

In General Electric television receivers, the R.F. amplifier employs a 6AU6 high-frequency pentode connected as a grounded-grid triode amplifier. (See Fig. 3.17.) The antenna is connected into the cathode circuit of the R.F. amplifier. L_1 is a simple high-pass filter designed to reject all low-frequency signals, especially those at the intermediate frequency. The cathode chokes. L_2 to L_6, are placed in series with the cathode

resistor to prevent the input-impedance from being lowered by the shunting effect of any stray capacitance to ground due to the cathode of the tube. The choke value is changed with frequency. R_1 and C_1 provide cathode bias.

The R.F. amplifier is coupled to the mixer tube through a wide-band transformer. One such unit is provided for each
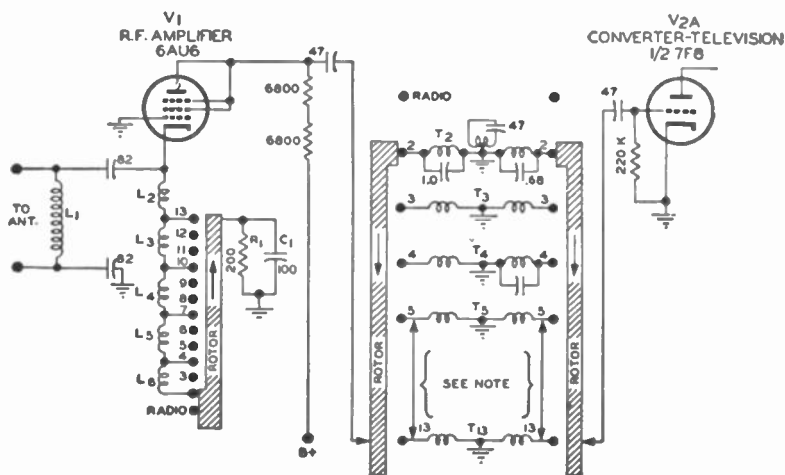
FIG. 3.17. The grounded-grid R.F. amplifier stage used in G.E. television receivers. (NOTE: R.F. coils and switch points for channels 6 through 12 not shown.) Coils T_6 through T_{12} correspond to channels 6 through 12 and are connected the same as T_5.

channel. The windings are self-tuned by the distributed and tube capacitances to provide maximum gain through a high L/C ratio. The R.F. coils for each channel are placed physically near the oscillator coils of the same channel (not shown) in order that both voltages will combine at the mixer grid.

Additional R.F. Tuning Methods. In the preceding paragraphs, continuous permeability and rotary switch tuners have been illustrated. (See Figs. 3.8 and 3.14B.) Additional methods which have been employed in commercial receivers include the rotary turret and the inductive type of tuner. The rotary turret type of tuner is best illustrated by the unit shown in Fig. 3.18.

This is the Standard Coil tuner and is used in the majority of present-day receivers. Separate coils are used for each channel and provision is made on the rotating drum for twelve sets of coils, covering channels 2 to 13. The antenna coil and the R.F. amplifier input coil are mounted on one form; the R.F. amplifier
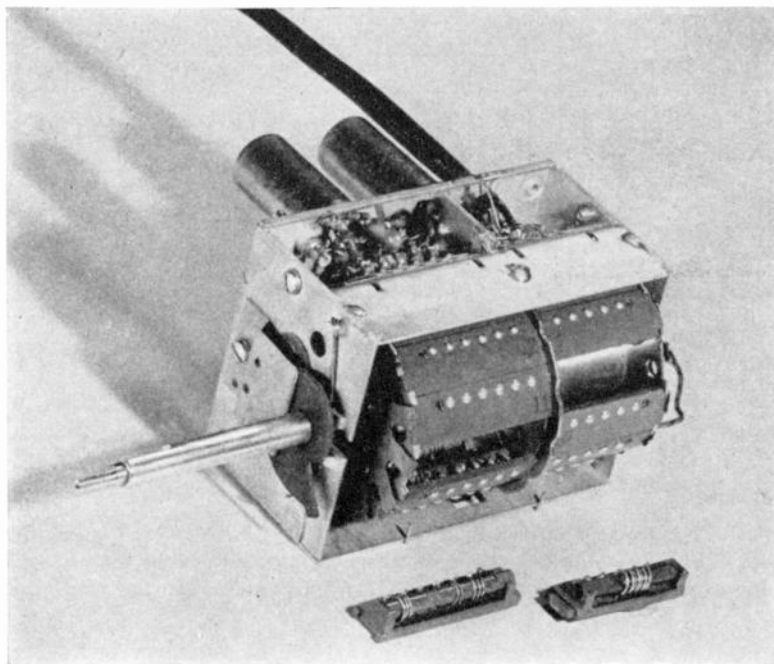
Courtesy Standard Coil

FIG. 3.18.   A rotary turret tuner employing separate tuning circuits for each television channel from No. 2 to No. 13.

output coil, the oscillator coil, and the mixer input coil are all grouped together on another form. These two units then constitute the complete set of coils for one channel. The forms are of the snap-in type and can readily be removed if necessary. The popularity of this tuner is due to its low cost, freedom from trouble, and good sensitivity.

An inductive type of tuner is the Inductuner shown in Fig. 3.19. This unit consists of three separate variable inductances

mounted on a common shaft. The coils, each containing ten turns, are wound on ceramic forms and movable trolley sliders make contact at each point on the coil.

Each trolley is grounded and, as it moves along, more and more turns of each coil section are shorted out, progressively raising the frequency of the circuit. The inductance can thus
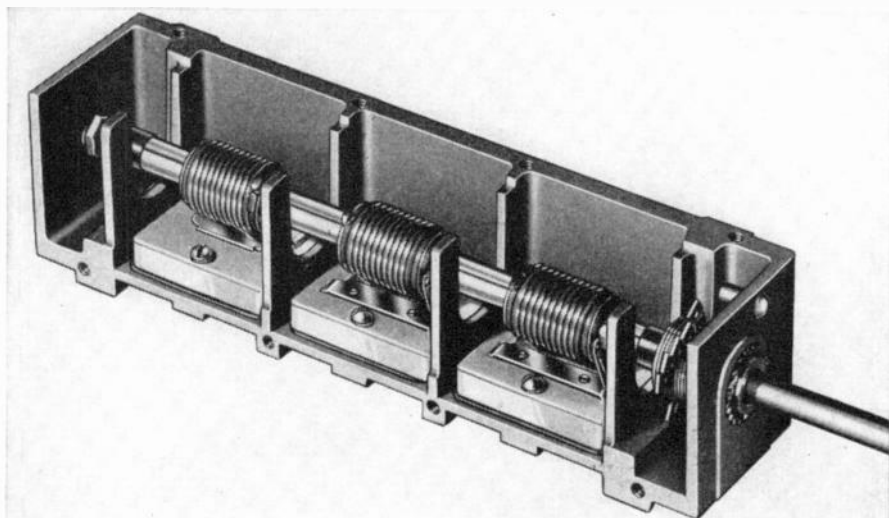
Fig. 3.19. The physical appearance of the Inductuner.

vary from 0.02 to 1.0 microhenry, permitting a tuning range from 44 to 216 mc.

The use of the "Inductuner" in DuMont television receivers is illustrated in Fig. 3.20. The input circuit leading to the antenna transmission line is an unbalanced arrangement having an impedance of 72 ohms. The signal is received in the cathode leg of the R.F. amplifier because the tube is being operated as a grounded-grid amplifier with both triode sections connected in parallel. The signal output of 6J6 R.F. amplifier is transferred to the mixer via the complex coupling network of L_1, L_{2A}, C_1, C_2, C_3, L_3, and L_{2B}. L_{2A} and L_{2B} form two sections of the three-

section Inductuner. L_1 and L_3 are end coils, inserted in series
with the Inductuner windings to obtain a better response at the
high end of the band. Each of these coils has but a few turns,
and, when the trolleys of the Ind ctuner are run out to the end
of their windings, only the end coils (L_1 and L_3) represent the
inductance still remaining in the circuit. In this way the high-
frequency response is kept up.
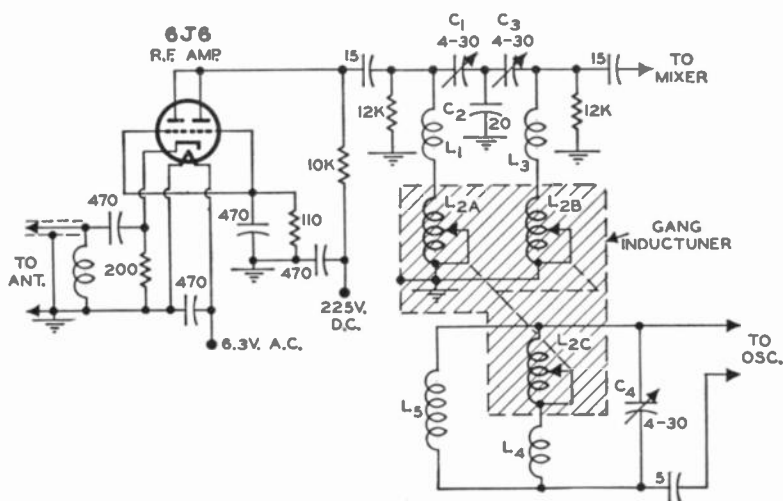
FIG. 3.20. Circuit diagram showing the use of the Inductuner in the R.F. section
of a television receiver.

The third winding of the Inductuner is employed in the oscil-
lator stage together with an end coil, L_4, a shunt coil, L_5, and a
shunt condenser, C_4. The shunt coil is required because the
oscillator frequency is higher than the incoming signal fre-
quency by an amount equal to the I.F.

Recently a modified Inductuner has appeared using a spiral
type of winding (see Fig. 3.21). Operation of this unit is iden-
tical to that of the older Inductuner, except that now the con-
tact arm moves around a spiral instead of along a solenoid.
The advantages gained are greater compactness, lower cost, and
increased mechanical stability. The smaller size permits a fourth

winding that can be used at the input to the R.F. amplifier.

Internal Tube Capacitances. As equally important as the mutual conductance of a tube are its interelectrode capacitances. It has already been noted that the gain of a stage is equal to the product of the mutual conductance of the tube and the load
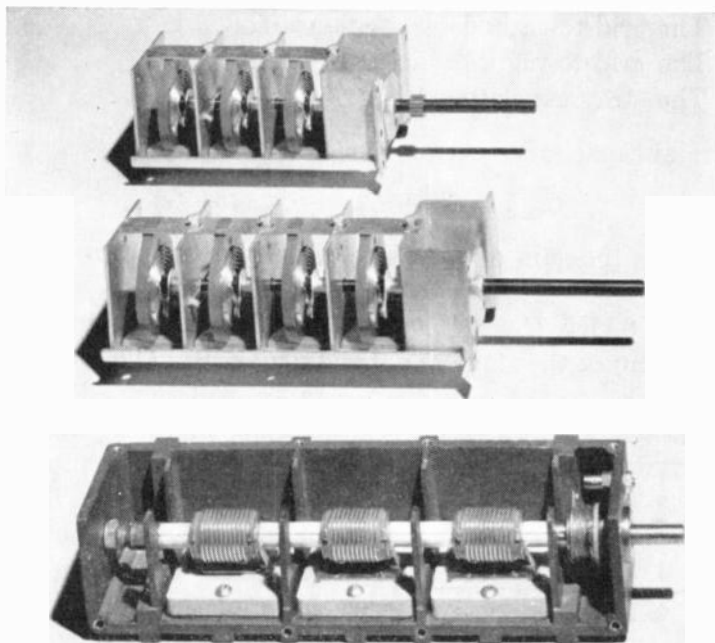
Fig. 3.21. A comparison of the old and the new Inductuners.

impedance. The load impedance, in turn, is essentially equal to the value of the resistor shunting the tuning coil and condenser. And, as we shall see in a moment, it is the value of the L to C ratio of the tuning circuit which determines how high a resistor we can use.

For greatest gain over any band, a high L to C ratio should be maintained in each resonant circuit. The capacitance which shunts the coil includes the interelectrode capacitance of the tube. As we make this capacitance smaller, the gain increases correspondingly. In addition, the value of the resistance R needed to load a tuned circuit is proportional to the reactance

of the capacitance across the coil. Thus, with a smaller capacitance, we obtain a higher capacitive reactance and the loading resistor is higher in value. The end result is more gain.

For the R.F. input stage, the minimum capacitance is determined by:

1. The grid-to-cathode capacitance, C_{gk}.
2. The grid-to-plate capacitance, C_{gp}.
3. The stray capacitance, C_s.

The total capacitance is equal to

$$C_{\text{total}} = C_s + C_{gk} + C_{gp}(1 + G)$$

where G is the gain of the stage, usually about 10 in these amplifiers.

For the 6AK5, C_{gk} is equal to 4 $\mu\mu$f, C_{gp} amounts to 0.015 $\mu\mu$f, and the gain of the stage may be taken as 10. The stray capacitance will depend upon the manner in which the stage is wired and may amount to an additional 10 $\mu\mu$f. The total, or 14.2 $\mu\mu$f, would then represent the minimum capacitance of the stage and would have to be considered as an addition to any tuning condenser inserted across the coil (see Fig. 3.22).
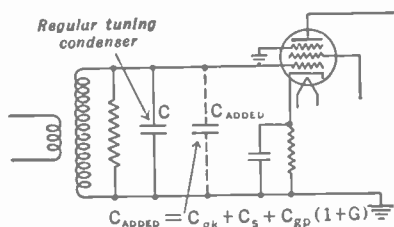
Fig. 3.22. At the higher frequencies, the stray wiring and internal tube capacitances represent an appreciable part of the total circuit capacitance and hence must be included in all computations.

At the broadcast frequencies (500 to 1,500 kc) in the ordinary home receiver, these tube and wiring capacitances are never serious when compared to the size of the tuning gang employed. Hence, very little thought is given to them. However, when frequencies as high as 90 to 100 mc are to be received, the tuning condenser may be even smaller than these additional capacitances and they can no longer be disregarded.

Whereas the wiring and tuning capacitances remain fixed once

the set has been completed, no such happy state of affairs exists for C_{gk} or C_{gp} $(1 + G)$. The latter values will vary as the gain of the stage varies. This occurs every time the input voltage changes. C_{gk} will change its value as the electron current is altered. The effect of the variation, if great enough, is sufficient to detune the stage. Again, these small items, insignificant in themselves, may become very influential as the frequency increases and the size of the coil and condenser decreases.
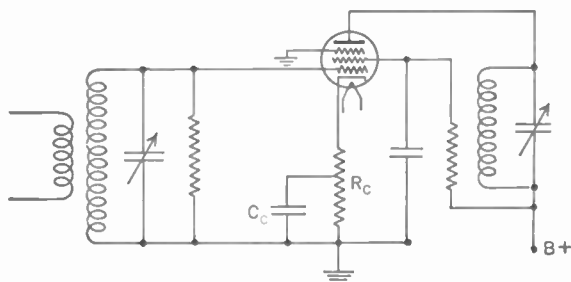
Fig. 3.23. By leaving R_c, either partially or totally unby-passed, it is possible to minimize the effect of tube capacitance changes with receiver operation.

It has been discovered that a small amount of negative feedback will minimize these variations. For this purpose, a portion of the grid-bias resistor is unby-passed. In doing this, however, the cathode is no longer directly connected to the condenser C_c and is not at a-c ground potential. Under these circumstances, the screen condenser and the suppressor grid should be tied directly to ground instead of to the cathode itself. A suitable circuit is given in Fig. 3.23.

We have considered only the minimum capacitance in the input circuit. A similar line of reasoning may be applied to the plate tuning circuit, where the total minimum capacitance is composed of the following:

1. The output capacitance, C_o, as obtained in any tube manual.

2. The wiring capacitance.

The list is short because it has been assumed that the output circuit is inductively coupled to the next grid. This coupling tends to separate the input capacitance of the next tube from the plate circuit of the preceding tube. However, if a direct connection is made to the next tube, the additional input capacitances must be taken into account.

From the foregoing brief discussion, it is quite evident that in designing R.F. television amplifiers of all types, tubes should be selected that have:

1. High mutual conductance values.
2. Low input and output capacitances.

It has been suggested that the usefulness of a tube may be determined by the ratio of (1) to (2), or

$$\frac{g_m}{C_{\text{in}} + C_o}$$

This ratio is called the "Figure of Merit" of a tube, and large values are desirable. It should be noted that both numerator and denominator of the ratio are important at the high frequencies. At the low frequencies, the tube capacitances have less importance and only g_m need be considered.

Tubes with Two Cathode Terminals. One final word about recent tubes which have been built with two cathode terminals. It has been found that the input impedance of vacuum tubes, which is ordinarily so high as to be considered infinite, begins to decrease as we raise the frequency of the signal. In the television channels above 50 mc, this tube loading on the attached tuned circuits causes a reduction in the gain and Q of the circuit. One of the causes for this reduction in tube input impedance is due to the inductance of the cathode leads within the tube itself. Why this is so can be seen from the following explanation.

The current of a tube must flow through the cathode lead wires and in so doing develops a voltage across the inductance of these wires. Note that this inductance is of importance only

when the signal frequency is high. The average or d-c component of the current does not enter into this consideration. The voltage produced across the lead inductance, although due to the plate current, is impressed between the grid and the cathode. As a result, the effective signal voltage acting at the grid of the tube is lowered because of the opposition of the cathode lead voltage. The situation is analogous to inverse feedback, except that the lead-inductance voltage is present even
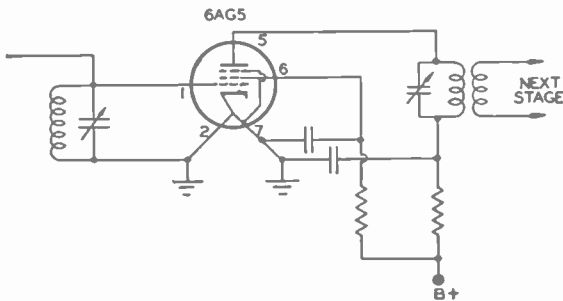
Fig. 3.24. The use of two cathode wires to eliminate the adverse effect of cathode inductance.

though the cathode of the tube is grounded directly to the tube socket. The lead inductance occurs within the tube itself.

Note that the voltage which is developed across the cathode-lead inductance is due to the plate current. So far as the plate circuit is concerned, this voltage is of little significance. It is at the grid, where the signal is applied, that the voltage is important.

To eliminate the effect of the lead inductance voltage on the input grid circuit, tube manufacturers have designed tubes with two wires leading directly from the cathode structure inside the tube to the tube base. In this manner, one terminal is available for the grid circuit return and one for the plate circuit and its current, and the two circuits are divorced from each other. In the circuit of Fig. 3.24 the 6AG5 R.F. amplifier tube possesses two cathode terminals. Even though both cathode terminals are grounded, pin 2 would be connected to the grid coil and con-

denser. Pin 7 is the cathode connection for the plate circuit. To it would be connected the screen-grid and plate by-pass condensers. The d-c plate current divides between both cathode terminals, but this is of no consequence since it does not contribute to the degenerative effect.

Servicemen should be cautious, in this respect, in accepting the connections of the two cathode terminals as shown on the manufacturer's schematic diagram. The diagram is not always an exact representation of the circuit, as laid out in the chassis, especially with regard to the separate connections of the same cathode. In many schematics, the cathode is grounded, but the diagram does not indicate that a separation exists as explained for Fig. 3.24. If anyone who is not familiar with the reason for the separate cathode terminals connected them together, the result would be a decrease in receiver sensitivity due to a lower input resistance.

THE H.F. OSCILLATOR, MIXER AND I.F. AMPLIFIERS

Converters—The Effect of High Frequencies. Present-day sound superheterodyne receivers obtain the conversion of the radio frequencies to the intermediate frequencies either at the first or at the second stage, depending upon whether or not an R.F. amplifier is employed. Economically, the best method of obtaining the conversion is through the use of a single tube operating both as a mixer and an oscillator. A typical circuit is given in Fig. 4.1. The desired intermediate frequencies appear in the plate circuit and are inductively transferred by the I.F. transformers to the appropriate amplifiers. In early sets, separate oscillators were widely employed; with the development of special tubes of the pentagrid converter type, however, merely one tube is required now.

The interchangeable use of the words "mixer" and "converter" is common practice, although there exists a definite technical difference. A tube is a mixer only when a separate oscillator is used. Its action then merely mixes or combines the R.F. input signal and the oscillator signal to obtain the difference frequency, or I.F. A converter combines the action of mixing and generating the oscillator voltage within one envelope.*

With increase in frequency, the stability and output of the oscillator section of a converter decrease. At the relatively high frequencies required for television, the *conventional* converter becomes unsatisfactory. The oscillator has a tendency to drift, and its output voltage is not constant. The only suitable

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* Since the interchangeable use of these two words in industry is extensive, we will follow the same practice. No confusion should result.

FIG. 4.1. A typical low-frequency pentagrid converter stage.

method of obtaining sufficient oscillator voltage, without appreciable frequency drift, is to separate the oscillator from the mixer.

Miniature high-frequency triodes and pentodes appear to find equal application as mixers in current television receivers. Incoming signals, at this point in the receiver, are extremely weak, and all extraneous noise must be prevented from approaching
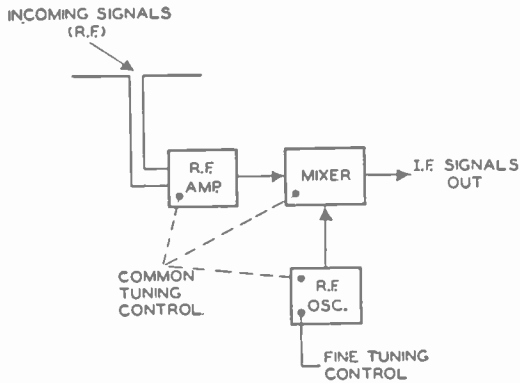
Fig. 4.2. A block diagram of the front-end section of television receivers.

signal strength. Triodes are superior to pentodes and the latter are superior to pentagrid converters because each element within a tube introduces a certain amount of noise into the circuit. In this respect, diodes would be the best tube of all to use, except that it is felt the additional amplification provided by triodes and pentodes outweigh whatever reduction in noise would result from the use of a diode. For the oscillator, triodes are almost universally used.

Energy from the oscillator may be capacitively or inductively coupled to the mixer. Two frequently used methods are shown in Fig. 4.3. Interaction between the input signal and the oscillator outside the mixer tube is kept as low as possible, to prevent any changes occurring in the oscillator frequency and to minimize oscillator radiations from appearing at the antenna. The

latter tendency must be especially guarded against in sets that do not have an R.F. stage ahead of the mixer.

It has been observed that any considerable amount of radiated signal can produce a complete loss of contrast or even a negative picture in near-by television receivers. When the interfering
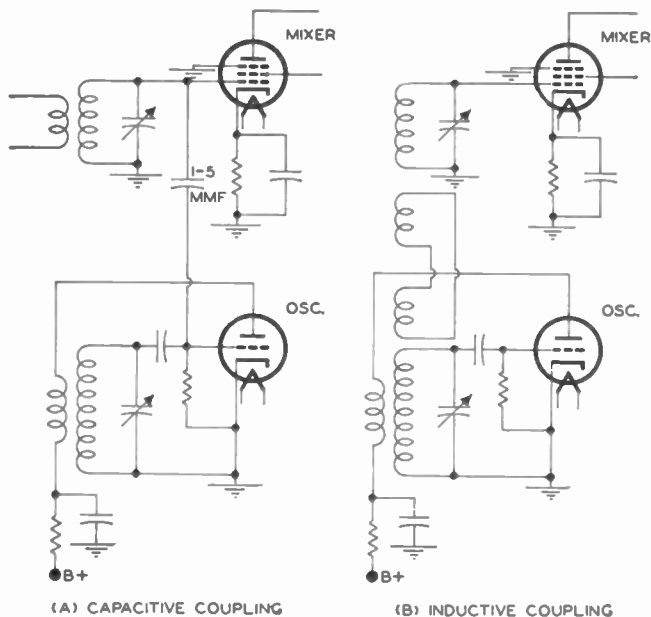
FIG. 4.3. Coupling energy from the oscillator to the mixer by inductive or capacitive means.

frequency is close to the picture carrier of the station being received by the other sets, the "beat" interference produces vertical, horizontal, or slanted stripes across the screen.

Within the mixer of the television receiver, the received signal and the oscillator voltage both modulate the electron stream to form the desired audio and video I.F. voltages. In nearly all sets, the signal from the R.F. amplifier is transformer- or impedance-coupled to the mixer. The oscillator voltage, as indicated, is transferred to the mixer tube either capacitively or inductively.

Oscillators. Perhaps the most frequently employed oscillator circuit in current television receivers is the circuit shown in Fig. 4.4B. It is known as the ultraudion and is equivalent in its action to the well-known Colpitts circuit. (See Fig. 4.4A.) In the ultraudion, the voltage division across the tank circuit is accomplished through the grid-to-cathode (C_{gk}) and the plate-to-cathode (C_{pk}) capacitances within the tube. The feedback voltage which sustains oscillations is developed across C_{gk}. In Motorola television receivers, the oscillator stage has the actual form show in Fig. 4.5A and the equivalent network indicated in Fig. 4.5B. The voltage-dividing capacitance network consists of the effective capacitance of C'_{gk} in series with the parallel combination of C'_{pk} and C_1, while C_t represents the combination of the grid-plate capacitance, the distributed capacitance, and C_2. C_2 is a temperature compensating condenser and helps reduce oscillator drift. In spite of this, some drift does occur, and C_1 is provided to permit the set user to adjust the oscillator frequency for the best sound output. Because C_1 is actually a vernier adjustment, it is labeled "fine-tuning control" and placed on the front panel. Any

Fig. 4.4. Circuit diagrams show the similarities between the Colpitts (A) and the ultraudion (B) oscillators. The circuit diagram (C) illustrates how the ultraudion is usually drawn.

shift in oscillator frequency immediately alters the I.F. produced as a result of the mixing action. The effect is the same as detuning the receiver. By means of the "fine-tuning" control, the oscillator frequency can be readjusted to its proper value. Condensers C_3 and C_4 keep the d-c plate voltage off the exposed coils. C_4 also makes it possible for the oscillator to develop grid-leak bias across R_1. A separate coil is brought in for each channel, and each coil can be adjusted individually as to frequency. This

is necessary because the oscillator frequency must be accurately set for each channel.
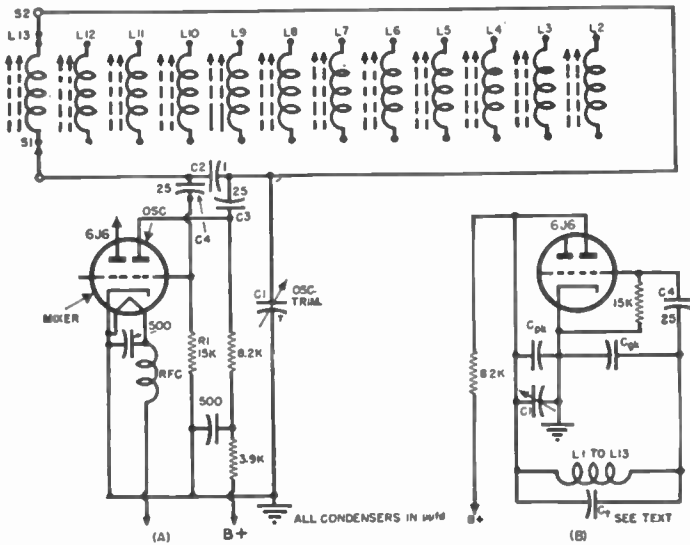
FIG. 4.5.   The ultraudion oscillator arrangement (A) and its equivalent circuit (B) as employed in Motorola receivers.

Modified Ultraudion.   In the Colpitts oscillator of Fig. 4.4A, it is entirely possible to shift the placement of the ground con-

FIG. 4.6.   The modified ultraudion circuit used by G.E. in their receivers.

nection from the cathode to the plate end of the tank coil without affecting the operation of the oscillator. Now, however, we must provide a different d-c path from the cathode to ground, otherwise the tube electron flow will be interrupted. For this, we can use an R.F. choke which provides the necessary d-c path but which still maintains the cathode at the required R.F. potential.   The corresponding shift in ground point can be applied to the ultraudion circuit, and an oscillator of this type is employed in G.E. tele-

vision receivers.   The actual circuit employed is shown in Fig.
4.6.

In sets using continuous tuning such as DuMont (Induc-
tuner) and Belmont (permeability tuning), no fine-tuning con-
trol is required.   Since the station is tuned in manually, oscillator
frequency drift can be compensated for directly by retuning.

FIG. 4.7.   (A) Another variation of the ultraudion oscillator.   (B) The various
tuning coils and condensers that are switched into the oscillator circuit for the
different television channels.

Still another variation of the ultraudion circuit is shown in
Fig. 4.7.   This differs from the previous circuit in possessing the
tuned circuit in its plate rather than in its grid circuit.   Grid-
leak bias is developed by the 30-$\mu\mu$f condenser across the 6,800-
ohm resistor in the grid circuit.   Grid current flows whenever
the cathode assumes a potential which is more negative with
respect to ground than the grid voltage present across the 30-$\mu\mu$f
condenser.   Actually, of course, this is the equivalent of driving
the grid positive with respect to the cathode, whereupon the grid
draws current.   This action is similar to that in any conven-
tionally connected tube.

In the circuit of Fig. 4.7A, the tuning coil L_1 remains in the
circuit at all times.   To change the resonant frequency of the
oscillator, additional condensers or coils are placed in parallel

with L_1. The added components used for each of the thirteen channels are shown in Fig. 4.7B. A testing point is provided to permit servicemen to measure the oscillator grid-leak bias voltage without actually going into the tuner employed in Andrea models.

Push-Pull Oscillator.   The simulated quarter-wave section transmission line tuner that RCA employs for their R.F. amplifier is also found in their oscillator circuit.   (See Fig. 4.8.)
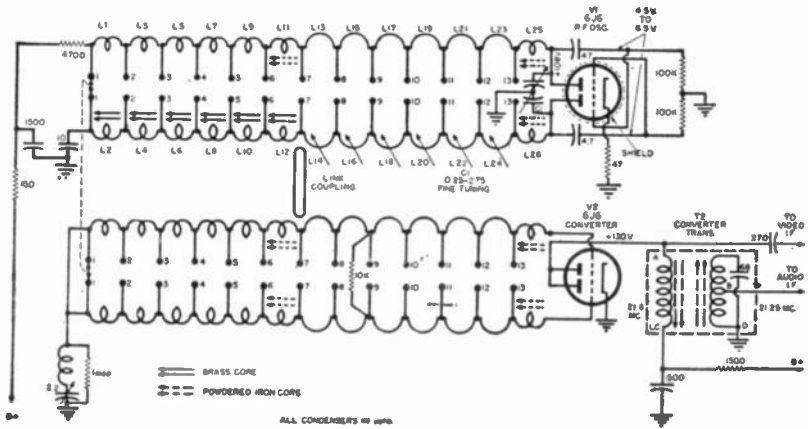
FIG. 4.8A. The simulated transmission line tuner employed in RCA television receivers. (NOTE: R.F. amplifier tuning section not shown. See Fig. 3.15.)

The oscillator is actually a push-pull arrangement with the R.F. plate voltage of one triode section feeding the grid of the other triode.   The channel switch, as it progressively moves down the line, adds more and more inductance to the line, effectively lowering the tank frequency.   For tuning, brass screws are placed near the high-frequency tuning straps L_{14}, L_{16}, L_{18}, L_{20}, L_{22}, L_{24}, and L_{26}, and brass cores are adjusted through coils L_2, L_4, L_6, L_8, L_{10}, and L_{12}.   For keeping the two sections of the line as closely balanced as possible, L_{11} and L_{25} are provided.

C_1 is a fine-tuning control which is connected across the entire tuning line.   It provides a frequency variation of approximately plus or minus 300 kc on channel 1, and this increases to plus or

minus 750 kc on channel 13. Coupling between the oscillator line and mixer line is accomplished by a single turn of link coupling and by physically placing the oscillator line close to the converter grid line.
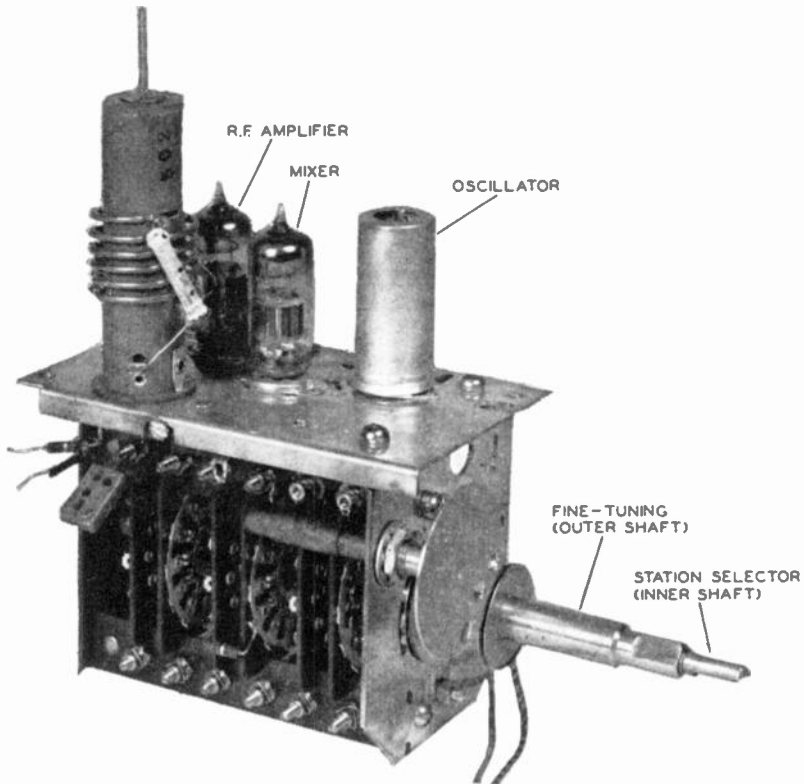
FIG. 4.8B. The RCA rotary switch tuner.

A.F.C. System. Philco television circuits employ an oscillator which at first glance appears to be similar to one of the preceding ultraudion oscillators. This much is true. (See Fig. 4.9.) However, further examination reveals that the second triode section of the 6J6 is also connected across the oscillator and therefore would affect its operation. This second tube is known as a reactance (or control) tube and, through its effect

on the oscillator, is able to counteract any reasonable shift in oscillator frequency. Here, then, is an automatic system for keeping the oscillator on frequency, removing the need for a fine-tuning control.

In order to understand and appreciate the operation of this reactance tube, let us determine how a tube can simulate the
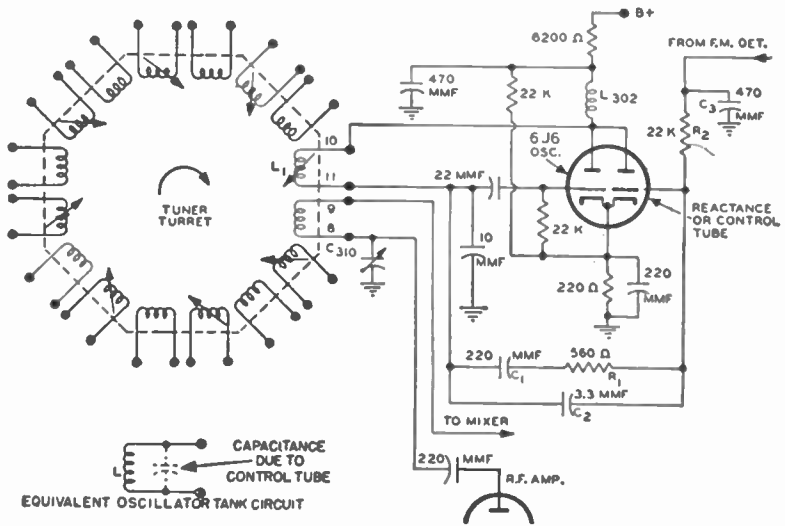
Fig. 4.9.   Circuit diagram of the Philco oscillator and control tube stage.

action of a resistance, a capacitance, or an inductance. In Fig. 4.10A, a tube is connected with normal plate and grid voltages, so that plate current is flowing through the tube. When we increase the plate voltage, the plate current will increase and the two will be in step within fairly wide limits of plate current flow. The same is true of a plate voltage decrease; the current will decrease in step. Since the two follow each other directly, we obtain essentially the same action as the voltage and current in a resistor and consequently the tube is functioning as a resistor, although, at some voltages, it acts as a nonlinear resistor.

Now, let us alter the circuit to the form shown in Fig. 4.10B. A source of R.F. voltage is connected to the plate of the triode

and the "B+" voltage now reaches the tube through an R.F. choke. The choke prevents the R.F. component of the plate current from passing through the d-c voltage source. In the same circuit, a small condenser and resistor transfer a portion of the R.F. voltage to the grid of the tube. Let us investigate this section of the circuit more closely.

Since C_1 and R_1 are placed directly across the R.F. voltage source, an R.F. current will flow through both components, the
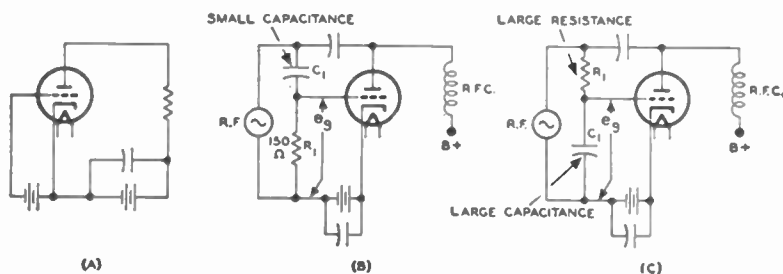
Fig. 4.10. Circuit diagrams show how a vacuum tube can be made to appear as a resistor (A), a condenser (B), or an inductor (C).

amount of current being governed by the impedances of C_1 and R_1. In the diagram it is specified that C_1 is small, resulting in a large impedance. The resistor, on the other hand, is low in value. Thus, the circuit impedance will be largely capacitive, and the current flowing through C_1 and R_1 will lead the R.F. voltage by approximately 90 degrees. The R.F. current, flowing through R_1, will develop a voltage e_g which is in phase with the R.F. current and leading the R.F. voltage from the generator by 90 degrees. It is further true that since e_g is also the alternating grid voltage for the tube, the plate current will lead the applied R.F. voltage by the same 90 degrees. Whenever any electrical component exhibits the property of having the current through it lead the voltage applied across it by 90 degrees, it is said to act like a capacitance. Thus, by properly connecting the tube, we have made it appear to the circuit as a condenser. The tube will have this effect on any circuit in which it is placed.

To indicate how a tube can be made to function as an inductance, we can employ the circuit shown in Fig. 4.10C. Now we find that R_1 and C_1 have been interchanged and the impedance of R_1 greatly exceeds the impedance of C_1, at the operating frequency of the R.F. voltage generator. The current now through R_1 and C_1 will be in phase with the applied R.F. voltage. However, across any condenser, the voltage always lags 90 degrees behind the current and, therefore, the R.F. grid voltage, in Fig. 4.10C, will lag the current through R_1 and C_1 by 90 degrees. By the same token, it will lag the R.F. generator voltage by 90 degrees. Within the tube, the plate current, being in phase with the grid voltage, will also lag the R.F. voltage by 90 degrees. To the circuit, the tube will appear as an inductance in which the current lags 90 degrees behind the applied R.F. voltage. (If desired, a high resistance can be shunted across C_1 to provide a leakage path for any electrons accumulated at the grid. With a high value of resistance, the circuit operation remains unchanged.)

In each of the foregoing instances, the amount of inductance and capacitance that the tube injects into the circuit will depend upon the amount of plate current flowing through the tube. If we increase the d-c bias for the tube in the positive direction, the plate current will increase and its reactive effect on the circuit will likewise increase. With a greater negative d-c bias, the opposite action and effect will occur.

We are now in a position to examine the operation of the Philco oscillator circuit. Referring to Fig. 4.9, we note that the left-hand triode of the 6J6 is connected as an ultraudion oscillator. The plate of the second triode is connected directly to the oscillator plate lead and consequently feeds its plate current into the oscillator tuned circuit. The grid of the control triode receives an R.F. voltage from the oscillator tuned circuit through the capacitive-resistance network of C_1, R_1, and C_2. The same grid also receives a d-c voltage from the F-M ratio detector (not shown here).

The R.F. voltage that the grid of the control triode receives from the essentially capacitive network of C_1, C_2, and R_1 produces a leading current through C_3 and R_2. At the frequency of operation of this circuit, the opposition of C_3 is low in comparison to R_2, and the capacitive current from C_1, C_2, and R_1 flowing through R_2 and C_3 produces a voltage across R_2 which leads the oscillator tank voltage by 90 degrees. Since this voltage is also the grid-driving voltage for the control tube, we find that the plate current of this tube will also lead the oscillator tank voltage by 90 degrees. Consequently, the plate current that the control triode feeds into L_1 will be a capacitive current, causing the tube to appear as a condenser shunted across L_1.

Now, whenever the oscillator drifts in frequency, a positive or negative resultant voltage will be developed at the ratio detector and this voltage will be fed back to the reactance tube. (How this positive or negative voltage is obtained will be discussed when we reach ratio detectors. For the moment let us just accept these results.) At the tube, a positive increase in d-c biasing voltage will cause the oscillator tank frequency to decrease, whereas a negative rise will cause the oscillator frequency to increase. In this way, oscillator frequency drift is instantly counteracted and the set is kept on frequency.

The positive rise in d-c grid voltage on the reactance tube will increase the capacitive current in the oscillator tuned circuit. A greater capacitive current is the same as adding a larger capacitance across L_1. This is so because $E = IX_c$ and, if I increases, with E constant, then X_c must have decreased. Since

$$X_c = \frac{1}{2\pi FC}$$

a decrease in X_c can be brought about by an increase in C. However, the frequency of a tuned circuit is equal to

$$F = \frac{1}{2\pi\sqrt{LC}}$$

and an increase in C decreases the resonant frequency of the tuned circuit. Conversely, a more negative d-c grid voltage will reduce the plate current of the reactance tube, thereby lowering C and raising the frequency of the circuit.

This is one of the first attempts to use automatic frequency control in a television circuit, although A.F.C. systems were standard equipment in A-M sets several years ago before the practice was abandoned as unnecessary.

A factor which is just as important as the circuit layout and resonant circuit design is the type of tube employed for the oscillator. Three important features that are sought when oscillator tubes are chosen are:

1. Special construction enabling it to oscillate readily at the high frequencies.

2. Low internal shunting capacitances.

3. A high value of mutual conductance to enable a strong output voltage to be obtained.

Oscillator Frequencies. In design, the oscillator frequency is placed above the sound and video frequencies.* By being located above both signals, the highest I.F. produced will be that of the video signal. To illustrate, refer to Chapter 1, where it was shown that in a 6-mc television channel, the audio carrier was 4.5 mc higher than the video carrier. For channel 2, 54–60 mc, the video carrier would be at 55.25 mc. (The remnants of the other sideband are from 54.00 to 55.25 mc, but these are useless and rapidly attenuated in the circuits.) From the video carrier, the picture sidebands extend for 4 mc up to 59.25 mc. The audio carrier would then be located at 59.75 mc.

Now suppose that the oscillator frequency is 81.00 mc. In the mixer tube, the 54- to 60-mc signals would combine with the oscillator frequency to form the following I.F. signals:

* This is true only in receivers employing the conventional television system. In receivers using the recently developed Intercarrier television sound system, the oscillator frequency is sometimes placed above the sound and video frequencies and sometimes below them. A complete chapter is devoted later to the Intercarrier system. At all other points in this book, unless otherwise stated, we are referring to the conventional system.

1. For the video, the I.F. will range from 21.75 mc to 25.75 mc. This is the difference between 81.00 mc and 55.25 to 59.25 mc. Actually, the I.F. generated will extend to 27 mc. However, the vestigial sideband remnants are from 25.75 mc to 27 mc and are not desired. The I.F. band-pass tuning transformer eliminates them.

2. For the sound, the I.F. will be centered at 21.25 mc. F-M is employed for the audio transmission, resulting in a frequency variation of plus and minus 25 kc about this center (21.25 mc) position.

In Chapter 1, Fig. 1.23B, the standard video transmission characteristic curve is shown. The remnants of the lower sideband are permitted to remain because of the difficulties encountered in attempting to separate the lower sideband entirely from the upper sideband without affecting the phase or amplitude characteristics of the desired upper sideband. At the receiver, the remaining or vestigial lower sideband must be attenuated, otherwise it is found to produce unequal response at the video detector output. This latter form of distortion arises because the lower video frequencies are contained in both the upper sideband and the remnants of the lower sideband. The higher video frequencies are present only in the upper sideband, having been eliminated from the lower sideband. If the transmitted signal waveform is permitted to remain intact, there would be proportionally more low video frequency voltage produced at the second detector output than high video frequency voltage. To prevent this, a receiver response characteristic such as shown in Fig. 4.11 is employed. At the carrier frequency, the response is 50 per cent down, increasing linearly toward the higher frequencies and decreasing for the lower frequencies. Roughly speaking, the lower video frequencies, for which there are two sidebands, receive half the amplification accorded those higher frequencies for which there is only one sideband. The overall result is an equal response for both the low and the high video frequencies.

The characteristic shown in Fig. 4.11 is the response curve of

the I.F. system of the receiver.   In any superheterodyne, it is
the I.F. stages which mostly determine the selectivity and sensi-
tivity of the receiver.

Indicated, too, in Fig. 4.11 are the frequencies which are at-
tenuated by means of trap circuits inserted in the various I.F.
amplifiers.   The reason for these circuits will be given presently.

The most serious disadvantage encountered by operating the
oscillator above the incoming television signal is concerned with
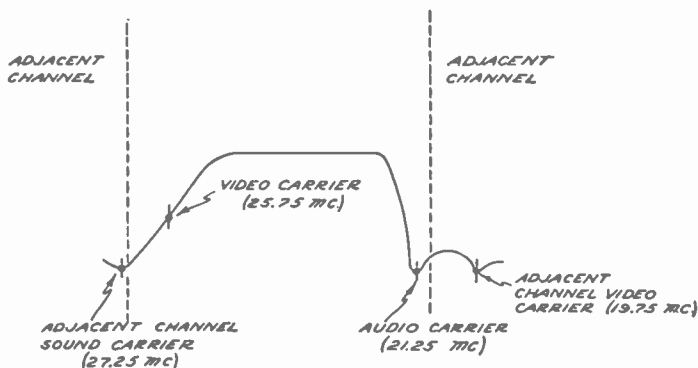
Fig. 4.11.   The recommended overall video I.F. response curve.

the difficulty in stabilizing a high-frequency oscillator.   Any
tendency on the part of the oscillator to wander (change fre-
quency) will cause detuning at the I.F. stages.   In the sound I.F.
stages, for example, the bandwidth is between 200 kc and 300
kc wide.   The F-M sound signal requires 50 kc (± 25 kc).   The
remainder is expressly provided to accommodate small varia-
tions that generally occur in the oscillator.   But these variations
must be kept small, as can be readily appreciated.   The fine-
tuning control, in those sets which do not contain an A.F.C.
system or continuous tuning, permits the observer to center the
oscillator should its drift become too great.   That is why this
control is extended to the front panel and given such an impor-
tant position.

Choice of Intermediate Frequencies.   Three basic factors
must be considered in the design of an I.F. system:

1. Frequency of the I.F. stages.
2. Gain.
3. Selectivity.

The procedure is to choose the operating frequency first and then to consider the problems of gain and selectivity together.

The choice of an intermediate frequency may appear, at first, to be quite simple since we know that at the lower frequencies it is easier to construct amplifiers which have high gain. However, there is a limit to how low a frequency can be used because of the stability of the circuits ahead of the I.F. system and because of the bandwidth required by the television signal itself. When a set is first turned on, it may require as much as an hour before the oscillator frequency stops drifting. When ordinary parts are used in the construction of a receiver, the oscillator may drift as much as 0.2 per cent in frequency. At 60 mc, this means a drift of 120 kc. Although a shift of this magnitude may not noticeably affect the reproduced image, it will certainly affect the television sound. The latter, it will be remembered, occupies a band approximately 50 kc (± 25 kc) wide. Hence, the stability of the oscillator and R.F. circuits will be governed by the F-M audio signal considerations. In the interests of stability, a low I.F. value is indicated. However, there are the video I.F. amplifier requirements to consider.

The I.F. tuned circuits must pass a band of frequencies 4 mc wide. Suppose we use the I.F. values which were used in the television receivers of 1939—8.75 mc to 12.75 mc. At the second detector, the demodulated video frequency voltages extending from 0 to 4 mc would have to be separated from the I.F. values, 8.75 to 12.75 mc. To effect a clear-cut separation between the video frequencies and the I.F., it is desirable to have their ratio as high as possible. At the low broadcast frequencies, the sound "spread" is only 5 kc, which is a small fraction of the 465 I.F. Thus, no difficult problem exists here. But in a television receiver, as noted above, the separation between the desired and undesired frequencies is considerably less and the

problem becomes more difficult. A high I.F. is desirable as this would simplify the problem of separation. As the I.F. value rises, the gain and stability decrease.

In addition to the above, there are various types of spurious responses capable of affecting a receiver and they, too, influence the choice of an intermediate frequency. The most important spurious responses to which a television receiver is subjected are:

1. Image Response.

2. Response of two stations separated in frequency by the I.F. value.

3. Direct I.F. response.

1. *Image Response.* Image response is due to the mixing of an undesired signal with the local oscillator signal in the converter stage to produce a voltage at the intermediate frequency. Since a frequency equal to the intermediate frequency is produced, this signal will be accepted and passed by the I.F. amplifiers. As an illustration, suppose a television receiver had an I.F. carrier value of 12.75 mc. This means that its bandpass extends from 12.75 mc to 8.75 mc. Further, suppose the set is tuned to the 54–60 mc television channel, No. 2. With the I.F. value specified, the local oscillator would be operating at 55.25 mc plus 12.75 mc or 68.00 mc. If a powerful station is, at the same time, operating in the 76-82 mc channel, its signal will, in some measure, appear at the mixer stage input. Mixing of this signal with the oscillator voltage within the mixer tube will produce signal voltages which will be at and sufficiently close to 12.75 mc to be accepted by the I.F. amplifiers. The result, at the cathode-ray tube, is distortion.

By choosing an I.F. value which is greater than half the entire band to be covered, it is possible to eliminate image response from that band entirely. For the widest television band, 174–216 mc, this requires an I.F. value in excess of 21 mc.

2. *Stations Separated by the Intermediate Frequency.* The second listed source of interference is due to stations separated by the intermediate frequency value. In this situation, one in-

coming signal acts as the mixing oscillator for the other signal, their difference frequency appearing at the output of the mixer or converter stage at the intermediate frequency.

There are two solutions to this problem. One is to provide sufficient discrimination in the circuits preceding the mixer so that they will reject two signals so widely separated in frequency. The other is to provide a high I.F., one which is slightly greater than the entire band. In the upper-frequency television band, this would be 42 mc. Actually, if there is any amount of decent selectivity in the input circuits, there is no need for an I.F. value this high.

3. *Direct I.F. Response.* The third form of spurious response is due to the direct reception of a signal equal in frequency to the I.F. itself. To avoid the need of incorporating special filters, wave traps, and shielding to prevent interference from this source, an I.F. is chosen whose frequency is not used to any appreciable extent for commercial or amateur transmissions. This accounts for such seemingly odd values as 10.7, 9.1, etc.

The foregoing discussion has, by no means, exhausted the subject of spurious responses. However, the important contributing factors have been covered and it is possible to see how they affect receiver design and operation. For the video I.F., a high value is indicated, and to a certain point, the higher the better. This will not only reduce interference from spurious responses but also simplify the problem of filtering the video signal in the detector output from the I.F. Opposing the use of a high I.F. are the disadvantages of reduced gain, necessity for greater care in selecting components to prevent excessive losses, additional shielding, and greater tendency of feedback through the tubes and adjacent circuits and the relatively narrow bandwidths of the audio F-M circuits. For the latter, stability in the local oscillator is highly important and since stability is more readily achieved at the low frequencies, a low I.F. is desirable. With all these considerations and in view of the fact that, at the moment it is more important to reduce spurious responses and other

outside interferences from reaching the screen, a relatively high I.F. is used. Typical values in use currently are:

Video—25.75–21.75 mc.

Audio—21.25 mc.

Note that, once the video I.F. value is specified, the audio is likewise determined because the audio carrier is always positioned 4.5 mc from the video carrier.

Separation of Video and Sound Signals. The television signal, at the output of the mixer, has been reduced to its I.F. values. In a typical receiver, the sound carrier would be at 21.25 mc and the video carrier, 4.5 mc above this, or at 25.75 mc. Between 25.75 mc and 21.75 mc, we have the full 4.0 mc of the video picture modulation. The problem now is to separate these two signals in order that each may be applied to its respective system. The video signal is amplitude-modulated and contains the blanking and synchronizing pulses together with the picture information. The sound signal, on the other hand, is frequently modulated. If the sound carrier and its modulation are permitted to reach the video second detector, slope detection will occur, producing an equivalent sound signal at the detector output. The path will then be unobstructed for this sound signal to reach the control-grid of the cathode-ray tube, and horizontal black and white bars will be visible on the screen. To prevent this, the F-M sound signal is separated from the video signal at some point after the mixer but before the video second detector. Furthermore, special trap circuits are placed at various points in the video system doubly to insure that no sound signal reaches the cathode-ray tube.

The foregoing method is followed by the majority of television receiver manufacturers. In the Intercarrier television sound system the sound and video carriers remain together until the stage preceding the cathode-ray tube, without adversely affecting the image. How this is achieved will be dealt with in

a later chapter. In the present discussion only receivers em-
ploying the early separation of sound and video signals will be
considered.

Separation of the video and sound signals can be accomplished
in several ways. In one popular method, the converter trans-
former (T_1 in Fig. 4.12) is a combination video I.F. transformer,
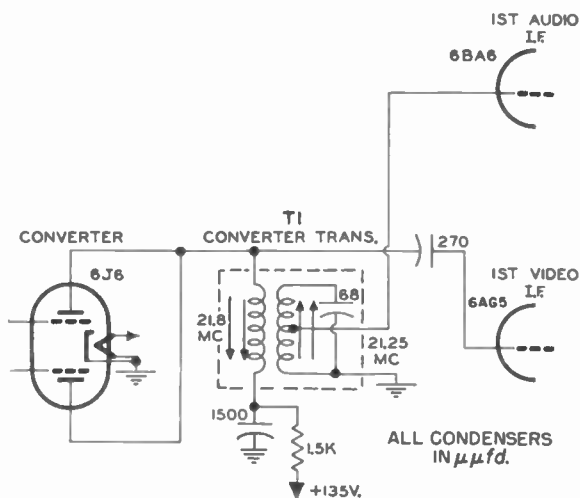
Fig. 4.12. A signal separation network used in RCA and many other television
receivers.

sound trap, and sound I.F. transformer. The primary winding
of T_1 is peaked at 21.8 mc, but since its frequency response is
fairly wide, all the video and sound frequencies appear across it.
The secondary of T_1 is a high-Q resonant circuit, sharply peaked
to 21.25 mc, the sound carrier I.F. value. The resonant circuit
absorbs the sound I.F. component from the primary, transferring
it to the grid of the first I.F. amplifier. The rest of the signal
on the primary of T_1 is unaffected by the trap and continues on
into the video I.F. system.

It should be noted that the secondary of T_1, although it ab-
sorbs a considerable portion of the sound I.F. voltage appearing
across the primary, does not absorb all of it. Hence, a second,

and sometimes a third, sound trap will be found at a subsequent point in the video system.

Another means of signal separation is shown in Fig. 4.13. The tuned circuit in the plate of the mixer tube is designed to pass signals having frequencies between 21.5 and 26.4 mc. The sound I.F. frequency, together with a portion of the video signal, is
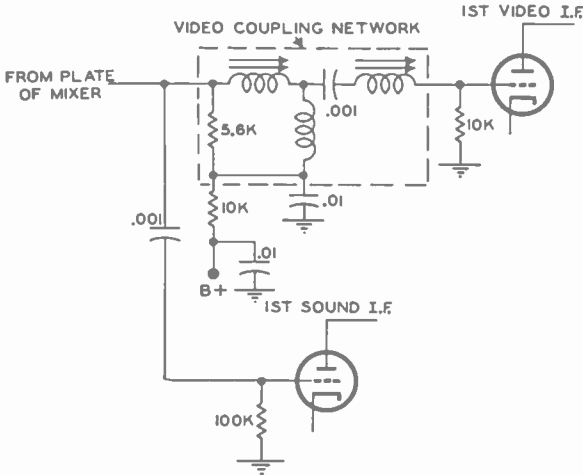
Fig. 4.13. In the circuit above, the entire signal is applied to the sound I.F.; however, because of the design of this section, only the F-M sound portion of the signal reaches the sound detector.

picked off at the tuned circuit and applied to the grid of the first sound I.F. amplifier. Although the full signal (sound and video) is applied to the sound system, only the F-M sound signal passes through because of the limiter stage which precedes the F-M detector and the limited response of the tuned circuits in this section. The limiter removes all amplitude modulation, permitting only the frequency variations to pass.

Signal separation by means of a series resonant circuit is shown in Fig. 4.14. C_1, in conjunction with L_1, forms a series resonant path from the plate of the mixer to ground at the sound intermediate frequency. (C_2, shunted across L_1, is used to achieve another effect. This will be discussed in a subsequent

section dealing with trap circuits.)   In any series resonant circuit, the opposition offered to an applied voltage is low when its frequency is equal to the resonant frequency of the circuit. Maximum current then flows through each component in this series branch.   Moreover, and this is important, the voltage
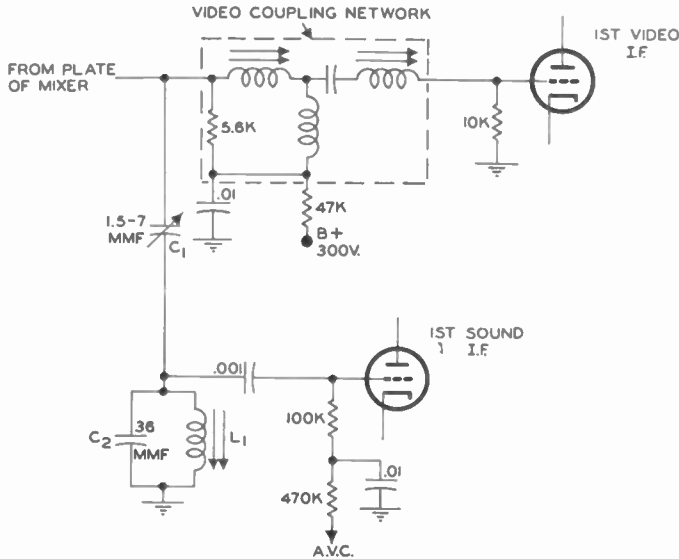
FIG. 4.14.   A series resonant circuit, C_1 and L_1 (the latter in conjunction with C_2), separates the sound and video I.F. voltages.

across each component at resonance is Q times the applied voltage, where Q is the Q of the circuit (generally this means of the coil).   Thus, if the applied voltage is 5 and the Q is 5, the potential across the series condenser and inductance, each, will be 25 volts.   It is true, of course, that the voltage across the coil is 180 degrees out of phase with the voltage across the condenser, and these, taken together, nullify each other.   However, if we consider each component by itself, the rise in voltage is considerable.   In the circuit of Fig. 4.14, the voltage fed to the grid of the first sound I.F. amplifier is developed across the coil of the series resonant circuit.   At the sound intermediate frequency, a

resonant rise in voltage occurs, providing a sizeable voltage for the grid of the first sound I.F. amplifier. At the same time, C_1, C_2, and L_1 form a trap, reducing the amount of sound I.F. signal penetrating the video I.F. system.

Still another method of signal separation is exemplified by the circuit shown in Fig. 4.15. Two tuned circuits are connected in
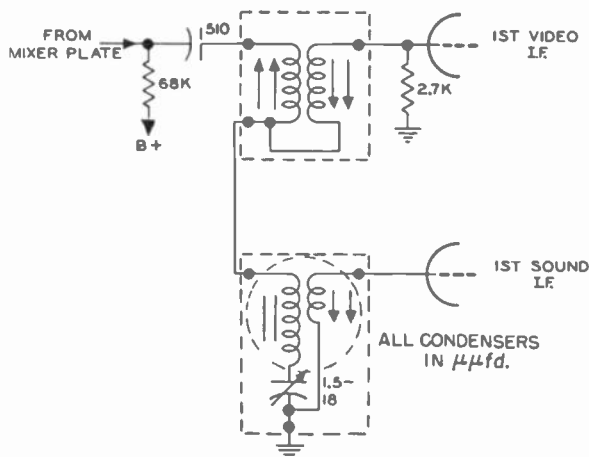
Fig. 4.15. Sound and video signal separation using two tuned circuits in series.

series in the plate circuit of the mixer. The top resonant circuit receives the video I.F. signal while the lower resonant circuit is sharply tuned to the sound I.F. Currents of both signals pass through both coils, but the greatest voltage drop in the top coil will be at the video I.F. and the greatest voltage drop in the lower coil will be at the sound I.F. The energy in each resonant circuit will then transfer to its respective system.

In some receivers, separation of the signals does not occur until the output of the first I.F. amplifier or even later. Thus, in Fig. 4.16, the signal is first passed through the first I.F. amplifier, whereupon a third winding is coupled to the interstage transformer and the energy it absorbs is fed to the control grid of the first sound I.F. Sometimes the manufacturer labels this first stage as the first video I.F. Actually, a better designation

would be, simply, first I.F., since both video and sound I.F. signals are amplified.

Most receiver designers effect the video and sound I.F. separation at the output of the first I.F. stage. However, there are a few receivers which delay this operation until the second I.F. or even third I.F. amplifier. By delaying the separation, the advantages of additional amplification are gained, which can be employed to reduce the number of sound I.F. amplifier stages. On the other hand, there is danger that enough sound F-M voltage will reach the video second detector to produce interference across the video screen.
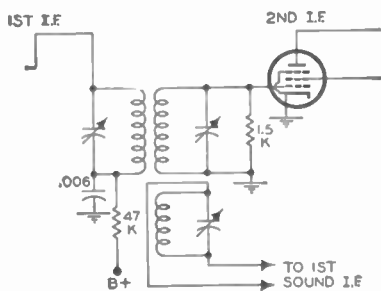
Fig. 4.16. Sound and video signal separation by means of a third winding on the interstage transformers.

Video I.F. Amplifiers. In any superheterodyne circuit, the major portion of the overall gain and selectivity is contributed by the I.F. amplifiers. (See Fig. 4.17.) Consequently, it is most important for all those working with television receivers to be
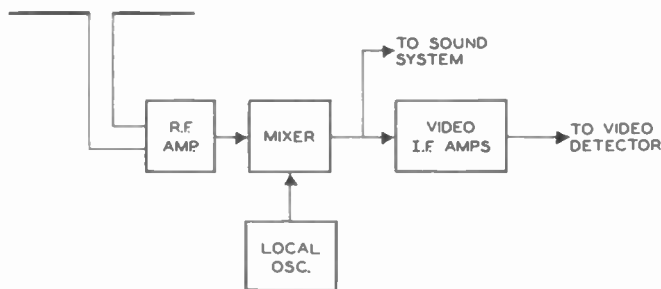
Fig. 4.17. The position of the video I.F. amplifiers in the television receiver.

familiar with the shape of the I.F. response characteristic and to understand why this particular form was chosen. The reason, as we will see, lies with the signal transmitted by the broadcast station.

A television signal, when broadcast, possesses the form shown in Fig. 4.18. It is amplitude modulated, but differs from conventional A-M signals in having essentially only one sideband. The other sideband, of which some remnants are still present, has been effectively suppressed. This is known as vestigial sideband transmission and is the standard in modern television. When any carrier is amplitude modulated an upper and lower
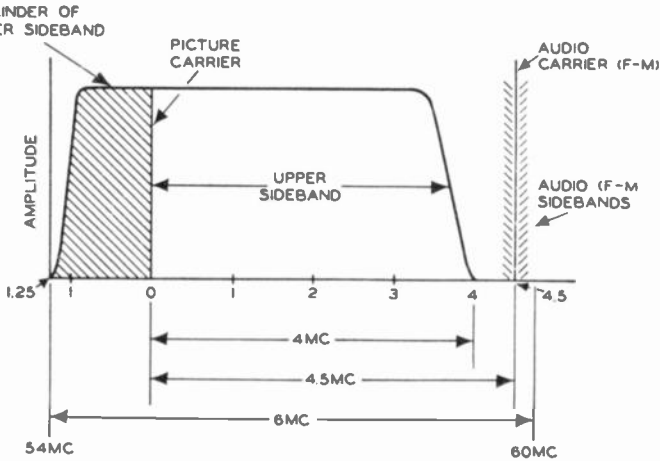
Fig. 4.18. The form of the television signal as broadcast by the television station.

sideband forms automatically. However, because identical information is contained in each sideband, only one sideband is required at the receiver.

Complete suppression of the lower sideband is the goal, but it is not economically achievable. It is impossible to eliminate completely one sideband using simple filters without, at the same time, distorting near-by portions of the remaining sideband. Hence, as a compromise between economy and easily adjustable circuits on the one hand, and minimum distortion and bandpass on the other, it was decided to remove all but 1.25 mc of the 4.0-mc lower sideband of the video signal. The transmitted signal, then, consists of this 1.25 mc plus the carrier plus 4.0 mc of the upper sideband. With the addition of the near-by

audio carrier and its sidebands, the full 6.0 mc allotted to each television station are obtained.

Within the receiver we must take the upper sideband, together with the remnants of the lower sideband, and provide a response characteristic in which all sideband frequencies will have available an equal amount of amplification. In sound A-M sets this presents no great problem because both sidebands are alike. But things are different in the television signal. Here, there is 1.25 mc of the lower sideband and 4.0 mc of the upper sideband.
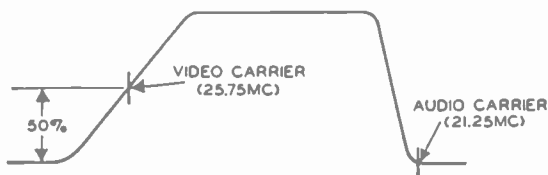
Fig. 4.19. The desired response curve of the video I.F. system.

The lower video frequencies (those having frequencies close to the carrier) are contained in both the upper sideband and the remnants of the lower sideband. On the other hand, all video frequencies above 1.25 mc are present only in the upper sideband, having been suppressed in the lower sideband. If both the low and the high video frequencies are accorded equal amplification in the receiver, proportionately more low video frequency voltage will be developed at the second detector output than high video frequency voltage. It is to prevent this that the receiver response characteristic shown in Fig. 4.19 is employed. At the carrier frequency the response is 50 per cent down, increasing linearly toward a maximum for the higher frequencies and decreasing for the lower frequencies. Roughly speaking, the lower video frequencies, for which there are two sidebands, receive half the amplification accorded all video frequencies above 1.25 mc. In this way, we equalize the response for the low and the high video frequencies. To the serviceman, the shape of this curve is important in his work on television receivers. When aligning the I.F. stages, he must be careful to

place the video carrier close to the 50 per cent point. At the
same time, the circuits should be adjusted to provide the maxi-
mum bandpass. Detail in a television image is dependent upon
the strength of the high video frequencies present. When the
response curve drops at the upper end of the curve, fine detail
becomes fuzzy and indistinct. Poor low frequency response
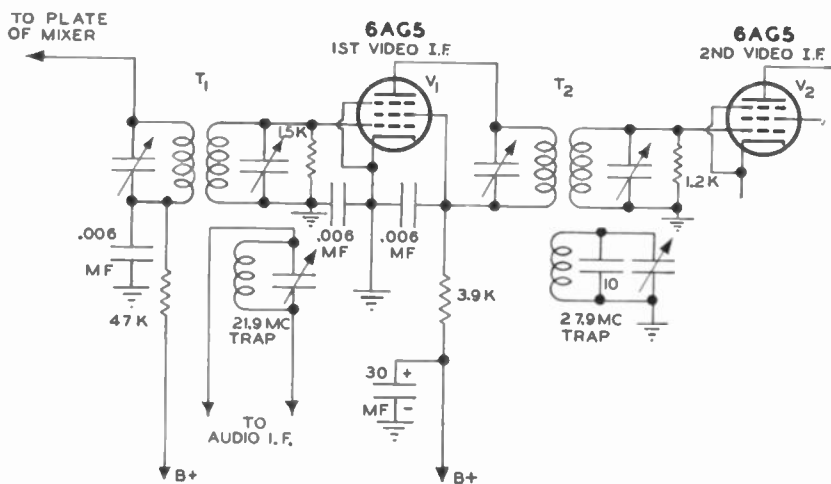
FIG. 4.20. A typical transformer-coupled video I.F. amplifier.

gives rise to poor synchronizing action, smearing, and a generally
darker image.

Occasionally the manufacturer's service manual will specify
that the video I.F. carrier is to be placed 60 or perhaps even 70
per cent of the way up the curve instead of the 50 per cent noted
previously. When this is requested, it is only because the video
carrier is not receiving full gain in the R.F. section of the set
and the loss occasioned here is offset by the greater amplification
in the video I.F. system.

Video I.F. systems can be conveniently classified according to
the type of interstage coupling employed. All systems can be
placed into at least one of the following categories; some make
use of two.

1. Transformer coupling.
2. Stagger-tuned coupling.
3. Complex coupling.

Transformer Coupling. Typical of the transformer-coupled video I.F. systems is the one employed in General Electric television receivers. (See Fig. 4.20.) Transformers T_1 and T_2 are overcoupled and heavily loaded with resistance to provide approximately a 4-mc bandpass frequency characteristic. A third winding in each transformer functions as a trap to attenuate certain undesirable frequencies. (A complete discussion of trap circuits will be given presently.) The overall response of this video I.F. system is shown in Fig. 4.21. The curve is approximately 4.0 mc wide, extending from 22.4 mc to 26.4 mc. The I.F. value of the video carrier is 26.4 mc and as such receives only 50 per cent of the total amplification. The video frequencies containing the image information then extend from this point to 22.4 mc. In this system the response at 22.4 mc decreases to 50 per cent, indicating reduced
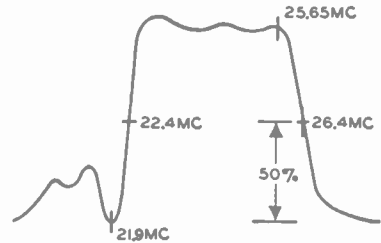
Fig. 4.21. The overall response curve of one transformer-coupled I.F. system.

amplification for the higher video frequencies. While a 4.0-mc bandpass is to be preferred, there are many sets being built which do not attain this goal. In sets using 7-inch image tubes, the full 4.0 mc are not required because the normal (not the optimum) viewing distance from the receiver is beyond the point where the detail corresponding to the higher video frequencies is visible. Hence, the bandpass extends for 2.5 mc or possibly 3.0 mc. Even in sets having larger screens the full 4.0-mc bandpass is sometimes not achieved because of economies in design.

In Fig. 4.20, only one I.F. stage is shown. Actually, there would be three or four, this number being required to provide sufficient amplification for the signal. Furthermore, some

method (to be shown later) would be provided to vary the bias on one or more of the I.F. amplifiers, thereby permitting control of the amplification received by the signal. The name of this control is contrast control.

Since trap circuits are an important adjunct to video I.F. systems, it might be worth while to consider their form and mode of operation at this point.

Trap Circuits for Television Receivers

Television receivers are continually beset by a host of interfering signals, any one of which is easily capable of distorting or completely destroying the desired image. Fortunately, many of these interfering signals never get beyond the input tuner and consequently are suppressed before any harm is done. Some, however, are so close to the channel frequency to which the set is tuned that they are able to penetrate the R.F. defense and reach the video I.F. system. This system actually constitutes the main bulwark against all interference and once a signal passes through these stages successfully, there usually exists no further stop-gaps between the video detector and the cathode-ray tube. Every effort must be made to suppress any signal which is capable of distorting the reproduced image.

In order to receive a 6-mc band of frequencies, the R.F. and converter tuning circuits are designed with a low Q. This means that the sides of the input curve are not very steep, like the sides of a rectangle, but tend to taper off gradually. Fig. 4.22A illustrates a typical input characteristic of a modern television receiver. With a response of this type, voltages at the frequency of the sound carrier of the next lower channel or the picture carrier of the next higher channel could penetrate through the R.F. stages and reach the video I.F. system. Unless trap circuits are inserted in the video I.F. system (or even beyond), the effect of these interfering signals will be detrimental to the image.

To ascertain the frequency of the most important interfering signals, suppose the receiver is tuned to channel 3 (60–66 mc)
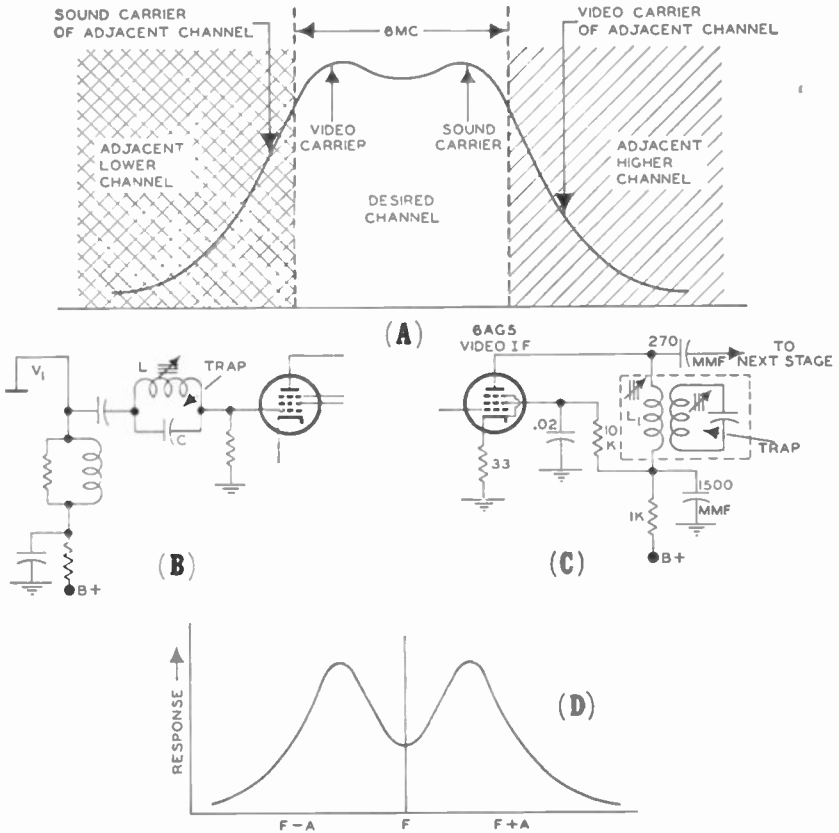
FIG. 4.22. (A) The R.F. response curve of most television receivers. Note that signals from adjacent channels can be received. (B) A series trap circuit. (C) An absorption trap circuit. (D) The double-humped response curve characteristic of closely coupled circuits.

and the video carrier I.F. value is 26.4 mc. The sound carrier of the next lower channel (54–60 mc) is at 59.75 mc. A signal at this frequency when mixed with the local oscillator (87.65 for

channel 3) will develop a difference frequency of 27.9 mc. This is one interference signal frequency.

The second interference signal is the picture carrier of the next higher channel (66–72 mc). When this beats with the same local oscillator, a difference frequency of 87.65 − 67.25 mc, or 20.4 mc, is produced.

The two frequencies—(1) sound from the next lower channel (27.9 mc) and (2) picture carrier from the next higher channel (20.4 mc)—must be eliminated from the video signal before it reaches the cathode-ray tube. Channel 3 is used in this illustration, but any other channel could have been chosen. In all cases where closely adjacent channels exist, the two interfering frequencies will be 27.9 and 20.4 mc for this receiver. Note, however, that there are channels which are not subject to such interference. Thus, channel 2 (54–60 mc) does not possess an adjacent lower channel; on the other hand, channel 4 does not possess a closely adjacent higher channel. By "closely adjacent" we mean channels which follow each other without any frequency separation. Channel 4 is followed by channel 5, but the end of channel 4 and the beginning of channel 5 are separated by 4 mc. Channel 4 is 66–72 mc; channel 5 is 76–82 mc. This 4-mc separation is sufficient to prevent any of the frequencies in channel 5 from adversely affecting channel 4. However, channel 2 (54–60 mc) is closely followed by channel 3 (60–66 mc), and interference is possible. The same is true of many of the other channels—hence the importance of using these traps. The trap frequencies will vary with the video and audio I.F. values employed in the circuit. The purpose of the traps, however, remains unchanged.

The objection may be raised that traps are not really necessary because under existing regulations adjacent channels are not assigned to *any one community*. This is true. However, communities which are located comparatively near to each other are assigned to adjacent channels. Thus, consider New York and Philadelphia, only 90 miles apart. New York is assigned channels 2, 4, 5, 7, 9, 11, and 13; Philadelphia is assigned chan-

nels 3, 6, 8, 10, and 12. Any set situated between these two cities would certainly be subject to considerable interference and would definitely require trap circuits. This same situation is true in many other parts of the country.

There is one additional trap which is found in television receivers and this is a trap designed to prevent the audio I.F. voltage of the same channel from reaching the cathode-ray tube. In any channel, the audio I.F. frequency is sufficiently close to the bandpass of video I.F. systems to be able to pass through to the cathode-ray tube unless special precautions are taken. This trap is even more important than any of the other traps because adjacent channel stations are not always present, but the sound of the same channel is. An indication of sound interference at the cathode-ray tube is the appearance of horizontal dark bars across the face of the tube. The width of the bars varies with the audio frequency; the intensity of the bars is proportional to the amplitude of the audio signal. When both the amplitude and the pitch of the audio signal change, ripples pass across the picture like water waves when the wind is high.

Placement of the Traps. The trap circuits are generally placed in the video I.F. system, although some manufacturers go so far as to include one or two in the video frequency amplifiers. The danger of permitting these interference signals to get too close to the cathode-ray tube is that they may become sufficiently powerful, because of successive amplification, to render a single simple trap incapable of attenuating them below the point of interference. Sound traps for the same channel must not be used until the video and sound signals have been separated.

Type of Traps. (a) *Series Traps.* A series type of trap circuit is shown in Fig. 4.22B. It is placed between two I.F. stages and tuned to the frequency to be rejected. Trap circuits are sharply tuned networks, designed to reject one frequency or, at most, a narrow band of frequencies. When a signal at the trap frequency appears at the plate of V_1 (Fig. 4.22B), the impedance offered by LC is high, absorbing most of this interference

voltage. A negligible amount appears across the input circuit of the following I.F. amplifier. At all other frequencies, the tank offers negligible impedance, and the desired signal passes easily.

(b) *Absorption Traps.* The absorption trap, shown in Fig. 4.22C, is the most widely used type of rejection circuit. It consists of a coil (and parallel fixed condenser) inductively coupled to the plate load of an I.F. amplifier. When the I.F. amplifier receives a signal at the resonant frequency of the trap circuit, a high, circulating current develops in the trap (as a result of the coupling between the trap and the plate coil), and the voltage in the video coil, at the trap frequency, becomes quite low. Consequently, very little of this interference voltage is permitted to reach the next amplifier.

To explain this action more fully, two resonant circuits closely coupled will give a double-humped curve, such as shown in Fig. 4.22D. Note the sharp decrease in primary current at the center frequency. In the case of the two tuned circuits of Fig. 4.22C, L_1 is tuned to a band of frequencies while the secondary is sharply set at one frequency. Since the primary band coverage includes this one frequency, there is a sharp drop in primary voltage at this frequency, due to the presence of the trap. It is this interaction between coils which produces the marked decrease in voltage at the trap frequency. The other frequencies in this signal are unaffected by the trap.

(c) *Cathode or Degenerative Traps.* A cathode trap, shown in Fig. 4.23A, is a sharply tuned parallel resonant circuit coupled to a coil in the cathode leg of a tube. The coil L_1, in series with C_1, forms a broadly tuned series resonant circuit to the same range of frequencies as L_2. This permits V_1 to function as a normal amplifier for all signals within this frequency range. However, at the resonant frequency of the trap, a high impedance is reflected into the cathode circuit (by the trap), and the gain of this stage is reduced by degeneration.

Another type of cathode trap, illustrated in Fig. 4.23B, places the parallel circuit directly into the cathode leg. At the resonant frequency of the trap the impedance in the cathode leg will rise,

producing a large degenerative voltage and reducing the gain of the amplifier. At all other frequencies, the impedance of this parallel network is low, and only a small degenerative voltage appears. There is thus only a slight loss in gain.

(d) *Parallel Traps.* Parallel traps are series resonant circuits which are placed across (or in shunt with) the circuit. (See Fig. 4.24.) At the frequency for which the trap is set, it acts as a short circuit, by-passing all signals of the same frequency to
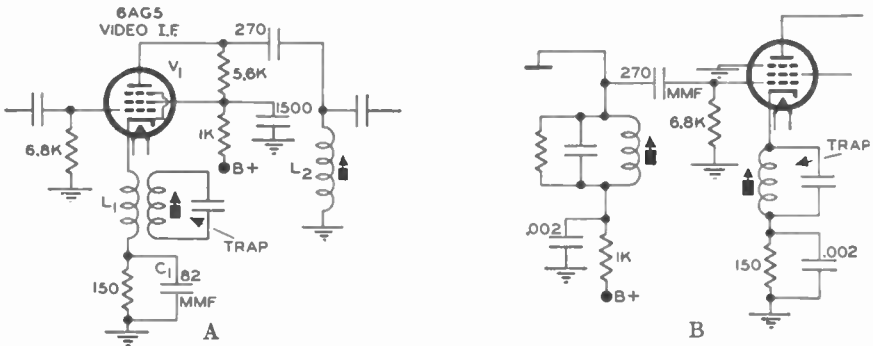
Fig. 4.23. Two types of cathode or degenerative trap circuits.

ground and preventing their further penetration into the circuit. At other frequencies the trap circuit presents a relatively high impedance, permitting these signals to proceed farther into the circuit.

The simplest type of parallel trap is illustrated in Fig. 4.24A. A condenser and a variable coil, in series with each other, are connected across the signal path. Any signal possessing the same frequency as the trap will "see" a virtual short circuit upon reaching this portion of the circuit. The simple condenser and coil trap is effective if the Q of this network (principally the coil) is quite high. However, when the Q is low, the tuning of the network is broad and more than one frequency is attenuated. A more efficient parallel trap and one which is used more extensively is shown in Fig. 4.24B.

At first glance, the trap network appears as a parallel resonant

circuit rather than a series resonant circuit. Let us, however, analyze its operation. The illustrative example, Fig. 4.24B, is taken from a DuMont television receiver. It is designed to by-pass or trap the audio carrier voltage of the signal being received. In this instance the I.F. frequency is 21.9 mc.

If we consider first L_1 and C_2, ignoring C_1 for the moment, then we have a parallel resonant circuit, tuned to 22.9 mc. The
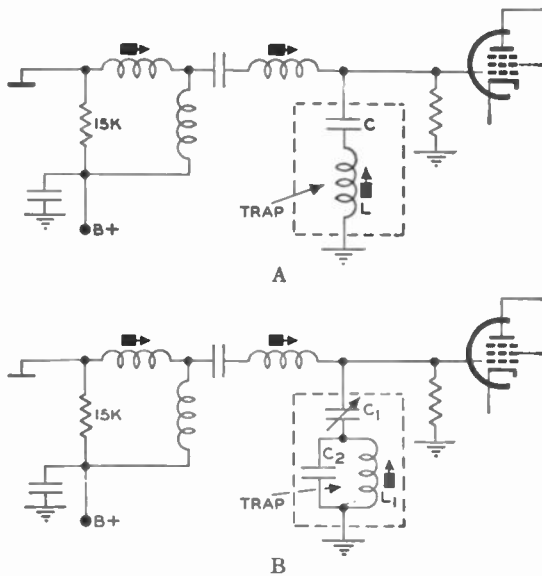
FIG. 4.24. Two types of parallel trap circuits.

coil Q is 200, and a fairly large voltage is developed across the combination at this frequency. Now, it is common knowledge that for all frequencies lower than its resonant frequency, a parallel resonant circuit appears inductive. (At the resonant frequency, of course, it presents a purely resistive impedance.) For frequencies above resonance, the impedance presented is capacitive. This latter fact can be understood by noting that for higher frequencies, the parallel condenser offers less impedance than the coil. Consequently most of the current flows through the condenser, and the circuit current possesses a leading phase.

Since the audio I.F. of 21.9 mc is below the 22.9-mc resonant frequency of L_1 and C_2, the parallel combination appears inductive to the audio I.F. signal. By resonating this inductance with C_1, we obtain a series resonant path for the audio I.F. signal, and the audio I.F. voltage is by-passed.

By providing a parallel resonant circuit (L_1 and C_2) for 22.9 mc. we obtain a sharp rise in voltage just beyond 21.9 mc. Since the 22.9-mc value is included in the range of the desired video frequencies (they extend from 26.4 mc down to 22.4 mc), we insure that the video frequencies are passed by the trap with negligible attenuation while, at the same time, forcibly suppressing the undesired audio carrier I.F. In the other parallel trap (Fig. 4.24A) the closely adjacent video frequencies are attenuated to a certain extent.

(e) *Bridged-T Traps.* A fifth trap, which is more complex than any of the foregoing circuits but also more effective, is the Bridged-T trap shown in Fig. 4.25A. L_1, C_1, and C_2 are resonated to the frequency of the signal to be rejected. Now, if the value of the resistor R is properly chosen, the attenuation imposed upon a signal to which L_1, C_1, and C_2 are resonated will be very great. Ratios of 50 and 60 to 1 are easily attainable using components which possess manufacturing tolerances.

Some understanding of the operation of this trap can be obtained if we take the Bridged-T network shown in Fig. 4.25B and transform it into the equivalent network of Fig. 4.25C. (This can be readily accomplished with well-known electrical theorems.) If the various components of the Bridged-T network C_1, L_1, and C_2 are properly chosen, Z_1 will have a negative value. If we make R equal to Z_1, then the total impedance between points 1 and 2 will become zero, effectively short-circuiting signals of the frequency to which the Bridged-T network is tuned. For all other frequencies the trap offers little shunting effect and the signals pass through with negligible attenuation.

Tuning the Traps. To adjust the traps to their proper frequencies, the following procedure is employed.

1. Connect an A-M signal generator having a frequency range from 18–30 mc to the grid of the mixer or converter tube.

2. Connect a vacuum-tube voltmeter across the load resistor of the video second detector.

3. Set the signal generator to the sound I.F. frequency.
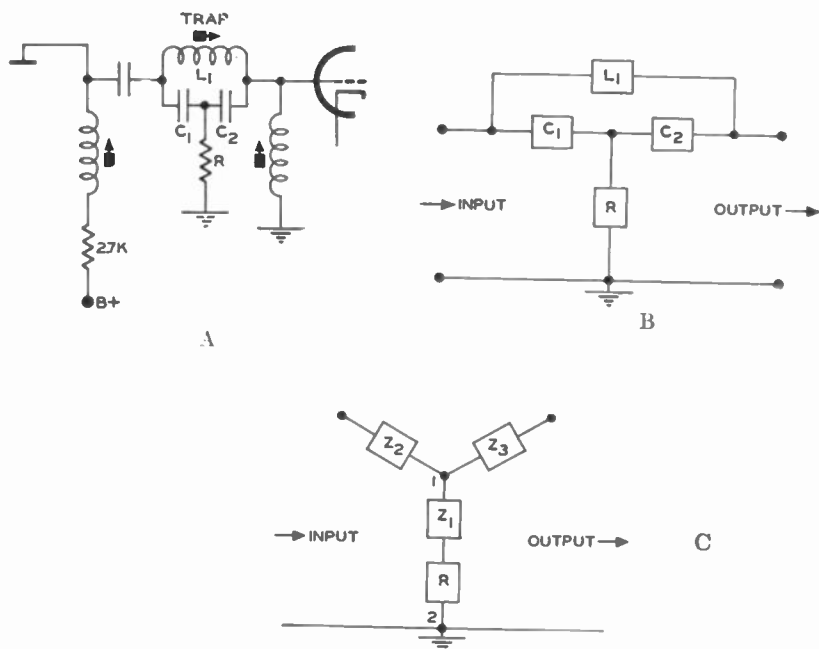
Fig. 4.25.   (A) A Bridged-T trap.   (B) The same circuit shown in block form.
(C) An equivalent electrical network.

4. Using a neutralizing screwdriver or wrench, change the capacitance or inductance of the proper trap until a minimum voltage is registered at the detector.   Consult the manufacturer's instructions for the resonant frequency of each trap circuit.

5. Follow the same procedure for each trap, each time altering the signal generator frequency to correspond.

For most television receivers, the traps are adjusted before any video I.F. alignment is begun.   During the video alignment

process, the traps' adjustment should be rechecked because they are affected to some extent by changes in the associated video I.F. tuning coils and transformers.

The order of importance of the various trap circuits are:

1. Sound signal of the same channel.
2. Sound signal of the next lower adjacent channel.
3. Picture carrier of the next higher adjacent channel.

If, for the sake of economy, the number of trap circuits are limited, No. 3 could be dispensed with first, and then No. 2.
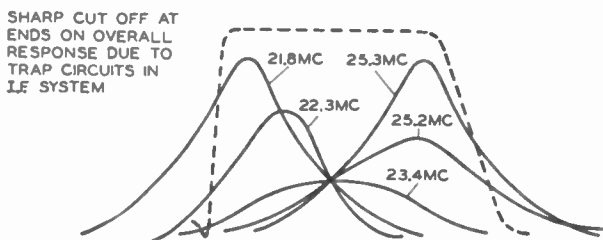
FIG. 4.26.   In the circuit of Fig. 4.28, fine stagger-tuned coils combine to produce an overall response of 4.0 mc.

Trap No. 1 is never omitted from receivers employing the conventional television system.

Stagger-tuned I.F. Systems.   The majority of sets today employ single tuned coils between each pair of video I.F. amplifiers. The coils themselves are stagger-tuned in frequency; that is, each one is peaked to a different frequency within the bandpass of the system.   Fig. 4.26 illustrates how five separate coils, each tuned to a different frequency, combine to give a 4.0 mc-bandpass.*

A simple stagger-tuned I.F. system is shown in Fig. 4.27.   The first tuned coil, located between the mixer and first video I.F. amplifier is peaked (in this circuit) to 21.8 mc.   Inductively

* It might be mentioned that it is not necessary for each coil to be peaked to a different frequency.   Two of the coils may be peaked to the same frequency, but these coils must not be placed in adjacent stages, otherwise oscillations will occur.

coupled to this coil is an absorption trap resonated at 21.25 mc. This is the I.F. value of the sound signal and the trap will absorb this frequency voltage from the incoming signal and transfer it to the sound I.F. amplifiers. The remainder of the video signal will be unaffected by the sound trap and continue on through the system. The second coil, between the first and second video I.F. amplifiers, is peaked to another frequency (here 25.3 mc)
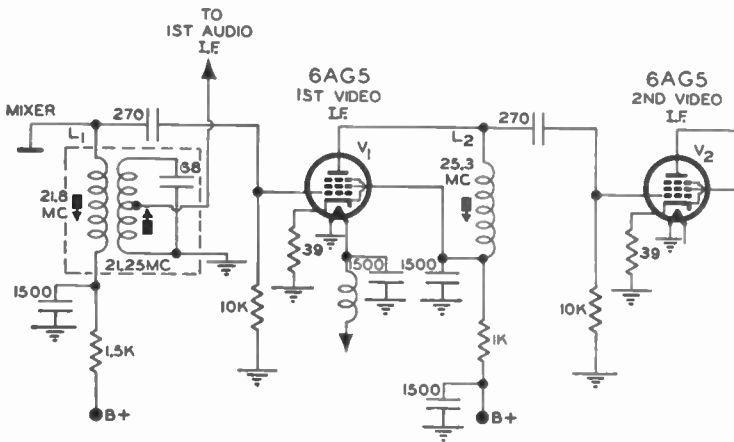
FIG. 4.27.   A stagger-tuned video I.F. amplifier.

within the video bandpass. In a similar manner, by adding two or three more I.F. stages, each possessing a coil tuned to a different frequency, we can achieve the desired 4.0-mc video bandpass. Fig. 4.28 illustrates, in semi-block form, a stagger-tuned video I.F. system used in many television receivers. The various peaking frequencies are:

$$
\begin{aligned}
&\text{Converter coil} \ldots \ldots 21.8 \text{ mc } (L_1)\\
&\text{1st I.F. coil} \ldots \ldots 25.3 \text{ mc } (L_2)\\
&\text{2nd I.F. coil} \ldots \ldots 22.3 \text{ mc } (L_3)\\
&\text{3rd I.F. coil} \ldots \ldots 25.2 \text{ mc } (L_4)\\
&\text{4th I.F. coil} \ldots \ldots 23.4 \text{ mc } (L_5)
\end{aligned}
$$

Fig. 4.26 indicates the relative gains and selectivities of each coil and the overall shape of the combined response (with the effect of the trap circuits included). Note that each coil has a
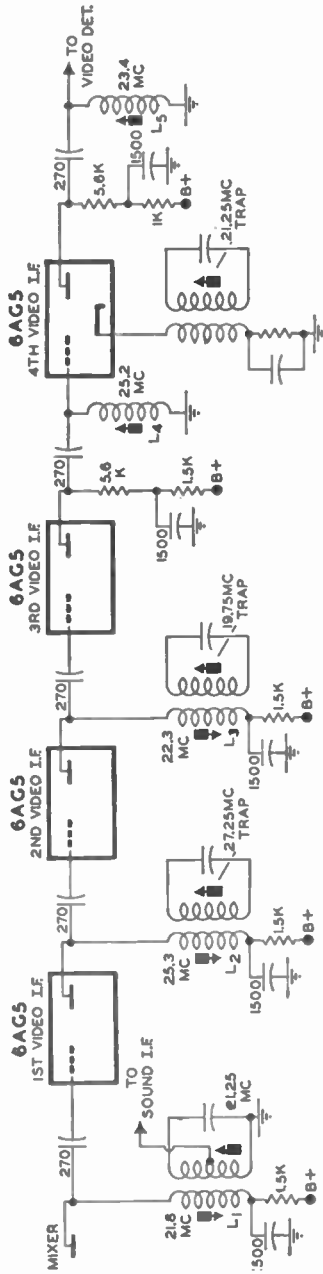
Fig. 4.28. A semi-block diagram of a complete stagger-tuned video I.F. system used in many television receivers.

fairly wide response and this is due chiefly to the low plate and grid resistors which are used in the circuit. In Fig. 4.27, for example, the grid resistor of V_1 is only 10,000 ohms. Since this is effectively shunted across L_1, it acts to reduce the Q of this coil and broaden its response. Just how broad this response is, is indicated in Fig. 4.26 by the curve marked 21.8 mc.

Four trap circuits are found in this system, of which the first three are absorption type traps. The first trap, coupled to L_1,
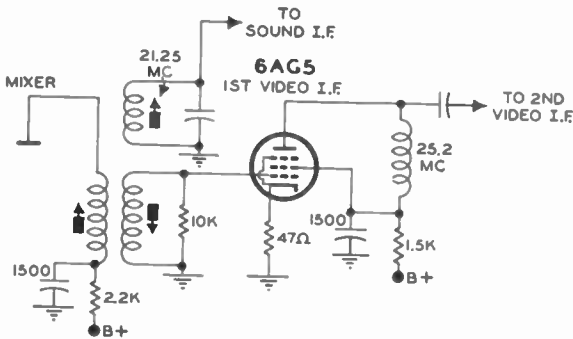
FIG. 4.29.   A combination of transformer-coupled and stagger-tuned video I.F. amplifier.

is tuned to 21.25 mc, the audio I.F. of this system. The voltage developed across this trap is fed directly into the sound I.F. system. The second trap is coupled to L_2 and is set for 27.25 mc, the frequency of the lower adjacent channel sound carrier. The third trap, coupled to L_3, is peaked to 19.75 mc, the higher adjacent channel picture carrier frequency. The final trap is a degenerative one, located in the cathode leg of the fourth I.F. amplifier and tuned to 21.25 mc. A contrast control network (not shown) regulates the amount of negative voltage applied to the first three I.F. amplifiers and the R.F. stage.

The number of video I.F. amplifiers employed in any set is determined chiefly by the price of the set. In quality receivers, possessing the full 4.0 mc-bandpass, there would be five stagger-tuned coils, using four video I.F. stages. In cheaper sets, where

a 3.0 mc-spread is common, three video I.F. amplifiers would be employed. Regardless of the number of stages used, the basic operation remains the same.

Sometimes a combination of single-coil stagger-tuned and transformer video I.F. amplifiers is employed. Thus, in Fig. 4.29, the signal from the mixer is transformer-coupled to the first video I.F. amplifier while, beyond this stage, single stagger-tuned coils are used throughout. A third winding on the transformer
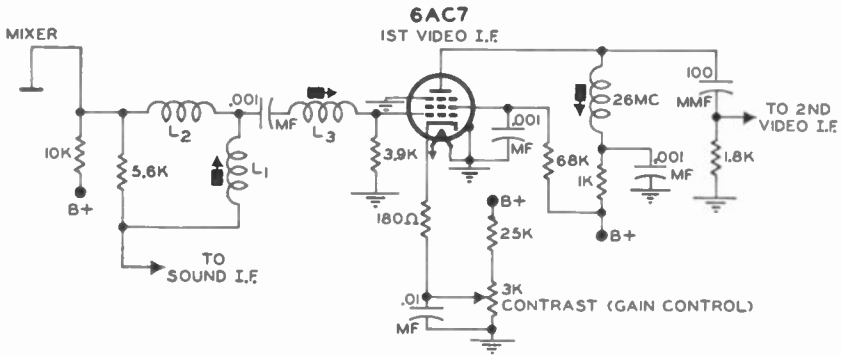
Fig. 4.30. Combining complex coupling with stagger-tuning.

functions as a sound trap, absorbing the sound I.F. voltage from the signal and transferring it to the sound I.F. system. Other trap circuits, coupled to the stagger-tuned coils, would be used in the video I.F. system.

Other video I.F. systems employ stagger-tuning in most of their stages and complex coupling between the mixer and the first video I.F. (See Fig. 4.30.) L_1, L_2, and L_3 form a complex-coupled network with a bandwidth of 4 mc (i.e., 22.4 to 26.4 mc). The sound I.F. is obtained from this tuned circuit, and the video I.F. passes through to the grid of the first video I.F. amplifier. The remainder of the video I.F. system employs stagger-tuned circuits which maintain the overall bandpass at 4.0 mc.

Stagger Tuning. Stagger tuning is employed so extensively in video I.F. systems that it might be instructive to analyze

these circuits in greater detail. As a first step in this analysis, let us define bandwidth.

A typical resonance curve for a parallel tuning circuit is shown in Fig. 4.31. The response is not uniform but varies from point to point. At the resonant frequency (labeled F_0 in the diagram) the response of the circuit is at its peak—or maximum. From this point, in either direction, the response tapers off until it
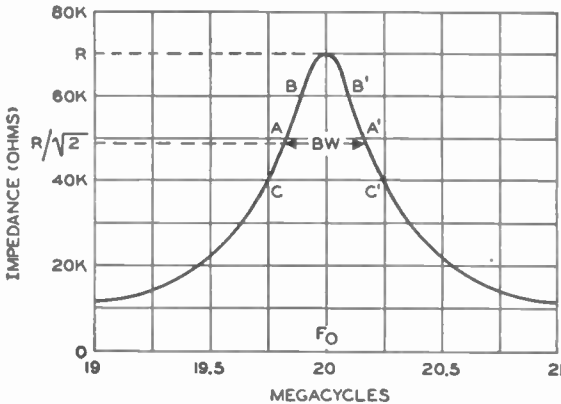
Fig. 4.31. The accepted definition for bandwidth of a tuned system.

soon becomes negligible. With a characteristic of this type, what would you say was its bandwidth? Obviously the answer to this question is arbitrary. We could say, for example, that all frequencies between the points B–B′ on the curve should be considered as part of the bandwidth. Or, we could choose points C–C′ and say that all frequencies which receive an amplification equal to that of C–C′ or greater should be considered as within the bandpass of the circuit. Note that this does not prevent other frequencies—those that receive less amplification—from passing through the circuit.

The arbitrary definition generally accepted for bandwidth is illustrated in Fig. 4.31. The bandwidth of a circuit is equal to the numerical difference in cycles between the two frequencies at which the impedance presented by the tuning circuit is equal

to 0.707 of the impedance presented at F_0 (i.e., the maximum impedance). Thus, in the response curve shown in Fig. 4.31, the impedance at points A–A′ is 0.707 $\left(\text{or} \dfrac{1}{\sqrt{2}} \right)$ of the impedance offered by the circuit at F_0. In this particular illustration, Fig. 4.31, the bandwidth is 0.4 mc.
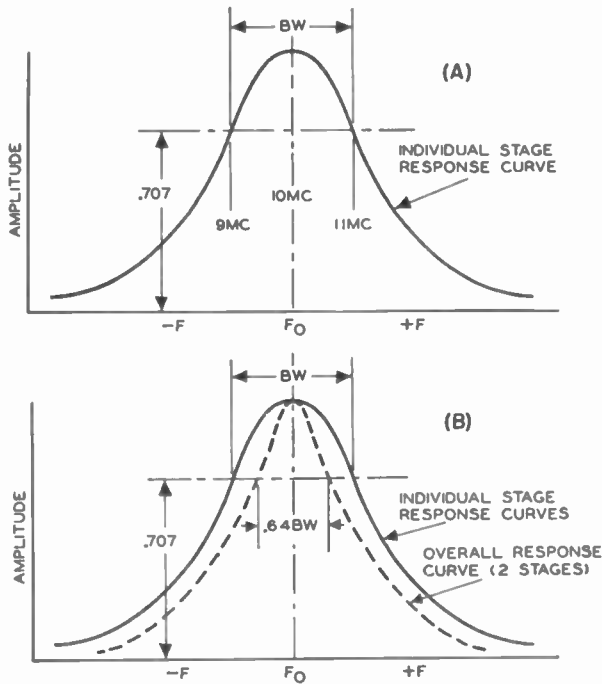
FIG. 4.32. Two tuned circuits, each peaked to the same frequency, produce an overall response in which the bandwidth is less than that of either curve taken separately.

A further note of importance is the fact that, if the gain of the circuit is considered as equal to 1 at F_0, it is down 3 db at points A–A′. That this is so can be seen from the following.

The definition of decibel is given by: db = 20 log (E_1/E_2) where E_1 here would be the voltage at F_0, and E_2 would be the voltage at points A–A′. For the sake of simplicity, let us as-

sign a value of 1 volt to E_1. At either point A or point A' the impedance offered to the same signal is $\dfrac{1}{\sqrt{2}}$ or 0.707 times as great. Hence, the voltage developed at either of these two points will be 0.707 volts. Substituting these values in the formula we have: db = 20 log (1/0.707) or db = 20 log 1.414, or about 3 db.

Points A–A' are also known as the "half power" points because $P = E_1{}^2/R$, and since $E_2 = \dfrac{E_1}{\sqrt{2}}$, then $P_{\mathrm{A-A'}} = E_1{}^2/2R$ which is one-half the power developed across R at F_0, the peak of the curve.

With this concept of bandwidth in mind, let us consider two single-tuned amplifiers, both tuned to the same frequency. If these two amplifiers are in cascade (i.e., follow each other), then the overall bandwidth is not equal to the bandwidth of either circuit, as one might expect, but to 64 per cent of this value. The reason for the shrinkage in bandwidth will be apparent from the following:

The response curve of the first amplifier, shown in Fig. 4.32A, has a maximum value of amplification of 1 at F_0, its peak, and 0.707 at the ends of the bandpass. Let us say that the mid-frequency is 10 mc, while the end frequencies of the bandpass are 9 and 11 mc respectively. If each of these three frequencies has an amplitude of 1 volt at the input to this tuned stage, then at the output they would possess the following values: at 9 mc— $1 \times 0.707 = 0.707$ volts; at 10 mc— $1 \times 1 = 1$ volt; and at 11 mc— $1 \times 0.707 = 0.707$ volts.

These same three frequencies are now passed through the second tuned circuit. Since this second circuit possesses the same characteristics as its predecessor, here is the result at its output: at 9 mc— $0.707 \times 0.707 = 0.49$ volts; at 10 mc— $1 \times 1 = 1$ volt; and at 11 mc— $0.707 \times 0.707 = 0.49$ volts. After passage through the two amplifiers, 9 and 11 mc are no longer within the 0.707 region about the resonant frequency of 10 mc. To find frequencies with voltages equal to at least 0.707 of the

10-mc voltage we must move *closer* to 10 mc. The result, of course, is a narrower bandpass; more accurately, 36 per cent narrower. (See Fig. 4.32B.)

Now let us consider two single-tuned amplifiers, each with the same bandwidth, but with their peaks separated (or staggered) by an amount equal to their bandwidth. (See Fig. 4.33.) The result is a response in which the overall bandwidth
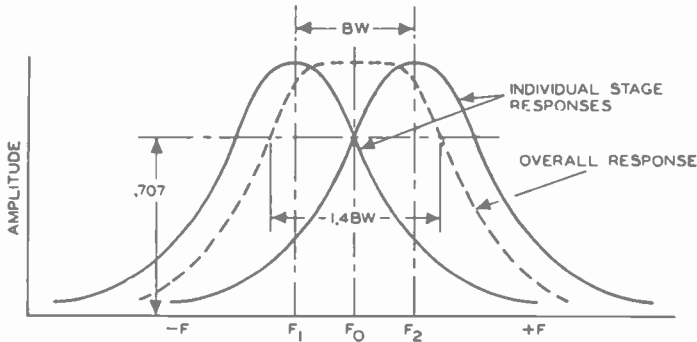
FIG. 4.33. By stagger-tuning two tuned circuits we obtain a wider bandpass. (See text.)

(to the 0.707 points) is 1.4 times the bandwidth of a single stage. The overall gain, however, is now only one-half that of the two stages tuned to the same frequency. This is so because at the center frequency of the overall response curve, the individual stage responses are only 0.707 of their peak response. The product of the stage gains is approximately one-half $(0.707 \times 0.707 \cong 0.5)$. This would be stagger tuning.

Now, to progress one step farther. We have seen that by stagger-tuning two tuned circuits, we achieve 1.4 times the bandwidth of a single stage but with only one-half of the gain. Suppose, however, we retain stagger tuning, but we decrease the bandwidth of each individual tuned circuit. The overall bandwidth of the stagger-tuned system will still be 1.4 times the bandwidth of the individual stages. However, because we have decreased the individual coil's bandwidth, 1.4 times this

new figure will be less than 1.4 times the previous figure when each individual bandwidth was greater. The advantage of this is that we still get a greater bandwidth than if we hadn't stagger-tuned the circuits, and the overall gain remains high.

A simple illustration will make this clearer. Suppose that the bandwidth of each individual stage is decreased to 0.707 of its original value. To do this, we raise the individual circuit Q's to 1.4 times their previous value which will provide an increase in gain by 1.4 times. Now, when the stages are staggered by an amount equal to this reduced bandwidth, the overall gain is one-half the product of 1.4 times 1.4. The answer is 1. Thus the overall gain is now the same as with the previous amplifier with both circuits tuned to the same frequency.

There are other systems which can give high gain and bandwidth, but the prime advantage of the stagger-tuned amplifier is its ease of alignment.

An important relationship and one which should be remembered by all radio men is the fact that bandwidth of any parallel resonant circuit (or an ordinary resistance-coupled amplifier) is inversely proportional to the amplification of that system. Expressed a little differently, we can say that *bandwidth × gain = constant*. Thus if we increase the bandwidth of a system by 1.5 times, we decrease its gain by the same amount. For any individual tuning coil, *bandwidth* = F_0/Q, where F_0 is its resonant frequency, and Q is the figure of merit of the coil. This expression tells us that, for any given resonant frequency, increasing the bandwidth can only be accomplished by decreasing the Q of the coil a proportional amount. However, if we raise the resonant frequency of the coil, maintaining Q constant, then the bandwidth will increase in like measure.

Complex Coupling. Thus far, we have considered transformer-coupled and stagger-tuned video I.F. amplifiers; now let us turn our attention to complex-coupled systems.

Philco, DuMont, Stromberg-Carlson, and Crosley have, at one time or another, used complex-coupled I.F. amplifiers.

In the Philco video I.F. system (Fig. 4.34) all interstage

circuits are capacitively coupled. Thus L_1 leading to the input I.F. amplifier transfers its energy to L_2 through C_1 and C_2. (L_1 and L_2 are not inductively coupled.) For alignment, L_1 and L_2 are peaked to different frequencies, and then C_2 is adjusted to provide the desired bandwidth. The trick here is to achieve the proper bandwidth without permitting any appreciable dip to appear in the center of the response curve. In this input
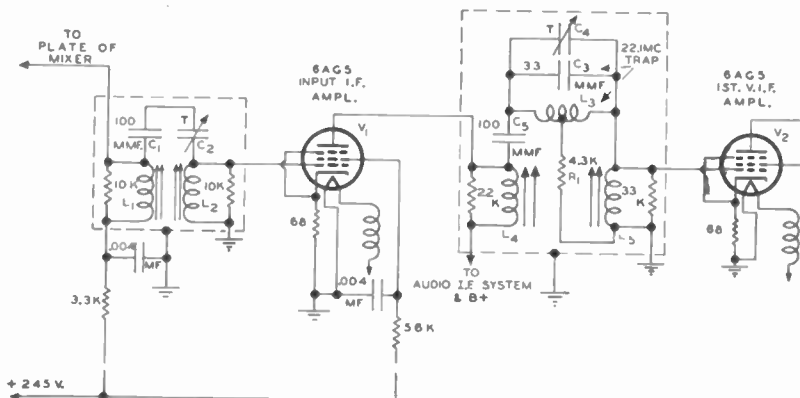
Fig. 4.34. A complex-coupled video I.F. system.

network, all signals between 28.1 and 22.1 mc are permitted to reach the amplifier tube 6AG5. The audio I.F. signal is then transferred to the audio system from the plate of the input I.F. amplifier. In the second coupling network located between V_1 and V_2, the accompanying audio I.F. voltage is sharply attenuated by the trap consisting of L_3, C_3, C_4, and R_1. (The reader will recognize this as a Bridged-T network.) L_4, L_5, and C_5 form the video I.F. coupling network similar to L_1, L_2, C_1, and C_2. The bandpass of this network is restricted to the 4.0 mc required by the video intermediate frequencies. The remaining video I.F. amplifiers of this system (not shown) are similar to the first two stages.

A second complex-coupled network is shown in Fig. 4.35. A common inductance, L_2, couples the signal energy from the mixer

plate to the grid of V_1. The mixer load circuit is L_1 plus L_2. The input circuit for V_1 is L_2 plus L_3. L_2 is thus the common element in both arms of this network and functions as the transferring agent. L_1 and L_3 possess variable cores in order that the bandpass of this network may have the proper width (4.0 mc). C_1 is a d-c blocking condenser, preventing the mixer B+ plate voltage from reaching the grid of V_1. C_2 is an ordinary by-pass condenser. An 8,200-ohm plate resistor broadens the response of the network to insure a 4.0 mc-spread.
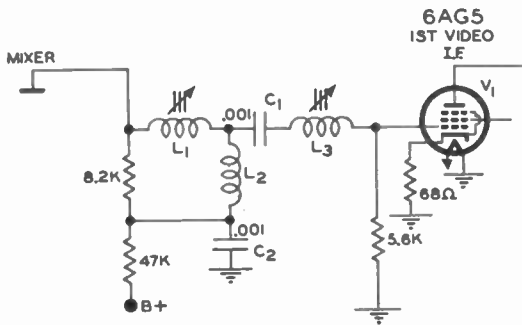
FIG. 4.35. A complex-coupled stage using a common inductance, L_2, to transfer the signal from the plate of the mixer to the grid of V_1.

Some readers will recognize the foregoing circuit as the familiar "T" network employed in some filters. Another complex arrangement would be the "pi" circuit shown in Fig. 4.36. Although an infinite number of such circuits are possible, few, besides the ones shown, are ever employed. Circuits more complex than these are too costly and too difficult to adjust to permit their adaptation to mass-produced television receivers.

Bifilar I.F. Coils. A new type of interstage coupling has recently appeared that resembles transformer coupling, yet differs from it in having only one tuning adjustment instead of the usual two. An illustration of a bifilar coil is shown in Fig. 4.37. The two coils comprising the unit are very closely wound, so much so, in fact, that the degree of coupling is close to unity. This means that practically all of the voltage developed across

the primary is transferred to the secondary winding.

Tuning of the bifilar coil is achieved with a single iron core inside the coil form. In most instances, the tuning rod extends above the top side of the chassis.

It can be shown by the proper circuit analysis that a 1 to 1 bifilar coil will produce the same selectivity curve and act in all other respects as a single-tuned coil having the same capacitances shunted across it and loaded down by the same resistors. Why, then, may you ask, should we desire to use bifilar coils? The
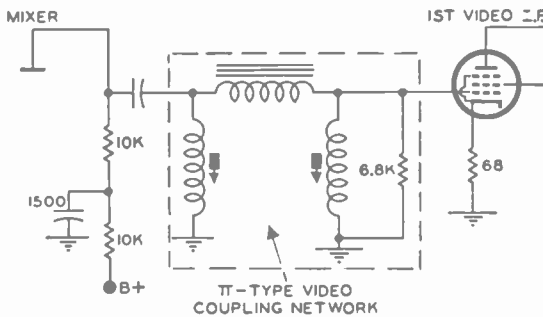
Fig. 4.36. A II-type video coupling network.
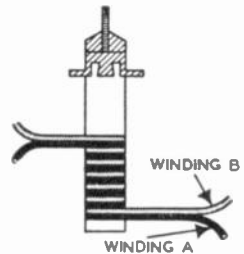
Fig. 4.37. An illustration of a bifilar coil.

reason, as we shall see in a moment, arises from the economic and operating advantages of these bifilar coils.

Before we consider these advantages, let us compare a video system using single-wound coils and a video system using bifilar coils. In Fig. 4.38 we have an example of the former; in Fig. 4.39 we have an example of the latter. Both systems were purposely chosen with the same number of stages so that this factor would not enter into the discussion. A comparison of Figs. 4.38 and 4.39 reveals that, by using bifilar coils in place of single-tuned coils, it is possible to eliminate each of the interstage coupling capacitors. In addition, the plate R.F. choke in the last I.F. amplifier may also be dispensed with. Thus a system employing bifilar coils is more economical than a system utilizing single-tuned coils. The operating advantage achieved through the use of bifilar coils is improved ability of the tele-

vision receiver to overcome the effect of noise. Here is how this comes about.

When a sufficiently strong noise pulse comes along, it drives the I.F. amplifier grid positive and grid current flows through the
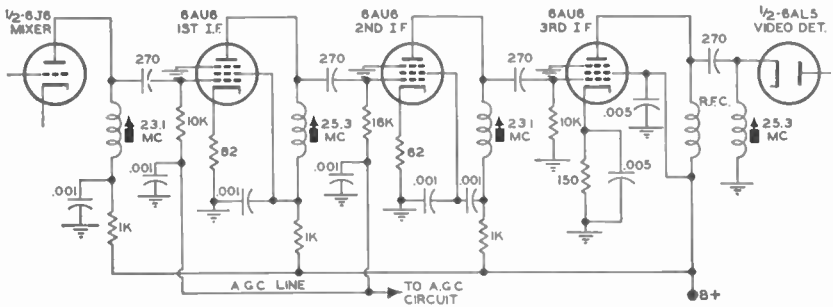
Fig. 4.38.   A video I.F. system using single-tuned coils.

grid circuit. Electrons flowing in any of the grid circuits of Fig. 4.38 will charge up the coupling condenser. When the noise pulse passes, the grid condenser does not lose its charge immediately, but instead discharges gradually, all the while maintain-
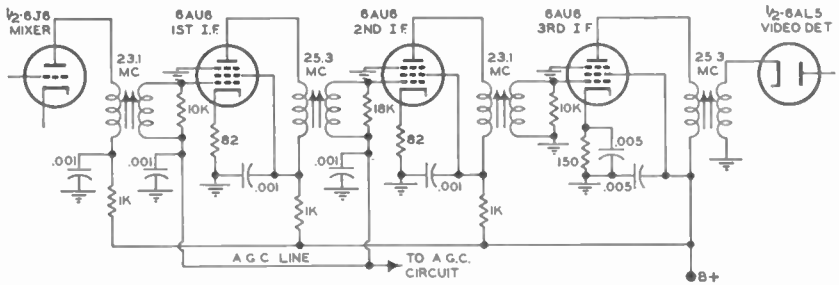
Fig. 4.39.   A video I.F. system with bifilar coils.

ing a fairly large bias on the tube. Until all this additional negative bias is removed, the gain of the tube remains lower than normal. It may even happen that severe noise pulse will drive the I.F. tubes to cutoff. When the noise pulse is such as to produce a black dot on the screen under the conditions indicated above, it will be found to be followed by a white tail.

Now let us consider the same circuit using bifilar coils. When a large noise pulse occurs and drives the grid of an I.F. amplifier positive, grid current flows. Now, however, there is no grid coupling condenser to charge up and so the grid returns to its normal bias just as soon as the noise pulse passes. The noise pulse may still produce a black or white dot on the screen (depending on its polarity at the cathode-ray tube), but black dots are not followed by white tails. Hence, the picture is not disturbed to the same extent.

Alignment of video I.F. systems using bifilar coils is achieved in the same manner as alignment of I.F. stages possessing single-tuned coils. Stagger tuning of the coils plus loading resistors provides the necessary bandwidth. Although trap circuits are not shown in either Fig. 4.38 or 4.39, they are used.

Usually, a system either employs all single-tuned coils or all bifilar coils. Occasionally, however, combinations of the two may be encountered. Thus, one manufacturer employed single-tuned coils in the first, second, and third I.F. stages and a bifilar coil in the grid circuit of the fourth I.F. stage. This last I.F. stage is the most susceptible to noise pulses since the signal has been considerably amplified by this time and by placing a bifilar coil here the grid is prevented from developing a large negative bias on noise pulses.

Contrast Control. The manual volume control is used in conjunction with the A.V.C. of a sound receiver. The adjustment permits the listener to set the volume level at the loudspeaker. In much the same manner, in a television set a potentiometer, known as the contrast control, allows the user either to increase or decrease the intensity of the image at the screen. Manual control of the strength of the video signal reaching the cathode-ray tube may be readily accomplished by varying the gain of one or more I.F. amplifiers. And the simplest way of varying the gain of a tube is through the negative grid bias applied between the grid and cathode. While there are many gain control arrangements possible for the I.F. stages, the following two illustrations are basic to most of the methods used. Gain con-
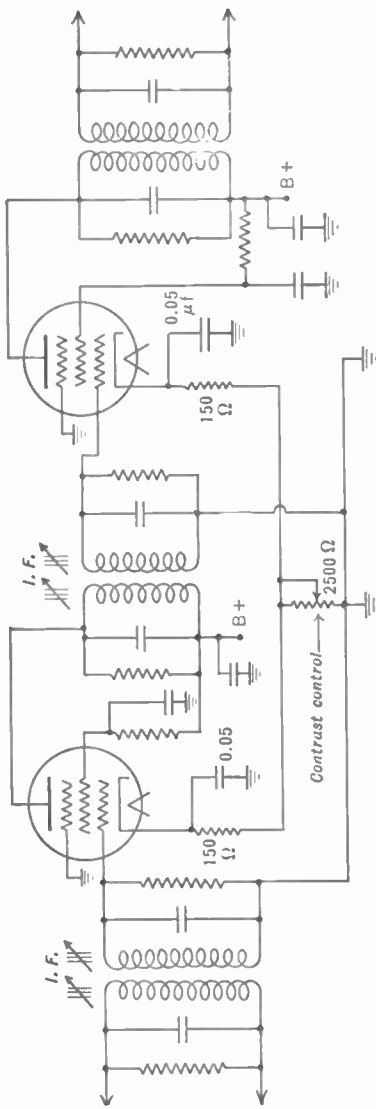
Fig. 4.40. One method of varying the gain of a stage. The potentiometer is called the contrast control.

trol for circuits other than the I.F. amplifiers will be illustrated
at the appropriate places.

It is characteristic of all amplifier tubes that the greater the
negative grid bias, the lower their gain. In Fig. 4.40, a section
of the I.F. amplifiers of a receiver is shown. Each tube is pro-
vided with one fixed resistor for minimum fixed bias while the
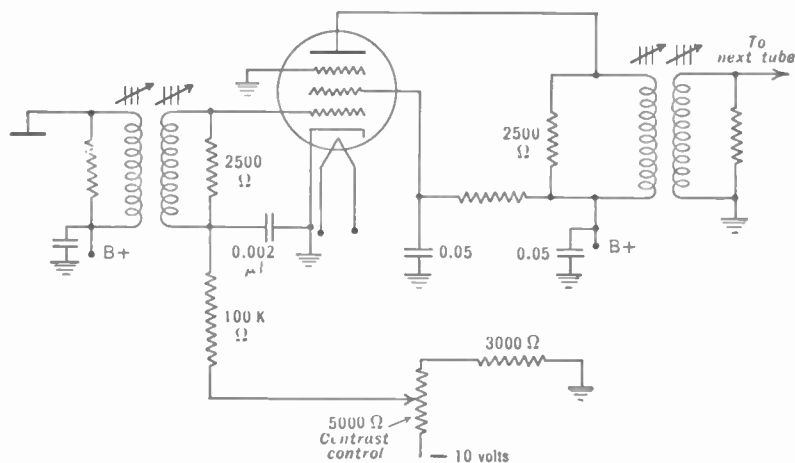
FIG. 4.41. Another method for varying the gain of the set.

remainder of the grid voltage is obtained across the 2,500-ohm
contrast control. The bias on each tube may then be varied by
movement of the arm on the potentiometer. There are the usual
small fixed condensors by-passing these resistors.

Another method, slightly different, varies the d-c bias (and,
indirectly, the g_m) on a single tube (or more) in the manner
shown in Fig. 4.41. The d-c biasing voltage is obtained from
the negative side of the power supply, and the position of the
center arm of the potentiometer determines how much of this
negative voltage reaches the grid of the controlled tube. Ex-
tended cut-off tubes are the only ones that permit satisfactory
variation of d-c bias over wide limits without too much distor-
tion, and they are always used.

CHAPTER 5

DIODE DETECTORS AND A.G.C. CIRCUITS

Detection of the Video Signal. In accordance with the general line-up that is peculiar to superheterodynes, the second detector follows the last I.F. amplifier. Detection in television receivers is carried out in much the same manner as in any ordinary sound broadcast receiver. The single diode connected

FORM OF INPUT VIDEO SIGNAL

2.5K

INCREASE

RECTIFIED OUTPUT FORM

4K
R_L

TO VIDEO AMPLIFIERS
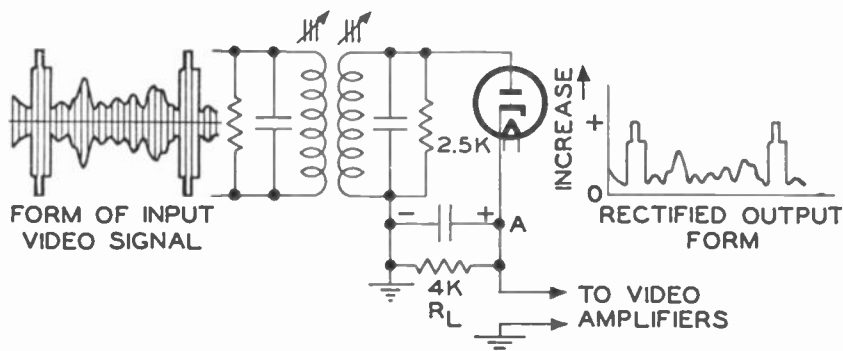
Fig. 5.1. A diode detector for a television receiver.

as shown in Fig. 5.1 is typical. The demodulated video signal with its blanking and synchronizing peaks is developed across R_L. The form of the signal, when it enters the second detector, is shown to the left of the figure. The rectified resultant is illustrated at the right.

As is true of diode operation, plate current flows only when the plate is positive with respect to the cathode. The effect of this action is to eliminate the negative portion of the incoming signal. This is of little interest here, since the positive and negative sections of the modulated video signal are exact duplicates of

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each other and either one may be used. Instead of a half-wave rectifier it is also possible to use the full-wave arrangement shown in Fig. 5.2 with a 6AL5 double diode.

Positive and Negative Picture Phases. At this point it is necessary to pause and consider the effect of the relative polarity of the voltage drop across the load resistor, R_L. It will be remembered from Chapter 1 that, for American television sys-
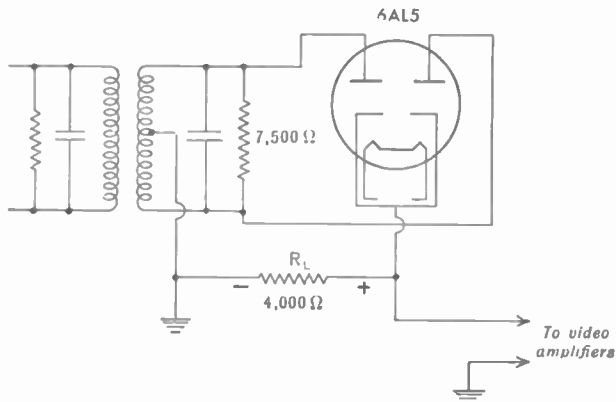
FIG. 5.2.   A full-wave detector.

tems, negative picture transmission is standard. This means that the brightest elements cause the least amount of current to flow while maximum current is obtained when the blacker than black region of the synchronizing signal is reached. This method of transmission was adopted because it was felt that better overall reception would be obtained.

The signal in the negative picture phase form, as shown in Fig. 5.3A, could not be applied directly to the grid of the picture tube, however, but first has to be reversed to the form of Fig. 5.3B. That this is essential is easily seen, for the blanking and synchronizing signals, when applied to the control grid of a picture tube, must bias it to cut-off. The objective can be attained only if the signal has the form given in Fig. 5.3B. The radio engineer calls this latter form of the television signal the positive picture phase. It is interesting to note that, if the negative

phase of the signal were applied to the control grid of the picture tube, all the picture values would be reversed and the observed scene would be similar to a photographic negative.

In sound receivers, no attention is given to the relative phase of the audio signal because our ears are insensitive to all but gross phase differences. Television, on the other hand, deals with visual images, and reversal of phase produces noticeable effects. Possible ways of altering the phase of the video signal are discussed in the following paragraphs.
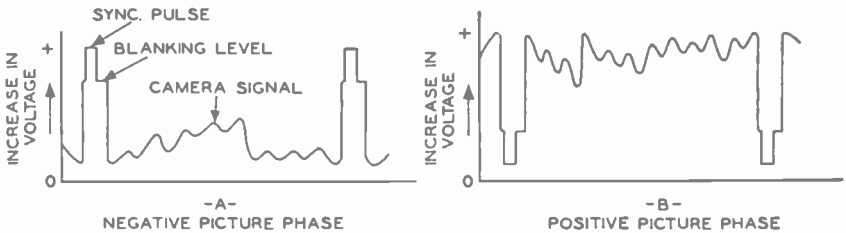
FIG. 5.3.   Rectified video signals may be obtained from the output of the detector in either one of the two forms shown, depending upon how the detector is connected.

Turning to the half-wave detector circuit of Fig. 5.1, let us investigate the voltage developed across R_L. The incoming signal has the same form as at the antenna, with the synchronizing pulses giving rise to the greatest voltages. At the diode rectifier, these synchronizing signals cause the plate to become the most positive, resulting in a greater voltage drop across R_L and having the polarity as shown. On the other hand, those portions of the video signal representing the bright segments of the image will have the least positive voltage at the diode plate, with a smaller resultant voltage drop at R_L. Thus, with this circuit hook-up, point A of resistor R_L will still give rise to a large positive voltage for the synchronizing signals, which means that the signal is still in the negative picture phase. The signal is unsuitable for direct application to the grid of the viewing tube.

The direction of the current flow through R_L may be altered
to give the opposite polarity quite easily. Merely reverse the
connections between the diode tube and the input transformer,
as in Fig. 5.4. Rectification now eliminates the positive half
of the modulated carrier and leaves only the negative half. Since
both contain the same information, nothing is lost. Point A
becomes more strongly negative for the blanking and synchro-
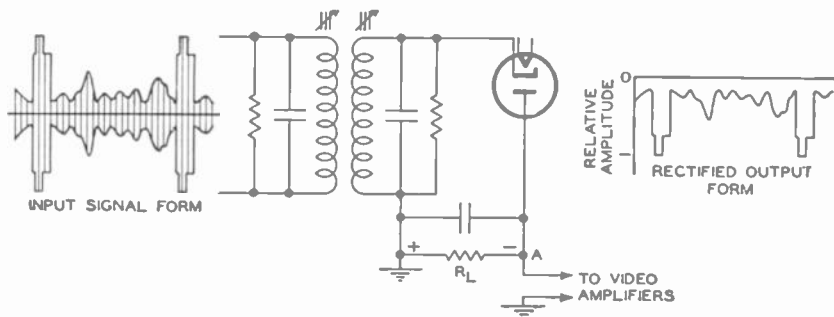
Fig. 5.4. A diode detector connected to give a positive picture phase output signal.
Note that with an inverted diode detector, only the negative half of the input
signal is rectified. In Fig. 5.1, the opposite is true.

nizing portion of the video signal while the bright elements cause
A to become less negative. When the signal is applied in this
form between the grid and cathode of the image tube, the largest
current will flow for the bright sections of the image and a
bright spot will appear on the fluorescent screen. For the blank-
ing and synchronizing parts of the signal, the voltage at the
grid (from point A) will be highly negative and the electron
beam will be cut off, as it should be.

The strength of the signal that is developed at the diode load
resistor is not strong enough to use directly at the picture tube.
Hence, further amplification is necessary. The following video
amplifiers, which are generally of the resistance-coupled type,
are capable of reversing by 180 degrees the polarity of any sig-
nal sent through them. (This will be proved in Chapter 6.)
Thus, if the video signal had a positive picture phase at the

diode load resistor, it would have a negative picture phase at the output of the first video amplifier. With another stage of amplification, the picture would be brought back to the positive phase again. As a general rule, then, an even number of video

FIG. 5.5. An illustration of why the number of video amplifiers after the detector is dependent upon the polarity of the signal obtained from the detector.

amplifiers is required if the picture phase across R_L in the detector is positive. For a negative picture phase at R_L, an odd number of video amplifiers is needed, this time for a positive picture to appear at the grid of the image tube. These conditions are given in block form in Fig. 5.5.

FIG. 5.6. A video detector and video amplifier feeding the signal to the cathode of the image tube.

The circuit of the video detector and the video amplifier used in a General Electric television receiver (Fig. 5.6) appears, at first glance, to violate the foregoing rules. Examination of the video signal developed across R_1 reveals it to be positively phased. This would require 0, 2, 4, or some other even number of video amplifiers. Actually, only one is present. The mystery

is resolved when we note that the output of the video amplifier is fed not to the control grid of the cathode-ray tube but to its cathode. The foregoing rules were drawn up with the tacit understanding that all incoming signals are applied to the control grid of the picture tube. This is the normal point of signal application. Signals applied to the cathode of a tube should differ by 180 degrees from the same signals applied to the control grid in order to produce similar results.

Detector Filtering and Peaking. The frequencies present in the detector circuit include the I.F. values, 21.25–25.75 mc, and the actual video signals themselves, 0–4 mc. The latter voltages are to be passed on to the video amplifiers and be strengthened to the point where they are able to modulate the electron current in the cathode-ray tube to produce an image on the screen. At the detector output, the intermediate frequencies must be properly shunted around the load resistor to prevent their reaching the following video amplifiers. In the receivers currently being produced, the problem of filtering the I.F. voltages has been made comparatively simple through the use of fairly high I.F. values. The rectified video signal has a maximum frequency of 4 mc. In early television receivers, the I.F. values ranged from 8.75–12.75 mc, and considerable filtering was required because of the low order of separation between the desired frequencies (0–4 mc) and those which were to be by-passed (8.75–12.75 mc). However, by increasing the separation between the two, we have simplified the problem considerably. Current recommended values for the video I.F. are between 20 and 30 mc. Adequate filtering can be obtained through the arrangement shown in Fig. 5.7. The rectified current passes through the low-pass filter composed of C_1, L_1, R_1, L_2, R_2, and C_2. C_1 is a small fixed condenser of 10 $\mu\mu$f, but actually there exists additional capacitance across this point produced by the tube and the wiring. At the other end of the filter, C_2 is shown in dotted form because no such component is inserted. However, the sum of the stray wiring capacitance plus the input capacitance of the following video amplifier produces the equiva-

lent of an actual condenser of 10–15 $\mu\mu$f. The two coils, L_1 and L_2, while forming part of the low-pass filter, at the same time maintain a good frequency response to 4 mc, thereby counteracting any tendency of the circuit to attenuate these higher video frequencies. More will be noted on this point in the succeeding chapter on video amplifiers. The 39,000-ohm resistor shunted across L_1 is to prevent the response of the coil from rising abruptly at the higher video frequencies because of a natural
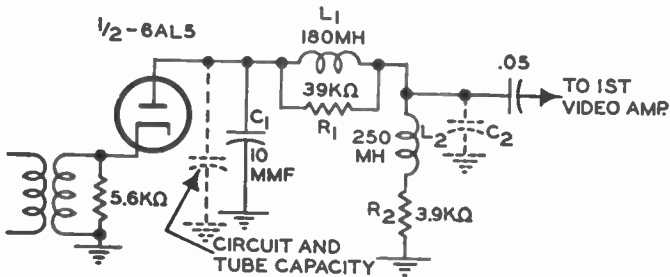
FIG. 5.7. A video detector circuit with a low-pass filter and load resistor.

resonant circuit formed by the coil and its inherent capacitance. The detector load resistor is R_2, 3,900 ohms.

The output of the second detector (Fig. 5.7), can be used for three purposes: (1) the video amplifier, (2) the automatic gain control circuit, if any, and (3) the synchronizing separator circuits. In the smaller, cheaper sets, advantage is taken of this fact actually to use the detector output voltage for each of these circuits. In more elaborate receivers, it is customary to employ separate tubes for each purpose. Connection of all the circuits to a single point would raise the total shunting capacitance at that point to a value that might readily by-pass the higher video frequencies. It must be remembered that each of the stages mentioned has a certain input capacitance, and, as the capacitance shunted across any point in the circuit increases, the reactance decreases. It does not require a very large capacitance to provide a low-impedance shunting path for video frequencies

of 4 mc. In low-priced receivers, the loss of the higher video frequencies is not too detrimental since a small screen does not require the very fine details for the presentation of a suitable image.

In place of a diode tube, many television receiver manufacturers have substituted the new germanium crystal detector 1N34. These new crystals, which were developed for radar, are well suited for operation up to 100 mc. The old cat-whisker crystal detectors which many radiomen still recall were much too critical in adjustment to be used for any such purpose. Furthermore, their large size produced a high internal capacitance which was detrimental to high-frequency operation. In the new germanium crystals the total capacitance from cathode to anode is only 3 $\mu\mu f$, which compares favorably with any of the miniature diodes.

Briefly, the theory of operation of a crystal is as follows: When two metals are brought into contact, electrons can flow as readily in one direction as in another. However, when a metal is brought into contact with a certain class of materials known as semi-conductors, electrons flow more easily in one direction than in the other. When we apply an alternating wave to a circuit containing a crystal, more current will flow in one direction, with the result that an average current will be produced. Hence, rectification has occurred. In this respect the crystal is less efficient than a diode, since current is permitted to flow in only one direction through a tube. In the crystal, current flows in both directions, although considerably stronger in one direction than the other. The smaller current, which is not desired, offsets some of the rectified voltage developed across the load resistor thereby lowering the ratio of voltage output to voltage input. With this ratio decrease, the detector efficiency drops.

The 1N34 is rated for an average anode current of 22.5 ma and a peak inverse anode voltage of 50 volts. These ratings are more than sufficient for detector operation.

A typical circuit using the 1N34 is shown in Fig. 5.8. The section of the crystal rectifier marked with a minus sign is equiva-

lent to the cathode of a diode tube. The other section, marked with a plus sign, represents the plate. On conduction, then, the maximum flow of electrons occurs from the negative to the positive plates.

A.V.C. and A.G.C. Automatic volume control (actually this should be called automatic gain control) in a broadcast receiver serves to keep the output constant while wide variations occur in the input signal. Once the manual volume control has se-
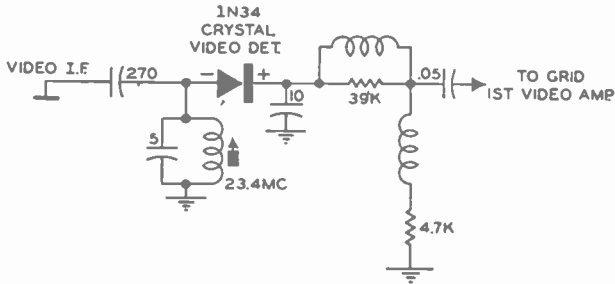
FIG. 5.8. A 1N34 germanium crystal as a video detector.

lected the output level that is desired, the A.V.C. system tends to keep it there. In addition, when tuning to other stations, no adjustments are necessary to prevent blasting. For television receivers, automatic gain control is advantageous in keeping the picture intensity fixed at one level while the actual video signal at the input of the set may be varying. The eye is far more critical of changes than the ear, and anything that would minimize unwanted variations in image intensity is very desirable. A.G.C. would be advantageous when switching from one station to another, for again input signal strengths may differ. Finally, more stable synchronizing operation is obtained if the signal fed to the synchronizing circuits is constant in amplitude.

In a broadcast receiver, the A.V.C. voltage is obtained at the second detector. The necessary audio signal is developed across the load resistor. A circuit frequently used is illustrated in Fig. 5.9, with the polarity of the A.V.C. voltage and the filter circuit included. It will be remembered that the object of the A.V.C.

is not to feed the instantaneous audio variations but rather an average voltage that depends upon the carrier level back to the R.F. and I.F. stages. If the audio variations were sent back to the preceding tubes, all musical passages, for example, would
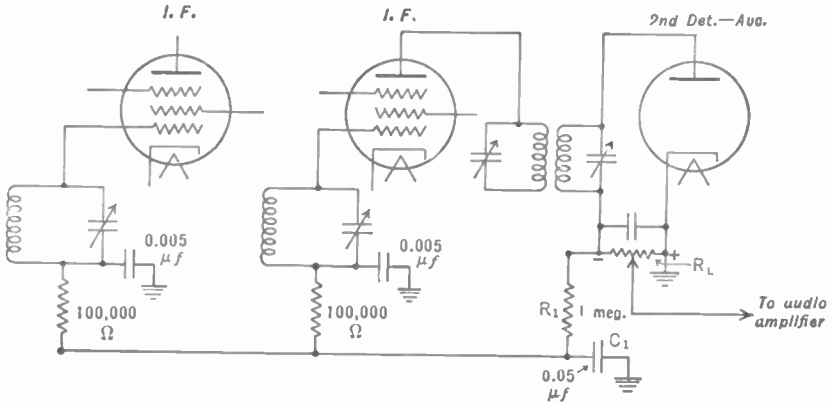
Fig. 5.9. A conventional A.V.C. circuit found in present sound receivers.

arrive at the speaker with the same intensity, in itself a form of distortion.

The desired A.V.C. voltage is obtained from the average voltage developed across the load resistor by the rectified carrier
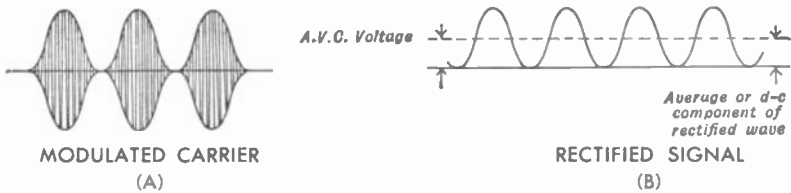
Fig. 5.10. The A.V.C. voltage developed across R_L represents the average value of the incoming wave.

signal. The incoming signal both before and after rectification by the diode detector is shown in Fig. 5.10. The detector output consists of a pulsating d-c voltage that contains a varying audio voltage, and an average d-c voltage dependent upon the carrier strength. The audio signal, since it is varying as much

above the average value as below, contributes nothing to the d-c voltage. The only way that the average d-c voltage can be changed is to alter the strength of the carrier. This is demonstrated in Fig. 5.11 where different levels of carrier signals are shown, all having the same audio component. The d-c voltage

Average or d-c voltage developed at detector

(A)
WEAK CARRIER

(B)
MEDIUM CARRIER

(C)
STRONG CARRIER
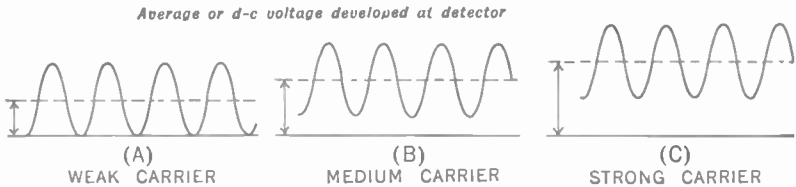
Fig. 5.11. These diagrams illustrate how the A.V.C. voltage is dependent upon the strength of the incoming signal, and not its modulation.

is then fed to the various controlled I.F. and R.F. stages. The purpose of the filter condenser C_1 and resistor R_1 of Fig. 5.9 is to prevent (or at least minimize) any audio voltage from reaching the controlled tubes.

The objectives in television receivers, through the use of automatic gain control, are similar to those of broadcast sound sets.

SYNC. PULSES (FIXED)

CAMERA SIGNAL

BLANKING LEVEL (FIXED)

AVERAGE VIDEO VOLTAGE (NOT FIXED)
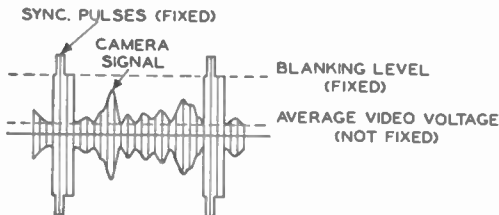
Fig. 5.12. An amplitude-modulated television signal. Only the fixed voltage levels are suitable for A.G.C. control since only these voltages vary directly with signal strength.

The means of obtaining the necessary voltage, though, is slightly different, due to the difference in the make-up of the video signals. A study of the television modulated signal in Fig. 5.12 reveals that, so far as A.G.C. is concerned, the rapidly varying camera signal is of no use to us. We desire some point which

will be indicative of the strength of the carrier and which does not change with anything but the carrier.

With the present system of transmission, the carrier is always brought to the same level when the synchronizing pulses are inserted. Thus, as long as the signal being received is constant in strength, the level of the synchronizing pulses will always reach the same value. If something should affect the carrier level, these pulses would likewise change. With the change, the gain of the set would require adjustment to maintain the previous level at the detector. Hence, the strength of the synchronizing pulses will serve nicely as a reference level for the A.G.C. system. It should be noted that the level of the blanking pulses (immediately below the top of the synchronizing pulse) is likewise fixed and may also be used.

Analysis of some of the circuits found in commercial receivers readily indicates how automatic gain control is obtained.

A simple yet effective method of developing a suitable A.G.C. voltage is employed in the Farnsworth television receivers. (See Fig. 5.13A.) The A.G.C. diode is one section of a 6AL5 and receives the incoming signal from the video I.F. system through a 0.5-μf condenser, C_1. The load for the A.G.C. tube is R_1, a high-valued resistor of 1 megohm. To understand better the operation of this circuit, consider the equivalent diagram shown in Fig. 5.13B. (The cathode resistor and condenser are omitted from the equivalent diagram because they do not affect the A.G.C. voltage development.) The A.G.C. tube will not conduct until its plate is driven positive with respect to its cathode. When this occurs, electrons flow from the cathode to the plate of the diode and into C_1 where the negative charge is stored. Very few electrons attempt to go through R_1 because of its high value. On account of the low impedance offered by the tube when it is conducting, C_1 charges up to the peak of the applied voltage, which is the value of the synchronizing pulses.

During the negative excursion of the incoming signal, the plate of the diode is driven negative with respect to its cathode and no conduction through the tube occurs. However, if we examine

Fig. 5.13B, we see that a complete circuit exists with C_1, R_1, and the input coil all in series. Since a voltage exists across C_1 and a complete path is available, current will flow, with the upper end of R_1 becoming negative with respect to ground. Because
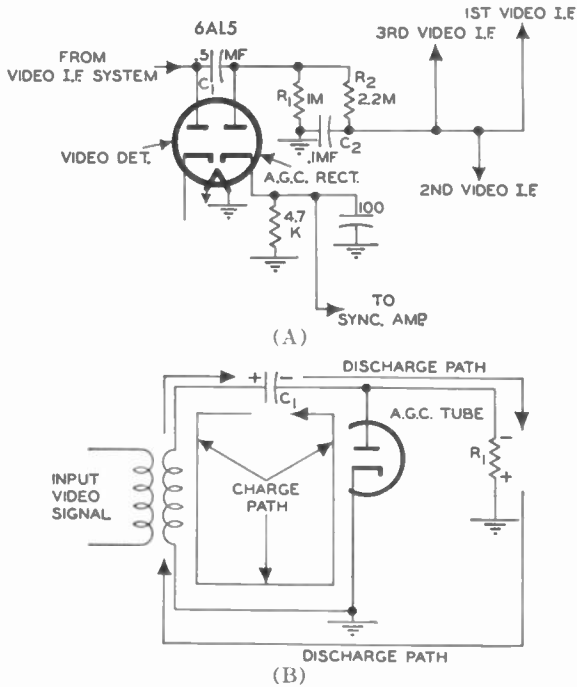
FIG. 5.13. (A) A simple A.G.C. network. (B) The equivalent circuit, showing the charge and discharge paths of C_1.

of the long time constant of R_1 and C_1, the charge accumulated across C_1 will discharge slowly through R_1, so slowly, in fact, that only a small percentage of the voltage across C_1 will be lost during the interval when the tube is not conducting.

When the incoming signal becomes positive again, the tube does not immediately conduct because the applied signal voltage must first overcome the negative voltage existing across C_1. Since C_1 has lost but little of its voltage, tube conduction will

occur only at the very peaks of the positive cycle. These peaks, of course, are the synchronizing pulses. Thus, the voltage across C_1 is governed entirely by the sync pulses, which is what we desire. The negative voltage across R_1 is filtered by R_2 and C_2 to remove the 15,750-cycle ripple of the horizontal sync pulse and then fed to the video I.F. amplifiers as the control voltage. It is interesting to note that the same diode also supplies the
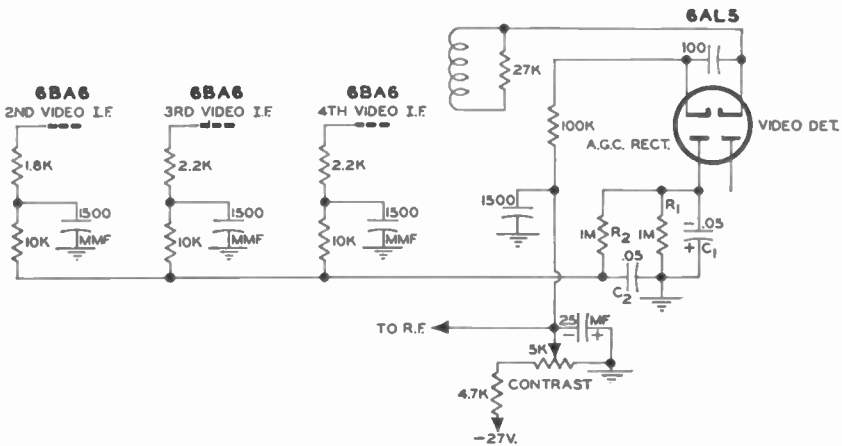
Fig. 5.14. The Garod A.G.C. Circuit.

sync pulses to the horizontal and vertical sync systems. Since current flows through this diode only at the sync pulses, voltage pips will appear across the 4,700-ohm resistor in the cathode leg of the tube at these times. These pips are tapped off and applied to the sync-separating circuits.

In Garod television receivers, the contrast control is incorporated into the A.G.C. network. (See Fig. 5.14.) The negative voltage of the contrast control is fed to two points—the R.F. amplifier and the A.G.C. section of a 6AL5 duo-diode. Since the voltage at the contrast control is negative and it is applied to the cathode of the A.G.C. tube, this tube will conduct, even in the absence of a signal. The tube current, flowing through the 1-megohm plate resistor R_1, will cause a negative

voltage (with respect to ground) to appear here. This negative voltage is then transferred through a low-pass filter (R_2 and C_2) to the grids of the second, third, and fourth video I.F. amplifiers. Thus, even in the absence of a signal, the bias on these tubes is governed by the contrast control.

When a signal arrives at the second detector, it is applied to the A.G.C. diode through a 100-$\mu\mu$f condenser. On the negative peak of each signal, the cathode will be driven even more negative, causing additional current to flow through the tube and increasing the negative charge on C_1 and the negative voltage across R_1. If the signal arriving at the A.G.C. diode is strong, the additional negative voltage across R_1 will be high. If the signal is weak, this additional negative voltage will be small. In this way, the signal will add to the contrast control voltage and will form an automatic regulator of the control grid bias. By inserting C_1 in the plate circuit of the diode, only the sync pulse peaks of the signal will be effective in changing the A.G.C. voltage. In operation, the contrast control is adjusted for normal picture contrast with a signal coming in. If the signal should increase, more negative bias will be applied to the controlled stages from the A.G.C. diode, lowering the gain available to the signal and reducing the signal to the level desired by the set observer. With a lowering of the signal, we have a corresponding decrease in negative voltage across R_1 and C_1, and the gain of the system rises. Thus, the average desired level is determined by the setting of the contrast control and the average level of the incoming signal. Any deviation from this is then automatically adjusted by the A.G.C. action.

A novel yet simple arrangement for the development of A.G.C. voltage is shown in Fig. 5.15. The entire video signal (containing signal voltages and sync pulses) is tapped off from the output circuit of the first video-frequency amplifier (6AC7) and applied to a 6SG7 sync-separator tube. The A.G.C. voltage is developed at the grid of the 6SG7 tube as a result of the grid-leak biasing arrangement employed here. The 6SG7 tube has

no fixed bias of its own. Hence, when a signal is applied through C_1, grid current flows for the positive portions of the signal, the amount dependent upon the strength of the signal voltage. Because of the high value of R_1 and R_2, the grid electrons flow into C_1, charging this to the peak value of the applied signal. This peak value, of course, is set by the sync pulses. The voltage developed across C_1 then discharges slowly through R_1 and R_2, de-

FIG. 5.15. An A.G.C. network employed in some television receivers.

veloping a bias across these two resistors which is negative with respect to ground. Because of the long time constant of the grid network, the charge on C_1 leaks off slowly, and only the sync pulses of the signal are able to overcome its negative charge and cause current to flow in the 6SG7. Thus, the voltage developed across R_1 and R_2 is governed by the sync pulses. The voltage across R_1 is applied, through a suitable filter network, to the last four video I.F. amplifiers as an automatic bias. The 6SG7 tube is known as a sync separator because only the sync pulses appear in its output. All the rest of the video signal is without effect because of the high negative grid-leak bias.

A system which is more complex and involves the use of a special A.G.C. amplifier is found in Philco receivers (Fig. 5.16). As before, the incoming video signal is received from the video I.F. system and applied to the video second detector and the

A.G.C. rectifier. In the cathode leg of the A.G.C. diode section
of the 6AL5, we have the long time constant network of R_1 (4.7
meg) and C_1 (0.05 μf). Initially the condenser charges up to
the peak value of the incoming sync pulses and thereafter dis-
charges slowly through R_1 during those intervals when the diode
tube does not conduct. Since the discharge is very slow, because
of the time constant of the circuit, much of the voltage estab-
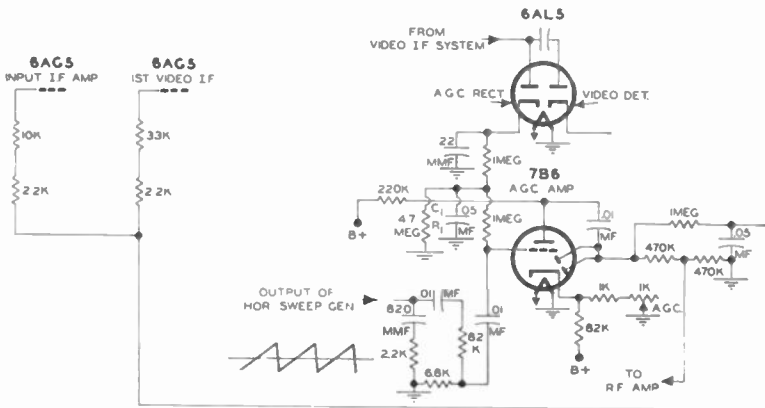
FIG. 5.16. The special A.G.C. network employed by Philco.

lished across C_1 will remain. Hence, only at the sync pulse tips
will current flow through the tube. The voltage thus established
across C_1 and R_1 will be governed by the level of the sync pulses
in the incoming signal.

As a result of the path of current flow through the A.G.C.
rectifier tube, the voltage at the ungrounded end of R_1 is posi-
tive. This voltage is fed to the grid of the triode section of the
7B6 A.G.C. amplifier. This positive voltage, however, is offset
by an even greater positive voltage that is obtained from the B+
power supply and applied to the cathode. Thus, the effective
control grid bias for the A.G.C. amplifier is negative although
the value of this negative voltage varies in accordance with the
voltage obtained from R_1 and C_1. The purpose of this arrange-
ment is to vary the bias of the 7B6 in accordance with the

strength of the incoming signal and yet maintain the overall bias negative.

A second voltage applied to the grid of the A.G.C. amplifier is obtained from the horizontal deflection system. This voltage is amplified in the 7B6 and then rectified by the diode section of the same tube. It is this rectified voltage which is finally employed as the A.G.C. voltage to control the gain of the R.F., input I.F., and first video I.F. amplifiers.

When the signal level increases, the A.G.C. rectifier develops more voltage across C_1 and R_1. This means more positive voltage for the A.G.C. amplifier (7B6) and a greater output from this tube because of the increased gain. The horizontal deflection voltage fed into the tube remains constant at all times and a more positive bias for the tube will produce a greater output. This means more rectified A.G.C. voltage fed to the controlled stages. However, since the final A.G.C. voltage is negative, the gain of the controlled stages decreases, counteracting the increased video signal and reducing the output to the normal level.

When the signal level decreases, less positive voltage appears across C_1 and R_1 and the A.G.C. amplifier bias becomes correspondingly more negative. Less gain in this tube provides less voltage at its output, and the negative A.G.C. voltage decreases. As a result, the gain of the controlled stages rises, and the signal level is again brought back to the normal level.

Whereas in previous A.G.C. systems, the output of C_1 and R_1 was used as the controlling A.G.C. voltage, here it is used to control the bias of the A.G.C. amplifier. The final product of both systems is the same, but this arrangement is more sensitive to carrier changes because of the addition of the amplifier. A divider network at the output of the diode section of the 7B6 feeds less A.G.C. voltage to the R.F. amplifier than to the I.F. stages. The potentiometer in the A.G.C. system permits the system to be adjusted for desired sensitivity.

Probably the most elaborate A.G.C. system currently in use is that employed in the RCA television projection receivers, shown in Fig. 5.17. A portion of the video signal output of the

fourth video I.F. amplifier is fed to the 6AL5 A.G.C. detector Since the time constant of the diode load resistor (R_1) and condenser (C_1) is somewhat longer than one horizontal line, only the peak sync pulses are effective in developing a voltage across this combination.

The -110 volts is applied equally to the plate and cathode of V_1 and consequently has no effect upon the operation of this tube.
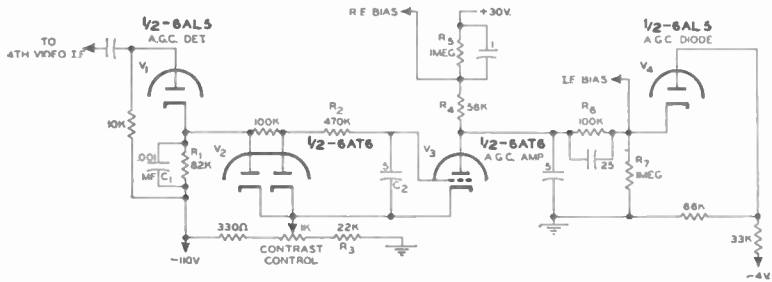
FIG. 5.17.   The elaborate A.G.C. system employed in RCA television projection receivers.

The voltage developed across R_1C_1 is fed to the A.G.C. amplifier. Across this path, however, we find two diodes designed as a two-stage clipper or noise-limiting network. Their purpose is to prevent noise pulses from seriously affecting this system. All television A.G.C. systems operate on the peak of the incoming signal and ordinarily this is the position of the synchronizing pulses. However, a sharp impulse of noise can extend even beyond these pulses and cause the system to react to it. In the RCA system, the double diodes provide a low-resistance path across C_1 and R_1 whenever noise pulses are present. In this manner they prevent C_1 from charging to the peak value of the noise pulses. As soon as the noise passes, the normal sync pulses assume immediate control of the circuit. Without the diodes, C_1 and R_1 would charge to the peak value of the pulse and maintain this condition until C_1 returned to its normal level. How long this would take would depend upon the charge placed across C_1 by the noise pulse and the time constant of C_1 and R_1. Under

extreme conditions, this excessive voltage will cause the receiver screen to become momentarily dark.

Under normal conditions, the plates of the diodes have a greater negative voltage than their cathodes. As a result, the diodes are non-conductive, and the voltage developed across C_1R_1 is transferred to V_3. However, when a large noise pulse arrives, the positive voltage developed across R_1C_1 is great enough to lower the -110 volts reaching the plates of the diodes to the point where their plate voltage is less negative (or, what is the same thing, more positive) than their cathode voltage. At this moment the diodes conduct, shunting their low resistance across R_1C_1 and preventing any large amount of voltage from developing here. When the noise impulse has passed, the diodes once again become non-conductive, permitting the normal voltage variations from R_1C_1 to reach V_3. For additional protection against noise, the integrating network of R_2C_2 acts to remove the effects of any noise impulses.

Thus, the only voltages which will affect the circuit are the normal variations in sync pulse levels due to changes in carrier amplitude. These are the changes to which we desire to have the circuit respond.

The d-c voltage at the cathode of V_3 is obtained from the voltage drop across R_3 and from part of the contrast control. With a weak signal input, this bias is sufficient to reduce the plate current of V_3 almost to cut-off, causing the plate voltage to drop to ground potential. (Note: Enough current flows so that the negative voltage developed across R_4 and R_5 counteracts the $+30$ volts applied to R_5.) The R.F. bias voltage, obtained from the junction of R_4 and R_5, is zero volts, and the I.F. bias is -1 volt. These biasing voltages permit the receiver to operate at maximum gain under weak signal conditions.

Upon the arrival of a strong signal, an increased positive voltage is developed across R_1C_1. This causes V_3 to conduct more strongly, forcing the voltage across R_4 and R_5 to become more negative. (In any tube, whenever the plate current increases, the negative voltage across its plate load resistors likewise in-

creases.) This drives the R.F. and I.F. bias voltages more nega-
tive, the precise amount dependent upon the strength of the
signal. (See Fig. 5.18.)

The bias-versus-signal-input chart indicates that the R.F. bias
is lower than the I.F. bias up to signal inputs of approximately
8,500 microvolts. Beyond this, the R.F. bias increases more
rapidly while the I.F. bias tends to taper off, finally reaching −4
volts at extreme signal strengths. This particular design was
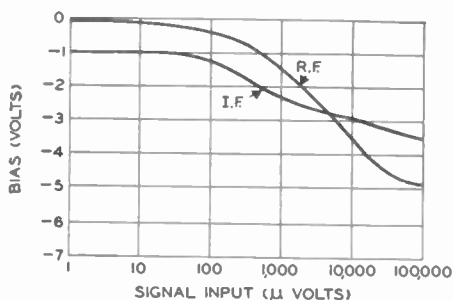
Fig. 5.18. The signal input versus bias control voltage for the A.G.C. network of
Fig. 5.17.

chosen in order to obtain the maximum signal-to-noise ratio
from the receiver. The R.F. stage is permitted to function at
full gain on all relatively weak signals. At the same time the
I.F. bias is gradually increased to prevent these stages from over-
loading. On strong signals, both I.F. and R.F. bias voltages rise
fairly rapidly. On very strong signals more bias voltage is ap-
plied to the R.F. tubes because more negative voltage is re-
quired to bring them to cut-off. In these projection sets, triodes
are employed in the R.F. stage. Now, although the triodes are
not generally classified as remote cut-off tubes, sufficient curva-
ture is present to require a fairly high negative voltage for
cut-off.

The behavior of the I.F. bias voltage is governed somewhat
by the presence of V_4. The plate of this tube has a potential of
approximately −2.5 volts and will not conduct until its cathode
voltage becomes more negative than this. The cathode voltage,

in turn, is determined essentially by the plate voltage of V_3, being connected to it through R_6. With an input signal of 1,000 microvolts, the plate potential of V_3 is approximately -2 volts, and V_4 remains non-conductive. When the input level rises to 10,000 microvolts, the plate voltage of V_3 becomes -5 volts. Now V_4 will conduct because its plate is more positive than its cathode. Because of the voltage drop in R_6, the I.F. bias rises only to -3 volts. With increasing signal strength, the I.F. bias gradually approaches -4 volts. When V_4 conducts, it shunts R_7, throwing an additional load across R_4 and R_5 and preventing the I.F. bias from becoming too highly negative.

The setting of the contrast control determines the initial d-c bias applied to the grid of V_3. If the negative d-c bias voltage to V_3 is increased, the set operates with greater gain because the I.F. and R.F. bias voltages are less negative. With more gain, a stronger signal will reach the cathode-ray tube and produce greater contrast in the picture.

CHAPTER 6

VIDEO AMPLIFIERS

Some Considerations for Video Amplifiers. Up to this point, the television signal has been received and amplified by an R.F. stage, converted to another frequency by means of a mixer, further amplified by the I.F. stages, and rectified by the diode detector. As has been pointed out previously, the amplitude of the video signal at the output of the detector is not capable of providing the necessary contrast variation at the cathode-ray viewing screen. Hence, further amplification is necessary. In this chapter the requirements, operation and structure of video amplifiers are described.

The rectified video signal, which contains the blanking, synchronizing and picture information, has a bandwidth that extends from 30 cycles to 4 mc. Every video amplifier must therefore be able to pass these frequencies without attenuation or phase distortion. These requirements are unusually severe, as may be appreciated by comparison with any high fidelity audio amplifier where the response is uniform for merely 15,000 cycles, and very little attention is given to phase distortion except in high fidelity systems. The ordinary amplifier, therefore, in its present form, is not suitable for the amplification of video signals. If it is to be suitable, revision is necessary.

It was indicated in Chapter 1 that, when the frequency response of a video amplifier fell off at the higher frequencies, the picture detail became impaired. The finer the detail to be reproduced, the higher the associated frequencies. The care that is taken in the design and construction of an amplifier will determine the type of image received on the screen of the picture tube. However, this is not the only governing factor. Another

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consideration must also be kept in view, one that relates to the size of the viewing screen. While it is true that 525 lines can be placed on a 5-inch screen as well as on a 12-inch screen, the amount of detail necessary for the smaller tube is not as great as for the larger screen. The reason for this may be quite simply found in the resolving power of the human eye.

Relation between the Eye and the Detail on a Viewing Screen. The resolving power of the eye is the ability of the eye to distinguish between objects that are placed close together. As an example, consider the card shown in Fig. 6.1, having two narrow lines located side by side. As long as the card is held fairly close to the eye, it is possible for an observer to see each line separately. As the card is slowly moved farther and farther away, it becomes increasingly difficult to see each line distinctly. Eventually a

FIG. 6.1. The power of the human eye to resolve or separate two objects that are closely spaced depends upon the distance from the eye to the objects. If the objects subtend a 1 minute angle at the eye, they may be seen separately.

point is reached where the eye is just capable of distinguishing between them. This is the limit of the resolving power of the eye for these two lines.

Quite obviously, the farther apart the lines are, or the wider they are, the more easily they may be separated from any given viewing distance. For the average person, it is claimed that as long as the two objects subtend an angle of 1 minute or more at the observer's eye, they may be seen as distinct units. This is known as the minimum resolving angle of the eye and is illustrated in Fig. 6.1. The reader can determine how wide a 1 minute angle is by dividing any circle into 21,600 equal wedge-shaped parts. The angle of any small section at the wedge end would then equal 1 minute or $\frac{1}{60}$ of a degree.

The distance that the observer must be from the objects in order to have the 1 minute angle subtended at his eye is known

as the critical resolving distance. If the observer is farther away than this distance, the two objects merge into one. With television, it is necessary for the observer to remain outside the critical resolving distance. Coming closer only reveals the separate scanning lines and this destroys the illusion of continuity.

From the foregoing line of reasoning, it would seem possible to calculate the exact viewing distance for any size object; actually, with television images, an observer may approach closer to the screen than the calculated figure and still be unable to distinguish one line from another. This becomes possible because the resolution of two lines, for example, depends not only on their separation, but also on the amount of illumination of the lines and their relative motion. The stronger the light, the more clearly they stand out. Under these conditions, the critical resolving distance increases.

On the other hand, the introduction of motion tends to make the line of demarcation less clear-cut and the objects blend into each other at much smaller distances than if they were stationary. The latter condition prevails for television images and hence the observer may view the screen from closer distances than if the motion were absent. In addition, due to the impossibility of obtaining perfect synchronizing action, the positions of the lines of the picture tend to change slightly during each scanning run, and this further obscures any clear division between lines.

Placing the same 525 lines on a 20-inch screen as on a 7-inch screen means that the proper viewing distance for the larger screen is greater than for the smaller screen. With the smaller screen, the ideal viewing distance is generally so small that ordinarily the observer never comes this close to the screen. Therefore many of the finer details of the picture are not seen, even though they are present on the screen. It is a realization of this fact that has led many manufacturers to design small receivers with bandwidths less than 4 mc. The finer detail is not essential.

The Low-Frequency Response of Video Amplifiers. Although it is possible to sacrifice some response at the high-frequency end of the 4-mc signal, the amplifier should possess a flat characteristic at the low end. This means uniform response to 30 cycles. Since amplifiers do not cut off sharply at any one frequency, but rather tend to decrease gradually, it is necessary for flat response at 30 cycles to have the curve extend downwards to 10 cycles, or even less.
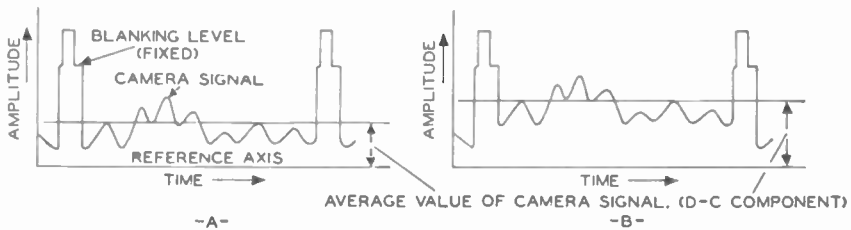
Fig. 6.2.   The height of the camera signal variations above the reference axis represents the amount of background illumination that the line (or scene) will possess.   This average value is known as the d-c component of the video signal.

To ascertain what loss of response at the low frequencies would mean, let us examine in some detail the camera signal, for it contains the information of the picture.   In Fig. 6.2 there is a section of the signal which might be obtained from the scanning of one line.   On either end of the line we find the blanking and synchronizing pulses.   These have a fixed level, always reaching the same voltage (or current) value whenever they are inserted into the signal.   The elements of the image itself are represented by the varying voltages between the pulses and naturally differ from one line to the next.   The engineer refers to these changing voltages as the a-c variations of the television signal.

In addition to the a-c variations, the synchronizing and blanking pulses of the video signal, there is another component, referred to as the d-c component.   Examine the two video signals placed side by side in Fig. 6.2.   The blanking levels of both are the same height and the a-c variations of each signal are identical.   The only difference is in the average level of the a-c varia-

tions of Fig. 6.2A as compared with the average of the a-c por-
tion of the signal of Fig. 6.2B. That of B is the greater of the
two. This average value represents the background illumina-
tion of the scene at that line and is the d-c component of the
video signal. The background illumination may vary from line
to line, but this situation is unusual. Generally it changes
slowly over the entire scene, and adjacent lines will have almost
equal d-c components.

When the value of the d-c component is high, as in Fig. 6.2B,
the people and objects of the scene being televised will appear
against a dark background. This is true because with negative
transmission every value is reversed. The darker the scene
(or element), the greater the current. As the scene becomes
brighter, there is correspondingly less current, and the a-c varia-
tions of the video signal move closer to the zero axis. Hence,
as the d-c value is less in Fig. 6.2A than in Fig. 6.2B, the back-
ground illumination of A will be brighter. Neither the people
nor the objects, however, have changed. Having a lighter back-
ground will convey the impression of daylight, sunshine and
clear weather. With a darker background, one obtains the oppo-
site impression.

At the transmitter, the d-c component may be inserted manu-
ally by an operator viewing the scene from a monitor, or auto-
matically by using the average current derived from the viewing
tube, where this is possible. If the latter cannot be accom-
plished, the light from the scene is allowed to fall onto a photo-
electric tube and the d-c component is derived in this manner.
Once obtained, it is inserted into the video signal, raising the
a-c component to the desired level.

From the discussion of the d-c component, which for the pres-
ent is sufficient, we can see that the average illumination of a
scene may change with each frame, or 30 times a second. Of
course, if the exact scene is televised without any variations, the
average illumination remains constant. Actually, however, this
condition occurs very infrequently and each frame scanned at

the camera has a different average value. In order to obtain the correct shading of the image background at the receiver, it is necessary that all transmitting and receiving circuits be capable of passing 30 cycles per second without too great attenuation. Any poor response would result in incorrect values for the background illumination and, as shown later, left-to-right stretching or smearing of large objects.

Phase Distortion. Frequency response is an important consideration in video amplifiers, but not the only one. Phase distortion, which can be tolerated in an audio amplifier, is capable of destroying the image on the cathode-ray tube screen and must also be given careful attention when an amplifier is designed. Since phase distortion is very seldom referred to in audio amplifiers, a brief discussion at this point may be helpful.

Phase distortion is produced when the time or angle relationship of electric waves to each other changes

FIG. 6.3. Two waves, 45° out of phase with each other.

as they pass through any electrical system. For a simple example, let us consider the two sine waves shown in Fig. 6.3. Curve A reaches its maximum value some small time before curve B and curve A is said to lead curve B by a certain number of degrees. The actual number depends on the manner in which these curves were generated. Suppose that, in this case, curve A leads curve B by 45°. If, after the output of the electrical system is reached, there is still this relationship between the two waves, then no phase distortion has been introduced. On the other hand, if the value of the angle is altered, the network has introduced some phase distortion.

As another example, consider the wave shown in Fig. 6.4A. This wave is actually composed of a fundamental wave in combination with its third harmonic. See Fig. 6.4B. If the effect of the network on each of these waves is different, the two waves may appear as in Fig. 6.4C, where the third harmonic wave has changed its position with respect to the fundamental, i.e., its

phase has changed. The resultant of the latter waves now as
sumes the shape given in Fig. 6.4D, which is certainly different
from the original form of Fig. 6.4A.

How Phase Distortion Is Introduced. Now that the effect of
phase distortion in changing the shape of a wave has been illus-
trated, let us see how the circuits found in video amplifiers may
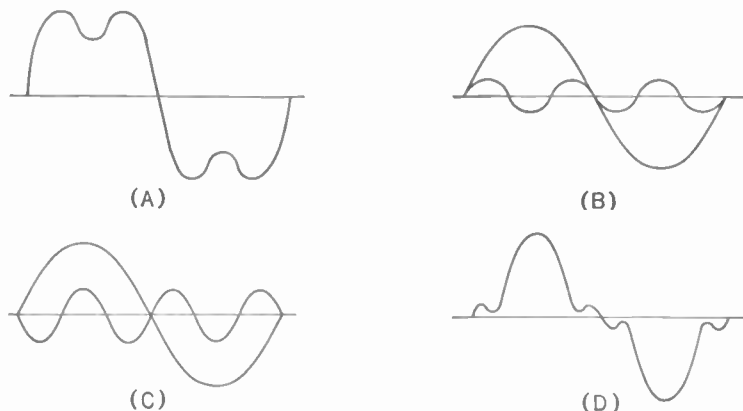
Fig. 6.4. The effect of phase distortion in changing the shape of a wave. The
composite wave at (A) can be broken down into the two waves at (B). If these
two component waves change their relative phases, then (D) shows one result.
There may be other combinations than the ones shown.

bring about such distortion. A resistance-coupled amplifier is
used, as it is the only type that can be easily and economically
adapted to satisfy the stringent requirements of wide-band am-
plifiers. A typical circuit is shown in Fig. 6.5A. For the first
part of the discussion only the low-frequency response of the
amplifier will be considered. With this assumption, a simplifi-
cation in the number of components of the amplifier may be
made, as indicated in Fig. 6.5B.

When an alternating voltage is applied to the input of T_1, an
amplified version of this voltage will appear across R_L, due, of
course, to the usual amplifier action of a tube. It is desired now
to transfer this a-c voltage to the grid of T_2, and this is accom-
plished through the series combination of C_c and R_g. How

much of the total voltage of R_L will appear across R_g is dependent on how great an opposition (or impedance) C_c presents to the a-c current flowing in this circuit. At low frequencies, the opposition of the condenser is high and a large part of the a-c voltage is lost. Less is available for R_g. This condition, as every radioman knows, is responsible for the poor low-frequency response of resistance-coupled amplifiers. Increasing the frequency will result in less voltage being lost across C_c and more will be available for R_g.
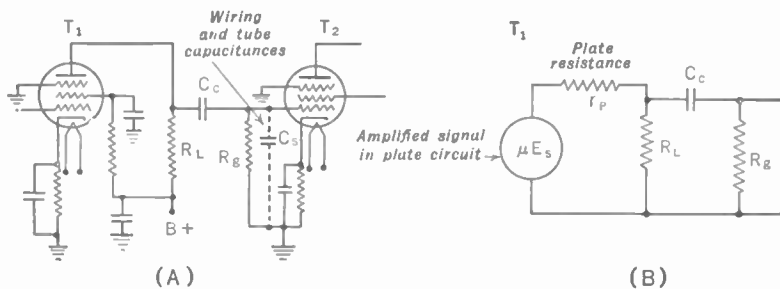
FIG. 6.5. A resistance-coupled amplifier (A) and its low frequency equivalent circuit (B).

The phase of the voltage at R_g is governed by the amount of opposition C_c offers to the a-c wave passing through the circuit. Consider, for example, what the phase of the a-c current would be if only C_c were present in the circuit. The current flowing would be 90° ahead of the voltage. Now, add a resistor in series with the condenser. The current flowing in the circuit becomes less than 90° out of phase with the applied voltage. The voltage drop across the resistor is in phase with the current flowing through it and hence would also be less than 90° out of phase with the applied voltage. The situation is shown in Fig. 6.6, where E_g is a little less than 90° out of phase with E_L.

As the opposition that C_c offers to the current in the circuit becomes less and less (say, with increasing frequency), R_g becomes more important and the current approaches closer and closer in phase with E_L. At the middle range of frequencies, the

opposition of C_c may be neglected entirely and E_g is in phase with E_L, similar to any other completely resistive circuit.

We see, then, that when voltages of many frequencies, and with no phase difference, are applied at E_L, the voltages appear-
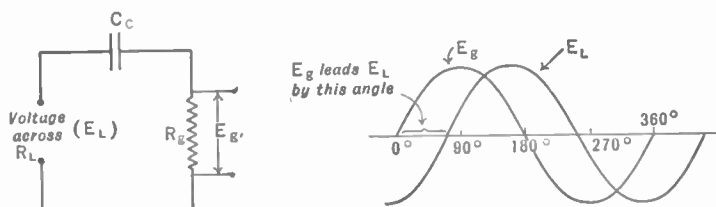
FIG. 6.6. At the low frequencies, E_g is out of phase with E_L because of the coupling condenser C_c.

ing across E_g have different phase relationships, the degree dependent upon each frequency.

The lowest frequency will have the greatest phase angle introduced while it is travelling from the output of the tube to the
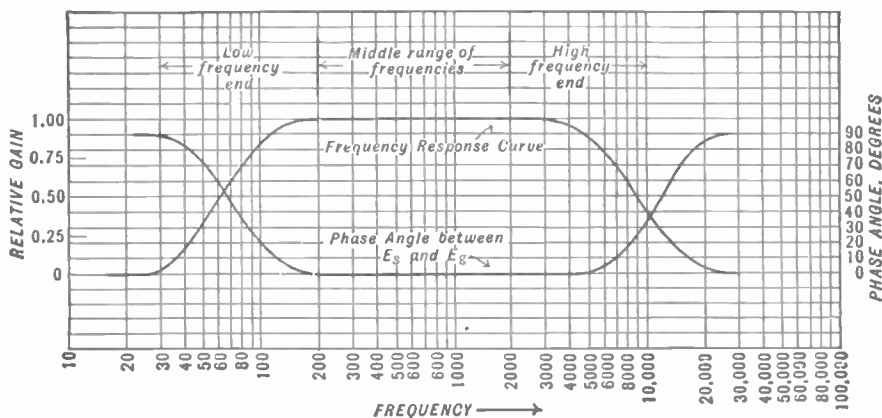
FIG. 6.7. The frequency and phase response of an ordinary resistance-coupled amplifier.

input of the next stage. As the frequency rises, the phase difference becomes less, gradually reaching zero. This characteristic of a resistance-coupled amplifier may be seen from the curve in Fig. 6.7.

A complex wave, which contains many frequencies, would have its shape altered when it passed through the resistance-coupled amplifier network. With a change in shape, the effect of the wave at the grid of the picture tube must certainly be different and the resulting image is distorted to some extent. By distortion, we mean that the image is not an exact duplicate of the original. The amount of change introduced into the picture detail depends on the degree of phase distortion.

Fig. 6.8. The equivalent circuit, at the middle frequencies, of the resistance-coupled amplifier of Fig. 6.5.

In the middle range of frequencies, from 200 to 2,000 cycles, C_c has no effect on the passing waves and can be disregarded. The equivalent circuit for the middle range now assumes the form shown in Fig. 6.8. Since only resistances are involved, there is no phase shift introduced between the voltages at R_L and R_g.

At the high frequency end of the band, the input capacity,
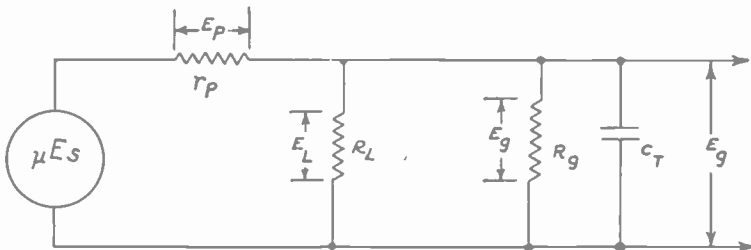
Fig. 6.9. The equivalent circuit, at the high frequencies, of the resistance-capacitance coupled amplifier of Fig. 6.5.

C_T, between the grid and cathode of T_2, becomes important and must be considered. C_T has the effect of offering an easy shunting path for the a-c voltages around R_g, and the voltage appearing across this resistor decreases with increasing frequency. Note, in Fig. 6.9, that C_T forms a parallel combination with R_g. As the frequency increases, more and more current flows through

C_T rather than R_g and soon the current becomes wholly a capacitive one. Again we see E_g and E_s differing by 90°, but in this case the phase angle increases with frequency, whereas for the low frequency action, the opposite was true. However, for both cases, the result is phase distortion. The graph of Fig. 6.7 shows how the phase angle between input and output voltages of the resistance-coupled network changes with frequency.

Results of Phase Distortion. To correlate the subject of phase distortion and its effect on the television picture, let us study the dependence of phase distortion and time delay. It has been noted that at the low frequencies the phase angle between input and output voltages increased to a maximum of 90° as the frequency decreased. Suppose that a video signal is sent through this r-c network containing (among others) two frequencies, say of 40 cycles and 90 cycles. From the preceding discussion, we know that the 40-cycle wave will receive a greater phase delay than the 90-cycle wave. Assume that the 40-cycle wave is shifted 45° and the 90-cycle wave, 10°. Obviously the two waves will no longer have the same relationship at the output that they had at the input, and by simple mathematics it is possible to compute their difference.

A 40-cycle wave takes $\frac{1}{40}$ of a second to complete one full cycle, or 360°. With $\frac{1}{40}$ of a second for 360°, it will take $\frac{1}{320}$ of a second for the wave to change 45°; $\frac{1}{320}$ of a second is approximately 0.003 sec. Thus there will be this time difference between a maximum occurring at the input to the next tube and that occurring at the output of the preceding tube. The appearance of one will lag behind the other by 0.003 sec.

The 90-cycle wave, we know, has a 10° phase angle introduced into it. One cycle, or 360°, of a 90-cycle wave occurs in $\frac{1}{90}$ of a second. Ten degrees would require only $\frac{1}{3240}$ of a second, or approximately 0.0003 sec. Thus the input and output variations will differ by this time interval for the 90-cycle wave.

At the cathode-ray screen, the electron beam moves across a 12-inch screen a distance of one inch from left to right in about 0.000,007 sec. The time interval is extremely short and, if waves

containing the 40 and 90 cycles receive the time displacements computed above, the end result is a displacement of the picture elements that they represent.   In actual television practice, the background illumination is determined by the low frequencies, and phase distortion in the video amplifiers causes a change in this shading.   If, for example, the background transmitted from the studio were perfectly white, by the time it appeared at the receiver screen phase distortion would have altered it.   It would now vary from white to grey, or even be black in some portions.

Any large objects or letters in the picture are distorted, too, by poor low frequency response.   They appear to smear across the image like the smearing of fresh paint.   The smearing effect is derived from the action described in the last paragraph, where we learned that phase distortion and time delay are directly related.   A slight time delay causes certain parts of the object to be displaced from the correct position.   The visible consequence of this displacement is smearing.   Since the beam moves from left to right, the extended stretching of large objects will always be toward the right, or in the direction that the beam is moving. Only large objects are affected, because they are the only ones represented by the lower frequencies.

At the high frequency end of the video signal, phase distortion results in the blurring of the fine detail of the picture.   The larger the size of the cathode-ray tube screen, the more evident this defect.   Although it may be tolerated on a small screen, any enlargement immediately causes it to become apparent.   Here is another reason why the larger sets require more careful design and construction.   Phase distortion may be eliminated if the phase difference between the input and output voltages is zero, or if a proportional amount of delay is introduced for each frequency.   Thus, a phase delay of 45° at 60 cycles is equivalent to a 90° delay at 120 cycles, etc.   The first introduces a delay of approximately 0.002 sec., similar to 90° at 120 cycles.   The net result is that all the picture elements are shifted the same amount, and correction is attained by positioning the picture. Phase shifts introduced by the electrical constants of one stage

are additive to those of any other stage. The total phase delay of a system is equal to the sum of all the individual phase delays.

Video Amplifiers and Their Design. The preceding paragraphs have indicated what requirements are necessary for high fidelity transmission and reception of television images. The methods whereby these requirements are met in practice represent an important consideration in modern television.

The type of amplifier that can be used to give the necessary 4-mc bandwidth is restricted, almost without exception, to resistance-capacitance coupled networks. Transformers and inductances, even when they are built to possess a 4-mc width, involve a disproportionate expense. On the other hand, r-c amplifiers have the advantage of small space and economy and are universally employed.

From knowledge of conventional resistance-coupled amplifiers that the radioman possesses he knows that a flat response is obtained in the middle range of frequencies, say from 200 cycles up to approximately 2,000 cycles with ordinary circuits. A frequency response curve is illustrated in Fig. 6.7 and applies to any ordinary r-c amplifier. As we are also interested in phase response, this, too, is indicated in Fig. 6.7. The frequency and phase characteristics of the amplifier, throughout the middle range, are suitable for use in video amplifiers, and this section of the curve requires no further improvement. However, the responses at either end of the curve are far from satisfactory and corrective measures must be taken. Fortunately, any changes made in the circuit to improve the high or low frequency responses of the curve will not react on each other (with one limitation noted later), and each end may be analyzed separately and independently. Let us begin first with the high frequency compensation.

When determining the high frequency operation of a resistance-coupled amplifier, we include the internal and external plate resistances, the grid input resistor of the next stage, and any shunting capacitances that are present in the circuit. The coupling condenser, C_c, offers negligible opposition to high fre-

quency alternating currents and can be disregarded. Fig. 6.9 shows the equivalent circuit of the r-c amplifier applicable under these conditions.

Since R_L and R_g are both resistances and are both constant in value, any change in high frequency response must be due to the shunting capacity C_T. The reactance of a condenser decreases with frequency and, in effect, the total impedance of the parallel combination of R_L, R_g and C_T becomes less as the frequency increases. The alternating voltage that is developed at the tube will divide between r_p. which is the internal tube plate resistance, and the parallel combination of R_g, R_L, and C_T. Since the value of the impedance of the parallel combination decreases, it means that more and more of the output voltage will be lost across the tube's plate resistance r_p. If less voltage reaches the grid of the next tube, less is available for amplification.

To increase the gain at the high frequency end of the response curve, it is obvious that the value of the shunting capacities should be decreased. The shunting capacity is composed of three components: (1) the output capacitance of the preceding tube, (2) the input capacitance of the following tube, and (3) the wiring capacitance to ground. For a typical video amplifier tube, the 6AC7, the output capacity is 5 $\mu\mu$f. The wiring capacitance may run from about 5 $\mu\mu$f to 15 or 20 $\mu\mu$f, whereas the input capacitance of the next tube might well be about 10 $\mu\mu$f and, unless tube construction changes radically, will remain close to this figure for most tubes. The wiring or stray capacitance can be reduced if care is taken when constructing the amplifier. The wiring capacitance will be kept at a minimum (about 5 $\mu\mu$f) if all leads are kept as short as possible, low-loss sockets are used, and the parts are intelligently placed.

With the foregoing reduction in the value of the capacitance, due perhaps in part to the use of tubes of small internal capacitance and in part to careful wiring, it is possible to increase the frequency response of an amplifier to 1 or 2 mc. The gain, however, especially near the end of the curve (shown in Fig. 6.10), is not uniform. To improve the response uniformity, the value
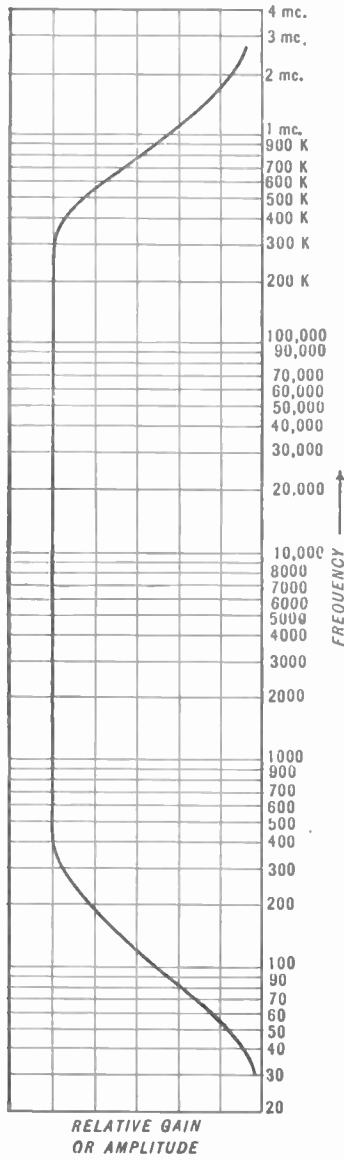
Fig. 6.10. Increase in the frequency response of a resistance-coupled amplifier with decrease in shunting capacity.

of the load resistor can be lowered, probably close to the impedance presented by the shunting capacitance. In this manner, the *effect* of condenser C_r is less and it does not begin to destroy the linearity of the frequency response curve until some higher frequency. The results for several resistor values are shown in Fig. 6.11. As the resistance becomes less, the flat portion of the curve increases, but the stage gain decreases. For many of the amplifiers found in commercial receivers, values of
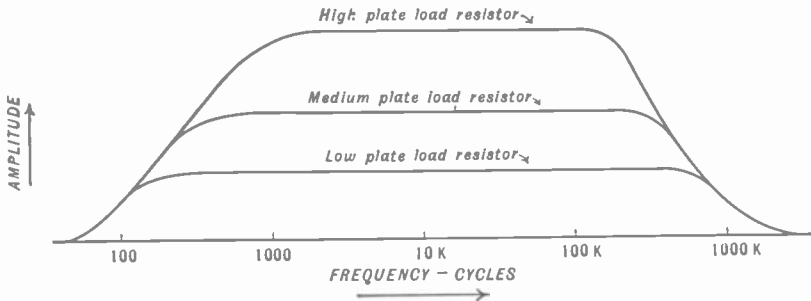
Fig. 6.11. By lowering the plate load resistor, it is possible to increase the extent of the flat portion of the response curve.

R_L as low as 1,500 ohms are used. This results in gains in the neighborhood of 20 or so per stage, which is not very high. Obviously, further extension of the frequency range of the amplifier by lowering the load resistance value is not very feasible.

A more satisfactory method of increasing the flat response of the amplifier can be obtained through the insertion of a small inductance in series with the load resistor. The inductance is so chosen that it will neutralize the effect of the shunting capacitances at least to the extent that we may improve the amplifier response at the upper frequencies.

A circuit diagram using this compensating inductance is given in Fig. 6.12. L is chosen to resonate with C_r at or above the highest frequency at which flat response is desired. In this manner, the peaking inductance tends to compensate for the loss caused by the capacitance C_r and the curve remains flat. If too much peaking is resorted to, the curve will rise sharply near the

(A)
EQUIVALENT HIGH-FREQUENCY CIRCUIT

(B)
ACTUAL CIRCUIT
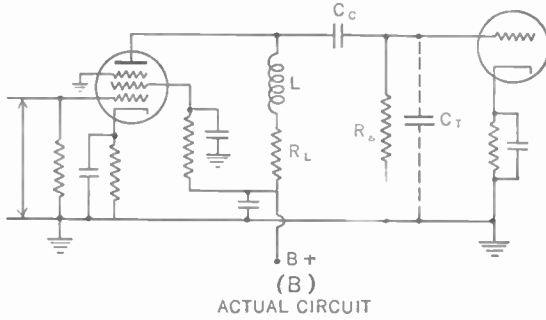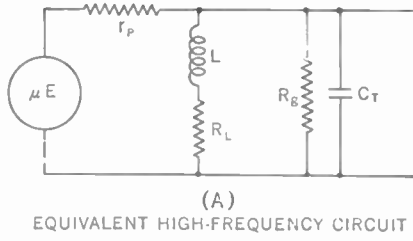
FIG. 6.12. High-frequency compensation for an r-c amplifier.
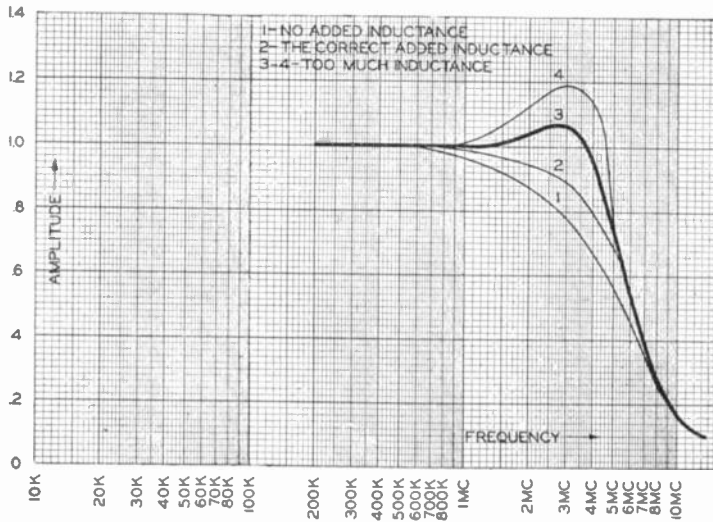
FIG. 6.13. The effect on amplifier response of the insertion of various amounts of peaking inductance in the plate load.

resonant point of L and C_T and result in a hump which is undesirable. The appearance of the response curve for several values of L is shown in Fig. 6.13. In practice the value of L is given by

$$L = (\tfrac{1}{2})C_T R_L{}^2 \text{ henrys}$$

where C_T = the total shunting capacity in farads,
  R_L = the load resistance in ohms.

With this value for L, curve 2 is obtained. It has also been found that the introduction of L improves the phase angle response of the network.
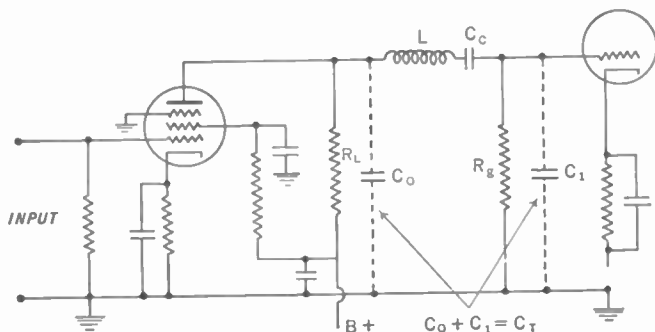
FIG. 6.14. High-frequency compensation by means of a series peaking coil.

A second method whereby the high frequency response can be improved is to insert a small coil in series with the coupling condenser, as illustrated in Fig. 6.14. This method gives higher gain and better phase response than shunt peaking. The added advantage of this type of coupling is due to the fact that the components of C_T are no longer lumped together in one unit, but have been separated. On the left-hand side of the series inductance we have the output capacitance of the preceding tube, while on the other side we find the input capacitance of the next tube. With this separation, the load resistor R_L may be chosen higher in value because only C_0 is directly across it and not the larger C_T. As C_0 is smaller than C_T, its capacitive reactance is greater and it will have less of a shunting effect on R_L. Hence, a larger

value of R_L is possible. The series combination of the inductance and the total capacitance is designed, by proper choice of L, to have a resonant frequency above the highest video frequency desired, which is generally 4 mc.

It has been found that best results are obtained when the ratio of C_1 to C_0 is approximately 2. To achieve this ratio, it may sometimes be necessary to add a small capacitor, although generally the 2 to 1 ratio will hold without any additions to the circuit capacitance. The value of the series coil, L, is given by

$$L = \frac{1}{8\pi^2 f^2 C_0}$$

where f = the highest frequency it is desired to have the amplifier pass.

C_0 = the output capacity of the preceding tube. To this we also add whatever wiring and stray capacitance would be associated with this portion of the coupling circuit.

It is further possible to combine shunt and series peaking and obtain the advantages of both. The shunt coil is designed to neutralize the output capacity of the preceding tube while the series coil combines with the input capacity (and stray wiring capacitance) of the next tube. With this double combination, it is possible to achieve 1.8 times more gain than can be derived through the use of shunt peaking alone. Furthermore, the phase distortion of the coupling network is lower than either of the previous two types. An amplifier using combined shunt and series peaking is shown in Fig. 6.15. A resistor is shunted across the series coil to minimize any sharp increase in circuit response due to the combination of the series coil inductance and its natural or inherent capacitance. The coil is designed to have a natural frequency considerably above the highest video frequency. In production, however, a certain number of coils will be produced with natural resonant frequencies within the range covered by the amplifier. The effect is a sharp rise in response, similar to curve 4, Fig. 6.13. It is to prevent this peak, if it

occurs, that the shunting resistor is used. Its value is generally four to five times the impedance of the series coil at the highest video frequency.
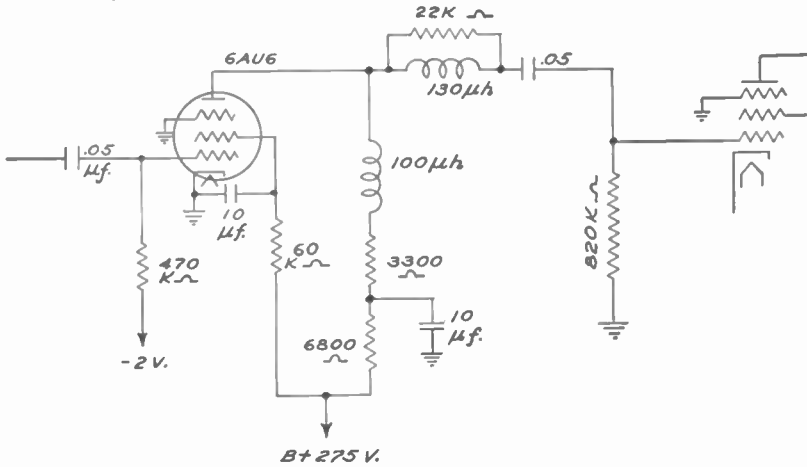
FIG. 6.15. A video amplifier employing series and shunt peaking.

For the combination circuit, the values of L_s, L_c, and R_L are obtained from the following relationships:

$$R_L = \frac{1.8}{2\pi f C_t} \text{ where } C_t = C_1 + C_0$$

$$L_s = .12 C_t R_L{}^2 \text{ (shunt coil)}$$

$$L_c = .52 C_t R_L{}^2 \text{ (series coil)}$$

f is the highest frequency it is desired to have the amplifier pass.

Low-Frequency Compensation. With the high frequency end of the response curve taken care of, let us determine what changes can be made to improve the low-frequency response. At this end of the band, it is possible to disregard the shunting capacities since their reactance, given by

$$X_c = \frac{1}{2\pi f C}$$

is very high, and they do not affect the low-frequency signal voltages in any way. Now, however, it becomes necessary to include the coupling condenser. The equivalent low-frequency

circuit was previously given in Fig. 6.5. The operation of the circuit, as explained, shows that, the lower the frequency, the greater the effect of the coupling condenser. The response gradually falls off because the reactance of C_c soon becomes dominant and a large portion of the output voltage of T_1 is lost here. The phase delay of the signal begins to change, eventually approaching 90°. As a result, the background illumination of the reproduced image is affected.

To increase the linear response at the low frequencies, either C_c should be made larger so that it will have less reactance, or R_g should be made larger. The limit of the size of either C_c or R_g is governed by several factors:

1. Too large a value of C_c increases the stray capacitance to ground and is certain to interfere with the high frequency response.

2. A large coupling condenser generally has an appreciable leakage current. This would permit the positive power supply voltage on the preceding plate to affect the grid of the following tube and bias it positively.

3. A large value of R_g could prove detrimental if the tube to which it is attached has even a slight amount of gas.

4. Finally, high values of R_g and C_c result in motor boating (or oscillations) due to the slow building up and leaking off of charge across the combination.

It is possible to improve the low-frequency response without making either R_g or C_c too large by inserting a resistor and condenser in the plate circuit of tube T_1, as indicated in Fig. 6.16. R_f and C_f are the two added components and they form the low frequency compensation circuit. Through the addition of this resistor and condenser, the impedance in the plate circuit is increased for the lower frequencies and greater gain results. At the high frequencies, C_f by-passes R_f and effectively nullifies it. Furthermore, C_f and R_f serve as a decoupling filter which aids in stabilizing the stage by preventing any low-frequency oscillations or motor boating from feedback between stages by way of the power supply.

The value of C_f in Fig. 6.16 is obtained from the expression:

$$R_L C_f = C_c R_g$$

where R_L, C_c, and R_g have previously been assigned values. R_L will be determined by the highest frequency to be passed by the amplifier and C_c and R_g will be as large as possible but within the limitations noted above. Finally, R_f should have a resistance which is at least twenty times greater than the impedance of C_f at the lowest frequency to be passed.
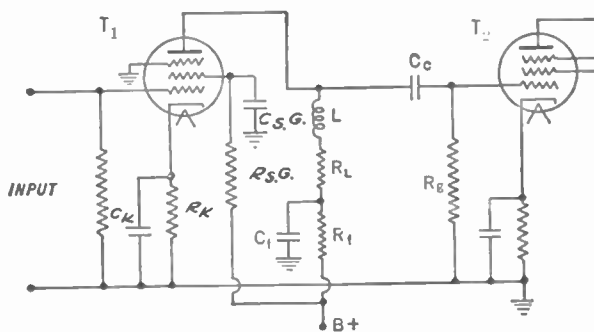
FIG. 6.16.   Low-frequency compensation (R_f, C_f) of an r-c amplifier.

C_f and R_f provide the greatest amount of compensation, but there are additional factors which influence the extent of the low-frequency response. One of these is the screen-grid dropping resistor and by-pass condenser. For best results, R_{sg} and C_{sg} should have a time constant which is at least three times as long as the period $(1/f)$ of the lowest video frequency to be passed by the amplifier. A second governing factor is the cathode resistor, R_k, and the cathode by-pass condenser, C_k. These should be chosen so that they satisfy the following expression:

$$R_k C_k = R_f C_f$$

Admittedly, the latter two circuits are not quite as important as the decoupling resistor and condenser, C_f and R_f, but they should be considered in the amplifier design.

In the design procedure of video amplifiers, the values of the
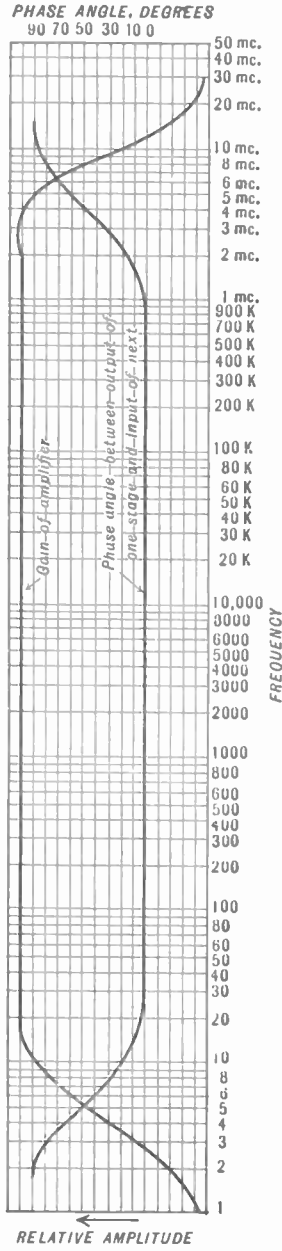
FIG. 6.17. The frequency response of a fully compensated resistance-coupled amplifier. An amplifier of this type is shown in Fig. 6.16.

high-frequency compensating components are chosen first.
These include R_L, L_s and L_c. Next, the low-frequency com-
pensating components, C_f and R_f, are computed, then R_{sg} and
C_{sg}, and finally R_k and C_k. The values of each of the latter three
resistors must fall within the operating characteristics of the
tube as recommended by the manufacturer. This imposes a
limitation. However, since we are concerned with a time con-
stant in each instance (as $C_f \times R_f$, $R_{sg} \times C_{sg}$, and $R_k \times C_k$)
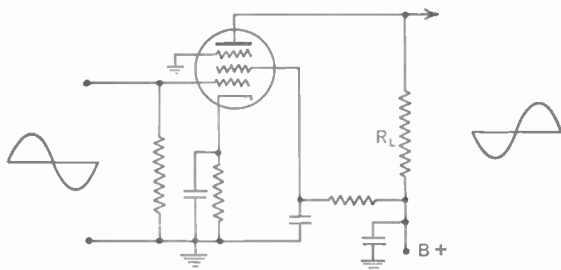
FIG. 6.18. The input and output voltages of a tube showing the 180° phase reversal.

rather than the individual value of each part, we can usually
satisfy all the required conditions.

When the high- and low-frequency compensating circuits are
applied to a video amplifier, the result appears as shown in Fig.
6.16. The frequency and phase response of this amplifier is
plotted in Fig. 6.17. The number of such stages required be-
tween the video detector and the cathode-ray tube will depend
upon the polarity of the signal at the output of the detector.
If the picture phase is negative, its current or voltage increases
as the picture elements become darker; an odd number of video
amplifiers must be used because each amplifier changes the sig-
nal by 180°. Hence, if the picture phase is negative, one stage
will convert it to a positive phase and the signal in this form can
now be applied to the grid of the viewing tube. Of course, three,
five, or any odd number of stages will also answer the purpose.
For a positive picture polarity at the output of the detector, an
even number of stages is necessary.

If there is any doubt as to how a signal is changed 180° when it passes through a tube, consider the following action. An a-c signal is applied to the grid of a tube, as indicated in Fig. 6.18. As the grid becomes increasingly positive, more plate current flows, resulting in a greater voltage drop across R_L, with the plate end of the resistor becoming more negative. Thus an increasingly positive grid gives rise to a decreasing plate voltage. These two voltages are 180° out of phase. For the opposite case, with the grid voltage going negative, the plate current decreases with a resultant decrease in the voltage drop across R_L. The plate voltage will increase.

It is well to remember that this 180° phase reversal in a tube has nothing at all to do with any phase distortion caused by the coupling condenser or shunting tube capacitances. The tube reversal merely has the effect of changing a positive picture phase into a negative picture phase or vice versa. The voltage output is still in step with the wave at the input and there is no time delay introduced at all.

CHAPTER 7

D-C REINSERTION

The Need for D-C Reinsertion into Video Signals. Although the signal at the output of the final video amplifier may have sufficient amplitude to be applied directly to the cathode-ray tube, its form may not be entirely suitable. The television signal, we know, contains an a-c component, a d-c component,
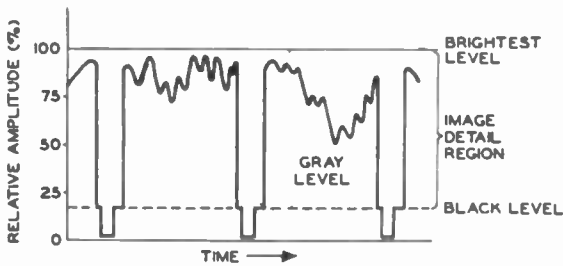
Fig. 7.1. Several lines of a typical video signal.

and blanking and synchronizing impulses. Of importance, at the moment, is the d-c component, its function within the video signal, and what happens when it is removed from the signal.

Several lines of a typical video signal are shown in Fig. 7.1. Between every two successive synchronizing and blanking pulses, we have the camera signal variations, ranging from white (at the most positive value) to black at the level of the blanking pulse. The signals are shown in the positive picture phase form. When applied to a cathode-ray tube, each different value of video voltage produces a different spot intensity on the cathode-ray tube screen and from all these light gradations we obtain the image.

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Suppose, now, we take a video signal and, while maintaining the same camera signal variations, we first move these variations closer to the blanking pulse level (Fig. 7.2A) and then shift the same variations as far away as possible from the blanking pulses (Fig. 7.2B). What would be the visual result in each instance? Since the blanking level represents the point at which the cathode-ray tube beam is supposed to cut off, moving the video signal closer to this level means that the overall background of the image will become darker. On the other hand, when the
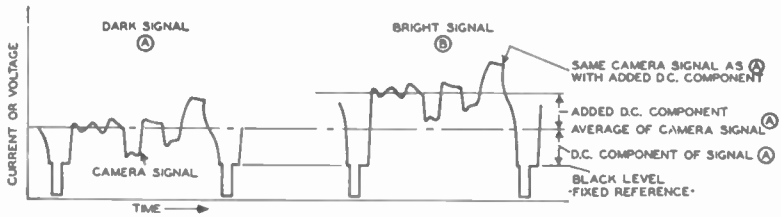
FIG. 7.2. Two video signals containing the same detail (a-c component) but different background brightness (d-c component).

video signal variations are farther away from the blanking level. the background of the image becomes brighter. Note, however, that because the video signal variations are identical in each instance, the same scene is obtained. The only thing we have altered by shifting the relative position of the video signal is the background brightness. In the first instance it is dark; in the second illustration it becomes bright. We can simulate the same conditions in a room by increasing or decreasing the intensity of the electric lights. This change does not affect the objects themselves in the room but merely the overall brightness of the scene.

To distinguish between the camera signal variations and the average level of these variations (or the average distance of these variations from the blanking level), it has become standard to call the latter the d-c component and the former the a-c component of the video signal. The average level of the signal can be altered by the insertion of a d-c voltage, thereby raising

or lowering the average level of the video signal and changing the background brightness of the image.

At the transmitter, the level of the blanking pulses is established as the dark level, at which point the electron beam in the receiver cathode-ray tube is to cut off and the screen, for that point, to be dark. When the a-c video signal variations obtained from the camera tube are combined with this blanking voltage and the sync pulses, we have a complete video signal. At any point along the program line, the distance between the average level of the a-c video signal and the blanking level may be varied (through insertion of a d-c voltage) to produce the desired shading or background brightness as dictated by the program director. Note that, since the d-c voltage moves the video signal variations closer to or farther away from the blanking level, we are using this level as a reference. Therefore, the level of the blanking pulses must remain fixed, and the signal is transmitted with this relationship maintained.

The second detector output in the receiver contains the full video signal, as shown in Fig. 7.1. The blanking pulse of each line is aligned to the same level. However, when the signal is passed through r-c coupled video-frequency amplifiers, the blanking pulses of the various lines are no longer lined up because the coupling condensers cause the video signal to possess equal positive and negative areas about the zero axis.

This situation has been encountered by the serviceman, although in slightly different form. Suppose we take three 60 cycle a-c voltages and three d-c voltages and combine them to form the signals indicated in Fig. 7.3A. (Voltages of this type are frequently found in power supplies where the a-c wave represents the ripple.) For the sake of this discussion, we have provided enough d-c voltage so that the positive peaks of all three waves reach the same level. Now, let us pass these voltages through a condenser. The result is shown in Fig. 7.3B. By removing the d-c voltages, each wave has as much area above the axis as below and, because of this, the positive peaks of the waves are no longer at the same level.

Let us look at the equivalent situation in a television system. In Fig. 7.3C there is shown three video signals taken at different moments from a television broadcast and representing three

(A) A.C. PLUS D.C.

(B) A.C. WITH D.C. REMOVED

(C) THREE VIDEO SIGNALS COMPLETE WITH A.C. & D.C. COMPONENTS

(D) VIDEO SIGNALS WITHOUT D.C. COMPONENT
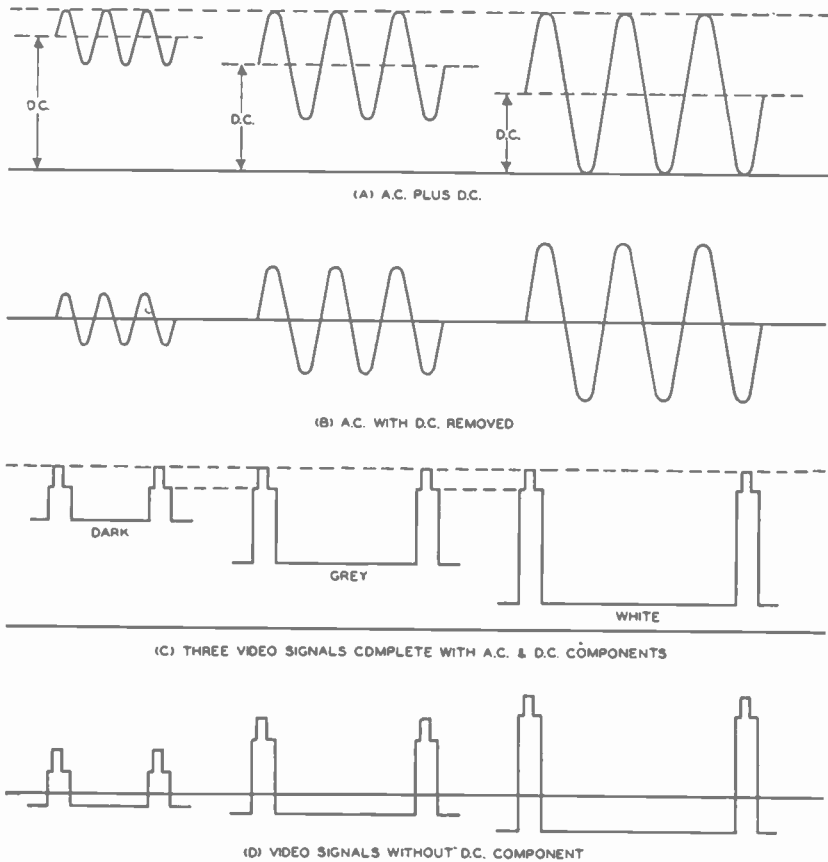
FIG. 7.3. An illustration of the effect of removing the d-c component from the video signal.

lines. One line is essentially white, one is grey, and one is dark or black. As they come out of the video second detector, all the blanking voltages are aligned to the same level. After passing these three signals through a coupling condenser, the signals possess the form indicated in Fig. 7.3D. For each signal, the

area above the axis is equal to the area below the axis. But because of this, the blanking voltages of the signals are no longer at the same level. In this condition, we say that the d-c component of the video signal is missing. The question now is: What effect will this variation in blanking level have on the image produced on the screen?

Each blanking pulse represents the dark level of each line. Since all lines in an image should have the same reference (or black) level, all blanking pulses should have the same voltage value. This was true of the video signal when it left the transmitter and it was true in the receiver just before we passed the detected video signal through a coupling condenser in the video-frequency amplifier system. After passage through this condenser, the blanking pulse levels were no longer aligned to the same level. If now we apply the three signals to an image tube (reverse polarity of Fig. 7.3D), here is what happens.

When the signal corresponding to a white line reaches the cathode-ray tube grid, we manually adjust the brightness control (which controls the bias for the image tube) to the point where the blanking pulse level just drives the tube into cut-off. Thus, as long as this signal remains, the negative voltage of the blanking pulse, added to the negative bias set by the brightness control, will just darken the screen at the blanking pulse level.

If now the grey video signal comes to the cathode-ray tube, we see that its blanking pulse level is less negative than the blanking pulse level of the previous video signal. Hence, here, the beam will not cut-off at the blanking pulse, and the beam retrace will be visible. We could produce the proper cut-off conditions by increasing the negative bias on the image tube, but this is impractical for several reasons. First, in any changing scene, the background shading changes too rapidly to be manually adjusted by the viewer. As a result, if the brightness control is set for a very bright picture, we will see the retrace lines when a darker picture arrives. Conversely, if the brightness control is set for a darker image, then when a lighter image is

viewed, part of the detail will be lost because of the greater cathode-ray tube grid bias.

Finally, the situation is even more aggravated when a dark video signal arrives. Now, we require an even greater negative bias and, when the brightness control is set correctly for this signal, it is much too negative for any of the two previous signals. If either of these two other signals is viewed with the bias set for this last signal, the image will appear too dark. On the other hand, when it is correctly set for a white picture, a black picture will appear too light, with even the retrace lines visible. The only solution to this state of affairs is to return all blanking voltages to the same level again, just as we found it in the incoming signal. *This, then, is the function of the d-c restorer in the receiver.*

Every cathode-ray tube has a definite characteristic curve. For a certain input voltage, a definite amount of light appears on the screen. All blanking pulses are purposely placed on the same level in order that the cathode-ray tube will react to them in the same manner throughout the entire reception of the signal. The same is true of white, grey, black, or any other shade that is transmitted for the scene. Any one color must produce the same illumination on the cathode-ray screen each time its corresponding voltage is present on the tube's control grid. However, this cannot occur unless all video signals have the same reference level. It is here that the usefulness of the d-c component becomes apparent. Through the use of this inserted voltage, all blanking and synchronizing pulses are leveled off and the image detail attached to these pulses is likewise correctly oriented.

To operate the television receiver properly, then, some method must be devised whereby the a-c video signals which appear at the cathode-ray tube are again brought to the same relative level that they had before the removal of the d-c component in the intervening video amplifiers. The problem resolves itself into one of reinserting a d-c voltage that will take the place of

the one removed. It should be understood that, for any given
scene, the average illumination can be set manually by the
brightness control. For a normal television broadcast, this would
hardly be feasible.

Reinserting the D-C Components. To understand why d-c
restoration is possible, it is necessary to know that removing the
d-c component from a video signal does not change its shape but
merely its reference level. This is evident when Figs. 7.2A and
B are compared. The same variations in the a-c components
still occur and the relationship of the a-c signal to the blanking
and synchronizing pulses remains the same, with or without the
d-c component. It is also seen that the brighter the line, the
greater the separation between the picture information varia-
tions and the pulses. As the scene becomes darker, these two
components move closer together.

It is from these relationships that we are able to reinsert the
d-c component; for, if we could develop a variable bias that
would effect each change in blanking and synchronizing pulse
voltage and act in such a manner that all pulses would be brought
to one common level, our purpose would have been achieved. It
would mean, for example, that if a video signal in its a-c form
were applied to the input of a tube where the process of d-c
restoration was to occur, a variable grid bias, developed here,
would return them to the same level again in the tube's plate
circuit. The bias would automatically adjust itself to suit each
individual case. Then, with the signals all lined up again, they
could be applied to the cathode-ray tube.

D-C Reinsertion Circuits.*   There are several methods
whereby the d-c component may be reinserted into the video
signal. Perhaps the simplest is the circuit diagram of Fig. 7.4.
Here the final video amplifier is operating at zero fixed bias, with
no signal applied to the grid. As soon as a signal does arrive,
grid current flows, the amount dependent upon the strength of

* The name "d-c reinsertion" circuit is common throughout the television
field. However, sometimes the name of "clamping" circuit it also heard. Both
refer to the same thing and may be used interchangeably.

the signal voltage. Thus, one of the conditions specified above, namely the signal determining its own bias, is obtained.

The form of the a-c signal applied to the grid of this last video amplifier tube must be of a negative phase, as shown in Fig. 7.4. It must be negative at the input in order that the proper positive phase will be obtained at the output where it is applied to the grid of the picture tube. Because there is no fixed bias on
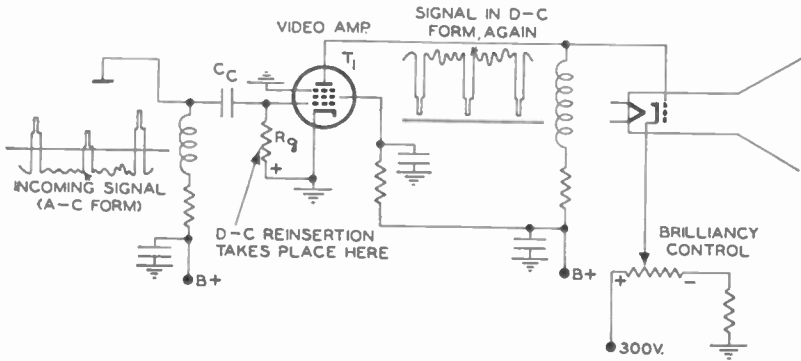
Fig. 7.4. A simple d-c reinsertion circuit. The bias developed across R_g varies with the incoming signal.

T_1, the grid will swing positive whenever the a-c signal is positive (above the zero line). Making the grid positive causes electrons to flow in this circuit, charging the condenser C_c. C_c, in turn, discharges through R_g. The electrons, in passing through R_g will develop a voltage, the amount dependent on how positive the grid is driven by the signal. This voltage across R_g is the operating grid bias and, in effect, acts in series with a-c signal applied to the tube. Since the current flowing in the grid resistor will depend on the extent the applied a-c signal goes positive, it is evident that the grid current will vary from one pulse to another. A large positive voltage (corresponding to a bright line) will cause a large current to flow through R_g and hence a large biasing voltage will develop here and will be applied in series with the signal. For a small positive pulse, such as is

obtained for a dark line, only a small biasing voltage will appear across R_g.

Now let us see how this variable bias brings each synchronizing pulse to the same level. Consider first a pulse of small amplitude. The pulse extends a small distance above the zero or reference line and, under the influence of this signal, the grid will go slightly positive. Consequently, only a small negative biasing voltage will develop across R_g. Let us assume that for the blanking level of the signal 5 ma of plate current will flow.

Now a large pulse, due perhaps to a bright line, arrives at the grid. Since its level is much farther above the zero line, the grid will be driven more positive and a greater grid current will flow. The result is a larger negative bias across R_g to counteract the increased positive value of the signal. At the blanking level of this signal, 5 ma of plate current should also flow. With the same amount of plate current flow for each blanking pulse, the output signals are all lined up again as indicated in Fig. 7.4. One further point should be kept in mind throughout this entire process. The bias developed across R_g does not vary each instant, but remains relatively constant from one pulse to another. Since the horizontal pulses are separated from each other by the camera signal, the bias will be constant for this detail. Thus, the detail of the picture is not smoothed out, as it would be if the bias on R_g changed with every single current variation. It merely changes at each pulse.

The time constant of the grid resistor R_g and the grid condenser C_c must be long enough so that the bias developed will last for at least one complete horizontal line, or from pulse to pulse. In practice, however, it may last longer, perhaps for several lines, since the average brightness of the background illumination seldom changes that rapidly.

Values of R_g range from about 400,000 ohms up to one megohm. C_c would be chosen so that the time constant ($T = R \times C$) is equal to the duration of one or more lines. Each line lasts for approximately 1/16,000 of a second.

The output of T_1, shown in Fig. 7.4, is applied directly to the

control grid of the cathode-ray tube. Direct coupling is neces-
sary since a condenser would remove the d-c component just
inserted. At the grid of the cathode-ray tube, a fixed bias be-
tween the grid and cathode is obtained from the power supply.
This bias sets the operating point for the tube and in conjunction
with the video blanking and synchronizing pulses, cuts off the
electron beam at the proper moments. The setting of this bias
will depend upon the strength of the signal reaching the grid.
A signal of small amplitude, say from some distant station, re-
quires more fixed negative bias on the grid than a stronger signal.

The dependency of the cathode-ray tube grid bias on the
strength of the arriving signal is illustrated in Fig. 7.5. For a
weak signal, the bias must be advanced to the point where the
combination of the relatively negative blanking voltage plus the
tube bias drives the tube into cut-off. However, with a strong
signal, the negative grid bias must be reduced; otherwise, some
of the picture detail is lost.

The Brilliancy Control. Since the bias of the cathode-ray
tube may require adjustment for different stations, or even for
various conditions on the same station, a potentiometer is con-
nected into the bias circuit, brought out to the front panel, and
called the brilliancy or brightness control. By its use, the ob-
server is able to adjust the bias on the grid of the picture tube in
order that blanking pulses just drive the grid to cut-off and so
that no retrace is visible on the screen.

The effects of the brightness control and the contrast control
previously described overlap to some extent. If the setting of
the contrast control is increased so that the video signal becomes
stronger, the brightness control must be adjusted to meet the
new condition, which means, of course, that no retraces are visi-
ble. Too small a value of negative grid bias allows the average
illumination of the scene to increase and permits some of the
return traces to become visible. In addition, the image assumes
a thin, watery, washed-out appearance. Too low a setting of
the brightness control, which will result in a high negative bias
on the picture tube grid, will cause some of the darker portions

of the image to be eliminated, and the average illumination of the scene will decrease. To correct this latter condition, either the brilliancy control may be adjusted, or the contrast control
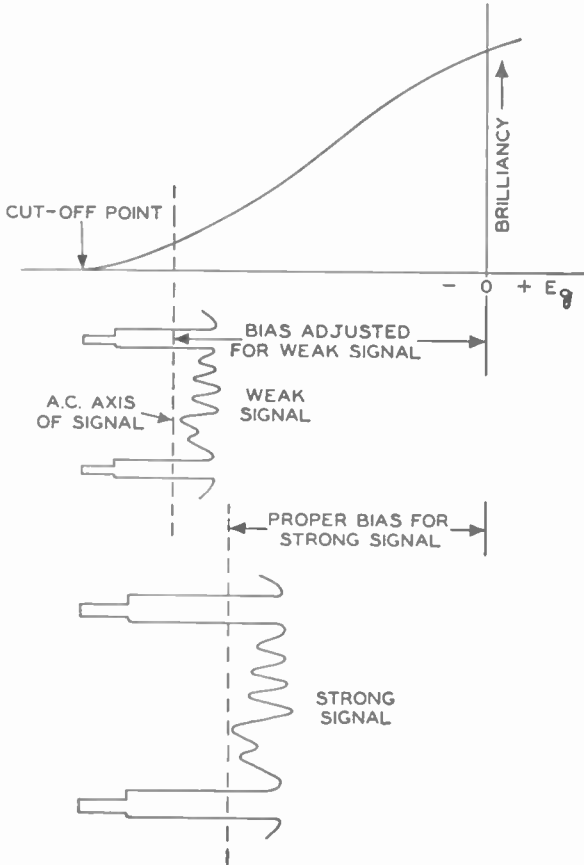
Fig. 7.5. Illustrating why the brilliancy control must be adjusted to suit the incoming signal.

setting can be advanced until the correct position is obtained. Finally, the focusing action of the tube is also affected by either the brightness control or the contrast control and will probably require a slight adjustment, too.

D-C Reinsertion with a Diode. The foregoing method of d-c reinsertion is attained simply and produces good results. One limitation of this method, however, is the fact that the B+ potentials on the screen grid and plate must be reduced in order that excessive current does not flow when no signal is being received. This reduces the overall gain available from this stage. Second, it is quite important that the screen-grid voltage be well regulated, otherwise the d-c restoring action is impaired.
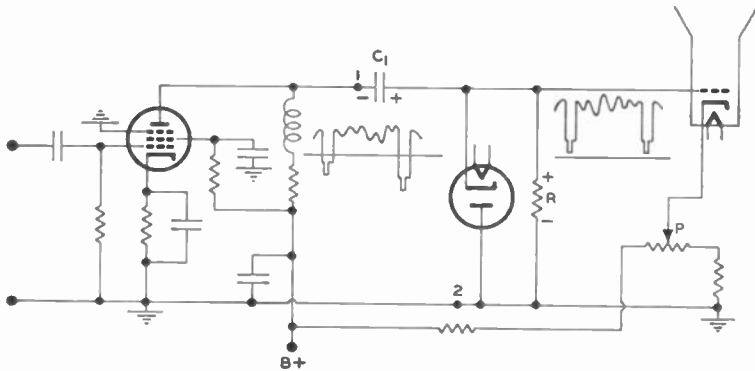
Fig. 7.6.   D-c reinsertion with a diode.

Another method exists which requires the addition of a diode tube, but which removes the highly positive voltage from the control grid of the cathode-ray tube (see Fig. 7.6). The signal here is in its a-c form until it reaches the input to the d-c restorer, composed of condenser C_1, resistor R, and the diode tube. The form of the signal, at this point, is the positive phase since no further reversals take place before the grid of the cathode-ray tube is reached.

In the signal applied to the restorer, the blanking and synchronizing pulses are below the zero line. When applied to points 1 and 2, the signal will cause point 1 to become negative with respect to 2. This follows from the action of an a-c wave. The other portion of the signal, which contains the image information, is above the line and, when it is applied across points 1 and 2, will make 1 positive with respect to 2. The diode in the

circuit conducts only when its plate is positive with respect to its cathode, or when point 2 is positive with respect to point 1.

The action of the d-c restorer is simple. When the polarity of the video signal at point 1 is negative, point 2 and the plate of the diode are positive. A flow of current will occur through the tube, and condenser C_1 will charge to a value dependent upon the strength of the signal acting at points 1 and 2. The polarity of the charge is indicated in Fig. 7.6. During the positive portions of the video signal at the input of the circuit, condenser C_1 will discharge through R, since the diode plate is now negative, and the tube is non-conducting. The value of R is high, about 1 megohm, and C_1 will discharge slowly.

The values of C_1 and R are so designed that the voltage on the condenser remains fairly constant throughout an entire horizontal line, or during the time that the positive a-c signal is acting on the picture tube grid. Note that this charge is between the grid and ground, or cathode, and hence acts as a variable bias in series with the a-c signal. When the negative portion of the signal (which is due mostly to the blanking and synchronizing pulses) acts at the input, the plate of the diode again becomes conductive. The charge on C_1 will now be automatically adjusted to the amplitude of the negative pulse. A bright line will place a larger positive voltage on the condenser C_1 than a darker line (positive picture phase here). The positive voltage will cause the grid to become more positive and the line will receive its correct value. The bias will raise each line until the blanking pulses are lined up again. Thus, in this instance, we have a bias developed which is proportional to the impulse amplitudes, which are in turn governed by the average brightness of the line, as previously explained. Potentiometer P is available and its adjustment will cause the grid to cut off on the application of all blanking pulses.

A slightly modified version of the foregoing circuit is used in many television sets. The circuit, given in Fig. 7.7, reveals that the diode tube is not placed across the entire plate output of T_1, but merely across a portion of it, obtained from resistor R_3. The

action of the a-c video signal across C_5,R_5, and the diode, results in C_5 charging to the peak value of the pulses. It then discharges partially through the 1-megohm resistor, and the effect of the condenser charge is to place its stored voltage in series with the a-c video signal so that the necessary d-c component is reinserted into the signal. The amount of charge on the condenser will naturally vary from line to line.

In some sets, tubes other than diodes are used, but in most cases, the tube elements are tied together in such a manner as
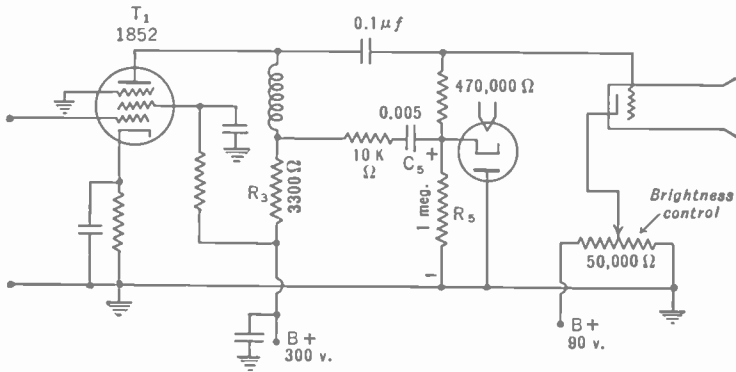
FIG. 7.7. A d-c reinsertion circuit that has been employed in commercial receivers.

to form the equivalent of a diode. Instead of using a diode tube for the d-c reinsertion, a 1N34 crystal may be substituted. Since crystals and diodes function in the same manner, the entire previous discussion can be applied here.

Diode restorers also can be utilized to function as clippers to separate the sync pulses from the rest of the video signal and then to transfer these pulses to the horizontal and vertical sweep systems. A typical circuit is shown in Fig. 7.8. Between every two horizontal sync pulses, C_1 discharges slightly through R_1, setting up the d-c restoration voltage here. Upon the arrival of a sync pulse, a short flow of current takes place through the tube and R_2 since this latter resistor is in series with the tube. These pips of current represent the sync pulses since they appear only when the peak pulses are present across the circuit.

There are variations of the foregoing diode restorer and clipper circuit which accomplish the same job but function slightly differently. Consider, for example, the circuit shown in Fig. 7.9.

V_2, the diode d-c restorer, receives the video signal from the plate V_1 through R_1 and C_1. Because of the way in which it is connected, V_2 will conduct only for the negative sync pulses of the video signal, charging C_1 in the manner already described. The d-c restorer biasing voltage is then developed across R_2 and,
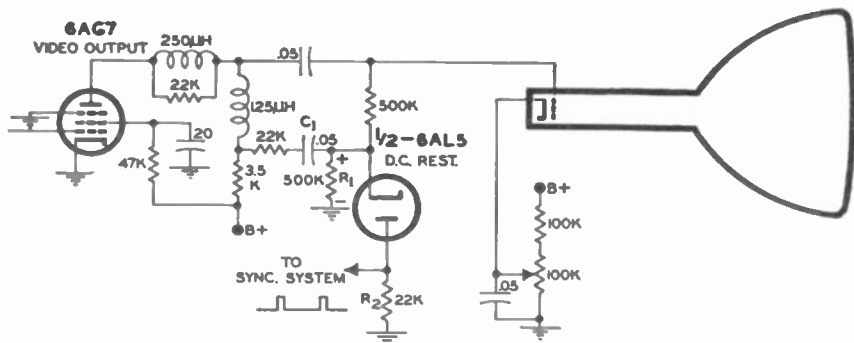
FIG. 7.8. A diode d-c restorer serving also as a sync clipper.

by varying the bias of the cathode-ray tube, reinserts the absent d-c component. Thus far the circuit is concerned with the d-c restoration.

The sync voltage is the voltage developed across R_3 since R_4 and R_5 are by-passed by C_2. When the positive half of the video signal is applied to V_2, this tube does not conduct since its plate is negative with respect to its cathode. This positive voltage, which represents only the picture information and not the sync pulses, is divided between R_1 (47,000 ohms), R_2 (1 megohm), and R_3 (33,000 ohms). The ratio of the voltage across R_3 to the total applied video signal is:

$$\frac{33,000}{1,080,000}, \quad \text{or} \quad \frac{33}{1,080}$$

This ratio is very small; hence not much voltage is fed to the sweep system.

On the negative half of the video signal, when the sync pulses are present, V_2 conducts, shunting out R_2. Now, the total applied video voltage is divided between R_1 and R_3, and the sweep system receives $\frac{33}{80}$ of the applied voltage. This means that approximately 14 times more sync voltage is transferred to the sweep system than picture voltage. Because of the presence of
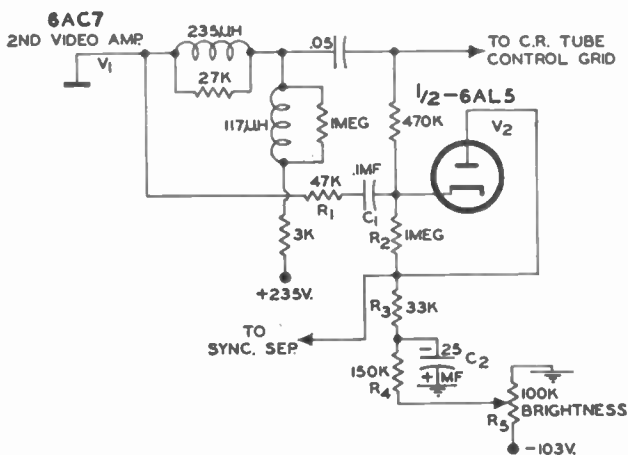
FIG. 7.9. Another combined d-c restorer and sync clipper.

some picture voltage, further separation is usually found in these systems.

Triodes and even pentodes may be connected to serve the dual function of d-c restorers and partial or total clippers. More will be given on this subject when the section concerned with clippers is reached.

It is possible to construct a television receiver requiring no d-c restoration. This can be done, provided that there are no coupling condensers between the video second detector and the cathode-ray tube. Refer to Fig. 5.6. The video-frequency amplifier in this instance is really a d-c amplifier and passes the signal it receives from the video second detector directly to the cathode of the image tube without any intervening condensers.

CHAPTER 8

CATHODE-RAY TUBES

Introduction. The cathode-ray tube, which is the very heart of the television receiver, is in many respects quite similar to the ordinary receiving tube. Like the receiving tube, it, too, has a cathode that emits electrons because of heat received from the heater wires. The flow of electrons, and hence the number, is regulated by the voltage on the electrodes in the same manner as any other tube. Once past the control grid, however, the electrons are narrowed down to a fine beam and subjected to focusing anodes and deflecting plates until the beam strikes a fluorescent screen located at the far end of the tube. At each point where the electron beam impinges on the screen, a spot of light appears. If the points follow in rapid succession, the motion can be made to appear continuous due to the persistence of vision phenomenon of the human eye.

For television receivers, the video signal containing the image detail is applied to the control grid, while the synchronizing impulses control saw-tooth oscillators that connect to the deflecting plates. Under the influence of these changing voltages, the beam is swept across the screen in step with the scanning beam in the camera tube at the studio. In the smaller cathode-ray tubes, focusing and deflection of the electron beam are accomplished by electrostatic means. For the larger tubes, say those that are 10 and 12 inches in diameter, electromagnetic focusing and deflection coils are found. The action of each type is different, although the end result is the same. Both methods are covered in this chapter.

The formation of the electron beam starts naturally at the cathode. The emitting surface, composed of thoriated tungsten

or barium and strontium oxides, is restricted to a small area in order that the emitted electrons progress only toward the fluorescent screen. They would serve no useful purpose in any other direction. The emitting material is thus deposited on the end of the nickel cathode cap that encloses the heater in the manner shown in Fig. 8.1 for a typical construction. The electrons, after emission, are drawn by the positive anode voltages into two electric lens systems. These form and focus the electrons into a sharp, narrow beam that finally impinges on the fluorescent screen in a small round point.
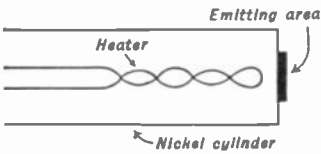
FIG. 8.1. Cathode and heater construction for a cathode-ray television tube.

The use of the word lens may puzzle the reader who thinks of this term only in connection with light rays, not electron beams. The purpose of a glass lens is to cause light rays either to diverge or to converge to a point. Electronically, the same results can be achieved and hence the reason for the carry-over of the name.

The First Lens System. In the first lens we find the cathode, the control grid, and the first anode arranged in the manner shown in Fig. 8.2. The grid, it is noticed, is not the familiar mesh wire arrangement found in ordinary tubes. For the present purpose it is a small hollow cylinder. The end nearest the cathode is partially closed by a round baffle, with only a small pinhole through which the electrons may pass. This restricts the area of the cathode that is effective in adding electrons to the beam and aids in giving the beam sharpness. The other end of the grid cylinder is entirely open and leads to the first anode. Here again a baffle restricts the direction of the electrons that make up the beam.

Due to the energy imparted to them by the cathode heating, the electrons leave the cathode surface with some small velocity. With no positive electric force (or field) to urge them forward, the electrons would tend to congregate in the vacuum space just beyond the cathode and form a space charge. Eventually, just

as many electrons leave the heated cathode surface as are re-
pelled by the negative space charge, and a state of equilibrium
exists. This condition can be broken and a flow of electrons
allowed to take place down the tube if a large positive voltage
is placed on the first anode.

The first anode, which is a hollow cylinder, does not have its
electric field contained merely within itself; it also reaches into
the surrounding regions. To be sure, the farther away we get
from the anode, the weaker the strength of the field. With zero
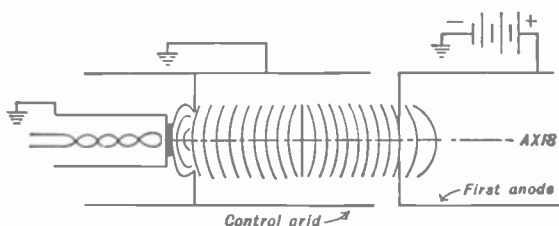
FIG. 8.2.   The first lens system of a television viewing tube.

potential on the control grid, there is nothing to counteract the
positive field of the anode, and the field extends through the
baffle of the control grid right to the cathode surface. Electrons
leaving this surface are urged on by the positive electric field
and accelerated down the tube, with the baffle restricting the
direction of the electrons to very small angles with the axis of
the tube.

The distribution of the electric equipotential lines outside the
first anode is shown in Fig. 8.2. In the diagram, the lines are
drawn through points that have the same electric potential, as
determined by actual measurements with a probe throughout
the region. It is interesting to note that these lines are not
straight, but tend to curve, the amount of curvature being in-
fluenced by the distance from the first anode and the control
grid. Cathode-ray tube design engineers use such field distribu-
tion diagrams to determine the effect of each electrode on the
electrons at the cathode and in the beam.

As a result of the bending of the electric field at the cathode, it can be proved by means of vectors that all electrons passing through the small hole in the control grid baffle will come to a focus or converge to a small area located near the first anode. This region is on the axis of the tube and is known as the cross-over point. The effect of the electric field is such that electrons near the outer edges of the control grid opening travel at an angle in order to get to the cross-over point, whereas electrons on the axis of the lens move straight forward to this point. The direction of some of the electrons is shown in Fig. 8.3.
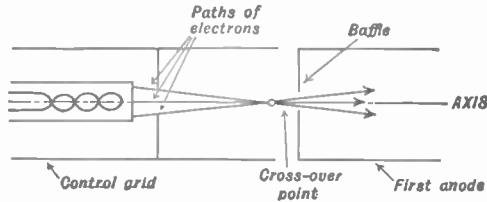
FIG. 8.3. A simplified diagram of the cross-over point in the first lens system. The two subsequent electronic lens systems are designed with this cross-over area serving as the starting point.

It is well to keep in mind that the shape of the electric field is determined by the placement of the electrodes and the voltages applied to them. The electrons are forced to converge to the cross-over point because this point can more readily serve as the supply source of the beam electrons than the cathode from which they initially come. The area of the cross-over point is more clearly defined than the relatively larger cathode surface, and it has been found that the electron beam is easier to focus if the cross-over area is considered as the starting point, rather than the cathode itself. The electrons that compose the final beam are then drawn from the cross-over point while other electrons come from the cathode to take their place. The greater the number of electrons drawn from this point, the brighter the final image on the fluorescent screen.

The control grid, in Fig. 8.3, is at zero potential. For ordinary purposes, this value of grid bias would permit too many

electrons to pass into the beam. Hence a negative bias is placed on the grid. In the larger cathode-ray tubes, the bias may rise as high as -80 volts. With a negative voltage on the control grid, the extent of the positive electric field is modified and it no longer affects as large an area at the cathode surface as it did previously with zero grid volts. Now, only electrons located near the very center of the cathode are subject to the positive urging force, and the number of electrons arriving at the cross-over point is correspondingly less. The intensity of the final electron beam likewise decreases. In the television receiver, the video signal is applied to the control grid and the resulting variations in potential cause similar changes in electron beam intensity.

For the beam arriving at the screen to remain in focus once the controls have been set, the position of the cross-over point must remain fixed. With normal variations of control grid voltage, this condition is obtained. With large variations, however, the position of the cross-over point tends to change, moving closer to the cathode as the grid becomes more negative. Thus a certain amount of defocusing will take place. Proper design generally keeps this at a minimum and, for most of the voltage variations encountered in television work, defocusing does not become too noticeable.

To summarize the purpose of the first lens system, we see that electrons leaving the cathode surface are forced to converge to a small area near the cathode. This offers a better point for the formation of the beam and its subsequent focusing.

The Second Lens System. The second lens system draws electrons from the cross-over point and brings them to a focus at the viewing screen. The system consists of the first and second anodes, as shown in Fig. 8.4. The second anode is operated at a higher potential than the first anode, is larger in diameter, and frequently overlaps the first anode to some extent. It is at the point of overlap of the two anodes that the second lens is effective, and it is here that the focusing action of the electron beam takes place. Electrons, when drawn from the

cross-over point established by the first lens system, are not all
parallel to the axis of the tube. Some leave at various small
angles, as shown in Fig. 8.3. The beam thus tends to diverge
and it is due to the second lens that these diverging electrons
alter their path and meet at another point on the axis. This
second point is at the screen. Those electrons moving straight
along the axis of the tube are not affected, in direction, by the
focusing action of the second lens.
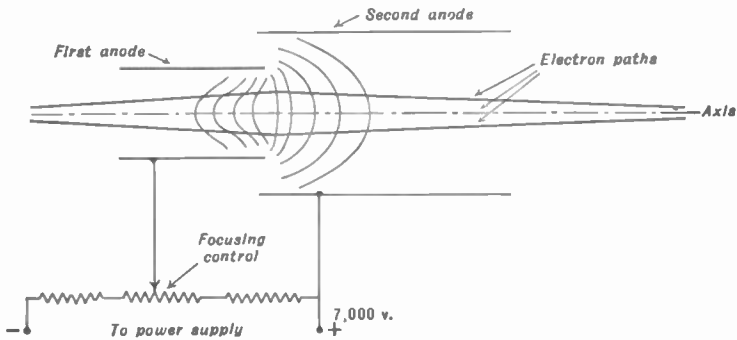
FIG. 8.4. The second lens system. Focusing of the electron beam at the viewing
screen is accomplished by varying the voltage at the first anode.

The operation of the second lens depends upon the different
potentials that are applied to the first and second anodes and
the distribution of the resulting electric field. The equipoten-
tial lines for this lens are drawn in Fig. 8.4, and it is to be noted
that the curvature of these lines changes at the intersection of
the two anodes. On the left-hand side, the electric field lines
are convex to the approaching electron beam, while to the right
of the intersection the lines are concave. Without resorting to
mathematical reasoning, it can be stated that the effect of these
oppositely shaped electric lines on the beam is likewise opposite.
Since we have seen that some of the electrons tend to diverge
after they leave the cross-over point, the field distribution must
be designed to overcome such a tendency. In action, the con-
vex equipotential lines force the electrons to converge to a
greater extent than the concave lines cause the electrons to di-

verge. Inasmuch as the convergence exceeds the divergence, the net result is a focusing of the electrons on the screen.

The ratio of the voltages, the size of the anode cylinders, and their relation to each other will determine the distribution and curvature of the electric lines of force; the latter, in turn, will determine the amount and the point at which the focusing takes place. In current cathode-ray tubes, the ratio of the first to the second anode voltages ranges from 3 to 1 to 6 to 1 or more.

In order that the electron beam leaving the cross-over point shall not diverge too greatly, a baffle is placed at the opening of
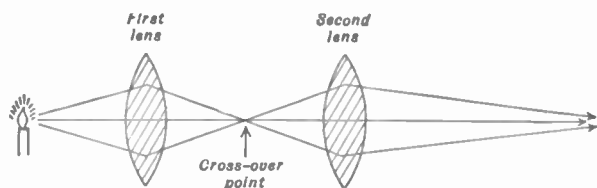
Fig. 8.5. The glass lenses used in focusing light rays illustrate the similarity between light wave and electron beam focusing.

the first anode, similar in construction to the baffle previously described for the control grid. The baffle again limits the width of the electron beam to the desired size. Practically, focusing control is accomplished by varying the voltage on the first anode by an arrangement shown in Fig. 8.4. This is the simplest way of altering the voltage ratio between the first and second anodes and, with it, the distribution of the electric lines of force of the lens system. An approximate optical analogy of the lens system is shown in Fig. 8.5 and may prove helpful in indicating the operation of the electric system.

Electrostatic Deflection. Once past the second anode, the electron beam speeds toward the fluorescent screen. However, the beam must first pass through two sets of deflecting plates mounted at right angles to each other. One set of plates is known as the horizontal deflecting plates, the other as the vertical deflecting plates. In television receivers, saw-tooth oscillators are electrically connected to these plates, and the electron

beam is subjected to changing voltages that force it to move
across and up (or down) on the screen. The 525 lines of each
frame are swept out in this manner. The synchronizing pulses
control the action of the saw-tooth oscillators in order to keep
the original and reproduced images in step with each other.
The same action of deflection can also be accomplished with
coils and will be presently described.

In commercial television receivers, two methods of applying
the deflecting voltages to the deflecting plates may be employed.
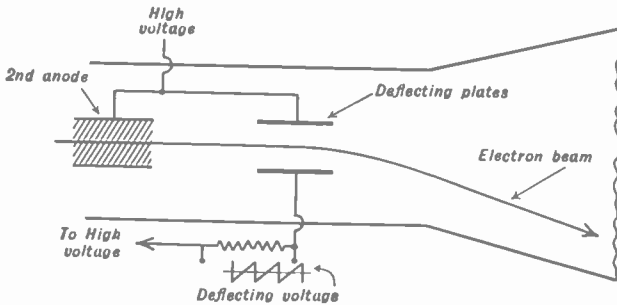
FIG. 8.6A. Deflection of electron beams. This unbalanced method, while simple in
construction, does not always give a clearly defined beam on all parts of the
fluorescent screen.

In one method, we find that the one deflecting plate of each set
is connected directly to the second anode while the other plate
receives the varying deflecting voltages. When this voltage is
zero, both plates (of each set) are at the same potential, which
in this case is equal to the second anode voltage. The electron
beam is therefore not subjected to any deflecting force and passes
unmolested through the center of the system. The reason that
the deflecting plates are at second anode potential is due to their
position in the tube. The beam, in leaving the second anode,
must not be slowed down. Any voltage difference between the
second anode and the deflecting plates would not only change
the velocity of the beam but would also produce defocusing at
the screen. To avoid all these difficulties, the deflecting plates
and the second anode are electrically connected.

With one plate permanently attached to the second anode and the other to the deflecting voltage, we have an unbalanced arrangement as in Fig. 8.6A. The plate with the varying potential will deflect the beam, an amount proportional to the acting voltage. For small voltage variations, the operation is satisfactory. At higher deflecting voltages (in larger tubes), a defocusing of the beam occurs. This effect is sometimes called astigmatism.
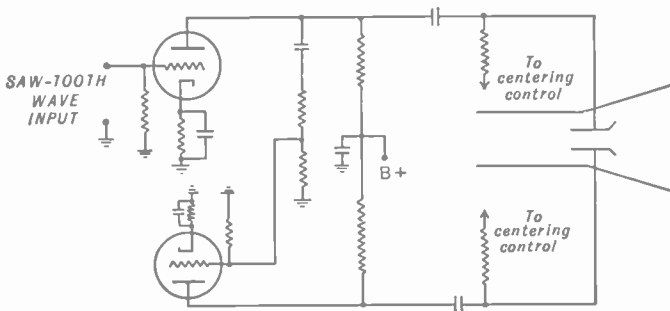
Fig. 8.6B.   A balanced deflection system.

The reason for the defocusing action may be explained as follows: The electron beam, once it leaves the second anode, is travelling toward the screen where it should come to a focus. Any electrical disturbances not part of the focusing action will tend to destroy the sequence. When varying voltages are applied to the deflecting plates, their average potential varies above and below the second anode voltage. The result, when the difference between the two becomes sufficiently great, is to throw the beam out of focus. In small tubes the voltage difference is not large enough to cause defocusing, but in larger tubes definite defocusing is observed. This is especially noticeable when the beam is at the ends of the screen, for it is at such points that the required deflection voltage is greatest.

The more desirable method, which is balanced, is shown in Fig. 8.6B. The voltages on both plates change and uniform force is exerted by the plates on the beam. As both deflection plate

voltages vary in opposite manner. the average *change* in voltage is zero.   However, now two tubes are required (push-pull), which increases the cost of the set.   Despite the latter fact, this method is the one used in receivers that employ electrostatic deflection.

To obtain maximum deflection of the beam without having it strike the edges of the plates, cathode-ray tube designers have flared the plates slightly at the ends.   The basic elements of a cathode-ray tube employing electrostatic deflection are shown in Fig. 8.7.

One further word about cathode-ray tubes.   It will be found that most manufacturers place a conducting aquadag coating entirely around the inside of the glass, extending from the first or second anodes almost (but not quite) to the fluorescent screen. An important function of this aquadag coating is to prevent the collection of free electrons that would otherwise accumulate on the glass walls of the tube.   In addition, it serves as a collecting anode for the secondary electrons which are emitted from the fluorescent screen when the electron beam impinges on the screen.   If we removed the aquadag coating, these secondary electrons would land on the glass walls of the tube and remain there.   Eventually, sufficient charge would develop to prevent proper functioning of the beam.   By coating the inside of the tube with aquadag and giving it a positive potential, we remove all this undesirable charge.   Internally, the coating is connected to the second anode.   When magnetic, instead of electrostatic, deflection is used, some manufacturers omit the separate cylindrical second anode and use the coating to perform this function, too.   Tests have proved that through the use of this dark coating, less light is reflected from the screen into the tube and then back to the screen again.   This reduction in reflection aids the contrast range available from a fluorescent screen.   Fig. 8.28 is an illustration of a tube possessing this aquadag coating.

Amount of Deflecting Voltages Necessary.   The amount of voltage that must be applied to the deflection plates in order to force the beam to travel from one side of the screen to the other

(A)
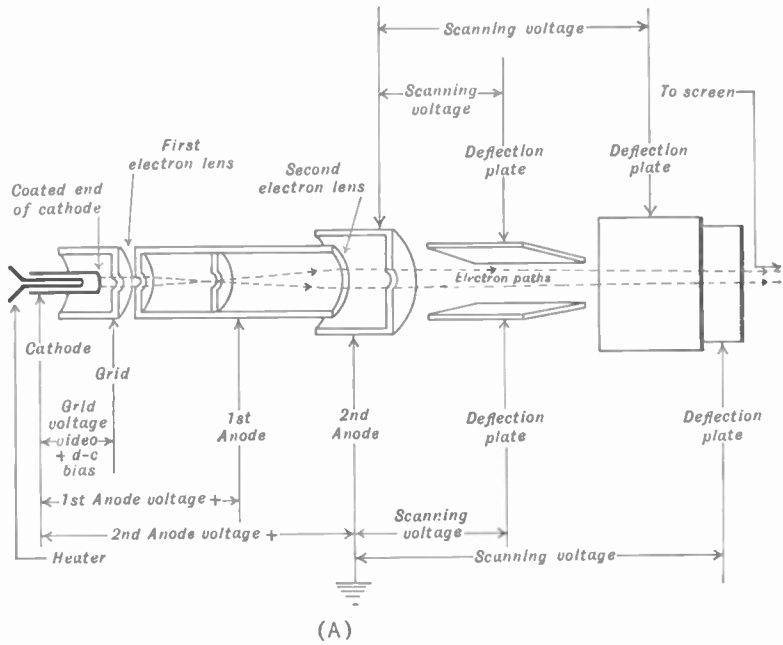
RMA BASING

(B)

Courtesy Sylvania Electric Products Corp.

Fig. 8.7.   The basic elements of a cathode-ray tube (A).   The great number of elements found in these tubes necessitate a larger tube base, as shown in (B).

will depend to a great extent upon the accelerating voltage of
the second anode and the width of the screen. A larger voltage
will accelerate the electrons more strongly and hence necessitate
a larger voltage on the deflection plates. The faster an electron
travels, the less time it spends between the plates, and a greater
deflection voltage is required to bend it. The deflection sensitiv-
ity, which is given for each tube in its characteristic data, then
decreases. On the other hand, lowering the second anode voltage
will permit the deflecting plates to exert greater control over the
electron beam for the same deflecting voltage.

In characteristic charts of cathode-ray tubes, the deflection
sensitivity may be stated directly or another unit, known as
the deflection factor, may be given. Many times both can be
found, although it is possible to compute one if the other is given.
To illustrate, consider the 20AP4 tube. The deflection sensi-
tivity is given as 1.2 mm/volt/kv as an average value. This
means that with 1.000 volts on the second anode (1 kilovolt or
1 kv), 1 volt difference between the first set of deflection plates
will move the beam 1.2 millimeters at the screen. If 2,000 volts
are placed on the second anode, the deflecting plates become less
effective in their action and 1 volt now moves the beam only 0.6
mm across the screen, or one half of its previous value. In
general, increasing the second anode voltage by a certain amount
decreases the distance the beam is deflected by a proportionate
amount (assuming no voltage change on the deflection plates).

Let us return to the figure of 1.2 mm/volt/kv. The deflection
factor is expressed as the number of volts on the deflecting plates
that would move the beam 1 inch with 1,000 volts on the second
anode. For the 20AP4, the figure given for the deflection factor
is 22 d-c volts/inch/kv, which means that 22 volts difference
between the first set of deflection plates will move the beam 1
inch on the fluorescent screen when 1,000 volts are on the second
anode.

To change from one set of units to the other, take the deflec-
tion factor, multiply it by the number of kilovolts on the second
anode, and then divide this figure into 25.4 (the number of

millimeters in 1 inch). The result is the deflection sensitivity in mm/volt/kv. To convert from the deflection sensitivity (in mm/volt/kv) to the deflection factor (in volts/inch/kv), we divide the number of millimeters by the voltage of the second anode in kilovolts and then divide this figure into 25.4. The foregoing procedure may seem complicated, but solving one or two examples will clarify the matter.

D-c volts are specified to avoid the confusion which might exist if a-c voltages were stated without specifying whether the values are peak, average or r.m.s. As an indication of the amount of deflecting voltage necessary, one DuMont 14-inch tube requires 130 d-c volts to move the electron beam 1 inch, with a second anode voltage of 4,000 volts. To cover the entire 14 inches, the large value of 1,820 volts would be required. With alternating voltages, this is the peak-to-peak value, because the positive portion of the signal swings the beam across one half the screen and the negative portion of the signal swings it through the other half.

Centering Controls. The electron beam, when not subject to any deflecting voltages, should hit the fluorescent screen at its center. In this position, a symmetrically placed image will result when the deflecting voltages are applied to the plates. In practice, stray electric and magnetic fields, or distortions of fields within the tube itself, may interfere and cause the beam to be displaced from the center position. In order to correct this condition, positioning controls for the vertical and the horizontal plates are generally available at the back of the receiver. A slotted drive screw permits adjustments to be made when necessary. Ordinarily, this should not be very often.

A popular method for applying correcting voltages to electrostatic deflecting plates to center the beam is shown in Fig. 8.8. A high fixed voltage is placed on one vertical and one horizontal deflecting plate from a tap between two 50,000-ohm resistors. In parallel with these two resistors are two 500,000-ohm potentiometers, the center arm of each going to the other vertical and

horizontal deflection plates. When the arms of the potenti-
ometers are in the center position, there is no d-c potential
difference *between* the plates of the horizontal and vertical sets.
A balance exists. Any change in the position of these potenti-
ometer arms, however, will make one plate more positive than
the other of either set and bend the electron beam in the desired
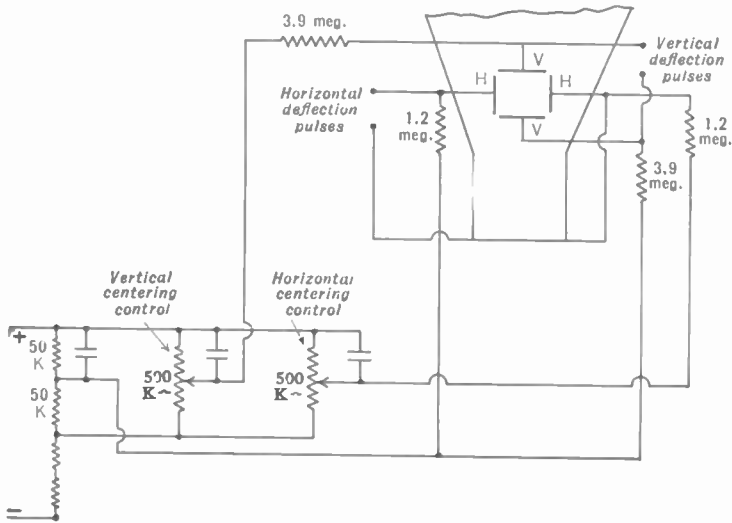
Fig. 8.8. Vertical and horizontal centering controls.

direction. The deflecting voltages for the image are applied
separately as shown, with large resistors placed in the centering
leads to act as connecting resistors to couple the deflecting volt-
ages to the plates themselves.

Magnetic Focusing. While the preceding discussion has been
concerned with electrostatic methods of focusing and deflecting
the electron beam, the same operations may be performed as
well magnetically. However, before any circuits are discussed,
it would perhaps be advisable to review the action of magnetic
fields on moving electrons.

From elementary electricity, it is well known that a wire
carrying a current has a circular magnetic field set up around

it, as shown in Fig. 8.9A. Suppose that the wire is placed in a magnetic field parallel to the magnetic lines of force. See Fig. 8.9B. There will be no interaction between the magnetic lines of the field and those set up by the wire. Why? Because the two *fields* are at right angles to each other.

For the opposite case illustrated in Fig. 8.9C, the current carrying wire is placed at right angles to the field lines of magnetic force. Above the wire the lines of both fields add, whereas
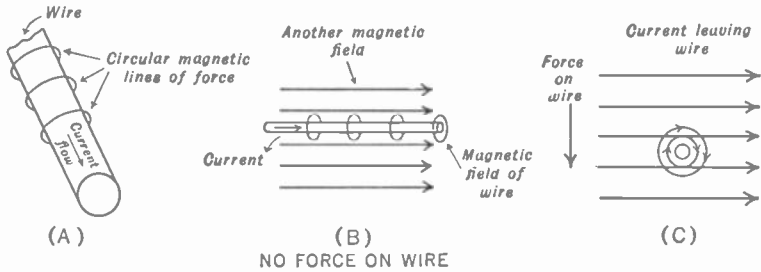
Fig. 8.9. The action of a wire carrying current when placed in a magnetic field.

underneath the wire they oppose and tend to cancel. Experiment indicates that a resulting force will act on the wire in such a way that it moves from the stronger part of the magnetic field to the weaker portion. This is indicated in the figure. The illustration represents the two extreme angles that the wire and the field can make with each other. Intermediate positions (those between zero and 90 degrees) will cause intermediate values of force to act on the wire.

The transition from a wire carrying electrons to the electrons themselves, without the wire, is quite simply made. With only electrons moving through space, the same circular magnetic field is set up about their path. From the preceding discussion, we know that electrons travelling parallel to the lines of force of an additional magnetic field experience no reaction from this field. On the other hand, if they enter the magnetic field at an angle to the flux lines, a force will be brought to bear on them and their path will be altered.

It is well to reiterate that for an electron to react with a magnetic field: (1) the electron must be moving, otherwise it does not generate a magnetic field; and (2) the moving electron must make an angle with the magnetic field in which it is travelling.

Now let us apply the foregoing facts to magnetic focusing. The focusing coil is slipped over the neck of the cathode-ray tube and placed just beyond the first anode. See Fig. 8.10. The first lens system remains essentially as in the previously
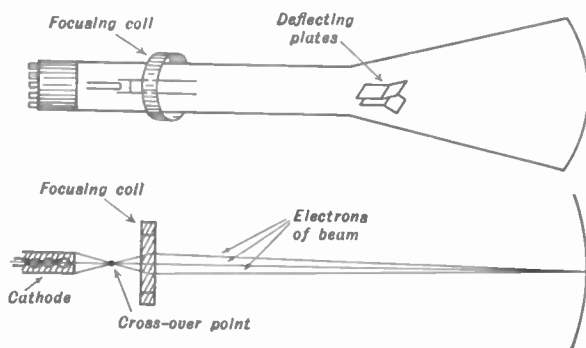
FIG. 8.10.   Magnetic focusing.

described electrostatically controlled tubes; it still converges electrons to the cross-over point. From this point, the electrons spread out and the focusing action of the coil begins to function. The second anode is eliminated, of course, since the coil has taken its place. In this case, however, the high positive potential of the aquadag coating inside the tube accelerates the electron beam.

The field of the focusing coil is parallel to the axis of the tube and is generated by direct current flowing through the coil. As long as the electrons leave the cross-over area and travel down the tube along the axis, the magnetic lines do not interfere with their motion. However, many electrons tend to spread out beyond the cross-over region, and it is on these electrons that the magnetic force reacts because they are moving at some small angle to the magnetic flux lines.

The path taken by electrons that are acted on by a magnetic field can be more easily understood if it is recalled that the resulting force on the electron is at right angles to both its motion and the magnetic field. The result of this force, as shown in Fig. 8.11A, is to cause the electron to move in a circular path. In this way the force on the electrons, the electronic motion, and the magnetic force are always at right angles to each other.
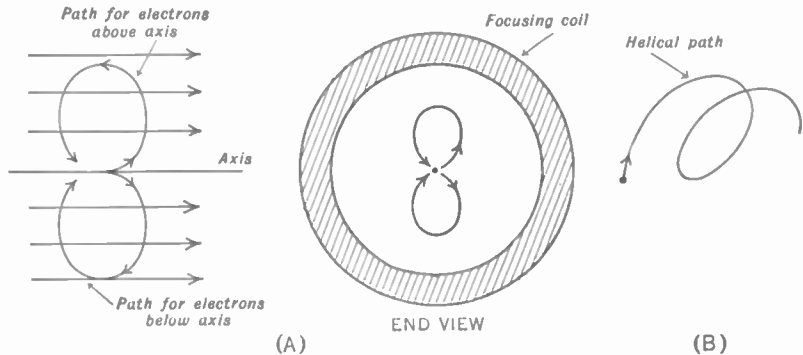
Fig. 8.11. Electrons, when cutting across magnetic lines of force, are made to move in a circular path (A). If, however, they are also subjected to an electrical force urging them forward, then their resultant path will be helical (B).

Apply these ideas to the action inside the cathode-ray tube. As the electrons leave the cross-over point at small angles to the magnetic field, they are subjected to a force that tends to make them turn in a circle. But at the same time that they are being forced to travel this circular path, they are also speeding forward. The resulting motion of the electron is known as helical and is similar to the action of a screw being turned into a piece of wood. It rotates while also moving forward. Fig. 8.11B may aid the reader to visualize the motion.

The electrons that are acted on by the magnetic field all come from the cross-over point that is situated on the axis of the tube. The minute they leave this point at some angle, the magnetic force starts to act, forcing them to move in a circular path back to the axis again. In the cathode-ray tube they are, at the

same time, also moving forward and hence when the circular path is completed the electrons will again be on the axis of the tube some distance away. The exact position down the tube where the electrons return to the axis is dependent upon the strength of the magnetic force and the forward velocity.

By suitable variation of the intensity of the magnetic field, it is possible to have the electrons return to the axis of the tube exactly at the screen. The beam is now focused. The greater the speed of the electrons, the stronger the magnetic field required. Thus, any changes that affect the velocity of the electrons, such as varying the first anode voltage, will also require readjustment of the current through the focusing coil.
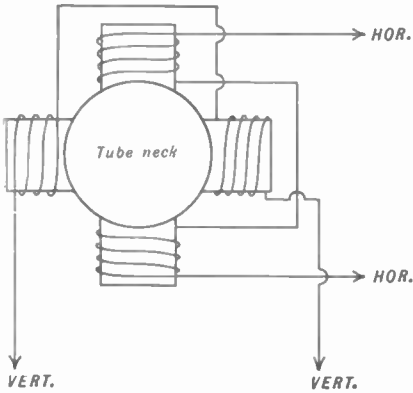
Fig. 8.12A. Electromagnetic deflection coil. This represents the physical placement of the windings.

To review the process, we find that the magnetic field causes the outgoing electrons from the cross-over region to travel in helical paths that will force them back to the axis again. With proper adjustment of the magnetic coil current, the electrons complete their circular path at the screen. Here they meet the other electrons that travelled straight along the axis (and not affected by the magnetic field) and a well-defined spot will result.

At other values of the magnetic field, defocusing occurs. As an exception to the last statement, it should be mentioned that by continually increasing the strength of the magnetic field the electrons can be made to do two (or more) complete revolutions before striking the screen. As each complete revolution brings the beam to the screen, a focused spot will appear. This process may be continued for as long as the magnetic coil will carry current.

It would appear from the preceding discussion that the magnetic field must extend all along the tube in order that the electrons are always under its influence. Their path would then be helical as described. However, for practical applications, only a small iron-core coil is slipped over the neck of the tube. This is shown in Fig. 8.13. The electron beam is thus subjected
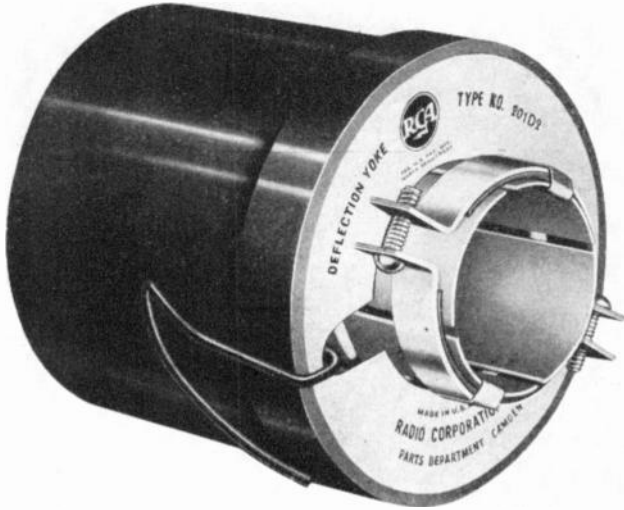
Courtesy RCA

FIG. 8.12B. A deflection yoke containing both horizontal and vertical deflection windings.

to the magnetic force for only a short time. During this period it is given enough of a twist so that it will move toward the axis; the forward motion then keeps it travelling along this path. The motion now is not truly helical, but the end result is satisfactory.

Electromagnetic Deflection. It is possible to deflect electrons by either magnetic or electrostatic fields. Electrostatic deflection has already been described and magnetic deflection will now be considered. Actually, little new need be added to understand the action of deflecting coils on the electron beam. Two sets of coils are placed at right angles to each other and mounted on the section of the tube neck where the electron beam leaves

the focusing electrode and travels toward the screen.   There
are four coils in all (two in each set), with opposite ones com-
prising one set.   These are connected in series in order to ob-
tain the proper polarity (see Fig. 8.12A).

A soft iron shell is placed around both sets of coils to act as a
shield.   The entire assembly is known as a yoke (see Fig. 8.12B).
For horizontal deflection, the coils are vertically placed whereas,
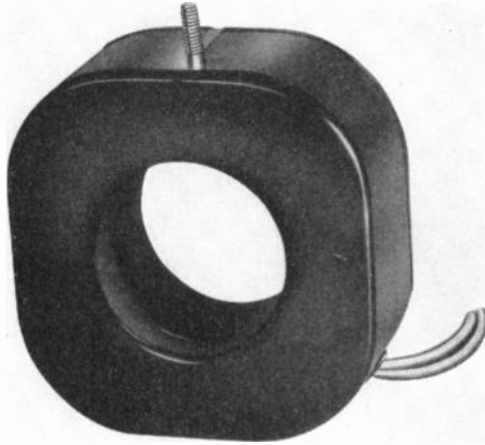
FIG. 8.13.   A focusing coil.

for vertical deflection, the coils are horizontally mounted.   This
reverse placement of the coils is due to the fact, stated above,
that the force on travelling electrons in a magnetic field is at
right angles to both the direction of motion and the lines of the
field.   After the coils have been oriented, saw-tooth shaped cur-
rent variations are sent through them.   The magnetic field flux
follows these current changes and causes the electron beam to
move back and forth (or up and down) across the screen, sweep-
ing out the desired pattern.

The reader should not become confused by the seemingly dif-
ferent actions of the focusing and the deflection coils.   At first
glance it may appear that one coil (the focusing coil) twists the
electron beam around so that it ends up at the screen in focus,

while the other coils (the deflecting coils) only cause the beam
to move either to the right or left or up and down. Actually the
action of all the coils is the same; the only difference lies in the
manner in which they affect the beam. With the focusing coil
the magnetic lines of flux are parallel to the axis of the tube and
the electrons that are moving away from the axis of the tube are
subjected to a strong twisting force that turns them back to the
axis. Their forward motion, given to them by the positive first
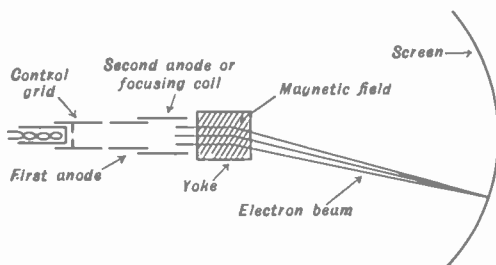
FIG. 8.14. Deflection by magnetic means.

anode, and sometimes by an intensifier ring, keeps them moving
toward the screen.

At the deflecting coils, the magnetic fields are at *right angles*
to the path of the beam. The beam, in moving through these
fields, has a force applied which is at right angles to the forward
motion of the electrons and the direction of the magnetic lines of
force. Here the effect of the field is not as great as at the focus-
ing coil, and the beam is merely deflected rather than bent all the
way around into a circular path. The influence of the field ends
when the electrons pass the yoke, but any sideward or up and
down motion imparted to the electrons while in the field is re-
tained. This is shown in Fig. 8.14. By varying the direction of
the flow of current through the vertical and horizontal deflecting
coils, it is possible to reach all points on the screen. This type
of deflection is used with the larger cathode-ray tubes.

When a yoke is inserted over the neck of the picture tube, it
is very easy to position it so that the image is not properly

oriented. This is indicated in Fig. 8.16. In this case, correction may be accomplished by rotating the yoke until the image is again properly positioned.

Fig. 8.15 illustrates the proper positions for focus, deflection, and ion-trap coils on the neck of a cathode-ray tube. The ion trap will be discussed presently.
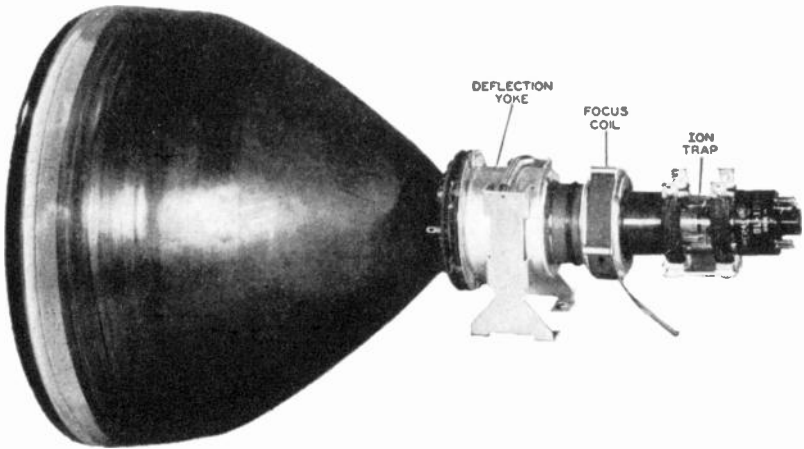
Courtesy G.E.

FIG. 8.15. The positions for a deflection yoke, focus coil and ion trap on the neck of a cathode-ray tube.

Cathode-Ray Tube Screens. Everything that has been done to the electron beam in the discussion thus far has been done with two ideas in mind, namely, to have it focus properly on the screen and to send it to different parts of the screen as well. Now let us consider the screen itself.

An electron gun, once constructed, can be subjected to considerable misuse without being permanently affected. On the other hand, failure to grasp the significance of certain precautions required to protect the fluorescent screen can readily result in a shortened period of usefulness and/or unsatisfactory operation throughout the life of the tube.

The phenomenon by which certain substances convert the energy of an electron beam into visible light is known as lumi-

nescence. Luminescence is further divided into fluorescence and phosphorescence. Fluorescence is luminescence which ends when the exciting agent is removed. Phosphorescence is luminescence which exists after the exciting agent is removed. Technically, then, the screens used in television should be called phosphorescent screens, and indeed the crystalline substances used for

Courtesy NBC

FIG. 8.16. Incorrectly positioned image due to improper placement of deflecting coil yoke.

these screens are known as phosphors. Unfortunately, however, the word "fluorescent" has become so widespread that one seldom hears the other, proper name. A tabulation of the most common phosphors in use in oscilloscopes, television receivers and radar equipment is shown in Table 8.1. For television, a combination of zinc sulphide and zinc beryllium silicate is used, this combination giving higher conversion efficiency than most other known compounds. It is interesting to note that the elec-

tron beam remains at any one point for approximately 0.1 of a microsecond, yet the light emission continues for two to three hundredths of a second, indicating that the zinc sulphide and zinc beryllium silicate are responsible through their phosphorescence for essentially all of the emitted light seen by the observer. A typical persistence curve for zinc sulphide is shown in Fig. 8.17.

RMA Designa-tion—Substance	Activator	Fluorescent Color	Phosphorescence (seconds)
PI—Zinc silicate	Manganese	Green	Med. -0.03-0.05
P2—Zinc sulphide	Copper	Blue-green	Long
P3—Zinc beryllium silicate	Manganese	Yellow-Gr.	Med. -0.05'
P4—P3 and zinc sulphide	Silver	White	Short 0.005
P5—Calcium Tungstate		Blue	Very short 5µsec. med. 0.005
P6—Zinc sulphide Zinc cadmium sulphide	Silver Silver	White	
P7—Zinc sulphide Zinc cadmium sulphide	Silver Copper	Blue Yellow	Med. -0.006 Long
PII—Zinc sulphide	Silver with a nickel quencher	Blue	Very short 10µ sec.

TABLE 8.1.   The most common phosphores used for oscilloscopes, television receivers and radar equipment.

The principal objective in the design of a cathode-ray tube is the production of an image having good brightness and high contrast. When the electron beam strikes the backside of the fluorescent screen, the light which is emitted distributes itself in the following approximate manner:

50% of the light travels back into the tube.
20% of the light is lost in the glass of the tube by internal reflection.
30% reaches the observer.

Thus, of all the light that is produced by the electron beam (and this, itself, is a highly inefficient process), only 30 per cent reaches the observer.

Image contrast is impaired because of the interference caused by light which is returned to the screen after it has been re-
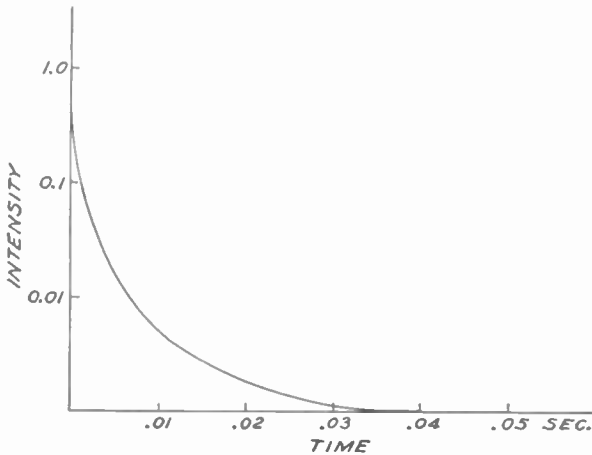
Fig. 8.17. A persistence curve for zinc sulphide, commonly used in P4 television screens.

flected from some other points. Some of these sources of interference are:

1. Halation.
2. Reflections due to the curvature of the screen.
3. Reflections at the surface of the screen face.
4. Reflections from inside the tube.

These are listed in the order of their importance.

Halation. If we take a cathode-ray tube and minutely examine the light pattern produced by a stationary electron beam, we find that the visible spot is surrounded by rings of light. These rings of light are due to a phenomenon known as halation (see Fig. 8.18). The light rays which leave the fluorescent crystals at the inner surface of the tube face travel into the glass and are refracted. Those rays which make an angle greater than θ do not leave the glass when they reach the outer surface, but instead are totally reflected back into the glass. At each

point where these reflected rays strike the fluorescent crystals, they scatter and it is this scattering of the rays that produces visible rings on the screen. These rings cause a hazy glow in the region surrounding the beam spot and reduce the maximum possible detail contrast. Contrast, it will be remembered, is the ratio of the brightness of two points, one of which is being
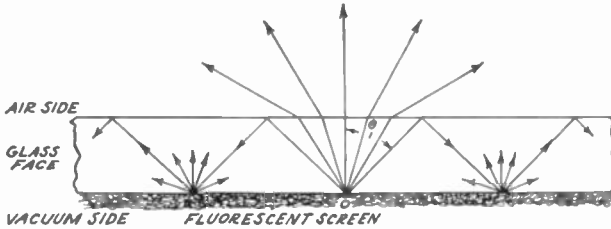
FIG. 8.18. Illustration of how reflections between the two sides of the glass can cause halation.

bombarded by the electron beam, the other, which is under cut-off conditions. It is desirable to have this ratio as high as possible in order to achieve "rich-looking" or high-quality images. Due to the scattering of the light, however, areas which should be in total darkness receive some light and the result is a reduction in the contrast ratio. A distinction is usually made be-
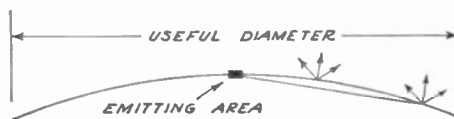
FIG. 8.19. Diffusion effects in nonflat screen.

tween the detail contrast ratio, which is defined above, and the overall field contrast. The field contrast ratio compares two sections of the screen which are widely removed from each other. Halation affects only detail contrast.

Reflections Due to the Curvature of the Screen. Loss in contrast due to reflections arising from the curvature of the screen is shown in Fig. 8.19. The remedy for this is the use of a flat

screen. Much progress has been made in this direction since the screen curvature greatly restricts the useful image area. One good example is the large 20-inch television tube. For two inches all the way around the circular perimeter, the image cannot be used because of the optical distortion introduced by the screen curvature.

Reflections at the Surface of the Screen Face. Light rays, when they travel from one medium to another, always lose a certain amount of energy at the intersection of the two media. At the cathode-ray tube screen, some light is reflected when it reaches the dividing surface between the air and the glass of the tube. The reflected light travels back to the inner surface and then back to the outer surface again. At each dividing surface, some of the light continues onward and some is reflected back into the glass. Absorption and dispersion quickly reduce the strength of these rebounding rays.

Reflections from Inside the Tube. In Fig. 8.20 we see how reflections from the inside surfaces of the tube can act to decrease the field contrast of the image. The loss in contrast from this source of interference can be made quite low by special shaping of the bulb walls, as shown in Fig. 8.20, and the use of the black aquadag coating. The aquadag coating is also useful for electrical purposes, acting as a shield and a path for the return of the secondary electrons emitted from the fluorescent screen. Secondary electrons must be emitted by the screen, otherwise the negative charge accumulation on the screen would soon become great enough to prevent the electron beam from reaching it.

A recent step toward improving screen brightness and contrast has been the addition of an extremely thin film of aluminum on the back of the fluorescent screen. The film is sufficiently thin to permit the electrons in the scanning beam to reach the fluorescent crystals. It will prevent, however, any of the light which is generated by the screen crystals from travelling back into the tube. This is shown in Fig. 8.21   The light which previously went back into the tube is now reflected toward the

observer. This is one improvement. In addition, the overall field contrast is improved by as much as ten times. However,
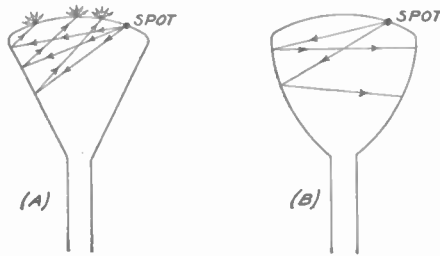
Fig. 8.20. The shape of the tube bulb can reduce internal reflections.

the detail contrast is not noticeably affected since it is governed primarily by halation, and the addition of the aluminum layer does not affect this.
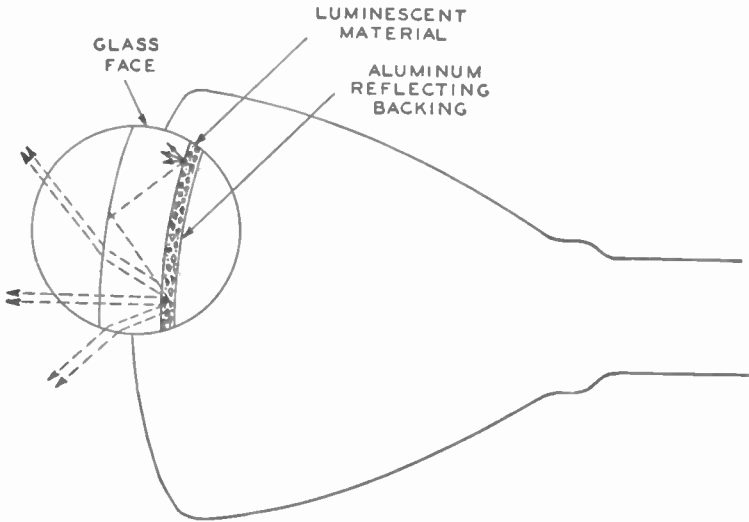
Fig. 8.21. An aluminum backing over the fluorescent screen prevents light from traveling back into the tube.

The metal film is extremely thin, being on the order of $3,500 \times 10^{-8}$ centimeters thick. Since even a layer this thin does interpose a barrier in the path of the electron, it is essential that

sufficiently high accelerating voltages be used.   In Fig. 8.22, a comparison between the efficiency curves of screens having the metallic layer and those which do not is shown.   At low accelerating voltages, the loss of energy by the electrons in pene-
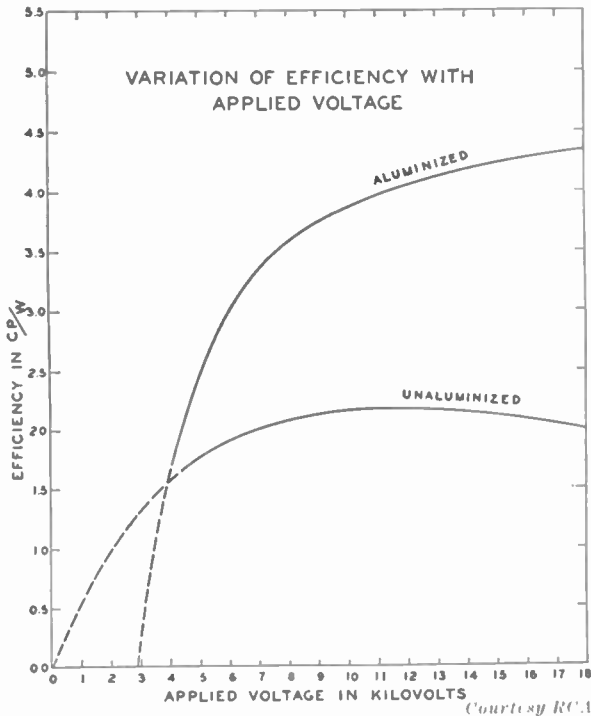
Fig. 8.22.   Variation in efficiency of aluminized and unaluminized screens.

trating the layer decreases their efficiency below that of similar electrons in tubes not possessing this layer.   The poorer efficiency continues until we reach the point where the curves intersect.

Beyond this region, the screen with the metallic layer proves to be quite superior to the ordinary tube.   The rapid rise in efficiency is due to a decrease in energy lost at the metallic barrier plus an increase in the overall brightness due to the light-resisting characteristics of the layer itself.

Sticking Potentials. An additional purpose which the aluminum film serves is to avoid undesirable effects due to poor secondary emission from the screen. The electrons in the beam, where they strike the screen, must somehow be brought back to the cathode. The fluorescent crystals themselves are essentially non-conductors. If the electrons from the beam were allowed to accumulate on these crystals, a point would soon be reached where a negative charge would accumulate sufficiently to prevent any additional electrons from reaching the screen. Originally, when tubes were first built, a thin metal film was deposited on the glass face of the tube and the fluorescent screen coated on this. The metal film was connected to the second anode, thereby assuming the same potential. When the electrons hit the fluorescent coating, they continued through to the metal film.

Further investigation revealed that, without the metal film, the tube would still work because of the secondary emission from the screen. The beam electrons, when they hit the fluorescent screen, imparted sufficient energy to the screen electrons to cause them to leave the screen. These emitted electrons reached the aquadag coating on the walls of the tube and by this path were conducted back to the cathode. The removal of the metal film was a considerable step forward toward obtaining a brighter image.

The return of the electrons by secondary emission was not without limitations. First, the number of secondary electrons emitted depended upon the velocity of the arriving beam electrons. If their velocity was too low, there was no secondary emission and the tube would not function in any satisfactory manner. As we step up the beam velocity, secondary electrons are emitted, with good tube operation to the point where there are just as many electrons arriving at the screen as are leaving. Beyond this, additional increase in beam velocity will produce no corresponding increase in light output. If it is found, for example, that the number of arriving and emitted electrons at the screen is equal when the second anode potential is 8,000 volts, then raising this voltage to 12,000 volts will produce no greater

light output, despite the higher voltage. This critical potential, at which the ratio of secondary electrons to beam electrons becomes equal to one, is known as the sticking potential. Any further increase in beam velocity will cause the ratio to decrease below one with the result that the screen accumulates sufficient negative charge to effectively reduce its potential to the critical point. No matter what the accelerating potential on the second anode may be, the effective screen potential cannot exceed its critical value. Thus, if the accelerating voltage is 12,000 volts, and the critical potential of the screen is 8,000 volts, then the light emitted from the screen will be on the basis of 8,000 volts, not 12,000 volts.

From the standpoint of screen manufacture it is desirable to have the critical potential as high as possible, certainly above the operating potentials of the tube. The new method of providing an aluminum film corrects many of the defects due to secondary emission difficulties and greatly increases the range of substances which can be used for screen phosphors. Previously, each material had to be carefully examined to determine whether its sticking potential was of a suitable value.

Ion Spots. Another matter of considerable importance is the elimination of the ion spot in tubes using electromagnetic deflection. No matter how carefully a tube is degassed or how well cathode coating is applied, it will be found that ions are present in the electron beam. These ions are either gas molecules which have acquired an electron, or else molecules of the outside coating material of the cathode. These ions possess the same charge as the electrons and are sensitive to the same accelerating voltages. In tubes employing electrostatic deflection, the ions and the electrons are similarly deflected and for all practical purposes may be considered as one. However, when electromagnetic deflection is employed, it will be found that these heavier ions are hardly deflected. As a result, they tend to impinge on the center of the screen in a steady stream and produce a thin film of deactivated material on the area exposed.

When the electrons in the scanning beam pass over this area, no light is produced. To the observer this appears as a dark patch.

The reason for the difference in deflection characteristics of the ion can be obtained from an inspection of the equations governing electromagnetic and electrostatic deflection. For the tube which employes electromagnetic deflection, we have

$$d = \frac{DLeH}{mv}$$

where d = the distance the beam is deflected on the screen,

D = distance from the deflection field to the screen,

e = charge of particle deflected,

H = strength of magnetic field,

v = velocity of travelling particle,

L = length of magnetic field,

m = mass of particle.

For electrostatic deflection, the expression is

$$d = \frac{1}{2} \cdot \frac{V}{E} \cdot \frac{S}{h} \left(D + \frac{S}{2} \right)$$

where d = the distance the beam is deflected on the screen,

V = potential difference between the deflecting plates,

E = forward accelerating voltage of the tube (i.e., second anode),

S = length of the deflection plate,

h = the separation of the deflection plates from each other,

D = distance from the end of the deflection plate to the screen.

With electromagnetic deflection the mass of the deflected particle appears in the equation; in electrostatic deflection it does not. Hence, the ions, because of their greater mass, will receive less displacement than electrons in electromagnetic systems. However, when the mass of the particle does not enter into consideration, ions and electrons receive similar treatment.

There are several methods available for preventing the ions from reaching the screen. First there is the bent electron gun, as

shown in Fig. 8.23. The cathode, when heated, will emit ions and electrons and these will be accelerated to the first and second anodes. However, the cathode is inclined at an angle to the rest of the gun structure and both particles would, if permitted to travel in a straight line, impinge on the side of the electron gun and never reach the screen. However, if a strong magnetic field is placed in the path of the particles, it is possible to alter the
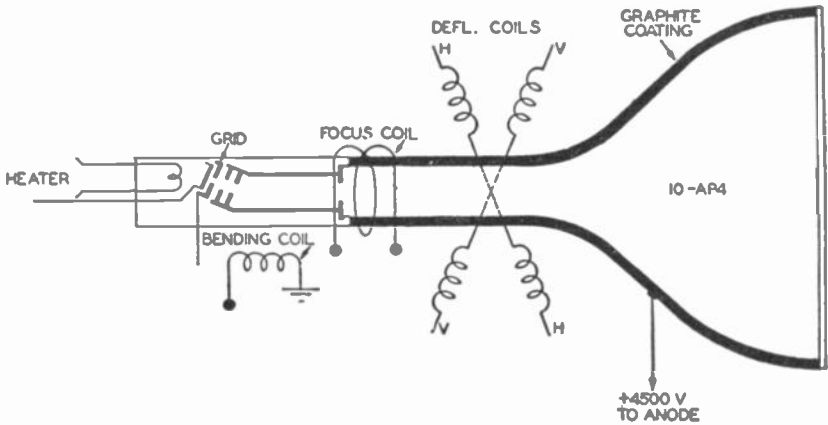
Fig. 8.23. Cathode-ray tube using a bent electron gun and magnetic field to eliminate ion spotting of tube face.

paths of the electrons sufficiently so that they travel toward the screen. The heavier ions, however, are not sufficiently deflected and as a result they hit the side of the electron gun. The magnetic field which causes this separation of ions and electrons is obtained from a small coil placed on the outside of the neck of the tube, above the cathode. The 10AP4 and some other tubes employ this type of ion trap. Within the last few years, the diagonal-cut ion trap shown in Fig. 8.24 has also been developed. Here is how this works.

The electrons and ions are emitted from the electron gun and travel forward. Immediately beyond the control grid there are two accelerating anodes (A and B of Fig. 8.24A) with an oblique gap between them. Because of the presence of this gap, the

electrons (and the ions) are bent in the manner indicated in Fig. 8.24B. With no other forces applied, the electrons and ions would strike anode B. However, if a magnetic field is introduced in the tube at right angles to the electrode, the electrons receive a counter force deflecting them upward and permitting them to continue through the gun. The ions, because of their greater mass and the fact that the magnetic field scarcely deflects them, strike electrode B and are removed from the beam path.

The magnets are clamped on the tube stem in the manner illustrated in Fig. 8.24C. The magnet to the rear is stronger than the forward magnet.

The ion trap may operate electromagnetically, in which case current flowing through the front and rear ion trap coils provides the necessary magnetic field (Fig. 8.24C), or the trap may contain fixed magnets of alnico (Fig. 8.25).

Fig. 8.24.   The diagonal-cut ion trap.

Adjustment of Ion Traps. When an ion trap is used, the following procedure indicates how to adjust the position of the unit properly:

Step 1. Clamp ion trap on tube, the pole piece of the largest magnet (or coil) positioned over the rear electrode A. The focus and deflection coils should be in place, as shown in Fig. 8.15.

Step 2. Turn the television set power on and allow 5 minutes for warm-up. Turn brightness control clockwise until raster appears on screen. Move the ion trap back and forth and around the neck of the tube until maximum light output is produced on the screen.

Step 3. If no position can be found at which a raster appears on the screen, check to make certain that the strongest (and usually the largest) magnet is closest to the tube base.

The third method of preventing ions from reaching the screen is accomplished by the aluminum layer mentioned previously. The depth of penetration of any particle is governed by the relationship,

$$\text{depth of penetration} = \frac{K(Ve)}{m}$$

where K = constant,
Ve = energy of particle,
m = mass of particle.

Since the ion has considerably more mass than an electron, its depth of penetration is less. By properly proportioning the thickness of the metallic screen, the ions are excluded, but the electrons in the beam are able to pass through.

Some of the more common cathode-ray tubes currently in use are listed in Table 8.2, together with their characteristics. The 3NP4 and the 5TP4 are both projection tubes producing an extremely intense image on their screen and requiring accelerating voltages of about 27,000 volts. All the other tubes listed are of the direct-viewing type, so-called because the images produced on their screen are viewed directly by the set

Courtesy G.E.

Fig. 8.25.   A fixed magnet type of ion trap.

user. Under these circumstances the image need not be as intense as that required by projection tubes, and the accelerating voltages used are correspondingly lower. Tubes with 7-inch screens require between 5,000–6,000 volts, while the 10-, 12-, 15-, and 20-inch tubes operate satisfactorily with 9,000–15,000 volts. It is to be noted that in all these tubes the accelerating voltages are far higher than normally encountered, and extreme caution should be exercised when working with them.

TABLE 8.2. Current TV Image Tubes and Their Characteristics.

Type	DIMENSIONS [inches]		Deflection Angle [degrees]	Envelope	Ion Trap Magnet	MAX. DESIGN CENTER VALUES	
	Overall Length	Outside Face Dimension				Anode Volts	Grid No.2 Volts
10BP4	17-5/8	10-1/2	50	Glass	Double	12,000	410
10CP4	16-5/8	10-1/2	50	Glass	None	12,000	410
10EP4	17-5/8	10-1/2	50	Glass	Double	12,000	410
10FP4	17-5/8	10-1/2	50	Glass	None	12,000	410
10MP4	17	10-1/2	52	Glass	Double	12,000	None
12JP4	17-1/2	12	56	Glass	None	12,000	410
12KP4	17-5/8	12-7/16	54	Glass	None	12,000	410
12LP4	18-3/4	12-7/16	54	Glass	Double	12,000	410
12QP4	17-1/2	12-7/16	54	Glass	Single	12,000	410
12RP4	17-1/2	12	56	Glass	Single	12,000	410
12TP4	18-3/4	12-7/16	54	Glass	Double	12,000	410
12UP4	18-5/8	12-7/16	54	Metal	Double	12,000	410
12VP4	18	12-7/16	55	Glass	Double	12,000	None
14BP4	16-13/16	9-11/16 x 12-1/2	70 diag.	Glass	Double	12,000	410
14CP4	16-3/4	9-11/16 x 12-1/2	70 diag.	Glass	Single	14,000	410
14DP4	16-3/4	9-11/16 x 12-1/2	70 diag.	Glass	Double	14,000	410
14EP4	16-1/2	9-11/16 x 12-1/2	70 diag.	Glass	Single	14,000	410
14FP4	16-1/8	9-11/16 x 12-1/2	70 diag.	Glass	Single	14,000	410
15AP4	20-1/2	15-1/2	57	Glass	None	15,000	410
15CP4	21-1/2	15-1/2	57	Glass	Double	15,000	410
15DP4	20-1/2	15-1/2	57	Glass	Single	15,000	410
16AP4	22-1/4	15-7/8	53	Metal	Double	14,000	410
16CP4	21-1/2	15-7/8	52	Glass	Double	15,000	410
16DP4	20-3/4	15-7/8	60	Glass	Double	15,000	410
16EP4	19-5/8	15-7/8	60	Metal	Double	14,000	410
16FP4	20-1/4	16-1/8	62	Glass	Single	16,000	410
16GP4	17-11/16	15-7/8	70	Metal	Single	14,000	410
16HP4	21-1/4	15-7/8	60	Glass	Double	14,000	410
16JP4	20-3/4	16-1/8	60	Glass	Double	14,000	410
16KP4	18-3/4	11-1/2 x 14-3/4	70 diag.	Glass	Single	16,000	410
16LP4	22-1/4	15-7/8	52	Glass	Double	14,000	410
16MP4	21-3/4	16-1/8	60	Glass	Double	14,000	410
16QP4	19-9/64	11-1/2 x 14-3/4	70 diag.	Glass	Double	16,000	410
16RP4	18-3/4	11-1/2 x 14-3/4	70 diag.	Glass	Double	14,000	410
16SP4	17-5/16	15-7/8	70	Glass	Double	14,000	410
16TP4	18-1/8	11-1/2 x 14-3/4	70 diag.	Glass	Single	14,000	410
16UP4	18-1/8	11-1/2 x 14-3/4	70 diag.	Glass	Single	15,000	410
16VP4	17-3/16	15-7/8	70	Glass	Single	15,000	410
16WP4	17-3/4	15-7/8	70	Glass	Double	15,000	410
16XP4	18-3/4	11-1/2 x 14-3/4	70 diag.	Glass	Double	15,000	410
16YP4	17-5/16	15-1/8	70	Glass	Single	14,000	410
16ZP4	22-1/4	15-7/8	52	Glass	Single	14,000	410
17AP4	18-5/8	12-1/4 x 15-3/8	70 diag.	Glass	Single	16,000	410
17BP4	19-1/4	12-1/4 x 15-3/8	70 diag.	Glass	Single	16,000	410
17CP4	18-1/2	12-1/4 x 15-15/16	70 diag.	Metal	Single	16,000	410
19AP4	21-1/2	18-5/8	66	Metal	Single	19,000	410
19DP4	21-1/2	18-7/8	66	Glass	Double	19,000	410
19EP4	21-1/8	13-3/16 x 17-1/16	70 diag.	Glass	Double	19,000	410
19FP4	22	18-7/8	66	Glass	Double	19,000	410
19GP4	21-1/4	18-7/8	66	Glass	Single	19,000	410
19JP4	20-13/16	13-3/16 x 17-1/16	70 diag.	Glass	Single	18,000	410
20BP4	28	20	54	Glass	None	20,000	410
20CP4	21-7/16	14-15/16 x 18-11/16	70 diag.	Glass	Single	18,000	410
20DP4A	21-3/4	14-15/16 x 18-11/16	70 diag.	Glass	Single	18,000	410
22AP4	22-7/8	21-11/16	70	Metal	Single	19,000	410
24AP4	23-5/8	24-1/8	70	Metal	Single	16,000	410
30BP4	23-9/16	30-1/8	90	Metal	Single	30,000	410

Electrostatic deflection is feasible only in 7-inch (or smaller) screen tubes. In larger tubes, a considerable deflecting voltage is required if deflection plates are employed. Since it is cheaper to develop high currents than high voltages, the trend has been toward electromagnetic deflection. This trend has been further intensified by the shortening of the overall length of the tube.

In electromagnetic deflection tubes used before the war, the deflecting angle of the electron beam was 40 degrees. (See Fig.
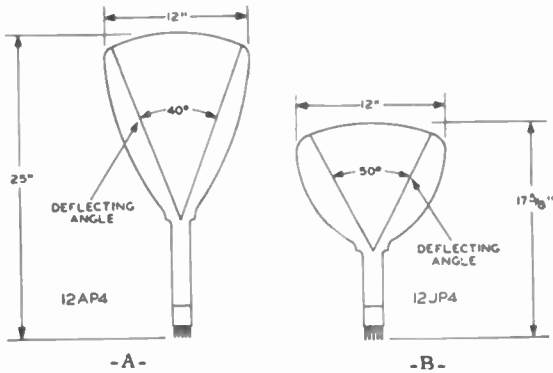
Fig. 8.26. (A) Pre-war television tubes. (B) Current television tubes. By increasing the deflecting angle, the overall tube length has decreased.

8.26.) In recent tubes, the deflecting angle has been increased to 50 degrees and more. The increased deflecting angle results in a shorter overall length (8 inches smaller for 12-inch tubes) and therefore permits the use of relatively large screen tubes in reasonably sized table model receivers. True, the increase in deflecting angle means greater deflecting currents, but this is readily met with only a slight increase in cost. Electrostatic deflection, on the other hand, would entail a significant rise in cost. Further, the use of electromagnetic deflection and focusing simplifies the internal construction of the cathode-ray tube. This may not lower the overall cost of the set because deflection and focusing coils are needed, but it does lower the replacement cost of the cathode-ray tube.

In the small 3NP4 and 5TP4 tubes, the deflection is electromagnetic instead of electrostatic for several reasons.

1. The second anode accelerating voltage is 27.000 volts while the first anode voltage is 6,000 volts. Since each tube is small, the separation between the deflection plates (with their average potential of 27,000 volts) and the first anode would be small, necessitating special precautions to prevent corona and arc discharges.

2. The system required to develop the extremely large deflection voltages needed with a 27,000-volt accelerating potential would involve a cost entirely out of proportion to the cost of the rest of the set. Special tubes, 27,000-volt isolating condensers, and additional amplifying stages are only some of the major items necessary.

3. Electromagnetic deflection not only permits a simplification in tube design, but requires no more power than that needed by a conventional 10-inch tube.

Special Cathode-Ray Tube Elements. While all cathode-ray tubes used for television take the same basic form, elements of all are not exactly similar. This is especially true for the larger screen tubes, say the 10- and 12-inch tubes. The simplest form that an electrostatically operated tube may take, which can also be called the basic form, is illustrated in Fig. 8.7. The elements follow in order: cathode, control grid, first and second anodes, and deflecting plates. An example of this type of tube is the 5JP4. Note that with the relatively greater number of connections required on a cathode-ray tube, the base contains eleven pins. Practically all cathode-ray tubes employ an 11- or 12- or 14-pin socket.

The use of colloidal graphite or aquadag has been mentioned before. In all tubes it connects electrically to the second anode internally. When the second anode voltage is high, say 9,000 volts or more, it is applied to the tube through an external cap connection on the side of the tube. When the voltage is not too high, application is made through a base pin.

Seven-inch electrostatic deflection tubes generally incorporate one additional element not present in Fig. 8.7. The new element is placed between the control grid and focusing (first) anode.
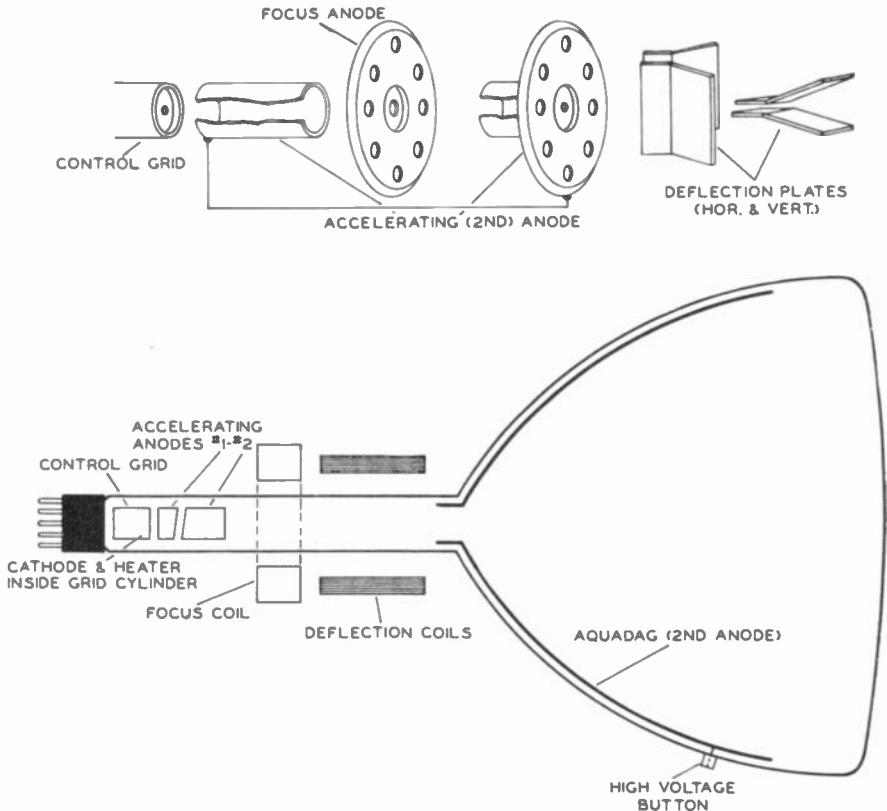
FIG. 8.27. (A) Modified construction of electron gun in 7 inch electrostatic deflection tubes. (B) Internal construction of 10BP4 electromagnetic deflection tubes.

Internally, it is connected to the accelerating (or second) anode. (See Fig. 8.27A.) Note that the new element is a small cylinder, whereas the focus and accelerating anodes are large, circular discs. The introduction of this new element acts to reduce interaction between beam focus and voltage variations at the control grid. The voltage variations at the control grid are brought

about by changing the setting of the brightness control or by
the incoming signal, and it is most desirable that beam focus be
independent of either of these changes.

When the deflecting and focusing functions of a tube are
accomplished magnetically, the internal structure is modified

Courtesy RCA

Fig. 8.28A. A 10BP4 television image tube.

accordingly. Thus, for the 10BP4 (Fig. 8.28A), the control grid
is followed by anode No. 1 (also known as grid No. 2) with 250–
400 volts, and this, in turn, is followed by anode No. 2, with 9,000
volts. (See Fig. 8.27B.) The aquadag coating, which is also
connected to anode No. 2, receives the 9,000 volts through a cap
on the side of the tube. The deflection, focus, and ion trap coils
would then be mounted over the neck of the tube.

A recent innovation in cathode-ray tube design is the metal-cone tube. This tube, Fig. 8.28B, contains a metal-cone envelope, producing a final product which weighs approximately 60 per cent less than an all-glass tube. When metal-cone tubes

Fig. 8.28B. A metal-cone picture tube.

are used, it is important to keep in mind that the metal cone itself serves as the second anode, from 9,000 volts upward, and therefore should not be touched while the receiver is in operation. After the power has been turned off, the metal cone should be grounded before human contact is made with it.

Rectangular Screens. It had been recognized for many years that a rectangular image on a circular screen is wasteful not only of screen area, but of cabinet space as well. The obvious solution was a rectangular screen dimensioned in the standard

4 to 3 ratio of the transmitted image. Until quite recently, manufacturing difficulties and obstacles presented by the rectangular tube shape prevented their mass production, but these have now been overcome and rectangular tubes are widely used. A rectangular picture tube, the 20CP4, is shown in Fig. 8.29.
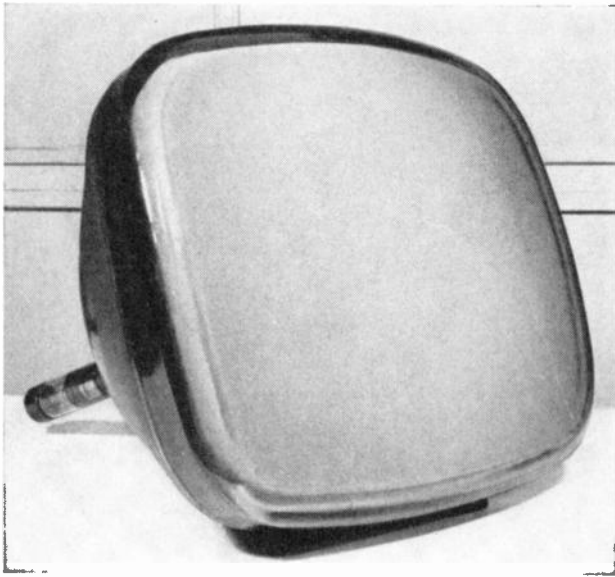
Fig. 8.29. A 20-inch picture tube.

To have the screen size numbering system of rectangular tubes conform to that employed for circular screens, it is standard procedure to use the diagonal length of the rectangular screen as the screen size. Thus, the 20CP4 shown in Fig. 8.29, has a diagonal length (from one corner to the opposite corner) of 20 inches. The reader can, from elementary geometry, then figure out that the screen sides will be 12 inches high and 16 inches wide.

Nomenclature of Cathode-Ray Tubes. In an effort to standardize the nomenclature used for cathode-ray tubes, the following system has been adopted:

1. The first number, whether of one or two digits, will represent the diameter of the screen.

2. The letter P, with the number following it, will indicate the type of fluorescent screen that the cathode-ray tube contains.

3. Any other letters found between the first number and P will be used to distinguish between tubes that may be just as large as each other, with identical screens, but possessing other differences. These differences may consist of the addition of another element (for example, an accelerating grid), another shaped-bulb, another tube socket, etc.

4. The letters A or B, when found following the screen type (P4), indicate that the screen glass of the tube is either of special construction or has been specially treated to help improve picture contrast. When the letter A is used (as in 16HP4A), it indicates that a special light-absorbing glass (known commercially as Teleglas), is being used for the screen plate. When the letter B is found, it indicates that the screen face has been frosted.

With the preceding rules as a guide, the 15AP4 tube would be approximately 15 inches in diameter, with a P4 fluorescent screen. There are different types of screens, depending upon the purpose to which the cathode-ray tube is put. In television, a white trace is desirable with a persistence that might be termed medium. This would be labeled P4. For oscillographic work, either a P1 or a P2 screen, having a green retrace, might serve better. Green is used here, in preference to white, because it gives a brighter trace with the same accelerating potentials. This feature is desirable as it is often necessary to observe oscilloscopes where the surrounding illumination is high. For long periods of viewing, however, white results in less strain on the eyes.

The P1 trace has a shorter persistence than the P2 trace, the latter being employed in oscilloscopes where transients are to be viewed. The P5 fluorescent coating is especially suited where

photographs are made of the pattern on the viewing screen. The radiation given off by this fluorescent screen is blue in color and of short persistence. Other types of screens have different properties that make them suitable for other particular applications (see Table 8.1).

Power Supplies in Television Sets. The power supply system in a television receiver is different from those with which we are
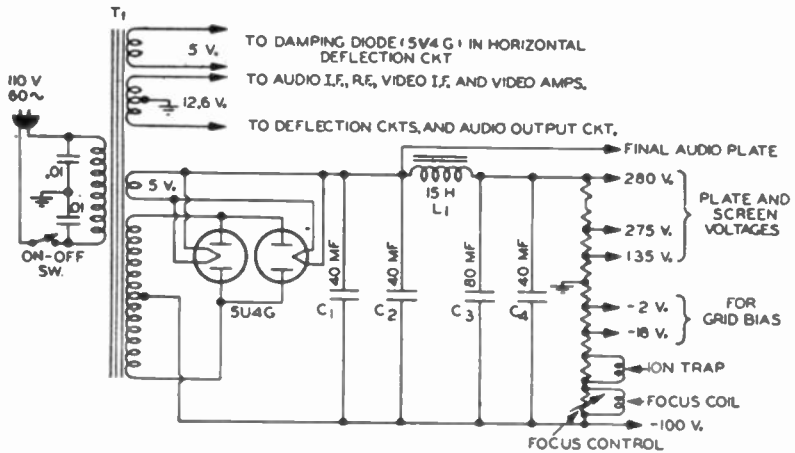
FIG. 8.30. A complete power supply for a television receiver.

familiar in ordinary sets. This is due, in part, to the higher voltages required for the operation of the cathode-ray tube. In a television receiver we are confronted with the task of supplying 400 volts to the plates of the ordinary tubes, while the picture tube must have voltages that range up to 30,000 volts (for projection tubes).

It is possible to construct one supply for both or to employ two separate supplies. For the latter case, one would be used for the image tube and the other for the remainder of the set. If one supply is decided upon, it must be capable of an output of 400 volts with 200 to 300 ma for the ordinary tubes and up to 30,000 volts at 1 ma for the picture tube. In one case we have low voltage, high current, while in the other instance there is

the opposite combination. For one composite unit, then, there would have to be 30,000 volts available with 1 ma and 400 volts at 300 ma. The unit would be bulky, expensive, and quite out of proportion with other sections of the set.

A more effective solution is two separate supplies. The low voltage, high current unit could then take its familiar form as in Fig. 8.30. The filter choke is the usual 15–30 henrys and the electrolytic condensers are rated at 30–80 μf, 500 volts. For the rectifier tube, operating full-wave, any of the following familiar tubes may be employed: 5U4, 5T4, 5X4, and 5Z3. One bleeder resistor (or several in series) placed across the output allows various voltages to be tapped off. It likewise provides better voltage regulation.

If negative voltages are desired, as they are in many television circuits, then the ground tap would be placed at a suit-

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Fig. 8.31.   A selenium rectifier.

able point along the bleeder chain, as in Fig. 8.30. Well-filtered d-c is almost an absolute necessity in television circuits, and hence a greater number of filtering condensers are used, both in the power supply itself and throughout the rest of the circuit.

Recently, small selenium rectifiers have been used in increasing numbers in the low-voltage supply of smaller television receivers. A typical selenium rectifier is shown in Fig. 8.31. These units take the place of vacuum-tube rectifiers and offer the advantages of compactness, reduced power consumption due to absence of filament power for the rectifier, and generally better voltage regulation than comparable rectifier tubes. At present, they are limited in the amount of reverse voltage they can withstand and the current they can safely pass. Because of these two limitations, selenium rectifiers are employed generally only in the smaller television receivers where the current requirements are not too high.

The rectifiers have two distinct poles, positive and negative.

They correspond to the plate and cathode of the vacuum tube. The positive side, indicated by a red dot of paint, or a plus sign, is equivalent to the cathode. The negative side, indicated by a minus sign or yellow dot, functions as the plate.

A typical application of the selenium rectifier to a television receiver is shown in Fig. 8.32. The selenium rectifier S_1, by itself,

FIG. 8.32. A transformerless low-voltage power supply using selenium rectifiers.

provides one output voltage of 120 volts. The rectifier is also used in combination with 1/2-25Z6 (V_1) to form a voltage doubler having an output voltage of 250 volts. Finally, a third tube, V_2, in combination with the selenium rectifier and V_1, forms a voltage tripler to provide an output voltage of about 375 volts. In transformerless sets, voltage doubling and tripling are necessary in order to achieve the 300–400 volts needed to drive the horizontal and vertical sweep systems. Selenium rectifiers cannot be used in place of V_2 and V_1 because of the greater voltages in these circuits. A second selenium rectifier, S_2, is connected to provide a negative output voltage of 140 volts.

In sets of this type, filament power is obtained by connecting

the filaments of the tubes in series across the line.   This is indicated also in Fig. 8.32.

To use the 60-cycle a-c directly for the development of high voltages, we would proceed a little differently.   Since the voltage required is very high, a half-wave rectifier is used.   For a full-wave rectifier to give the same voltage output, twice as many turns would be necessary on the transformer.   Although each half of the secondary will now carry half as much current, permitting the use of a smaller size wire, the cost of the transformer would still be higher.   In addition, it is found that the filtering problem is not appreciably increased if the rectified current contains a 60-cycle ripple instead of 120 cycles, obtained from a full-wave rectifier.   The reason is the low value of current drain.   Hence, half-wave rectification is almost always employed.

Ordinary rectifier tubes cannot be employed in the cathode-ray tube power supply because of the high inverse peak voltage.   The 5-volt tubes listed will withstand only about 1,600 volts, much too low for the present purpose.   Tubes suitable are the 2X2, 2Y2, 2V3, or 879, to mention a few.   These have high inverse peak voltage ratings, generally one and one-half to two times more than required.

The filtering section of the high-voltage power supply, if built along conventional lines, would also become too expensive.   Electrolytic condensers, designed to withstand these high voltages, would be large, costly units.   It has been found more economical to solve the filtering problem with small condensers and large filter chokes (or resistors) rather than with large condensers and small chokes, as in low-powered units.   The condensers used range in value from 0.01 μf up to 1 μf, with a working voltage dependent upon the output of the transformer.   The choke need not be unnecessarily large, despite the high inductance, because the current flowing is small and fine wire can be used.   In many sets, a series resistor rather than a choke is used.

In addition to the single pi-type filter, a bleeder resistor is connected across the circuit.   As before, this acts to stabilize the voltage output of the power supply and permit various taps

to be made; for example, for the focusing anode and the cathode
brightness control.   The value of the bleeder resistor depends
upon the current drain of the several electrodes of the tube.
Since the current drain is small, and the voltage large, the re-
sistance will be correspondingly large, generally several megohms
in value.   Due to the small current, a low wattage rating will
suffice.

Whereas one tapped resistor might conceivably be used, this
is never the case.   It is more economical to insert small resistors

FIG. 8.33. A high-voltage power supply designed along conventional lines.

in series, each with 1 watt rating. A disadvantage of using one
resistor results from the tendency of a carbon resistor to develop
an internal arc if subjected to this high voltage. With several
resistors, the voltage across each is proportionately less and arc-
ing does not appear. Potentiometers of suitable value giving
the desired voltage variation are used for the focusing control,
the brightness control, and the horizontal and vertical position-
ing controls. A typical high voltage supply evolved by the fore-
going design is shown in Fig. 8.33.

R.F. Power Supplies. As we increase the value of the voltage
desired from the high-voltage supply, we find that the cost and
the bulkiness of the unit increase, too, but at a much greater rate.
In an effort to evolve a more economical solution, research was
directed toward other avenues of approach. From these investi-
gations, two power supplies have been developed which appear

to offer at least partial relief from the cost and bulkiness of the conventional supply. One unit develops R.F. oscillations, sustained by a relatively small 60-cycle power supply. The output of the R.F. oscillator is then rectified, and the high-voltage thus is obtained. The other unit obtains its voltage from the inductive kick-back of the horizontal deflection coils.

The first type or R.F. power supply is shown schematically in Fig. 8.34. A 5V4-G full-wave rectifier operating from the
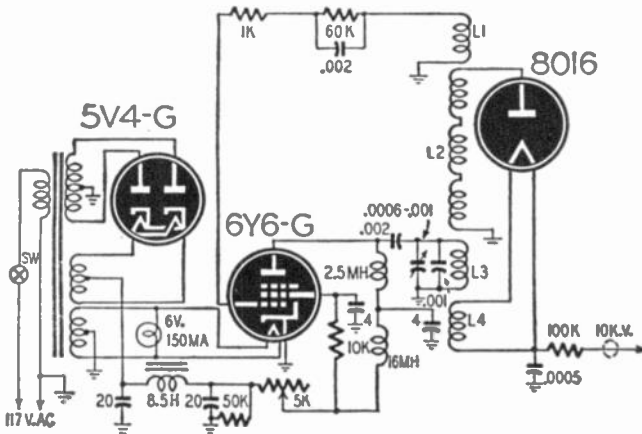
FIG. 8.34. An R.F. power supply. The filament of the 8016 rectifier also operates on R.F.

60-cycle line supplies the 300–350 volts necessary to drive the 6Y6-G oscillator tube. The oscillator itself is a conventional tuned plate, untuned grid tickler coil arrangement. Frequencies of oscillation vary anywhere from 85 kc to 300 kc. The secondary coil, L_2, which contains more turns than the tuned primary, steps up the low oscillator voltage to approximately 10 kv. Voltage step-up is set at one-half maximum obtainable in order to provide high efficiency and good voltage regulation.

The feedback coil, L_1, to sustain oscillations is coupled to L_2, instead of L_3 directly, to obtain greater stability. The oscillator tube is biased for class C operation and hence has relatively low plate voltage loss. This is in the interests of efficiency. The

6Y6 (or 6L6) beam power tube is capable of developing 15 watts of power with 80 per cent efficiency at 350 volts. The screen-grid voltage is made self-regulating by a series resistor. Screen-grid voltage, under operation, varies from approximately 65 volts at no load to 120 volts at full load.
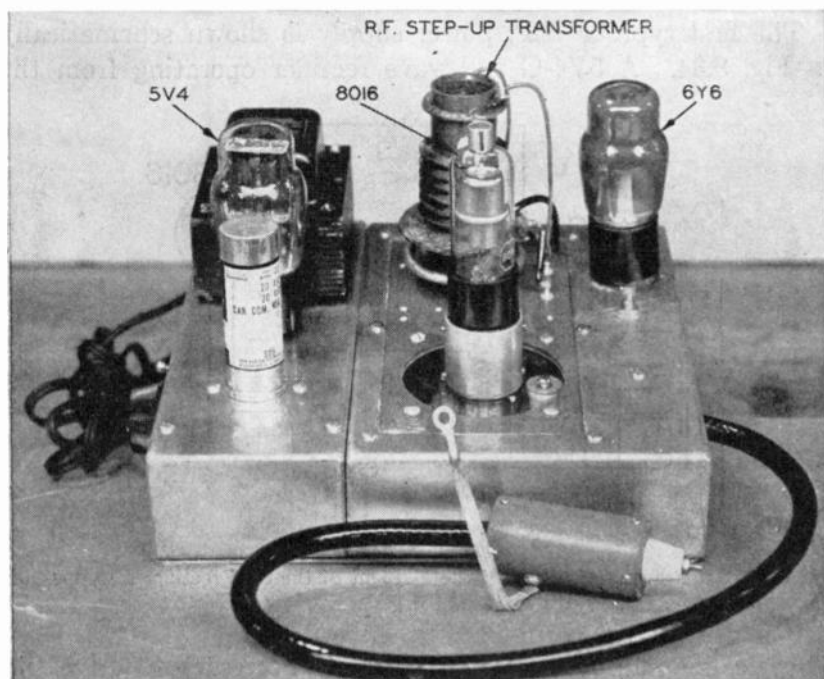
Fig. 8.35A. The entire R.F. power supply.

The high-voltage rectifier is a half-wave unit employing a specially designed 8016 tube. Standard high-voltage rectifiers, such as the 2X2, 2V3-G, or 879 require considerable heater power. The 8016, however, takes only .25 watts and can obtain its power directly from the oscillator. At the high frequency of the oscillator, a 500-$\mu\mu$f condenser and a 100,000-ohm resistor provide sufficient filtering. A photograph of the entire R.F. unit is shown in Fig. 8.35A; in Fig. 8.35B the high-voltage step-up transformer is shown separately.

The Inductive Fly-back Power Supply. The second high-frequency power supply is based on an idea conceived by P. T. Farnsworth about 1930. Only recently, however, has a good practical model been evolved. The voltage induced in any inductance is governed by the relationship

$$e_L = -L\frac{di}{dt}$$

As the time interval, dt, is made smaller, e_L becomes greater. In the horizontal deflection coils, the retrace interval dt is on the order of 7 microseconds and a large voltage is produced. By rectifying the pulse, voltages to 30 kv can be obtained.

A circuit schematic of an "inductive kick" or reaction power supply is shown in Fig. 8.36. The horizontal discharge tube, V_{120B}, is actuated by a positive pulse applied to its grid and discharges condenser C_{179}, 680 $\mu\mu$f. At the end of the positive pulse, the discharge tube lapses back into cut-off and the condenser C_{179} starts to charge for the next cycle again. The deflection waveform produced by C_{179}, R_{210} and R_{187} in series will, when applied to the deflection coils, produce a linear left-to-right motion of the electron beam across the face of the screen and a

Fig. 8.35B. The high-voltage step-up transformer.

rapid retrace. The output tube, V_{126}, is the driving tube for the deflection transformer, the high-voltage rectifier, the deflection coils and the damping tube. The output tube, a beam tetrode of the 807 type, is controlled by the deflection voltage which it receives from the discharge tube.

The shape of the deflection wave applied to the grid of V_{126}

is shown in Fig. 8.37A. During the interval labeled A–B, this voltage is rising, causing the current through the horizontal output transformer to rise steadily, and forcing the beam to move across the screen of the image tube at an even rate of travel.
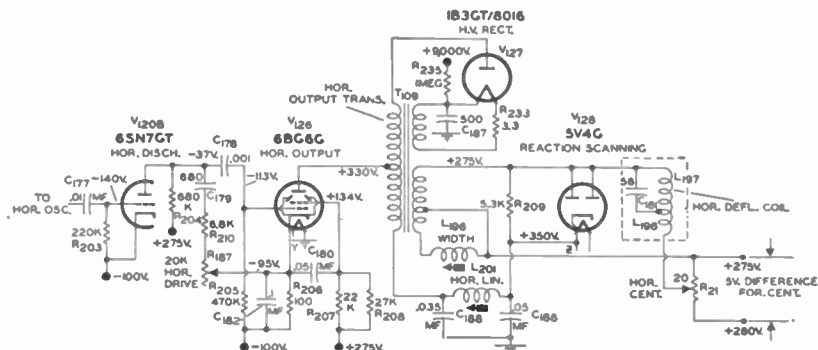
FIG. 8.36. A circuit schematic of an "inductive kick" or reaction type of high-voltage power supply.

At point B, the grid voltage drops sharply, cutting off the tube's plate current. The magnetic field, which has been steadily building up in the output transformer, collapses quickly, inducing a large positive pulse of voltage in the primary winding. (See Fig.
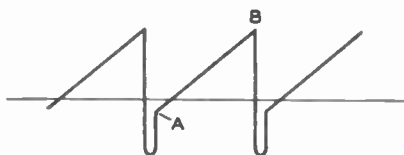
(A) Grid voltage at horizontal output tube.

(B) Induced voltage in primary winding of horizontal output transformer.

FIG. 8.37A and B. Voltage waveforms in horizontal amplifier circuit of Fig. 8.36.

8.37B.) The plate of the 8016 rectifier is connected to the top of the primary winding, and the positive pulse of voltage is rectified, filtered, and fed to the second anode of the cathode-ray tube. Since 15,750 such pulses appear each second, adequate filtering can be achieved using a single 500-$\mu\mu$f condenser. Fila-

ment power for the 8016 is obtained from a 2 to 3 turn secondary winding on the same transformer. A photograph of the output transformer is shown in Fig. 8.37C.

In both the R.F. and fly-back methods of developing high voltages, failure of the low-voltage power supply will automatically
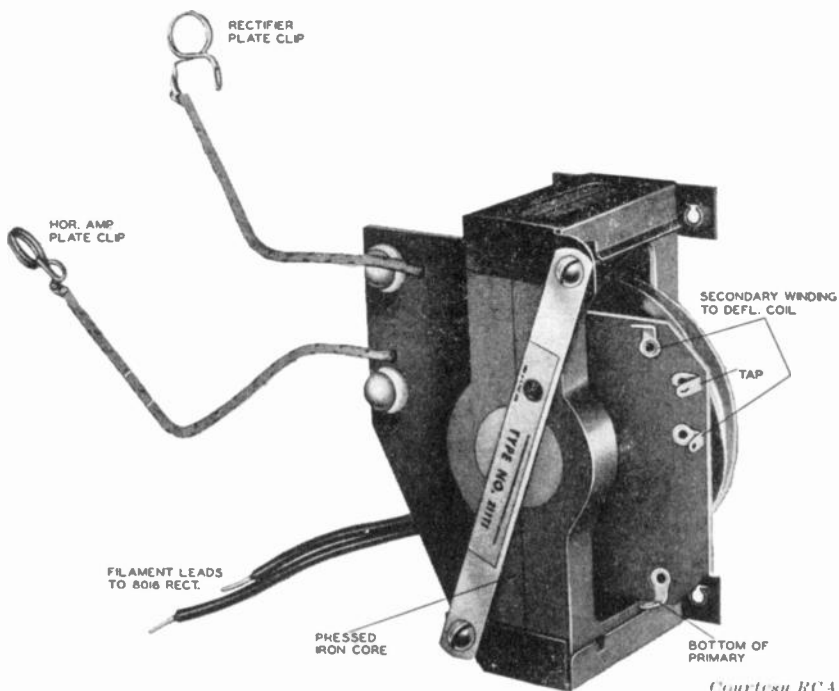
FIG. 8.37C. The horizontal output transformer in the high-voltage fly-back system.

remove the high voltage from the circuit. As an added precaution in the fly-back system, failure of the horizontal sweep system to develop the proper deflection wave will have the same effect. This eliminates the possibility of a stationary spot appearing on the image screen, with subsequent burning and insensitizing of the screen.

Beam Relaxor Circuit. A method for developing high voltage which is similar in some respects to the fly-back method is

employed in the circuit shown in Fig. 8.38. It consists of a horizontal output stage which is an oscillator, driving the horizontal deflection coils directly and, during beam retrace, developing the necessary high voltages by the inductive fly-back method.

The 6L6 horizontal output tube operates as an oscillator having its grid connected to the primary of the horizontal output

Fig. 8.38. The Beam-Relaxer circuit.

transformer and its plate attached to a tap on the secondary winding. The screen grid receives negative horizontal sync pulses from the preceding sync clipper tube. These pulses lock-in the oscillator so that its frequency is kept in step with the incoming sync pulses.

To start the analysis of the circuit, assume that the tube has just been cut off, due either to the oscillator operation or the arrival of a negative sync pulse at the screen grid. (When the system is operating properly, the two actions will occur simultaneously.) With the stoppage of plate current, the magnetic flux of the transformer collapses, inducing a high negative poten-

tial on the grid of V_1 and a high positive potential on the plate. The voltage reversal brought about by the field collapse is also applied to the horizontal deflection coils, causing the beam to retrace rapidly.

After the field has collapsed completely, the high negative potential on the grid of V_1 decreases and the tube begins to conduct again, the rate of current flow being determined by the plate resistance of the tube and the inductance of the plate winding of the transformer. The plate resistance of the tube is controlled by the bias on the grid and this, in turn, is a function of the resistance in the cathode circuit. Hence, by varying the cathode resistance, we can control the period of oscillation of V_1. The variable resistor is thus a "hold control."

The magnetic flux on the transformer starts building up now, and a positive potential is induced in the grid winding, thereby aiding the current growth throughout the circuit. Because of the positive grid voltage, plate current flow increases until the tube reaches saturation. As current saturation is approached, the amount of positive induced grid voltage begins to decrease until a point is reached at which the voltage in the cathode circuit is sufficiently high to overcome the positive grid voltage and force the tube into cut-off. If the oscillator is properly synchronized, this will also be the moment for the arrival of a negative sync pulse to the screen grid. We are now back to our starting point, completing one cycle of oscillation.

A 6L6 purposely is used for the oscillator because its plate current-plate voltage characteristics show a sharp "knee" or bend when plate current saturation is reached. This causes the tube to attain saturation sharply, cutting off the oscillator sharply and initiating a rapid retrace. A tube not of the beam power type would operate in this circut, but since its characteristics do not possess this sharp "knee," the retrace time would not be so rapid and the induced voltage not so great.

Scanning voltages which drive the horizontal scanning coils are obtained from the primary winding of the output transformer. Also across this winding are connected R_1, L_1, and C_1

which affect the horizontal linearity and which are designed to damp out any shock-excited oscillations that might develop in this winding. The potential developed across cathode resistor R_2 is a function of the average plate current and may be used for centering the image horizontally on the screen. One side of the deflection coil is connected to the movable arm of R_2, while the other end connects to a fixed tap. We can change the relative voltage polarity between these two points from positive to negative; in this manner, we can shift the beam to the right or left, as desired.

The incoming sync pulses may be obtained directly from the video signal itself, or an automatic frequency control network of a type to be described in Chapter 10, may be used.

Two 8016 high-voltage rectifiers are connected across the full secondary of the transformer, using the high surge of voltage during retrace to develop an output voltage of 9,000 volts. In the previous circuit only one such rectifier was used, the reason being the greater driving voltage developed by the horizontal output amplifier and the larger number of turns on the output transformer.

To understand how the two rectifiers use a lower voltage (here about 6,000 volts) to provide an output potential of about 9,000 volts, let us analyze the circuit operation using the equivalent diagram of Fig. 8.39. During the retrace interval, the voltage developed across the full secondary of the output transformer rises sharply to 6,000 volts. This causes V_2 to conduct, and C_2 charges to 6,000 volts (after the first few cycles) with the polarity as indicated. In the longer interval between retraces, C_2 and C_3 are seen to be essentially in parallel with each other through the secondary winding and R_3, R_4, and R_5. Hence, C_3 also charges up to the full 6,000 volts.

At the next retrace interval, 6,000 volts once again appear across the transformer. If we pause at this moment and add up the voltages existing between points A and B, we see that the transformer voltage and the voltage across C_3 are equal to

12,000 volts. Opposing this are the 6,000 volts across C_2. Thus, between points A–B there are 6,000 volts with point A positive with respect to point B. This potential is applied to V_3, causing this tube to conduct, and C_4 charges to 6,000 volts with the polarity indicated. If now we use the voltages across C_2 and C_4, we can obtain an output voltage of 12,000 volts. Because of the presence of the four load resistors, the nominal output voltage is reduced to 9,000 volts.
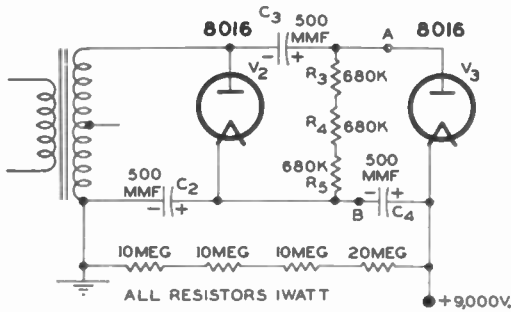
FIG. 8.39. Equivalent circuit of the high-voltage rectifier network in Fig. 8.38.

We could, by adding another tube to this combination, raise the output voltage (at no load) another 6,000 volts. The line of reasoning follows the foregoing discussion exactly.

Projection Television Systems. A common complaint from persons who first witnessed television programs of a few years back was directed at the small viewing screen. Observation, if carried on for any appreciable length of time, proved fatiguing to the eyes. To reduce the eyestrain to a minimum, attention was directed toward increasing the size of the image. The 3- and 5-inch screens were gradually enlarged, passing successfully through 7- and 10-inch models and finally arriving at the 16-, 17-, and 20-inch tubes now commercially available.

Whether the trend will continue further is problematical, for increased tube size is accompanied by difficulties in manufacture, additional costs, and greater danger to life should anything happen structurally to the tube. Diameters of 30 inches prob-

ably represent the practical limit for direct viewing television screens.

For most purposes, television receivers with screens 9 inches or greater provide sufficient area for forming bright, well-defined images. These may be viewed for several hours at a time without placing too great a strain upon the observer. Admittedly, however, larger images, say 16 by 20 inches, would be even more desirable, and to date two projection systems have been designed.
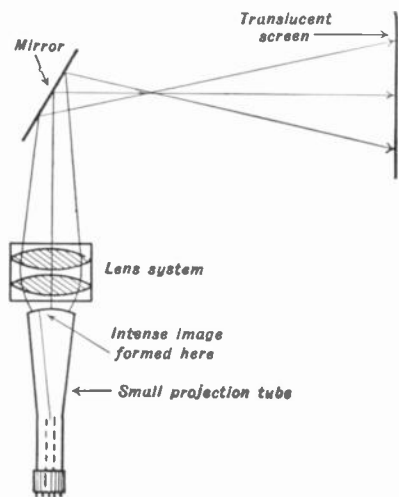
Fig. 8.40. Projection system to obtain large images.

In one method, the image is formed on the screen of a small cathode-ray tube and then enlarged, using several projection lenses similar to those employed in motion-picture equipment. (See Fig. 8.40.) The chief disadvantage of this method is its poor efficiency. Specially treated lenses, having a large aperture and good transmission of light, deliver to the viewing screen only about 6 per cent of the light present on the screen of the cathode-ray tube. Consequently, even with intense images developed on the cathode-ray screen, the final image is bound to be dim and difficult to see.

As an illustration, consider the 5-inch projection tube, with its 3- by 4-inch image. The total area here is 12 square inches. If the image is enlarged to fill a screen 15 by 20 inches, the total area becomes 300 square inches, and the light which was originally concentrated in an area of 12 square inches is now spread over an area of 300 square inches. The brightness is thereby reduced by the ratio of 300/12 or 25 to 1. This, of course, assuming 100 per cent transmission. If now we take

into account that the transmission efficiency is only 6 per cent, then the brightness is decreased by a factor of 400 to 1 rather than 25 to 1.

Increasing the brightness of the image developed on the tube screen would be one partial solution to this problem, but the cost involved can readily place the equipment in the same expensive class as large cathode-ray tubes. A second approach to the problem, and one which appears to have greater possibilities, is to increase the efficiency of the lens system.

The first attempt in this direction was tried with the lens system shown in Fig. 8.40 and several difficulties were immediately encountered. In order to capture as much light as possible being emitted from the screen, the lens should be as large as possible. However, as the lens becomes larger, the number of distortions or "aberrations" multiply. (There are principally six aberrations that must be corrected; namely, chromatic aberration, spherical aberration, coma, astigmatism, curvature of field, and distortion.) To correct for these aberrations in a fairly satisfactory manner, we require several lens elements, say possibly 3. However, in a wide-angle system, more than 3 lens elements should be used. As more elements are added, the cost of the system rises. The greater the number of lenses in a system, the greater the total loss of light at the intersecting surfaces and the lower the overall efficiency. Finally, with large lenses, the elimination of some aberrations is accompanied by a greater accentuation in others.

This was the impasse that faced television engineers until the adaptation of the Schmidt reflective optical system to television. Schmidt, an instrument maker at the Hamburg, Germany, Observatory, invented his optical system in 1931. The system, originally designed for astronomical telescopes, was built around a large spherical reflecting surface or mirror. (See Fig. 8.41.) Use of this type of reflecting surface offered several immediate advantages:

1. Mirrors are completely free of chromatic aberrations.
2. Under comparable design of focal distance and diameter, a

spherical mirror has a spherical aberration one-eighth that of a single lens. The need for correction is still present, but the problem is now considerably simplified.

3. By placing a small aperture or opening at the center of curvature of a spherical mirror, all the monochromatic aberrations (except spherical aberration) are eliminated.

We are thus left with essentially two problems to solve. One is spherical aberration and the other is curvature of the field.
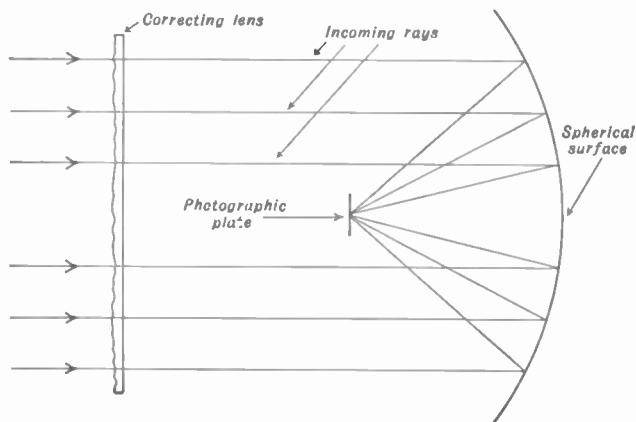
FIG. 8.41.   Original arrangement of the Schmidt lens system.

The latter is quite simply resolved by curving the screen of the projection tube to suit the curvature of the mirror. To eliminate spherical aberration, a special correcting lens is employed. The correcting lens introduces into the beam an amount of spherical aberration which is equal to that introduced by the mirror but is opposite in sign. As a result, the two neutralize each other, effectively removing the last great defect of the spherical mirror. With this lens in place, we have optical system possessing an efficiency of 25 per cent with magnification of 5. Compare this to the meager 6 per cent obtainable using the refractive lens system of Fig. 8.40.

For use in television receivers, there are several modifications of the original Schmidt lens system as designed for astronomical

use. In RCA and G.E. projection receivers, the optical mirror is mounted at the bottom of the cabinet with its axis vertical, projecting the image straight up and onto a flat mirror inclined at 45 degrees to the beam of light and throwing the image on
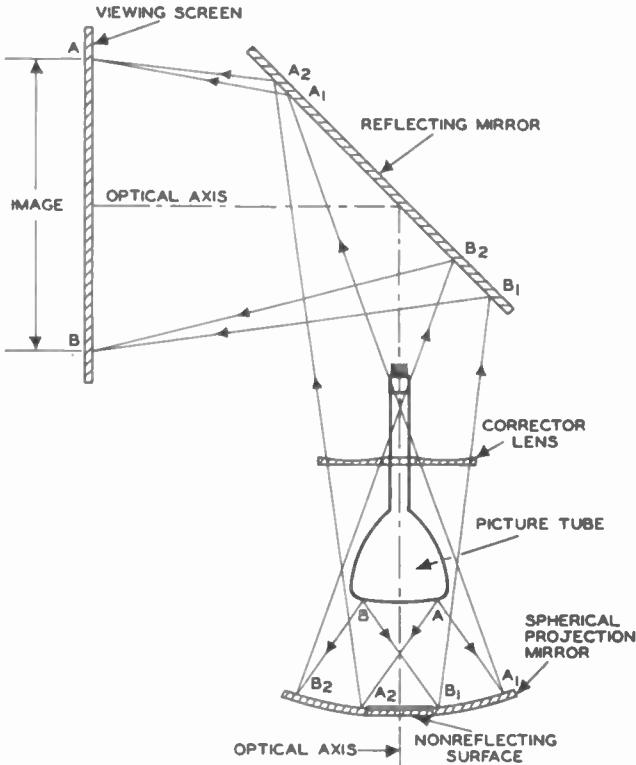
FIG. 8.42A. The adaptation of the Schmidt optical system to G.E. and RCA projection television receivers.

a translucent screen. (See Fig. 8.42 A and B.) The throw or distance between the correcting lens and the viewing screen will depend upon the diameter of the correcting lens and the spherical mirror. To increase the size of the projected image, the distance or throw must increase, necessitating large cabinets, a larger mirror, and a larger correcting lens. Eventually the optical system becomes awkward and bulky. A compromise is

thus necessary between the size of the final image and the cost
and size of the set. For each different throw or magnification,
we require a different correcting lens. This, it will be noted,
differs from a refractive lens system where the size of the pro-
jected image can be increased merely by changing the position
of the lenses and the screen.

Courtesy RCA

FIG. 8.42B. A large screen (20 by 16 inches) receiver. The image from a small
projection-type tube is enlarged to permit comfortable viewing by many people.

In Philco projection television receivers the arrangement of
the optical system components is slightly different as shown in
Fig. 8.43. The distance between the corrector lens and the
screen is $33\frac{1}{2}$ inches, and variations of plus or minus 10 per
cent are permissible without leading to any serious deterioration
of image quality. Each of the reflecting plane mirrors in all
these optical systems are front-surfaced mirrors to prevent ghosts
which would occur from reflections at the surface of the glass
of a rear-surfaced mirror.

The translucent screens upon which the final image is pro-
jected has, in itself, directional properties which concentrate
the light in certain desired directions. If the screen was a per-
fect diffuser of light, it would produce illumination which was
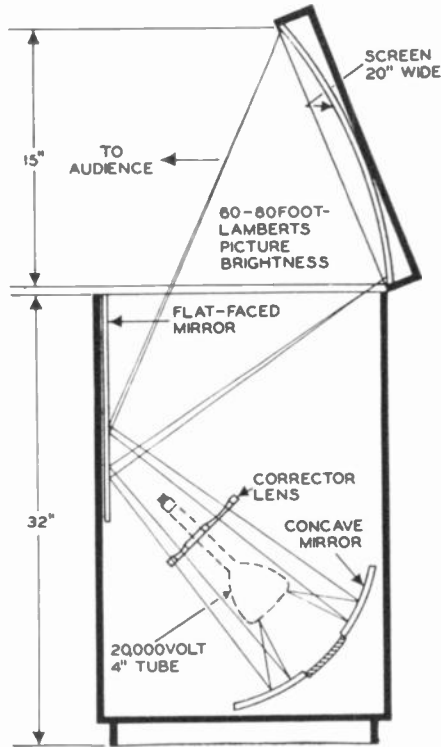
FIG. 8.43. The optical system in the Philco projection television receiver.

equally visible all over the room. Graphically this could be
shown as indicated in Fig. 8.44. At all points throughout a
hemisphere whose center coincides with the screen equal il-
lumination would be received from the screen. Since many of
the extreme angles of this hemisphere are never (or very sel-
dom) used for viewing due to foreshortening of the image, it is
advantageous to concentrate the light that would normally go
to these points toward those angles that are most used for view-

ing. To do this, the translucent screen is made directional in the vertical and horizontal directions. Not only does this cause the final image to be brighter than it would be using the perfect dif-

Fig. 8.44. The distribution of light from a non-directional screen is uniform throughout a hemisphere whose center coincides with the screen.

fuser screen, but it also presents the added advantage of greatly reducing the susceptibility of the screen to any stray light from lamps located in the viewing room.

In the Philco projection receiver, the screen is designed to have a viewing sector which extends 60 degrees horizontally and 20 degrees vertically. (See Fig. 8.45.) To achieve this directivity, the screen contains a large number of vertical grooves, random-shaped. These vertical grooves are responsible for the horizontal directivity of the screen. To achieve the 20-degree vertical directivity, the screen surface is made concave. (See Fig. 8.43.) The screen, in addition to its directional properties,
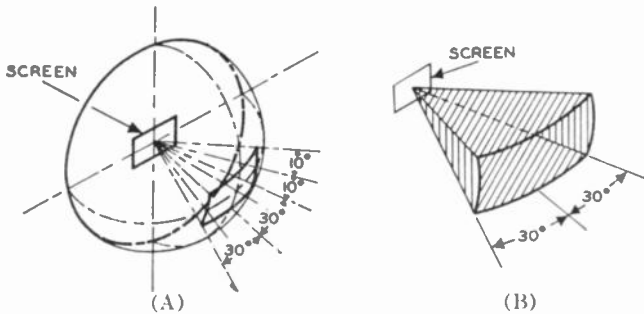
Fig. 8.45. (A) The vertical and horizontal directivity of the Philco viewing screen. (B) The 60° horizontal viewing angle.

also possesses a great many minute or lenticular elements, each of which redistributes or diffuses the light reaching it uniformly throughout the desired sector. The overall brightness of this screen is about 50 foot-lamberts.

Since the optical system is mounted at an angle and projects on the screen at an angle, a rectangular image projected from the face of the picture tube would appear on the screen as a trapezoid (the image would have sloping sides with the top larger than the bottom). (See Fig. 8.46.) On the other hand, by projecting a trapezoidal image from the tube, we obtain a rectangular image on the screen. This latter method is the one used in the Philco system.

Formation of the trapezoid pattern is achieved by applying a magnetic field at right angles to the electron beam. To produce this magnetic field, two oppositely polarized permanent magnets are mounted

FIG. 8.46. A trapezoid.

opposite each other on the end of the projection tube. (See Fig. 8.47.) An iron pole piece, curved to fit the sides of the tube, is attached to each magnet and is used to produce a strong field for deflecting the electron beam upward near the tube face. The oppositely polarized ends of the magnets farthest from the tube face cause a lesser and downward deflection of the beam
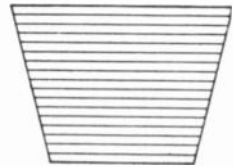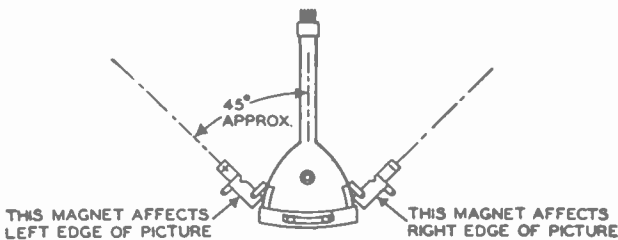
Fig. 8.47. The special magnets mounted on the cathode-ray tube in Philco projection receivers.

before it is deflected upward. The result is the same as that which would be produced if the face of the tube were tilted inward; the distance the beam travels to the bottom of the image is reduced and the distance to the top is increased. This creates the desired trapezoidal pattern. The magnets are adjusted for the proper keystoning pattern by moving them toward (parallel

to the tube neck) or away from the tube (at right angles to the tube neck).

In the RCA and G.E. projection receivers the additional bar magnets are not required because the translucent screen is not slanted and because it is perpendicular to the axis of the optical system. Hence, a rectangular image on the projection tube face appears as a rectangle on the screen. The translucent screen used in these sets is composed of two lucite sheets with a partial diffusing layer between them. The back sheet has a fresnel lens molded into its rear surface. The front sheet has vertical ribs molded into its outer surface. The fresnel lens functions to concentrate the light into a narrow viewing angle. The vertical ribs act to increase the horizontal directivity above that obtained with a flat surface. The diffusing layer eliminates interference patterns between the fresnel lens and the vertical ribs. The screen and lens combination gives a gain of approximately five over that which would be obtained from a ground glass screen.

In the RCA and Philco receivers, the projection tube, the spherical mirror, and the correcting lens are all mounted in what is known as an "optical barrel." (See Fig. 8.48.) The spherical mirror is mounted in the bottom of the optical barrel and held against a knife edge by 3 sets of springs. The spring pressure is strong enough to hold the mirror securely against the knife edges, but not sufficient to distort the spherical mirror.

The 5TP4 is held in a retaining ring within the optical barrel, the face of which is approximately half way between the correction lens and the mirror. The tube is adjusted to position by controls on the side of the optical barrel. Optical focusing is accomplished by moving the picture tube up and down vertically. Other adjustments are needed to secure proper centering of the picture tube on the optical axis of the mirror. The correction lens is held in the ring on top of the barrel and secured by three spring fingers.

Another variation of the Schmidt optical system as adopted for television is that devised by North American Philips. The

PICTURE TUBE
CLAMP SCREW

FOCUS LEVER
CLAMP SCREW
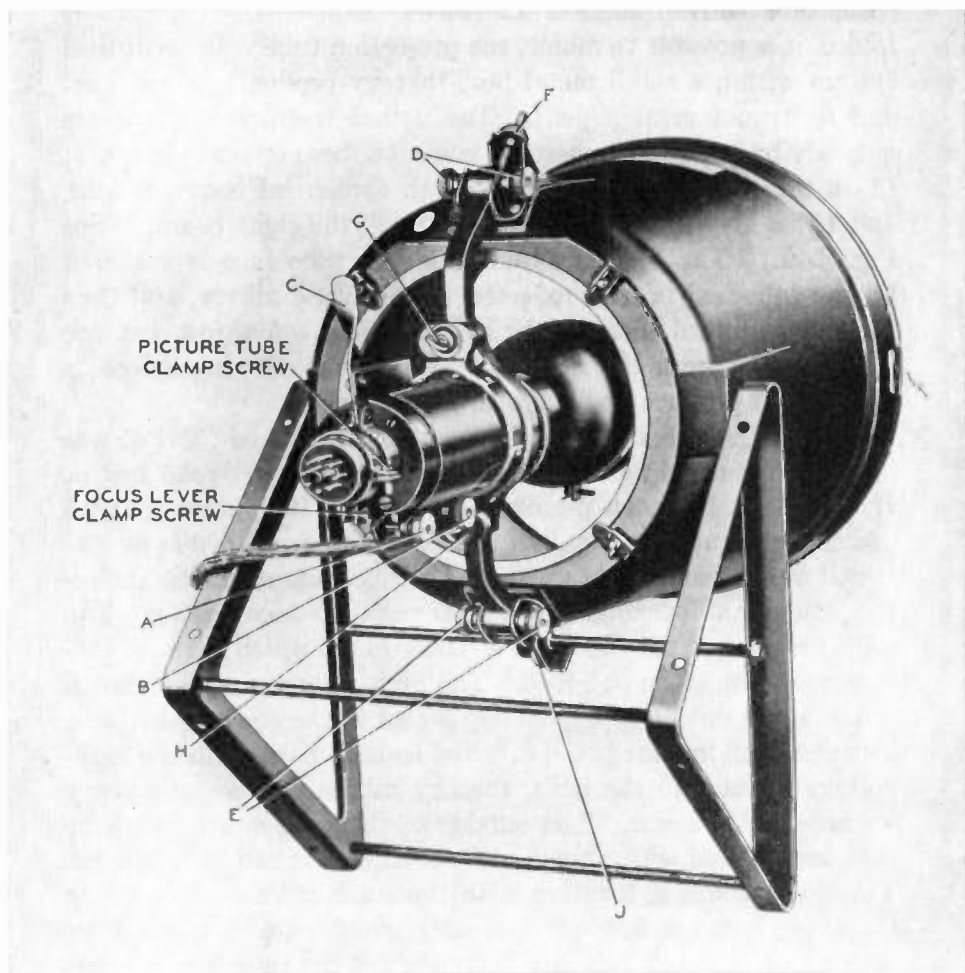
FIG. 8.48.   The "optical barrel" which contains the projection tube, the spherical mirror, and the correcting lens.   Points lettered **A** through H indicate physical positioning adjustments.

system, known by the trade name of "Protelgram," is an adaptation of the "folded" Schmidt system and occupies only half the space of a conventional arrangement. Since the light path is folded, it is possible to mount the projection tube with its optical system within a small metal box, thereby producing a compact and dustproof arrangement. The actual metal case measures only 8½ by 8½ by 9 inches. It contains three optical elements: (1) a 6-inch spherical mirror, (2) an aspherical corrector lens, and (3) a special plane mirror to "fold" the light beam. (See Fig. 8.49.) The light emitted from the tube face is gathered by the spherical mirror, reflected to the plane mirror, and then projected upward through the corrector lens. A throw distance of 31 inches from the corrector lens to the viewing screen is required to produce an image 12 by 16 inches.

A special, small-sized cathode-ray projection tube (3NP4) was designed for this unit. The tube screen diameter is 2.5 inches, and a 1.4 by 1.86-inch picture is obtained. It appears that 2.5 inches constitute the smallest practical size from which an enlarged image can be obtained. The tube uses magnetic deflection, magnetic focusing, and 25,000 volts for acceleration. The spot diameter at the tube face is 0.003 inches which permits 450-line resolution to be obtained. The high-voltage anode terminal consists of a button in a glass cup sealed to the cone of the tube. The glass cup lengthens the external leakage path from the high-voltage contact to the coils, thereby minimizing any tendency for arc-over to occur. The outside of the cone and part of the neck are covered with a conductive coating that can be grounded. This outer coating, together with the conductive coating inside the tube, forms a $300\text{-}\mu\mu f$ condenser which can be utilized for filtering of the high voltage. The neck of the tube is quite narrow and, in conjunction with a deflection angle of only 40 degrees, permits full deflection to be achieved using only as much deflection current as ordinarily supplied to a 10BP4 direct-viewing tube operating at 9 kv.

A 25-kv second anode is needed for the 3NP4 with better than average stability, and a new, compact unit was designed   (See

CABINET
MIRROR

CORRECTOR
LENS

PLANE
MIRROR

VERTICAL
DEFLECTION COIL

HORIZONTAL
DEFLECTION COIL

VIEWING
SCREEN

FOCUS
COIL

CONCAVE
MIRROR

PROJECTION
TUBE

FOCUS COIL
TILT
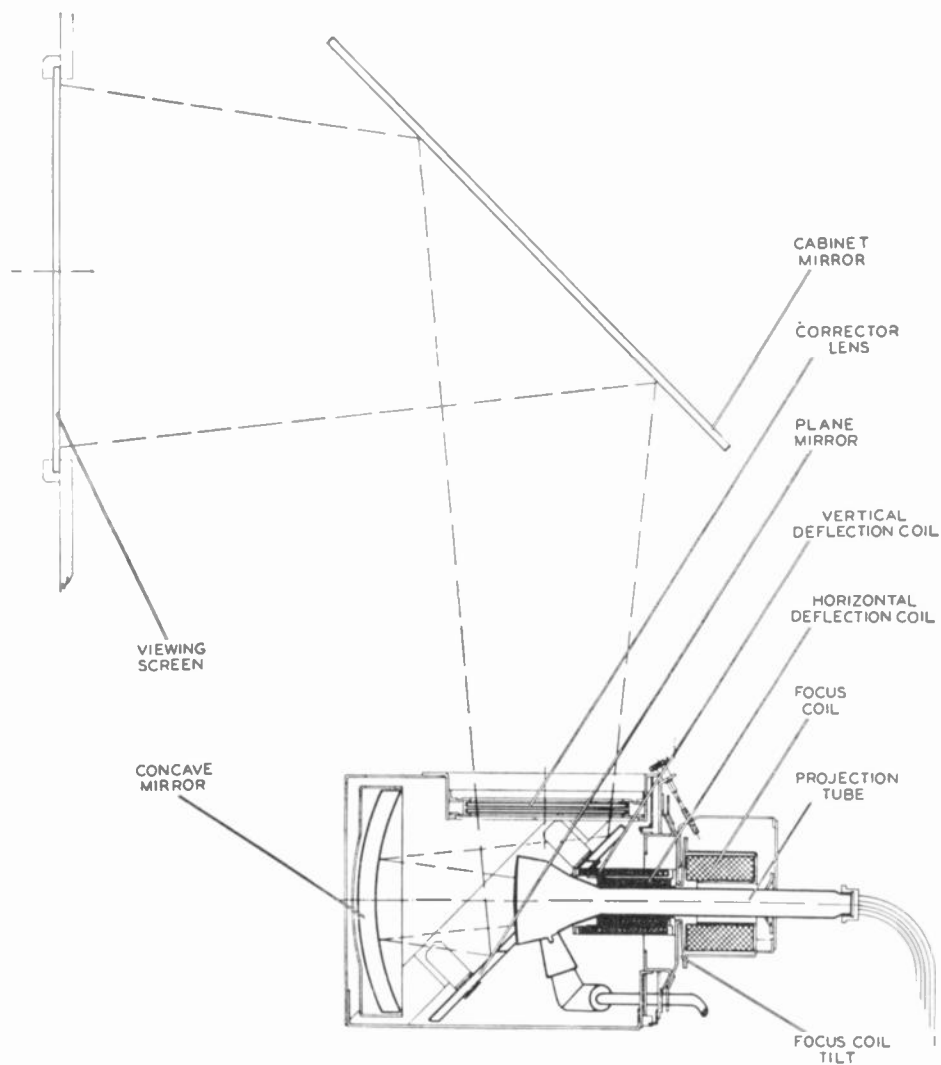
Courtesy North American Philips

Fig. 8.19 The various components of the optical unit of the North American Philips projection system.
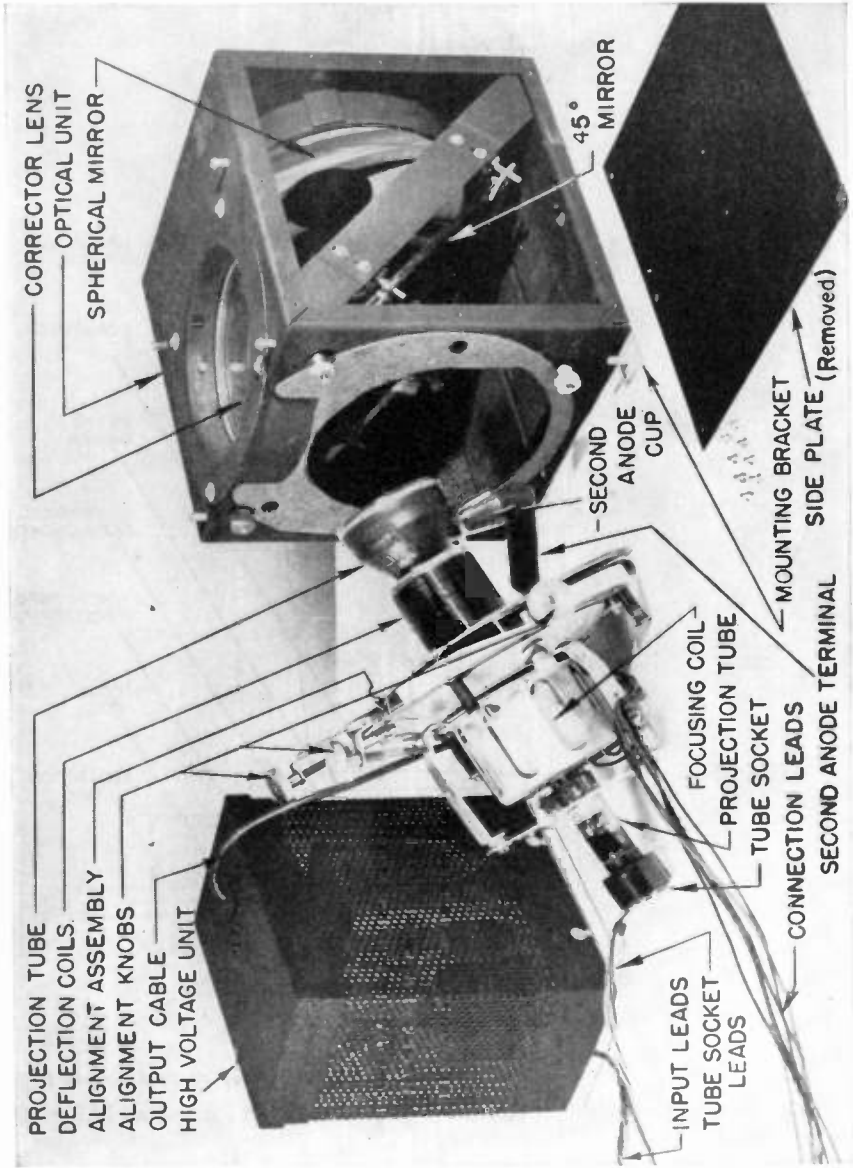
Fig. 8.50. The complete assembly, including power supply, of the North American Philips projection system.

Fig. 8.50.) This high-voltage supply is known as a pulse type, and it differs from the fly-back type previously discussed in that a separate pulse generator is employed, operating at a frequency which is considerably lower than the horizontal sweep frequency.

The circuit of the power supply shown in Fig. 8.51 consists of a blocking oscillator, a driver amplifier, and a three-tube cascaded high-voltage rectifier. The blocking oscillator is con-

Fig. 8.51. Schematic diagram of the high voltage unit of the North American Philips projection system.

ventional in form and operates at a frequency of about 1,200 cycles per second. It produces a saw-tooth voltage which is applied to the grid of the following 6BG6 driver amplifier. The grid of this tube is biased beyond cut-off so that its plate current flows only at the peaks of the saw-tooth. (See Fig. 8.52.) At the tip of the saw-tooth, the grid voltage of the 6BG6 drops sharply back into cut-off, stopping the flow of plate current and shock-exciting the transformer. Because of the inductance in the transformer windings and the stray capacitance across them, the system is shocked into oscillations. The values of these components were chosen to produce transient oscillations having a frequency of about 30 kc. These oscillations continue until the next flow of plate current from the 6BG6. This is indicated in Fig. 8.52. In the fly-back system, a damping tube

placed across the output transformer, damped out all but the
first cycle of oscillations. In this circuit no such damping oc-
curs, and the oscillations are present throughout the interval
between plate current pulses of the 6BG6. At these moments
the conducting 6BG6 loads down the circuit, stopping the oscil-
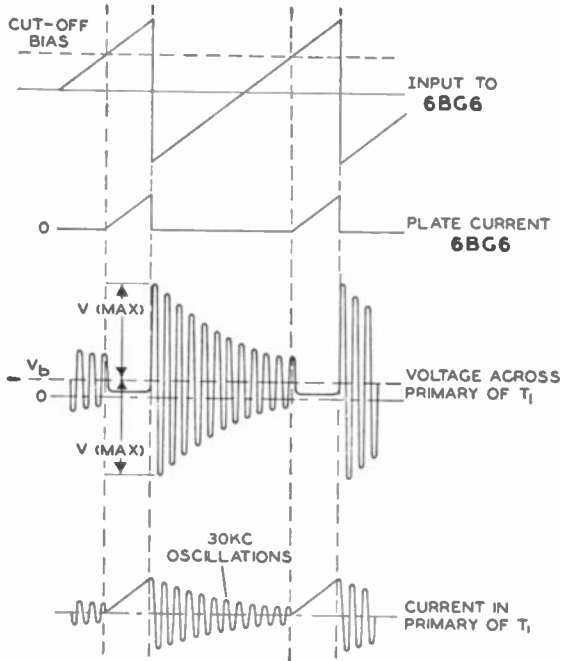
FIG. 8.52.   Current and voltage waveforms in circuit of Fig. 8.51.

lations.   The sudden stoppage of the plate current at the end
of each plate current pulse shock-excites the transformer into
oscillations at its natural frequency of 30 kc.

The voltage developed across the full primary winding of the
output transformer is rectified by the three 8016 tubes to pro-
vide an output voltage of 25,000 volts. Since the high voltage
is developed here a little differently than in the previous high-
voltage systems discussed, a brief explanation follows.

On the first positive oscillation peak (8,500 volts), current

flows through V_1 and C_1 charging the latter condenser to the full peak voltage with the polarity as shown. On the first negative peak, the voltage across the primary transformer winding adds to the voltage across C_1 to cause V_2 to conduct and charge C_2 to a peak value which is twice the transformer voltage, or 17,000 volts. Current, in this instance, flows from the cathode of V_2 to its plate, through C_1 and the transformer primary, to C_2 and thence back to the cathode of V_2 again. On the next positive peak, C_3 is charged by current flowing through V_3 and C_2, the transformer primary, and C_1 to C_3 and then back to the cathode of V_3 again, completing the circuit. The voltage across C_2 adds to the voltage across the transformer primary to feed a positive voltage to the plate of V_3. Opposing this voltage is the potential across C_1. The total positive voltage at this instant is $2V$ (from C_1) plus V (from the transformer) or $3V$. Opposing this is V from C_1. Hence, C_3 receives $2V$ ($3V - V$). or 17,000 volts. By using the voltages across C_3 and C_1 we can obtain an output voltage of 25,500 volts. Actually, the output voltage is somewhat lower than this.

The output transformer contains another winding which is used for regulation purposes. The voltage developed in this winding is fed to the diode section of the 6SR7 tube where it is rectified and applied as a negative voltage to the grid of the 6BG6. If the output voltage tends to increase, more negative bias is applied to the 6BG6, reducing its interval of conduction and thereby reducing the amount of energy imparted to the transformer. This will tend to lower the amplitude of its oscillations and reduce the high voltage. On the other hand, a reduction in high voltage will cause less negative bias to appear at the grid of the 6BG6, increasing its interval of conduction and resulting in oscillations of greater amplitude in the transformer.

With this self-regulating arrangement, the voltage output is maintained constant within the limits set for this design. An external low-voltage power supply is needed to provide B+ at 350 volts for the 6SR7 and 6BG6 plus 6.3 volts a.c. for their filaments.

A careful evaluation of present projection tubes as compared to a direct-viewing tube indicates the following:

1. Brighter images can be produced on direct-viewing screens.

2. The angle of vision of a direct-viewed image is greater than the viewing angle of projection screens.

The projection images are of good quality and those currently available are recommended for purchase. A 16- by 20-inch image can be easily and comfortably seen by a roomful of people.

SYNCHRONIZING CIRCUIT FUNDAMENTALS

Synchronizing Pulses. Up to this point we have studied the action of the various stages of the television receiver in amplifying and changing the form of the video signal so that it was finally suitable for application to the grid of the picture tube. Nothing, however, has been said so far about the method of supplying the proper voltages to the deflection plates (or coils) so that the image will be swept out properly on the cathode-ray screen. To accomplish this, we must obtain the synchronizing pulses from the video signal and apply them to other circuits that will eventually connect directly to the deflecting plates of the picture tube. Since each line has a separate synchronizing pulse, it becomes possible to lay them out on the screen in their proper position exactly as they were scanned on the camera tube mosaic. The synchronizing pulses that are responsible for the correct positioning of the various lines are referred to as the horizontal synchronizing pulses, or perhaps more simply, as the horizontal pulses. These pulses are diverted to amplifiers that control the action of the horizontal deflecting plates and coils.

After the electron beam sweeps out the correct number of horizontal lines and arrives at the bottom of the picture, a vertical synchronizing pulse is applied to the vertical deflection plates, and the beam is rapidly brought back to the top of the screen again. This vertical pulse is transmitted along with the horizontal pulses in the video signal, separated by filters at the receiver, and applied to a set of amplifiers that end at the vertical deflection plates. The block diagram of Fig. 9.1 illustrates the general path of all the synchronizing pulses within a television receiver.

Pulse Separation from the Rest of the Signal. To use the pulses of a video wave, they must first be separated from the other portions of the signal. The separation may occur anywhere, from the video detector to the last video stage before the cathode-ray tube. In practice, commercial set designers have generally chosen to obtain the input for the synchronizing stages from some point beyond the video detector, generally at the output of the last video amplifier. At these points, the signal has
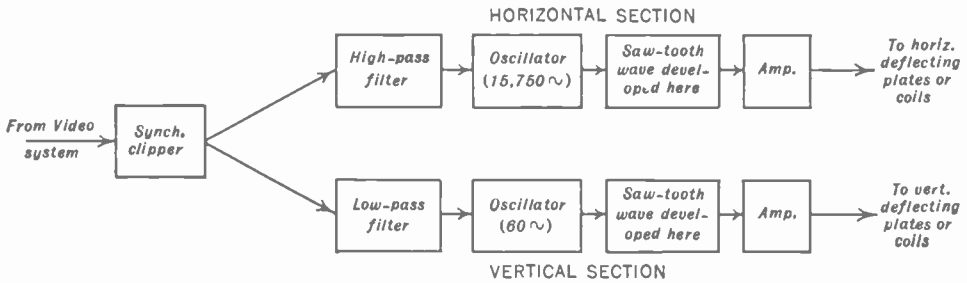
Fig 9.1. A block diagram of the entire synchronizing section of a television receiver.

sufficient amplitude and is in proper form so that it can be made to control the horizontal and vertical deflecting oscillators with a minimum of additional stages. For example, set designers often do not apply the video signal to the separating tube until it has passed through the first video amplifier. In this way an extra pulse amplifier is eliminated.

Since it is necessary to obtain the synchronizing pulses from the incoming wave, it is first imperative that the signal be in its d-c form. This should be evident by reference to the figures of Chapter 7 where the a-c and d-c forms of a video signal are illustrated. While the signal is always in its d-c form at the output of the detector, it may not be so if obtained from the plate circuit of some following amplifier. In this case, d-c restoration is necessary, and the method of achieving it is shown in the circuits that follow.

The tube that separates the synchronizing pulses from the rest of the wave is called the clipper. Both horizontal and verti-

cal synchronizing pulses are clipped from the wave by this tube, the further separation of these two pulses then occurring at another point beyond this stage. The type of tube that may be utilized for the synchronizing separation is not restricted. Practically every type is suitable since the action consists merely in biasing the tube so that only the top portions of the video wave (where the pulses are found) affect the tube and cause current to flow.
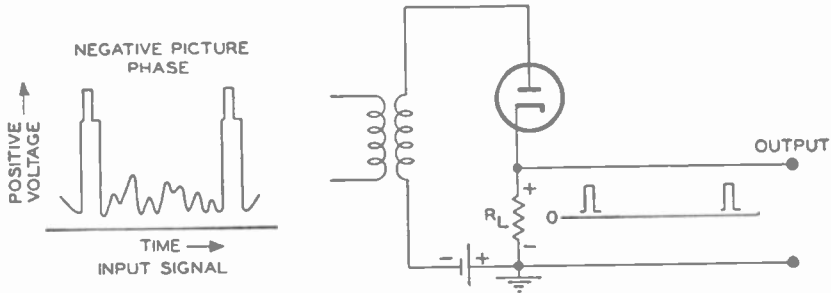
Fig. 9.2. A diode clipper. This operates with input signals having negative phases.

Diode Clippers. A possible diode clipper circuit is shown in Fig. 9.2. The video signal is applied between plate and ground while the output voltage is developed across the diode load resistor R_L. The small battery is inserted with its negative end toward the plate. This prevents current from flowing until the video signal acting on the tube becomes sufficiently positive to counteract the negative biasing voltage. Current then flows. With the circuit constants properly chosen, current should flow only at the synchronizing pulses which are the most positive for a signal having negative phase, and the output will consist only of these short pulses of current. The picture phase at the input of this diode must be negative, as in Fig. 9.2.

By inverting the diode, as in Fig. 9.3, it becomes possible to apply a positive picture phase to the tube and again obtain only the pulse tips across R_L. The d-c biasing voltages necessary for these diodes may be taken from the low-voltage power supply.

It is not very practical to use a biasing battery or power-

supply d-c voltage for the diode clipper tube. We require some arrangement that is completely automatic in its operation, altering its operating point as the amplitude of the received carrier varies. A simple, yet effective, circuit is shown in Fig. 9.4A. The diode clipper uses the time constant of R and C to bias the tube so that all but the synchronizing pulses are eliminated. Condenser C and resistor R form a low-pass filter with a comparatively long time constant, equal to approximately 10 horizontal lines. Therefore, the voltage developed across R (and C) will be determined by the highest voltage applied across the input terminals. This, of course, means the synchronizing pulses. Throughout the remainder of the line, while the video voltage is active, the plate is never driven sufficiently positive to overcome the positive cathode bias.

A commercial application is shown in Fig. 9.4B. One half of a 6H6 is used for picture signal detection (not shown) while the remaining half is devoted entirely to pulse rectification and clipping. R_1 and R_2 are the pulse detector load and here the rectified signal is developed. The time constant of the load is set by R_1 and C_1. At the arrival of each pulse to the tube, a short flow of current occurs, recharging C_1, and, at the same time, producing a pulse across R_2. This voltage is passed on to an 1852 synchronizing pulse amplifier. The series inductance L maintains a good response in the connecting network to the higher frequency components of the square-shaped pulses. Any decrease in high-frequency response here would have the effect of rounding out the steep sides of the synchronizing pulses, thereby destroying the effectiveness of their triggering action. It can readily happen that the synchronizing oscillators will trigger at slightly differing intervals, causing sections of the image to "tear out." The appearance of such an image is identical to that obtained when interference is active in the circuit.

A more frequent application of the diode sync separator uses the circuit shown in Fig. 9.5. The composite video signal is applied across terminals A-B. As a start, we will assume that C_1
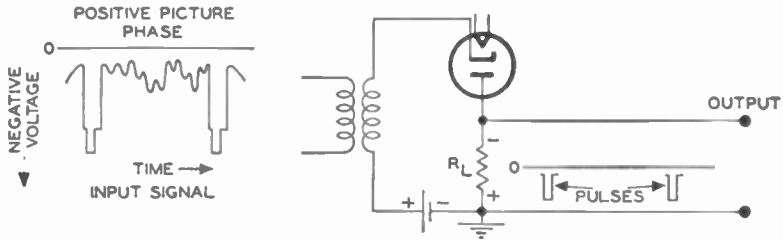
FIG. 9.3.   An inverted diode clipper, suitable for input signals having a positive picture phase.
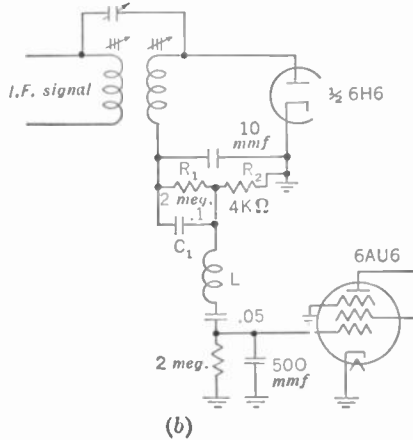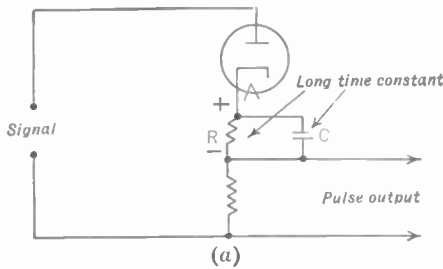
FIG. 9.4.   (A) Fundamental diode clipper circuit.   (B) The commercial application.

is uncharged. Upon the application of a signal, electrons flow from cathode to the plate of the tube and thence to the nearest plate of C_1. From the other plate of C_1, an equal number of electrons will flow to terminal A, through whatever circuit is connected between this point and terminal B, up through R_2, and back to the tube again. C_1 will become charged, its potential equal to the peak potential of the applied video signal. During the second and all subsequent lines, V_1 will not conduct until the applied signal is able to overcome the negative charge

existing across C_1, and this will only be true when the sync pulses are active. At these moments, current flows through the circuit in the manner described above and a pulse of voltage appears across R_2. At all other times V_1 will be kept at cut-off by the negative charge across C_1.
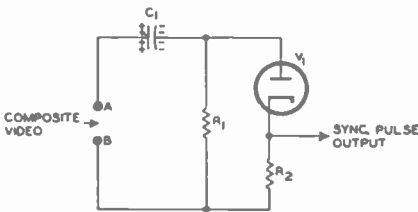
Fig. 9.5. A second and more frequent application of a diode as a sync separator.

When V_1 is not conducting, C_1 discharges through R_1, and it is actually this discharge through R_1 that makes the plate of the diode negative with respect to its cathode. As before, the time constant of C_1 and R_1 is made sufficiently long so that only the sync pulses cause current flow through the circuit.

If the reader will now refer to Chapter 7, he will see that the diode d-c restorer circuits which also functioned as sync clippers utilized a similar circuit. The d-c restorer action was obtained from C_1, R_1, and V_1 (Fig. 9.6). The negative voltage which developed across R_1 was fed through a resistor, R_3, to the cathode-ray tube, where it combined with the video signal, bringing all sync pulses to a common level. At the same time, R_2, in series with V_1, received a pulse of current each time the tube conducted. Since this occurred only when the sync pulses were active, only the sync pulses appeared across R_2.

When the video signal at the plate of the last video-frequency amplifier is fed to the grid of the image tube, signal phase is

positive, which means that the sync pulses possess the most negative potential of the signal. Therefore the diode V_1 must be inverted. (See Fig. 9.6A.) On the other hand, when the video signal is fed to the cathode of the image tube, the sync pulses have the most positive potential of the video signal, and the diode is placed as shown in Fig. 9.6B. Circuit operation, in either instance, is the same.

In some television receivers, the sync separator shown in Fig. 9.6A is combined with two 6SN7 tubes, for the purpose of
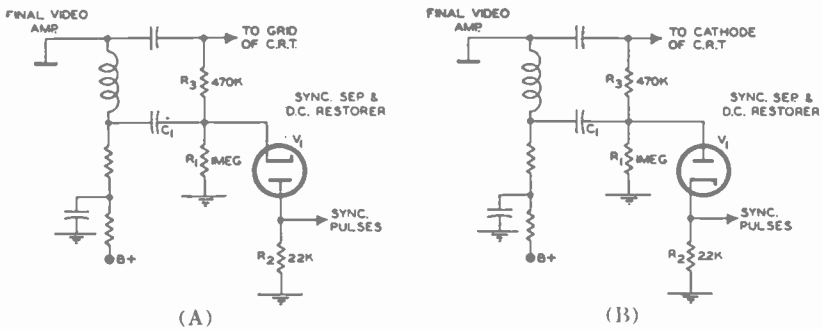
Fig. 9.6. Combining sync separation with d-c restoration.

clipping and squaring off the sync pulses, before these are applied to their respective sweep oscillators. (See Fig. 9.7.) In spite of the different names applied to these duo-triodes on the manufacturer's diagram (i.e., sync amplifier and sync separator), all perform essentially the same jobs of amplifying and clipping the sync pulses. The final tube is called a sync separator possibly because the pulses appearing in its cathode circuit are applied to the vertical and horizontal sweep oscillators. Note, however, that the separation of the vertical and horizontal sync pulses from each other is not performed by the tubes but by the high- and low-pass filters leading to each oscillator. All the sync pulses—and these include both vertical and horizontal— are applied to the low-pass filter composed of R_1, R_2, and R_3 plus C_1, C_2, and C_3. The low-frequency (60-cycle) vertical pulses

are permitted to pass while the effect of the 15,750-cycle horizontal pulses is made negligibly small.

By the same token, the pulses reaching the horizontal blocking oscillator must pass through the high-pass filter consisting
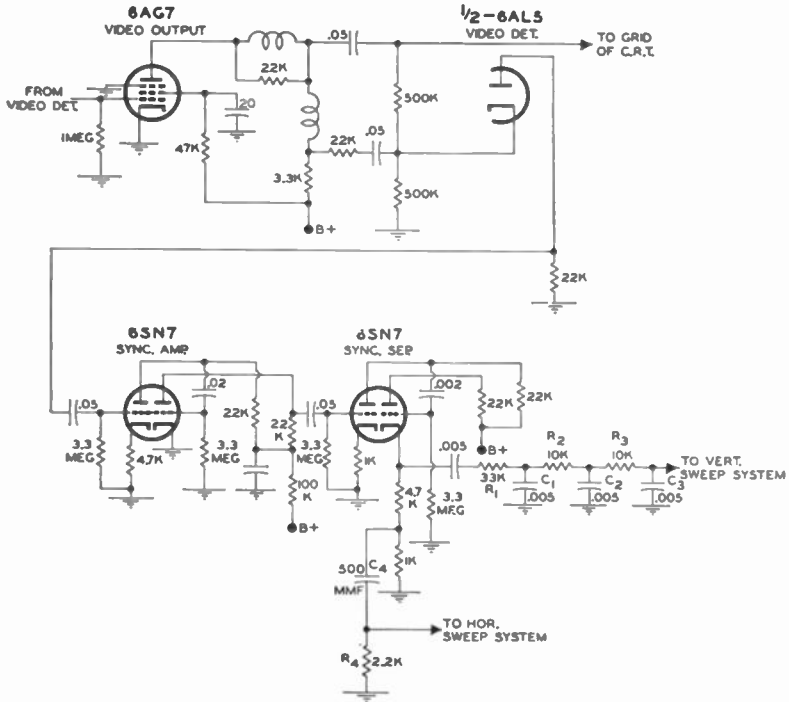
FIG. 9.7. A complete sync separation and amplifying network using the diode sync separation of Fig. 9.6(A).

of C_4 (500 $\mu\mu f$) and R_4 (2,200 ohms). This circuit is known as a differentiating network and produces a sharp pip at the leading and lagging edges of each rectangular pulse. The pip due to the leading edge is then used to sync the horizontal oscillators.

Maintenance of synchronization is an important consideration in the design of even the cheapest television receiver, and one way to achieve sync stability is by successively amplifying and shaping the sync pulses obtained from the video signal. A point

to remember is that *complete* separation of the sync pulses from the image detail voltages is seldom achievable using a single diode or triode. Hence, whenever these tubes are employed as sync separators, they are usually followed by one or more amplifiers and shaping circuits. A pentode with a sharp cut-off characteristic may be used by itself if economy is important.
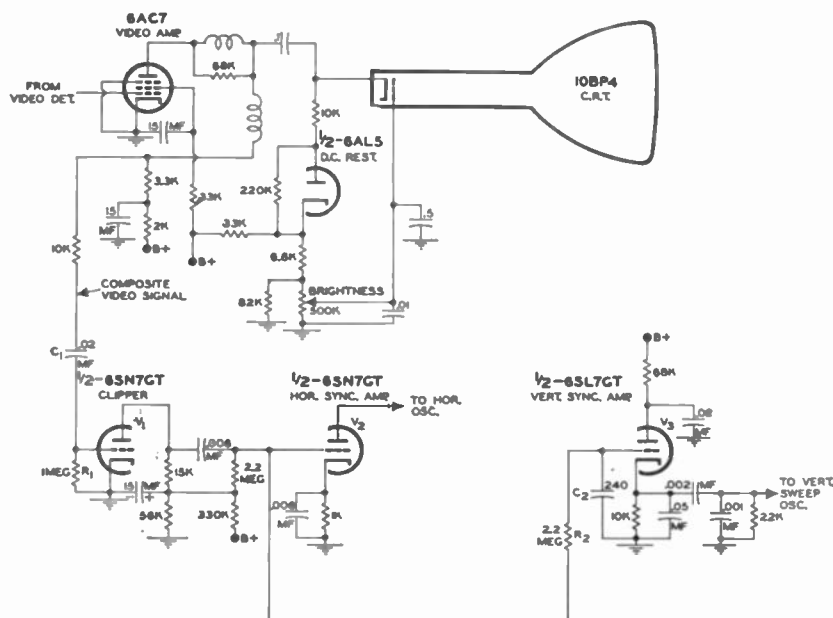
FIG. 9.8. A triode (V_1) sync clipper.

Triode Sync Separators. Since a triode (or a pentode) can do anything a diode can, and provide amplification as well, it is natural to expect to find these tubes used as sync separators. An application involving a triode sync clipper is shown in Fig. 9.8. The triode is biased by grid-leak bias developed across C_1 and R_1. The pulses in the video signal fed to the sync clipper triode V_1 possess the most positive polarity of the signal. Electrons will then flow in the grid circuit, charging the coupling condenser. Because of the high value of R_1, the charge on C_1

will leak off slowly, causing a fairly steady bias voltage to develop across the grid resistor. This biasing voltage prevents plate current from flowing except for the most positive values of the incoming signal, which are the synchronizing pulses. A low plate voltage (14 volts) causes the tube to saturate readily, thereby tending to square off the sync pulses and to limit any noise pulses that may appear in the signal.

The signal from V_1 is fed to two circuits: One portion is fed to the grid of V_3 through an integrating network (R_2 and C_2) which is a low-pass filter. The wide vertical pulses pass through the filter, are amplified by V_3, and then cathode-coupled to the following vertical multivibrator sweep oscillator. The horizontal sync pulses, on the other hand, do not develop sufficient voltage across C_2 appreciably to influence V_3. Further integration of the sync signal is provided in the cathode circuit of V_3.

The second circuit to which the output of V_1 is fed is the horizontal sync amplifier V_2. This tube operates into an automatic frequency control (A.F.C.) network which automatically regulates the frequency of the horizontal sweep oscillator. Not shown in Fig. 9.8, but indicated in Fig. 10.12 is coupling transformer T_1 which acts as a high-pass filter or differentiator by virtue of its low inductance; that is, in the secondary, the original sync pulses are transformed into positive and negative pips. Only the pip which is produced by the leading edge of each pulse is used.

The combination of a triode d-c restorer and sync separator is a common one. (See Fig. 9.9.) The grid and cathode of the triode V_1 function as a diode d-c restorer, providing a positive d-c voltage across R_1 which is added to the video signal applied to the control grid of the image tube through a 1-megohm resistor. Since the applied video signal has a positive picture phase (the sync pulses are most negative), the grid of the tube is grounded and the signal is received by the cathode. Current flows through the triode only when the negative applied voltage is sufficiently large to overcome the positive potential developed across the cathode resistor R_1. This occurs only during the sync

pulse interval, producing amplified sync pulses across the plate
load resistor. The pulses receive further amplification by triode
V_2 and then are transferred to separate vertical and horizontal
sync amplifiers. The vertical system contains two additional
amplifiers while the horizontal system contains what is es-
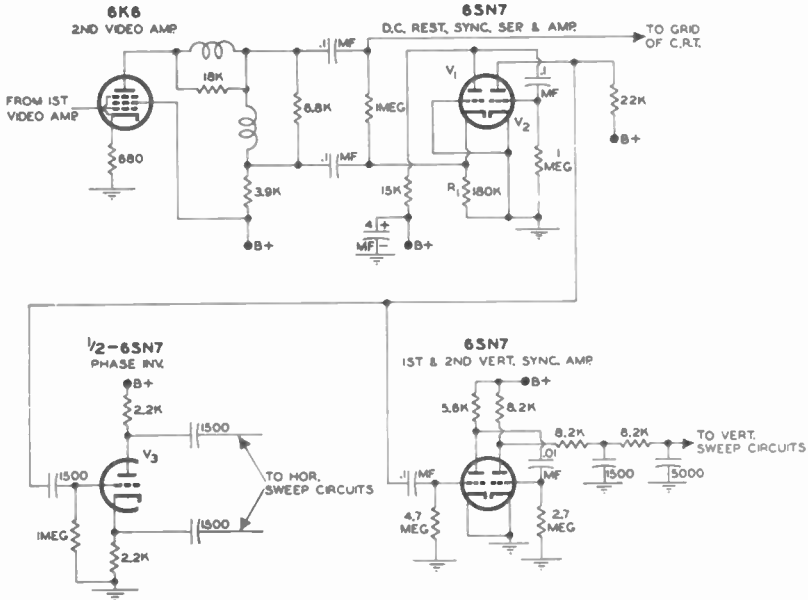
FIG. 9.9. A triode (V_1) employed as a sync separator and d-c restorer.

sentially a cathode-follower and phase inverter feeding into an
A.F.C. circuit.

Another triode sync separation circuit is shown in Fig. 9.10.
The first triode V_1 is a normal voltage amplifier. Its output is
the complete video signal and is applied to the grid of V_3 with
the sync peaks in the positive direction. In the input circuit
of V_3, a diode, V_2, is connected from grid to ground. This diode
has -14 volts applied to its plate terminal and will not conduct
until the 14 volts are neutralized by a signal which is at least
14 volts above zero reference level (ground). When this occurs,
the diode conducts, effectively preventing the signal at the grid

from rising any further. The grid of V_3 is biased by the same −14 volts, preventing the tube from conducting until part of this voltage has been neutralized. The video detail voltage variations of the incoming signal are unable to overcome this negative bias and thus the video detail voltage up to approxi-
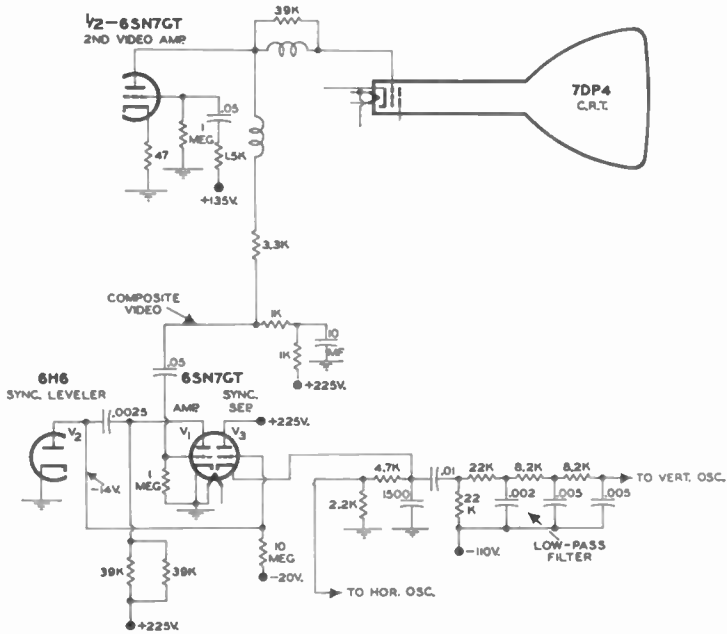
Fig. 9.10. A widely used triode sync separation circuit.

mately the blanking level is removed. Only sync pulses, which extend in the positive direction, are able to force V_3 to conduct, producing positive pulses in the cathode circuit which are then fed through appropriate filters to the vertical and horizontal blocking oscillators.

V_2 serves as a sync leveler, tending to provide a constant pulse output. Because of the amplification accorded by V_1, the sync pulses of all normal signals reaching V_3 extend more than 14 volts above the zero reference axis. Hence, all sync pulses drive the diode into conduction, preventing further rise of the pulse

beyond 14 volts and leveling off the tips of all sync pulses. For signals too weak to develop sufficient voltage at the output of V_1 to drive V_2 into conduction, leveling does not occur and the sync amplitude variations reach the sweep oscillators, impairing sync control.

Pentode Sync Separators. To obtain clean-cut sync separation, sharp cut-off pentodes are usually more satisfactory than
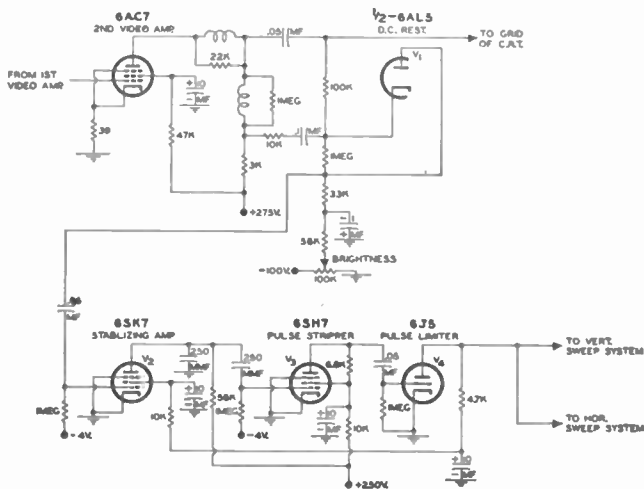
FIG. 9.11. A pentode sync separator circuit.

either triodes or diodes. The circuit of Fig. 9.11 was shown, in part, in Chapter 7. It was noted there that the diode d-c restorer circuit (V_1) delivered 14 times more sync voltage to V_2 than video detail signal. However, an appreciable amount of video signal still remains, and consequently further clipping is necessary. Note that, although V_1 is labeled as a sync separator in commercial diagrams, this is not strictly so. Complete pulse separation is achieved by the following three-stage system containing a sync amplifier, a sync separator, and a second sync amplifier or limiter. Let us analyze each in turn.

The first sync amplifier is a 6SK7 pentode which has a remote cut-off characteristic. The signal received from the d-c restorer

network has a polarity such that the sync pulses are in the nega-
tive direction, which tend to drive the tube toward plate cut-off.
With a weak signal, such as S_1 of Fig. 9.12, the sync pulse oper-
ates over the relatively high-gain portion of the curve. With
large signals, such as S_2, the sync pulse extends into the curved,
or low-gain, portion of the tube characteristic. The result is a
more constant sync pulse output. Noise pulses are also sup-
pressed by this action, improving the sync-to-noise ratio.
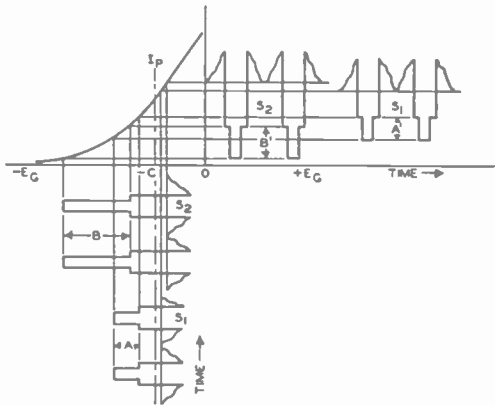
FIG. 9.12.   The action of V_2 in Fig. 9.11 in stabilizing the sync pulse output of V_1.

The sync separator stage V_3 clips the signal just above the
blanking level and removes all the video portion of the signal.
This is accomplished by using the sync pulses of the signal to
drive the grid of V_3 positive and by establishing a negative grid-
leak bias. Although some d-c bias is applied to this stage from
the power supply, it is considerably smaller than the grid-leak
bias and serves mainly to prevent noise peaks from operating
the sweep oscillators when no sync signal is reaching the sync
separator. The 6SH7 tube in this stage has a sharp cut-off
characteristic.

The sync pulses reaching the grid of the third sync amplifier
are negative in polarity and must be inverted before they can
be applied to the sweep oscillators. These pulses are sufficiently
strong to drive V_4 into cut-off, clipping the signal. The result
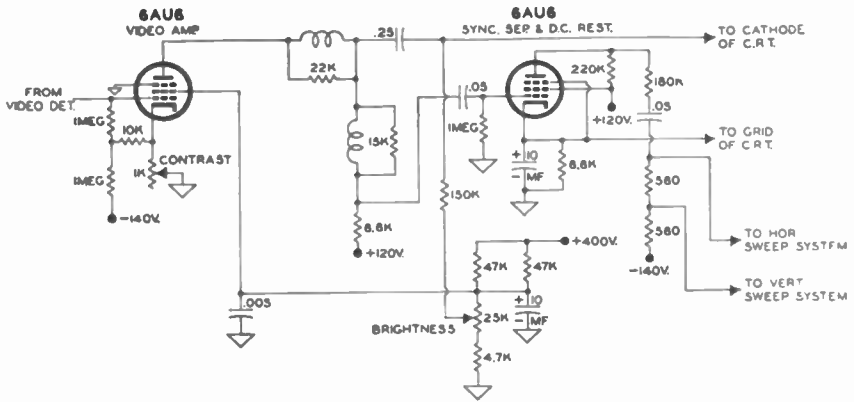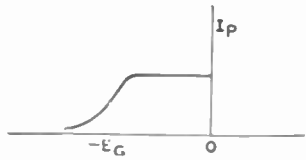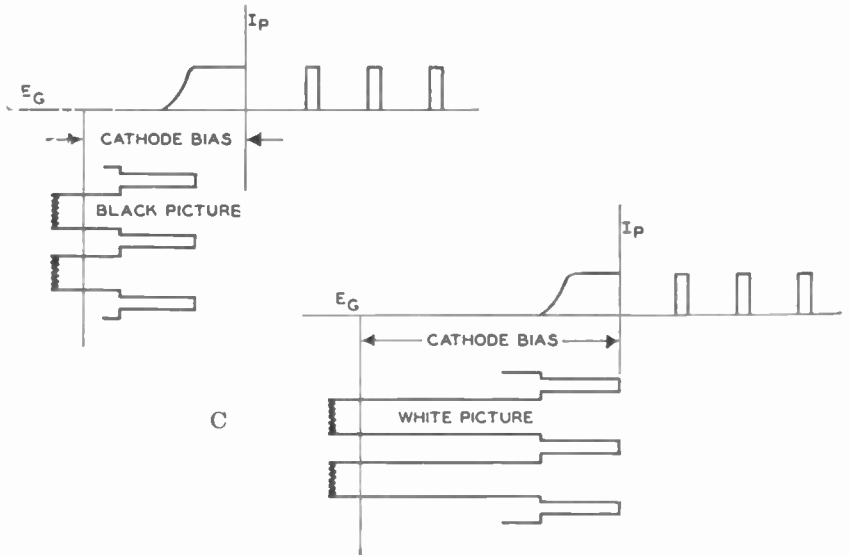
Fig. 9.13. (A) A pentode sync separation circuit using a 6AU6. (B) Characteristic of 6AU6 with the load resistance and voltages specified. (C) Operation of 6AU6 with black and white pictures.

is a square-topped wave. Through the use of this fairly elaborate network, a constant sync pulse output is obtained with peak-to-peak video signal variations of from 6 to 60 volts on the grid of the picture tube. Systems which utilize fewer stages of sync separation are more sensitive to signal strength variation, and the stability of their synchronizing circuits diminishes rapidly with lowering of the signal strength.

Fig. 9.13A is a final illustration of a pentode sync separator. The tube, a sharp cut-off 6AU6 pentode, clips the sync from the composite signal and produces a d-c restoration voltage across its cathode bias resistor. The tube contains a large load resistor in its plate circuit and a relatively large resistor in its cathode leg. The result of this combination, particularly the large plate resistor, is to produce a characteristic such as shown in Fig. 9.13B. The cathode bias produced varies with the average amplitude of the applied signal and will be great enough to place all video detail information beyond cut-off, permitting only the sync pulses to appear in the plate circuit. (See Fig. 9.13C.) The pulses are sufficiently strong, with normal signals, to extend into the flat region of the curve. Thus, sync clipping at either end is obtained. Because of the rather large amplitude of the output pulses, a voltage divider network is connected to the plate load resistor, and the sync pulses are tapped off at appropriate points and then fed to the horizontal and vertical oscillators through filter networks.

Pulses and Their Form. So far, only general terms have been used when discussing the synchronizing pulses of video waves. Their purpose has been stated time and again, but nothing definite has been given as to the actual means of accomplishing their objective. There is nothing in sound receivers that even closely resembles this action, and a detailed examination becomes necessary. The pulses, separated from the rest of the wave as outlined above, will be held in abeyance while we develop in greater detail the form and functions of the horizontal and vertical pulses.

It is already known that, as each horizontal line signal arrives

at the grid of the picture tube, the electron beam should be in correct position, ready to sweep out the information contained in the signal. The position of the electron beam is controlled by saw-tooth oscillators. In order that the oscillator shall have the beam in the correct position, horizontal synchronizing pulses are inserted into the video signal. They could have been sent separately, but the present method is cheaper and simpler in operation. It is to be noted and continually kept in mind that the function of the horizontal synchronizing pulses is to trigger an oscillator in order to bring the electron beam from the right-hand side of the screen to the left-hand side. Once the beam is at the left-hand side, the oscillator is no longer directly under the control of a pulse and goes about its normal function of sweeping the beam across the screen. Thus each horizontal pulse that precedes the line detail sets up the beam in readiness for the scanning out of this information. The next pulse arrives when the beam is at the far right-hand side of the screen, at the end of a line.

There are 525 lines sent out every $\frac{1}{30}$ of a second. In one second, then, we have 525 times 30, or 15,750 lines. This means that the frequency of the horizontal pulses is 15,750 per second, or one arrives every $1/15{,}750$ sec. The time interval is quite small, being only 0.00006 sec.

In similar manner, the vertical pulses serve the purpose of bringing the electron beam back to the top of the screen for the beginning of each field. With interlaced scanning (described in Chapter 1), every other line is scanned, with each field ($\frac{1}{2}$ frame) taking $\frac{1}{60}$ of a second. The beam next sweeps out the lines that were missed, this also in $\frac{1}{60}$ of a second. The total frame, with all lines, is accomplished in $\frac{1}{60}$ plus $\frac{1}{60}$ of a second, or $\frac{1}{30}$ of a second. Thus we see that the vertical pulses must occur once every $\frac{1}{60}$ of a second, or 60 times in one second. This frequency is considerably less than that of the horizontal pulses and it is because of this fact that they can be separated with comparative ease.

With the preceding ideas in mind, let us closely examine the

construction of the video signal with its synchronizing pulses. In Fig. 9.14 several lines of an image are shown, complete with the detail information, blanking voltages, and horizontal synchronizing pulses.   The blanking and synchronizing voltages occupy approximately 20 to 25 per cent of the total signal amplitude.   Notice that the blanking voltage retains its control over the cathode-ray tube grid for some time before and after each synchronizing pulse.   This is done to make certain that
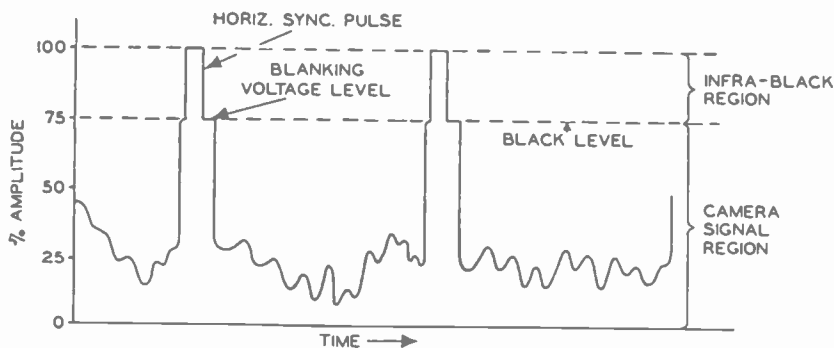
FIG. 9.14.   A video signal with its synchronizing (horizontal) pulses.

no beam retrace is visible at all on the screen.   As soon as the blanking voltage relinquishes control of the grid, the line detail becomes active once again.   All the lines of one field follow this form, the only difference occurring in the camera detail of the various sections of the image.

At the bottom horizontal line, it is necessary to insert a vertical impulse that will bring the beam back to the top of the screen again.   During the period that the vertical pulse is active, it is imperative that the horizontal oscillator should not be neglected.   For, if this did occur, the horizontal generator probably would slip out of synchronization.   To avoid this the vertical pulses are arranged in serrated form and accomplish vertical and horizontal synchronization simultaneously.

Serrated Vertical Pulses.   To understand the form of the vertical pulse that has finally been evolved, start with the volt-

ages shown in Fig. 9.15. At the bottom of the image, a long
vertical pulse is inserted into the signal. This controls the ver-
tical synchronizing oscillator and forces the beam to be brought
back to the top of the screen. No provision is made in the sig-
nal, in this preliminary form, to provide horizontal oscillator
control while the vertical pulse is acting. As stated above, such
a condition is undesirable as it permits the horizontal oscillator
to slip out of control. To prevent this, the vertical pulse is
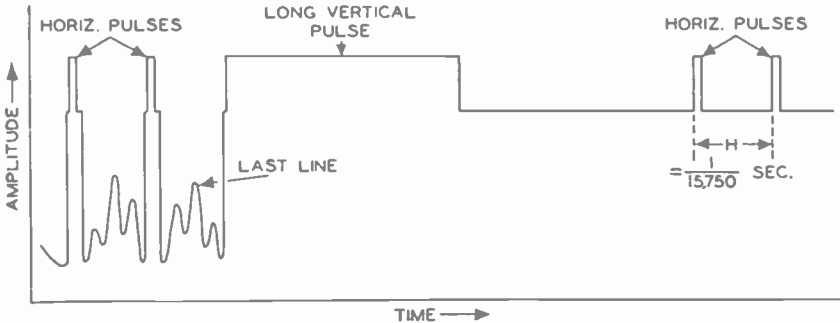
FIG. 9.15. The basic form of the vertical synchronizing pulse.

broken up into smaller intervals and now both actions can occur
simultaneously. The vertical synchronizing pulse, in the modi-
fied form, is shown in Fig. 9.16 and is known as a serrated verti-
cal pulse.

While the vertical pulse is broken up to permit the horizontal
synchronizing voltages to continue without interruption, the
effect on the vertical pulse is substantially unchanged. It still
remains above the blanking voltage level practically all of the
time it is acting. The interval is much longer than the previous
horizontal pulse frequency. The two pulses are still capable of
separation because their wave forms are different, as can be seen
in Fig. 9.16.

Due to the fact that an odd number of lines is used for scan-
ning, the form of the signal just prior to the application of the
serrated vertical pulse must be still further modified. With an
odd number of lines, 525, each field contains $262\frac{1}{2}$ lines from the

beginning of its field to the *start* of the next. This is important
and has not been overly stressed before. In Fig. 9.17, reprinted
from Chapter 1, the notation is made that the end of the visible
portion of each field occurs at the bottom of the image. How-
ever, the actual end of that field is not reached until the beam
has been brought back to the top of the screen again. At the
end of the visible portion of the first field, the beam must be
interrupted at point D and the vertical synchronizing pulse in-
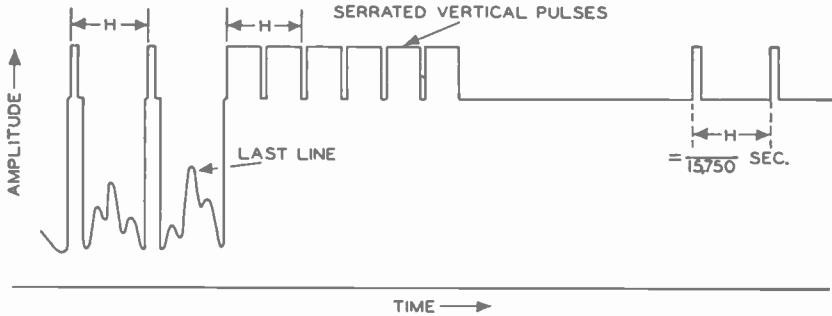
FIG. 9.16. The serrated vertical synchronizing pulse.

serted. Point D, we can see, occurs during the middle of a hori-
zontal line. From D, the beam is brought up to point E, and the
second field is begun. The visible portion of the latter field is
completed at point F, the end of a complete horizontal line, and
is returned to point A to repeat the entire sequence. These
events are mentioned here for review. The reasons for employ-
ing this particular method of scanning were explained in Chap-
ter 1.

When the beam is blanked out at the bottom of an image and
returned to the top, it does not move straight up, but instead it
moves from side to side during its upward swing. The reason is
due to the rapidity with which a horizontal line is traced out as
compared to the vertical retrace period. In fact, there are ap-
proximately 20 horizontal lines traced out while the vertical
synchronizing pulses are bringing the beam back to the top of

the picture. Thus, in each field, 20 horizontal lines are lost in the blanking interval between fields. Of the 525 lines which are specified, only $525 - 2(20)$ or 485 lines are actually effective in forming the visible image.

The method for arriving at the figure of 20 horizontal lines is quite simple. The electron beam is blanked out for approximately 1,250 microseconds between fields while the beam is being shifted from bottom to top of the image. During this interval, the horizontal sweep oscillator is also active. Thus, the beam, while it moves up under the influence of the vertical deflection voltage, is also moving back and forth because of the horizontal deflection oscillator. One horizontal line requires $1/15,750$ secs or 64 microseconds. Dividing this 64 into 1,250, we find that approximately 20 horizontal lines are traced out.

Fig. 9.17. The motion of the electron beam in interlaced scanning. For simplicity, the retrace from point D to point E has been shown as a straight line.

In a frame, which contains two fields, 40 lines are thus lost. To see these retrace lines, turn up the brightness control on a television receiver when no station is being received and only the scanning raster is visible.

The fact, brought out above, that the vertical pulse is once inserted into the video signal when a horizontal line is half completed and once at the end of a complete line, necessitates a further modification of the video signal just prior to the arrival of the vertical pulse. A serrated video signal for each case is illustrated in Fig. 9.18. The half-line difference between the two diagrams may not affect the horizontal synchronizing generator operation, but it can cause the vertical oscillator to slip out of control.

To have the vertical pulse oscillator receive the necessary triggering voltage at the same time after every field, a series of six equalizing pulses is inserted into the signal immediately be-
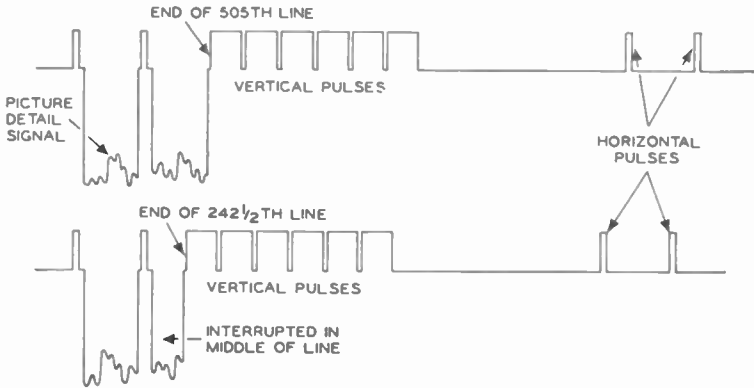
FIG. 9.18. The form of the video signal at the end of 242½ and 505 lines. The equalizing pulses are not shown here.

fore and after the vertical synchronizing pulses. These equalizing pulses, shown in Fig. 9.19, do not disturb the operation of either oscillator (as will be shown later), yet they do permit the vertical pulse to occur at the correct time after every field.
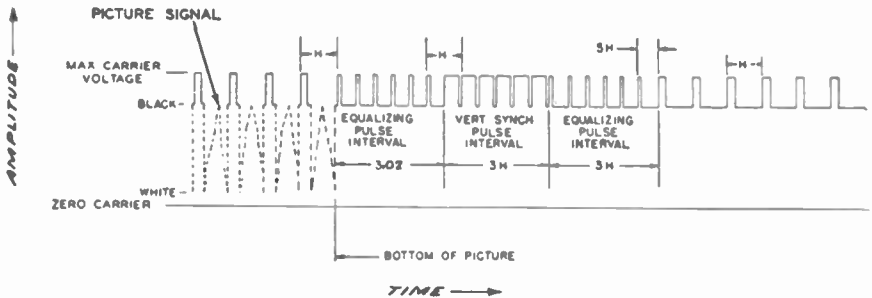
FIG. 9.19. The position of the equalizing impulses in the video signal.

Once the serrated vertical pulse is ended, the six equalizing pulses are again inserted in the signal, and the line detail assumes control while the next field is swept out. One vertical

pulse occurs at the end of every 262½ lines, while a horizontal
pulse appears at the end of each line.

Vertical and Horizontal Separation.   The separation of the
vertical and horizontal pulses from each other is based on their
frequency (or wave form) difference and not on their amplitude
since the latter is the same for both.   The two pulses are com-
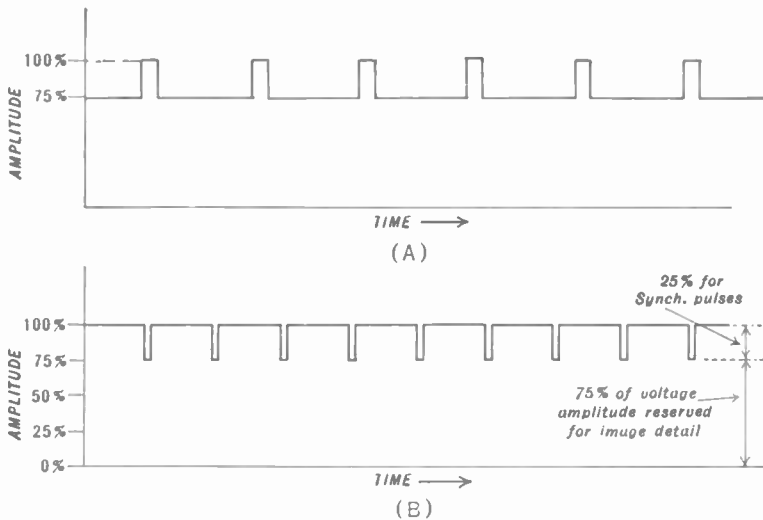
FiG. 9.20.   A comparison of the waveforms of horizontal (*A*) and vertical (*B*)
pulses.

pared in Fig. 9.20.   Note that the horizontal pulse is much
shorter in duration than the vertical pulse, rising and falling in
5 microseconds.   Essentially, then, a low-pass filter will develop
the vertical pulse voltage at its output, while a high-pass filter
will have only the horizontal pulse voltage at its output.   These
two distinct pulses can then be fed to their respective oscillators,
controlling them in accordance with the dictates of the signal
being received.

The operation of a filter and its effect on a wave are not diffi-
cult to understand.   The filters employed separate the vertical
and horizontal pulses from each other and then modify their

waveform so that they are suitable for controlling the frequency of the oscillators that follow. To see how this occurs, let us apply a square-top pulse to the high-pass filter shown in Fig. 9.21, the output being obtained from the resistor.

At the application of the first edge of the square-wave pulse (known as the leading edge), a momentary flow of current takes place through the resistor to charge the condenser fully to the value of the applied voltage. Once the full value is reached, nothing further occurs all along the flat portion of the pulse
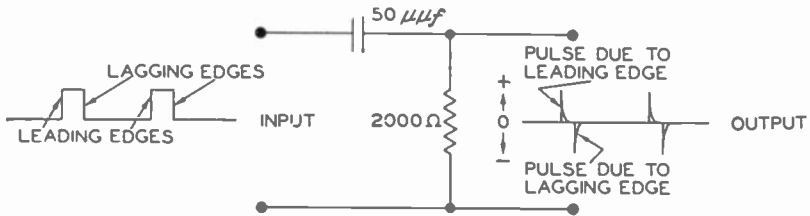
Fig. 9.21. A high-pass filter and its effect on the horizontal synchronizing pulses.

because a condenser (and hence, a condenser and resistor in series) reacts only to changing (or a-c) voltages, not to steady (or essentially d-c) voltages. The voltage along the flat top of the pulse is steady. At the next (or lagging) edge of the pulse, where the voltage drops suddenly, another momentary flow of current takes place, this time in the opposite direction, discharging the condenser. The result of the application of the square-wave synchronizing pulse to the input of the high-pass filter is the output wave indicated in Fig. 9.21.

Each incoming synchronizing pulse gives rise to two sharp pulses at the output of the filter, with one above and one below the reference line. This, of course, is due to the fact that one is obtained when the front edge of the incoming pulse acts on the filter and one when the lagging edge arrives.

For control of the sweep oscillator, only one of these two output pulses is required. If the first pulse at the output of the filter is negative (below the line) and a positive pulse is required, the conversion is readily made. Merely apply these pulses to

an amplifier and the first pulse becomes positive. The amplifier introduces a phase shift of 180°, which is equivalent to reversing every value in a wave. The oscillators that are used, either the blocking or multivibrator types, respond to the first pulse, becoming insensitive immediately thereafter to other pulses that do not occur at the *proper point* in the oscillator fre-
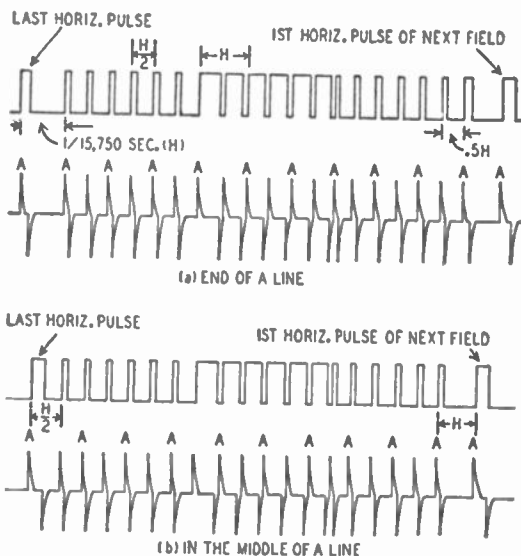
FIG. 9.22. Conditions during vertical pulses. The pips labeled "A" control the horizontal sweep oscillator.

quency interval. When the next horizontal pulse arrives, it is again in position to control the oscillator action. In this manner, any pulse occurring at an intermediate interval is without effect. One or two exceptions to this will be noted later.

The foregoing action of a high-pass filter indicates how the serrations of the vertical pulse permit control of the horizontal synchronizing oscillator during the application of the vertical pulse. In Fig. 9.22 are shown the input wave and the output pulses of a high-pass filter. Of all those present, only the positive pulses that occur at the proper time (1/15,750 of a sec) affect the horizontal oscillator. These active pulses are indi-

cated by "A" in the figure. Note that all active pulses are evenly spaced and differ by 1/15,750 sec. The conditions shown in Fig. 9.22A occur only when the vertical pulses are inserted at the end of a line. Fig. 9.22B shows the situation when the field ends on a half line. Now the same equalizing and serrated pulse pips are not active in controlling the horizontal oscillator. Because of the difference in field ending, the control has shifted to those pips which were inactive in Fig. 9.22A. However, the shift has in no way interfered with the timing in the control pips. This shift from field to field illustrates why all the equalizing and vertical pulses are designed to produce pips twice in each horizontal line interval.

The long vertical pulses are without effect on this filter because of its small time constant and, further, because the output is obtained from across the resistor. As soon as a vertical pulse is applied across the terminals of the filter, a short, sharp, current fully charges the condenser. With the condenser charged to the full voltage value, no further current flows through the resistor until another change occurs. The output is taken from across the resistor and, with current flowing only a very short time, a short, sharp pulse of voltage is obtained. At the lagging edge of the input wave, another quick flow of current brings the condenser voltage back to its previous value and again a voltage pulse develops across the resistor. Hence, only *changes* in the input wave appear across the output resistor, because it is only at these times that a current flows in the filter, either to charge or discharge the condenser. The serrations inserted in the vertical pulse provide the changes that cause current to flow in the high-pass filter. Thus control can be maintained at the horizontal oscillator even when the vertical pulse is acting.

Vertical Pulse Filters. For vertical pulse separation, we use a low-pass filter of the type shown in Fig. 9.23. This is identical with the high-pass filter, except that the positions of the condenser and resistor have been interchanged and the output is obtained from the condenser. Besides the difference of position, the time constant of the condenser and resistor is much greater

than that of the previous filter. A long time constant means that the condenser will charge and discharge slowly and will not respond as readily as the previous filter to rapid changes in voltage. Hence, when a horizontal pulse arrives at the input of this filter, its leading edge starts a *slow* flow of current through the resistor, and the condenser begins to charge. But this charging process is slow and, almost immediately afterward, the lagging edge of the wave reaches the filter and reverses the current flow, bringing the condenser back to its previous value. Very little
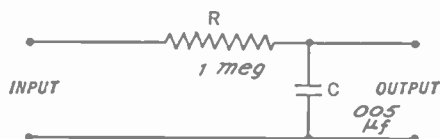
FIG. 9.23. A low-pass filter. The condenser combines (or integrates) all the serrated vertical pulses until the output voltage rises to the necessary level where the vertical synch oscillator will react.

change has occurred during this short time interval. And the vertical synchronizing oscillator is designed so that it does not respond to these small fluctuations.

What is true of the effect of the horizontal pulses on the vertical filter is even more true with respect to the equalizing pulses, which rise and fall much more rapidly. Essentially, then, we have eliminated the possibility of the higher frequency pulses affecting the operation of the vertical synchronizing generator. Fig. 9.24 shows the output voltage of the filter on the application of these higher frequency waves. Their voltage level is below the dotted line which represents the point that the voltages must reach in order to affect the generator.

The building up of the voltage across the condenser for the output begins when the serrated vertical pulses are reached. Even though the pulse is serrated, it still remains above the reference line for a relatively long time. The condenser charges slowly in the manner indicated in Fig. 9.24. The small notches in the wave are due to the serrations. At these points, for a

small fraction of a second, the voltage drops and then rises again. As previously noted, these changes affect the horizontal filter but leave the vertical filter output substantially unchanged because of their rapid disappearance.

Equalizing Pulses. We can pause for a moment here and determine more clearly the reason for the equalizing pulses. In Fig. 9.25 is shown the build-up of vertical deflecting voltage across the output of the vertical filter, once for the vertical pulse
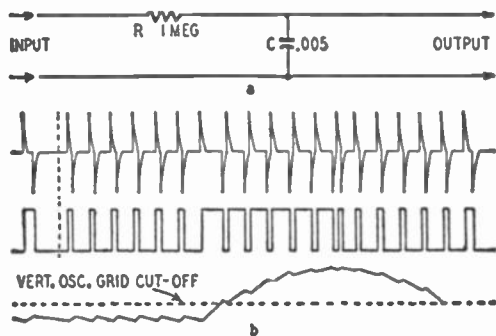
FIG. 9.24. (a) Low-pass filter for separating the vertical and horizontal pulses; (b) the waveform of the rise in voltage across the condenser due to vertical pulses.

that comes at the end of a line, and once for the pulse that comes in the middle of a line. In the top illustration of Fig. 9.25, we see that each horizontal pulse causes a slight rise in voltage across the output of the vertical filter, but this is reduced to zero by the time the next pulse arrives. Hence there is no residual voltage across the vertical filter due to the horizontal pulses. Only when the long, serrated vertical pulse arrives is the desired voltage increase obtained.

However, the situation in the lower illustration of Fig. 9.25 is slightly different. Here the last horizontal pulse is separated from the first vertical pulse by only half a line. Any horizontal voltage developed in the vertical filter will thus not have as much time to reach zero before the arrival of the first vertical pulse. This means that the vertical build-up does not start from zero, as in the top illustration, but from some small voltage

value. As a result, the dotted line is reached sooner than if the voltage rise had started from zero. Since the dotted line represents the firing point of the vertical oscillator, we see that this oscillator is triggered a small fraction of a second too soon. The time actually involved is quite small, but it does prove sufficient to upset the precision interlacing of modern television images.
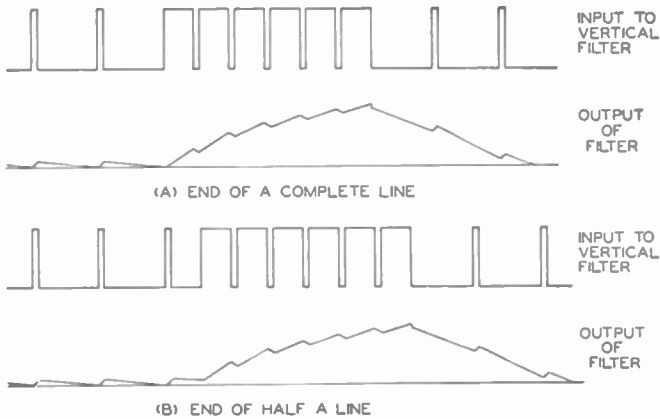
Fig. 9.25. The difference in voltage conditions before a vertical pulse when no equalizing pulses are used.

With the insertion of equalizing pulses before and after every vertical pulse, the voltage level established before the start of each vertical serrated pulse is essentially the same, and the vertical oscillator is triggered at the proper moment in each instance.

After the complete vertical pulse has passed through the filter, the charge on the condenser output gradually returns to the small value it had previously, the voltage due to the horizontal pulses (see Fig. 9.24). These pulses develop a very small voltage, far from sufficient to affect the vertical oscillator. Only the larger, longer vertical pulse $\frac{1}{60}$ of a second later can accumulate enough voltage to trigger the oscillator.

From a comparison of the vertical and horizontal pulse forms shown in Fig. 9.21 and 9.24, we may get the impression that the

vertical pulse is not very sharp. This is because the vertical pulse is shown extended over quite a few horizontal pulses and the comparison exaggerates the extent of the vertical pulse. If the vertical pulse were drawn to a larger interval, then it too would appear sharp. So far as the vertical synchronizing oscillator is concerned, this pulse occurs rapidly and represents a sudden change in voltage.

The polarity of the pulses, as obtained at the output of their respective filters, may or may not be suitable for direct application to the controlled synchronizing oscillators. It all depends upon the type of oscillator to be controlled. For a blocking oscillator the leading pulse must be positive. Since the polarity of the pulse is negative at the output of the synchronizing clipper, and consequently also negative at the output of either filter, a reversal of 180° must be introduced. This is accomplished by applying the pulse to an amplifier before application to the oscillator. If a multivibrator type of oscillator is employed, either a positive or negative pulse may be used, depending upon where it is introduced. This will be more fully developed presently.

Synchronizing Oscillators. From the block diagram of the components of the synchronizing section of a receiver (Fig. 9.1), we see that the oscillator is the next stage in the path of the synchronizing pulse. Before actually studying the operation of the stage itself, let us first review its function.

The electron beam must move across the screen at the regular rate of 15,750 times a second. Its path, as explained in Chapter 1, is not straight across the screen, but tilted slightly downward. At the end of the line, it is brought rapidly back to the left-hand side of the screen. The type of voltage at the horizontal and vertical deflecting plates that will accomplish this distinct motion is the saw-tooth wave drawn in Fig. 9.26. This wave gradually rises linearly and then, when it reaches a certain height, returns rapidly to its starting value.

A condenser, connected to a battery (or other source of sup-

ply) through a resistor, will gradually charge in a manner approximately as shown in this figure. When the condenser voltage reaches a predetermined value, a pulse from the oscillator completely discharges it and the voltage build-up begins again. Without going much further into this sequence at this point, we see that the pulse from the synchronizing oscillator controls the action of the charging condenser and, through it, the action of the electron beam across the screen. The oscillator itself is controlled by the pulse in the television signal. In this way the entire network is tied together and coordinated.

It may perhaps occur to some that if the function of the synchronizing oscillator is merely to transmit pulses along to the charging condenser, would it not be possible to apply the synchronizing pulses directly, without the intervening oscillator. The answer is Yes. However, the reason this is never done in practice is because

Fig. 9.26. A saw-tooth wave. Either the voltage or the current may assume this form.

there are times when no television signal is being received or when the signal is so weak that its pulses are not strong enough to actuate the condenser. At these times, and with no oscillator, the electron beam would just remain at one point on the screen. The result—a burned out screen. With an oscillator, though, the electron beam is continually swept across the screen, signal or no.

The Blocking Oscillator. The blocking oscillator is one of two popular synchronizing oscillators used in modern television receivers. In common with all oscillators, feedback of energy from the plate to grid must occur. A transformer is employed for this purpose. Any change of current in the plate circuit will induce a voltage in the grid circuit which will act to aid this change. To examine this situation in detail, consider the operation of the oscillator when a disturbance occurs in the circuit acting to increase the plate current. To aid this increase, a positive voltage is induced in the grid through transformer T (see Fig. 9.27A). With the grid more positive than before, more

plate current will flow, resulting in the grid becoming rapidly
very positive. A positive grid means that electrons will flow in
this circuit, charging condenser C_2. The electrons reaching the
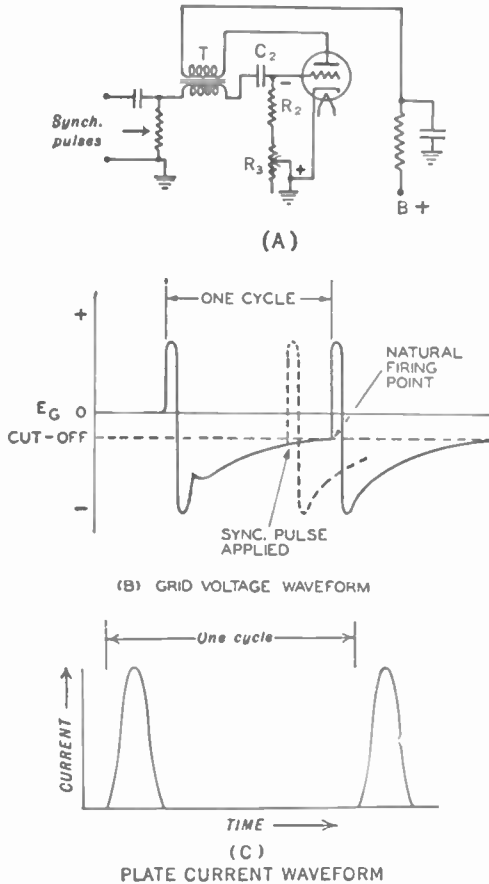
FIG. 9.27. A blocking oscillator (A). The grid voltage variations are illustrated
at (B) while the form of the plate current is given at (C).

grid pile up on the right-hand plate of C_2. With resistors R_2
and R_3 low in value, the charge on the condenser would leak off
rapidly and the action of the oscillator would continue. In prac-
tice, however, R_2 and R_3 are made high, combining with C_2 to

give a long time constant. The electrons on C_2 discharge slowly to the cathode, placing a negative voltage on the grid, as shown in Fig. 9.27A.

Because of the slow discharge of C_2, electrons which have accumulated on the grid remain there in sufficient numbers to give it a large negative bias, sufficient to block or stop the plate current flow. Gradually the electrons accumulated on C_2 pass through R_2 and R_3 back to the other plate of C_2. Then the negative bias on the grid slowly becomes less. When the discharge is almost complete, electrons from the cathode once again reach the plate, plate current starts up, quickly reaches its high value, drives the grid positive, and the process repeats itself. Thus, during every cycle there is a short, sharp pulse of plate current, followed by a period during which the tube blocks itself until the accumulated negative charge on the grid leaks off again. The frequency of these pulses is determined by C_2, R_2, and R_3.

The form of the voltage drop across R_2 and R_3 is shown in Fig. 9.27B. In C, the plate current pulse occurs once in every cycle. It is possible to control the frequency of this oscillator if a positive pulse is injected into the grid circuit at the time indicated in Fig. 9.27B. To be effective, the frequency of the controlling pulse must be near the free frequency of the oscillator. By free frequency, we mean the natural frequency at which it will oscillate if permitted to function alone. This is controlled by C_2, R_2, and R_3.

The point at which the synchronizing pulse should be applied to the grid of the oscillator is illustrated on the curve of Fig. 9.27B. A positive pulse, applied to the oscillator grid when it is at this point of its cycle, will bring the tube sharply out of cut-off and cause a sharp pulse of plate current to flow. Then, at the application of the negative pulse of the horizontal synchronizing voltage which follows immediately, the oscillator is no longer in any position to respond. The grid has now become so positive that it is unaffected by the second negative synchronizing pulse. It is only when the grid condenser C_2 is almost completely discharged, that any pulse will *effectively* control the

oscillator's frequency. This accounts for the firm control of the correct horizontal pulses. Equalizing pulses which occur at the half-way point in the oscillator cycle do not possess sufficient strength to bring the tube out of cut-off. It also explains why a positive synchronizing pulse is required, as stated several paragraphs before.

In short, then, it is observed that the synchronizing pulse controls the start of the oscillator's cycle. If left alone, the
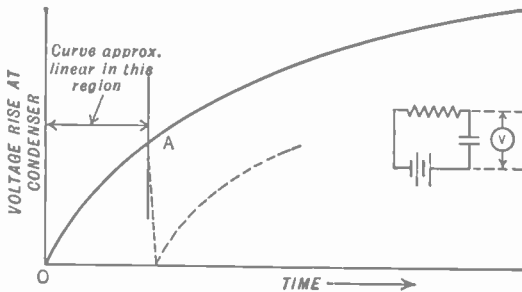
FIG. 9.28.   The manner in which a voltage across a condenser increases when a potential is applied through a series resistor.

oscillator would function at its natural period which, more often than not, would not coincide with the incoming signal. Through the intervening action of the synchronizing pulse, both oscillator and signal are brought together, in step. Naturally, for effective control, both synchronizing pulse and oscillator frequency must be close enough together to permit locking-in.

Resistor R_3 is made variable in order to provide adjustment of the oscillator frequency. It is commonly known as the "Hold Control" since it can be varied until the frequency of the blocking oscillator is held in synchronism with the incoming pulses. It is generally placed in the rear of the television receiver where a serviceman may reach it easily for any necessary adjustment.

The output from the oscillator may be taken from either the plate or the grid circuits and used directly on the charge and discharge condenser, or it may be applied through another tube. The simplest method of obtaining the saw-tooth deflection waves

is shown in Fig. 9.29. But before this diagram is analyzed, it may be helpful if we discuss briefly the saw-tooth wave and its properties.

Saw-Tooth Waves. The desired shape that the saw-tooth waves should have is shown in Fig. 9.26: a long, straight, gradual rise in voltage until a predetermined value is reached, and then a quick, sudden drop to the initial starting level. The process then repeats itself, 15,750 times a second for the horizontal oscillator and 60 times a second for the vertical oscillator.

Practically, the simplest way of obtaining the gradual rise in voltage followed by a sudden drop is by charging and discharging a condenser. If a condenser is placed in series with a resistor and a source of voltage, the flow of current through the circuit will cause the voltage across the condenser to rise in the manner shown by the curve of Fig. 9.28. This curve is not linear along its entire length, but the approximation to linearity at the beginning section of the curve is close enough for most practical purposes. Hence, if the condenser is discharged just as it reaches point A on the curve, we will have a satisfactory saw-tooth wave suitable for application to the deflecting plates of a cathode-ray tube. The discharge of the condenser should be as rapid as possible since during the time the condenser is discharging the electron beam is blanked out at the tube and no picture detail is appearing on the screen. The shorter the time spent in discharging the condenser, the greater the interval during which the useful portion of the video signal may be acting at the screen.

A simple and inexpensive method of charging and discharging a condenser to produce the necessary saw-tooth waves is given in Fig. 9.29. Triode T_1 is connected as a blocking oscillator, and the charge and discharge condenser is placed in the plate circuit. From the preceding discussion of the operation of these oscillators, we know that a short, sharp pulse of plate current flows once in every cycle. During the remainder of the time, the grid is negatively biased beyond cut-off and no current flows in the plate circuit.

Throughout the time when no plate current is flowing, con-
denser C_1 is charging because one side of this condenser connects
to the positive terminal of the power supply through resistors
R_1 and R_4, and the opposite plate of the condenser is attached
to ground. The charge this condenser absorbs assumes the
polarity shown in Fig. 9.29.

When plate current does start to flow, it is only for a very
short period, and during this time the resistance of the tube
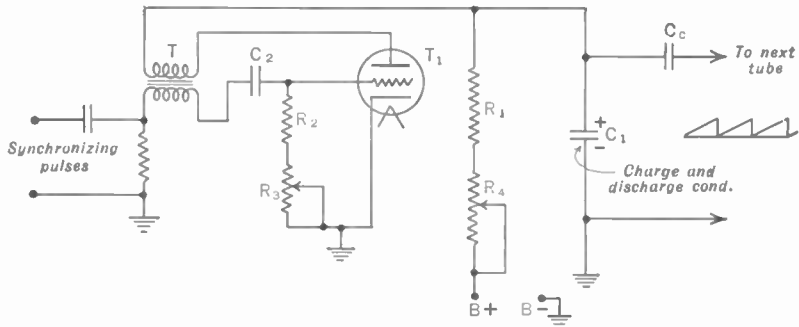
FIG. 9.29. A simple method of obtaining a saw-tooth voltage from a condenser.
This voltage, when applied across the cathode-ray deflecting plates, will control
the action of the election beam in the desired manner.

becomes very low. Condenser C_1, which is actually in parallel
with the tube, then quickly discharges through this low resist-
ance path. At the end of the short pulse of plate current, the
grid has been driven very negative by the accumulation of
electrons in C_2 and the tube becomes non-conducting again.
C_1 no longer has this easy path for discharging and slowly starts
to charge, as previously explained. The saw-tooth variation in
voltage across C_1 is transmitted to the next tube, an amplifier,
through coupling condenser C_c. The process repeats itself,
either at the horizontal scanning frequency or at the vertical
frequency, depending upon its constants.

It will be noted from the foregoing action that, the instant
the synchronizing pulse arrives at the oscillator, it triggers the
oscillator, the tube becomes conducting, and the condenser de-

veloping the saw-tooth voltage discharges. Hence, whenever a pulse arrives at the grid of the blocking oscillator, the condenser discharges and the electron beam is brought back from the right-hand side of the screen to the left-hand side. This action is true in all such synchronizing oscillators.

Resistor R_4 is made variable to permit adjustment of the width of the picture. As more of its resistance is placed in the circuit, the amount of charging current reaching C_1 is lessened, with a subsequent decrease in the voltage developed across C_1 during its period of charging. A small voltage *variation* at C_1 means, in turn, a small voltage applied to the deflecting plates. The length of the left to right motion of the electron beam is consequently shortened, resulting in a narrower picture at the viewing screen. This is the reason for labeling R_4 the "Width Control." In the vertical synchronizing circuit, this same control would affect (and adjust) the height of the picture. Here it would be labeled the "Height Control."

In many television receivers, an extra tube is used to discharge the saw-tooth voltage generating condenser. The circuit, shown in Fig. 9.30, is basically as simple as the preceding method. A 6X7 double triode is used, with the first tube functioning as the blocking oscillator. The synchronizing separator tube feeds the oscillator (through its grid circuit) the necessary pulses and synchronizes the oscillator's frequency to that of the incoming signal. The blocking oscillator then goes through its cycle, the grid becoming positive for a small fraction of a second, drawing grid current, and almost immediately thereafter developing a very negative charge that gradually leaks off through the variable resistor R_1.

The grid of the discharge tube is connected directly to the grid of the first triode and hence goes through the same voltage variations as the blocking oscillator grid. When the grid is negative, condenser C_2 is charging in the plate circuit of the discharge tube, since no plate current is flowing at this time. The condenser is charging through resistors R_2 and R_3. The moment the grids of both tubes become positive, the discharge

triode conducts, and C_2 discharges quickly. The next instant the grids are driven negative (beyond cut-off), and C_2 starts the charging process again. The remainder of the cycle is similar to that of the preceding circuit.

With the circuit of Fig. 9.30, a single tube need not be used for the dual functions of blocking oscillator and discharge tube.
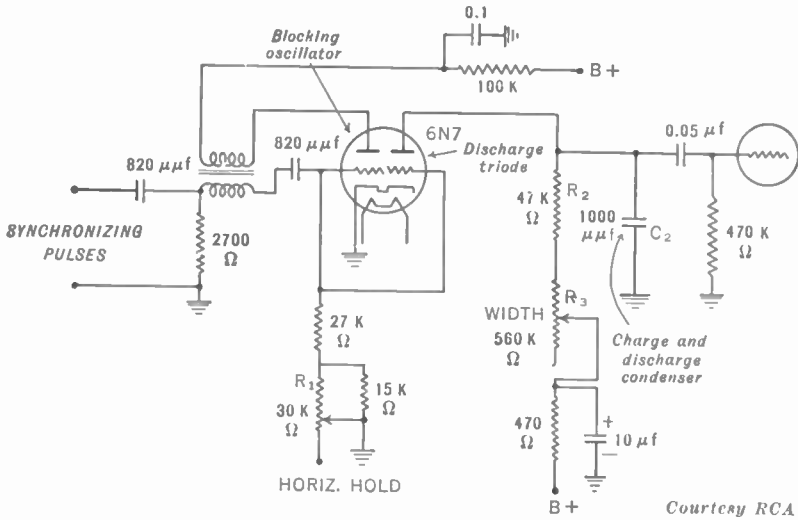
FIG. 9.30. A commercial circuit used for obtaining saw-tooth voltages in television receivers.

The use of two triodes (the two halves of 6N7) permits each circuit to be designed and operated more efficiently.

Multivibrator Synchronizing Oscillators. In addition to the blocking oscillator, multivibrator generators have been favored by some manufacturers to serve as the synchronizing oscillator. Essentially, the multivibrator is a two-stage resistance-coupled amplifier, with the output of the second tube fed back to the input of the first stage. Oscillations are possible in a circuit of this type because a voltage at the grid of the first tube will cause an amplified voltage to appear at the output of the second tube which has the same phase as the voltage at the grid of the first tube. This is always the case with an even number of re-

sistance-coupled amplifiers, but never with an odd number. The output of an odd number of such stages is always 180° out of phase with the voltage applied at the input of the first tube. The two voltages thus oppose, rather than aid, each other.

The operation of a multivibrator is best understood if we trace the voltage and current changes through the various circuit elements. To start, let us assume that the power supply has just been connected across the circuit. See Fig. 9.31. Due
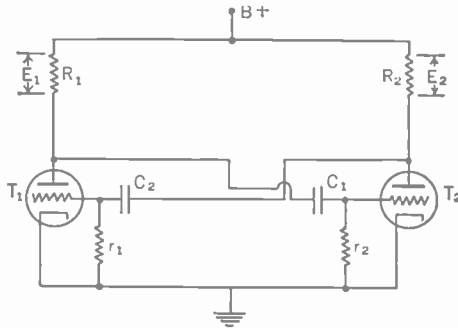
FIG. 9.31.   The fundamental multivibrator circuit.

perhaps to some slight disturbance in the circuit, the plate current of tube T_1 increases. This produces an increase in the voltage across R_1, with the plate end of the resistor becoming more negative. Condenser C_1, which is connected to R_1 at this point, likewise attempts to become more negative, and the grid of T_2 also assumes the same potential. The net result is a lowering of the current through T_2 and R_2.

The lowered voltage across R_2 means that the plate end of this resistor becomes less negative, or relatively positive to its previous value. Condenser C_2 transmits this positive increase to the grid of T_1 and, consequently, even more plate current flows through R_1. The process thus continues in this manner. with the grid of T_1 becoming more and more positive and driving the grid of T_2 increasingly negative by the large negative charge built up across r_2 and C_1. The plate current of T_2 is rapidly brought to zero by this action.

Tube T_2 remains inactive until the negative charge on C_1 discharges and removes some of the large negative potential at the grid of T_2. The path of discharge of C_1 is through the relatively low resistance r_p of tube T_1 and the relatively high resistance r_2. When C_1 has discharged sufficiently, plate current starts to flow through R_2, causing the plate end of the resistor to become increasingly negative. This now places a negative charge on the grid of T_1, and the plate current through R_1 decreases. The lessening of the voltage drop at R_1 causes the plate end of the resistor to increase positively, and the grid of T_2 (through C_1) receives this positive voltage. The increased current through R_2 quickly raises the negative grid voltage on T_1 (through C_2) and drives this tube to cut-off. When the excess charge on C_2 leaks off, the process starts all over again. C_2 loses its accumulated negative charge by discharge through r_p of T_2 and r_1. Contrast this path with that of C_1.

The entire operation may be summed up by stating that first the plate current of one tube rapidly rises, driving the second tube to cut-off. This condition remains until the second tube is released from its cut-off state and commences to conduct. It is now the first tube which is cut-off. When the first tube is again permitted to conduct, the second tube is driven into nonconduction. The switching continues in this manner, with the frequency largely determined by the grid resistors and condensers, r_1, r_2, C_1, and C_2.

If a synchronizing pulse is applied to either of the grids, and if its frequency is close to the natural frequency of the oscillator, it is possible to control the period of the multivibrator effectively.

Fig. 9.32 illustrates how the multivibrator may be employed to control the charge and discharge of a condenser, thereby developing the required saw-tooth voltages. The same multivibrator is used, with the addition of the charge and discharge condenser C_3. When tube T_2 is not conducting, the power supply will slowly charge C_3 through resistor R_2. The moment that the grid voltage of T_2 reaches the cut-off point of the tube,

the tube starts to conduct and its internal resistance decreases. Condenser C_3 then discharges rapidly through the tube. During the next cycle, T_2 is again non-conductive, and again C_3 slowly charges. C_4 transmits the voltage variations appearing across C_3 to the next amplifying tube. Resistor r_2 is made
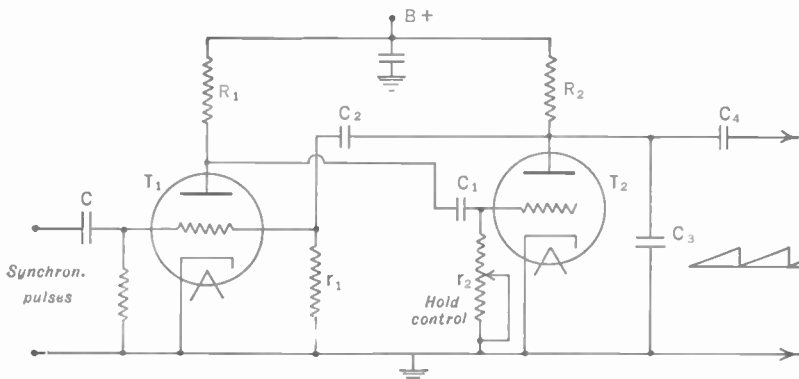
Fig. 9.32. How a multivibrator may be connected to control the charging and discharging of a condenser to derive saw-tooth waves.

variable to permit adjustment of the multivibrator so that it can be locked in with the synchronizing pulses. Hence r_2 is the hold control.

TYPICAL VALUES OF COMPONENTS SHOWN IN FIG. 9.32

60 Cycles	*15,750 Cycles*
T_1—½6SN7, 6N7, 6F8	T_1—½6SN7, 6N7, 6F8
T_2—⅙6SN7, 6N7, 6F8	T_2—⅙6SN7, 6N7, 6F8
r_1—2.2 megohms	r_1—220,000 ohms
r_2—1.0 megohms	r_2—100,000 ohms
R_1—100,000 ohms	R_1—47,000 ohms
R_2—2.2 megohms	R_2—500,000 ohms
C_3—0.1 μf	C_3—500 $\mu\mu$f
C_1—.01 μf	C_1—.001 μf
C_2—.05 μf	C_2—.005 μf

The desired form of the saw-tooth synchronizing pulses is a slow rise in voltage, followed by a rapid decrease. Toward that end, C_1 and r_2 of Fig. 9.32 are designed to have a considerably longer time constant than C_2 and r_1. C_1 and r_2 will discharge

slowly, maintaining T_2 in cut-off while C_3 slowly charges. During this interval, T_1 is conducting. Upon the application of a negative synchronizing pulse to the grid of T_1, this tube is forced into cut-off, while T_2 rises sharply out of cut-off and into conduction. C_3 now discharges rapidly. Because C_2 and r_1 have a small time constant, T_1 does not remain cut-off very long and as soon as C_3 has discharged, T_1 begins to conduct, again cutting off the plate current of T_2. The ratio of the time constants of C_1, r_2 and C_2, r_1 is in the vicinity of 9 to 1.

In many commercial receivers, a slightly altered form of multivibrator circuit is used, although the basic operation remains the same. This oscillator is shown in Fig. 9.33. Feedback between tubes is accomplished in two ways: through the coupling condenser C_1 and the unby-passed cathode resistor, which is common to both tubes.

The charge and discharge condenser C_2 is placed in the plate circuit of the second triode. During the portion of the multivibrator cycle when triode T_2 is not conducting, C_2 is essentially across the power supply and charges through resistors R_1 and R_2. When a sharp negative pulse of voltage is applied to triode T_1, the plate current of this tube decreases, causing the plate end of resistor R_3 to become increasingly positive. As the grid of T_2 is connected to this part of R_3, it too will become more positive. The plate current through T_2 will rise sharply, developing enough voltage across the common cathode resistor to bring T_1 to cut-off. T_2, however, continues to conduct because its grid has received sufficient positive voltage from the potential variation across R_3 to partially counteract this high negative cathode bias. T_1, not having this positive grid voltage, is forced into cut-off. During this period, when T_2 is conducting heavily, its internal resistance is low and C_2 discharges through it.

The high positive voltage on the grid of T_2, which resulted in a large plate current flow for an instant (and permitted C_2 to discharge), makes the grid draw current. This immediately biases the grid to cut-off (similar to the blocking oscillator).

brings T_1 out of cut-off, and permits C_2 to charge again. Resistor R_4 is made variable to permit adjustment of the frequency of the multivibrator. R_2 controls the amount of the charging
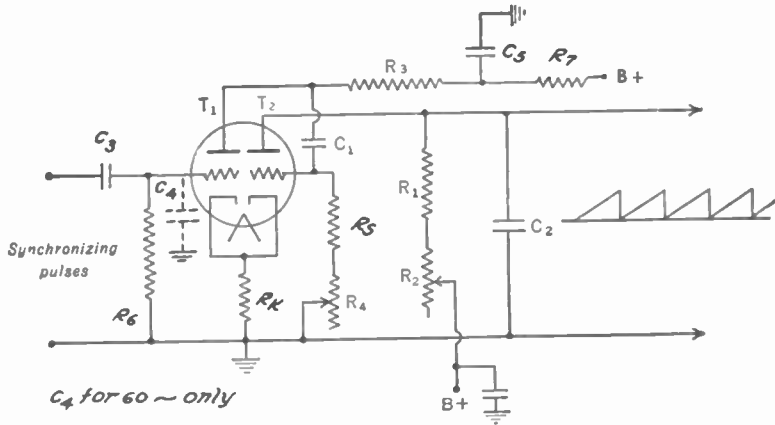
Fig. 9.33.   Another widely used form of multivibrator. This is known as a cathode-coupled multivibrator.

current flowing into C_2, and this in turn regulates the extent of the electron beam sweep across the screen. It is the width control.

TYPICAL VALUES OF COMPONENTS SHOWN IN FIG. 9.33

60 Cycles	15,750 Cycles
T_1 6SN7 / 6N7, T_2 6F8	T_1 6SN7 / 6N7, T_2 6F8
R_1—1.0 megohm	R_1—470,000 ohms
R_2—2.0 megohm	R_2—500,000 ohms
R_3—100,000 ohms	R_3—47,000 ohms
R_4—1.2 megohms	R_4—50,000 ohms
R_5—1.2 megohms	R_5—33,000 ohms
R_6—2.2 megohms	R_6—2,000 ohms
R_7—100,000 ohms	R_7—100,000 ohms
C_1—.01 μf	C_1—.001 μf
C_2—.1 μf	C_2—500 $\mu\mu$f
C_3—.01 μf	C_3—50 $\mu\mu$f
C_4—.001 μf	C_4—not necessary
C_5—.1 μf	C_5—.006 μf
R_k—470 ohms	R_k—470 ohms

Here, as before, the incoming synchronizing pulses serve to alter slightly the time at which a flip-over from one tube to the other takes place. Without these pulses, each tube would conduct for a portion of the cycle, just as in the case of the previous multivibrator.

While a negative synchronizing pulse at the grid of T_1 will cause C_2 to discharge, we may obtain the same effect if a positive synchronizing pulse were fed to the grid of T_2. The negative pulse, however, results in a more stable arrangement and is generally used. This fact explains the statement made several paragraphs before when it was pointed out that either a positive or negative synchronizing pulse could be used to actuate a multivibrator. For the blocking oscillator, it will be remembered that a positive pulse was required.

The phrase "synchronizing an oscillator" is quite frequently used when describing the operation of television circuits. There are, however, many technicians who are not completely clear as to the exact mechanism of this synchronization. To clarify this point the following explanation is offered.

In a television receiver, the pulses of the incoming signal take control of the free-running sweep oscillators and lock them into synchronism with the pulse frequencies. We are referring, of course, to the horizontal and vertical synchronizing pulses. It is highly improbable that the first pulse, when it reaches the oscillator, arrives at such a time as to force the free-running oscillator exactly into line. Generally, this does not occur until after several pulses of the incoming signal have reached the sweep oscillator. Let us examine the means whereby the receiver oscillator is gradually forced into synchronization with the incoming pulses.

In order to synchronize an oscillator, the pulses must be applied to the oscillator input. In Fig. 9.34 we have the grid voltage waveforms of a multivibrator and, beneath them, the triggering pulses as they are received from the preceding pulse separator networks. Suppose the first pulse, at A, arrives at a time when the grid is quite negative and thus this pulse is un-

able to bring the tube out of cut-off. The second pulse, at B, arrives when the tube is conducting. Thus, it drives the grid more positive and has very little effect on its operation. The conditions for the third pulse are similar to those for the second pulse. The fourth pulse, at D, arrives at a time when the grid of the tube is negative. However, this pulse is able to drive the grid positive, thereby initiating a new cycle. Thereafter, each succeeding pulse arrives at a time when it will bring the tube out of cut-off and the sweep oscillator is securely locked in as
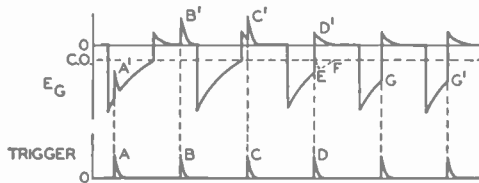
Fig. 9.34. Illustrating how the incoming pulses lock-in the synchronizing oscillators.

long as the pulses are active. It is important that the pulse reach the grid of the oscillator when it can raise the tube above cut-off. Unless it can do this, it will be without power to lock in the oscillator.

One final word about the foregoing oscillators. As the grid voltage approaches the cut-off value, it becomes increasingly sensitive to noise pulses which may have become part of the signal. A sufficiently strong interference pulse, arriving slightly before the synchronizing pulse, could readily trigger the oscillator prematurely. When this occurs, the electron beam is returned to the left-hand side of the screen before it should and the right-hand edge becomes uneven. Severe interference causes sections of the image to become "torn" (see Chapter 15). To prevent this form of image distortion, many television receiver manufacturers have designed synchronizing systems which respond only to long period changes in the pulse frequency. Since interference flashes seldom have regular pattern, they cannot affect these special systems. Several such systems are analyzed in Chapter 10.

We have now completed a description of each of the components of an ordinary television synchronizing section. In the next chapter several commercial synchronizing systems are examined in detail to illustrate how the various components are combined to form an integrated unit.

CHAPTER 10

DEFLECTING SYSTEMS

An Electrostatic Deflection System. The schematic of an electrostatic deflection system is shown in Fig. 10.1. This circuit was chosen for analysis because it is representative of many of the electrostatic deflection systems found in television receivers.

We pick up the signal path at the grid of the final video-frequency amplifier. The video signal is amplified by the tube and applied to the cathode of the image tube and to a 6AU6 pentode functioning as a d-c restorer and sync separator. This portion of the circuit was previously described in Chapter 9, and it was then shown that a d-c restoration voltage would develop across the cathode resistor of the 6AU6 while, at the same time, only the vertical and horizontal sync pulses would pass through the tube and appear in the plate circuit. The sync pulses are then fed to the vertical and horizontal deflection systems. Thus far, note that we have only achieved sync pulse separation from the rest of the video signal. The vertical and horizontal sync pulses have not been separated from each other.

The d-c restoration voltage is applied to the grid of the cathode-ray tube, while the complete video signal is received by the cathode of the tube. This arrangement is employed here because the video signal polarity, at the output of the video amplifier, is such that the sync pulses are positive with respect to the rest of the signal.

To separate the vertical and horizontal sync pulses, integrating and differentiating filters are placed before the vertical and horizontal oscillators respectively. The differentiating network inserted in the grid circuit of the horizontal multivibrator con-

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Fig. 10.1. A complete electrostatic deflection system.

sists of a 220-$\mu\mu$f condenser and a 4,700-ohm resistor. The integrating network placed in the signal path leading to the vertical sweep oscillator (also a multivibrator) consists of two 4,700-ohm resistors and two 0.005-μf condensers. With these filters, only the proper sync pulses reach each sweep oscillator.

Turning our attention first to the horizontal sweep system, we see that it consists of two duo-triodes (12SN7's). The first 12SN7 is the multivibrator, operating at a frequency of 15,750 cycles. A 250,000-ohm potentiometer permits variation of the horizontal frequency and is the hold control. The saw-tooth deflection voltage is developed across C_1 in the plate circuit of the second triode section of V_1. A width control regulates the amount of voltage developed across the condenser. One triode section of V_2 receives the saw-tooth voltage, amplifies it, and applies it to one horizontal deflection plate of the 7JP4 image tube. The same triode also feeds a small portion of this voltage to the second triode section of V_2, whose plate is connected to the other horizontal deflection plate in the cathode-ray tube. In this manner, push-pull deflection is achieved.

The vertical system, containing V_3 and V_4, is almost identical in design. A 1-megohm potentiometer in the multivibrator circuit controls the vertical sweep frequency, and a 10-megohm potentiometer regulates the height of the image. C_2 is the charge and discharge condenser, developing the necessary saw-tooth deflection voltage which, after passage through V_4, is applied equally, but in opposite phase, to the vertical deflection plates in the 7JP4. A variable resistor, R_1, serves as the vertical linearity control. Its function is to correct the shape of the saw-tooth waves so that they rise more linearly. The name of the control is derived from this action. The need for correction arises from the tendency of the charging voltage across C_2 to increase in a manner not quite linear. This fact was pointed out in a preceding paragraph where it was stated that, if only a very small portion of the curve were used, the resulting wave would be satisfactory. This situation is still true. However, if only the most linear portion of the charging curve is

used, the voltage developed across the charging condenser is small. This requires a considerable amount of amplification, accomplished only through additional amplifiers. As a practical solution it is customary to permit the voltage across the charging condenser to extend somewhat beyond the linear portion, and to compensate for this non-linearity by a special control. Good results are obtained in this manner and one push-pull stage of amplification following the charge-and-discharge condenser is usually sufficient.

In this system, R_1 regulates the amount of voltage fed back from the output of the vertical sweep amplifiers to the input and in this way is able to offset tapering or rounding off of the deflection voltage developed across C_2.

In both multivibrators (V_1 and V_3), the grid and cathode of each triode section are both returned to -140 volts instead of to ground. Since the voltage is applied equally to both elements, it does not constitute a grid bias voltage. Instead, it is used here, in conjunction with a positive 400 volts applied to the plates of the tubes, to provide an effective plate voltage of 540 volts. Thus a fairly linear saw-tooth voltage of large amplitude can be developed across C_1 and C_2.

In addition to the saw-tooth deflection voltages, each of the deflection plates receives a d-c voltage for the purpose of centering the electron beam. Two centering controls, one for the vertical set of plates and one for the horizontal set, permit variation of the d-c voltage on one of the deflection plates of each set. The d-c voltage on the other plate is kept constant.

The high-voltage power supply shown at the bottom of the diagram is of the R.F. type described in Chapter 8. It develops 5,000 volts which are applied to the centering controls and a bleeder network. At appropriate points along the bleeder network, voltages are tapped off for the accelerating electrode in the 7JP4 and for the first anode. The latter voltage is made variable, providing a focusing adjustment of the electron beam. Low voltages (those applied to the remaining tubes in the set) are developed separately by a power supply using diode and

selenium rectifiers. Voltages available are $+250$ volts, $+400$ volts, $+120$ volts and -140 volts. The $+250$ volts is used solely for powering the high-voltage R.F. supply.

Saw-Tooth Current Waves. Up to this point, electrostatic deflection has been described in detail. We have seen that a saw-tooth voltage wave is necessary at the deflecting plates in order to swing the electron beam properly across the screen. The simple charging and discharging of a condenser is sufficient to obtain the desired wave shape. If the same saw-tooth voltage is applied across the coils of an electromagnetic deflecting system, it will be found that the electrons no longer move across the screen in the desired manner. The reason is quite simple. In order to cause the electron beam to move slowly across the screen from left to right and then rapidly back to the left-hand side again, the beam must be subjected to a field of force that is varying in a saw-tooth wave manner. In the electrostatic case, a saw-tooth voltage at the plates will do this. In electromagnetic deflection, applying a saw-tooth voltage to the coils will not result in a saw-tooth current wave through the coils. And, since the magnetic flux varies directly with the current through the coil and not with the voltage across it, the flux variation will likewise differ from the necessary saw-tooth shape. If the charging and discharging of a condenser is to be utilized at all, then a correction becomes necessary in order that the voltage applied across the deflecting coils will develop a saw-tooth current wave.

The final form of the voltage wave applied to the deflecting coils is derived by analyzing the components of the coils and their action when subjected to voltages of various shapes. Each coil contains inductance plus a certain amount of resistance. As far as the resistance is concerned, a saw-tooth voltage will result in a saw-tooth current. For the inductance, considering a pure inductance, a voltage having the form shown in Fig. 10.2B is needed for saw-tooth current flow. Combining both voltage waves, we obtain a resultant that varies in the manner

shown in Fig. 10.2C. A voltage of this type, when placed across the deflecting coils will give a saw-tooth current, and the magnetic flux, varying in like manner, will force the electron beam to sweep across the screen properly. Note carefully that the resultant wave is not obtained by combining the two voltage waves in *equal* measure. If the deflection circuit contains more inductance than resistance, the resultant wave will be closer in form to Fig. 10.2B. On the other hand, if the resistance pre-
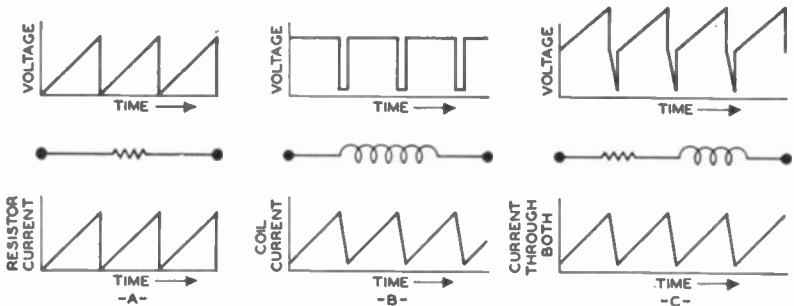
Fig. 10.2.   By applying the voltage shown above each electrical component, the saw-tooth waves shown below the component are obtained.

dominates, then the resultant wave will resemble Fig. 10.2A more.

With the correct shape of the voltage that must be placed across the deflecting coils known, the next problem is to generate the voltage. It was found that this could be accomplished readily by obtaining the output from the charging condenser and a series resistor in place of the condenser alone. The circuit is shown in Fig. 10.3. In the diagram, the condenser is charged by the current passing through resistor R_2 from the battery. During this period the voltage is rising from A to B. When the oscillator tube is triggered and the tube is conducting heavily, the plate voltage drops nearly to cathode potential. Condenser C_1 discharges during this time. The conduction time, however, is short and C_1 is unable to discharge completely before the tube is again cut-off. The plate voltage does not have to rise slowly

from cathode potential, but instead rises immediately to whatever voltage still remains across the condenser. Thereafter, it rises slowly in a fairly linear manner until the arrival of the next pulse. R_2 is made variable to permit adjustment of the output voltage so that the proper size of the image may be attained.

The only difference, it is noted, between the methods for generating suitable deflecting voltages for electrostatic and electromagnetic systems is the components at the output terminals. For electrostatic deflection, the output is taken from a con-

denser alone whereas, for the electromagnetic deflection, a series resistor is included. Either combination may be used with the blocking oscillator or the multivibrator.

An Electromagnetic Deflection Unit. The system undertaken for this analysis is shown in Fig. 10.4. A portion of the

FIG. 10.3. A common method for generating deflecting voltages suitable for application to deflecting coils.

entire video signal is taken from the plate circuit of the first video-frequency amplifier, 6AC7, and applied to the control grid of the 6SG7 sync separator, V_1. At this point, the video signal polarity is such that the sync pulses possess the most positive polarity. Since the cathode of V_1 is grounded, the tube does not have any grid bias until a signal is applied. Grid current then flows for the most positive portions of the signal (here, the sync pulses), establishing grid-leak bias across C_1 and the connecting grid resistor R_1. With the low plate voltage on the tube (9.5 volts), plate current will flow only at the most positive portions of the video signal, and only the sync pulses will appear across the plate load resistor.

The output of V_1 is now sent to two separate amplifiers. One portion of the signal goes to V_{3A} where the now negative sync pulses are amplified, inverted, and then fed to the grid of the vertical blocking oscillator V_{3B}. An integrating network consisting of R_2 (39,000 ohms) and C_2 (0.01 μf) prevents any ex-

FIG. 10.4. A complete electromagnetic deflection system.

cept the vertical sync pulses from developing enough voltage across C_2 to trigger the vertical blocking oscillator. V_{3A}, while amplifying the pulses, also functions as a clipper because of its low plate voltage (34 volts), tending further to clip off any video signal still remaining at this point in the circuit.

The vertical blocking oscillator is conventional in form, being triggered when the vertical sync pulse voltage across C_2 has attained the proper value. The peaked saw-tooth deflection wave necessary for magnetic deflection is developed across C_3 and R_3. This wave is fed to V_5, where two triode sections of a 6SN7, connected in parallel, amplify the deflection wave and then transfer it through an output transformer to the vertical section of the deflection coil. A variable resistor of 5,000 ohms is inserted in the cathode circuit of V_5 to provide control of vertical linearity. The vertical blocking oscillator contains a hold control to adjust its frequency, if the oscillator should drop out of synchronization, and a height control to adjust the vertical size of the image.

In the secondary circuit of T_1, there are two resistors and a condenser, R_5, R_6, and C_4. The function of R_6 is to permit a small current to flow through the vertical deflecting coils for centering the electron beam. A fixed tap is provided for one connection to the vertical coils, while the other end of the coil is attached to the center, movable arm. In this way it is possible to have a small current flow either in one direction or another, or to have no current at all when the movable arm is at the tap. A similar arrangement is found in the horizontal deflecting circuit (resistor R_{12}).

Condenser C_4 and resistor R_5 are designed to eliminate any tendency on the part of the deflecting coils to set up oscillations. In winding these coils, it is impossible to eliminate distributed capacitance between turns; hence the inductance of the coils and this distributed capacitance form a parallel resonant circuit (see Fig. 10.5). Every $\frac{1}{60}$ of a second, a sharp pulse of voltage develops across the circuit, and, if one of the frequency components of this pulse is near the resonant frequency of the coil inductance and distributed capacitance, oscillations will be set up. The

result is the appearance of spurious lines at the top of the image. These occur here because the oscillations are set up immediately after the pulse of voltage appears across the coils and the beam, after the pulse, is at the upper side of the screen.

By inserting a simple RC circuit in parallel with the inductance of the deflecting coils (and their distributed capacitance) it becomes possible to dampen quickly any oscillation that may be set up. As in any other parallel resonant circuit, the ampli-

FIG. 10.5. The distributed capacitance inherent in deflecting coils.

tude of the oscillations can be decreased if a relatively low resistance is placed across the circuit. The action resembles the loading of the input tuning circuits in the R.F. and I.F stages. Further damping precautions consist of R_7 and R_8, placed in parallel with each section vertical deflecting coil (there are two connected in series), and the 6SN7 output triode. Its low plate resistance affords some damping in itself.

In the horizontal deflecting system, where the pulses have higher component frequencies, it is even more important that stringent measures be taken to eliminate these unwanted oscillations.

Turning now to the horizontal sweep system, we find that the sync pulses are received by V_{2A} from V_1, amplified, clipped, and then fed through a differentiating network (R_9 and C_5) to the grid of the blocking oscillator V_{2B}. The peaked deflection voltage developed across C_6 and R_{13} is applied to V_4, a 6BG6 pentode output amplifier, and then transferred through an output transformer to the horizontal deflection coils.

The output circuit of the horizontal deflection system differs in several respects from the same portion of the vertical system. For one thing, a damping tube (V_6) is employed instead of an RC damping network. An ordinary RC parallel damping circuit would prevent very large voltages from being built up across the

coils because of its loading effect, and large voltages are required when the pulse is quickly moving the electron beam from one side of the screen to the other. Changes occur more rapidly than in the much slower moving vertical circuit. Furthermore, an RC filter at this point would lengthen the return time of the beam, an undesirable feature.

More efficient operation is obtained using V_6, whose purpose in this circuit is twofold. It functions as a damping circuit to suppress oscillations that are set up in the secondary during beam retrace, and, in addition, it converts some of the large amount of energy developed in this circuit into d-c potential which is combined with the d-c voltage of the power supply to provide an increased voltage to the horizontal output amplifier, V_4.

In order properly to interpret the action which occurs in this circuit, the following relationships within the horizontal scanning interval must be known. A complete horizontal scanning cycle requires 1/15,750 of a second, or approximately 64 microseconds. Of this, the visible portion of the horizontal trace is about 53 microseconds long. The blanking interval, then, is 11 microseconds long, and during this time the beam must be returned to the left side of the tube, the trace started and made linear. In order that all this be accomplished within the 11 microseconds, the return trace can be allotted only 7 microseconds.

During the trace period, the voltage across the yoke windings is constant, as shown in Fig. 10.6C. This will produce a linearly rising saw-tooth current in the coils. In addition, there is a small amplitude saw-tooth voltage which compensates for the resistance in the circuit. When the negative pulse of the applied wave reaches the grid of the output tube, the plate current is suddenly cut off since the tube is driven deep into cut-off.

The magnetic field, which has been steadily building up in the output transformer, begins to collapse. The rate of collapse is determined by the natural resonant frequency of the system; this is about 75 kc in order to insure a sufficiently short retrace

period. The voltage generated by the collapsing field is negative on the damping tube, preventing this tube from conducting. Thus, there is actually no load across the transformer, and the system, if left in this condition, would oscillate vigorously. This is actually done for one half cycle. At the end of the first half

(a) Grid Voltage at Horizontal Output Tube

(b) Current in Deflection Coil

(c) Voltage Across Deflection Coil
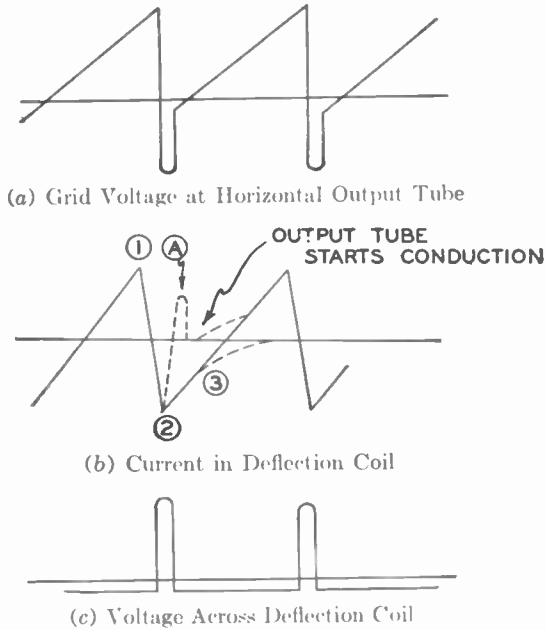
Fig. 10.6. The various current and voltage relationship in the horizontal deflection output circuit.

cycle, the yoke current reaches a maximum value in the reverse direction to which it was flowing at the end of the trace period. The induced yoke voltage now reverses polarity, and the damping tube begins to conduct. By now beam retrace has been completed and the next trace must be started.

The energy which was developed in the coil by the output tube in the latter part of the last trace has not been completely dissipated. Very little energy was lost during the first half cycle of retrace because the damping tube was non-conductive

and the circuit had few losses. When, after the first half cycle, the damping tube does begin to conduct, it places such a heavy load across the deflection coil that further oscillations are prevented. The field begins to decay at a rate determined by the load of the damping tube across the coil.

Before we proceed further, let us stop and note carefully the sequence of events. When the negative portion of the deflecting voltage drives the grid of the output tube to zero, the deflecting yoke, output transformer, and other incidental components form a resonant circuit which is shocked into oscillation. The time of a half cycle of this oscillation (75 kc) is about 7 microseconds and so the retrace occurs within its allotted time. At the end of a half cycle, the damping tube begins to conduct, causing the oscillatory voltage to decay in essentially a linear manner. Note, however, that very shortly after this the output tube begins to conduct again and this additional power in conjunction with the decay current in the deflection yoke produces a linear trace motion of the electron beam.

The waveforms in Fig. 10.6 illustrate graphically the action within the circuit. Fig. 10.6A shows the voltage applied to the grid of the horizontal output tube. In Fig. 10.6B we have the current in the deflection coil, as indicated by the heavy solid lines. At point (1), the tube is driven into cut-off, and the magnetic field collapses and reverses itself. At point (2) the retrace interval has ended, although the cathode-ray tube is still blanked out.

The dotted curve A shows what would occur if the damping tube did not begin to conduct and prevent the oscillations from continuing. From point (2) to point (3) the energy remaining in the deflection yoke is decaying in a fairly linear manner. At point (3), this energy has begun to die off, and at this moment the output tube starts once again to conduct. The resulting interaction of these two currents is a linear rise in current. This sequence of events is repeated each cycle.

The damping tube serves not only to prevent continued oscillations in the deflection coils after retrace, but also to convert

some of this energy to a useful d-c voltage. At the time the horizontal output tube is brought into cut-off, a tremendous amount of energy is in the output transformer. Part of this energy is used to bring the electron beam from the right-hand side of the screen to the left-hand side. When this has been accomplished, a considerable amount of energy remains, which would result in continued oscillations if the damping diode did not begin to conduct at this moment, not only preventing the continuance of the oscillations, but also rectifying the pulse into d-c. This rectified voltage appears across R_{10} and R_{11}, the diode load resistors, and amounts to about 70 volts. This, then, is the reason one end of R_{10} is labeled $+280$ volts, and the other end, $+350$ volts. The plate voltage for the 6BG6G tube is supplied through the damping diode, and consequently this tube receives the benefit of the additional voltage. Condenser C_7 maintains the B+ on the plate of the 6BG6G tube when the 5V4G tube is not conducting.

A small variable coil is shunted across part of the secondary winding of the horizontal output transformer, and by varying the inductance of the coil we can vary the amount of voltage developed across this winding and hence the picture width.

The high-voltage power supply derives its power from the collapse of the field in the output horizontal transformer during the retrace interval. When the 6BG6G plate current is cut off, a positive pulse appears on the primary of the output transformer. This is stepped up by auto-transformer action and rectified by the 8016 diode. Since the frequency of these pulses is 15,750 cycles per second, sufficient filtering is provided by a single 500-$\mu\mu$f condenser. The 9,000 volts generated are fed to the second anode of the cathode-ray tube by way of a side seal on the side of the tube. C_8, C_9, and L_1 filter out the 15,750-cycle ripple present in the 70 d-c volts developed by V_6.

Automatic Frequency Control Systems. Use of the incoming sync pulses to trigger and control the vertical and horizontal sweep oscillators represents the simplest, most economical, and most direct method of controlling the motion of the electron

beam in the image tube. Unfortunately, however, this method possesses limitations and disadvantages which outweigh its economy and simplicity. Perhaps the greatest disadvantage is its susceptibility to noise disturbances arising from electrical apparatus and equipment operating in the vicinity of the receiver. The noise pulses, combining with the video signal and extending usually in the same direction as the desired sync pulses, pass through the same stages as the pulses and arrive at the sweep oscillators. They do their greatest damage when they arrive during the interval between sync pulses. If the amplitude of the noise pulses is sufficiently great, they will trigger the sweep oscillator, initiating a new cycle prior to its proper time. When the vertical oscillator is so triggered, the picture will move vertically either up or down, until the proper sync pulses in the signal can again assume control. If the horizontal oscillator is incorrectly triggered, a series of lines in a narrow band will be jumbled, giving the appearance of streaking or tearing across the image. When the interference is particularly heavy and persistent, the entire picture becomes jumbled and may even be thrown out of horizontal sync permanently, requiring manual adjustment of the horizontal hold control.

Of the two sweep systems in a television receiver, interference is particularly destructive to the horizontal system. To understand why this is so, we must examine the nature of most interference voltages and their effect upon the vertical and horizontal sweep oscillators.

Whenever a blocking oscillator is triggered, for example by a sync pulse, its grid, after a short period of conduction, becomes highly negative as a result of an accumulation of electrons on the grid condenser. This negative voltage is sufficient to keep the tube beyond cut-off until the charge on the grid condenser has decreased to a value at which current is permitted once again to flow through the tube. In most circuits now in use, the condenser discharge occurs in the manner shown in Fig. 10.7. At the start, the discharge is fairly linear. However, as the amount of charge contained in the condenser decreases, the discharging

rate decreases and, for more than half the discharge cycle, may be said to be exponential. In Fig. 10.7, the exponential region extends from points A to B.

Now, when the negative charge existing on the grid condenser is large, the oscillator is relatively immune to incoming positive pulses. With continued discharge, however, the immunity decreases. Experience has indicated that off-cycle triggering of the oscillator is generally concentrated in the last 15 per cent of
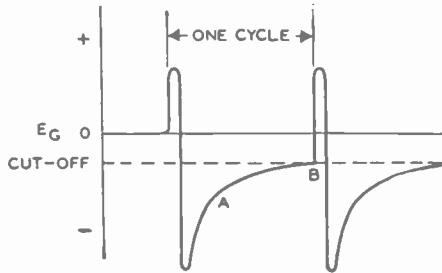
FIG. 10.7. The manner in which the grid voltage of a blocking or multivibrator oscillator varies.

its discharge cycle. This is true regardless of the frequency at which the oscillator is operating. Hence, one would expect to experience equal difficulty with both deflecting systems in the receiver. That this is not so is due to the nature of the noise pulses and the type of filters inserted before each sweep oscillator.

Noise pulses which are most troublesome to television receivers possess high amplitude, but are narrow in width or, what is the same thing, are of short duration. (The energy in noise pulses is distributed over a wide range of frequencies. In order for a peak to occur, the phase relationship among the various frequencies must be such as to permit them to add, forming the high-amplitude pulse or peak. This condition, however, usually exists only for a brief interval, which explains the narrow width of these pulses.) When the pulses reach the path leading to the horizontal sweep oscillator, they are readily passed because of the short time constant of the filter leading to the horizontal

system.   A short-time-constant filter is necessary because the horizontal sync pulses themselves have a time duration of only 5 microseconds.   On the other hand, the filters leading to the vertical system have a long time constant and automatically act to suppress the effects of all horizontal sync pulses and noise pulses of short duration.   The presence of this low-pass filter (called an integrating network) is largely responsible for the greater immunity to noise pulses enjoyed by the vertical system. Of course, when a wide noise pulse is received, it contains enough energy to cause offtime firing of the vertical oscillator, but the annoyance caused the viewer from this source is seldom great. To reduce the susceptibility of the horizontal sweep system to noise pulses of any type, several automatic frequency (and phase) control systems have recently been developed.

In each of these special control systems an oscillator is set to operate at 15,750 cycles, and the output of the oscillator controls the horizontal motion of the electron beam across the screen of the image tube.   The next step is to synchronize the frequency of this sweep oscillator with the incoming horizontal sync pulses of the signal.   This is accomplished through an intermediate stage known by one of the following names: Control tube, AFC phase detector, or horizontal sync discriminator.   Whatever the name, what this intermediate network does is to compare the frequency of the incoming horizontal sync pulses with the frequency of the receiver horizontal sweep oscillator.   If a difference does exist, then a d-c voltage is developed which, when fed back to the horizontal sweep oscillator, is used to change its frequency until this is exactly equal to that of the incoming sync pulses.

Note that the incoming sync pulses are not applied directly to the sweep oscillator.   They are merely compared (in frequency) with the output of the sweep oscillator and, if a frequency difference exists, then a d-c voltage is developed which, when fed back to the sweep oscillator, forces its frequency back into line with that of the sync pulses.

Now (and here is the crux of the whole matter), by having the

d-c control voltage pass through a long-time-constant filter be-
fore it reaches the sweep oscillator, we can eliminate the effects
of any noise impulses and permit only relatively slow changes in
frequency of the sync pulses (which may occur at the transmit-
ter) to affect the sweep oscillator. We have thus incorporated
into the horizontal sweep system a long-time-constant filter
somewhat similar to that present in the vertical sweep system.

Remember, it was the long-time-constant filter in the vertical
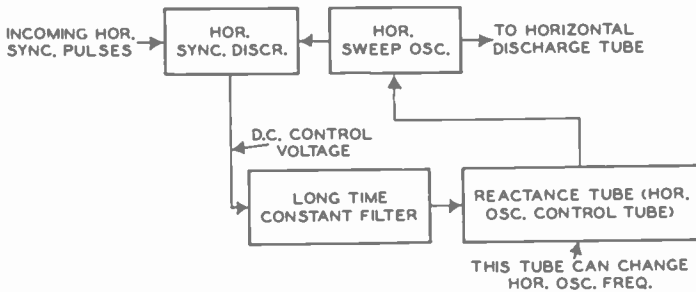
Fig. 10.8. A block diagram of the A.F.C. system shown schematically in Fig. 10.9.

sweep system that gave this network its immunity from most
noise pulses (which have a short-time duration). A long-time-
constant filter could not be used directly in the horizontal system
because it would have prevented the desired horizontal sync
pulses (together with the noise pulses) from reaching the hori-
zontal sweep oscillator. Hence the need for the indirect method
outlined above.

Now let us analyze the various automatic frequency control
systems currently in use.

Horizontal A.F.C. Systems. One of the most popular A.F.C.
systems used is shown in block form in Fig. 10.8. In this circuit,
a stable Hartley oscillator is set at 15,750 cycles per second.
Connected to the oscillator is a synchronizing discriminator cir-
.cuit which receives the pulses of the incoming television signal
and compares the frequency and phase of these synchronizing
pulses with the generated sine wave of the Hartley oscillator.
Any slight variations between the two will produce a d-c voltage

which is applied to the grid of a reactance tube after passing through a long-time-constant filter. The plate circuit of this reactance tube is connected across the tuning circuit of the Hartley oscillator, and, as the d-c voltage at the grid of the reactance tube varies, it will alter the plate current of this tube and with it the oscillator frequency. (It is suggested that the reader refer to page 105 of Chapter 4 where the operation of reactance
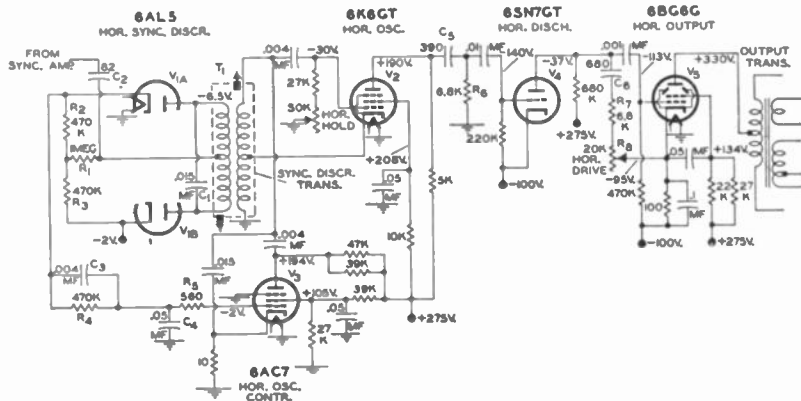
FIG. 10.9. An automatic frequency control system widely used in television receivers.

tubes was discussed. It was shown there how they could control the frequency of an oscillator.)

The schematic diagram of the circuit is shown in Fig. 10.9, with the parts allocated as follows:

1. V_{1A} and V_{1B} comprise the horizontal sync discriminator circuit.
2. V_2 is the horizontal sweep oscillator.
3. V_3 is the reactance or horizontal oscillator control tube.
4. The long-time-constant network consists of C_3, C_4, and R_4.

Now let us see how all these operate as a unit.

The sweep oscillator (V_2) is the well-known Hartley. The oscillator coil T_2 is inductively coupled to the horizontal sync discriminator by means of a center-tapped primary winding, T_1.

Each diode in the discriminator circuit is connected across half of T_1, receiving sine-wave voltages which are equal in amplitude but opposite in phase. Disregarding R_1 for the moment, the voltages appearing across T_1 will affect this circuit in the following manner:

During one half cycle, the top end of the secondary of T_1 is positive, forcing V_{1A} to conduct. Its current flows from cathode to plate, through the top half of the coil, through R_1 and R_2 back to the cathode again. The voltage developed across R_2 is such that the bottom end is negative and the cathode end is positive. Throughout this interval, V_{1B} is non-conductive because the sine-wave voltage applied to its plate is negative.

During the next half cycle, V_{1B} conducts and V_{1A} is cut off. Current now flows through this tube, up through the bottom half of the secondary winding of T_1, through R_1 and R_3 back to V_{1B} again. The voltage developed across R_3 is such that its top end is negative. If the circuit is operating properly, the voltages across R_2 and R_3 will be equal. However, when these two voltages are added, the resultant will be zero because of the back-to-back placement of the two resistors. In this circuit the voltages are added, which means that no output voltage will be obtained, using this network alone. However, inspection of the circuit reveals that the horizontal sync pulses are also added to this circuit by means of C_2 and R_1. C_2 connects to the output of the sync separator and transfers the horizontal pulses appearing here to R_1 where both V_{1A} and V_{1B} receive this pulse voltage in equal amplitude and phase. Now, let us see how this alters circuit operation.

A horizontal sync pulse can arrive at one of three times. It can appear across R_1 when the sine-wave voltage at T_1 is zero; it can arrive when V_{1A} is conducting; or it can arrive when V_{1B} is conducting. If the pulse arrives when the sine wave applied to each tube is passing through zero, there will be no change in circuit conditions. The incoming synchronizing pulse appears across R_1 and combines with the sine-wave voltage from each half of the secondary coil T_1 to form the driving voltage for each

diode. If the pulses arrive when the sine-wave voltage across T_1 is zero (Fig. 10.10A), then each diode will receive the same pulse voltage, and the same amount of rectified voltage will appear across the diode load resistors R_2 and R_3. The total net output from both tubes will be canceled because their load resistors are connected in opposition (back-to-back).

Note again that the reason each diode produces equal voltages across R_2 and R_3 at this moment is that there is no sine-wave voltage and each tube receives the same synchronizing pulse voltage from R_1.

Suppose, however, that the pulse arrives at some other instant. Two such situations are shown in Fig. 10.10B and C. In Fig. 10.10B, the pulse arrives when the top diode is positive (and conducting) and the bottom diode is cut off. Obviously, then, there will be, on the average, more voltage developed across R_2 than across R_3. The average voltage, over one cycle, will be positive, and this, fed to V_3, will make its grid more positive. On the other hand, if we consider the

FIG. 10.10. Illustrating how the horizontal synchronizing discriminator separates.

situation of Fig. 10.10C, we see that R_3 will receive the greater voltage and that, on the average, the voltage from the combination will be negative. The effect on V_3 will be different in each instance. It is seen, therefore, that the double-diode arrangement of V_1 is a very sensitive phase discriminator and will develop an output voltage which may be negative, zero, or positive, depending upon the phase of the pulses with respect to the voltage generated by the Hartley oscillator.

The d-c voltage developed in the phase discriminator, together with a fixed negative biasing voltage (-2 volts), is applied through the long-time-constant filter of C_3, R_4, and C_4 to the

grid of a reactance tube, V_3. This tube is so connected that its plate current is 90 degrees out of phase with the voltage across it, and consequently it appears as a reactance. (How a tube can be made to function as a reactance was previously described in Chapter 4.) Since V_3 is connected directly across the tuning coil of the Hartley oscillator, changes in its plate current will produce changes in the frequency of the oscillator and force the oscillator to operate at the frequency of the synchronizing pulses. The d-c voltage developed at the phase discriminator is fed directly into the grid of the reactance tube and thereby controls the plate current flow. In this manner, all differences in frequency between the synchronizing pulses and the Hartley oscillator are instantly corrected.

C_3, R_4, and C_4 form a long-time-constant filter to block the passage of rapid changes in d.c. from the phase discriminator produced by noise pulses. Only the relatively slow changes in frequency caused by differences between the Hartley oscillator and the incoming horizontal sync pulses are permitted to reach V_3. A hold control is available in case the Hartley oscillator frequency should be too far from the frequency of the incoming pulses.

Horizontal Discharge. A horizontal discharge tube, V_4, follows the horizontal oscillator and produces, in its plate circuit, the peaked deflecting voltage which will drive the horizontal deflecting coils. In V_2, the Hartley oscillator is connected between the screen grid and the cathode. The plate circuit contains only a resistance, and consequently the waveform found here is not the symmetrical sine wave that would be produced by a resonant circuit; rather it has the form shown in Fig. 10.11A. The peak-to-peak voltage on the grid of V_2 is approximately 130 volts. This grid swing produces a square wave in the plate circuit, with a peak-to-peak voltage of 225 volts. The square wave is differentiated by C_5 and R_6, resulting in the waveform shown in Fig. 10.11B. The positive portion of the differentiated wave is sufficiently sharp to trigger the discharge tube. The discharge tube is normally at cut-off due to bias produced

by grid rectification of these pulses from the oscillator. The positive pip of the pulse overcomes this bias and drives the tube into heavy momentary conduction. During this period, the plate voltage of V_4 falls to cathode potential, and C_6 does not discharge completely because of R_7 and R_8, both of which are in series with C_6. When V_4 becomes non-conductive again, its plate voltage rises quickly to a value determined by the charge remaining on C_6. From this point the plate voltage rises slowly, and we get the desired deflection waveform. This is transferred to the horizontal output tube V_5.

General Electric A.F.C. System. Another approach to automatic frequency control of the horizontal sweep oscillator is the system shown in Fig. 10.12. V_{2A}, V_{2B}, and V_3 correct the frequency of the horizontal multivibrator, V_4, whenever it drifts away from the frequency of the incoming sync pulses. V_{2A} and V_{2B} receive voltages from the horizontal

(a) Plate of horizontal oscillator 225 volts peak-to-peak

(b) Input to horizontal discharge tube 100 volts peak-to-peak

Fig. 10.11. The various waveforms in the horizontal oscillator and discharge circuit.

sweep system and from the incoming pulses. The two voltages are compared as to frequency, and any difference produces either a positive or negative voltage at the grid of V_3. These changes are amplified and then transferred to the multivibrator, whose frequency is changed accordingly.

In detail, the automatic horizontal frequency control network functions as follows: The incoming horizontal sync pulses are transferred by means of T_1 to the two diodes, V_{2A} and V_{2B}, with the polarity as shown in Fig. 10.12. (Although V_{2A} and V_{2B} are triodes, they are connected to function as diodes.) The top end of the secondary of T_1 develops a positive pulse voltage, and the bottom end, a negative pulse. The positive pulse causes V_{2A} to conduct, and the negative pulse on the cathode of V_{2B} causes this tube to conduct also. The current flowing through V_{2A}

Fig. 10.12. The A.F.C. system employed by G.E. in their television receivers.

charges capacitor C_3 to approximately the peak value of the applied pulse while the current flowing through V_{2B} charges C_4. The polarity of each voltage is indicated in Fig. 10.12. During the interval between pulses, each condenser discharges, the electrons moving from C_3 down through R_1 and R_3 to C_4 and from the other plate of C_4 through the secondary transformer winding back to C_3. The discharge is slow and the voltages developed across R_1 and R_3 prevent V_{2A} and V_{2B}, respectively, from conducting until the arrival of the next pulse.

Feeding into this circuit is another voltage. This is a saw-tooth voltage which develops across C_5 from pulses which are applied to it from the secondary of the horizontal output transformer. This saw-tooth voltage possesses the same frequency as the horizontal sweep oscillator since it is this stage which drives the horizontal output amplifier. The saw-tooth voltage is applied in equal measure to each tube; this means that the plate of V_{2A} and the cathode of V_{2B} receive the same polarity voltage (of the saw-tooth wave) at the same time. Thus, at the discriminator, we have both the ingredients needed to check the operating frequency of the horizontal oscillator against the frequency of the incoming pulses.

The comparison of the two frequencies occurs only at the instant the sync pulses arrive, for it is only at this moment that V_{2A} and V_{2B} conduct and therefore are in a position to respond to the saw-tooth voltage. As in the previous a.f.c. circuit, three situations are possible.

First, if the sync pulses arrive at a time when the saw-tooth wave is passing through zero, then current will flow through V_{2A} and V_{2B}, recharging C_3 and C_4 for any voltage that they may have lost during the interval between pulses. This flow of current will remain within the branch of the circuit formed by the two tubes and the secondary of T_1. No voltage will appear between point A and ground to affect the d-c amplifier, V_3, and by this, the horizontal multivibrator. Actually this represents the desired condition since it indicates that the frequency of the sweep oscillator and the sync pulses are in step with each other.

The second situation occurs when the sync pulses arrive and the saw-tooth voltage is positive at this moment. Under this condition V_{2A} will receive a positive pulse and a positive saw-tooth voltage. V_{2A} will conduct more strongly than usual, with current not only charging C_3, but also flowing through R_1 to ground and from ground up through C_1, R_2, and C_2 to the cathode again. This flow of current through R_2, C_1, and C_2 will establish a voltage here which is positive with respect to ground.

At the same moment that V_{2A} is conducting more strongly, conduction through V_{2B} is reduced because the positive saw-tooth voltage partially offsets the negative sync pulse applied to the cathode of V_{2B}. Since the current flow through V_{2B} is reduced instead of increased as it is through V_{2A}, it cannot offset the positive voltage at point A. This potential, applied to the grid of V_3, increases the current through V_3, driving the plate of this tube more negative. Since the grid of the horizontal multivibrator is connected to the plate of V_3, it, too, becomes more negative, thereby altering its frequency. In this instance, the change is toward a lower frequency.

The third situation occurs when the pulses arrive and the saw-tooth voltage is negative. Now, V_{2B} conducts more strongly than V_{2A}, its current flowing not only into C_4, but also through R_2, C_1, and C_2 to ground and from here to R_3 and back to V_{2B}. The voltage developed this time at point A is negative with respect to ground which reduces the current flow through V_3 and acts to speed up or raise the frequency of the horizontal multivibrator.

Filter R_2, C_1, and C_2 responds only to slow changes, thereby preventing fast-acting noise pulses from affecting the operation of the multivibrator. V_5 is the horizontal output amplifier. It receives the peaked deflection voltage, amplifies it, and uses this voltage to drive a high-voltage rectifier (8016) and the horizontal deflection coils. The tuned circuit in the cathode leg of the multivibrator is resonant to 15,750 cycles and serves to stabilize the frequency of this unit.

D-C Control of Oscillator Frequency. In the previous A.F.C. system of Fig. 10.9, the d-c control voltage was applied to a

reactance tube and this, in turn, varied the sweep oscillator fre-
quency. In the present A.F.C. system (Fig. 10.12), the d-c con-
trol voltage developed by the sync discriminator is used directly
to alter the frequency of the horizontal sweep oscillator. This
direct method of frequency control is readily adapted to multi-
vibrators and blocking oscillators.

To understand what happens when the d-c control voltage is
applied directly to an oscillator, consider the operation of a
blocking oscillator.

It was noted in Chapter 9 that the length of time a blocking
oscillator was cut off was determined essentially by the time
constant of the grid circuit. When the grid resistor and con-
denser values are high, the charge accumulated across the grid
condenser diminishes slowly and the tube is kept cut off for a
longer period of time. When these values are low, the cut-off
interval of the tube is shortened accordingly.

If now, we raise the negative bias on the grid (by adding a
negative voltage from some external source), we can see that
to reach the cut-off bias value of the tube, using the same grid
resistors and condenser, will require a longer time than if no
such negative voltage had been added to the circuit. And if the
tube is kept cut off for a longer length of time, then obviously
the frequency generated by this oscillator will be lower.

On the other hand, injecting a small positive voltage on the
grid of the oscillator will decrease the total negative voltage
developed here by the circuit operation and permit the tube to
return to conduction sooner. The result: Generation of a higher
frequency. It is precisely in this manner that the d-c control
voltage developed by the above sync discriminator circuit varies
the frequency of the sweep oscillator. While only the action of
a blocking oscillator has been analyzed, the reasoning for a multi-
vibrator is similar.

The circuit in Fig. 10.13 is an automatic frequency control
network which operates in a manner very similar to that of the
preceding G.E. system. The incoming sync pulses are fed, in
equal amplitude but opposite polarity, to two diodes, V_2 and V_3.

The plate of V_2 receives a positive horizontal sync pulse at the same time that the cathode of V_3 is receiving a negative sync pulse from V_1. Because of the polarity of these pulses, both diodes will conduct at this instant, with the coupling condensers charging up to essentially the peak pulse value. During the interval between pulses, the two diodes will be kept cut-off.

In addition to the sync pulses, V_2 and V_3 also receive a saw-tooth voltage from the horizontal sweep amplifier. As in the
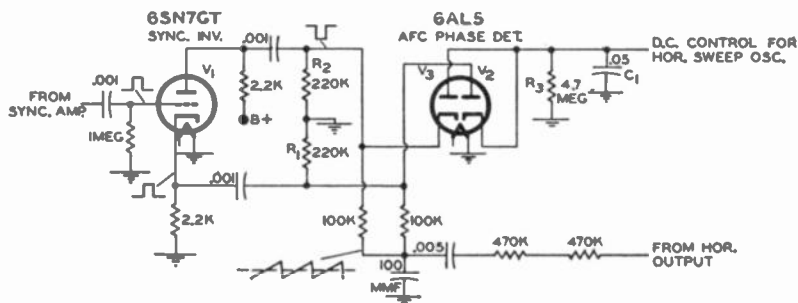
Fig. 10.13. An A.F.C. system closely similar to the one shown in Fig. 10.11.

previous system, the saw-tooth wave will be going through zero at the time the sync pulses reach V_2 and V_3 if the frequency of the horizontal sweep oscillator is properly synchronized to the incoming pulses. If a frequency difference exists, the saw-tooth voltage will not be going through zero when the sync pulses arrive. If the saw-tooth voltage has some negative value at this instant, V_3 will conduct more strongly than V_2, and a negative resultant voltage will appear across C_1 and R_3. (A negative saw-tooth voltage favors V_3 because this voltage is applied to the cathode of the tube.) The negative voltage across C_1 is then passed on to the following sweep oscillator, changing its point of operation and consequently its frequency.

By the same token, arrival of the sync pulses when the saw-tooth voltage is positive will cause V_2 to conduct more strongly than V_3, producing a resultant negative voltage across C_1. (A positive saw-tooth voltage favors V_2 because it is being applied

to the plate of this tube.) The effect of the sweep oscillator of the positive voltage across C_1 will be opposite to that produced by a negative voltage.

C_1 and R_3 form a fairly long-time-constant filter, permitting only the voltage variations due to differences between the frequency of the sync pulses and the saw-tooth voltage to develop

(A) Block Diagram

(B) Actual Circuit
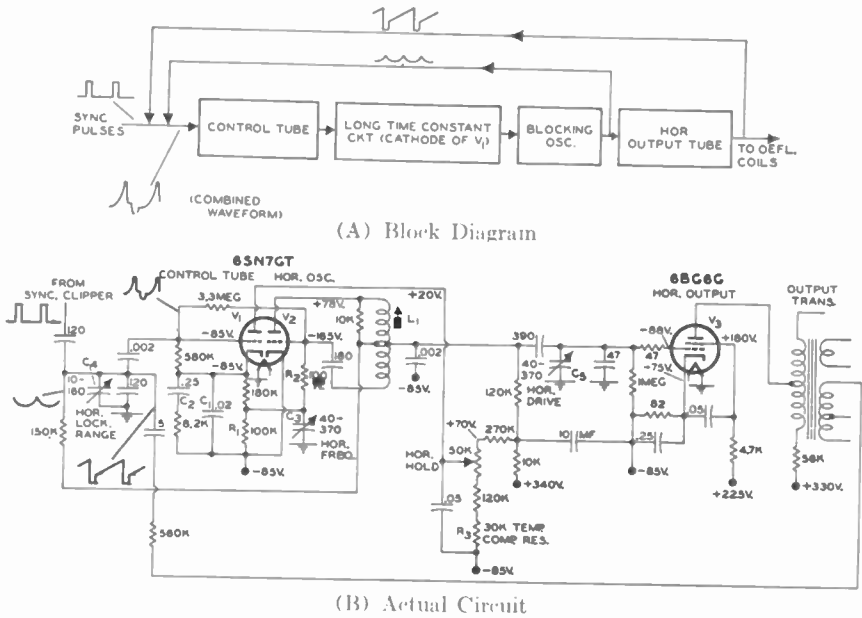
FIG. 10.14.   The pulse width A.F.C. system. (NOTE: The waveforms are shown as to shape only and not to indicate relative size.)

here. Momentary voltage variations due to noise pulses are effectively suppressed.

The d-c control voltage obtained from C_1 could be applied directly to the horizontal sweep oscillator and, in some receivers, it is. On the other hand, a more sensitive arrangement is obtained when the d-c control voltage is amplified before being applied to the horizontal oscillator.

Pulse Width A.F.C. System. Another A.F.C. circuit which has gained wide acceptance is that shown in Fig. 10.14. It con-

sists of a single control tube, a long-time-constant filter and a
blocking oscillator. The 6BG6G horizontal output tube is added
to the diagram because part of its output voltage is fed back
to the control tube. Basically, the horizontal oscillator is a free-
running oscillator and discharge circuit. It does not receive the
incoming pulses directly, but, should its frequency differ from
that of the pulses, then the control tube V_1 will alter the negative
bias on the grid of the blocking oscillator and thereby change
its frequency. It can do this because the cathode resistor R_1
of the control tube is common
to the grid of the blocking
oscillator. The incoming sync
pulses, positive in polarity,
are applied to the grid of V_1
through a 120-$\mu\mu$f condenser.
This same grid also receives a
pulse from the horizontal out-
put transformer and a small
portion of the voltage from

V_i GRID CUTOFF

NORMAL   SYNC. TOO   SYNC. TOO
CONTROL   LATE   EARLY
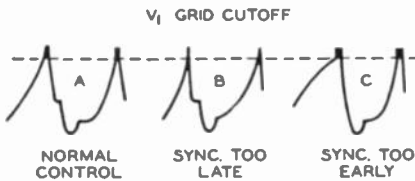
Fig. 10.15.   Horizontal control wave-
forms. Shaded area above dotted line is
portion of waveform effective in produc-
ing oscillator control voltage across V_1.

the output of the blocking oscillator. The pulse from the output
transformer and the voltage from the oscillator form a combined
wave, which then reacts with the incoming sync pulses to main-
tain the blocking oscillator on frequency. (Fig. 10.14 illustrates
the shape of the various voltages reaching V_1. The wave ob-
tained from the output of V_2 is originally a saw-tooth voltage,
but it is converted into a parabolic wave by the 150,000-ohm
resistor and C_4 before reaching V_1.)

The combined wave is specifically designed to have fairly steep
sides (see Fig. 10.15) in order that any difference in frequency
between the blocking oscillator and the incoming sync pulses
will have a marked effect on the circuit. Here is how this occurs.

A portion of the bias from the blocking oscillator is applied
to the grid of the control tube and is sufficient to keep the control
tube cut-off except when the incoming sync pulse is high on the
slope of the grid waveform (the combined wave mentioned pre-
viously) as shown in Fig. 10.15A. If the blocking oscillator

changes phase so that the pulse arrives at a time when it is down the slope, the amount of time that V_1 conducts will decrease. This is indicated in Fig. 10.15B by the narrow width of the waveform extending above the cut-off point of tube V_1. On the other hand, if the blocking oscillator frequency changes so that the sync pulse arrives at a time when it is closer to the top of the combined wave (Fig. 10.15C), then the plate conduction time of V_1 will increase. When the control tube conducts, C_1 and C_2 in its cathode circuit will charge to a d-c potential proportional to the length of time that current flows through the tube. This d-c potential is applied as a bias to the grid of the blocking oscillator, thereby altering its frequency and tending to bring it back into line. The components of the cathode circuit of V_1 form a fairly long-time-constant filter which averages the plate current pulses.

There are five controls associated with this circuit and they function as follows: The blocking oscillator transformer, L_1, is slug-tuned to permit coarse adjustments in oscillator frequency. C_3, connected across the resistor common to the control tube and blocking oscillator, can provide fine adjustments in frequency. The horizontal hold control will affect the plate voltage of the control tube and, in this manner, the amount of voltage developed across R_1. This is the only front-panel control of the group. C_4 is part of a voltage divider network that controls the amplitude of the waveform on the grid of the control tube. C_4 will therefore control the point at which V_1 starts to conduct. Finally, C_5 is part of a capacitance voltage divider and regulates the amount of voltage reaching V_3. It partially controls the width of the picture and partially the linearity of the left-hand side of this image. An additional linearity control located at a subsequent point in the horizontal sweep system regulates the overall horizontal linearity.

Several components of the oscillator and control circuits have special coefficients or characteristics and, in case of failure, should be replaced only by an exact duplicate. R_2 is a special

resistor capable of stability of 1 per cent or better. R_3 is a high negative coefficient resistor to compensate for warm-up drift. It is mounted within about $\frac{1}{4}$ inch of the power transformer and chassis for good heat transfer.

Improved Circuit. A recent modification of the pulse width A.F.C. system, principally that of inserting a parallel resonant circuit (L and C) in the plate lead of the horizontal oscillator,
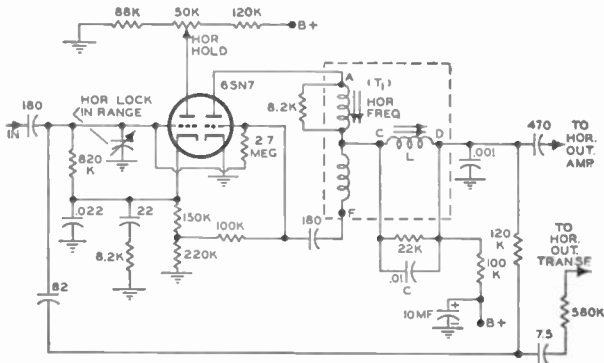
FIG. 10.16. A recent modification of the pulse width A.F.C. network. Many commercial names have been applied to this circuit, but Synchro-Guide appears to be the most common.

has resulted in increased stabilization and greater noise immunity. See Fig. 10.16. How this is achieved can be seen from the following explanation.

L and C form a parallel resonant circuit which is placed in series with the $B+$ lead going to the plate of the horizontal oscillator. The oscillator, being a blocking oscillator, is cut-off for more than 90 per cent of the cycle and conducts heavily for 10 per cent of the time or less. Let us consider the oscillator when it is conducting heavily. During this interval, the heavy current drawn through L and C prevents this circuit from oscillating. At the same time a voltage is developed across these components with the polarity as indicated in Fig. 10.17A.

When the blocking oscillator drops into cut-off, the current flowing through the tube and the resonant circuit—L,C—ceases

abruptly. This sudden stoppage of current excites $L.C$ into resonance, the coil attempting to maintain the flow of current. The polarity of the voltage developed across the coil required to do this is shown in Fig. 10.17B and is seen to be exactly opposite to its previous polarity in Fig. 10.17A.
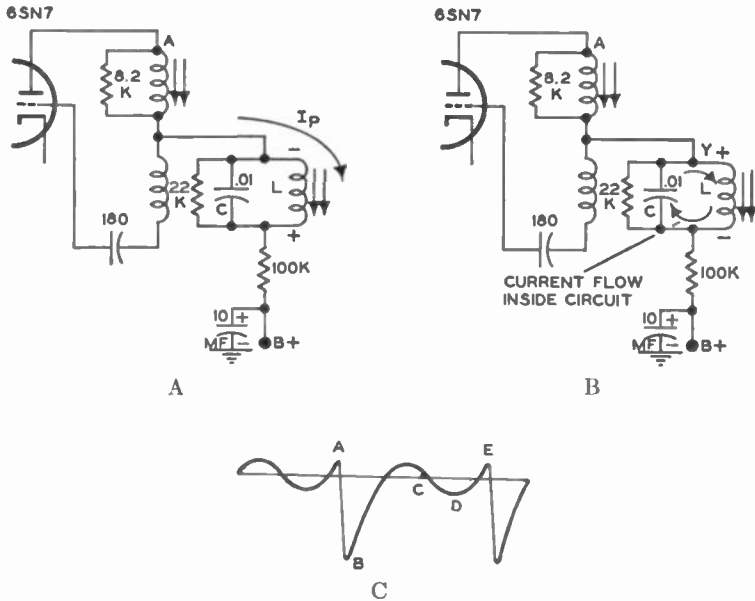
FIG. 10.17. Diagram illustrating how L and C (of Fig. 10.16) help stabilize the pulse width A.F.C. system.

Referring to the waveform developed in this circuit at point Y, at time A in Fig. 10.17C the blocking oscillator drops into cut-off, and at time B the resonant circuit reverses its voltage polarity in an attempt to maintain the flow of current.

Thereafter the current in the resonant circuit $L.C$ flows first into the lower plate of C, then reverses and flows into the other plate. The frequency of this circuit is close to 15,750 cycles, and so it has time to complete one cycle before the blocking oscillator again conducts heavily, at time E, damping out the oscillations in L and C.

Now, the ability of this additional resonant circuit to improve
the noise immunity of the blocking oscillator is due to the fact
that near the end of the discharge cycle, when the cut-off voltage
on the oscillator grid is low, the voltage developed across L,C is
negative. In Fig. 10.17C, this is the region CDE. This negative
voltage opposes the $B+$ voltage from the power supply and, in
so doing, reduces the susceptibility of the blocking oscillator to
any noise pulses that may appear at this time.
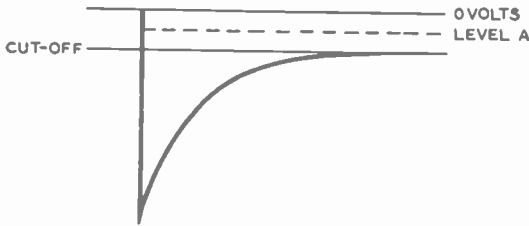
Fig. 10.18. See text for explanation.

Here is why this is so. When the plate voltage of a triode
decreases, the negative voltage required to cut off the plate cur-
rent decreases. In other words, the cut-off point approaches
closer to zero volts. With the $B+$ plate voltage going down
(because of the opposition voltage across L and C), we achieve
the same effect as bringing the cut-off level of the tube closer
to zero. See Fig. 10.18. With the cut-off level thus moving
upward, it will require a stronger noise pulse to raise the grid
voltage up to this new cut-off level in order to have current flow
through the tube again for the start of the next cycle.

On the other hand, in the region near E of Fig. 10.17C, the
voltage across L and C is going in the positive direction, aiding
the $B+$ voltage and preparing the plate circuit for the triggering
pulse which is about to occur.

Resonant stabilizing circuits have been used in the multivibra-
tor as well as in the blocking oscillator. The operation in either
circuit is the same.

CHAPTER 11

A TYPICAL TELEVISION RECEIVER—ANALYSIS AND ALIGNMENT

Television Receiver Cabinets. Television home units may contain not only the television receiver itself, but may also incorporate additional A-M and F-M chassis to take care of the other broadcast services available to the public. The additional space required would not be very great. Since the television receiver already contains an F-M receiver section for reception of the sound waves associated with the image, it would be a comparatively simple matter to add another F-M tuner that would receive the regular F-M bands. The same discriminator and audio section of the television audio chassis could be employed for all the F-M signals on any band, whether sound or television audio.

For the familiar 500- to 1,500-kc sound frequencies, the audio section, including the loudspeaker of the television receiver, eliminates the need for a separate assembly, which would only cause duplication. Once again, a tuner would suffice. With the present methods of building midget sound receivers, this added chassis would easily fit in one corner of the cabinet. And last, but not least, is the record player, a welcome addition to any receiver. These combinations, which are certain to be continued, offer products having good sales appeal to the public. It is much easier (and neater) for the home to have one general purpose receiver, than several separate units scattered about, each for a specific purpose. The popularity of the modern multi-purpose meter in the radio laboratory indicates that the technician feels the same way about his laboratory.

Receiver Panel Controls. The front panel controls that are associated with television receivers fall into two categories:

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those dealing with the audio section of the receiver, and those associated with the video chassis. Straddling both groups would probably be the regular tuning control and the fine tuning control, adjusting the reception of both signals simultaneously. Of the audio controls, little need be added to what is already known. One volume and one tone control permit all the variation ordinarily desired, even with the greater audio range available with F.M.

For adjustment of the video portion of the television receiver, the number of controls vary with each manufacturer. Some manufacturers provide only focus, contrast and brilliancy controls; others include the hold controls. All try to keep the number of front panel controls to a minimum; anything that will simplify the operation of the receiver for the layman is desirable and certain to make the television receiver a more popular instrument.

a. Focus. The focus control is perhaps the simplest control to understand and to adjust properly. The front panel knob is rotated until the image becomes sharp and clear. Under normal operating conditions this control will require little attention, beyond an infrequent adjustment, due perhaps to changes in voltage. Since many power supplies are not regulated, this source will probably prove to be the main reason for the majority of adjustments.

In early cathode-ray television tubes, too great a voltage variation at the control grid was also responsible for defocusing the beam. The position of the cross-over point in these tubes was influenced by the voltage at the control grid. As the incoming signal varied in intensity, especially over large values, the cross-over point was found to move back and forth, the displacement being directly proportional to the voltage amplitude at the grid. Since the cross-over point is considered as the starting point for the electron beam and since the tube design is based upon this assumption, it can readily be appreciated that any variation in the position of this area would displace the point at which the electron beam came to a focus. As a result the image at the

screen was affected. In the newer types of viewing tubes, this defect has largely been corrected by designing the tube elements so that the position of the cross-over point is relatively fixed and less dependent upon the voltage on the control grid.

b. *Contrast.* The second basic control is the knob labeled "contrast." This adjustment on a television set is similar in its action to the volume control on a sound receiver. The contrast potentiometer varies the amplification that the video signal receives. The greater the strength of the video voltage applied to the control grid of the cathode-ray tube, the more intense will be the image on the screen. A high setting might be desirable if the surrounding light is strong, or at least bright enough to interfere with the clear perception of an ordinary lighted screen.

In many receivers, the contrast control does not vary the output voltage directly. Rather it accomplishes this by controlling the gain of several tubes throughout the set. If the control is advanced too far, the regulated tubes are placed on a portion of the characteristic curve that is not linear. The result is distortion. It is well known that the human eye is more critical of distortion than the ear. In sound receivers, distortion percentages can run as high as 15 per cent and still be tolerated. In the case of the eye, this amount would prove unsatisfactory.

In the majority of present sets, the control is located electrically in the I.F. section of the receiver. To permit as large a variation as possible without excessive distortion, remote cut-off tubes are employed. There does not appear to be any general agreement on the number of stages that should be controlled by the contrast potentiometer, but the number seldom runs beyond three. If automatic gain control is employed, the contrast potentiometer is generally incorporated into this network.

c. *Brilliancy Control.* Another panel adjustment for the video section of the television receiver is the "brilliancy control." This works in close conjunction with the contrast control, and it cannot be set until the contrast potentiometer is set to the desired point. It will be recalled that the brilliancy potentiometer varies the bias on the grid of the cathode-ray tube and, in this

manner, the operating point of the tube. With a strong video signal, it seems reasonable that the bias on the grid of the viewing tube should be different than when the incoming signal is weaker. The correct setting of the brilliancy control will just bias the cathode-ray tube so that the blanking voltage level causes cut-off of the electron beam. Refer to Chapter 7. Too low a setting permits the beam retrace to become visible; too high a setting eliminates some of the darker detail of the reproduced image. The adjustment is not critical, as long as it is advanced far enough to eliminate all retraces.

d. Hold Control. There has recently been developed an automatic synchronizing oscillator which adjusts its frequency according to the rate of the incoming synchronizing pulses. It has good stability and is relatively insensitive to noise pulses which, in the ordinary sweep oscillator, can initiate the start of a new cycle prematurely. When this system is functioning properly, there is little need for placing this control on the front panel. However, with the conventional type of multivibrator and blocking oscillators, most manufacturers have found that the signal synchronizing pulses do lose control and manual adjustment is then required. Hence, many television receivers contain hold controls on the front panel. In time, when a foolproof system has been adopted by all receivers, these controls will probably be relegated to a position at the rear of the chassis, where only the serviceman will need to adjust them.

The proper adjustment of the control is achieved when a single stationary image appears on the screen. There is one hold control for the vertical system and one for the horizontal system.

In addition to the controls just described for the video chassis, and the two for the audio chassis, we find another knob labeled "fine tuning." This is a vernier variable condenser connected across the oscillator tuning circuit. With it, small variations in the oscillator frequency can be compensated. This control is especially necessary at the high frequencies where small percentage variations mean greater frequency changes. The regular tuning is accomplished by means of push buttons or a selector switch.

Secondary Controls. The other variable controls associated with the video chassis of the television receiver are placed within easy reach at the rear of the set. They are placed there for the convenience of the radio serviceman and are generally not to be touched by the ordinary user of the set. A list of these rear secondary controls includes the following:

1. Vertical linearity.
2. Horizontal linearity.
3. Vertical centering.
4. Horizontal centering.
5. Vertical size.
6. Horizontal size.
7. Damping controls, if deflection coils are employed.

The exact number found, of course, will depend upon the elaborateness of the receiver design. No discussion of the action of the controls is deemed necessary here as it would merely be a repetition of what has been given in previous chapters.

A Modern Television Receiver. An interesting example of modern television receiver design is the RCA table model television receiver shown in Fig. 11.1. This is a 30-tube, direct-viewing, 10-inch table model, television receiver. Twelve channels are covered, with an F-M sound system. The various oscillator frequencies for each of the twelve channels are as follows:

Channel Number	Channel Freq. Mc	Picture Carrier Freq. Mc	Sound Carrier Freq. Mc	Receiver R.F. Osc. Freq. Mc
2	54–60	55.25	59.75	81
3	60–66	61.25	65.75	87
4	66–72	67.25	71.75	93
5	76–82	77.25	81.75	103
6	82–88	83.25	87.75	109
7	174–180	175.25	179.75	201
8	180–186	181.25	185.75	207
9	186–192	187.25	191.75	213
10	192–198	193.25	197.75	219
11	198–204	199.25	203.75	225
12	204–210	205.25	209.75	231
13	210–216	211.25	215.75	237

Operating controls, those on the front panel, are (see Fig 11.2):

Channel selector⎤
Fine tuning   ⎦ .... Dual control knobs

Picture (contrast)   ⎫ ...... Dual control knobs
Sound volume and on-off switch⎭

Horizontal hold⎤ .... Dual control knobs
Vertical hold   ⎦

Brightness........................ Single knob

The non-operating controls, those which are mounted on the rear of the chassis, include:

Horizontal centering	Horizontal oscillator frequency
Vertical centering	Horizontal oscillator phase
Width	Focus
Height	Focus coil
Horizontal linearity	Ion trap coil
Vertical linearity	Deflection coil
Horizontal drive	

The purpose and use of each of the controls will become evident as the analysis of the circuit proceeds.
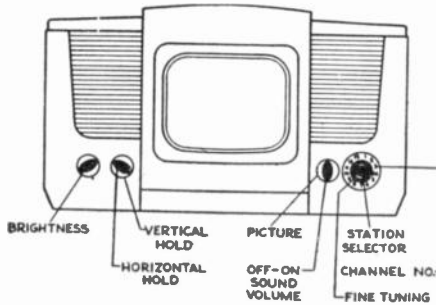
FIG. 11.2. The front panel operating controls of the RCA table television receiver.

A block diagram of the receiver is shown in Fig. 11.3. In this receiver, a recently developed system of automatically controlling the sweep oscillators has been applied to the horizontal system only. The operation is excellent, with the horizontal system slipping out of control very infrequently. The full
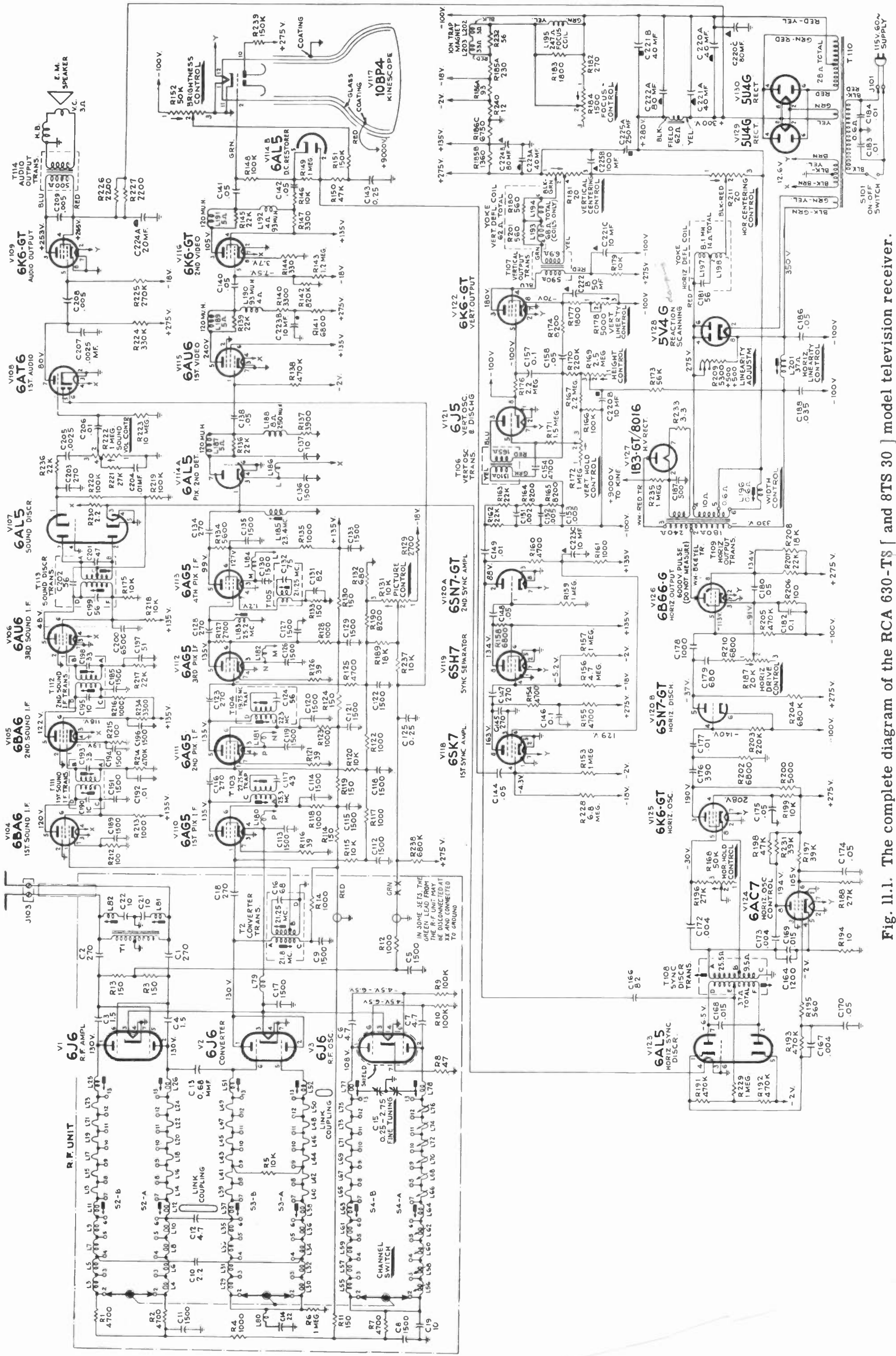
Fig. 11.1. The complete diagram of the RCA 630-TS [and 8TS 30] model television receiver.
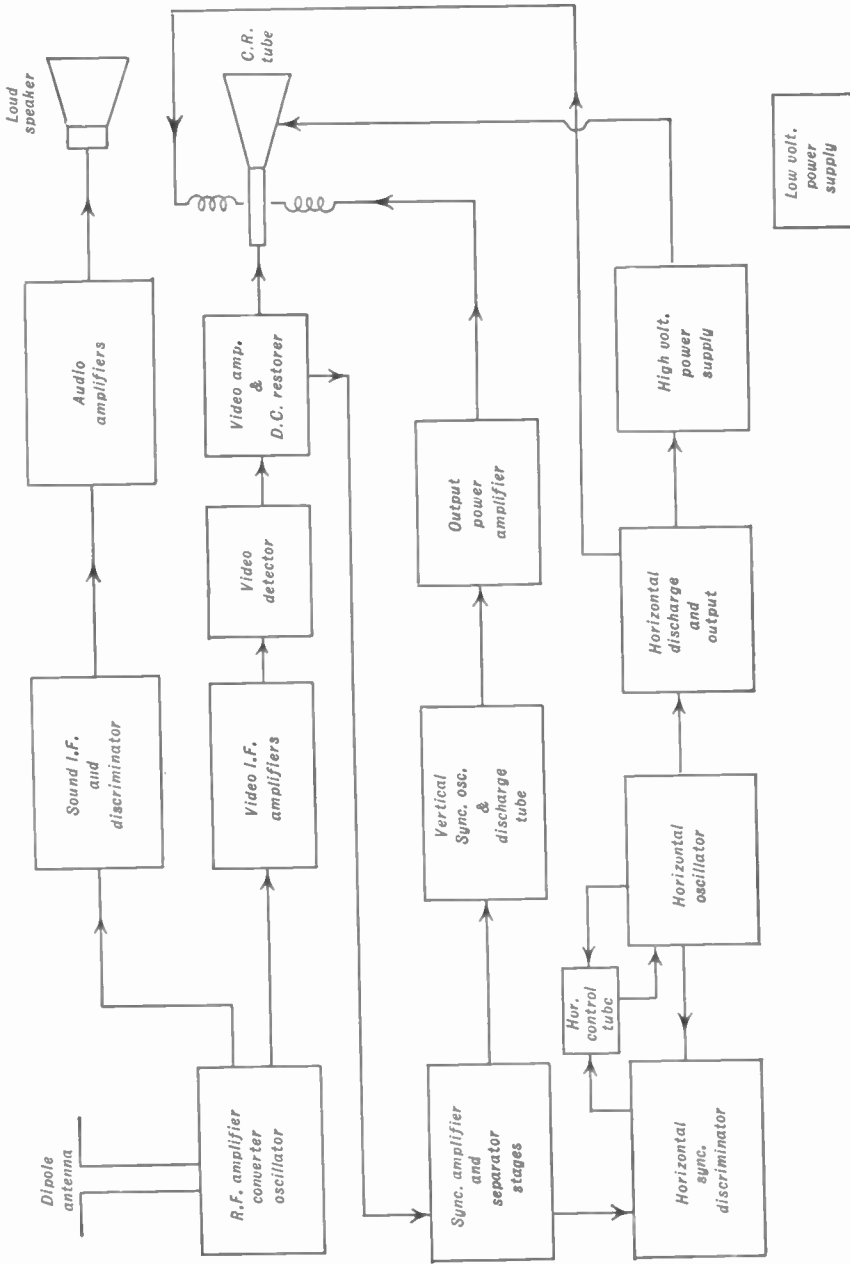
Fig. 11.3. A block diagram of the television receiver shown in Fig. 11.1.

schematic diagram of this receiver is shown in Fig. 11.1. In the explanations that follow, it is recommended that the schematic be followed closely.

An antenna trap, consisting of L_{82}, C_{22}, L_{81}, and C_{21}, is incorporated to eliminate interference that may arise from F-M stations that are on the image frequency of a television station. In other instances interference between two television stations may be observed. For example, assume that two television stations in a city are operating on channels 6 and 10. When the receiver is tuned to channel 6, a small amount of oscillator voltage (109 mc) is present on the R.F. amplifier grid. This 109-mc voltage beats with the channel 10 video carrier and produces an 84.25-mc signal. This falls within channel 6 and causes interference. A similar case occurs between channels 5 and 7. A series resonant trap across the R.F. amplifier grid circuit will remove the oscillator voltage and eliminate the interference. To adjust the trap, tune in the station on which the interference is observed. Then, adjust both cores of the trap (L_{82} and L_{81}) for minimum interference in the picture.

R.F. Unit. The R.F. section of the receiver contains a 6J6 R.F. amplifier, a 6J6 converter, and a separate 6J6 oscillator. The 6J6 is a triode and ordinarily triodes are not very suitable for high-frequency use. However, the 6J6 is specially designed for high-frequency operation and will give excellent results, provided that it is properly connected. The input circuit contains a half-wave antenna which connects directly to the grids of each triode section of a 6J6 through a transmission line. The input circuit is untuned, T_1 being used to short-circuit all low-frequency signals picked up by the antenna. R_3 and R_{13} are terminating resistors for a 300-ohm antenna transmission line.

The two sections of the 6J6 R.F. amplifiers are connected to function as push-pull amplifiers. Although these triodes are specially designed for high-frequency operation, they may sometimes oscillate at the higher television frequencies. To prevent this, the grid-to-plate capacitances of the tubes are neutralized by means of C_3 and C_4.

The 12-channel tuning arrangement in the plate circuit of the R.F. amplifier is a novel adaptation of a quarter-wave transmission line. The line is balanced and consists of 12 series inductances in each section of the line. Coils L_{25} and L_{26} provide the proper inductance to tune the circuit to the highest television channel, 210–216 mc. Iron-core slugs in L_{25} and L_{26} permit adjustment of each coil. L_{13} to L_{23} on one side of the line, and L_{14} to L_{24} on the other side of the line are fixed sections which are added in series to L_{25} and L_{26} as the shorting bar is moved progressively down the line. Note that the highest frequency is obtained when the shorting bar is closest to the plates of the tubes. With each movement to the left, more inductance is inserted into the circuit, thereby lowering the resonant frequency of the line. Since all the inductances are in series, the alignment procedure starts with the highest frequency channel and progresses down to the lowest channel.

The physical construction of each of the inductances L_{13} to L_{24} is a small non-adjustable silver strap between the switch contacts. Each strap is cut to represent a 6-mc change in frequency. Coils L_{11} and L_{12} bridge the gap between 174 mc and 88 mc. For the 5 lower television channels, L_3 to L_9 and L_4 to L_{10} are used. These coils are constructed in the form of a figure eight.

The Mixer. The grid circuit of the push-pull 6J6 mixer is similar to the plate circuit of the R.F. amplifier. The signal is transferred between the two circuits by means of C_{10}, C_{12}, C_{13}, and a single-turn link coupling. This combination provides close coupling and results in a response which is 6.0 mc wide on all channels. Station switching is accomplished by means of a movable shorting bar which is ganged to the bar in the R.F. amplifier circuit.

L_{80} and C_{14} form a series-resonant circuit and prevent I.F. feedback in the converter by grounding its grids for signals of the I.F. value. It becomes unnecessary, therefore, to neutralize the mixer triodes. The grids of the mixer tube receive the signal and oscillator voltages in push-pull and the I.F. signals which

are thus produced are in phase at the triode plates, permitting the plates to be connected in parallel.

A 10,000-ohm loading resistor is shunted across the tuning circuits of the 7 lower channels in order to achieve the proper bandwidth, 6.0 mc. In the 5 highest channels the necessary bandwidth can be obtained without resort to this artificial loading. As we raise the frequency of the resonant circuit, the 6.0-mc bandwidth represents a smaller and smaller fraction of the resonant frequency and consequently it becomes easier to achieve. Thus, for example, we can design a tuning circuit with a band-pass of 10 kc at 1,000 kc quite readily, whereas if a 70- or 80-kc bandpass is desired, at the same 1,000 kc, we would have to resort to artificial loading.

The Oscillator. In the oscillator circuit, which also is push-pull, each of the coils in the quarter-wave line are adjustable by means of brass cores. There is no loading of the oscillator since a single frequency rather than a band of frequencies is desired. Manual adjustment of the oscillator frequency can be accomplished by means of C_{15}. The adjustment is approximately ± 300 kc on channel 2; this increases to approximately ± 750 kc on channel 13. The oscillator signal is coupled to the mixer by means of a single-turn link coupling.

The output of the mixer appears across transformer T_2, from which point the circuit branches off into two directions. Capacitively coupled to T_2 is the first stage of the video I.F. system; inductively coupled to the first tube is the sound I.F. system. The resonant secondary of T_2 is tuned to 21.25 mc, which is the sound center I.F. The 21.25-mc currents generated in the mixer stage and flowing through the primary of T_2 induce these audio voltages into the resonant secondary and from here they are transferred to the audio I.F. system. Let us first trace the signal through the audio circuit, then return and follow the signal through the various stages of the video system.

The sound system contains three I.F. amplifiers, a Foster-Seeley type of discriminator and two stages of audio amplification. The sound discriminator bandwidth between peaks is

350 kc. The signal is received by a 6BA6 amplifier which is functioning as a Class A amplifier. The second I.F. amplifier, also a 6BA6 tube, is operating as a partial limiter, using a combination of grid-leak and cathode bias. The limiting action is completed in the third I.F. amplifier, utilizing grid-leak bias which has a very short time constant. The grid-leak combination is composed of 22,000-ohm grid resistor and a 51-$\mu\mu$f grid condenser. There is no cathode bias.

The operation of an F-M system depends upon the correct adjustment of the I.F. and discriminator stages. The proper alignment procedure for the present system will be given later in this chapter. The operation of the limiter and discriminator stages is examined in detail in Chapter 12.

The output of the discriminator consists of the audio frequencies, as broadcast at the studio. These are transferred, via the volume control, to the audio amplifiers. Both audio stages are entirely conventional in their construction, acting merely to strengthen the audio signals until they are strong enough to operate the loudspeaker. The audio system contains only a volume control, there being no provision made for tone control. There is, however, a tone-compensating network placed across the volume control. The speaker will deliver 2½ watts of undistorted power and a maximum of 4 watts with tolerable distortion.

Video System

The separation of the video and the audio signals occurs in the plate circuit of the mixer, at transformer T_2. The audio signals are applied to the audio system by the secondary resonant circuit, whereas the video voltages are coupled directly from the primary of T_2 into the grid of the first picture I.F. amplifier, a 6AG5. Note that both types of voltages present across T_2 are not entirely separated and hence a portion of the audio voltage does reach the video I.F. system. However, this will be attenuated by trap circuits.

The overall response characteristics of the video I.F. amplifiers

are shown in Fig. 11.4. The carrier is located at the right-hand side of the curve and the highest video frequencies (corresponding to 4 mc) are located at the left-hand side of the response characteristic. This reversal of position, in comparison to the manner in which these frequencies are received, is because the
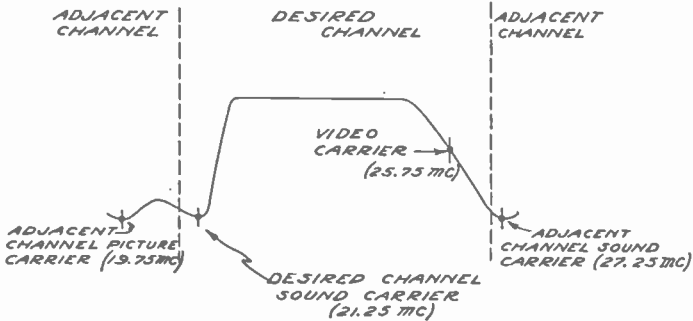
Fig. 11.4. The receiver over all video I.F. response curve.

local mixing oscillator is higher in frequency than the incoming signal. Upon mixing, the highest video frequencies are closest to the oscillator frequency and their difference will be less than the difference between the carrier and the oscillator frequencies. The response curve follows the form recommended by the RMA, with the curve being 50 per cent down at the carrier frequency. The reason for this peculiar shape was noted previously.
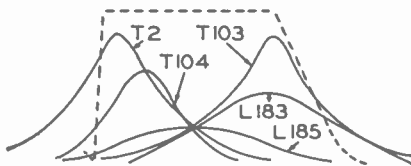
Fig. 11.5. The relative gains and selectivities of each coil video I.F. system. The effects of the traps are not shown.

To understand how this response characteristic is achieved, we must examine the tuned circuits of the four video I.F. amplifiers. In place of the conventional double-tuned transformers, we find only one tuned circuit in each stage (omitting, for the moment, any traps that may be used). This form of coupling is known as impedance coupling. Each coil is tuned to a different frequency. The effective Q of each coil is fixed by the

shunt plate load or grid resistor of the succeeding stage. Thus, at the output of the first video I.F. stage, the 10,000-ohm grid-leak resistor of the second video I.F. tube acts as the shunting resistor across T_{103}; between the second and third video I.F. stages, the shunting resistor is a 4,700-ohm grid-leak resistor, etc. Fig. 11.5 shows the relative gains and selectivities of each coil and the manner in which they combine to produce the desired overall characteristic. The sharp cut-off at 21.25 mc is due to the sound traps in the video system tuned to this frequency.

The various video I.F. transformers are peaked to the following frequencies:

$$\begin{array}{ll}
T_2 \text{ (primary)}\ldots\ldots & 21.8 \text{ mc} \\
T_{103} \text{ (primary)}\ldots\ldots & 25.3 \text{ mc} \\
T_{104} \text{ (primary)}\ldots\ldots & 22.3 \text{ mc} \\
L_{183}\ldots\ldots\ldots\ldots & 25.2 \text{ mc} \\
L_{185}\ldots\ldots\ldots\ldots & 23.4 \text{ mc}
\end{array}$$

Since each coil is peaked to a single frequency, the alignment procedure is considerably simplified. More on this later.

Traps. In this video I.F. system, three trap or attenuation circuits are provided. One is for the sound of the same channel, one is for the sound of the next lower adjacent channel, and the third is for the video carrier of the next higher adjacent channel. In reality there is a fourth trap circuit, this being the secondary of T_2. The sound signal frequencies contained in the plate currents of the mixer are absorbed, to a great extent, by the tuned secondary of T_2. This secondary is resonant to the sound I.F. values. That portion of the sound voltage which does reach the video I.F. stages is then completely eliminated by the trap circuit T_{105} located in the cathode leg of the fourth I.F. amplifier, V_{113}.

The traps in T_{103} and T_{104} are, like that of T_2, absorption traps. They are resonated to the frequency that we desire to eliminate and, by being closely coupled to the primary, they greatly attenuate the response of the circuit to that particular frequency. Two resonant circuits, closely coupled, will give a doubled-humped curve, such as shown in Fig. 11.6. Note the

sharp decrease in primary current at the center frequency. In the case of the two tuned circuits in either T_{103} or T_{104} the primary is tuned to a band of frequencies, whereas the secondary is sharply resonant to one frequency. Since the primary band coverage includes this one frequency, there is a sharp drop in primary current at this frequency because of the presence of the trap. It is this reaction which produces the marked decrease at each of the trap frequencies. The other frequencies in the signal are unaffected by the trap.
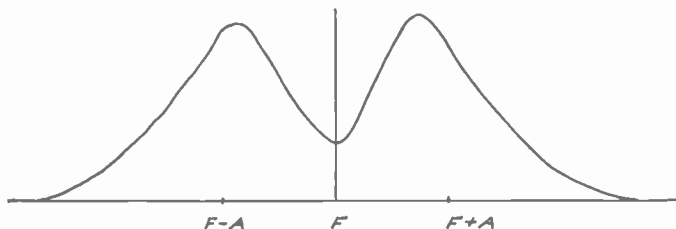
Fig. 11.6.   The double-humped response of two closely coupled coils.

The final trap is in the cathode circuit of the fourth video I.F. amplifier V_{113} and is tuned to the accompanying sound carrier I.F. The primary of T_{105} forms a series resonant circuit with C_{131} at 23.4 mc. This provides a low impedance to this frequency and permits the tube to function as a straight amplifier, with gain. However, at the resonant frequency of the secondary, 21.25 mc, a high resistance is reflected into the cathode circuit and the stage functions as a degenerative amplifier. The loss introduced in this manner is sufficient, in conjunction with the decrease inserted at T_2, to prevent any sound carrier voltage from reaching the cathode-ray tube.

Contrast Control. The four video I.F. amplifiers are straightforward impedance-coupled stages. There is no A.G.C. employed in this receiver, but there is a manual contrast control that controls the bias of the R.F. amplifier and the first three video I.F. stages. The term employed in this receiver for the contrast control is "picture control," but its function remains unaltered. By controlling the bias, we control the mutual gain

(G_m) of the tube and therefore the gain which is applied to the signal.

The manner in which the contrast control is connected and how it operates is not immediately apparent. The wiring, if traced from the contrast control, will be found to reach the grid of the R.F. amplifier and the grids of the video I.F. amplifiers by separate paths. This becomes clearer if we arrange the contrast control circuit to the form shown in Fig. 11.7A. Now we

(A)   (B)
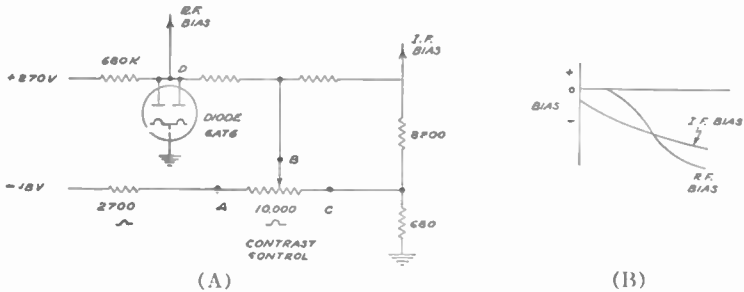
Fig. 11.7.   (A) The contrast control circuit in the receiver.   (B) The variation in
R.F. and I.F. grid voltage due to this control.

see that the duo-diode sections of the 6AT6, first audio tube (V_{108}), are also part of the contrast control circuit. The object of this fairly elaborate system is to provide optimum signal-to-noise ratio in the receiver. The R.F. amplifier is permitted to run at essentially full gain over a considerable range of the contrast control. The gain of the R.F. stage is reduced when it becomes necessary to prevent distortion in the first I.F. amplifier.

When the contrast control is in the maximum gain position, or when the movable arm B is at point C, the I.F. bias is approximately -1 volt. The R.F. bias is taken from the plates of the diodes. Since the diode plates are positive with respect to the grounded cathodes (due to the $+270$ volts), the tube conducts heavily. The plate resistance of a diode is inversely proportional to the amount of voltage between the plate and cathode. When the tube conducts heavily its plate resistance is quite low, and, for all practical purposes, point D is at ground poten-

tial. Since the R.F. amplifier grid connects to this point the R.F. grid bias is also zero. This is shown in Fig. 11.7B.

As we move the control arm *B* of the contrast potentiometer away from point *C*, the negative bias on the grids of the I.F. amplifiers increases. The contrast potentiometer is part of a series network (of the 2,700-ohm and 680-ohm resistors) which connects from the 18-volt power supply terminal to ground. The closer point *B* moves to the −18-volt terminal, the more
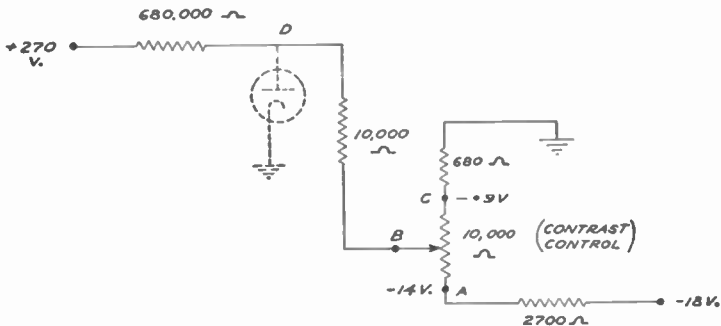
Fig. 11.8. A simplified diagram of the contrast control circuit.

negative it becomes. While this is occurring, the voltage at point *D*, where the R.F. grid bias is established, has changed very little *because* (and this is important) the diode is still conducting. In fact, it might appear from the circuit diagram, Fig. 11.7, that the diode would always conduct. Such, however, is not the case. When the contrast control voltage is reduced still further, point *D* actually becomes negative and the diode stops conducting. Thereafter, the R.F. bias voltage changes rapidly and becomes even more negative than the I.F. grids.

The circuit is unusual and merits further analysis. To see how point *D* can become negative, even though it is attached (through a 680,000-ohm resistor) to +270 volts, let us simplify the diagram somewhat by removing the diode and the connection to the I.F. grids. The result is shown in Fig. 11.8. The points *A*, *B*, *C*, and *D* are still marked as before. We now see that the leads from the +270-volt and the −18-volt power sup-

plies have the contrast control and the 680-ohm resistor in common. For the -18 volts, there is the series path consisting of the 2,700-ohm, the 10,000-ohm (contrast control), and the 680-ohm resistors to ground. Point A is then approximately -14 volts, and point C is -0.9 volts. The current from the positive 270-volt supply flows through the 680,000-ohm resistor, the 10,000-ohm resistor, a portion or all of the contrast control and the 680-ohm resistor. Most of the 270 volts is dropped across the 680,000-ohm resistor, leaving so little for the remaining resistors that, when point B is moved toward point A, the negative voltage overcomes the positive voltage and point D actually becomes negative.

Connecting a diode from point D to ground reduces the potential of this point to approximately zero when the diode conducts. However, when, as just noted, the center arm of the contrast potentiometer is moved toward the negative supply, point D becomes negative and the diode ceases to conduct.

Video Second Detector. The second detector, a diode, is connected to produce a positively phased signal. In this form, the synchronizing pulses are the most negative and the brightest portions of the image are the most positive. This type of output voltage is necessary because there are an even number of video amplifiers between the detector and the cathod-ray tube. The diode load resistor R_{137} is 3,900 ohms. The circuit is fully compensated, employing both series and shunt peaking, with L_{187} and L_{188}. The 39,000-ohm resistor across L_{187} is to prevent excessive peaking should the self-inductance and self-capacitance in the coil resonate within the video signal range. The response of this network decreases rapidly above 4 mc and prevents the video I.F. from reaching the video amplifiers.

Video Amplifiers. Two stages of video amplification increase the strength of the signal until it is capable of fully modulating the cathode-ray beam. The total gain is 30 and the frequency response extends to 4 mc. Each stage is designed with high- and low-frequency compensation. The high-frequency compensating components are the series and shunt coils, such as L_{189}, L_{190},

L_{191}, etc. The low-frequency compensating components are the decoupling networks between the lower end of the load resistors and the power supply: for example, C_{223B} (10-μf electrolytic condenser) and R_{141} (6,800-ohm dropping resistor) in the plate circuit of V_{115}.

The first video amplifier receives its bias directly from the negative side of the power supply. The stage is so designed that with a normal signal input at its control grid, the tube is working over most of its operating range. Any large noise signal above the synchronizing level will drive the grid into cut-off and the noise will be limited. The second video amplifier is controlled by a combination of cathode bias and fixed bias from the power supply.

D-C Restorer. All of the video amplifiers are RC stages and will not pass the d-c component in the detected video signal. Hence, d-c restoration is necessary. The method employed in this receiver is almost identical with that described in Chapter 7 and requires little additional explanation. The synchronizing pulses are obtained from the d-c restorer and fed to the first synchronizing amplifier. Note that in this receiver the synchronizing pulses are not fed to the vertical and horizontal sweep amplifier circuits until the signal has reached the cathode-ray tube. Separation at some other point after the video detector would also have been feasible. In the present instance, the video amplifiers help to improve the sync-to-noise ratio, as explained above.

Synchronizing Amplifier and Separator. The input to this section of the receiver is obtained from the d-c restorer where the synchronizing signal is partially separated from the video signal. The synchronizing pulse, at the grid of V_{118}, is in the negative direction. To remove completely any remaining blanking and video portions of the signal, the signal is amplified by the 6SK7 (V_{118}) and applied to the grid of the following 6SH7 with the synchronizing pulses in the positive direction. The synchronizing amplifier is required because the level of the signal on the

grid of the cathode-ray tube will vary with the strength of the carrier or the setting of the contrast control. By using a tube having an extended cut-off and providing sufficient amplification, the signal, as obtained at the output of the final video amplifier, can be amplified and a clear-cut separation effected. The 6SH7 is biased to cut-off and only voltages which are going positive will produce a flow of current in its plate circuit. Since the 6SK7 inverts the incoming negative pulses, these are positive at the grid of the 6SH7. The remainder of the signal, however, is negative and hence is removed. The final and complete separation is accomplished by the clipper (one-half of 6SN7). Through the use of this fairly elaborate network, a constant synchronizing pulse output is obtained from the clipper with peak-to-peak video signal variations of from 6 to 60 volts on the grid of the picture tube. Here, then, is the justification for this method of synchronizing pulse separation. Systems which feed the signal directly into a clipper stage are more sensitive to signal variation with the result that the stability of their synchronizing system diminishes rapidly with lowering of the signal strength.

At the output of the clipper, the vertical and horizontal pulses must be separated from each other and fed to their respective systems. The horizontal pulse is of very short duration (5 microseconds); the vertical pulse lasts for the relatively long interval of 190 microseconds. The low-pass integrating network consisting of R_{163}, R_{164}, R_{165}, C_{151}, C_{152}, and C_{153} will by-pass the quickly rising and falling horizontal pulse. The vertical pulse, on the other hand, will pass through the network and reach the grid of the 6J5 vertical blocking oscillator and discharge tube.

During the negative portion of the cycle, the grid of the 6J5 is held beyond cut-off and C_{158} is charging through R_{169} and R_{170}. When the synchronizing pulse arrives, it drives V_{121} into conduction, and C_{158} discharges through the secondary winding of T_{106} and the 6J5 tube. The current in T_{106} induces a positive voltage on the grid of the 6J5, which further reduces the plate resistance of the tube and permits C_{158} to discharge even faster.

The sequence follows the pattern of operation of all such block-
ing oscillators, and the waveform developed across C_{158} and R_{174}
is shown in Fig. 11.9. This type of waveform is obtained from
peaking circuits (C_{158} in series with R_{174}) and, when applied to
a coil, will produce a saw-tooth current.
Adjustment of R_{169} will vary the ampli-
tude of the deflection voltage and is, of
course, the height control.

FIG. 11.9. The shape of the
deflection voltage wave at
the input to the vertical
output amplifier.

The circuit, in its present form, ap-
pears to bear no resemblance to charge
and discharge circuits previously dis-
cussed in Chapter 10. However, by a
rearrangement of the components, the similarity is readily ap-
parent (see Fig. 11.10).

To develop sufficient driving power, the output of the 6J5 is
applied between the grid and cathode of the 6K6 power ampli-
fier. In the cathode leg of this amplifier, a variable resistor
functions as the vertical linearity control. Variation of resist-

FIG. 11.10. The vertical oscillator and discharge circuit, rearranged to more con-
ventional form.

ance in the cathode leg has the effect of producing slight varia-
tions in the shape of the saw-tooth wave by shifting the operat-
ing point of the tube. We can alter or "distort" the shape of
the saw-tooth wave to a form which will produce a more linear
motion of the cathode-ray beam.

In shifting the operating point of the 6K6 by the linearity

control, we also vary the gain of the tube. This will affect the height of the image. Accordingly, whenever the linearity control is adjusted, we must also adjust the height control. Conversely, adjustments of the height control affect the shape of the saw-tooth voltage on the V_{121} plate and require adjustment of the linearity control. The 6K6 is matched to the vertical deflecting coils by means of T_{107}. The vertical coils are sufficiently damped (by means of the two 560-ohm shunting resistors) to prevent any shock-excited oscillations from existing in the coils for any length of time. A centering control provides a means for sending a d-c current through the coils, in either direction for centering the beam on the screen.

Horizontal-Sweep Oscillator System. The horizontal-sweep oscillator system contains an automatic frequency and phase control which frames the picture and also possesses the desirable noise immunity, lack of which has proven so destructive in designs employing the usual trigger-type of scanning oscillator. In this circuit, a stable Hartley oscillator is set at 15,750 cycles per second. Coupled to the oscillator is a synchronizing discriminator circuit which receives the pulses of the incoming television signal and compares the frequency and phase of these synchronizing pulses with the generated sine wave. Any slight variations between the two will produce a d-c voltage which is applied to the grid of a reactance tube. The plate circuit of this reactance tube is connected directly across the tuning circuit of the Hartley oscillator, and, as the d-c voltage at the grid of the reactance tube varies, it will alter the plate current and with it the oscillator frequency.

The Hartley oscillator is V_{125} (6K6) and it is conventional in form. The oscillator coil (secondary of T_{108}) is closely coupled to the primary winding. The primary winding is center-tapped and tuned by means of C_{168}. Since each diode is connected across half of the primary coil T_{108}, each receives voltages which are equal in amplitude but opposite in phase. The operation of this system was described in Chapter 10 and the reader is referred there for a step-by-step analysis.

Horizontal Discharge. The horizontal discharge tube follows the horizontal oscillator and produces, in its plate circuit, the peaked deflecting voltage which will drive the horizontal deflecting coils. In V_{125}, the Hartley oscillator is connected between the screen grid and the cathode. The plate circuit contains only a resistance, and consequently the waveform found here is not the symmetrical sine wave that would be produced by a reso-

Fig. 11.11. Plate of horizontal oscillator 225 volts peak-to-peak.

nant circuit; rather it has the form shown in Fig. 11.11. The peak-to-peak voltage on the grid of V_{125} is approximately 130 volts. This grid swing produces a square wave in the plate circuit, with a peak-to-peak voltage of 225 volts. The square wave is differentiated by C_{176} and R_{202}, producing the wave shown in Fig. 11.12. The positive portion of the differentiated wave is sufficiently sharp to trigger the discharge tube. The discharge tube is normally cut-off due to bias produced by grid rectification of these pulses from the oscillator. The positive pip of the pulse overcomes this bias and drives the tube into heavy momentary conduction. During this period, the plate voltage of V_{120B} falls to cathode potential, and C_{179} discharges rapidly. However, the conduction period is quite short, and C_{179} does not discharge completely because of R_{187} and R_{210}, both of which are in series with C_{179}. When V_{120B} becomes non-conducting

Fig. 11.12. Input to horizontal discharge tube 100 volts peak-to-peak.

again, its plate voltage rises quickly to a value determined by the charge remaining on C_{179}. From this point the plate voltage rises slowly, and we get the desired waveform as shown in Chapter 10. This is transferred to the horizontal output tube (V_{126}) via C_{178}.

Horizontal-Deflection and High-Voltage Circuits. This receiver is one of the first to use the recently developed system of generating the high voltage necessary for the cathode-ray tube

from the "kick" of the retrace of the horizontal deflecting volt-
ages. To provide adequate deflection and, at the same time, to
build up the necessary high voltages required by the cathode-ray
tube, a 6BG6-G (807 type) tube is used as a power amplifier.
The plate of this tube is connected to one winding of the deflec-
tion transformer and the deflecting voltage from the discharge
tube is applied to its grid. The function of V_{128}, the reaction
scanning tube, is to stop oscillation of the deflecting system at
certain times and to help provide a linear trace. In addition,
this same tube rectifies a portion of the voltage from the yoke
kickback and uses it to supply additional voltage for the 6BG6
tube. The operation of this circuit was described in detail in
Chapter 10, and the reader is referred there.

There are two adjustments for the picture width, R_{187} and
L_{196}. Both are necessary because, although their adjustment
alters the width of the image, they perform other functions.
R_{187} determines the ratio of high peaking and saw-tooth voltage
on the grid of the output tube. This affects the point on the
trace at which the tube conducts. Clockwise rotation of the con-
trol increases picture width, crowds the right side of the picture
and stretches the left side. L_{196} varies the output and hence the
picture width by shunting a portion of the secondary winding of
T_{109}. Clockwise rotation of the control increases the picture
width and causes the right side of the picture to stretch slightly.
Both controls must be adjusted whenever the position of either
one is changed.

From the H.V. rectifier (8016), 9,000 volts are taken, and
applied to the second-anode aquadag coating of the cathode-ray
tube. Very little filtering of this high voltage is necessary since
the frequency of its ripple is high (15,750 cycles). The filter
capacitance is a small 500-$\mu\mu$f condenser. The stored energy is
small, and the high voltage is prevented from proving fatal in
most instances. The remaining potentials required by the cath-
ode-ray tube are low and are supplied by the low-voltage power
supply. In this manner, the high voltage (9,000 volts) is ac-

tually decreased by 250 volts (at most), but this value of voltage is negligible in comparison to the high voltage.

Low-Voltage Power Supply. The low-voltage power supply furnishes the power for every stage of the receiver, including the low-voltage electrodes of the cathode-ray tube. The design of the low-voltage power supply is conventional, using two 5V4G rectifiers in parallel in order to obtain the 400 volts at 290 ma required by the set. The full 400 volts are not all positive, the ground connection being so placed that 300 volts are positive and 100 volts are negative. The supply is well filtered to prevent interaction between the many stages (and their many diverse operations) in the set.

Cathode-Ray Tube. The cathode-ray tube (10BP4) is a magnetically deflected and focused tube using a deflection yoke, a focus coil, and an ion trap magnet. The deflecting coils receive their driving power from the output transformers of the horizontal and vertical deflecting systems. The focus and ion trap coils are connected into the negative portion of the low-voltage power supply, and means are provided whereby the current through the focus coil may be varied. The adjustment of the ion trap coil is accomplished by physically changing its position on the neck of the cathode-ray tube until the brightest image is obtained. The relative position of these several components is shown in Fig. 11.13. The deflection yoke is closest to the bulb of the tube, the focus coil is in the center and the ion trap is near the tube base.

The simplicity of the internal construction of the 10BP4 tube is evident from the diagram. The few necessary elements required to form and accelerate the electron beam are quite readily manufactured. All the remaining operations are performed electromagnetically by external coils. These coils are easily positioned on the neck of the tube and, if held rigidly in place by clamps, will give satisfactory and stable operation. In addition to simple construction, the electromagnetically operated tube permits wide angle deflection with tube lengths of reasonable size.

Variation of the control grid to cathode potential is obtained by means of R_{152}, the brightness control. This control is connected into the d-c restorer circuits, but has no effect on this circuit because the d-c potential introduced by this control reaches the two elements of the d-c restorer in equal strength.
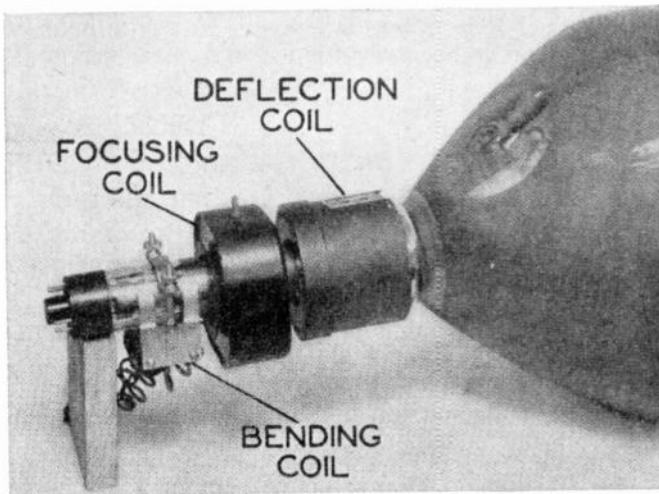
Fig. 11.13.   The placement of the deflection, focusing and bending coils on the neck of a cathode-ray tube.

Alignment of the Receiver—Equipment Required.   For the proper alignment of television receivers, the following basic pieces of electrical apparatus are required: a cathode-ray oscilloscope, a wide-band sweep oscillator, a signal generator, a vacuum-tube voltmeter, and a marker signal that is capable of indicating specific frequency points on the test pattern swept out on the oscilloscope screen.

a. Oscilloscope.   The cathode-ray oscilloscope is today a completely familiar piece of test equipment among the serviceman's electrical testing apparatus. Its greatest use, that of observing waveforms of different voltages and frequencies in the receiver, provides the repairman with a positive means of rapidly determining exactly what is occurring at all points in the circuit under

test. It eliminates guesswork and permits accurate adjustments to be made until the correct operating conditions are attained. For a television receiver, satisfactory images are observed only if the various intervening circuits are functioning properly. The requirements become more stringent as the size of the screen increases and small defects become more readily apparent.

The cathode-ray oscilloscopes that are at present on the market differ little from each other for the same size screen. As the size of the screen is made larger, the number of controls available on the front panel increase, but the basic operation remains the same. The advantage of the larger-sized oscilloscopes is their greater possible viewing screen area and the improved frequency response of the vertical and horizontal amplifiers. For television alignment work, however, even a small 3-inch oscilloscope will prove satisfactory. A popular 5-inch model is shown in Fig. 11.14.

b. Alignment Oscillators. Because of the wide bandwidths that are peculiar to television receivers, the familiar signal generator, where only one frequency is available at any one time, is not especially suitable, by itself, for receiver alignment. With a single frequency entering the circuit, it is possible to determine only one point on the frequency response curve. To do this for a 6-mc or even 4-mc band would require too much time for ordinary service, where time is an important factor in determining the cost of the job. To meet the special requirements imposed by television receivers, special sweep oscillators, like the unit illustrated in Fig. 11.15, have been developed.

These generators are designed for operation on any of the more commonly used television bands. At the desired band, obtained by means of a tuning dial, the oscillator provides an output that sweeps from the lowest to the highest frequency of the band and continuously repeats this sweeping at a rate of 60 cycles per second. Thus the response of the circuit is tested at every point within the band. The image on the screen of an oscilloscope connected to the circuit indicates the result in-
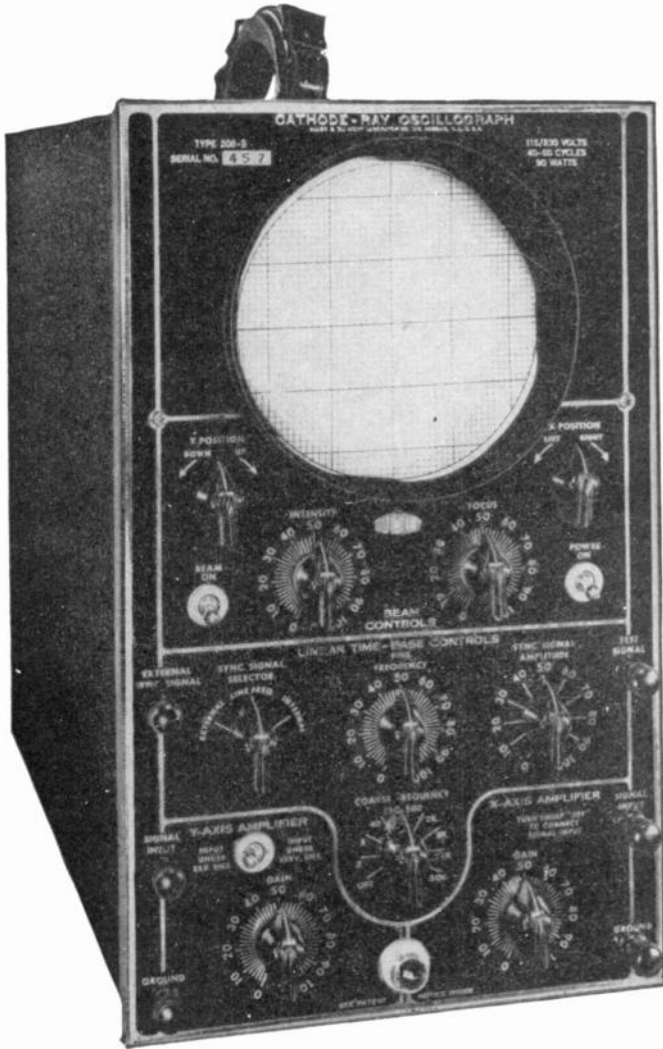
FIG. 11.14. A modern service oscilloscope.

stantly. To keep the image on the screen stationary, a small portion of the 60-cycle sweep frequency is fed to the horizontal amplifier (through the external synchronizing posts) of the oscilloscope for synchronization.

FIG. 11.15. A signal generator covering the F-M and television bands.

In addition to the coverage of the R.F. bands of the receiver, the alignment oscillator also provides I.F. video and sound frequencies in order that these sections of the receiver may also be serviced. The video I.F. channel oscillator covers the most frequently used I.F. values, sweeping over their band in the same manner as for the R.F. circuits. All ranges extend beyond

the actual frequencies required, a feature useful in definitely indicating the end points of the resonant bandpass circuits.

c. *Single Signal Generators.*   Although the television receiver employs wide-band tuning circuits, the conventional amplitude-modulated signal generator is not entirely without application. In the receiver just analyzed, the I.F. single-tuned circuits are peaked with such a signal generator.   Signal generators which generate one frequency at a time are also useful for marker points, as will be seen presently, and for testing the local high-frequency oscillator of the receiver.   Finally, in emergencies when no wide-band signal generator is on hand, a single signal generator can be used to provide a fairly satisfactory receiver alignment.   All in all, the advent of television receivers has, in no way, reduced the usefulness of the standard signal generator.

d. *Vacuum-Tube Voltmeters.*   The vacuum-tube voltmeter has always been a very handy instrument to have around, and with television receivers it becomes even more important.   The vacuum-tube voltmeter, when properly constructed, has negligible loading effect on the circuit across which it is placed.   In this respect it gives a true indication of the conditions in the circuit under test.   Recently, vacuum-tube voltmeters have been developed, using small, high-frequency diodes and triodes, which have a good response to frequencies as high as 700 mc.   With an instrument of this type, it is possible for the serviceman to go directly into the R.F. oscillator and I.F. circuits of the television receiver and determine directly the voltages existing there.   With conventional d-c meters, or even vacuum-tube voltmeters of limited frequency characteristics, it is impossible to do this.   In these instances, the signal which is fed in at the R.F. or I.F. stages cannot be used until it has reached the second detector and has been rectified.   The high-frequency vacuum-tube voltmeter accomplishes this directly at the point where it is placed and thus provides an indication directly at the desired point. A modern, high-frequency vacuum-tube voltmeter is shown in Fig. 11.16.
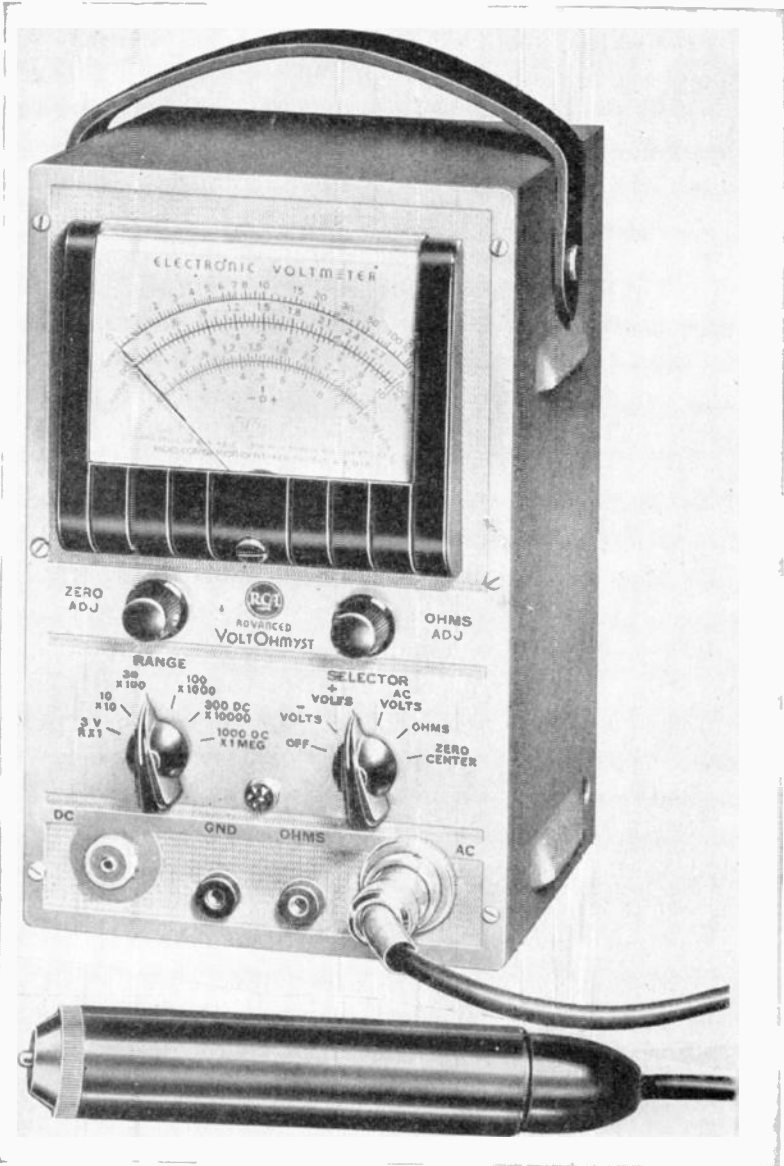
Fig. 11.16. A vacuum-tube voltmeter capable of measuring voltages with frequencies up to 200 mc.

e. Marker Signals. The final piece of apparatus may be incorporated either in the signal generator or supplied by an external signal generator that is capable of providing a single accurately calibrated signal. The purpose of a marker signal is to indicate the frequency at various points in the response curve observed on the oscilloscope screen. This will aid in adjusting the trimmer condensers or tuning slugs in the resonant circuits to the desired bandpass characteristics.

As an example, consider the response curve of Fig. 11.4 which is a standard I.F. response curve. This curve would be observed if we connected a signal generator at the grid of the first I.F. amplifier, and if the generator were sweeping through the I.F. values. Ordinarily the frequencies obtained from a signal generator cover a wider range than desired in the I.F. amplifiers. Hence, the exact points where the I.F. transformers should begin to cut off must be indicated on the oscilloscope screen. It is here that the marker system comes in.

If a manufacturer states in his service notes that the I.F. stages are designed to pass frequencies ranging from 21.75 to 25.75 mc, then on the visible response curve these two points should be indicated and made to appear at the appropriate points of the curve. The curve would be obtained if we connected a signal generator which was sweeping from 16 to 30 mc. Thus, while we know that the circuit is responding to the incoming signals, the precise range is unknown unless the end points of the response curve are given definite frequency values. To indicate the frequency of each end point, a marker system is employed. The values for these points are obtained from the manufacturer's service data. For example, if an I.F. range from 21.75 to 25.75 mc is desired, these two points would be checked on the visible response curve and the tuning circuits would be aligned for proper response between them.

To obtain marker points on the oscilloscope screen, two methods are generally employed. In the simplest method, the sweep signal generator contains an internal oscillator that superimposes its signals on the I.F. being swept out (16 to 30 mc). The

indication of the marker point in the visible pattern is either a slight wiggle or else a dip in the curve at this point. (See Fig. 11.17.) Note that while two marker points are indicated in Fig. 11.17, only one would be seen at a time. First the marker oscillator would be set to 25.75 mc and its position noted on the curve and then set to 21.75 mc and its position checked again.

The above-mentioned video I.F. band limits, 21.75 mc and 25.75 mc, represent the entire 4 mc that can be employed to
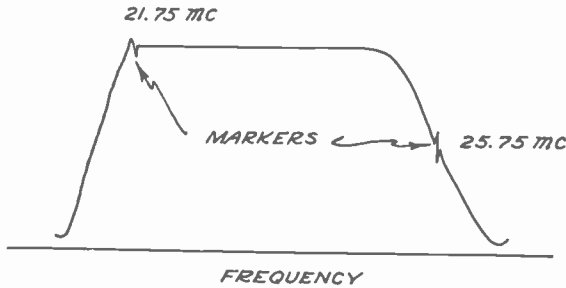
Fig. 11.17. The use of marker points for definitely indicating a frequency on a response curve.

transmit the details of the televised scene. Many receivers with small viewing screens do not require as wide a band and probably would be designed to pass only 3 mc or less in the I.F. amplifiers. In these instances, reference to the manufacturer's instructions will quickly indicate the band limits, and the marker frequencies can be changed accordingly.

If the sweep oscillator does not contain an internal device for supplying the marker points, then these may be obtained by the following method. Take another signal generator and place its output leads in parallel with those of the sweep generator, using two 50-$\mu\mu$f isolating condensers in the leads of the marker generator. Set the frequency of this second oscillator accurately to one of the frequencies it is desired to check on the response curve. Say this is 25.75 mc. With the equipment turned on, a wiggle (or pip) will appear on the overall response curve at 25.75 mc. Note whether the response at this point is as indi-

cated by the manufacturer in his service manual. Now change the marker frequency to 21.75 mc and note where this appears on the response curve. In this particular receiver (Fig. 11.1), 25.75 mc represent the video carrier, and 21.75 mc the end of the video bandpass. Other frequencies that should be checked are the trap frequencies. (See Fig. 11.4.) These include 21.25 mc, the sound carrier of the same channel; 27.25 mc, the lower adjacent channel sound carrier; and 19.75 mc, the upper adjacent channel picture carrier. At each of these points the response should be very low. In other sets that the serviceman will encounter, other frequency values will be used. The procedure, in any event, remains the same and requires only changing the frequency of the marker signal to these values.

It is advisable not to turn the amplitude of the indicating signal generator too high, but to keep it as low as possible (and still obtain a marker line).

This second method is highly flexible. While the sweep oscillator is moving back and forth across the band, the marker signal generator is set at one frequency. The setting of the marker generator can be altered at will, providing the serviceman with a means for identifying each point on the visible curve. Generally, marker signals incorporated with the sweep generator do not have this range of freedom but are restricted to certain chosen points.

Video I.F. Stages. Alignment of the several stages of a television receiver does not differ basically from the procedure followed in the more familiar A-M sets. For television, it is true that more care must be exercised and the equipment is more extensive, but the alignment starts at the same place—the I.F. stages—and ends at the R.F. stages at the input of the receiver. In order to illustrate the general method, let us use the receiver shown in Fig. 11.1 as our example, pointing out the sequence of events and adjustments to be followed. While we will use the specific components of the present set, similar sections of other receivers may readily be substituted for similar results.

The recommended order of alignment is as follows:

1. Video I.F. traps.
2. Video I.F. transformers.
3. Sound discriminator.
4. Sound I.F. transformers.
5. R.F. stages.

To start, connect the A-M (or single) signal generator to one of the grids of the mixer tube. The ground lead of the generator connects directly to the chassis of the receiver; the output lead is in series with a 50-$\mu\mu$f condenser and attaches to one of the grids of the mixer tube. The vacuum-tube voltmeter is placed across the video second-detector load resistor, or R_{137}. Set the generator to each of the following frequencies and tune each specified adjustment for *minimum* indication on the meter.

T_{104}... 19.75 mc
(Adjacent Channel Video Carrier Trap)
T_2 (top).. 21.25 mc
(Accompanying Sound Trap)
T_{105} (top)...................................... 21.25 mc
(Same as preceding trap)
T_{103} (top)...................................... 27.25 mc
(Adjacent Channel Sound Trap)

The next step is the alignment of the video I.F. transformers. The signal generator is set for each of the frequencies to which the coils are tuned and then the proper coil is adjusted for *maximum* response on the meter. The frequencies at which each coil is peaked are:

T_2 (bottom)..................................... 21.8 mc
(Converter Output)
T_{103} (bottom).................................... 25.3 mc
(1st Video I.F.)
T_{104} (bottom).................................... 22.3 mc
(2nd Video I.F.)
L_{183} (top of chassis)............................. 25.2 mc
(3rd Video I.F.)
L_{185} (top of chassis)............................. 23.4 mc
(4th Video I.F.)

If any of the transformers (T_2, T_{103}, and T_{104}) require any appreciable adjustment, it is advisable to recheck the traps at these coils. In this system, there is a possibility of I.F. oscillations if two or more of the I.F. transformers are tuned to the same frequency. I.F. oscillations will cause a voltage in excess of 3 volts to appear across the diode load resistor. This voltage is not affected by R.F. signal input and sometimes it is independent of the setting of the contrast control. To stop the oscillations, shunt the grids of the first three I.F. amplifiers to ground with 1,000-$\mu\mu$f condensers. Then connect the signal generator to the grid of the fourth I.F. amplifier tube and adjust the coil in the plate circuit of this tube (L_{185}) for maximum response. Shift the signal generator to the grid of the third I.F. amplifier. Remove the shunting condenser here and, with the generator set to the proper frequency, adjust the plate-tuned circuit of this tube for maximum response. Repeat this procedure for the second and then the first I.F. amplifier. The oscillations should now be completely gone if the circuits are functioning properly.

The entire video I.F. system is now adjusted. An overall check should be run, with the sweep oscillator connected to one of the triode grids of the mixer. A condenser of 50 $\mu\mu$f is inserted in series with the output lead of the generator. The vertical or indicating plates of the oscilloscope are attached across the second-detector load resistor. In this circuit the resistor is R_{137}. For a stationary image on the screen, a small amount of synchronizing voltage is taken from the sweep generator and applied to the terminals marked "External Sync" on the oscilloscope front panel. To aid further in stabilizing a single image on the screen, a phase control is available on most sweep generators to permit changing the phase of the synchronizing signal until a single stationary pattern is obtained. With the oscilloscope power on and the unit operating properly, the I.F. response should be visible on the screen. Check the shape of the curve against the one recommended by the manufacturer. With a variable marker obtained by the method described above, check each of the end points of the response curve and the trap fre-

quencies. If any slight adjustments are required, they are made with the sweep generator on so that the effect on the overall curve is seen.   However, if it is found that any considerable adjustment is necessary, then the entire alignment procedure should be redone.

The form of the overall video I.F. response curve when the circuit is improperly aligned is indicated in Fig. 11.18 A and B. The proper shape is the one in Fig. 11.18C.

Sound Discriminator Alignment. With the video I.F. stages functioning in good order, we next tackle the sound I.F. system and the F-M discriminator. (It is suggested that those readers who are not familiar with the operation of F-M receivers read Chapter 12 before continuing.)
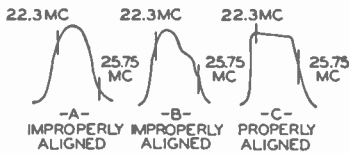
Fig. 11.18. The form of the video I.F. response curve for proper and improper alignment.

To align the discriminator, set the signal generator for approximately 1 volt output at 21.25 mc. Connect the generator output lead to the grid of the third sound I.F. The ground lead goes to the receiver chassis. The vacuum-tube voltmeter is set to the 10-volt scale. It is then connected to the point where R_{219} and R_{220} join. Now detune the secondary winding of T_{113} and adjust the primary winding of the same transformer for maximum indication on the meter.

The reason for this procedure is that the discriminator is a balanced circuit and produces across both load resistors (R_{219} and R_{220}) no output at the center sound I.F. (21.25 mc in this case). By connecting the meter across half the load and throwing the secondary of the discriminator out of adjustment, we can tune the primary winding to its proper peak. Next, to bring the secondary (and the discriminator) back into balance, we proceed as follows:

Connect the vacuum-tube voltmeter to the top of R_{220}. This places it across both load resistors. Adjust the secondary of T_{113} for zero indication on the meter. On one side of this zero

point, the meter will read a positive d-c voltage and, on the other side, a negative d-c voltage. The best procedure, then, is to move slowly back and forth about the zero point, each time lessening the extent of the excursion until the exact zero point is reached.

The object, when aligning a discriminator, is to make its response linear over its operating range of frequencies.

The linear section is that portion of the discriminator characteristic between points A and B (Fig. 11.19). The primary winding of the discriminator transformer (T_{113}) governs the extent of the linear portion of the curve between the end points where the curve reaches its peak and begins to fall off. The secondary winding governs the position of the crossover point. The cross-over point should be located midway between the upper and lower peaks. We

Fig. 11.19. Discriminator characteristic curve.

can use the sweep generator to see the entire curve at one time and determine whether both of the foregoing conditions are fulfilled. This is the next step.

The sweep generator is connected to the grid of the third I.F. sound amplifier. Set the sweep bandwidth to approximately 1 mc with the center frequency at 21.25 mc and with an output voltage of 1 volt. The vertical input terminals of the oscilloscope are connected between the top of R_{220} and ground. The pattern that is obtained should be as shown in Fig. 11.19. If the curve is not symmetrical or the linear portion sufficiently long, both trimmers of T_{113} will have to be readjusted. The curve should be linear for at least 200 kc. A separate generator used to provide a variable marker will indicate the extent of the linear portion.

Sound I.F. Alignment. Most F-M receiving systems include several I.F. stages operated as conventional amplifiers. The last

I.F. amplifier or two just preceding the discriminator are designed to function as limiters. As explained in Chapter 12, a limiter operates in such a manner as to provide a fairly constant output with input signals that vary in strength. A characteristic curve is shown in Fig. 11.20 and illustrates the limiting action graphically. It is at this point in the F-M receiver that much noise and all amplitude modulation are removed. In the present
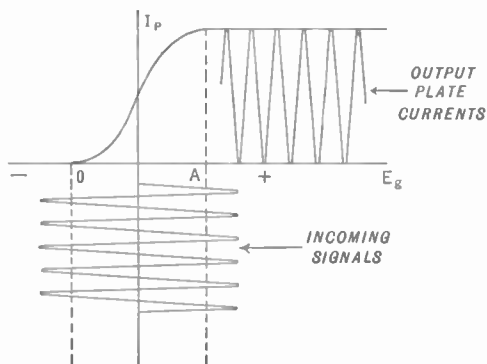
Fig. 11.20. The characteristic curve for a limiter. As long as the incoming signal extends beyond O-A, the output will be free of amplitude modulation.

receiver, there are two normal sound I.F. amplifiers, V_{104} and V_{105}, and one limiter, V_{106}. V_{105}, however, functions as a partial limiter.

In order to obtain the action of limiting, the stage generally employs grid-leak bias and relatively low plate and screen voltages. Since the amount of grid-leak bias developed in the grid circuit of the limiter is proportional (for relatively small input voltages) to the strength of the incoming signal, the indicating meter may be placed across this resistor when aligning the amplifiers which precede this stage.

To align the sound I.F. stages, connect the oscilloscope to the third sound I.F. grid-leak resistor, R_{217}. It is suggested that a 33,000-ohm isolating resistor be placed in series with the oscilloscope lead that connects to the top of R_{217}. (We are still using the vertical input terminals of the oscilloscope.)

Connect the sweep generator to the grid of the second sound I.F. amplifier and insert a 21.25-mc marker signal from the other signal generator at the same point. The pattern obtained on the oscilloscope screen should be similar to the illustration in Fig. 11.21 with the marker pip in the center of the curve. Transformer T_{112} is adjusted for maximum gain and symmetry about the 21.25-mc marker.

It is important that the sweep oscillator output be kept as low as possible—as low as it is possible to obtain a usable indication on the oscilloscope screen. Too large an input signal will produce a broadened response curve, permitting misadjustments to pass unnoticed and possibly causing distortion on weak signals.

Place the sweep oscillator and signal generator at the grid of V_{104} and adjust T_{111} for maximum gain and symmetry about the 21.25-mc marker. This completes the adjustment of the sound I.F. system.

As an alternate procedure, it is possible to align the I.F. stages

Fig. 11.21. The shape of the response curve and the position of the marker frequency when aligning the F.M., I.F. stages.

using the A-M signal generator and the vacuum-tube voltmeter. The generator, however, must be capable of indicating various points about the center frequency (in this case, 21.25 mc). For example, it should provide settings of ± 25 kc, ± 50 kc, ± 75 kc, and ± 100 kc about 21.25 mc. The procedure, then, is to peak each of the I.F. amplifiers and note, by shifting above and below the center frequency, how symmetrical the response is. For the I.F. amplifiers, the indicating meter is connected across the limiter grid-leak resistor. For the discriminator transformer alignment, we follow the procedure outlined above. To check the symmetry of the discriminator response, the meter is placed across both load resistors. Equal (and of opposite polarity) voltage readings should then be obtained for equal frequency distances above and below 21.25 mc. For example, 21.25

mc. + 25 kc should produce a meter reading which is equal in value and opposite in polarity to the reading obtained when the incoming signal is at 21.25 mc — 25 kc.

R.F. and Converter Circuit Adjustment. If the television receiver is so designed that the R.F. and converter input circuits can be aligned without using the receiver oscillator, it is desirable that they be adjusted first and then the oscillator. If this cannot be done, then the oscillator will have to be adjusted first, and then the R.F. and converter units. In the receiver under
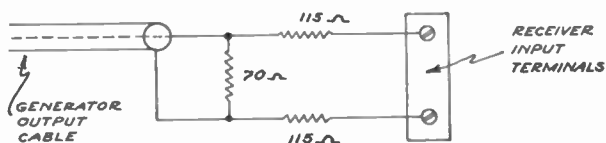
FIG. 11.22. A simple method of matching the impedance of the generator cable to the receiver input.

discussion. the various stages can be separately aligned and so the R.F. and converter stages are taken first.

Connect the R.F. sweep oscillator to the receiver antenna terminals. To simulate actual operating conditions, the output of the generator must match the impedance of the receiver input terminals. A simple method of effecting such a match is shown in Fig. 11.22.

A resistor equal to the impedance of the generator output cable is connected across the two leads of the generator cable. Let us suppose this is 70 ohms. The difference between this resistance and the input impedance of the receiver is then computed and two resistors, both equal to half the value computed, are placed each in one of the wires leading to the receiver antenna terminals. Thus, in the example given. 300 ohms — 70 ohms gives a difference value of 230 ohms. Half of this is 115 ohms and resistors of this value are placed in each lead, as shown in Fig. 11.22. The system is matched since the generator "sees" 70 ohms and the receiver "sees" 300 ohms. The values of the

resistors need not be exactly matched, but they should be within 5 per cent of the required values. They must also be non-inductive.

Returning to the alignment, connect the oscilloscope to the junction of L_{30} and R_6 through a 10,000-ohm resistor. The contrast control is set for approximately -1.5 volts bias on the R.F. stage. This represents the normal position of the contrast control when a station is being received and the amount of bias on the tube will affect the response curve somewhat. Connect the marker signal generator loosely to the receiver antenna terminals.

We are now ready for the alignment. Because of the design of the tuning circuits, the high-frequency channels are adjusted first. Of these channels, No. 7 has the narrowest response and is taken first. Switch the receiver to channel 7. Set the sweep oscillator to cover channel 7. Insert markers of channel 7 picture carrier and sound carrier, 175.25 mc and 179.75 mc. Adjust L_{25}, L_{26}, L_{51}, and L_{52} for an approximately

Fig. 11.23. The R.F. response characteristics of the RCA receiver.

flat-topped curve between the markers. Normally, this curve appears somewhat overcoupled or double-humped with a 10 or 15 per cent peak to valley variation and the markers occur at approximately 90 per cent response (see Fig. 11.23, channel 7).

The response of channels 8 through 13 is checked in turn. Typical response curves are shown in Fig. 11.23. It should be found that all these channels have the properly shaped response with the markers above 70 per cent response. If the markers do not fall within this requirement on one or more of the high-frequency channels, it will be necessary to readjust L_{25}, L_{26}, L_{51}, and L_{52} for a compromise position. There are no individual channel adjustments. Usually the most critical of the high-

frequency channels is channel 7; the higher we go in frequency, the broader becomes the response of the circuit.

Channel 6 is next aligned in the same manner, care being taken to change the set selector switch and the frequency readings of the signal and marker generators. Channel 6 is in the lower frequency television band and we now adjust L_{11}, L_{12}, L_{37}, and L_{38} for an approximately flat-topped response curve symmetrically located between the markers. From channel 6 we shift to channel 5 right on down through channel 2, each time making the necessary changes in the receiver selector switch and the various generators. In all instances, the markers should be above the 70 per cent response point of the curve. If this is not so, L_{11}, L_{12}, L_{37}, and L_{38} should be retouched. On final adjustment all channels must be within the 70 per cent specification.

The amount of coupling between the R.F. amplifier and converter lines is governed by the link coupling. If the coupling is too tight, there will be greater than a 30 per cent dip at the center of the response curves. If this is found to be the case, coupling should be decreased until the dip is no greater than 30 per cent.

R.F. Oscillator Adjustment. There are several methods that may be employed to align the oscillator, but the simplest method is to feed a single signal into the receiver at the R.F. sound carrier frequency and adjust the oscillator for zero output from the sound discriminator. It is evident that the sound I.F. circuits must be properly aligned if this method is to produce accurate results.

Connect the signal generator to the receiver antenna terminals. This is the generator that produces only a single frequency for each setting of the dial. The vacuum-tube voltmeter is connected across both load resistors of the discriminator. Since the lower frequencies are obtained by adding inductance, it is necessary to align channel 13 first and then work back to channel 2. The receiver channel switch is set at channel 13. The signal generator is adjusted for 215.75 mc, this being the position of the R.F. sound carrier in channel 13. (The position for this carrier

in each channel is given at the beginning of this chapter.) Adjust L_{77} and L_{78} for zero voltage on the meter. As the coils are adjusted, the meter will go from either positive or negative values through zero to voltages of the opposite polarity. A vacuum-tube voltmeter with a center zero scale should be used.

Each lower channel is then adjusted in order, the generator frequency and the receiver selector switch being altered to the
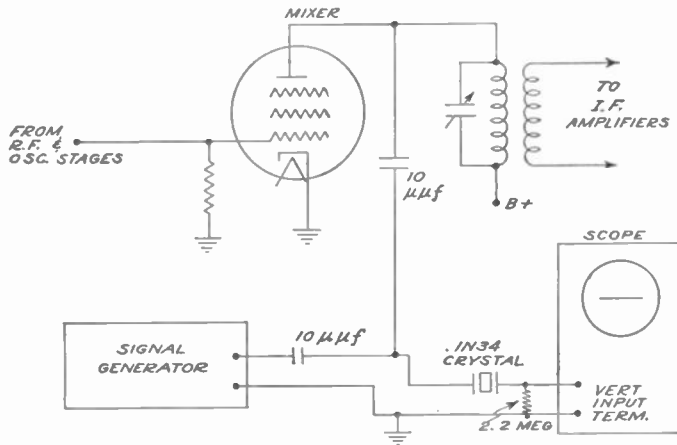
FIG. 11.24. A means of checking and aligning the receiver oscillator frequency. The oscillator signal is taken from the plate circuit of the mixer in order not to disturb the oscillator operation.

appropriate value. The proper oscillator coil to be adjusted for each channel can be obtained from the complete circuit schematic diagram. For example, adjust L_{76} for channel 12. L_{74} for channel 11, etc. After the oscillator has been set on all channels, start back at channel 13 and recheck to make sure all adjustments are correct.

The fine tuning control is set to the middle of its range while making all oscillator adjustments.

An alternate method of aligning the high-frequency oscillator is illustrated in Fig. 11.24. The receiver oscillator signal voltage beats with the output of an accurately adjusted signal generator in a small IN34 crystal detector. The beat frequency voltage is

then fed to an oscilloscope. If the two voltages possess the same frequency, there will be zero beat and a straight line obtained on the oscilloscope. If the receiver oscillator is off frequency, the beat frequency waves will be visible on the oscilloscope screen. The receiver oscillator is then adjusted for zero beat indication (a straight line).

In this method, the signal generator must be capable of providing accurately the oscillator signal frequency for each band. These frequencies are listed at the beginning of this chapter.

CHAPTER 12

FREQUENCY MODULATION *

General Outline. Frequency modulation, although only a newcomer so far as radio broadcasting is concerned, has definitely been chosen as the method of transmitting the audio portion of television programs. This choice was the result of several factors. Of the two systems available today, A-M and F-M, the latter has been proved capable of better reception under adverse conditions. It is easier to minimize interference from other near-by stations operating on the same frequency with frequency modulation than with amplitude modulation. Finally, there is the matter of cost, a factor especially applicable to transmitters. Because of the arrangement of the circuits in a frequency-modulated transmitter, it is more economical to produce a given wattage signal with this equipment than to produce the same wave with amplitude modulation. Specifically, the large difference in cost between the two systems lies in the audio power required to produce a certain strength signal. With A-M, the audio power is generally 50 per cent of the carrier power, which may entail many thousands of watts for a powerful station. On the other hand, in F-M, the audio required represents only a fraction of the output power and can be more easily generated.

The power relationship that exists in an amplitude-modulated wave between the sidebands and the carrier is in the ratio of 1:2 for 100 per cent modulation. This is only the average power and, when the equipment is designed, it must be capable of

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* Due to space limitation, only the most important aspects of F-M can be considered here. For a more detailed analysis, the reader is directed to "F-M Simplified" by the same author, published by D. Van Nostrand Co., Inc.

handling the much higher peak (or surge) power. Naturally, this requirement materially increases the cost of the station. In F-M transmission, the power output does not increase with modulation and no additional provision for handling excess power need be made.

The matter of fidelity is not stressed because, contrary to popular opinion, just as much fidelity is available with A-M as with F-M. It is only on the present crowded broadcast band (500 to 1,500 kc) that space is not available to permit the full 10,000 or 15,000 audio cycles to be reproduced. Given sufficient ether space, both systems have equal fidelity.

In order to discuss radio using frequency modulation, it first might be best to point out the differences between A-M and F-M waves and then to see why these differences exist. Toward that end, the following list has been tabulated:

Factor	F-M	A-M
Amplitude of Signal....	Remains constant	Varies with per cent of modulation
Audio Voltage.........	The frequency spread of signal is determined by the strength of the audio voltage	Determines the amplitude of the wave
Audio Frequency.......	The frequency of the audio modulating voltage will determine how rapidly the F-M wave will change from one frequency to another	The audio frequency controls the speed with which the amplitude of the wave changes
Signal Spread..........	The number of sidebands depends upon the amplitude of the modulating signal. In television, this spread is restricted to 25 kc on either side of carrier	Limited to 5 kc on either side of the carrier frequency. It is determined by the frequency of the modulating audio wave

The ordinary amplitude-modulated waveform, as it might appear for 100 per cent modulation, is shown in Fig. 12.1A. The audio-modulating signal adds to or subtracts from the amplitude of the carrier. When the modulating signal becomes too strong, overmodulation occurs and the carrier is driven to

zero for some short time. This is illustrated in Fig. 12.1B.
Note that, whereas the amplitude of the wave may increase as
much as possible, it can only decrease to zero. Whenever over-
modulation occurs, the waveform becomes distorted and the
greater number of frequencies that are generated by this process
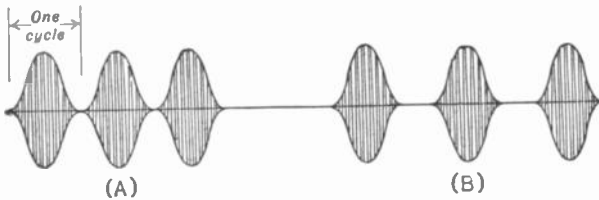
Fig. 12.1.   Amplitude-modulated waves.   (A) 100% modulation,
(B) overmodulation.

causes the bandwidth of the station to increase. Hence all com-
mercial broadcasting stations are careful to see that their output
never reaches 100 per cent modulation.

A frequency-modulated wave is constant in amplitude, but
varies in frequency. It would appear as pictured in Fig. 12.2.
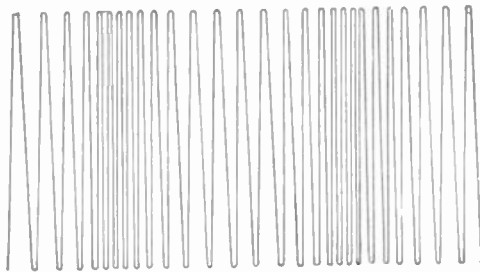
Fig. 12.2.   Frequency-modulated wave.   The changing spacing between cycles
indicates different modulating frequency intensities.

The property of constant amplitude makes the frequency-modu-
lated wave so important. Most of man-made and natural inter-
ference has been found to affect the amplitude of a wave much
more than its frequency. For the A-M signal, the interference
distorts the waveform and, with this, the intelligence contained

therein.   F-M, on the other hand, contains its intelligence in its
changing frequencies.   At the F-M receiver, one of the I.F.
stages, called the limiter, smooths any irregularities in the am-
plitude of the incoming signal and by this process eliminates the
interference.

   The frequency bandwidth of an F-M wave depends upon the
strength of the impressed audio voltage.   At the transmitter,
the carrier frequency is fixed by a self-excited oscillator.   This
frequency is the mean or center frequency of the broadcast
station.   When the sounds that are to be transmitted are fed into
the microphone, the mean frequency of the transmitter is varied.
The louder the audio signal, the greater the deviation.   For
example, a frequency deviation (or change) of 50 kc in the out-
put might occur for a strong audio voltage, whereas only a 1-kc
change would occur if the audio voltage were weak.   In the
A-M case, the amplitude and not the frequency of the wave
changes for different audio sound levels.

   The rapidity with which the F-M transmitter frequency moves
from one point to another is determined by the frequency of the
modulating sound.   A high-pitched sound would cause the fre-
quency of the F-M transmitter to change more rapidly than if
60 or 100 cycles were used.

   One definite advantage obtained with frequency modulation is
due to the observed (and calculated) fact that, if two signals
are being received simultaneously, the effect of the weaker signal
will be eliminated almost entirely if it possesses less than half
the amplitude of the other stronger signal.   This means that for
one signal to completely override another at the receiver, their
amplitudes need be in the ratio of 2:1, or more.   With a good
antenna, it is easy most times to tune in one station in sufficient
strength so that the other interfering station or stations are
eliminated entirely.   No such situation exists with A-M signals,
where interfering stations can be heard when even a 100:1 re-
lationship exists between the various carrier amplitudes.

   Transmitters.   It would be difficult to analyze the functions of
a frequency-modulated transmitter by comparing it with the

more familiar amplitude-modulated transmitter because of the great dissimilarity between them. Consider the two basic methods used to develop an F-M signal shown in block form in
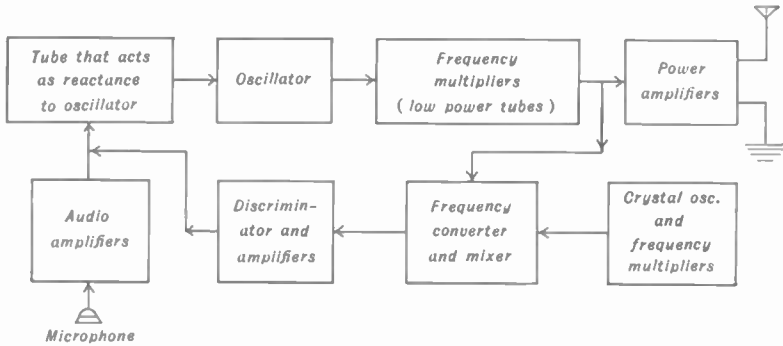
Fig. 12.3. Crosby system or reactance-tube method of producing F-M waves.

Figs. 12.3 and 12.4. In Fig. 12.3 we have the reactance-tube, or Crosby, system, whereas in Fig. 12.4 we have the Armstrong method of frequency-modulated transmission. Although both
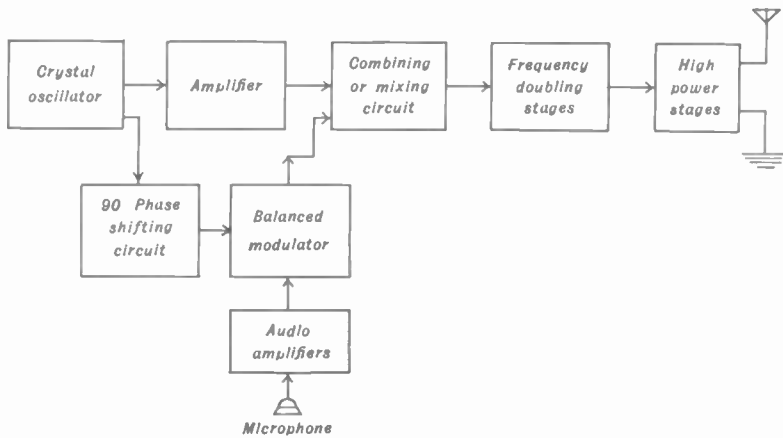
Fig. 12.4. Armstrong system of frequency modulation.

methods are highly involved and mathematically complex in design, a sufficiently simple explanation is possible to indicate the general functions of the various stages of each of the systems.

In the Crosby transmitter, the heart of the process is to be found in the reactance tube. This tube and its circuit are directly connected to a single frequency oscillator, the latter being perhaps some form of Hartley oscillator. As long as no audio signal is impressed on the grid of the reactance tube, no plate current variations will occur in the output of the tube, which is directly connected across the tuning coil of the oscillator. Under such conditions, the oscillator generates its mean or carrier signal frequency. Any receiver tuned to this transmitter would not, at this particular moment, receive any audio output.

Upon speaking into the microphone, however, a varying voltage is generated which is amplified by conventional audio stages and placed on the grid of the reactance tube. These audio variations cause the reactance tube plate current to assume different values. Because the plate current must pass through the oscillator coil and because of the phase relations of the associated circuit, the reactance tube may be made to appear either inductive or capacitive to the oscillator, thus causing its frequency to increase or decrease. This is the first step in the formation of a frequency-modulated signal. The audio variations have directly affected the frequency of the oscillator, with a stronger audio signal causing a greater change in frequency than a weaker audio signal.

The frequency variations or deviations from the mean or carrier frequency are at this point quite small. For example, with a mean frequency of 1 mc, the audio voltage may cause a frequency variation of perhaps plus and minus 10 kc about the 1 mc. Feeding this signal into a doubler stage will result in an output of 2 mc having a frequency deviation about this carrier value of plus and minus 20 kc. By applying more of these multipliers, the final carrier frequency is obtained having a frequency variation of plus and minus 100 kc (200 kc in all). While the values used here as illustrations may not be the exact figures found in practice, they do illustrate how the final signal spread is obtained. In any one stage, the frequency range must

be a small percentage of the mean or carrier frequency at that point in order to prevent distortion.

The other sections of the transmitter shown are concerned with keeping constant the mean frequency of the self-excited oscillator. The manner in which this is accomplished is indicated in Fig. 12.3. A crystal oscillator generates a single, stable frequency. The output from the crystal oscillator is passed through a sufficient number of frequency multiplier stages so that a frequency equal to the exact carrier frequency of the transmitter (as fixed by the F.C.C.) is reached. This signal from the crystal oscillator section is then fed to a mixer where it combines with the actual carrier of the transmitter itself. If there is no difference between these two values, no voltage is sent back to the reactance tube. However, if somthing has caused the transmitter carrier frequency to drift, a resultant voltage will be obtained from the discriminator, and the bias of the reactance tube will be varied accordingly. A positive change in bias of the reactance tube will affect the oscillator frequency one way, while a negative change will result in the opposite reaction. In either case, the output of the discriminator will always act so as to bring the mean frequency of the main oscillator back to its correct value. With accurate adjustment, the transmitter carrier will always remain at its assigned value, the limits being determined by the correcting crystal oscillator.

A second system commonly used for producing frequency modulation is shown in block diagram form in Fig. 12.4. In this transmitter, the fundamental frequency is determined by a crystal-controlled oscillator operating at about 200 to 300 kc. A portion of the output of this oscillator is fed to an amplifier while the other portion is sent through a 90' phase-shifting circuit and a balanced modulator. The modulator merely combines the phase-shifted carrier with the audio-modulating voltage. Due to the action of a balanced modulator, sidebands are generated, just as in any ordinary amplitude-modulated transmitter. The one difference, however, lies in the fact that the carrier is automatically suppressed and only the sidebands ap-

pear at the output of the stage. These sidebands, when re-combined with the original carrier, will cause frequency modulation, although at this point the amount of frequency variation about the carrier is not very great.

From this point on, frequency multipliers increase the amount of frequency deviation obtained until it is as large as desired. Then isolating power amplifiers increase the strength of the signal and feed it to the transmitting antenna. The heart of this system is in the 90° phase-shifting network, for it is through its action that frequency modulation is obtained.

In the description of the two systems, only the basic outlines have been given. The number and type of stages that are found depend upon the output power desired and the frequency of the transmitter. However, except for the last few power amplifiers, the intervening tubes may be of the small inexpensive receiving type commonly found in home sets. Thus we can see that the audio power required in either one of these two systems is very small, much less than the amount necessary with amplitude modulation.

F-M Receivers. Although it is difficult to draw a comparison between A-M and F-M transmitters, it is possible to show the similarity between the respective receivers. The F-M receiver is a superheterodyne in practically all instances, although radio-frequency sets are also possible. The superheterodyne offers so many more advantages than a simple radio-frequency receiver that the latter is seldom used.

The block diagrams of Fig. 12.5 illustrate the differences between A-M and F-M superheterodynes. Besides the limiter and discriminator stages in the F-M receiver, both sets would appear to be exactly alike, and indeed might easily be mistaken for each other from an ordinary schematic. Up to the limiter stage, the essential difference between the two types of receivers resides almost wholly in the tuning circuits that connect each stage. In F-M, these circuits must be capable of receiving higher frequencies and also be capable of passing a wider band of side frequencies associated with the F-M carrier. In the ordinary

F-M receiver, designed for use between 88 and 108 mc, each station is allowed sidebands ranging up to 75 kc on either side of the carrier. For television audio, merely 25 kc is used, the narrower bandwidth simplifying somewhat the problem of receiving both the video and the audio carriers simultaneously.

One special feature common to many F-M receivers is the use of a separate oscillator that feeds the mixer tube and helps gener-

BLOCK DIAGRAM OF A-M SETS
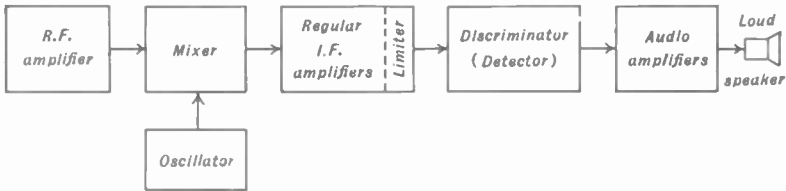
BLOCK DIAGRAM OF F-M SETS

FIG. 12.5. A comparison of the block diagrams of A-M and F-M receivers.

ate the I.F. At the higher frequencies employed for the television audio, normal drifting by the oscillator produces more marked effects than it does in the lower frequency broadcast receivers. At 60 mc, 2 per cent frequency drift would shift the signal beyond the bandpass of the audio I.F. circuits; at 1 mc, the same percentage shift is only 20 kc and would not shift a signal beyond the bandpass of circuits designed for a ±75-kc signal spread. The separate tube arrangement results in greater stability, with drift reduced to a smaller fraction than would be present in designs using the same tube for mixing and generating the oscillator voltage. Often, such additional devices as compensating ceramic condensers are placed in the oscillating tank circuit in order to counteract tendencies on the part of the other frequency determining components to change with operating conditions.

The most common I.F. in use today for the F-M receiver (not associated with television) is 10.7 mc. Other manufacturers prefer 9.1 mc. One disadvantage of a high I.F. (for the present) is the lower gain per stage. However, with the introduction of newer tubes, the objection may disappear and the higher frequencies become standard. As noted in previous chapters, television audio I.F. stages are centered at 21.25 mc. Also, as a
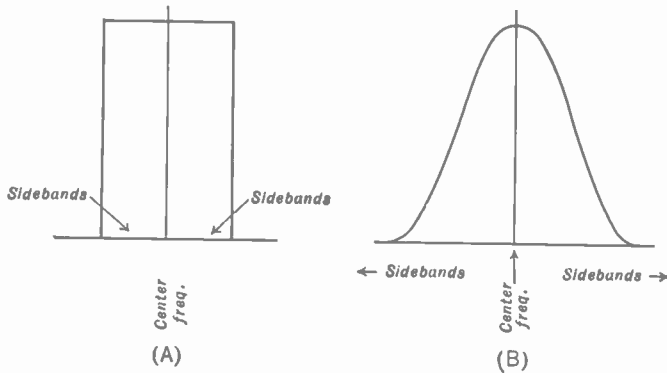
Fig. 12.6. Receiver response curves. (A) is the ideal curve, (B) a typical practical result.

consequence of the reduced gain, even with the lower I.F., we generally find one or two more I.F. amplifiers in F-M receivers than in A-M superheterodynes.

Limiters. The first significant difference between the A-M and F-M superheterodynes is noted at the limiter stage or stages. Essentially, the purpose of a limiter is to eliminate the effects of amplitude variations in the F-M signal. While it may have been true that the frequency-modulated signal left the transmitter with absolutely no amplitude variations, this is almost never true by the time the signal reaches the limiter.

To digress for a moment, let us see where, in the receiver itself, various portions of the F-M signal could have received more amplification than other parts of the signal, the result naturally causing some frequencies to possess greater amplitudes. An ideal response curve for a tuned circuit is shown in Fig. 12.6A.

With such a characteristic, each frequency within the signal would receive uniform amplification. Such a happy situation, however, is seldom encountered in practice. The more usual state of affairs is illustrated by the curve of Fig. 12.6B. Here it is apparent that the center frequencies receive more amplification than those located farther away. Hence, even if the incoming signal were perfectly uniform, by the time it arrived at
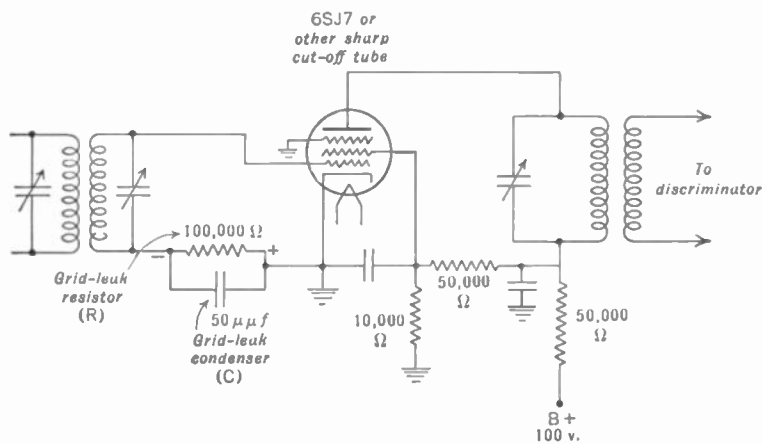
Fig. 12.7. A familiar limiter stage circuit.

the limiter amplitude variations would be present. The result would be distortion if this wave were allowed to reach the speaker. It is for the limiter to remove the amplitude variation.

Some radio men seem to have the mistaken idea that it is the discriminator that eliminates the noise in the signal, and not the limiters. Noise, once it reaches the discriminator, will pass through, except for the rather infrequent case when it occurs at the mid-frequency of the particular I.F. band used. With the function of the limiter so important, let us see what constitutes correct operation for this stage.

A typical limiter stage is given in Fig. 12.7. Inspection reveals that low plate and screen voltages are used, in addition to grid-leak bias in the input or grid circuit. The low electrode

voltages cause the tube to reach current saturation with moderate signals at the grid. The use of grid-leak bias aids in keeping the output plate current (and hence the output signal) constant for different input voltage levels. It is readily apparent that, with F-M signals of different amplitudes arriving at the grid of the limiter, a constant output for each would mean the elimination of any amplitude distortion, which is just what is desired. With the limiter so designed that it will easily saturate,
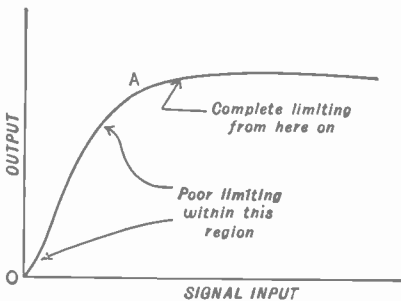
FIG. 12.8. The characteristic curve for a limiter.

amplitude variations can be eliminated and, with them, most disturbing noises. This is all possible because of one fact—namely, that much man-made or natural interference affects the amplitude of the radio signal more than its frequency. By the simple device of smoothing out the amplitude differences of the incoming waves (without affecting their fundamental frequency), we eliminate the noise or interference. This is one reason for the extensive use of F-M.

A limiter characteristic curve is shown in Fig. 12.8. Notice that the output signal of the tube increases with input signal until a certain voltage is reached. Beyond this point, known as the knee of the curve, point A, the limiter plate current remains substantially constant for all stronger input voltages. Since complete limiting begins at this point, the signals at the antenna of the receiver must receive sufficient amplification to force the limiter tube to operate beyond point A. From this point, the output of the limiter will remain constant. Any signal which is so weak that it is unable to operate the tube beyond OA will have its noise appear in the limiter output.

The situations for weak and strong signals may be demonstrated graphically. The curve OAB in Fig. 12.9 is the relationship between the input grid voltage or signal and the resulting

plate current in the output of the limiter. With the tube biased
to point C, the input signal voltage will vary about this point.
Consider the first small signal coming in. As it varies the grid
bias, corresponding changes take place in the plate circuit and at
no time will the plate current be forced to its saturation value.
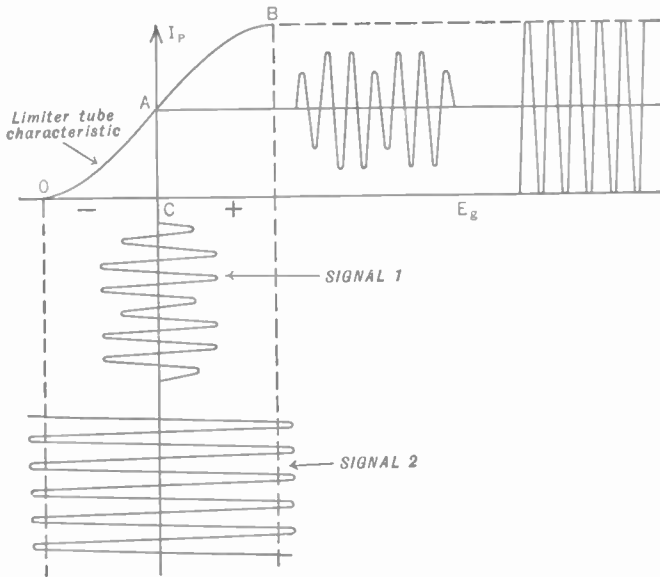
Fig. 12.9. These curves illustrate that the incoming signal must reach a certain
amplitude before the limiter stage will saturate.

This means that any noise and amplitude distortion contained in
this signal will be amplified and reproduced in the plate circuit
and, from here, go to the discriminator. Frequency modulation
in this case will not eliminate the interference.

Now consider the second signal voltage. At all peak points
of the signal, plate current saturation is reached on the positive
peaks, while current cut-off is responsible for smoothing out the
negative peaks. In the output circuit, all trace of amplitude
distortion has been clipped or eliminated. When this signal is
fed to the discriminator, it should give noise-free operation.
Thus, while a limiter provides F-M with its greater advantages,

care must be taken to see that it is properly operated; otherwise its usefulness is lost. The F-M receiver must be so designed that all desired signals to the input receive sufficient amplification. When this is done, the plate current of the limiter will give constant output.

It should be mentioned that, by clipping off the top of the waves in order to have them all reach the same level, we are introducing amplitude distortion into the signal. Ordinarily this would be objectionable but, in the present case, the new frequencies generated by this clipping are harmonics of the frequencies arriving at the limiter, and the resonant circuit in the output of the stage does not react to them. Thus the harmonics are filtered out and can cause no damage. Only signals having frequencies within the bandpass limits of the resonant coil and condenser develop sufficient voltage to be passed on to the next inductively coupled circuit.

It is possible to design limiters on the basis of low plate and screen voltages alone, but better results and more amplification are obtained if grid-leak bias is added to this combination (see Fig. 12.7). With the insertion of grid-leak bias, it is possible to raise the electrode voltages, increasing the gain somewhat. The tube initially has zero bias with no signal at the grid. As soon as a signal acts, the grid is driven slightly positive, attracts electrons, and charges the condenser C, Fig. 12.7. This condenser attempts to discharge through R but, due to the relatively long time constant of R and C, the discharge occurs slowly. Because of current flow through R, a voltage is developed, with the end nearest the grid becoming negative. This voltage will act as a bias, varying in value as the incoming signal varies and in this way tending to keep the plate current steady within rather wide limits of input voltage. A strong signal causes the grid to become more positive, resulting in a greater current flow through R. A larger bias is developed. A weaker signal will cause less voltage, resulting in essentially the same amount of plate current. Usual values of C range from 30 to 60 $\mu\mu f$ and, for R, between 50,000 and 200,000 ohms.
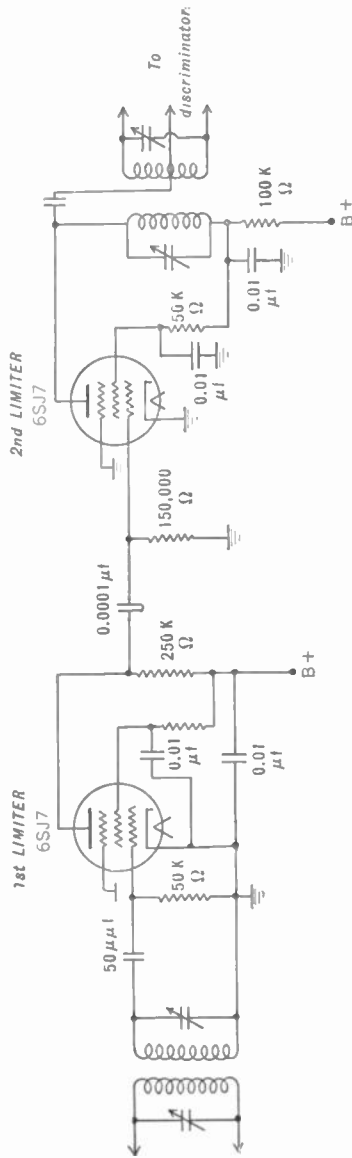
Fig. 12.10. A dual limiter circuit.

Because the voltage across R, the grid-leak resistor, will vary with the amplitude of the incoming signal, this point of the limiter is generally used for two purposes: one is for aligning the preceding I.F. amplifiers, and the other is for magic-eye tuning devices. The tuning eye operates on differences in voltage and this point in an F-M receiver is well suited to indicate the strength of the incoming signal.

For alignment, the vertical cable of the oscilloscope, when placed across the ends of the grid-leak resistor, will indicate the
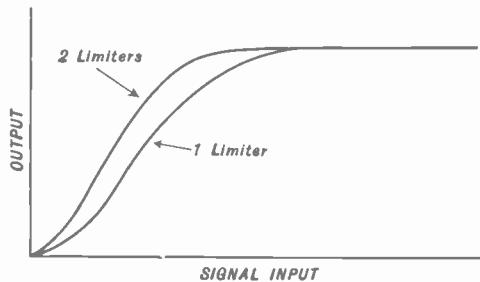
Fig. 12.11.   A comparison of limiter characteristic curves for single and dual stages.

form of the signal and will permit the adjustment of the preceding I.F. transformers for maximum response. It will be recalled that this process was used in aligning the set described in Chapter 11.

Although one limiter stage serves satisfactorily, better results can be obtained with two stages, one following directly behind the other. The circuit of two limiters in cascade is shown in Fig. 12.10, and their characteristic curve is given in Fig. 12.11. With two limiters, the knee of the resulting curve becomes sharper and provides better limiting action. In all limiter circuits, sharp cut-off pentodes are used, with tubes having the highest values of G_m preferred.

The Discriminator.   The purpose of the second detector in an amplitude-modulated set is to obtain the audio variations from the incoming modulated signal. The same stage in a frequency-modulated receiver must derive the audio variations from the

different incoming frequencies. Thus, although the end product
in both cases is the same, the methods used are quite different.
We know that with F-M a large frequency deviation from the
carrier means a loud audio signal, whereas a small frequency
deviation means a weak audio note. Hence, some circuit must be
devised that will develop voltages proportional to the deviation
of the various incoming frequencies about the carrier.

A simple circuit that discriminates against various frequen-
cies is the elementary parallel (or series) resonant circuit. As is
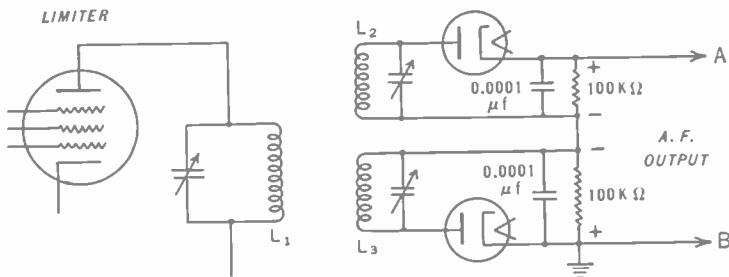
Fig. 12.12.   A simple discriminator circuit.

well known, this circuit will develop maximum voltage at the
resonant frequency, with the response falling off as the frequency
separation increases on either side of the central or resonant
point.

One of the first discriminators used in F-M receivers contained
two resonant circuits in an arrangement as shown in Fig. 12.12.
The primary coil L_1 is inductively coupled to L_2 and L_3, each of
which is connected to a diode tube. Each tube has its own load
resistor, but the output of the discriminator is obtained from
the resultant voltage across both resistors.

In order to determine the frequencies to which L_2 and L_3
must be tuned, it should be recalled that when an audio-modu-
lating signal alters the frequency of an F-M transmitter it varies
this frequency above and below one central or carrier value.
Thus, for a sine wave, the maximum positive portion would
increase the frequency, say by 40 kc, while the maximum nega-

tive section would decrease the carrier frequency by the same
amount. At intermediate points, less voltage would cause cor-
respondingly less frequency deviation.

To have the discriminator function in a similar manner over
the same range, L_2 and L_3 are each peaked to one of the two
end points of the I.F. band. For example, if the I.F. band
spread extends from 21.15 mc to 21.35 mc (with 21.25 as the
mean or carrier frequency), L_2 might be peaked to 21.15 mc,
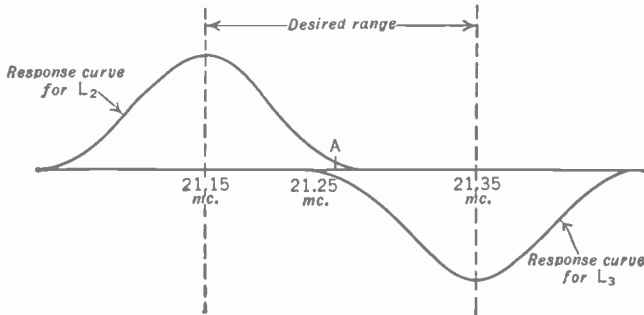
Fig. 12.13.   The overall response curve for the discriminator of Fig. 12.12.

and L_3 would be peaked to 21.35 mc. The response curves would
then appear as in Fig. 12.13.

The two curves are positioned in the manner shown because
of the way their load resistors are connected in the circuit.
According to the arrangement, the voltages developed across
them tend to oppose each other, as indicated by the polarities
across the resistors in the circuit of Fig. 12.12.

At the center frequency, point A of Fig. 12.13, the two volt-
ages developed across the load resistors cancel each other and
the resultant voltage is zero. By similarly adding the voltages
at other points about the carrier, we obtain the overall resultant
curve shown in Fig. 12.14. This is the familiar S-shaped curve
of all frequency discriminators and shows how the output volt-
age of the second detector will vary as the incoming frequencies
change. Specifically, suppose the signal acting at the input to
the discriminator at any one instant has a frequency of 21.31

mc.   The amount of voltage developed at the output is given
by point 1 on the vertical axis.   Then, at the next instant, if the
frequency should change to 21.19 mc, the output voltage is indi-
cated by point 2.   Notice that all frequencies below 21.25 mc
result in positive output voltages, whereas all those above 21.25
mc give rise to negative output voltages.   In this way, the audio
voltages that modulated the carrier frequency at the transmitter
are extracted in the receiver.
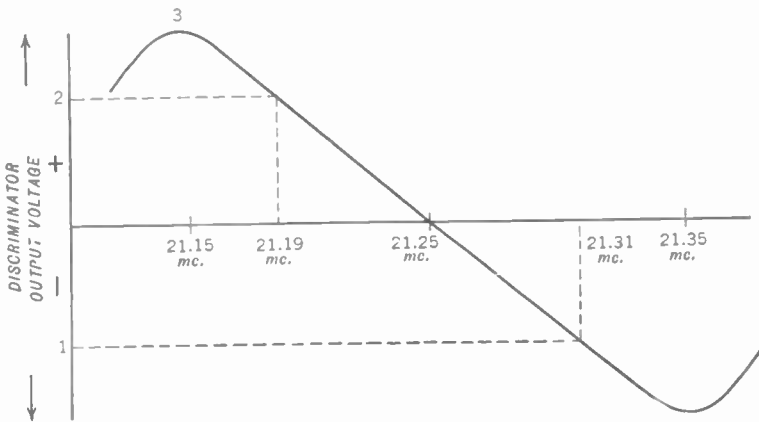
FIG. 12.14.   The resultant S-shaped discriminator characteristic curve obtained by
adding the two separate curves of Fig. 12.13.

The useful portion of this discriminator characteristic curve
is the linear portion included between the two maximum points,
3 and 4.   Any non-linearity along this section of the curve would
produce amplitude distortion in the output audio signal.   When
discriminators are designed, the maximum points 3 and 4 are
generally set much farther apart than required in the particular
receiver.   This insures a linear curve at those frequencies that
are actually used, since the response characteristic has a tend-
ency to curve near the maximum peaks.   By utilizing a smaller
range, amplitude distortion in the output signal is kept to a
minimum.   The sections of the curve of Fig. 12.14 beyond points
3 and 4 are completely disregarded.   The frequency of the out-

put voltages is determined by how rapidly the frequency of the incoming I.F. signal varies. A large frequency deviation in the input signal gives rise to a strong output wave, and the rapidity with which this incoming frequency changes determines whether the strong output will be high or low pitched.

A Modified Discriminator. It may be wondered why the preceding circuit was described in such detail if it is not used in
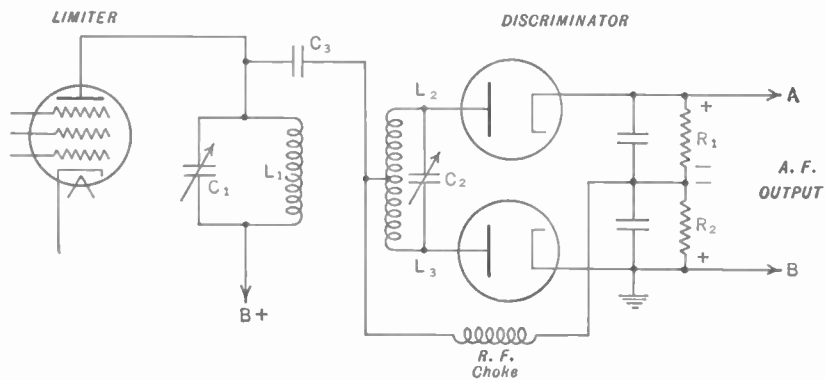
FIG. 12.15. A common discriminator in today's F-M receivers.

modern receivers. The reason lies simply in the ease with which this circuit brings out the fundamental conversion process at the second detector of an F-M receiver and because it is basically the same as the present-day discriminator of Fig. 12.15. Instead of employing two separate condensers for the secondary circuits, only one is used. R_1 and R_2 are the load resistors, one for each diode, and the resultant output audio voltage is still obtained across points A and B. The use of one, instead of two, condensers results in greater ease in aligning the circuits and economy in construction. The tap divides the secondary coil into essentially two identical coils, L_2 and L_3.

Circuit operation depends upon the voltages developed across L_2 and L_3 for the various incoming frequencies. The voltages add vectorially with the voltage in the primary coil L_1, which is brought over to the secondary circuit through condenser C_3.

A complete discussion of the operation of this circuit would involve determining the phase relationships between the various coils, for it is only in this way that the different voltages appearing at the output of the discriminator can be computed. The different phase relations are brought about by the changing frequencies that enter the discriminator. For example, at resonance the secondary tuning circuit acts purely resistive to
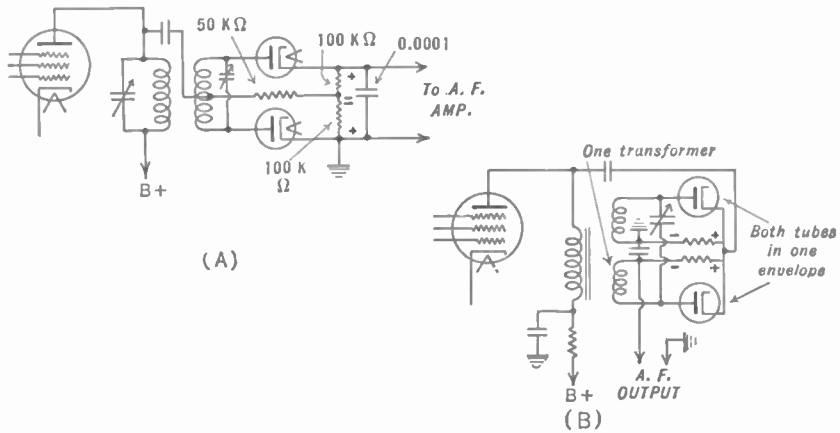
Fig. 12.16. Two additional discriminator circuits found in use. The arrangement in (B) has the advantage of placing both cathodes at the same potential. This permits use of duo-diodes with one common cathode.

an incoming signal. For frequencies above resonance, the inductive reactance of the secondary circuit predominates whereas, for frequencies below resonance, the capacitive reactance determines the phase of this circuit. As these phase relations fluctuate, the output voltage taken from across R_1 and R_2 likewise changes. A characteristic curve similar to the S-shaped one of Fig. 12.14 is obtained for this discriminator.

There are many variations of this discriminator schematic, two of the more common ones being given in Fig. 12.16 A and B. The output terminals for each type are clearly indicated. They connect to the following audio amplifiers. The discriminator of Fig. 12.16B is used in General Electric television re-

ceivers. This design, while still being fundamentally the same as the others, permits a tube with a single cathode to be used, which is advantageous for some circuits.

The need for limiter stages arises because the discriminators noted in the preceding paragraphs are sensitive to the amplitude of the incoming signal. Stating this in other words, these discriminators are not pure F-M detectors. It is the purpose of the limiter to eliminate any amplitude variations contained in the arriving signal and present to the following discriminator a signal which is wholly F-M. It has long been recognized that the development of a detector which was immune to A-M and therefore did not require a limiter would greatly simplify the bulk and cost of the F-M receiver. Excessive amplification must be given to a signal before it reaches the limiter in order to have the signal drive the limiter into saturation. Such a detector has been developed and its operation is considered in the following paragraphs.

F-M Ratio Detector. To understand why a ratio detector is immune to A-M distortion in the incoming F-M signal, let us compare its operation with that of the ordinary discriminator.

In the discriminator circuit of Fig. 12.15, let the signal coming in develop equal voltages across R_1 and R_2. This would occur, of course, when the incoming signal is at the center I.F. value. Suppose that each voltage across R_1 and R_2 is 4 volts. When modulation is applied, the voltage across each resistor changes, resulting in a net output voltage. Say that the voltage across R_1 increases to 6 volts and the voltage across R_2 decreases to 2 volts. The output voltage would then be equal to the difference between these two values, or 4 volts.

However, let us increase the strength of our carrier until we have 8 volts, each, across R_1 and R_2, at mid-frequency. With the same frequency shift as above, but with this stronger carrier, the voltage across R_1 would rise to 12 volts and that across R_2 decrease to 4 volts. Their difference, or 8 volts, would now be obtained at the output of the discriminator in place of the previous 4 volts. Thus the discriminator responds to both F M and

A-M. It is for this reason that limiters are used. The limiter clips all amplitude modulation off the incoming signal and an F-M signal of constant amplitude is applied to the discriminator.

When unmodulated, the carrier produced equal voltages across R_1 and R_2. Let us call these voltages E_1 and E_2 respectively. With the weaker carrier, on modulation, the ratio of E_1 to E_2 was 3 to 1 since E_1 became 6 volts and E_2 dropped to 2 volts. With the stronger carrier, on modulation, E_1 became 12 volts and E_2
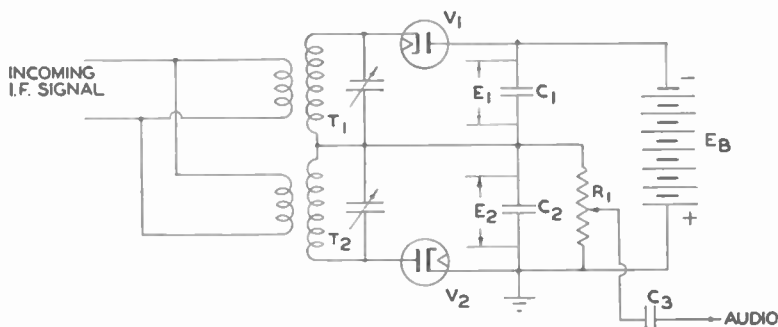
FIG. 12.17.   Preliminary form of the ratio detector.

dropped to 4 volts. Their ratio was again 3 to 1, the same as with the previous weaker carrier. Thus, while the difference voltage varied in each case, the ratio remained fixed. This demonstrates, in a very elementary manner, why a ratio detector could be unresponsive to carrier changes.

An elementary circuit of a ratio detector is shown in Fig. 12.17. In this form, the detector is similar to the detector of Fig. 12.12, where each tube has a completely separate resonant circuit. One circuit is peaked slightly above the center I.F. value (say T_1); the other peaked to a frequency below the center (say T_2). The output voltage for V_1 will appear across C_1 and the output voltage for V_2 will be present across C_2. The battery, E_b, represents a fixed voltage. Since C_1 and C_2 are in series directly across the battery, the sum of their voltages must equal E_b. Also, due to the manner in which the battery is connected to V_1 and V_2, no current can flow around the circuit until a signal

is applied. Now, while $E_1 + E_2$ can never exceed E_b, E_1 does not have to equal E_2. In other words, the ratio of E_1 to E_2 may vary. The output voltage is obtained from a resistor connected across C_2.

When the incoming signal is at the I.F. center value, E_1 and E_2 will be equal. This is similar to the situation in the previous discriminator. However, when the incoming signal rises in frequency, it approaches the resonant point of T_1 and the voltage across C_1 likewise rises.

For the same frequency, the response of T_2 produces a lower voltage. As a consequence, the voltage across C_2 decreases. However, $E_1 + E_2$ is still equal to E_b. In other words, a change in frequency does not alter the total voltage, but merely the ratio of E_1 to E_2. When the signal frequency drops below the I.F. center point, E_2 exceeds E_1. The sum, however, of $E_1 + E_2$ must equal E_b. The audio variations are obtained from the change of voltages across C_2. Condenser C_3 prevents the rectified d-c voltage in the detector from reaching the grid of the audio amplifier. Only the audio variations are desired.

The purpose of E_b in this elementary explanatory circuit is to maintain an output audio voltage which is purely a result of the F-M signal. E_b keeps the total voltage $(E_1 + E_2)$ constant, while it permits the ratio of E_1 to E_2 to vary. As long as this condition is maintained, we have seen that all amplitude variations in the input signal will be without effect.

The problem of deciding upon a value for E_b is an important one. Consider, for example, that a weak signal is being received. If E_b is high, the weak signal would be lost because it would not possess sufficient strength to overcome the negative polarity placed by E_b on the tubes V_1 and V_2. The tubes, with a weak input voltage, could not pass current. If the value of E_b is lowered, then powerful stations are limited in the amount of audio voltage output from the discriminator. This is due to the fact that the voltage across either condenser—C_1 or C_2—cannot exceed E_b. If E_b is small, only small audio output voltages are obtainable. To get around this restriction, it was decided to let

the average value of each incoming carrier determine E_b. Momentary increases could be prevented from affecting E_b by a circuit with a relatively long time constant.

The practical form of the ratio detector is shown in Fig. 12.18. It uses the phase-shifting properties of the discriminator of Fig. 12.15. R and C_3 take the place of E_b and the voltages developed across R will be dependent upon the strength of the incoming carrier. Note that V_1 and V_3 form a series circuit with R
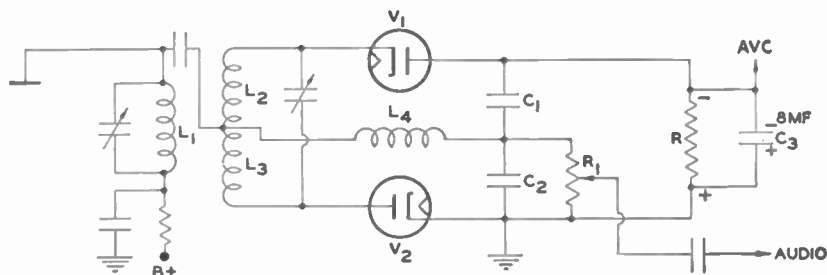
Fig. 12.18.   Practical form of the ratio detector.

(and C_3) and any current flowing through these tubes must flow through R. However, by shunting the 8-μf electrolytic condenser across R we maintain a fairly constant voltage. Thus, momentary changes in carrier amplitude are merely absorbed by the condenser. It is only when the *average* value of the carrier is altered that the voltage across R is changed. The output audio-frequency voltage is still taken from across C_2 by means of the volume control.

Since the voltage across R is directly dependent upon the carrier strength, it may also be used for A.V.C. voltage. The polarity of the voltage is indicated in Fig. 12.18.

Ratio Detector Modifications.   Another form of the ratio detector is shown in Fig. 12.19. L_4, instead of receiving its voltage from the primary L_1C_1 through a direct capacitive connection, is now coupled inductively to L_1. Circuit operation remains unchanged because the voltage across L_4 still depends directly upon the voltage existing across L_1.

The two foregoing ratio detectors (Fig. 12.18 and 12.19) are unbalanced circuits, so-called because V_1 and V_2 are not equally balanced against ground. We can transform these circuits into a balanced ratio detector by moving the position of the ground connection, as shown in Fig. 12.20. In place of one stabilizing condenser (C_3) and resistor, R, we now have two of each. Their function, however, remains the same.

To see how this circuit works, let us assume that the voltage coming in is at the I.F. mid-frequency. Equal voltages will be
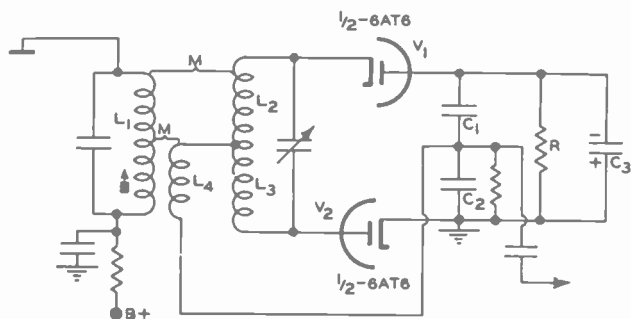
FIG. 12.19. In this ratio detector, L_4 receives its voltage from L_1 by inductive coupling.

applied to V_1 and V_2, and equal voltages will appear across C_4 and C_5, with the polarity noted. At the same time, there will be a voltage developed across A-B equal to the average value of the signal. Half this voltage will appear across R_1C_6, and half of the total voltage will be across R_2C_7. Since C_4 is in parallel with R_1 and C_6, all will have the same voltage. The same is true of C_5, R_2, and C_7. As a consequence of these conditions, there will be no *difference of potential* between points C and D and no audio output. This, again, is similar to the previous discriminators.

Now let the signal frequency swing below the mid-I.F. value. V_1 will receive more voltage than V_2 and more voltage will develop across C_4 and less across C_5. The carrier amplitude has not changed, however, because this is an F-M signal, and conse-

quently the voltage between points A and B remains the same. To use numerical values, assume that the voltage across R_1C_6 is 6 volts. Because of the signal frequency shift, the voltage across C_4 rose from 6 to 9 volts, while C_5 dropped from 6 to 3 volts. Since E_{C4} is now greater than E_{R1}, and E_{C5} is less than E_{R2}, currents will flow in these circuits. These currents, flowing through R_3, will develop a voltage drop of 3 volts here, with point C positive and point D negative. If now we add the voltages around both branches, we see that they check out.
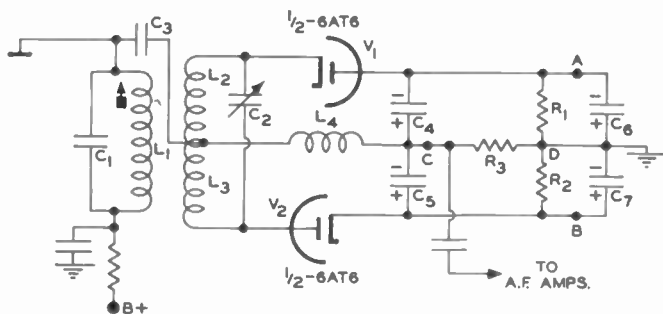
Fig. 12.20.   A balanced ratio detector.

The rise in voltage across R_3 results in an audio output. When the signal swings in the opposite direction, C_5 receives more voltage than C_4, and the polarity of the voltage across R_3 reverses. In this manner, for signal frequency swings above and below the center point, positive, zero, and negative voltages will develop across R_3. This is the audio output voltage. At all times, the sum of the voltages across C_4 and C_5 must equal the average carrier voltage present between points A and B. Changes in frequency do not alter the total voltage but merely the ratio of E_{C4} to E_{C5}. That is why this is known as a ratio detector. Changes in signal amplitude will not change the ratio of E_{C4} to E_{C5}.

To illustrate this, consider the example used in the foregoing paragraph. A signal frequency shift caused the voltage across C_4 to rise from 6 to 9 volts, while the voltage across C_5 dropped

from 6 to 3 volts. The ratio of E_{c4} to E_{c5} is 9/3 or 3/1. Now let us assume that the carrier amplitude is doubled, momentarily. This would double both sides of our ratio but leave the value of the ratio unchanged. Thus, $9/3 = 18/6 = 3/1$.

Any momentary increase in carrier will affect the numerator and denominator of this ratio in like measure and consequently leave the basic value of the ratio unaltered. The same is true of carrier decreases. Actually, because of the presence of the long-time-constant network of R_1C_6 and R_2C_7, the momentary changes in carrier amplitude only *tend* to make the voltages across C_4 and C_5 go up or down. By the time the voltage in the circuit actually changes, the pulse or disturbance has passed.

Several forms of the balanced ratio detector commonly encountered are shown in Fig. 12.21. In the first circuit (Fig. 12.21A) R_1 is inserted to provide better balance between both halves of the circuit, and R_2 limits the peak plate current drawn by each diode section of the 6AL5. C_1 shunts I.F. voltages away from the audio output, while R_3 and C_2 comprise a de-emphasis filter to equalize the audio signal back to its original form. An A.V.C. voltage can be obtained from the negative side of the 4-μf stabilizing condenser.

In Philco television receivers, the ratio detector is made to furnish also a correction voltage to the oscillator control tube (see Chapter 4) whenever the R.F. oscillator drifts in frequency. How this action is achieved can be seen from the following. Between points A and B (Fig. 12.21B) the detected audio voltage is developed. At the center intermediate frequency, to which the ratio detector is aligned, the voltage developed between points A and B is zero. When the signal frequency swings above this value, point A becomes positive with respect to point B; when the frequency drops below the center I.F., the voltage becomes negative. In this manner, the frequency variations which constitute the F-M signal are converted into equivalent audio voltages. Thus, the *average* voltage between points A and B is zero when the audio I.F. carrier coincides with the frequency to which the ratio detector is peaked. The audio

filter network $R_1R_2C_1C_2$ connected to point A (actually, of course, between points A and B) will return zero voltage to the oscillator control tube.

Consider, now, what happens when the R.F. oscillator drifts in frequency. The incoming audio R.F. carrier, mixing with the
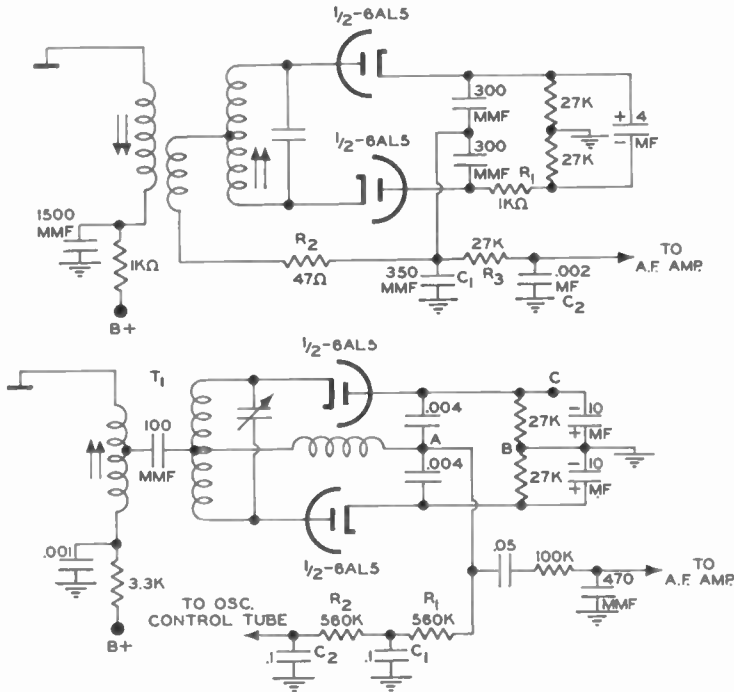
FIG. 12.21. Two commonly used variations of the balanced ratio detector.

altered oscillator frequency, is not reduced to the proper I.F. As a result, the balance of the ratio detector output is upset, and the *average* voltage between points A and B will not be zero. If the oscillator frequency drift causes the audio intermediate frequencies to be higher than normal, the average voltage between A and B becomes positive. Conversely, a drift in the opposite direction produces a negative average voltage between A and B. These positive and negative voltages, fed back

to the oscillator control tube, are opposite in their effect on the oscillator tuning circuit and, if properly applied, will correct the drift. C_1, C_2, R_1, and R_2 filter out the instantaneous audio variations, for it is obvious that if the oscillator frequency changes with each audio variation, no audio output at all would be obtained.

There is one further circuit found in F-M receivers that is not used in A-M sets which is the so-called "de-emphasizing filter." It was required because the greatest audio frequency noise is

(A)
ACCENTUATOR AT
F.M. TRANSMITTER

(B)
DE-ACCENTUATOR AT
F.M. RECEIVER
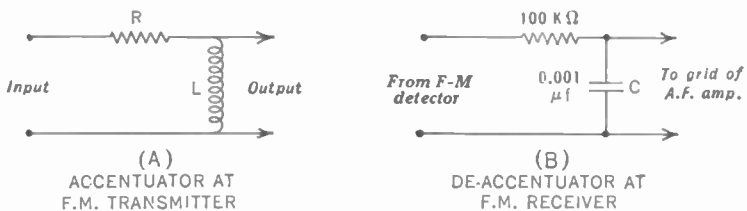
Fig. 12.22. Two circuits that help maintain the fidelity of the higher audio frequencies in F-M systems.

generated in the transmitter at the higher frequencies, from 5 kc up. Since the audio signals in this higher range have less amplitude than the low-frequency audio notes, a high-frequency accentuator circuit is incorporated at the transmitter to improve the signal-to-noise ratio. A typical accentuator filter, sometimes also referred to as a pre-emphasis filter, is given in Fig. 12.22A. The higher frequencies, in passing through the network, lose less voltage than the accompanying low frequencies. The over-all response flattens.

At the receiver, the opposite must occur if the initial relationship between the various frequencies is to be maintained. Hence, a de-emphasis network is inserted between the discriminator output and the first audio amplifier. The circuit shown is in Fig. 12.22B. It will be recognized as one form of a low-pass filter, with the corrected voltage appearing across condenser C. The voltage from this point is passed on to the audio amplifier as shown.

The audio amplifiers that follow the discriminator are engineered for flat response up to 15,000 cycles. This frequency response extension is easier to achieve here than in video amplifiers, and little change in basic amplifier form will be noticed. A single or push-pull power amplifier provides sufficient power to drive 12-inch speakers. For the home, this permits adequate volume.

The Audio System in Television Receivers. The sound signal, once it has been divorced from the video signal, is passed through one or more of its own I.F. amplifiers before it reaches the F-M detector. At the detector output, the resultant audio voltage is further amplified until it is sufficiently strong to drive a loudspeaker. The elaborateness of the final audio system will be governed, in large measure, by the price of the receiver. In table model receivers, 12-inch speakers are rare, and the audio system is patterned closely after the current A-M midget sets. When the unit is housed in a console cabinet, a larger speaker is used, with a subsequent rise in the quality of the audio output.

Servicemen who are not familiar with F-M circuits may be inclined to believe that F-M, I.F. amplifiers differ, radically, from A-M, I.F. stages. Actually, this is not so. From a servicing standpoint, the F-M I.F. system of a television receiver differs in only two respects from its A-M counterpart—in the frequency of operation and in the bandpass of its tuned circuits. The center frequency is 20 mc or more, and the bandpass is between 150 kc and 350 kc. In all other respects A-M and F-M systems are similar, and knowledge of one system may be transferred to the other.

The television F-M signal, when fully modulated, occupies a bandwidth of approximately 50 kc (plus or minus 25 kc about the carrier). The audio bandpass, however, is designed for a greater frequency variation in order to minimize audio distortion when the mixing oscillator drifts in frequency. At 100 mc, a drift in frequency of 0.1 per cent produces a change of 100 kc, which is more than sufficient to throw the audio signal com-

pletely out of the bandpass of the audio I.F. amplifiers. However, with normal frequency drift and a fine-tuning control at the oscillator, the audio signal can be kept within the circuit frequency boundaries. In this respect, it is important for the serviceman to realize that the fine-tuning control is adjusted until the sound comes through, clear and undistorted. When this is accomplished, if detail does not appear as sharp as desired, little can be done to correct this except re-alignment of the video I.F. circuits. The fine-tuning control is incorporated primarily for the audio signal.

The number and type of audio I.F. amplifiers will depend upon the type of F-M detectors in use, i.e., the Foster-Seeley discriminator or the ratio detector. The latter further appears in two forms, balanced and unbalanced. The Foster-Seeley circuit, while essentially an F-M demodulator, will, at the same time, also respond to A-M. Consequently, one of the I.F. stages preceding this detector must be operated as a full limiter. For the ratio detector, either in balanced or unbalanced form, complete limiting is unnecessary because the detector is fairly unresponsive to A-M over wide ranges of signal amplitude. Consequently, in a system employing the latter detector, every I.F. stage will be an amplifier, although partial limiting is quite common in the last I.F. stage in order to maintain a fairly constant input to the detector. Engineering tolerances in ratio detector transformers are often such as to require this limiting.

A television sound system employing a Foster-Seeley discriminator is shown in Fig. 12.23. The first and second stages have single iron-slug tuned coils, which resonate with a fixed condenser of 20 $\mu\mu$f and the tube capacitances to the audio intermediate frequency of 21.9 mc. Shunting resistors are not required for these coils because at 21.9 mc a bandpass of several hundred kilocycles can be readily achieved by regulating the Q of the coil. The third stage is a limiter, using grid-leak bias and low plate and screen voltages to cause the tube to saturate readily. The limiter grid resistor is kept small, so that the grid
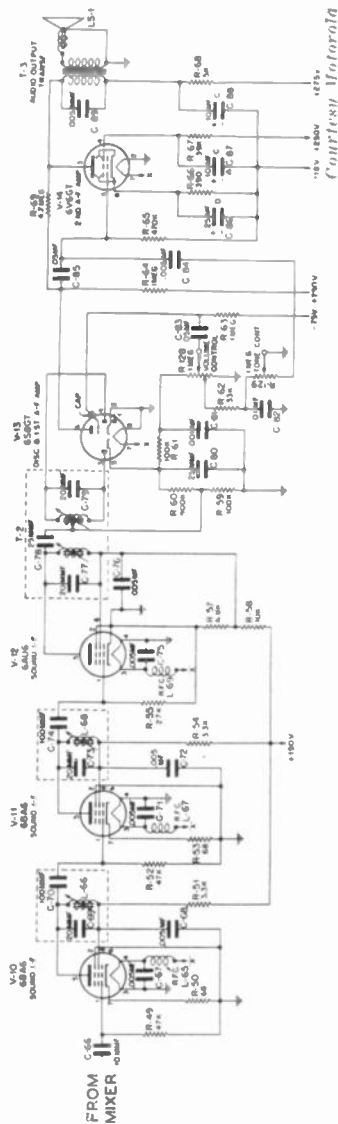
Fig. 12.23. The complete audio system in a television receiver using a Foster-Seeley F-M detector.

Courtesy Motorola

Fig. 12.21. An audio system using a balanced ratio detector.

Courtesy Philco

time constant will be small. In this way, the effect of sharp pulses of interference (generally from ignition systems) are reduced or eliminated.

Fig. 12.24 illustrates a television sound system using a ratio detector.

INTERCARRIER TELEVISION SOUND SYSTEM

To this point we have been studying what might conveniently be called the conventional television receiver. In this receiver, shown in Fig. 13.1, the audio and video signals, after passage
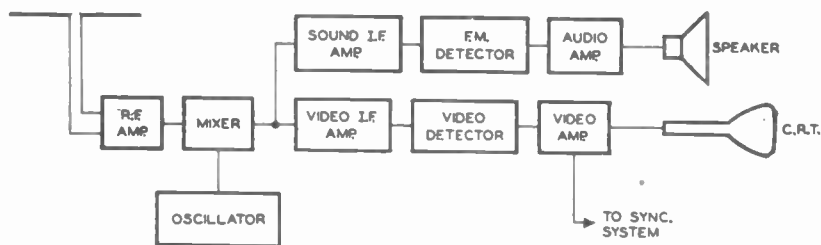
Fig. 13.1. A block diagram of a receiver employing the conventional television system.

through a mixer, are reduced to their I.F. values. At some point after the mixer and before the video second detector, the sound I.F. signal is removed from the video I.F. system and fed to a separate set of I.F. amplifiers which are peaked to the sound I.F. value. After two or three I.F. stages, the audio signal is fed to an F-M detector where it is converted to audio frequencies. This is then followed by one or more stages of audio amplification after which the signal is powerful enough to drive a loudspeaker. Once the two signals have been separated, every precaution is taken in the video system to prevent any sound voltage from reaching the video detector and the subsequent cathode-ray tube. Usually these precautions consist of one or more trap circuits distributed throughout the video system following the point of signal separation.

While this system will operate successfully when properly designed, it does possess several disadvantages when cost becomes an important design factor. Thus, one of the most important stages in the television receiver, the local oscillator, is also one of its weakest points. We know that the sound I.F. value is the difference between the frequency of the local oscillator and the frequency-modulated sound carrier. If the frequency of the local oscillator should drift, either during the warm-up period when the set is first turned on or during the operation of the receiver, then the difference frequency produced by the mixer will change too. Thus, consider a television receiver tuned to channel 3 and designed for a sound I.F. of 21.25 mc. On channel 3, the audio carrier frequency is 65.75 mc and since the oscillator frequency is above this by an amount equal to the sound I.F., the oscillator frequency will be 65.75 mc plus 21.25 mc, or 87.00 mc. The sound carrier is frequency-modulated, and the modulation shifts the audio carrier frequency plus and minus 25 kc. In other words, the total audio signal for channel 3 can be expressed as 65.75 mc plus or minus 25 kc.

In the sound I.F. system (including the input discriminator coil), the bandpass is about 200-300 kc, although generally the discriminator response is linear only for about 150 kc. If the local oscillator should drift by as little as 75 kc, it is possible for the sound I.F. signal to shift to a non-linear portion of the discriminator characteristic, thereby causing audio distortion. Now, a drift in frequency of 75 kc, with the oscillator functioning at 87 mc, represents a change of less than 0.09 per cent; at 200 mc, the same frequency drift represents a change of 0.03 per cent. Using ordinary components, combined with the station selector rotary switches, it can hardly be expected that the local oscillator will not drift more than this during warm-up and even during subsequent operation. It is due to this very situation that oscillators are provided with "fine-tuning" controls which, extended to the front panel, permit the observer to correct for oscillator drift. While such controls remedy the drifting temporarily, it is annoying to have to use this control several

times during each set operation. Furthermore, the oscillator frequency is extremely sensitive to tube capacitance, and it is not uncommon to find that the oscillator frequency is altered sufficiently by a tube change to require a complete realignment of the oscillator circuit. Finally, in time, the resistive and capacitive components themselves will change sufficiently in value, even without a tube change, to require a complete realignment also.

The local oscillator is the source of other annoyances. Any inadequate filtering of the B+ voltage used by the local oscillator will cause the oscillator frequency to vary at a 60-cycle or 120-cycle rate. This results in phase and frequency modulation of the local oscillator, which passes through the sound I.F. system and F-M detector and appears as an audible hum. The only remedy for this is complete filtering of the power supply. We also obtain phase and frequency modulation when acoustic feedback from the speaker causes oscillator coils, condensers, and tube elements to vibrate. Vibrations of the cores in permeability or slug-tuned coils or the plates in a condenser can be a difficult annoyance to eliminate.

Solutions to all of the foregoing problems are not unknown, but they usually involve sufficient additional expense to make them unattractive in today's competitive market. Manufacturers are constantly on the alert for methods of decreasing the cost of television receivers and the recently devised Intercarrier television sound system appears to offer economic advantages, as well as the elimination of the annoying effects of oscillator drift.

Basic Principles of Intercarrier System. In sets employing the Intercarrier system, the various stages follow the sequence shown in Fig. 13.2. A quick comparison of this illustration with that of Fig. 13.1 reveals that separation of the audio and video signals does not occur until both signals have passed through the video second detector and the video-frequency amplifiers. Thus, at first glance, every precaution which was previously taken to insure that the sound voltage did not reach the cathode-ray tube is now seemingly ignored. Another fact which appears

contrary to previous principles is the passage of the F-M signal through the A-M video detector where the possibility of slope detection exists. We thus appear to have here an unworkable combination used as the basis for the Intercarrier system. Let us examine the operation of the Intercarrier system closely to see how these difficulties are resolved.

From the block diagram (Fig. 13.2) it is seen that the audio and video signals are received by the R.F. stages of the receiver,
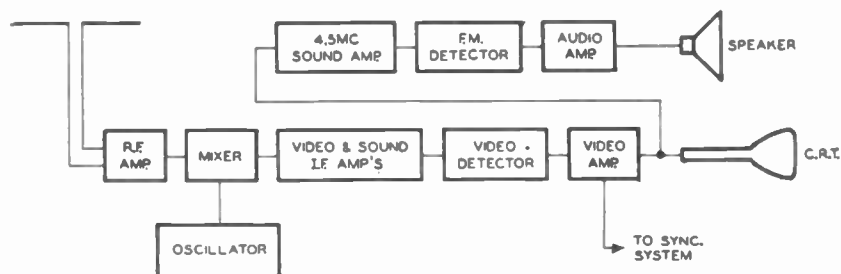
Fig. 13.2.   A block diagram of the receivers using the Intercarrier systems.

lowered in frequency at the mixer by beating with the local oscillator voltage and then passed together through the I.F. system.

The carrier I.F. values after passage through the mixer are the same as they would be using the conventional system of Fig. 13.1.   The intermediate frequencies assigned to each carrier are a function only of the local oscillator setting and to this point in the receiver both systems are identical.   The first departure appears in the I.F. system.   Although the video I.F. response characteristic for a conventional receiver is as shown in Fig. 13.3, it must now be widened to include the sound I.F. signal as well. However, instead of providing the sound carrier with as much amplification as the video signal receives, we provide it with considerably less amplification, and it is specifically because the sound carrier receives this lesser amount of amplification that the system is able to function.   This is important, for if the level of the sound carrier is not kept considerably below the level of the video signal, the latter signal becomes completely unusable.

To understand why the sound carrier level must be considerably below the video signal level, let us look ahead in Fig. 13.2 to the video detector. The video and sound I.F. signals reach this point, in the Intercarrier system, after passage through the I.F. system. Now, a detector (such as used ordinarily for the video second detector) operates basically in the same manner as the previous mixer. In both, a mixing process occurs. Thus, in the mixer stage (which has long been known as the first de-
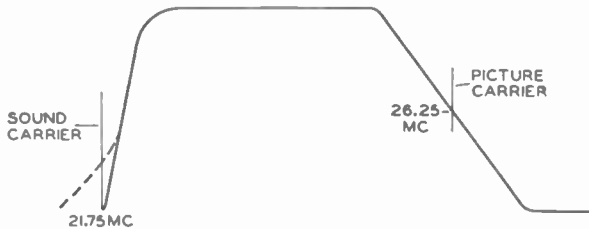
FIG. 13.3.   The solid line curve represents the desired response for the I.F. system in a conventionally operated television system. The dotted curve represents the modification needed to adapt the response to a receiver operating on the Intercarrier system.

tector), the local oscillator voltage beats with the incoming signal or signals to produce the I.F. signal. At the video second detector, a beating or mixing takes place between the video and sound I.F. carriers with the result that a 4.5-mc beat note is produced. In this case we could consider the video carrier as being equivalent to the local oscillator and the audio carrier as the incoming signal. The result of the mixing is a 4.5-mc beat note. In addition, we also obtain all of the 0–4 mc video frequencies from the video signal, obtained when the video carrier beats with each of the video sidebands.

The reason for keeping the level of the sound carrier low can now be given. Consider the two carriers shown in Fig. 13.4 A and B. Assume the larger one to be the video carrier and the smaller one to be the audio carrier. If these two signals are mixed together, a ripple will be produced in the resultant wave (Fig. 13.4C) which will have a frequency equal to the difference be-

tween the carrier frequencies—in this case, 4.5 mc. As long as
the *amplitudes* of the two carriers differ considerably, the am-
plitude of the 4.5-mc beat note will remain small and unaffected
by any amplitude modulation contained in the video carrier.
Here is one of the pivotal points in the Intercarrier television
sound system. *By maintaining the sound carrier small in com-
parison to the video signal, we obtain a 4.5-mc beat note which*
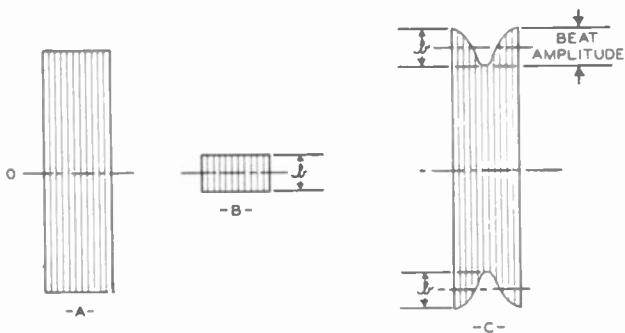
Fɪɢ. 13.4. (A) The video carrier. (B) The sound carrier. (C) The resultant wave.

*contains only the frequency modulation of the original sound
R.F. carrier and practically none of the video modulation.*

The sound carrier is continually shifting back and forth be-
tween the limits of plus and minus 25 kc. In the mixing process
in the video second detector this frequency modulation is im-
parted by the sound I.F. carrier to the 4.5-mc beat note. The
4.5-mc signal represents the difference between the video and
sound I.F. carriers. The frequency of the video carrier is fixed,
but the frequency of the sound carrier continually shifts back
and forth. This changes the value of the beat note. Thus,
while we speak of 4.5-mc as the beat note, we actually mean a
beat note with a center frequency of 4.5 mc, but which shifts
back and forth about this value to the limits of plus and minus
25 kc. This frequency shifting, remember, represents the sound
intelligence of the television broadcast.

Now let us see how the foregoing is employed to make the
Intercarrier television sound system workable. When the video

carrier (with its amplitude modulation) and the audio carrier
are received at the receiver, they have substantially the same
amplitude. (The F.C.C. regulations state that the power of
the sound carrier must be 50 to 150 per cent of the power of
the video carrier when transmitting synchronizing pulses. How-
ever, most stations transmit equal sound and maximum am-
plitude video carriers.) After passage through the mixer stage,
the two signals are converted to their I.F. values and are ready
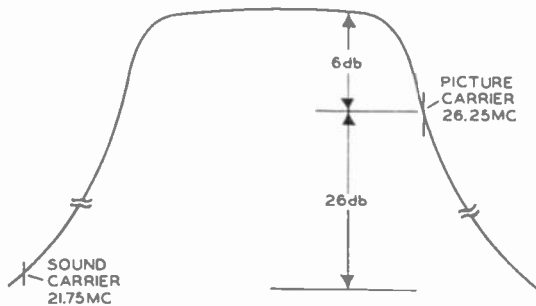
Fig. 13.5. The proper I.F. response curve for Intercarrier receivers.

to pass through the I.F. system. If we are to keep the degree
of amplitude modulation of the beat note signal to a minimum,
it is desirable to keep the level of the sound carrier at least 26 db
below the peak video carrier level at the second detector. This
means that the amplitude of the sound carrier should be reduced
to about 5 per cent of the maximum picture carrier amplitude.
In order to achieve this, the I.F. system through which both
signals pass is designed to have the response characteristic
shown in Fig. 13.5. At the frequency of the sound I.F. carrier,
the response curve is 26 db down from the video carrier fre-
quency point.

After passage through the I.F. system, the signals are fed to
the video detector, where the I.F. frequencies are removed, leav-
ing only the video frequencies, which extend from 0 to 4.0 mc,
and the 4.5-mc beat note that is produced when the two carriers
beat against each other.

At the output of the video second detector the complete signal, including the 4.5-mc voltage, is usually passed through the video-frequency amplifiers. The sound signal, it must be remembered, was reduced considerably in the I.F. system and thus requires a corresponding increase in amplification following the video second detector in order to bring it back to a usable value. Even after passage through the video-frequency am-
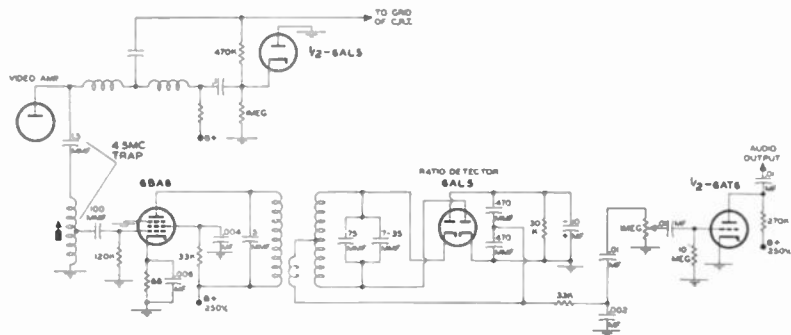
FIG. 13.6. The method of separating the sound signal (4.5 mc) from the video signal. Shown also is the sound system.

plifiers, its average level seldom exceeds one or two volts. Thus, what is done is to transfer this voltage out of the video system into an audio I.F. amplifier, tuned to 4.5 mc, and after one stage of amplification, apply it to an F-M detector for conversion into audio frequencies. Thereafter, one or two audio amplifiers bring the signal to the desired strength for normal operation of a loudspeaker.

We might pause and note here that the actual number of stages devoted exclusively to the sound signal is less in the Intercarrier system than in the conventionally designed sets. This usually means a savings of two to three stages.

To remove the 4.5-mc voltages from the video system, a series resonant trap is connected from the plate of the final video-frequency amplifier to ground. (See Fig. 13.6.) The voltage developed across the coil is amplified by a 6BA6 4.5-mc am-

plifier and then made available to the F-M detector. Through
the use of a series resonant circuit, essentially all the 4.5-mc
voltage is removed from the video path and thereby does not
reach the cathode-ray tube. The 6BA6 operates as a limiter
and serves to present a fairly constant output when widely vary-
ing signals are applied to its input. This is desirable, especially
if some form of tuning control is provided, otherwise the set
user might attempt to tune for loudest sound, which would
seriously distort the picture.

We are now in a position to appreciate fully the reasons for
the reduction in sound carrier prior to the video second detector.
First, if the video and audio carriers are comparable in strength
when they reach the video second detector, the resultant 4.5-mc
beat note will contain a considerable amount of amplitude modu-
lation. Also, the amount of this amplitude modulation will vary
as the modulation of the video carrier changes. Since no F-M
detector now in practical use is able to remove completely or to
ignore amplitude modulation in an F-M signal, the audio out-
put will be distorted to an extent dependent upon the amount
of amplitude modulation present in the signal. Even the use
of a limiter prior to the detector does not altogether alleviate
this trouble. With the amplitude of the sound carrier reduced
to about 5 per cent of the video carrier, the 4.5-mc beat note am-
plitude remains substantially constant as the level of the video
carrier varies between 15 and 100 per cent of its peak value.

Another consideration in conjunction with the use of com-
parable audio and video carriers is the manner in which the
audio voltage can affect the picture. Since the sound carrier is
frequency modulated, one way to convert an F-M signal into
an audio voltage is by means of slope detection. Now, if the
sound signal receives 26 db less amplification than the video sig-
nal in the I.F. system, it will be quite small and, even if 30 per
cent of this signal suffers slope detection at the video second de-
tector, the interference from this source will be approximately
33 db below the video signal and generally unnoticeable. How-
ever, if the audio signal is large at the detector, then even a 10

per cent slope detection will produce enough audio voltage to develop horizontal bars across the screen. It will probably be found that with a large audio signal, more than 10 per cent slope detection occurs, further aggravating the situation.

If the 4.5-mc signal itself reaches the control grid of the cathode-ray tube, a fine line pattern will appear on the screen. This will occur if the audio signal is strong at the video detector output and does not receive the proper amount of reduction. However, if the audio signal is reduced by the 26 db already specified, then its affect, after the shunting effect of the series resonant pick-off circuit, will again be so small as to be negligible.

Thus, we see from the foregoing why it is mandatory for the video carrier to be considerably stronger than the audio carrier, at the video detector, if the Intercarrier system is to function properly. It also explains why the presence of the sound signal, even as far as the last video-frequency amplifier, does not materially affect the image on the screen.

In receivers employing the conventional system, it has recently become common practice to insert a 4.5-mc trap in the grid or plate circuits of the first video-frequency amplifier following the video second detector. This is done to prevent any 4.5-mc voltage, which may be generated in the video detector, from reaching the cathode-ray tube. In the mass production of many television receivers, the sound carrier may not receive the full attenuation required to suppress it completely. Hence this additional precaution. In Intercarrier sets, the sound I.F. receives some amplification, as noted.

To see how the Intercarrier system is applied commercially, let us analyze the schematic diagrams of two sets employing this system.

INTERCARRIER TELEVISION RECEIVERS

An Intercarrier receiver schematic is shown in Fig. 13.7. The front end of the receiver contains a 6AU6 R.F. amplifier, a 6AG5 mixer, and a 6J6 push-pull oscillator. Examining this

section of the receiver briefly, we find that the antenna signal
is fed between the grid and cathode of the R.F. amplifier in a
balanced arrangement, against ground, so as to terminate prop-
erly a 300-ohm transmission line. The input circuit is untuned,
the input coil L_1 serving as part of a high-class filter designed to
permit all the television signal frequencies to pass but to at-
tenuate extraneous signals at the I.F. frequency. For strong
local signals, an attenuator pad is provided (not shown) to pre-
vent overloading of the amplifiers with resultant distortion to the
image and sound.

The plate circuit of the R.F. stage is tuned by what is,
electrically speaking, a single-tapped inductance. Mechanically,
this coil takes the form of several individual coils which are cut
in or out of the plate circuit by the rotary 12-position band
switch.

The 6J6 oscillator is a push-pull arrangement with the coil
for channel 2 (the present first channel) permanently in the
circuit. For the remaining channels, 3–13, a second coil is placed
in parallel with this coil, reducing the oscillator frequency to the
proper value. Each coil is tuned by brass slugs accessible from
the front panel. The output from the R.F. amplifier and the
oscillator are condenser-fed to the grid of the 6AG5 mixer tube.
Additional transfer of energy by means of a single turn of link
coupling is provided between the R.F. amplifier and the mixer
for the upper channels.

The oscillator, in this receiver, operates above the incoming
audio and video carriers on all channels. In Intercarrier sets
this need not be true as we will see presently. The video car-
rier I.F. is 37.3 mc, and the sound carrier I.F. is 32.8 mc.

The I.F. system contains three stages, of which two employ
transformer coupling and the third impedance coupling. Each
I.F. transformer has only one adjustment, a powdered iron slug
accessible from the top of the chassis. The I.F. string is stagger-
tuned to two frequencies, 34.8 mc and 36.9 mc, resulting in the
overall response characteristic shown in Fig. 13.8. The curve is

Fig. 13.7. A portion of an Intercarrier receiver.

fairly flat-topped, and the amplification accorded the sound
carrier is 20 db less than that received by the video carrier fre-
quency. (The previous 26 db figure specified would be a more
desirable value. However, in commercial sets values from 15
to 26 db will be found. With the smaller figure we obtain a
larger sound voltage at the pick-off point and this can be used
to advantage in designing the audio system. On the other hand,
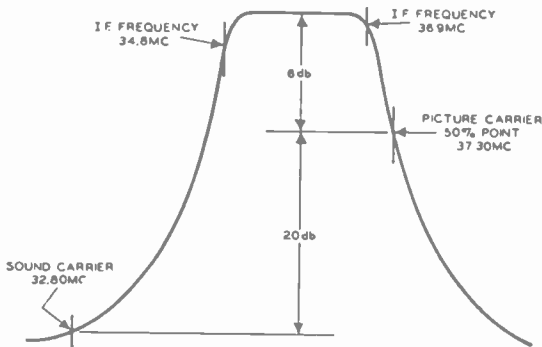
FIG. 13.8. The overall I.F. response curve of the receiver shown in Fig. 13.7.

there are the pitfalls previously described when the sound carrier
level approaches close to the video signal amplitude.)

The video second detector is an A-M half-wave rectifier, in-
corporating high-frequency compensation in order to maintain
the circuit response for the high video frequencies and the 4.5-
mc beat frequency. The signals are amplified by one stage of
video-frequency amplification, after which the sound carrier is
tapped off the plate of the video amplifier by a 4.5-mc trap
and fed through a 4.5-mc I.F. amplifier to a ratio detector, and
then to the audio amplifier, audio output, and speaker. The
coupling network between the plate of the video amplifier and
the cathode-ray tube will pass most of the video frequencies
but attenuate any of the 4.5-mc voltage that may attempt to
pass through. From the output circuit of this same video am-
plifier a portion of the signal is also fed to a sync separator and
d-c restorer tube. Sync systems in Intercarrier television re-

ceivers are similar to the sync networks in conventional tele-
vision receivers. The use of an Intercarrier sound system does
not affect this portion of a television receiver.

At first glance the 4.5-mc take-off trap in the plate circuit of
V_9, the video amplifier, appears to be a parallel resonant circuit.
However, the 2.2-$\mu\mu$f condenser, in conjunction with the coil
and the 68-$\mu\mu$f condenser across the coil, forms a series resonant
circuit at 4.5 mc. The 68-$\mu\mu$f condenser neutralizes enough of
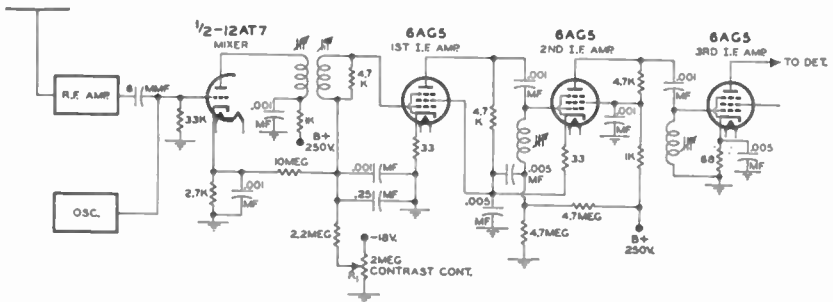
Fig. 13.9. An I.F. system having a symmetrical response to permit changing the
relative position of the local oscillator frequency with respect to incoming tele-
vision signals. See text.

the inductance of the coil to which it is connected so that what
inductance remains can resonate with the 2.2-$\mu\mu$f series con-
denser at 4.5 mc. The operation here is identical with the
series resonant traps used in the video I.F. systems of some
conventional television receivers, which were previously de-
scribed in detail.

This particular set uses an A.G.C. circuit controlling the R.F.
and the first two I.F. stages. The A.G.C. voltage is developed
by a separate diode section of the 6AL5; the other section of this
tube is the video detector. It is important to remember, when
aligning the I.F. system, that the sound carrier marker appears at
a point which is roughly 20 db down from the level of the video
carrier. Furthermore, the video carrier should be 50 per cent
down (i.e., 6 db) from the maximum amplitude of the response
characteristic.

H.F. Oscillator Frequency Changeover. It was noted, several paragraphs back, that, with the Intercarrier system, the local oscillator frequency could be placed above the incoming television signal frequency on the low band (54–88 mc) and below the incoming signal on the high band. This practice is actually followed in the circuit shown in Fig. 13.9. The incoming sound and video signals are amplified by an R.F. amplifier, then fed to a mixer where they are combined with the local oscillator voltage to produce the desired I.F. signals.
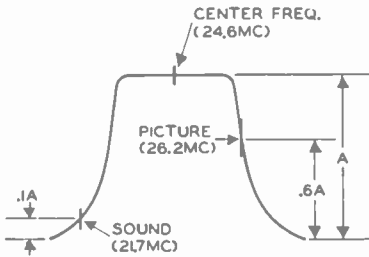
Fig. 13.10. Overall response curve of mixer transformer and I.F. amplifiers for channels 2 to 6.

The I.F. system contains an overcoupled transformer and three single-tuned coils. Each of the single coils are tuned to different frequencies (stagger-tuned) while the mixer transformer is purposely overcoupled to cover the total bandwidth. For channels 2 to 6, the overall response curve of the I.F. amplifiers is shown in Fig. 13.10. (This includes the mixer transformer.) The video carrier I.F. is 26.2 mc and receives 0.6 of the full amplitude of the system. The sound I.F. is at 21.7 mc, and this signal receives only 0.1 of the full amplitude. The video carrier thus receives 6 times, or 15.6 db, more amplification than the sound carrier.

In Fig. 13.11, we have the I.F. response curve for channels 7 to 13. The video and sound I.F.
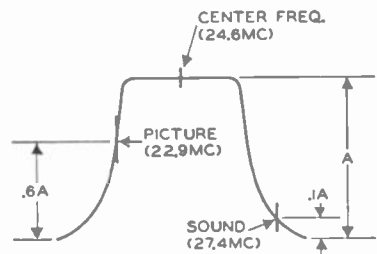
Fig. 13.11. Overall response curve of mixer transformer and I.F. amplifiers for channels 7 to 13.

carriers receive the same amplification as in channels 2 to 6, but they are now located on different sides of the response curve. This can be explained if we examine the local oscillator frequency for each of the channels. (See Table 13.1.) For the lower chan-

TABLE 13.1. A TABULATION OF THE VARIOUS CHANNELS, VIDEO CARRIER, SOUND CARRIER, AND LOCAL OSCILLATOR FREQUENCIES IN THE TELEVISION RECEIVER SHOWN IN FIG. 13.9

Channel Number	Channel Frequency	Picture Carrier Frequency	Sound Carrier Frequency	Receiver R.F. Osc. Frequency
2	54–60	55.25	59.75	81.45
3	60–66	61.25	65.75	87.45
4	66–72	67.25	71.75	93.45
5	76–82	77.25	81.75	103.45
6	82–88	83.25	87.75	109.45
7	174–180	175.25	179.75	152.35
8	180–186	181.25	185.75	158.35
9	186–192	187.25	191.75	164.35
10	192–198	193.25	197.75	170.35
11	198–204	199.25	203.75	176.35
12	204–210	205.25	209.75	182.35
13	210–216	211.25	215.75	188.35

nels, the oscillator frequency is above the carriers; for the upper channels, the oscillator frequency is below. This is possible in Intercarrier systems because of the absence of any trap circuits in the I.F. stages and the resulting approximately symmetrical response curve. Furthermore, the sound beat note frequency of 4.5 mc is determined at the transmitter and not at the receiver. Oscillator frequency switching is not possible in conventional television sets because of the sound take-off trap and other traps usually employed in the I.F. stages. These are fixed tuned, and their frequencies cannot be altered as they would have to be if the oscillator frequency position (with respect to the two carriers) were shifted. For the upper channels, the video carrier I.F. value is 22.9 mc, and the sound carrier I.F. is 27.4 mc. Note that in each instance the sound carrier is 15.6 db below the level of the video carrier. Although this is not the 26 db suggested, it will still provide satisfactory operation.

The gain of the I.F. system is controlled by R_1, the contrast control. This control regulates the bias of the first and second I.F. amplifiers, although, seemingly, connection of the control is made only to the grid of the first amplifier. Examination of the circuit, however, reveals that both these tubes are con-

nected in series. As the grid voltage of the first I.F. amplifier
is made more negative, less current flows through both tubes,
effectively raising the positive potential applied to the plates
of each tube. Since the cathode of the second I.F. amplifier is
directly connected to the plate of the first I.F. amplifier, the
cathode voltage also rises. This is equivalent to a negative in-
crease in the grid potential of the second tube. Thus, the con-
trast potentiometer controls the bias of the first and second I.F.
amplifier and thereby the level of the output voltage.

Advantages of the Intercarrier System. Now that we have
examined the underlying principles of the Intercarrier system
and noted its application to commercial receivers, it might be
well to evaluate its advantages and limitations. One big ad-
vantage offered through the use of Intercarrier system is its rela-
tive independence of many of the difficulties which beset the
local oscillator and which affect the quality of the output in
conventional television receivers. Thus, consider what happens
when the oscillator frequency drifts. In both systems, the re-
sultant video and sound I.F. values will shift. Suppose that
this shift is 200 kc. In a receiver employing the conventional
television system, the video signal will be negligibly affected be-
cause a 200-kc shift is unimportant when compared to the total
video spread of 4.0 mc. In the sound I.F. system, however, the
discriminator linearity extends usually for ± 100 kc on either
side of the I.F. carrier frequency, and a shift of 200 kc will re-
move the signal from the linear portion of the characteristic,
distorting or causing the complete loss of audio output.

Compare this with the same effect in a receiver employing the
Intercarrier system. Since separation of the two signals does
not occur in the I.F. system, the only effect this produces is
to shift the position of the two signals along the I.F. response
curve. This will alter somewhat the amplification accorded
these signals, but not to an appreciable extent since 200 kc is
negligible compared to the 4.5-mc bandpass. When the two
signals reach the video second detector, the resultant 4.5-mc

beat note will be obtained since the difference between the two carriers is fixed at the transmitter and nothing that occurs at the receiver can alter this relationship. The 4.5-mc beat note will then pass through the video-frequency amplifiers and into the sound system, unaltered by the local oscillator change in frequency.

Shifting of the local oscillator frequency due to hum or microphonics will likewise have negligible effect in the Intercarrier system because. no matter how the oscillator frequency changes, the difference between the two carrier frequencies remains 4.5 mc. and it is from this difference that the sound output is obtained.

Fine-tuning controls are employed in conventional television receiver sets to counteract any drift of the oscillator frequency. Since oscillator drift—within nominal limits—does not appreciably affect the operation of a set using the Intercarrier system, this control may be dispensed with. However, some of the Intercarrier receivers on the market still include a fine-tuning control. With the control available. less precautions need be observed in designing the front-end tuning system. with resultant economy.

Another advantage offered by the Intercarrier system is a simplification in the design of the receiver. The number of stages in the sound I.F. system is reduced by two to three since the sound signal is first passed through all the video amplifiers before being transferred to the sound system. Furthermore, tolerances of the local oscillator are not critical, permitting the use of cheaper components, with less care required in the layout. In the I.F. system, the bandpass may be made symmetrical, as previously demonstrated. permitting the manufacturer to design the oscillator so that it operates above the video and sound carriers on the lower television band and below these signals in the upper television band. Since it is cheaper to construct a stable low-frequency oscillator than a stable high-frequency oscillator, additional economy is possible. All these

considerations point up the desirability of using the Intercarrier system.

Disadvantages of the Intercarrier System.   The Intercarrier system is not without disadvantages, however.   The appearance of the sound at the loudspeaker is dependent upon the mixing action that occurs in the video second detector.   If something should happen to prevent the transmission of the video carrier—and this can and has happened—then no output at all is obtained at the receiver.   Note that this is peculiar to Intercarrier systems and is not true in sets employing the conventional system.   While it may be argued that the foregoing set of conditions seldom occurs, yet there is another manifestation of the same effect that appears more frequently.   Thus, when a white line or series of white lines is being transmitted, the video signal level drops down to a very low value.   If care is not observed at the transmitter, the level may easily drop to zero (corresponding to 100 per cent modulation), resulting momentarily in no video signal. This causes the sound to disappear, also momentarily.   This is usually repeated at line frequency (15,750 cycles) or field frequency (60 cycles) producing a 60- or 15,750-cycle buzz in the receiver.   (The 60-cycle buzz is more evident because most people cannot detect a note as high as 15,750 cycles.)   To prevent this, it is necessary to check transmitter modulation carefully.   Current F.C.C. regulations merely specify that the amplitude of the video carrier, when transmitting maximum white, may not be more than 15 per cent of the maximum video carrier amplitude (which is attained when the sync pulses are sent). If this is amended to specify a definite minimum, say 10 per cent, then we would insure that the video carrier would never be lost.

Another factor that requires careful observance is the incidental phase or frequency modulation that sometimes develops in the video carrier when it is receiving the video intelligence. It has been found that under some circumstances, the video carrier will receive a small amount of phase or frequency modulation while it is being amplitude modulated at the transmitter. In the subsequent mixing that occurs in the video second de-

tector at the receiver, this phase or frequency modulation is passed on to the 4.5-mc sound signal and is not removed at the F-M detector. The result again is a 60-cycle buzz or a 15,750-cycle note.

Precautions are necessary in receivers, too. Here, the greatest single factor affecting proper operation is the relative magnitude of the video and sound carriers at the time they are mixed in the video detector. If the amplitude of the video carrier is very large compared to that of the sound carrier, then the amplitude of the beat note is very nearly independent of the amplitude of the video signal. This means that the F-M 4.5-mc beat note will not be affected by any modulation contained on the video carrier. Now, this stress on keeping the amplitude of the beat note as constant as possible arises chiefly because the F-M detector and the limiter which precedes it are not insensitive to amplitude modulation when such modulation appears in a sizable amount. Most servicemen believe that an F-M detector and limiter will not respond at all to amplitude modulation, which is true if the amplitude modulation is small. However, if it becomes large, then it will affect the output of the F-M detector and distort whatever audio signal is present.

The value of 26 db as the difference between the amplification accorded the video and sound I.F. carriers will insure that the 4.5-mc beat note receives little amplitude modulation.

Finally, there is the problem of attempting to maintain the sound limiter and detector tuned circuits at precisely 4.5 mc. Any deviation from this value, due to altered components, usage, humidity, etc., will cause the sound signal to be displaced to a non-linear portion of the detector characteristic, thereby producing a distorted output. Nothing short of a complete realignment of these stages will correct this condition. In sets using the conventional system, this condition can be corrected by retuning the local oscillator, using the fine-tuning control.

CHAPTER 14

SERVICING TELEVISION RECEIVERS

Introduction.   Television receivers, in their present state of development, are critical mechanisms that require accurately adjusted circuits if the maximum enjoyment is to be derived. Indiscriminate replacement of component parts, a practice quite popular for many sound receivers of today, will generally cause more grief than good and should be discouraged.   Careful adherence to manufacturer's values is especially important in the timing circuits of the receiver deflection systems.   Hold controls permit some variation of the oscillator's frequency, but the limits are fairly narrow.   Wide discrepancy between the values of the replacement parts and those specified by the manufacturer would render synchronization impossible.

Experienced servicemen utilize the indications (or lack of them) obtained from the loudspeaker of a sound receiver to their greatest extent.   Probably the best example of the usefulness of the indications from the speaker in servicing work is the hoarse, rasping sound obtained when a filter condenser in the power supply becomes defective.   The set continues to operate, but with reduced volume and the characteristic distortion of sound.   A receiver with this trouble, in the hands of an expert serviceman, would be repaired in less time than it takes to describe the defect.   The greatest difficulty in trouble shooting is experienced when the set is completely dead and no sound is obtained.

A television receiver, in addition to having a loudspeaker for its sound, has an even better source of indication, the viewing screen.   The eye is a more critical judge than the ear, and defects in television sets reveal their causes far more readily

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than comparable defects in sound receivers. The two (sound and sight) combine to facilitate television service work to a remarkable degree. True, a certain amount of experience is required, but it can be obtained in a relatively short time. With the basic principles (as presented in previous chapters) clearly in mind, the radio technician should have little trouble in associating the various distortions of the image with specific circuits throughout the receiver.
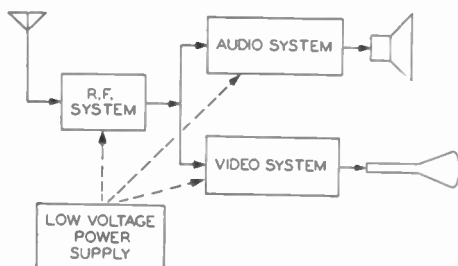
Fig. 14.1.   Television receivers can be roughly divided into sound and video systems.

Servicing Divisions of Televison Receivers. All television receivers can be roughly divided into sound and video systems, both receiving their signals from the R.F. system and their power from the low-voltage power supply.* (See Fig. 14.1.) Anything which affects both the audio output and the picture must reside in a section common to both, i.e., the R.F. system or the low-voltage power supply. Thus, when the serviceman is presented with a defective television receiver, he will check, as a first step, the audio and video outputs against each other. Distortion in both will point immediately to either the R.F. section of the receiver or the low-voltage power supply. On the other hand, distortion in only one system will immediately eliminate the unaffected system (sound or video), the R.F. section of the receiver, and the low-voltage power supply. Here

* We are concerned at the moment only with television receivers employing the conventional system. Servicing of Intercarrier television sound system receivers will be considered at the end of this chapter.

we have, by a simple observation, narrowed down the defect to a relatively limited section of the receiver and reduced wasteful servicing time by a considerable amount.

Once the defect has been narrowed down to a specific section of the receiver, the next step is to analyze that particular section

Fig. 14.2.   A block diagram of the audio section of a television receiver.

with a view toward further localization.   This brings us to the block diagrams shown in Figs. 14.2 and 14.3.   In the audio system, the general breakdown consists of the I.F. amplifiers, the F-M detector, the audio amplifiers, and the loudspeaker.   In the video system we have, in addition to an equivalent I.F. section,
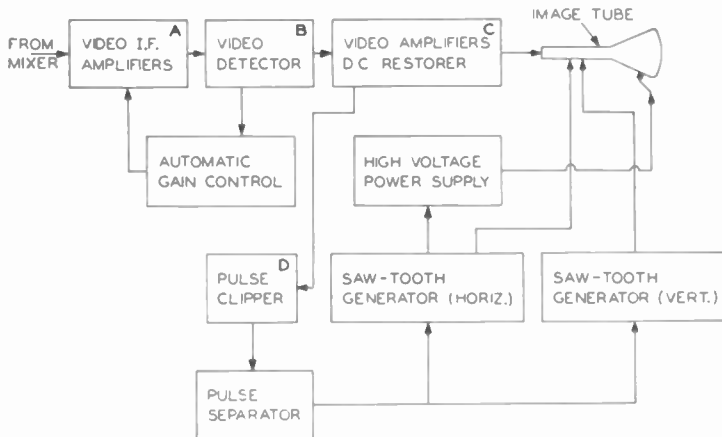
Fig. 14.3.   A block diagram of the video section of a television receiver.

a second detector and video amplifiers, the vertical and horizontal sweep systems.   Furthermore, recent television design has placed the high-voltage power supply in the horizontal sweep system.   Although this is not true of all receivers, it is true of most sets.

Once the difficulty has been traced to a particular system in the receiver, we are in a position to conduct a further analysis of our defective receiver. In the video system, for example, breakdown of the signal path in sections A, B, or C will prevent the video signal from reaching the cathode-ray tube. Under these conditions the sound will be heard loud and clear and the image tube will have a scanning raster, but no image. The scanning raster will be due to the sweep oscillators which continue to function because they are self-oscillating. These oscillators are not being triggered, but they do oscillate.

As another illustration, suppose the circuit opens up in section D. The sync pulses will be prevented from reaching the sweep oscillators; consequently the oscillators will not be controlled by the incoming signal. On the other hand, image signals are reaching the cathode-ray tube. The visual result will be a picture which is scrambled because the various sections are not being placed on the screen in proper sequence. The audio section will be unaffected.

These are but two of the many clues that the serviceman receives each time the set becomes defective. In this chapter we will undertake the analysis of many common clues that are encountered in defective television receivers. Recognition and interpretation of these signposts will help the serviceman in 90 per cent of his work.

The Power Supplies. The power unit of a television receiver is composed of two sections. One division deals almost exclusively with the cathode-ray tube, whereas the other supplies the operating voltages for the remaining tubes in the set. These two units are physically separate, but the operation of the high-voltage supply is dependent upon the proper operation of the low-voltage supply. This is so because current high-voltage units are either of the R.F. or flyback type and, therefore, receive their driving voltage from circuits powered by the low-voltage supply. (See Chapter 8.)

The surest indication of high-voltage failure is the appearance of a perfectly blank screen. If a blank screen is accompanied

by normal sound, then we know that the low-voltage power supply is operating normally and we can concentrate on the high-voltage system. However, a blank screen and no audio is generally due to a defective low-voltage supply and this should be tackled first.   .

High-voltage power supply failure will cause a dark screen but there may be other causes for the same condition. What these are will depend upon the manner in which the high-voltage is generated. Thus, if the receiver possesses an R.F. high-voltage power supply, then a dark screen generally will be due to failure of the high voltage or a defective cathode-ray tube. If the filament of the picture tube is lit, check the high-voltage system. With a kilovoltmeter, measure the output of the high-voltage power supply. If the voltage is low, replace the oscillator tube. If this doesn't help, replace the high-voltage rectifier tube. Measure the d-c voltages in the oscillator circuit. As a final step, make resistance (continuity) checks in the high-voltage system.

When the high voltage is developed by the inductive "flyback" method, the number of factors which can produce a blank screen increase. There are not only the high-voltage unit itself and the cathode-ray tube but, in addition, the horizontal deflection system. As a first step, measure the voltage at the output of the high-voltage supply with a kilovoltmeter. If the voltage is zero, or low, determine whether the horizontal deflection system is operating properly by checking the waveform at the horizontal output tube. If the waveforms are correct, the trouble exists in the 8016 rectifier circuit. Either the high-voltage winding is open, the 8016 tube defective, its filament is open, or the condenser-resistor filter circuit is defective.

The absence of any deflection waveform indicates that the trouble exists in the horizontal deflection system. This system is best checked with an oscilloscope, noting the wave shapes at various points in that circuit, and comparing these with the illustrations given by the manufacturer. Note that a distorted wave may cause some high voltage to appear, although this

voltage may be low. A distorted deflection wave will visibly affect the horizontal linearity of any image appearing on the screen.

It is well to distinguish between a dark screen, which is due to no high voltage, and a screen containing a scanning raster but
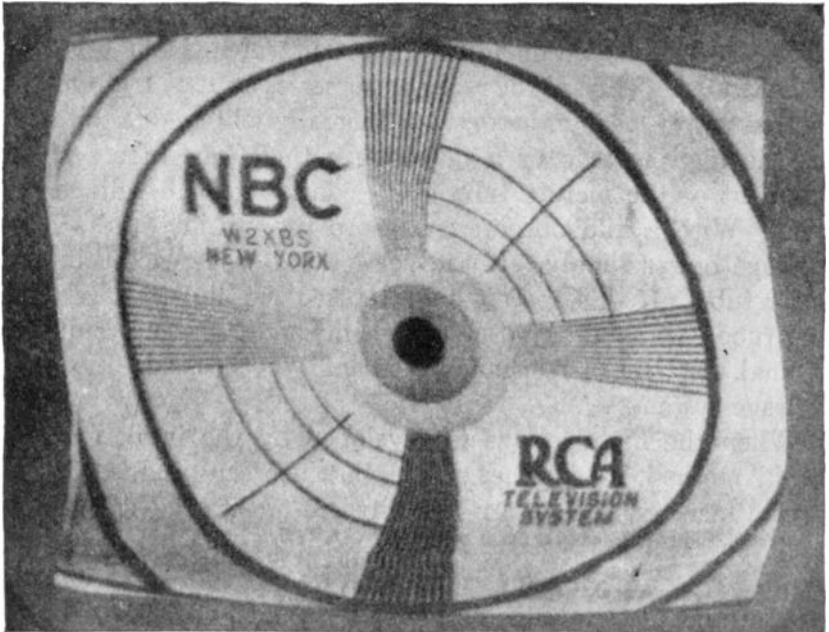
Courtesy RCA

Fig. 14.4. Distortion due to ripple in horizontal deflection system.

no image. The latter difficulty, when accompanied by a normally functioning audio system, indicates a defective video system. In this case, the horizontal deflection system and the high-voltage power supply are both operating satisfactorily as revealed by the appearance of the scanning raster.

Ripple Effects. We have up to this point been concerned with the overall operation of the two power supplies of the television receiver. The symptoms have dealt with the appearance or non-appearance of any voltage across the output of these units.

It may also occur that, although voltage is being obtained from the rectifier systems, the filtering is incomplete. The most common causes of improper filtering are (1) an open filter condenser, and (2) too great a load on the unit, due perhaps to some partial short circuit elsewhere in the receiver. The latter

FIG. 14.5. Unfiltered A.C. ripple in vertical deflection amplifiers.

trouble, by the large current drain on the power supply, lowers the inductance of any series filter chokes and prevents them from functioning properly. The general overall effect is reduced output voltage with relatively large amounts of ripple. It is from the latter that the defect becomes most apparent. Let us see how this ripple will be evident at the screen.

It has been indicated many times in previous chapters that the eye is more critical to defects than the ear. Special precautions are taken to prevent any audio signal voltages from

passing through the video amplifiers and reaching the control grid of the picture tube. When such variations do pass, the general result is the appearance of horizontal (or vertical) black and white bars across the picture. With ripple from a defective power supply, however, the result may appear as shown in Figs. 14.4, 14.5, or 14.6, depending upon which circuit is affected.

FIG. 14.6. A large percentage of ripple voltage in the video amplifiers.

The first of these defects, Fig. 14.4, is due to excessive ripple in the horizontal deflection circuits, and the image on the screen acquires a very disconcerting weaving. For the same defect in the vertical deflection amplifiers, Fig. 14.5 is an example with the weaving now present in the vertical direction. Excessive ripple or hum in the video circuits will generally result in the appearance of wide, dark bands across the screen, sometimes completely obscuring a large section of the image. (See Fig. 14.6.)

Sounds vs. Filter Ripple. Because sound signals produce an effect closely paralleling that of a-c ripple in the video stages,

it is best to consider them at the same time. Some similarity of effects at the image is to be expected since ripple is merely low-frequency audio. However, the difference in frequency is great enough so that the two may be distinguished. Ripple produces one or two dark bands across the screen whereas sound modulation voltages, being of a higher frequency, produce many more. Improper positioning of the fine tuning control, or general misalignment of the tuned circuits, is responsible. If the oscillator (or the signal) is not correctly positioned, the proper I.F. frequencies are not formed. In this event, the sound traps in the video I.F. amplifiers become ineffective because they are fixed at one frequency. The sound voltages now reach the control grid of the viewing tube and produce inter-ference. When the system is properly aligned, a slight ad-justment of the position of the fine tuning control is all that is needed. With the circuits out of alignment, a general retuning as outlined in Chapter 11 must be undertaken. Fig. 14.7 is a photograph of an image containing sound modulation voltages.

Another test as to whether the bands across a screen are due to sound interference or ripple from the power supply can be ascertained by observing their duration. The sound (music, voices) will vary in intensity and, when it stops, the bands dis-appear. Distortion from the power supply is steadier in in-tensity. Tuning the set to another station does not alter the position of the bands. And, while on the subject of image dis-tortion, it should be kept in mind that too strong a signal may also be the cause of the same symptoms, due to overloading of the preceding tubes. Thus, while sound modulation bands across the image may at first indicate that the set is misaligned, the serviceman should switch the receiver to different stations before definitely deciding on a complete realignment. If the source of the interference bands arises from too strong a signal, the antenna may have to be relocated to decrease the strength of the received signal.

The amount of ripple present in the low-voltage power unit can be measured readily with an oscilloscope. The test is made

with the receiver B+ connections in normal position, since a ripple in the d-c output voltage may appear under load, but be quite negligible when the current drain is light. The ground post of the oscilloscope is connected to the receiver chassis, and a lead with a series 1-μf condenser from the B+ to the vertical

FIG. 14.7. The visual result when sound voltages reach the cathode-ray tube.

plate's binding post completes the circuit. It is possible to test the high-voltage unit in the same way, but this is seldom necessary and should be done only with the greatest care.

As a general rule, when servicing low-voltage power supplies, the following is true:

1. The output voltage will decrease and the ripple percentage will increase when the input filter condenser opens. By input filter condenser is meant the first condenser after the rectifier tube.

2. The output voltage will be only slightly affected, but the ripple current will increase quite perceptibly if the output filter condenser opens.

The Cathode-ray Tube. The cathode-ray tube circuit has several controls and adjustments associated with it and an incorrect setting on any of these controls can produce a distorted picture or no picture at all. This is especially true with electromagnetic deflection tubes because of the critical positioning of the coils on the outside of the tube neck. Some of the more common troubles encountered are as follows.

a. *Cathode-ray tube is brightly illuminated and brightness control is ineffective; sound is normal.* The image will appear thin and washed out but held perfectly in place by the synchronizing pulses. It would appear, at first thought, that a video amplifier stage is defective. However, the trouble exists in the cathode-ray tube because, although a weak signal will produce a thin, watery image, this is always accompanied by noise spots (snow in the image) and poor synchronizing section. Since neither of the last two aspects are present, only the bias circuit (brightness knob) of the cathode-ray tube can be at fault. Check the voltage between the control grid and cathode of the image tube. Check the brightness control for continuity. If this potentiometer is found to be good, try another cathode-ray tube. There may be leakage between the image tube grid and cathode. A gassy tube can produce the same symptoms.

b. *Small picture with the mask not completely filled.* (See Fig. 14.8.) Picture size control depends upon the type of deflection employed in the receiver. With electromagnetic deflection, picture size is controlled by the amplitude of the vertical and horizontal deflection voltages and by the placement of the deflection yoke. Check the latter first by moving the deflection yoke along the neck of the tube. Rotate each of the size controls. If neither of these produces the proper size image, check the B+ output of the low-voltage power supply. Too low a voltage can be the cause. When the image is small in one direction only, check the output of that particular deflection

system.   With electrostatic deflection, the amplitudes of the vertical and horizontal deflection voltages are the only controlling factors of picture size.

c. *Picture on slant*.   With electromagnetic deflection tubes, rotate the deflection yoke; for electrostatic deflection tubes, reposition tube.
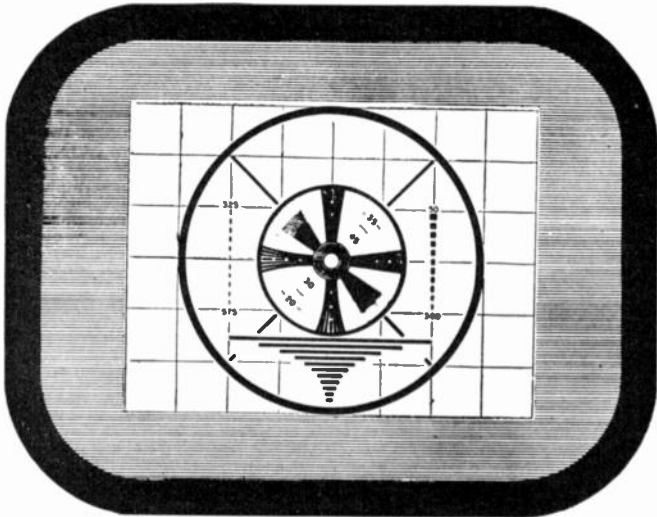
Courtesy Belmont Radio

Fig. 14.8.   An image which is too small in the vertical and horizontal directions.

d. *No raster or image on screen*.   Check alignment of ion trap coils.   They may be reversed, improperly positioned, or open. Lack of high or low voltages can have the same effect and this has already been noted.

There is one situation that is sometimes encountered in this respect.   In many sets, the ion trap coil is placed in the negative section of the low-voltage power supply, and it can readily occur that this section of the supply opens up (or is shorted out) with the result that the ion trap coils receive no current, although high and low B+ voltage exists.   If the ion trap coil does not seem to function in any position, check the voltage across this coil.

e. *The appearance of a dark area at one edge of the screen* can be traced directly to an improper alignment of the ion trap. (See Fig. 14.9.)

f. *Picture cannot be centered.* When electromagnetic deflection is employed, centering of the image is achieved in one of three ways:
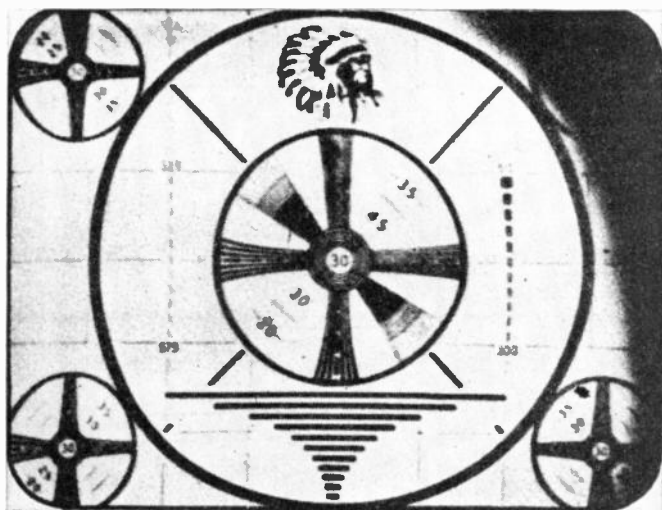
Fig. 14.9 Improper placement of ion trap.

1. Adjustment of the vertical and horizontal orientation of the focus coil. Wing nuts are provided on the focus coil, enabling us to vary the vertical and horizontal position of the coil.

2. Focus coil position adjustment plus centering potentiometers. The potentiometers, one for vertical centering and one for horizontal centering, govern the amplitude and direction of the current through the deflection yoke. Picture centering is controlled chiefly by the setting of these potentiometers. Minor adjustments are made by physically adjusting the focus coil position.

3. Centering potentiometers only. The focus coil can only

move forward or backward along the neck of the cathode-ray tube and has little control over the position of the image.
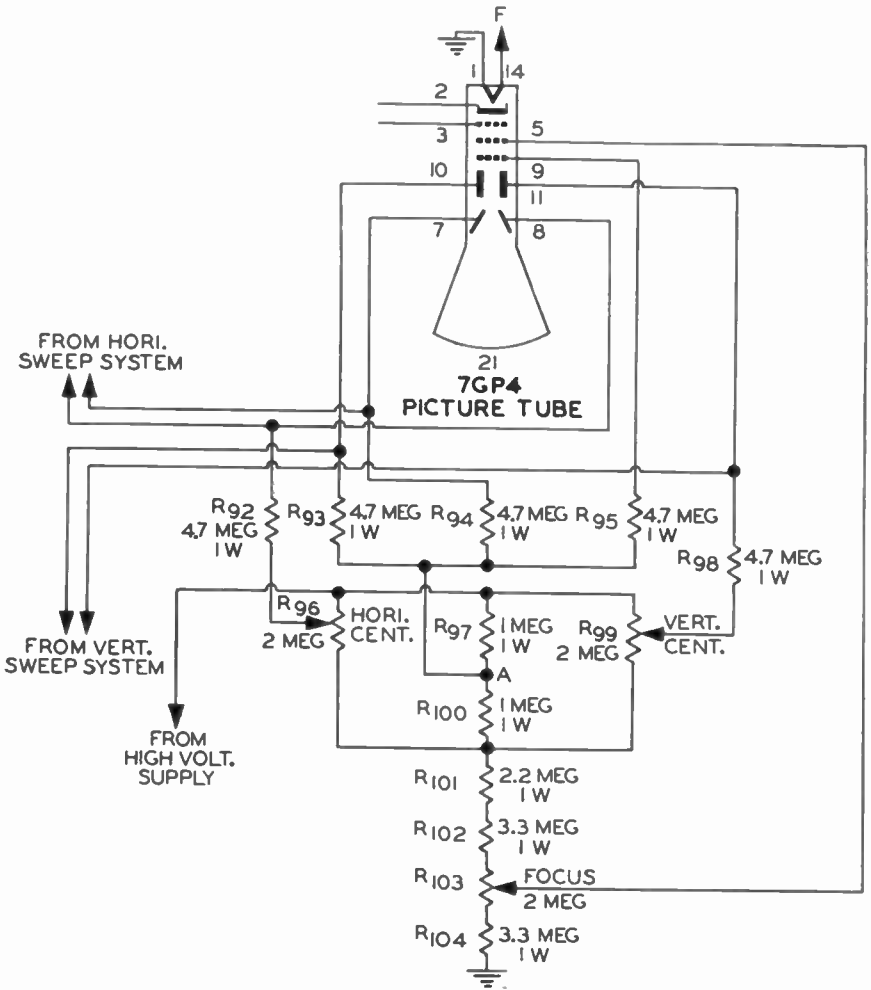
FIG. 14.10.   The positioning and focus control circuits for electrostatic deflection tube.

Determine which method is employed in the receiver and make the proper adjustments in order to center the picture. Complete inability to center the image indicates a defective com-

ponent in the centering circuit. Voltage and resistance checks should reveal the source of the trouble.

In electrostatic deflection tubes, such as the 7GP4 shown in Fig. 14.10, horizontal and vertical centering controls are attached directly to the deflection plates. The high positive potential from point A is applied to one horizontal and one vertical deflection plate. In parallel with R_{97} and R_{100} are two po-
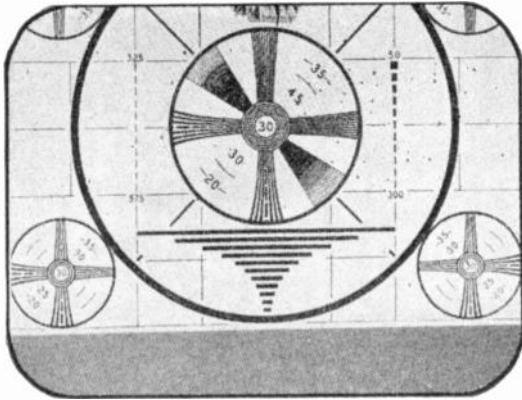
FIG. 14.11. Vertical centering misadjusted.

tentiometers (2 megohms each), with the center arm of each going to the remaining vertical and horizontal deflection plates. When the arms of the potentiometers are in center position, there is no d-c potential difference between each set of deflection plates. A balance exists. Any change in the position of these potentiometer arms, however, will make one plate of either set more positive than the other and bend the electron beam in the desired direction.

Figs. 14.11, 14.12, and 14.13 show how the picture is affected when the centering controls and adjustments are incorrect.

Horizontal Deflection Circuits. The next section of the receiver that we shall consider is the horizontal deflection circuit.*

* There is no particular significance to the order in which these sections are being discussed, merely one of convenience in explanation.

A block diagram of a typical horizontal deflection system of a television receiver is given in Fig. 14.14, together with the location of the various controls associated with each stage.

The purpose of the entire horizontal deflection system is to provide saw-tooth voltages or currents that force the electron beam to move from side to side in accordance with the motion described in previous chapters. The synchronizing pulses con-
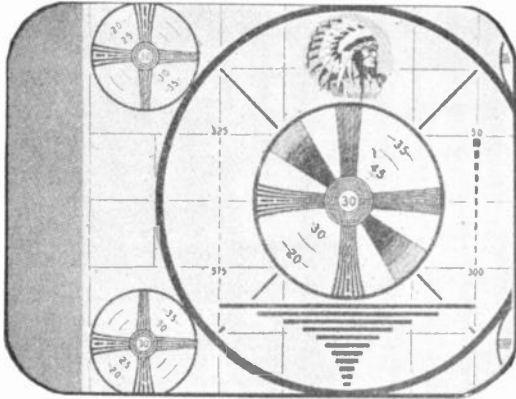
FIG. 14.12. Horizontal centering misadjusted.

tained in the incoming signal keep the frequency of the horizontal deflection voltages at a value determined at the transmitter. Any interference, whether it originates in the receiver or at some outside source, may prevent correct operation of the deflection amplifiers. Any distortion becomes immediately apparent on the viewing screen. By coordinating what we have learned regarding the operation of these circuits, together with what occurs when some circuit component becomes defective, analysis should proceed smoothly. The more common image distortions are described in the following paragraphs. Improper setting of any of the controls may also affect the image and hence will be classified as defects. This is as much a practical possibility as an inoperative tube, or a burned-out resistor.

Complete failure of the horizontal deflection circuits will

either cause the screen to go blank or else produce a narrow vertical line on the screen. The first will occur when the flyback type of high-voltage supply is employed in the receiver.
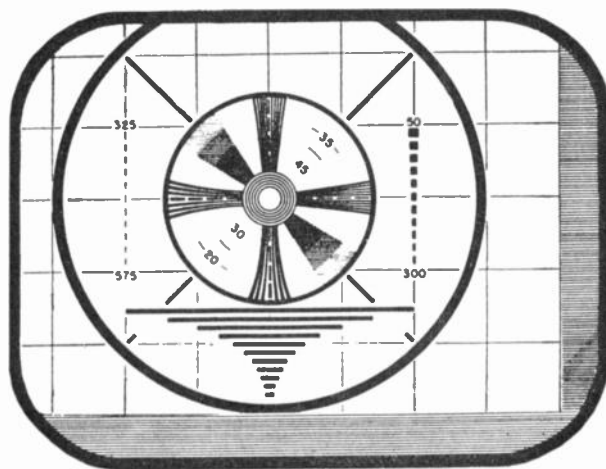
Fig. 14.13. Vertical and horizontal centering controls not properly adjusted.

The vertical line is observed when the high voltage is generated by an R.F. type of unit. To localize the defect, signal tracing with an oscilloscope is the only feasible method. The voltages present in both vertical and horizontal sweep systems have
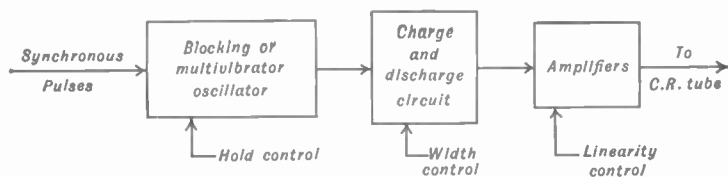
Fig. 14.14. Block diagram of horizontal deflection system, together with the controls associated with each section.

distinctive waveforms which are not changed by the incoming signals. What better method is then available than comparing the wave shapes of the voltages in the defective receiver with the corresponding waveforms given by the manufacturer in his

service manual. One example are the illustrations in Figs. 14.15 and 14.16. These are the proper waveforms present in the vertical and horizontal deflection circuits of Fig. 14.17. The peak-to-peak voltage values are also important in waveform
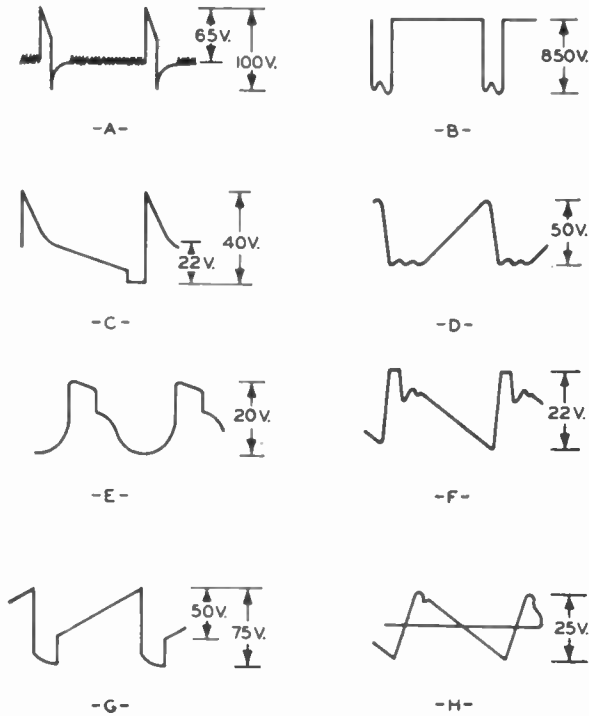
Fig. 14.15. The waveforms shown above were taken at the following points in Fig. 14.17: (A) Plate of V9B. (B) Across the horizontal deflection coils. (C) Across R30, in the circuit of V15A. (D) Cathode of V12. (E) Cathode of V11. (F) Across R31, in the circuit of V10A. (G) Across R44, at the grid of V12. (H) Across C29, leading to T7.

checking and these should be carefully noted. When the wave-amplitudes are found to be appreciably smaller than recommended by the manufacturer, tubes and the B+ power supply voltages should be checked. On the other hand, distorted or improperly shaped waves usually indicate defective condensers and/or resistors in the circuits.

It has been stated before and it will be stated again that tubes are, by far, the most important source of trouble in present-day television receivers. Hence, when trouble is traced to the de-
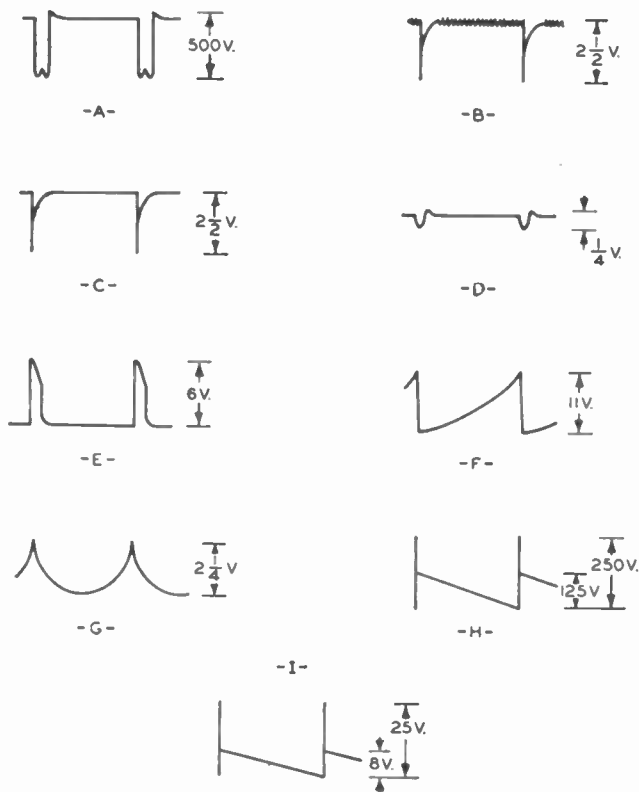
FIG. 14.16. These waveforms were taken from the following points in Fig. 14.17: (A) Junction of C61 and R52, near V14. (B) Grid of V15B. (C) Cathode of V15B. (D) Grid (pin #1) of V16. (E) Cathode of V16. (F) Grid of V17. (G) Cathode of V17. (H) Plate of V17. (I) Across the vertical deflection coils.

flection systems, check the tubes first. If the tubes test O.K. and they are all lit in the receiver, remove the set chassis from the cabinet and place it on the workbench so that each of the socket terminal pins of the deflection tubes can be reached. (Until the tubes are tested, there is no need to remove the
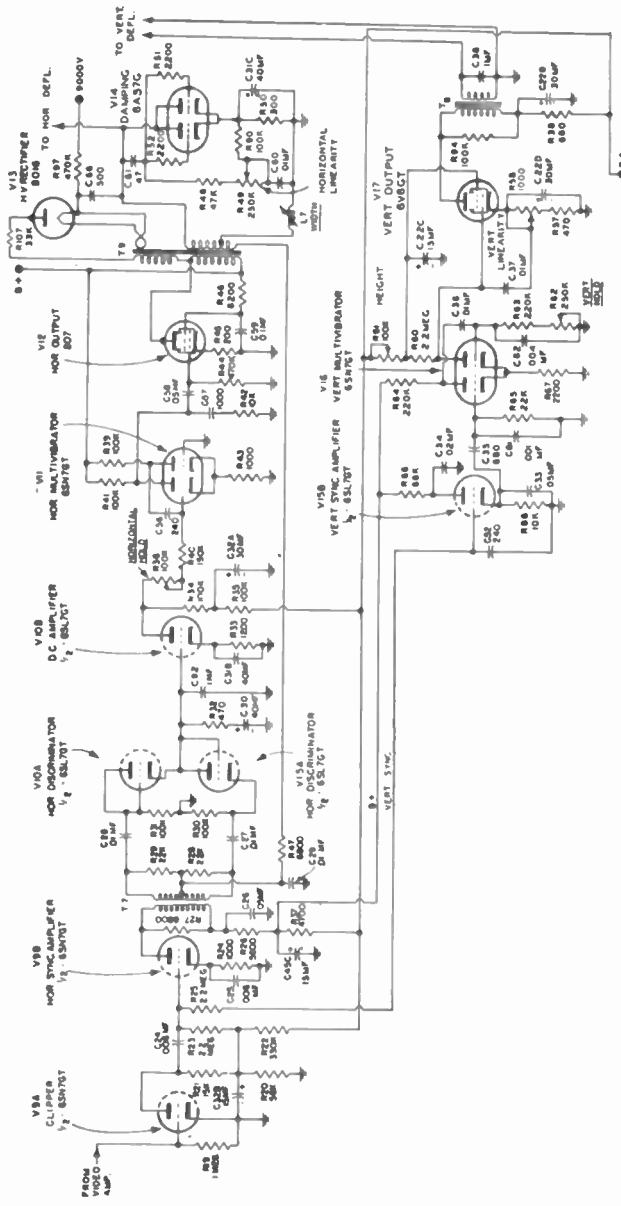
Fig. 14.17. A deflection system used by General Electric.

chassis from the cabinet. This is time-consuming and, in view of the preponderance of tube failures, unnecessary in many instances. However, when the tubes test good, the chassis should be made available for circuit checks.)

Take an oscilloscope and connect the grounded vertical input terminal to the receiver chassis. Connect a test prod to the other vertical input terminal. We are now ready to check circuit waveforms. Starting at the plate of the synchronizing oscillator, check plate and grid waveforms of each tube, working toward the deflection plates or coils of the cathode-ray tube. At the point where the waves disappear or are not in their proper form, voltage and component checks should be made to determine the reason for the wave change or disappearance. It is desirable to use a ruled plastic mask for the oscilloscope screen and note approximately the peak-to-peak voltage values of each of the waveforms checked. Variations of 10 to 15 per cent from the recommended values can be accepted since the adjustment of various controls can readily affect the wave amplitude by this amount.

Complete failure is not the only trouble encountered with horizontal (or vertical) sweep systems. Some of the more frequent defects are described below.

Loss of Synchronization. Loss of horizontal synchronization is indicated when the picture assumes the distorted appearance of Fig. 14.18. In the latter, the image appears to slip in a horizontal direction. If the slippage is great enough, it results in several images overlapping, and no detail can be clearly distinguished. In the absence of too large an input signal, slow rotation of the horizontal hold control will bring the oscillator back to the correct operating frequency at which one stationary image is again visible. Failure of the hold control to correct the oscillator frequency generally indicates a faulty component in this generator. Individual checking of the parts is the only solution.

Closely allied to loss of synchronization due to incorrect oscillator frequency is loss of synchronization due to the reception of

signals which overload the receiver. Not only will the image be adversely affected by the overloading of the video amplifiers, but the distorted voltages obtained by driving the R.F. and I.F. tubes too hard may easily obscure the signal synchronizing pulses. An image that was obtained when the incoming signal was too powerful is given in Fig. 14.19.
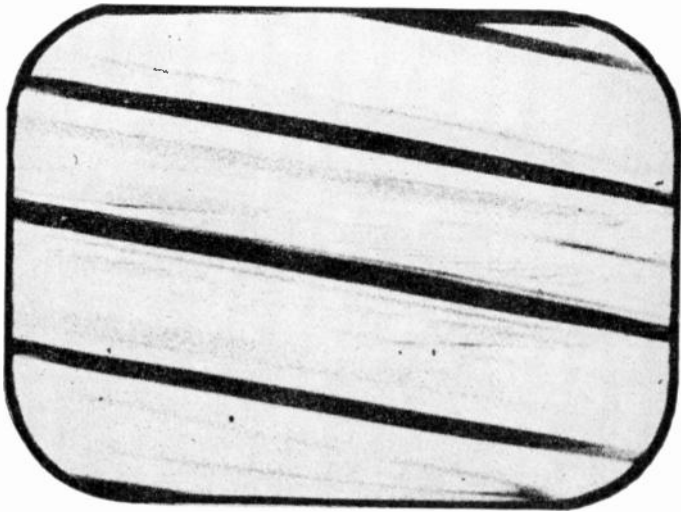
Fig. 14.18. Improper adjustment of horizontal hold control.

Interference. Still another source of synchronizing loss, causing parts of the image to be "torn out," is due to interference. The interference may be due to car ignition systems, sparking in a-c operated machinery, starting and stopping of street cars, lightning flashes, and numerous other forms of natural or man-made disturbances. In sound receivers, these noises are commonly referred to as static. In particular, the short staccato type of interference proves most troublesome.

To see electrically what occurs when a sharp interfering pulse enters the synchronizing network, let us revert to the action of the synchronizing oscillator. Fig. 14.20 shows the grid voltage variation at the blocking oscillator. The feedback voltage from

the plate to the grid, via the coupling transformer, drives the
grid strongly positive. From the immediate flow of grid cur-
rent that follows, the series capacitor charges and forces the grid
far beyond cut-off. The tube is now near point A of the curve.
As the charge on the grid condenser gradually leaks off through
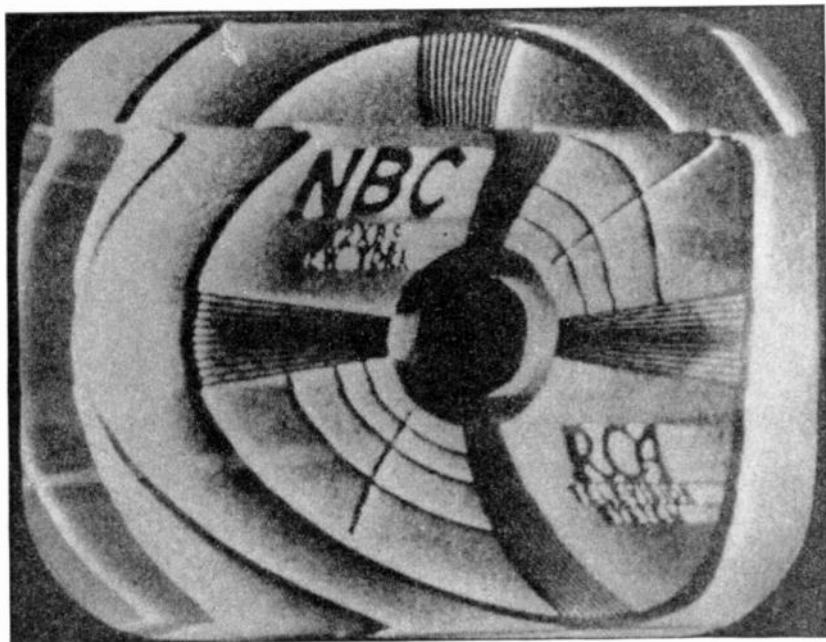
FIG. 14.19.   Distortion due to a very powerful signal.

R_g, the voltage at the grid follows the curve outlined until point
B is reached. At this point, a synchronizing pulse drives the
grid positive, thereby controlling the charge and discharge con-
denser in the following circuit.

The foregoing is the natural sequence of events. However,
upon the arrival of a sharp pulse of interference voltage, the
oscillator is made to trigger the charge and discharge circuit
some short time before point B. The result: a section of the
image is missing because the beam was brought back to the left-

hand side of the image too soon. The effect is the same as if a small portion of the scene had been torn away. Hence the origin of the term "tear" with regard to reproduced images.

The persistence, strength, and regularity of the interference will determine to what extent the image is affected. Obviously the sharp pulse of interference voltage must possess sufficient strength to drive a negative grid of the blocking oscillator into the region above cut-off if the oscillator is to be tripped. From
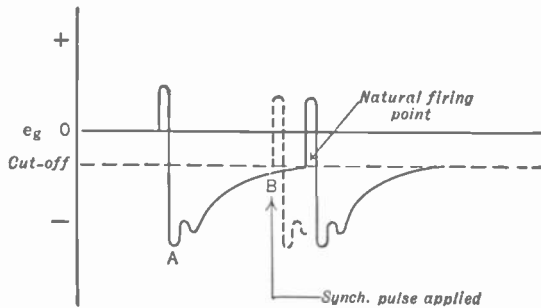
FIG. 14.20. Output waveform of blocking oscillator. The synchronizing pulse at B controls the frequency of this generator.

the curve of Fig. 14.20 we see that a larger pulse voltage would be required at A, for example, than at B. As the grid becomes less negative, the oscillator becomes more sensitive to incoming disturbances.

Besides the loss of synchronization that occurs with the reception of interference, it is also observed that black streaks appear in the image even if the synchronizing action is not hampered. It has been found that interference tends to add to the incoming video signal more than it tends to subtract from (or lower) it. Under the present system of negative picture modulation, addition of voltage would only cause that portion of the reproduced picture to become darker when it is finally scanned on the fluorescent screen. Hence the reason for the black streaks in the picture. Subtraction or lowering of the video signal voltage would result in brighter streaks. These sometimes oc-

cur. But, on the average, the interference is additive, and a greater number of black streaks is observed.

Incidentally, the fact that dark streaks prove less annoying than white streaks was responsible, in part, for the adoption of negative picture transmission as contrasted with the English system of positive picture transmission.

So far as the serviceman is concerned, there are certain measures that can be taken to minimize the interference but, if these fail, reception of television signals at that location may be impossible. Probably the surest way of eliminating interference is at the source itself. If the trouble is traced to one specific piece of electrical machinery in the house, standard R.F. chokes or by-pass condensers often prove helpful. Interference arriving at the receiver through the power lines may be minimized by employing the same R.F. suppressor units at the plug. Many of these preventive measures are those that servicemen have employed with sound receivers.

For interference that reaches the receiver via the antenna or the connecting transmission lines, the following has been found useful:

1. Use of shielded transmission line in place of spaced or other unshielded arrangements.

2. Proper matching of the transmission line, both at the antenna and at the receiver input circuit.

3. Re-routing the placement of the connecting line.

4. Use of more directive antenna systems. Reflectors placed behind the antenna will greatly narrow the angle of maximum reception and not only decrease the tendency to receive interference from all directions, but improve the signal strength considerably.

5. Positioning the antenna at various other locations until the best place is found. Generally, the higher the antenna, the better the signal-to-noise ratio becomes.

Which of the foregoing methods will prove most useful will have to be determined by each serviceman. Certain measures

may work better in some locations but prove to be unsatisfactory in others. A little patience will solve most ordinary problems.

Width Control. An important control associated with the horizontal deflection system is the width control. Electrically this is a variable resistor which is generally placed in series with the charge and discharge condenser and which controls the charging rate of this condenser. A low setting of the control means that the condenser will charge rapidly and to a larger value than if the control is turned to a position that places more resistance in the circuit. The width of the reproduced image varies accordingly.

Failure of the image to assume its required width may first be met by turning the horizontal width control to the position that should give maximum width. Unless something is wrong with this potentiometer, variation of its setting will increase or decrease the width of the picture. Even with this adjustment, the picture may not reach the required width. In this case, check the amplifiers that follow in the horizontal deflection system to see whether they have the correct d-c voltages at their elements. An inoperative or weak output amplifier will generally prevent the image from attaining the necessary width. Tube subsitution is the best means of determining whether or not the tube is defective.

Reduced image size, especially when it occurs in both the horizontal and vertical directions, may sometimes be due to improper placement of the electromagnetic deflection yoke. To test whether this is the cause, simply move the yoke back and forth and note the effects on the image.

Horizontal Linearity. Most television receivers, especially those having larger screens, incorporate a horizontal linearity control. As previously noted in Chapter 9, the purpose of the control is to correct any tendency toward non-linearity of the saw-tooth voltage or current. It accomplishes this by placing the tube to which it is attached on a section of the characteristic curve that will correct the effects of non-linearity in the saw-tooth wave.

The visual consequence of non-linearity in the saw-tooth wave is to cause the image to crowd together (in a horizontal direction) at some section of the image. Generally, with the present system of using saw-tooth wave shapes for deflection, the crowding takes place on the extreme sides of the screen. Fig. 14.21 illustrates a typical form of non-linear horizontal deflection.

To determine the cause of this non-linear velocity of the electron beam, let us consider the formation of the deflecting voltage.
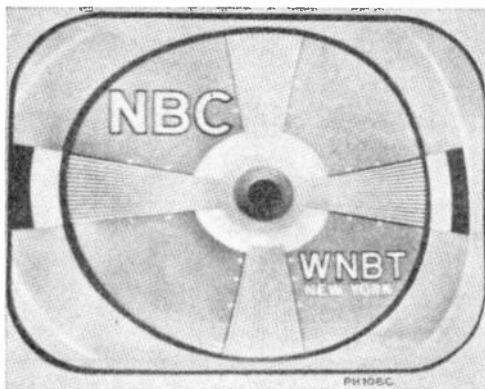
Courtesy RCA

FIG. 14.21. An image containing horizontal non-linearity.

While specific reference is made to saw-tooth voltage in this discussion, saw-tooth current waves are subject to the same explanation.

The formation of a saw-tooth wave is accomplished by allowing a condenser to charge slowly through a series resistor and then discharge more rapidly through a tube. At the time of discharge, the plate resistance of the tube is quite low and, in effect, a short is placed across the condenser. The discharging action occurs much more rapidly than the charging process and hence may almost always be considered as linear. Even if the discharge is not fully linear, the blanking of the electron beam throughout this interval removes its effects from our view and does not affect the reproduced image to any noticeable degree.

On the charging part of the cycle, however, any non-linearity will definitely make itself noticeable and does interfere with our enjoyment of the picture.

The actual source of the non-linearity of the charging cycle or forward trace of the beam is due to the action inherent in the charge of a condenser. The charging curve followed by a condenser is reproduced in Fig. 14.22. As noted previously, the
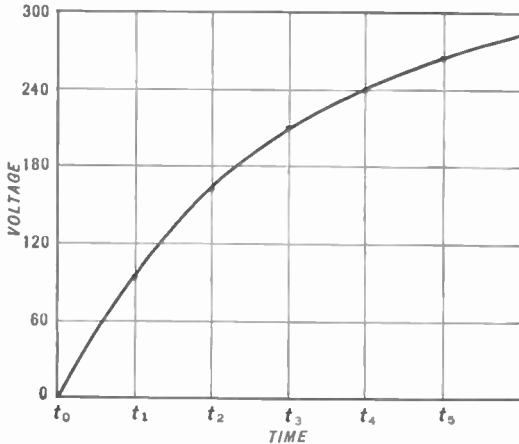
FIG. 14.22.   Charging curve for a condenser.

complete curve is exponential and only at the very beginning may the rise of voltage be considered linear. As time increases beyond this linear portion, equal intervals of time do not cause equal increases in voltages.

To illustrate, let us note the increase in voltage during several equal time intervals. From the first instant, in charging the condenser to time t_1, the voltage across the condenser increases from zero to approximately 91 volts. From t_1 to t_2, which represents a time interval as long as from t_0 to t_1, the condenser voltage increases to 165 volts, an increment of only 74 volts. Continuing, we see that during the t_2 to t_3 time interval, the condenser voltage again increases, this time by 45 volts or up to an actual voltage of 210. With each successive time interval, less and less voltage is being added to the condenser.

The effect of the unequal charging rate is to deflect the electron beam from left to right at a correspondingly uneven rate. At first, upon starting, the beam moves at a fairly constant rate. However, the farther over it gets, the slower the speed. Since the incoming signals are arriving in a steady stream, the net result is a crowding together of the image at those points where the beam is moving less rapidly. The same amount of picture detail or information must be placed within a smaller space; hence the crowding effect.

This defect becomes more annoying as the viewing screen becomes larger for, with a larger area to cover, a larger deflecting voltage must be applied to the deflecting plates. To obtain this increased deflecting voltage, we have two alternatives. Either we may take a larger voltage from the condenser by allowing it to charge more rapidly, or more amplifier stages may be added to the deflecting system of the receiver. Each method possesses disadvantages, but manufacturers generally choose added amplification. Since even a small section of the curve of Fig. 14.22 has a certain amount of non-linearity, additional amplification tends to accentuate it. A special linearity control is added to the amplifiers to offset this distortion.

The linearity control attempts to add enough tube distortion to correct or counteract the distortion in the saw-tooth wave. When this is properly accomplished, even the largest television images are uniform throughout their width (or length).

The foregoing discussion might lead one to believe that crowding of the image occurs only at the right side (due to non-linearity in the horizontal sweep system) or at the bottom of the image (for vertical non-linearity). Generally this is true only when electrostatic deflection is employed. With electromagnetic deflection, the waveforms are more complex and non-linearity may appear at any side of the image.

Horizontal Damping Circuit. The last common defect encountered in the horizontal deflection system is failure of the horizontal damping tube. Since need for such damping circuits arises only when electromagnetic deflection coils are employed,

this defect will not appear in receivers having electrostatic deflection tubes.

The necessity for a damping tube arose when it was discovered that the return trace pulse voltage set up oscillations in the electromagnetic coils. The purpose of the tube is to eliminate these "shock-excited" oscillations as quickly as possible. It forms a low-resistance path across the secondary of the hori-
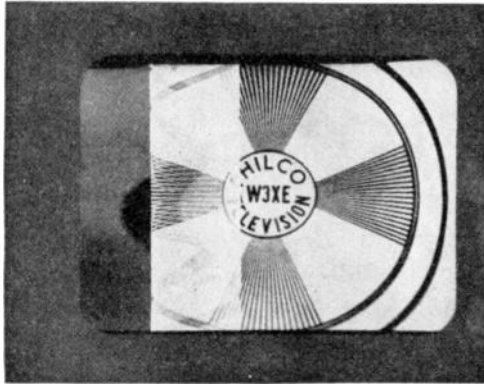
Courtesy Philco

FIG. 14.23. The appearance of the image when the damping tube is defective.

zontal output transformer and absorbs as much energy as possible during this interval. As a result of the absorption, the interfering wave rapidly dies out.

As the oscillations are set up when the beam is rapidly moving from right to left, the distortion appears on the left-hand side of the image. See Fig. 14.23. Hence, if only this particular side of the image is distorted or uneven, the first place to test is the damping circuit and any resistors and condensers associated with it. The most frequent source of failure is the damping tube itself.

Vertical Deflection System. Difficulties in the vertical deflection system are perhaps the easiest to analyze because the voltages developed here deal only with the vertical sections of the image. There are no high-voltage power supplies associated

with this system, such as we find in many horizontal deflection systems. When only the vertical deflection system is affected, analysis of the source of the defect is simple and straight-forward.

1. *The most positive indication of complete failure of the vertical system is the appearance of a narrow, horizontal line on*
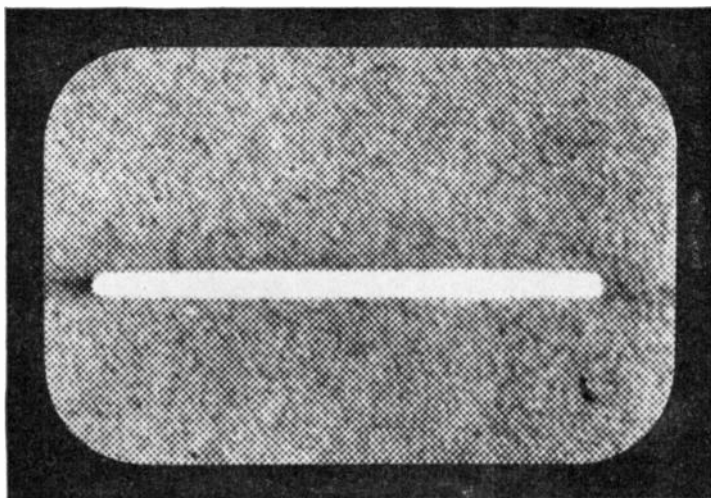
Fig. 14.24.   Complete loss of vertical deflection.

the cathode-ray tube screen.   (See Fig. 14.24.)   The first com-ponents to check are the vertical oscillator and amplifier tubes. If these are working, check the vertical sweep waveforms with an oscilloscope, starting at the vertical oscillator tube and pro-gressing forward to the vertical output amplifier. Once the de-fective stage is located, voltage and resistance checks will re-veal the defective component.   Keep in mind, when making the foregoing tests, that an open in the windings of the vertical deflection coils is also a possibility. This does not usually occur, but it can.

2. *Failure of picture to lock-in vertically.*   (See Fig. 14.25.) Ordinarily, if the vertical hold control is rotated, a point will be found where the frequency of the oscillator is brought sufficiently

close to the incoming vertical synchronizing pulses to permit
lock-in. The picture then becomes stable. However, if the oscil-
lator is not functioning properly, or the vertical synchronizing
pulses are not reaching the oscillator, then perfect lock-in will
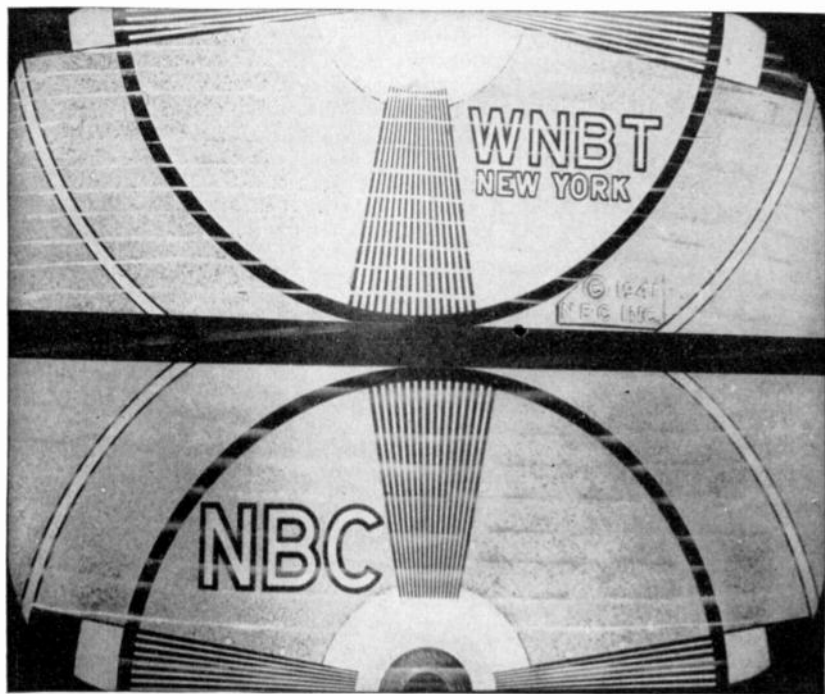
Fig. 14.25. Incorrect setting of vertical hold control. This picture was retouched
slightly to bring out the loss in interlacing that generally accompanies this
condition.

not occur. Hence, when the vertical hold control proves in-
effective, make the following tests:

a. Check the waveform at the input to the vertical sweep
oscillator and compare this with the manufacturer's.

It would be well, at this point, to determine whether the pulses
reaching the vertical sweep oscillator are sufficiently strong to
maintain control. It is quite possible that the path from the
sync pulse separator to the vertical oscillator does not trans-

mit the full vertical pulse. Reasons for this may be defective coupling condensers, open resistors, or components which have changed value appreciably. Resistors can be checked by measurement and condensers by substitution. Check, too, the amplitude of the complete video signal at the point where the sync pulse separation occurs. The image on the screen will also help determine whether sufficient signal strength is present.

b. If the foregoing test indicates normal operation, check the waveform at the output of the vertical sweep oscillator. Note whether variation of the vertical hold control has any effect on the frequency of the observed waveform. A lack of such frequency variation indicates an open resistor in the grid circuit containing the hold control. Check the resistors and condensers for the defective component.

3. *Picture "bounces" when set is jarred*. Check all the tubes in the vertical synchronizing system for microphonics. Mere tapping of each tube, while in the set, is inclusive. The best test is to replace each tube, in turn, with one known to be good.

Incidentally, too strong a signal or too high a setting of the contrast control can produce a jumpy picture. When this condition is present, the tubes are driven to saturation, obliterating or otherwise distorting the synchronizing pulse waveforms. The result is poor sync control of the sweep oscillators. In sets where the horizontal system employs some form of automatic control, noise disturbances or weak signals will affect the vertical sweep system to a greater degree than the horizontal system. However, when such control is absent, both will be affected almost equally.

4. *Picture height insufficient*. (See Fig. 14.26.) In a normally functioning receiver, rotation of the height control will produce the proper picture height. Inability to obtain this result may be due to one or more of the following reasons:

a. Weak vertical output amplifier tube.

b. Lowered plate and screen voltages on vertical oscillator and vertical amplifier tubes.

c. Low line voltage.

d. Improper placement of the deflection yoke. Items c and

d will affect the width of the image too. Hence, if the width is normal, these items can be disregarded.

5. *Picture compressed at top or bottom.* (See Fig. 14.27.) This is an indication of poor linearity of the vertical deflection voltage. The vertical saw-tooth deflection wave is developed in the plate circuit of the vertical sweep oscillator, amplified by
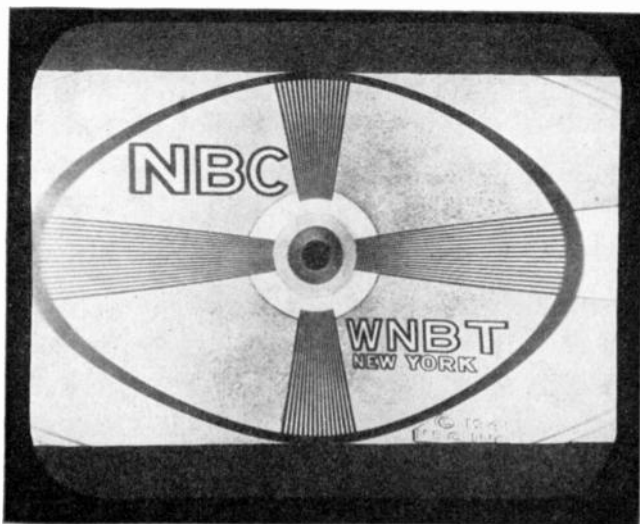
FIG. 14.26. Picture height insufficient.

the vertical output amplifier, and then applied to the vertical deflection coils. If this wave does not have the proper form, if portions of it curve or bend more than they should, then the electron beam in the cathode-ray tube will not travel down at an even rate. The visual result will be a bunching of lines in some sections of the image and a spreading apart in others. This is known as poor linearity. When the image displays this type of distortion, the vertical sweep and amplifier circuits contain the trouble.

To correct the defect, try adjusting the vertical linearity control, if any. Most receivers contain one such control, although some have two. If these adjustments fail, change the vertical

output tube. If the non-linearity still persists, check (preferably replace) the condenser and/or resistor which develop the deflection wave. In Fig. 14.28, these would be C_{101}, R_{82}, and R_{132}. Check, too, R_{86}, R_{134}, and C_{105}, because these also influence the shape of the deflection wave. Finally, grid, plate and screen voltages of the vertical output amplifier should be checked against the manufacturer's recommended values.
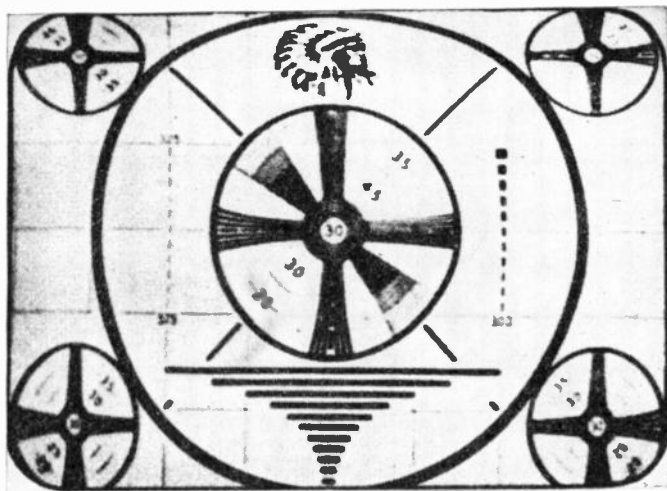
FIG. 14.27 Picture compressed on top, indicating poor vertical linearity.

Defective Clipper Action. One additional source of trouble in the deflecting circuits of the television receiver arises from defective operation of the clipper tube in separating the incoming synchronizing pulses from the rest of the video wave. With no synchronizing pulses to trigger the deflection oscillators, the reproduced image is no longer an exact duplicate of the scene at the studio. Probably the best indication of loss of synchronizing action is to be found in the apparent decrease in the number of scanned lines. Without proper guidance by synchronizing pulses, there is a greater tendency of the scanned lines to fail to fall into place between the previously scanned lines. It takes but a slight displacement of the electron beam to have
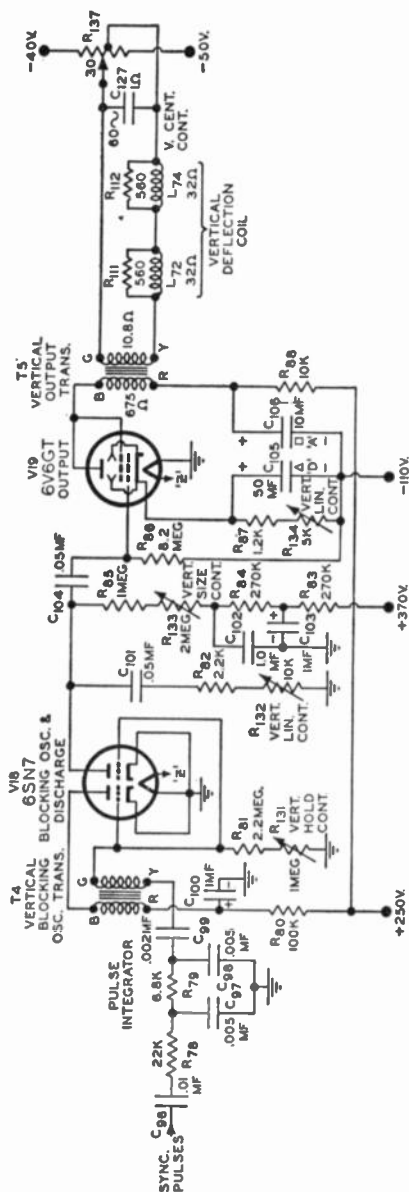
Fig. 14.28.   The vertical deflection system of the Motorola television receiver, Model VT101.

one line fall partially or completely over the adjacent line of the previous field. The result is known as pairing of lines and, to the observer, the effect is the same as if the total number of lines decreased. Naturally, the image details suffer. Testing the clipper tube in a tube checker, or placing an oscilloscope at the input of the deflecting oscillator circuit, will readily indicate whether or not the tube is functioning properly.

Synchronization between the output voltage of the charge and discharge condenser and the incoming signal pulses may also be observed on an oscilloscope. Connect the vertical leads from the oscilloscope into the grid circuit of the amplifier following the saw-tooth wave generator circuit. This places the output pulses on the screen of the oscilloscope. Adjust the oscilloscope for external synchronization and, from the external synchronization jacks, connect two leads to the output of the clipper tube. This connection feeds the incoming pulses to the oscilloscope's horizontal deflection plates. If the deflection voltages are being controlled by the incoming pulses, a stationary pattern should be observed. If the two are not synchronized, the pattern will not be locked in.

The Video Circuits. Thus far, we have observed distortions of the image due to defects in the power supplies and the deflection circuits.

Now let us turn our attention to the video circuits. These include all of the video I.F. stages, the video detector, and the video-frequency amplifiers. The video circuits deal only with the picture signal and the synchronizing pulses. However, at some point in the video system, a portion of the signal is transferred to the clipper tube where the synchronizing pulses are separated from the picture information. The pulses then go on to the sweep oscillators. This separation of pulse and picture signal can be of good use when analyzing the symptoms of a defective receiver. Suppose, for example, we find that the picture voltages are reaching the cathode-ray tube, but that the synchronizing action is poor. Obviously, then, the trouble probably exists in the sync separator or clipper stages. On the other

hand, if we find that pulses are reaching the sweep oscillators, but the screen contains only a scanning raster, then the trouble must lie somewhere between the point where the pulses are tapped off and the cathode-ray tube. Finally, if both the picture and the incoming synchronizing pulses are unable to pass through the video system, then the defect must lie ahead of the point where the synchronizing pulses are tapped off. By becoming familiar with the paths taken by the various signals through the receiver, the serviceman will be able to narrow down the source of the defect to a specific section of the receiver.

A defect in any of the video amplifiers or even in the synchronizing system will, in no way, affect the audio system. Hence, a sure indication that the trouble does not exist in the R.F. section of the receiver but at some point where only the video signal is present is the presence of clear sound with a distorted (or no) image.

When no image is visible on the screen and the sound output tells us that the trouble must lie in the video system, then the first servicing step is to test all the tubes in this system. This can be done by replacing each tube with tubes known to be good without removing the chassis from the cabinet. Checking all the tubes will take about 10 minutes and, if this is the cause of the trouble, will greatly reduce servicing time. If, however, the tubes are O.K., then the chassis will have to be removed from the cabinet and the following test undertaken.

Apply a 400-cycle audio signal, obtained from an audio signal generator, across the load resistor of the video second detector. Alternate horizontal black and white bars will appear across the screen. If the screen remains blank (i.e., it shows only the scanning raster), move the audio generator toward the cathode-ray tube, one stage at a time, until the defective amplifier is found. Voltage and resistance checks will then quickly reveal the defective component.

If the test signal can pass through the video detector and video-frequency amplifiers, the next test is made on the video

I.F. amplifiers. For this we need an A-M signal generator having a frequency range that covers the video I.F. frequencies.

Set the generator to any frequency within the video I.F. range (except the trap frequencies), turn the modulation on, and apply the modulated signal to the control grid of the first I.F. tube. If the circuit is functioning, black and white horizontal bars will appear across the face of the screen. If there is no indication on the screen, start at the final video I.F. amplifier and move the generator back stage by stage until the point of failure is located. This method of testing the video I.F. system does not reveal how well the system is functioning but merely whether or not a signal can get through. Sets are seldom thrown markedly out of alignment by the failure of any one component; hence, it is almost always safe to assume that if a signal can pass through a stage or group of stages, that portion of the system is operating satisfactorily.

Unless a video amplifier becomes completely inoperative, in which case no image at all is obtained on the screen, indications of other defects will be evident only by their effect on the image. With regard to a video-frequency amplifier tube and its circuit, the following defects may occur:

1. A defective low-frequency compensating network.
2. A defective high-frequency compensating network.
3. Improper voltages at the tube electrodes.
4. An inoperative tube or a defective component.

When the low-frequency compensation network is defective, the larger objects in the image "smear." (See Fig. 14.29.) Check defective coupling and by-pass condensers, or grid load resistors in the video amplifiers, such as V_{115} (Fig. 14.30). Check C_{138}, C_{140}, C_{141}, C_{223B}, R_{138}, R_{142}, R_{143}, R_{148}, etc. Smearing may be due to an overloaded video amplifier. Overloading of the video amplifier may also occur because of insufficient bias on the control grid, resulting in grid current. Check the bias and possible grid current of V_{115} and V_{116}.

Similar to the foregoing trouble is the loss of fine detail and the blurring of small objects. This defect is most apparent when

the station test pattern is received; the vertical wedges near
the center of the pattern are not sharp and distinct, and ad-
justment of the focus control does not clear up the difficulty.

The fine detail in a television image is produced by the
higher video frequencies. Improper alignment or too narrow
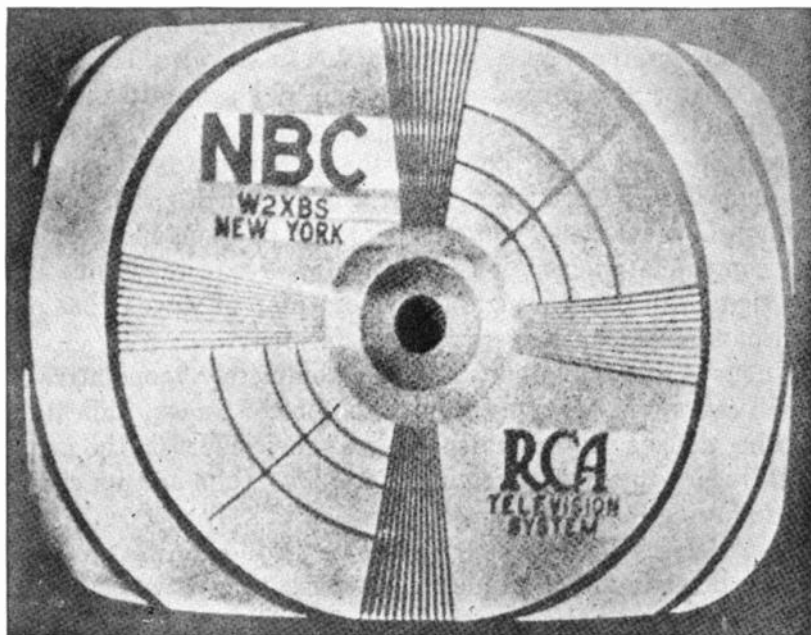
Courtesy RCA

FIG. 14.29. A visual indication of poor low-frequency response in video system.

a response of the video I.F. amplifiers may be one cause; other
reasons are: defective video amplifier tubes, V_{115} and V_{116};
defective peaking coils, L_{187}, L_{188}, L_{189}, L_{190}, L_{191}, and L_{192}, in
Fig. 14.30; and defective interstage coupling condensers, such
as C_{138}, C_{140}, and C_{141}. It is well to remember that lower-
priced receivers are designed generally for less than the full
4.0-mc video response. Consequently, the image obtained in
these sets will not contain as much detail as the images pro-
duced in more carefully designed receivers.
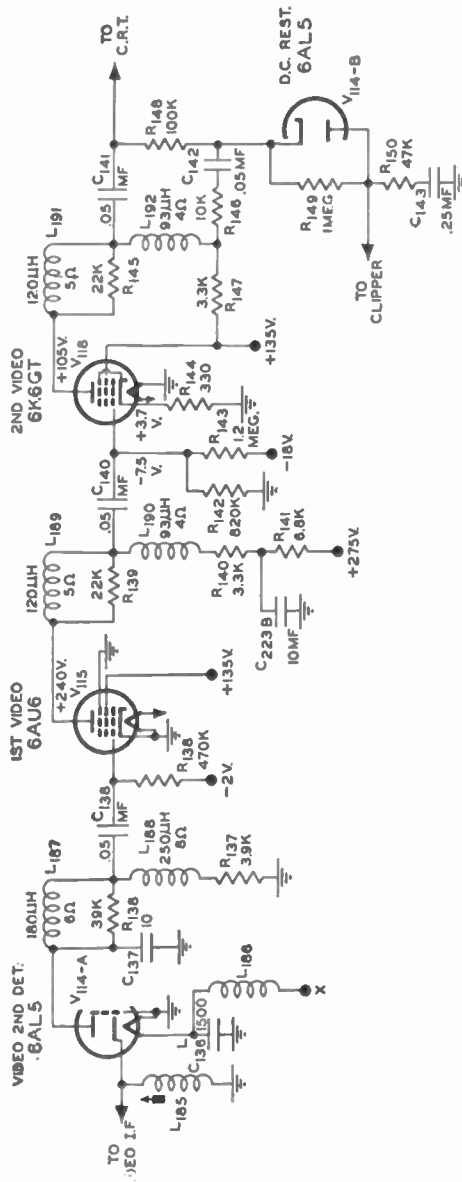
Fig. 14.30. A video-frequency system widely used.

When a highly distorted image is obtained and the sound is normal, check the setting of the contrast control. If the image can be restored to normal by lowering the setting of the contrast control, it is an indication that the incoming signal is strong enough to overload the video amplifiers when the gain is turned up too high. If the incoming signal is too strong, insert an attenuation pad between the end of the transmission line and the receiver input terminals. (See Fig. 14.31.)

It is also possible for the same distorted indication to exist and the contrast to prove ineffective. In this case, the grids or even the contrast control has become grounded, causing all tubes controlled to operate at maximum amplification. Check the grid bias of each I.F. tube.
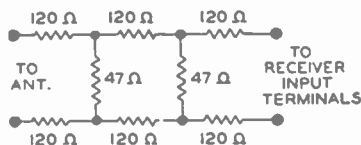
Fig. 14.31. An attenuation pad. As many sections as desired may be added.

Microphonic Tubes. One defect which arises from time to time and which has not been covered by the preceding material is due to microphonic tubes. A microphonic tube is one in which the elements are not rigidly fixed. Any vibration sets the elements in motion, generating transient currents. As long as nothing disturbs the elements, they operate normally. But, when the vibrations set up by the sound reach these tubes, transient voltages are generated. In the speaker, the familiar hollow sound is heard, while on the screen the image tends to flicker as if suddenly jerked out of synchronization. Some engineers describe this effect by saying that the picture seems to "bounce." Other visual effects of microphonic tubes are loss of synchronization and partial distortion of image details. Sometimes tapping helps the serviceman to locate the microphonic tube and sometimes individual replacement of each tube is necessary. Whatever the method, it follows closely the practice employed for present-day sound receivers. Noise due to resistors and partial shorts fall into the same category.

R.F. System. When both the video and the audio outputs are adversely affected, the source of the trouble either will lie in those stages which receive the complete television signal or else originate at some point external to the receiver. The sound portion of the television signal is frequency modulated and is less affected by external interferences than the amplitude-modulated video signal. Consequently, if the source of disturbance is not within the receiver, then, in most instances, a clear audio output will be obtained plus an image which has interference patterns. It is only infrequently that external interferences are sufficiently powerful to wreck a normal audio signal.

An open circuit in the antenna system or an antenna which is down will produce either a very weak and noisy signal in the receiver or no signal at all. If the antenna is down, the audio will usually be heard quite clearly. When weak, noisy signals are reported by the set owner, examine the antenna system before removing the receiver to the shop. If the antenna system is bad and this has been overlooked, then the receiver will operate normally in the shop.

Once the serviceman has convinced himself that the defect lies in the R.F. section of the receiver, he tries next to localize the component. The common stages, those which affect both audio and video signals, include the R.F. amplifier, the mixer, the high-frequency oscillator and, in some sets, one or two of the I.F. amplifiers. Tube substitution is recommended first.

If the tubes are not defective, measure the voltages on these tubes and compare them with the manufacturer's values. The oscillator grid voltage is especially important in this respect, because absence of a voltage here is an indication that the stage is not oscillating.

Finally, resistance checks of the tuned circuits themselves should reveal the source of the trouble.

Audio Stage Servicing. In servicing or trouble shooting the F-M audio section of a television receiver, we can use to advantage the condition of the viewing screen image as an aid in locating the source of the defect. For example, suppose the

sound is distorted, or even absent. If the reproduced image at the same time is appearing clear and undistorted, then we know immediately that only those circuits that deal exclusively with the sound contain the trouble. The R.F. and mixer stages are eliminated. The servicing problem is simplified.

Again, if both the sound and image are adversely affected, the trouble probably lies in some circuit common to both, or at some external source. Poor positioning of the fine tuning control, or improper alignment of the R.F., I.F., or oscillator stages will be indicated by one or more of the following conditions:

1. Sound interference bars in the viewing screen image.
2. Distorted sound or image.
3. No reception of sound or image.

Once the defect has been attributed to one or more circuits, signal tracing procedure is generally the surest and quickest means of actually isolating the defective component. In the video portion of the receiver, the oscilloscope proved helpful. Now, a signal generator, frequency modulated, is the most effective. By successively moving the output leads of the signal generator back (or away from) the discriminator, the point at which the signal is no longer heard with normal volume contains the trouble. Voltage and continuity checks will quickly narrow the possibilities until isolation of the source is achieved. Space limitations here prevent an extensive discussion of trouble-shooting methods but, with the use of a signal generator and the manufacturer's data, not much trouble should be encountered in locating practically all normal defects.

SERVICING INTERCARRIER RECEIVERS

The differences between the conventional and intercarrier television systems will necessitate some changes in the servicing technique of these latter receivers. In Intercarrier sets, we know, for example, that the picture signal must be present at the video second detector in order for the 4.5-mc beat note to be developed. Thus, if no sound or video output is obtained

from a receiver, but a scanning raster is present on the screen, then the difficulty may exist at one of two places. There is a possibility that no video carrier is being transmitted by the broadcast station and this may quickly be checked on another receiver. This second receiver should preferably employ the conventional television system, although a set operating by the Intercarrier method will also serve satisfactorily. Absence of any image on either of these receivers indicates that no video signal is being received from the station. Another test that immediately suggests itself is to switch to another channel on the same receiver and to note whether any image is obtained.

If it is found that a video carrier is being transmitted, but neither sound nor image output is obtained from the receiver, then the difficulty must lie in one of the stages preceding the point of separation of the 4.5-mc audio signal from the video system. Check the schematic diagram of the receiver to determine exactly where this point is. In some sets it occurs at the output of the first video-frequency amplifier; in others it occurs just prior to the cathode-ray tube. Wherever it is, work from this point forward toward the front end of the receiver. Tubes are checked first. If these are good, then an A-M signal generator should be used to determine where the signal path is broken. Remember that the appearance of an image on the screen is not dependent upon the presence of the sound signal.

To test the video-frequency amplifiers, connect an audio-oscillator across the video detector load resistor and observe whether black and white horizontal bars appear across the screen. These will be seen if the video frequency amplifier is operating. If this stage tests O.K., we turn next to the I.F. system. To test the I.F. system, all we need do is set an A-M signal generator at the video carrier intermediate frequency, amplitude modulate this with the internal 400-cycle or 1,000-cycle note of the generator, and watch for the appearance of black and white bars on the screen. Any one of the A-M signal generators on the market covering the I.F. range (20–35 mc) would be suitable. Start at the I.F. stage nearest the video second detector and

progressively move toward the mixer until the defective stage is located. To test the R.F. end of the receiver, if this becomes necessary, connect the output leads of an R.F. signal generator to the input terminals of the receiver. Set the generator at the video carrier frequency for the channel to which the receiver is tuned. This signal should also be amplitude modulated. If the R.F. amplifier, mixer, and local oscillator are operating, black and white bars will again appear across the screen. If this indication is absent, check tube voltages, especially the grid voltage of the oscillator.

The appearance of an image on the screen, with no accompanying audio, will almost invariably mean that the trouble lies in the sound system. This includes the 4.5-mc amplifier, the F-M detector, and the audio amplifiers. Conversely, the appearance of sound but no image means that the video path, following the point of separation, is open. This may include a video amplifier tube (if any), the cathode-ray tube, or coupling condensers and resistors. The amplifier tube is best checked by substitution. The cathode-ray tube is checked by inspection, noting whether or not a raster is visible and whether rotation of the brightness control has any effect on the raster intensity. Affirmative answers to both these questions indicate that the cathode-ray tube is O.K. The simplest remaining method of finding the break is by means of an oscilloscope. Start at the separation point and move toward the grid (or cathode) of the cathode-ray tube, noting where the video signal disappears. At this point employ resistance and/or voltage checks to localize the defective component.

The foregoing defects will present few difficulties to the serviceman as long as he understands the basic operation of the Intercarrier television sound system. A far greater headache is the appearance of a 60-cycle buzz from the sound channel. A common complaint made by the customer is that the set was operating properly when first bought, but that it now contains a buzz which is present only while the station is on the air. If the station goes off the air or the set is switched to a channel on

which there is no station, the buzz disappears. Here are the causes for this annoyance and how it may be corrected. (Not infrequently, servicemen will be called upon to service brand new sets which also possess this buzz. The method of attack for these receivers is the same as that for the above receivers.)

In the preceding discussion outlining the basic operation of sets employing the Intercarrier system, great stress was placed on the fact that the level of the sound carrier should be considerably lower than the level of the video carrier. One reason for this was that the amplitude modulation would be imparted to the 4.5-mc beat note if the two carrier levels became comparable in amplitude. When this modulation becomes great enough, the system is unable to eliminate it, and the audio output becomes distorted. This, essentially, is the main reason for the appearance of the 60-cycle buzz. At some point prior to the sound take-off point, the sound signal received enough amplitude modulation to affect appreciably the F-M detector.

The buzz frequency is 60 cycles because the amplitude of the synchronizing pulses are generally greater than any of the other video signal components and, if the F-M signal is amplitude modulated at all, it is by the 60-cycle vertical pulses or the 15,750-cycle horizontal sync pulses. Since a frequency of 15,750 cycles is inaudible to most people, only the 60-cycle buzz is noted.

Appreciable amplitude modulation may occur in any of the video-frequency amplifier stages following the video second detector. These video amplifiers usually operate with a fairly large grid swing and the amplification and transconductance of any of these stages may vary considerably due to the video and sync modulation. Any significant variation in amplification will produce amplitude modulation of the 4.5-mc beat note signal. Hence, proper operation of these stages is most important. Overloading due to a decrease in the emission of one of the tubes, a change in bias voltage, or a decrease in plate or screen grid voltages (due either to the power supply or to a change in the component parts values) will also cause the appearance of this

60-cycle buzz.   Thus, as a first step in eliminating this annoyance, check the screen, plate, and control grid voltages of the video amplifiers, and compare these with the values specified by the manufacturer.   A variation of more than 10 per cent can be significant.

Another cause for amplitude modulation of the 4.5-mc signal is overloading of the I.F. amplifiers.   When overloading occurs, the gain supplied the sound carrier varies with the video and sync modulation.   Here again check the tube voltages to determine whether the stage is operating as specified by the manufacturer.   The audio buzz may appear only when the contrast control is too far advanced, disappearing when the control is set at a lower video level.   In this case, insertion of an attenuation pad between the transmission line and the receiver will decrease the incoming signal strength to the point where advancing the contrast control as far as it will go will permit a good image to be obtained on the screen without resulting in the audio buzz.

Buzzing may also be due to improper alignment of the 4.5-mc take-off coil or of the F-M detector transformer.   In nearly all intercarrier receivers, some amplitude modulation is imparted to the 4.5-mc beat note.   When the sound system and the F-M detector transformer are properly aligned, the system is at its optimum operating condition for eliminating the effects of any small amount of amplitude modulation in the 4.5-mc signal.   Any deviation from this aligned condition will decrease the ability of the system to combat interference.   Hence, carefully check the frequency response and linearity of the discriminator transformer and the 4.5-mc pick-off coil.   Be sure to use as small a signal as possible when aligning the 4.5-mc amplifier and the succeeding F-M detector circuit, since strong signals cause the tubes to load down the tuning coils, altering their response characteristics.   In this respect, one large manufacturer whose sets were suffering from the 60-cycle buzz found that the ratio detector transformer needed replacement because of its poor balance.   Therefore carefully check both halves of the detector response curve to see that they match.

Finally, an incorrect setting of the local oscillator frequency, if sufficiently far from its proper frequency, will also produce the buzz. What happens is the shifting of the sound carrier along the I.F. response curve to a point where it receives more amplification than it should with this system. The setting of the oscillator frequency becomes increasingly critical as the amplification accorded the sound carrier in the I.F. system increases. In an Intercarrier receiver previously analyzed, the level of the sound carrier was 15.6 db below that of the video carrier, whereas a better value would have been 26 db. It is to be expected, therefore, that the setting of the oscillator frequency will be more critical in this certain set than in other receivers, which provides for a greater db difference between the two carriers in the I.F. system. It is interesting to note that while the first of these models did not contain a fine-tuning control, the more recent models do.

It is not always true that the appearance of the 60-cycle buzz indicates that the receiver is at fault. As indicated earlier, the station may be the offender. When there is more than one station locally, switching to these other stations will soon indicate where the difficulty lies. If the buzzing is evident with every station, it is safe to assume that the set is at fault. On the other hand, if the buzz is present only for one station, then the receiver is operating normally and the trouble arises at the transmitter. When a community is served by only one station, the best method is to observe whether other Intercarrier receivers exhibit the buzz. It is a good practice to have a monitor receiver on at all times, one which is kept in top operating condition. This will serve as a standard against which sets brought into the shop or those in the customer's homes can be compared.

CHAPTER 15

COLOR TELEVISION

Introduction. Emphasis throughout the preceding chapters has been directed entirely to the underlying principles of transmission and reception of so-called black-and-white images. In such a system, only black, white, or intermediate shades appear on the receiver viewing screen. The result is similar in all respects to the ordinary motion picture. Although the reproduced image is certainly far from being an exact duplicate of the full-colored scene originally televised at the studio, it does impart sufficient information to prove highly fascinating. The public has long been accustomed to this form of entertainment in the theater and now accepts the same type of image in a television receiver quite naturally. Undoubtedly black and white images will be standard in television receivers for several years at least. But nearly all television engineers are willing to concede that colored images are more desirable and will eventually replace the present system.

The receivers which are currently being manufactured are wholly for the reception of black-and-white images. Black-and-white television has been in commercial operation since the late thirties, and an extensive compilation of engineering data has been accumulated. Color television, on the other hand, has been almost completely a laboratory tool, designed and operated by engineers. It lacks sufficient field tests and, what is more important, it has not been placed in the hands of laymen to any appreciable extent. Hence, there is no mass of decisive results, such as exists for black and white television. It is because of these inadequacies that the F.C.C. is carefully reviewing all proposed color television systems before determining whether any

system thus far developed is suitable for commercial adoption. In the following pages a description will be given of the more important of these proposed color television systems.

Advantages of Colored Images. The appeal of color television lies in its greater naturalness. We live in an environment that contains many varieties of color, and it is only natural to desire the same life-like qualities in television. Color in an image heightens the contrast between elements, brightens the highlights, deepens the shadows, and appears to add a third dimension to an otherwise flat reproduction. It is interesting to note that more detail appears to be present in colored images containing fewer lines than corresponding black and white pictures. This is the actual testimony of lay observers. Only on close inspection does the increased line spacing become apparent. Perhaps many readers have noticed the remarkable differences between technicolor films and ordinary motion pictures. The same results are observed with television.

Color Television Systems. The proposed color television systems which are receiving the most consideration are those advanced by CBS (Columbia Broadcasting System), RCA, and CTI (Color Television, Incorporated). All are similar in the sense that all are sequential systems (i.e., the primary colors are picked up by the camera, are transmitted, and are viewed at the receivers one after another). They differ because in the CBS system one color, during one scanning, occupies an entire field; in the RCA system, the colors are presented in sequence in the form of dots; and in the CTI system, the colors are presented in sequence by lines. Because of these differences, the CBS system is referred to as a "field sequential" system, the RCA system as a "dot sequential" system and the CTI system as a "line sequential" system.

CBS SYSTEM

The phrase "field sequential" represents the heart of the CBS system. A thorough understanding of this phrase is essential to

a full understanding of color television. Let us start first with some elementary ideas on color and proceed from there.

Color, physicists tell us, is a property of light. If we take sunlight and pass it through a glass prism, a variety of colors are produced. White sunlight contains all colors but, owing to the limitations of the human eye and to the fact that the colors produced by the prism blend into each other, we can count only six fairly distinct colors (red, orange, yellow, green, blue, and violet). Upon closer inspection of this color distribution, numerous fine gradations may be distinguished, both between different colors and within any one color itself. For example, red, when it first becomes definitely distinguishable from its neighbor, orange, possesses a different shade than one finds at the other end of the red band where infrared wavelengths are approached.

It is a common experience with all persons who are not color blind to find that objects which possess one color under an electric light may assume a considerably different color when examined in the sunlight. The difference is due to the manner in which the color of a body is determined. The color of an object is a function of the wavelengths of the light which the body does not absorb. Thus, if we shine white light on a body and none of it is absorbed, we see a white body. However, if under the same white light the object appeared blue, then the object would be absorbing all the other components of white light and be reflecting blue.

To obtain the true color of an object, we must examine it under a light which contains all the wavelengths of the visible spectrum. Thus, a blue object appears much darker under an ordinary incandescent lamp than it does in sunlight. The reason is that the light of the lamp has an excess of red and a deficiency of blue. Since a blue object will reflect only blue rays, it will reflect less light under an incandescent lamp and give a darker appearance. In sunlight, blue and red are present to the same extent and the object assumes its proper color.

With objects that are transparent, the color is determined by the light which is transmitted through the object. Thus, in a

green piece of glass, green is permitted to pass through whereas the other colors are absorbed.

The Primary Colors. From among all the thousands of colored shades and tints marketed commercially, it has been discovered that three pure colors will essentially reproduce any color visible to the human eye. The colors required are red, green, and blue, and these have been named the primary colors. Because these colors are contained in the spectrum obtained by passing white light through a prism, they are also known as chromatic colors. Further, since the number is three, television engineers refer to our present system as a trichromatic system.

The Additive Process. To obtain a certain color, we can combine the three primary colors in definite proportions. Yellow may be derived from combinations of red and green; orange by other proportions of the same two colors; white by using all three, etc. We form, in other words, any color, shade, hue, or tint that is desired simply by changing the proportions of the primary colors. Because the result is determined by the addition of these colors, the term "additive" is frequently applied to this method. Another significance to the word "additive" is that by using the complements of the primary colors (blue-green, magenta, and yellow) we may evolve the same desired shades by a subtraction method. Subtraction of colors is used to a great extent in photography but has not been used in television.

In the CBS system, the light rays reaching the camera tube must first pass through a filter disc containing red, green, and blue filters. At any one instant, only one colored filter is in position in front of the camera tube, intercepting all of the light. Consider the green filter in position to intercept all the incoming light rays at any one moment. Then, theoretically, all but green light would be absorbed by the filter and only green permitted to reach the camera tube. This green light will activate the photosensitive cathode or mosaic plate, and electrons will be emitted. The electron beam then scans the surface and electrical pulses are generated only at those points affected by the incoming light The remainder of the scene containing other colors of light is

prevented from reaching the camera surface. All this, of course, at just one particular moment.

When the scanning beam reaches the bottom of the image, the next colored filter is swung into position. The beam, meanwhile, has been brought back to the top of the image, in readiness for the next scanning run. Suppose the filter is blue. Now, only this color of light reaches the photosensitive surface to be transformed into electrical charge and transmitted through the associated electrical circuits. The same process is repeated for the next, or red, filter. Hence we see that through the use of properly synchronized filters, any scene being televised is analyzed into the three primary colors. Actually, of course, the filters are never pure. A certain band of colors is permitted to pass through, rather than just one specific color alone.

Receiver Action. At the receiver the different signals derived from each scanning at the camera tube arrive in the same sequence in which they left the studio. In order to obtain an exact reproduced image, therefore, the same filter must be in place in front of the viewing screen when the signals are being traced. With the red filter in position, for example, the observer should receive light only from the red sections of the televised scene. The next instant, on the following scanning run, the next filter swings in front of the cathode-ray viewing screen; and so on for the third filter. The process continues to repeat itself for as long as the equipment is in use.

The observer, in viewing the resultant pattern, does not see three separate images, but merely one, formed by combining all three in his mind's eye. Image follows image in swift succession, and the action appears to flow smoothly.

Because of the importance of correctly synchronizing the rotation of the filter disc at the receiver with the disc at the transmitter, the receiver disc is driven by an induction motor. Synchronization is accomplished by sending a special sync pulse along with the signal to control the rotation of the induction motor. Through a form of magnetic braking, the disc starts at

the proper time and is always in position. Improper operation of the rotating disc would impart incorrect color values to the various sections of the image.

Color Filters. A color filter disc used in CBS transmitters and receivers is shown in Fig. 15.1. At the studio, either an Image Dissector or an Image Orthicon camera tube is used to receive the
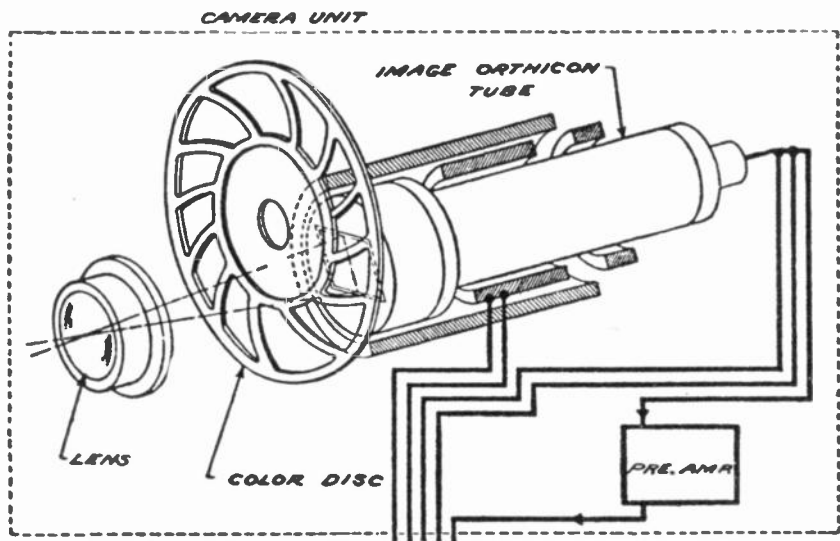
FIG. 15.1. The incoming light rays are filtered by the color disc before reaching the camera tube.

light rays from the scene being televised. See Fig. 15.2. The camera tubes differ slightly from those used in the black-and-white monochromatic cameras in that they are more sensitive to the three filter colors; otherwise they function in exactly the same manner as described in Chapter 1. A rotating color disc is placed in front of the camera tube, its speed synchronized with the action of the electron beam or scanning aperture within the camera tube. The color disc contains the three primary filters, red, blue, and green. The following explanation is indicative of the scanning sequence and its time interval within the camera tube and at the receiver.

Suppose that at any one instant the red filter is in front of the camera tube. During this time the red filter is permitting only light from the red-colored sections of the scene to reach the photosensitive cathode within the camera tube. With the red filter in position, the electron beam scans the mosaic and the

Courtesy CBS

FIG. 15.2. A color live pick-up camera using an Orthicon tube.

electrical pulses corresponding to the red-colored sections of the scene are formed and transmitted through the video amplifiers. The filter in front of the camera tube remains in this position throughout the entire scanning run of one field (202½ lines)* of the electron beam.

As soon as this scanning has been completed, the next filter, blue, moves into position. It remains there while the electron

* The CBS system uses 405 lines instead of the 525 lines used in the current black-and-white television system and therefore one field (odd or even lines) contains half of 405 lines or 202½ lines.

beam again scans the mosaic plate, this time across the 202½ lines not included in the previous run. The final filter, green, reaches the position in front of the viewing tube just as the electron beam is ready to start another scanning run, this time over the same 202½ lines that were first scanned when the red filter was in position. The electrical pulses from each of these scannings follow each other in succession through the various transmitter amplifiers.

Analyzing the scanning process, here is what we find. For the first field all the odd lines were scanned with the red filter in position. During the next field, the even lines were scanned with the blue filter in front of the camera tube. Finally, during the third field, the green filter intercepted all the light arriving at the mosaic. In this latter interval, the odd lines were again scanned. Thus each color was obtained at the mosaic, but only for half an image.

Summarizing this action:

Red filter—odd lines
Blue filter—even lines
Green filter—odd lines

As we continue scanning, the red filter should again be in position at the fourth field. This time the even lines are scanned. Hence we note that it took three runs from the initial run to obtain complete images, with even and odd lines scanned with the red filter in front of the tube. On the fifth scanning period or field, the blue filter intercepts the incoming light. The electron beam now passes over the odd lines. On the next or sixth run, the green filter will be in position and then even lines will be scanned. The complete sequence up to this point is given as follows:

Field	Filter	Lines Scanned
1st	red	odd
2nd	blue	even
3rd	green	odd
4th	red	even
5th	blue	odd
6th	green	even

To scan an image *completely* in all colors requires 6 scannings with the electron beam. From here the sequence starts all over again.

At the receiver (Fig. 15.3) the pulses arrive in the same order in which they were transmitted. As they are traced on the cathode-ray tube screen, the corresponding colored filter should be in position in front of the viewing screen. The observer, in viewing the image through the rotating filter, sees these colors as they appeared when they entered the camera tube. The lines
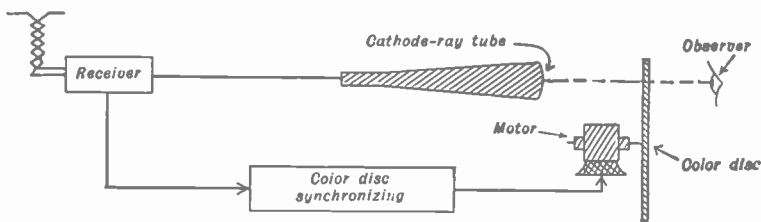
FIG. 15.3. CBS basic color receiver.

are traced so rapidly that each individual color sequence blends into the next, and only the completed image appears to be present. This is similar to the action with conventional television images. Here, too, the even and odd lines are scanned separately, but the observer integrates them both in his mind to form the resultant complete image.

Color Sequence Rates. For the satisfactory transmission of color images, the rate of sending each field (i.e., the scanning rate) is increased from $\frac{1}{60}$ of a second to $\frac{1}{144}$ of a second. This represents an increase in ratio of 2.4:1. To remain within the confines of a 6-mc bandwidth (actually 4.5 mc when the vestigial sidebands are removed), the number of scanning lines would have to be decreased and the value arrived at was 405. The necessity for this decrease in the number of lines rests in the fact that 4.5 mc is capable of providing a maximum of approximately 8,000,-000 changes in light intensity per second (after deducting synchronizing pulses and flyback time). These 8,000,000 light changes must be divided among: the number of picture elements

along each line (horizontal definition); the number of lines per picture (vertical definition); and the number of times each picture is scanned. If any one factor is increased, one or more of the others must be lowered.

Since $\frac{1}{144}$ of a second is required to scan one field, or one-half of 405 lines, $\frac{1}{72}$ of a second is needed for a complete picture area

TABLE 15.1. A table of the color sequences and their time duration in the CBS system of color television.

	Image scanned once with every color 1/48 sec. One frame					One field		
TIME DURATION	$\frac{1}{144}$ Sec.	$\frac{1}{144}$ Sec.	$\frac{1}{144}$ Sec.	$\frac{1}{144}$ Sec.	$\frac{1}{144}$ Sec.	$\frac{1}{144}$ Sec.	$\frac{1}{144}$ Sec.	$\frac{1}{144}$ Sec.
LINES IN IMAGE SCANNED	Odd	Even	Odd	Even	Odd	Even	Odd	Even	etc. ⟶
COLOR OF FILTER	Red	Blue	Green	Red	Blue	Green	Red	Blue

Complete color sequence ($\frac{1}{24}$ sec.)

or frame. Hence, we have 72 complete picture areas per second being transmitted from the studio. From the preceding discussion, we know that after $\frac{1}{72}$ of a second the image will have been scanned once by each of two colors. For example, for the first and second periods of the preceding scanning runs, red and blue would have been the colors used. To transmit a complete image (odd and even lines) in color, six scanning runs are necessary which would require a time of $6 \times \frac{1}{144}$ or $\frac{1}{24}$ of a second. The chart in Table 15.1 shows the sequence of the various fields, the time interval for each, and the associated color filter that should be in position in front of the receiver viewing screen and the studio camera.

The chart enables us to follow the color transmission sequence, noting the various time intervals required. To illustrate, we can see from the chart that it takes $\frac{1}{48}$ of a second to scan an image once with every color. To cover the even and the odd lines of each image with every color requires 6 scanning periods, of $\frac{1}{24}$ of a second. And, finally, for just one frame in $\frac{1}{72}$ of a second, we would have the odd lines scanned for one color, the even lines for another.

Reason for an Increased Scanning Rate. An increased scanning rate is necessary with the CBS system because of the structure of the system and the limitations of the modern fluorescent screen. From the previous analysis, we know that the three color fields follow each other on the screen. However, the images produced by each of these colors at the cathode-ray tube screen are not superimposed at the screen but in the viewer's mind. At the screen, the light from one color field must die out before the next field (and its associated filter) becomes active. With black and white television, that section of the image due to a certain field remains while the next successive field is traced out, this being possible since the two do not interfere with each other. Consequently, phosphors possessing slower decay characteristics can be used, substantially aiding the suppression of flicker. In the CBS color system, however, the light decay must be more rapid, and all traces of one field must be completely erased by the time the electron beam scans out the next field with a differently colored filter in position in front of the screen. Color breakup occurs unless this precaution is observed and this is the main reason for the use of a field repetition rate of 144.

A second reason for an increased scanning rate is that only one color is transmitted at a time, this same color not appearing again until the other two colors have been scanned. Suppose that a scene contained only one solid color over a large section of its area. Electrically speaking, this would mean that light reached the observer but once every $\frac{1}{48}$ of a second. The other two filters would be inactive in transmitting this one color. Signals once every $\frac{1}{48}$ of a second give only 48 frames per second. A small

amount of flicker becomes apparent. However, if the lower scanning rate of the black and white images were employed instead, then, under these conditions of one color, only 20 frames would be received per second. The flicker at this frequency proves too annoying to be tolerated. To minimize this effect, it was decided to increase the scanning rate.

One disadvantage arises from the use of a color filter disc. The light, as it passes through this disc, is reduced in amount by approximately 86 per cent. Stating this in another way we may say that the transmission efficiency of the filter is about 14 per cent. This reduction means that brighter images must be formed on the viewing screen if the image seen by the observer is to be comparable in brightness to that obtained with black and white images.

Color Disc Synchronization. In this color system, synchronization must be maintained not only for the elements of the image itself, but also for the color disc at the receiver. The synchronizing pulses for the color disc must accomplish two things: they must keep the disc rotating at the same speed as the disc in the studio camera; and they must insure that the proper colored filter is positioned in front of the screen at the correct instant. The latter control is necessary when first starting up or when changing stations, for chances are that in both cases the proper colored filter will not be in correct position. The synchronizing circuit automatically adjusts the position of the disc until it falls into line.

To obtain color disc speed synchronization, a circuit such as that shown in Fig. 15.4 could be employed. While this circuit may not be precisely the circuit used in the most recent CBS color television receivers, it will illustrate how disc synchronization can be obtained. A 144-cycle, saw-tooth wave is taken from the vertical deflecting system and fed into the grid of the left-hand triode of a 6FS tube. After this voltage is amplified, it is applied through a 0.1-μf condenser to the grid of the second triode of the 6FS. In addition, a 144-cycle voltage, developed in a generator mounted on the rotating shaft of the color disc, is also

FIG. 15.4. Color disc speed synchronizing circuit.

Courtesy I.R.E.

fed to this grid.   It is to be noted that a 144-cycle voltage will be obtained from the generator only when the disc is rotating at its proper speed.   If the speed falls below this value, the frequency of the generated voltage will decrease.   Conversely, if the disc is rotating at a higher speed, the generator voltage frequency will increase.

The two voltages—that coming from the generator and that from the first triode—will then mix in the second triode, and the resulting current is applied to a magnetic brake.   The brake, through this current variation, corrects the speed of the induction-type motor turning the color disc.   The current sent through the magnetic brake depends directly upon the difference between the frequency of the synchronizing pulses and the voltage developed by the generator mounted on the color disc shaft.   Thus speed synchronization is accomplished.   The circuit will not, however, correct the disc phasing if the wrong filter should be in front of the viewing screen.   For example, it would be very easy for the red or green filters to be at the screen when actually the blue filter should be there.   Starting the disc turning at the wrong moment could be responsible.   Changing to another station, where the color synchronization is different, could be another reason.   Whatever the cause, the disc is improperly phased and the foregoing circuit in its present form is unable to rectify the condition.

To provide the receiver with some positive means of identifying one color from the others, a series of square pulses are inserted into the signal immediately preceding each red field. These pulses, which have a frequency four times greater than the horizontal synchronizing pulses, are inserted directly after the vertical synchronizing pulses so that no interference in vertical synchronization is incurred.   Horizontal synchronization is maintained because every fourth leading edge of the additional series of pulses will trigger the horizontal oscillator at the correct time. Thus, the remainder of the receiver operates normally.   Synchronizing signals for the other two colors are unchanged.   See Fig. 15.5.

In the receiver, the 117-kc (approx.) identifying pulse is separated from the other pulses by a tuned circuit (see L_1 and C_1, Fig. 15.6). This 117-kc signal is then fed to the grid of a pentode while, at the same time, a mechanical rotating cam (contractor)
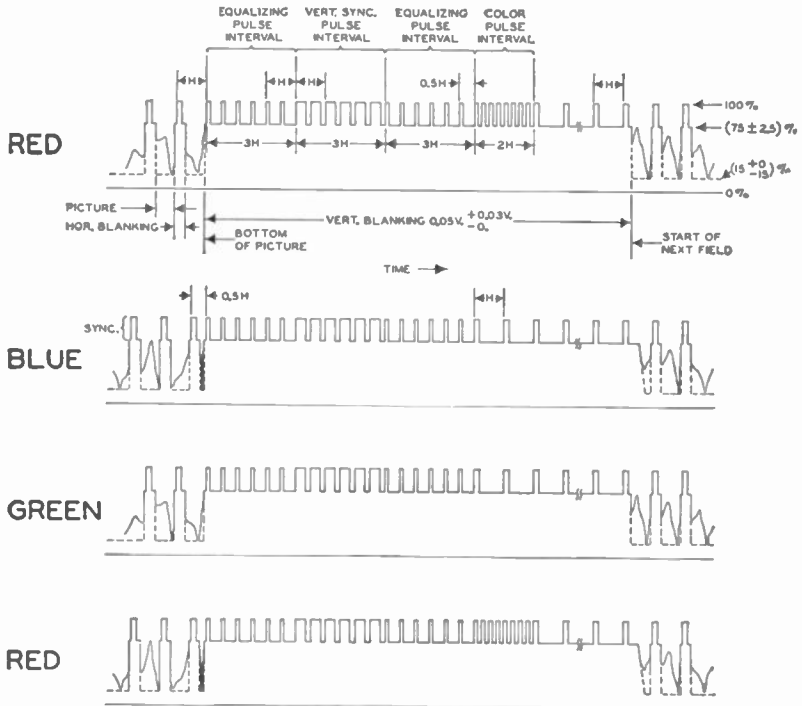
FIG. 15.5. Synchronizing pulses in the CBS color system showing the portion of the color identifying signal in the red field.

alters the voltages on the screen grid at the rate of 48 cycles per second. Electrically, we have the effect of mixing the 117-kc pulses with a 48-cycle pulse within the tube. The result of the mixing, for both the in-phase and out-of-phase conditions, is indicated in the diagram. In-phase voltage is desired, for this represents normal operation. Out-of-phase voltage results when the color disc is not presenting the proper filter to the fluorescent viewing screen.
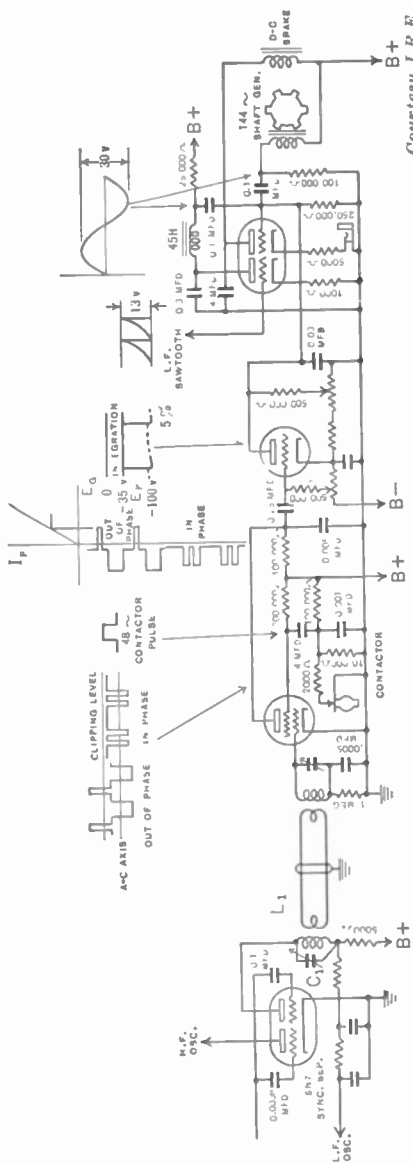
FIG. 15.6. A color-disc synchronizing and phasing circuit.

Courtesy I.R.E.

Now let us see how this combined voltage is used to correct the phase of the rotating color disc. The combined voltage from the pentode tube is fed through a triode clipper tube and integrator circuit to the grid of the double triode which controls the brake on the induction motor. Now we have these added two tubes which also have an effect on the last triode. When the 117-kc and 48-cycle pulses are in phase, they permit the brake circuit to function normally, as described; if they are out of phase, the brake circuit becomes inoperative, and the speed of the color disc changes until it falls into line.

To start or stop the brake circuit, the plate current from the clipper tube is made to flow through the grid resistor of the brake triode. If the incoming pulses to the clipper are in phase, no current flows in this tube and the brake triode is unaffected. However, if the pulses are out of phase, current does flow and the drop across the 250,000-ohm grid resistor of the brake triode develops enough negative grid voltage to cut off the tube. There is now no control of d-c brake current, and the color disc speed is not regulated. Because the plate of the clipper is directly attached to the grid of the braking tube, no positive voltage is permissible. Instead, the cathode of the clipper tube is made approximately 100 volts negative, equivalent to making the plate positive with respect to the cathode.

One final word of explanation about the circuit. The mechanical contractor that varies the positive screen voltage of the pentode tube is mounted on the shaft of the rotating color disc. It has two extended sections which press against a contact and insert a 2,000-ohm resistor in the circuit. For the remainder of the revolutions, this 2,000-ohm resistor is out of the circuit. Through the alternate insertion and removal of the resistor, we are able to alter the screen voltage of the tube.

The screen voltage is varied at a rate of 48 times per second (equivalent to a 48-cycle pulse) because of the color scanning sequence. Each color is at the screen for $\frac{1}{144}$ of a second. Then, for the two succeeding periods (each $\frac{1}{144}$ of a second), one of the other two colors is functioning. Thus any one color, say red,

would be at the screen once in every three periods, once in every $\frac{3}{144}$ of a second, or $\frac{1}{48}$ of a second. If the color disc is properly phased, the 117-kc indicating pulses and the 48-cycle pulses should arrive at the mixing pentode at the same time. On the other hand, if the color disc is not properly phased, the 48-cycle pulse will act at the pentode during one of the other color fields and hence be out of phase with the 117-kc synchronizing pulses. At the color disc, the contractor is mounted so that it will alter the pentode screen voltage in synchronism with the red filter at the screen.

A natural question pertains to the action of a color television receiver when the color disc is disconnected. What type of image would appear now? The observed image would be black and white. An apparent loss in detail might be imagined, but actually both contain the same number of lines. The apparent loss is psychological, due in part to the greater variation in hues, shades, and tints inherent in colored images. When they are removed and an identical black and white image substituted, there appears to be a corresponding loss in detail. Aside from this, however, either type of image may be received with a color television set.

An experimental color television receiver is shown in Fig. 15.7. Notice that the screen appears almost as dark as the mahogany cabinet itself, due to the intervening color filter. Any light entering the filter is greatly reduced by absorption at the disc, and the amount of reflected light is small.

RCA System

In the RCA color television system, the same sequential principle of sending one color after the other is still maintained. However, in the present system, each color is not presented continuously in a series of fields, as in the CBS system, but in a series of dots or pulses.

To start at the studio, the scene to be televised is picked up by a color camera containing three camera tubes. The light entering the camera is made to pass through special mirrors (known

technically as dichroic mirrors) which possess the property of being able to reflect one color but pass all others. Thus, a red dichroic mirror will reflect red light, but permit all other colored light to pass through. In the color camera, red and blue dichroic
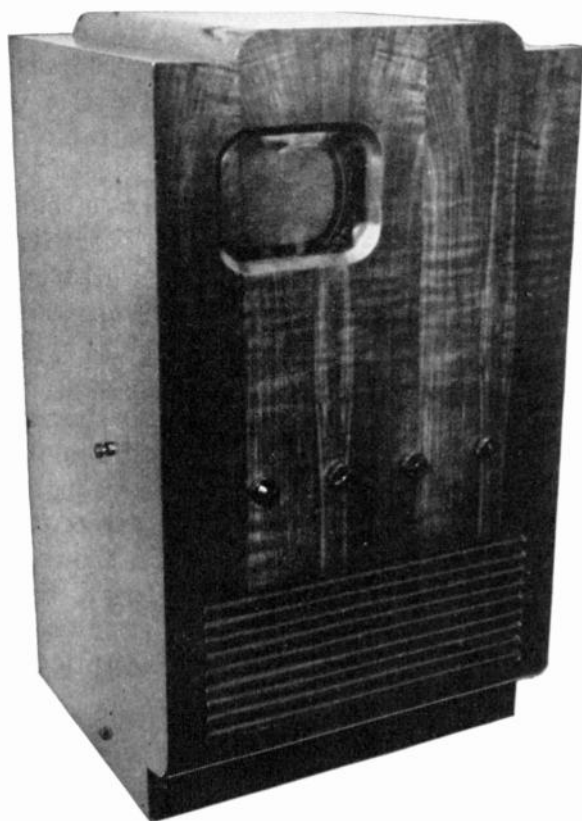
FIG. 15.7.   An experimental color television receiver.

mirrors are arranged in the manner shown in Fig. 15.8. The portion of the incoming light which is red is reflected by the red dichroic mirror (and a second plain mirror) into one camera tube. The blue portion of the incoming light is reflected by the blue dichroic mirror (and a second ordinary mirror) into another camera tube. What remains of the light after passage through

these two mirrors—green—is received by the third camera tube. In similar manner, every bit of light reaching the camera is sorted into its primary color components.
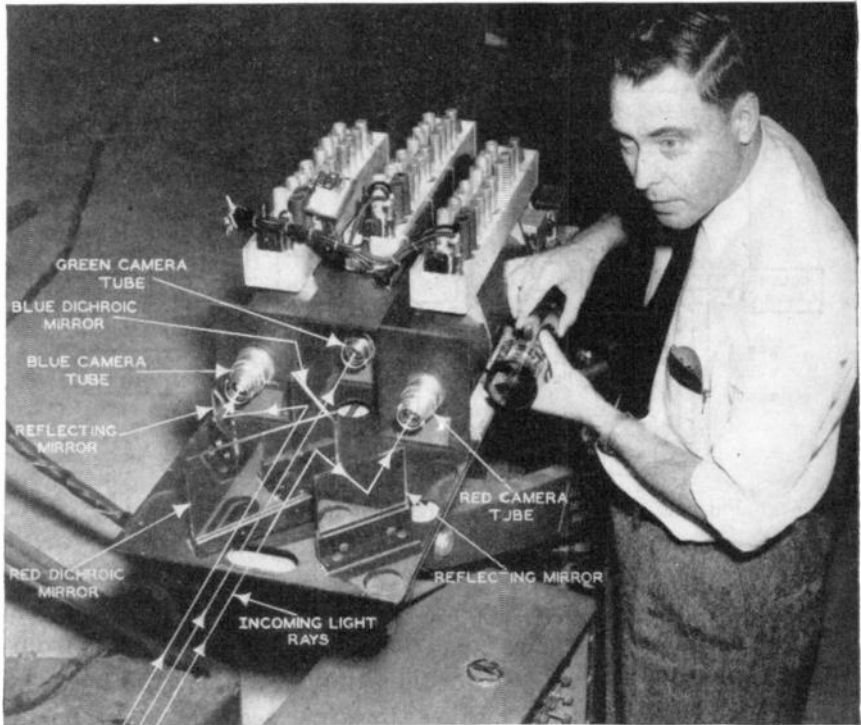
FIG. 15.8. RCA's new color television camera with cover removed. In the center foreground are two dichroic mirrors which allow green rays to pass through to the lens of the center Image Orthicon tube, while reflecting red rays via a silvered mirror to the right-hand tube, and blue rays by another mirror to the tube on the left.

The output from each camera is now transferred through separate low-pass filters (which pass only video signals having frequencies up to 2 mc) to an electronic sampling tube. See Fig. 15.9. At the same time this is happening, portions of the three color signals from the cameras are combined in electronic Adder No. 2 and passed through a high-pass filter where video fre-

quencies up to 2 mc are suppressed and those from 2 to 4 mc are transmitted. This division of color signals is known as a mixed-highs system. Why this particular method was chosen will be indicated presently.

The mixed-high frequencies are fed to Adder No. 1, which is
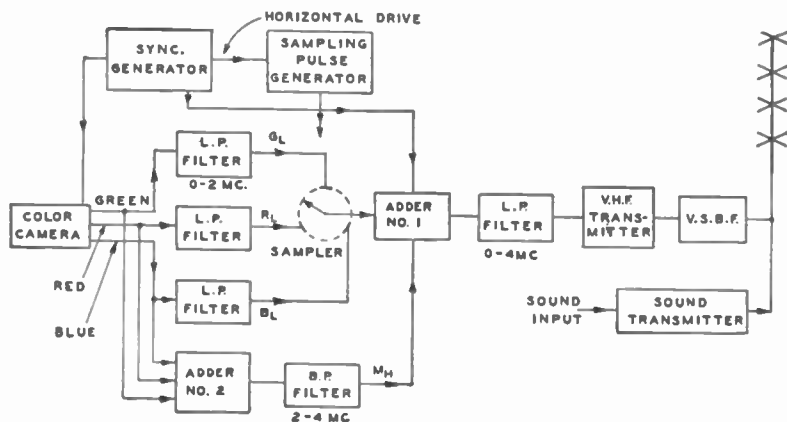
Fig. 15.9. Block diagram of the color television transmitter.

also receiving signals from the electronic sampler. However, while the mixed-high frequencies are arriving in a continuous stream, the low frequencies are arriving in the form of pulses from the electronic sampler. Within the sampler, an electron beam is revolving at a rate of 3.8 million times per second.* The beam thus comes in contact with the color signal from each camera 3.8 million times in each second providing Adder No. 1 with this many samples from each color, one sample arriving every 0.263 microsecond ($0.263 = \frac{1}{3.8}$). Fig. 15.10 shows the output of the sampler for a short period of time. In Fig. 15.10A the output of the sampler for the green signal is shown. A green sample appears every 0.263 microsecond.

At a time 0.0877 microsecond after the green sample, a sample is taken of the voltage from the camera receiving the red rays of

* The sampler need not necessarily be this type of tube. However, to aid in understanding the operation of this circuit, the above tube is assumed to be used.

light. This time delay is one third of the time between successive green samples. The red samples themselves, however, are spaced 0.263 microsecond apart. Blue samples are taken at the same
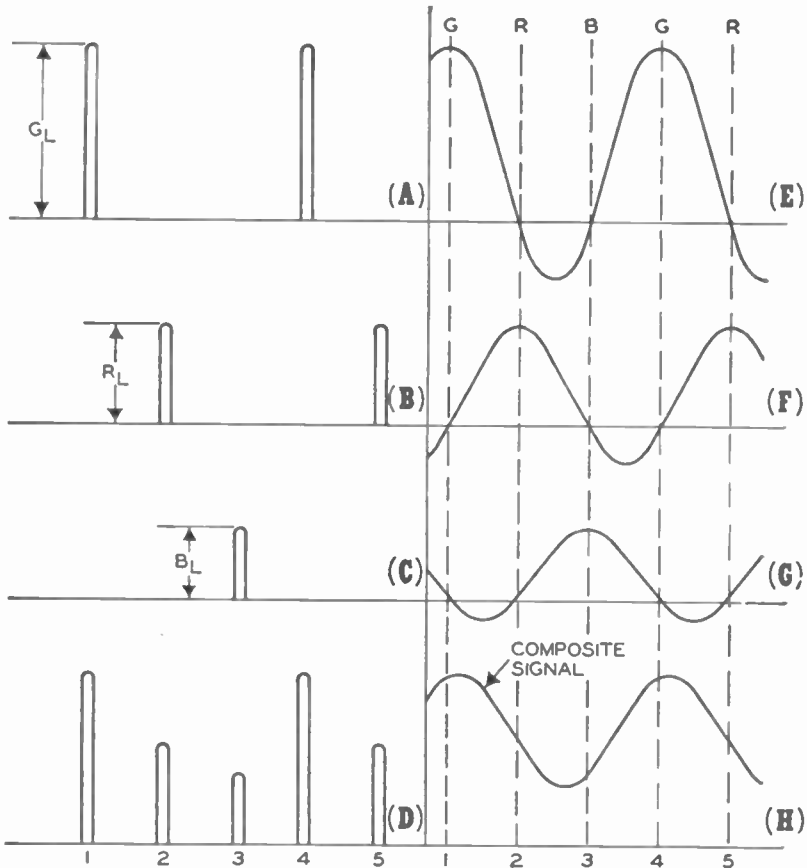
FIG. 15.10. The manner in which the sampling system at the transmitting end operates.

rate as the red and green samples and appear 0.0877 microsecond after a red pulse of voltage. The composite sequence of these voltage pulses is shown in Fig. 15.10D. For any particular scene, the strength of each pulse would depend upon the amount and shading of the color rays reaching the camera.

The pulses at the output of the sampler tube are fed to Adder No. 1 where they are combined with the mixed-highs signal. At this point standard synchronizing signals from a synchronizing generator are also added. The signals are applied now to a low-pass filter (passing frequencies from 0–4 mc) where the pulses of voltage from the electronic sampler are smoothed out. Each of the smoothed-out pulses now becomes a sine wave having a frequency of 3.8 mc and a d-c component which is the average of the pulse sample. See Fig. 15.10E, F, and G. It should be noted in these sine waves that, when any one color signal reaches its maximum value, the other two color signals are passing through zero. This is important, for it insures that, when the signals are again sampled at the receiver, only one color will be obtained during each sampling.

Although the three sine waves are shown separately in Fig. 15.10E, F, and G, they actually combine in the low-pass filter to form the composite signal shown in Fig. 15.10H. It is this composite signal which combines with the mixed-highs signal and the various standard synchronizing pulses to form the complete video signal. The remainder of the transmitter now follows the usual sequence of amplifying this voltage, impressing it onto an R.F. carrier and sending it out over the air to the receiver. These remaining circuits are similar to those employed in black-and-white television transmitters.

Color Television Reception. The color television signal at the receiver, together with the accompanying sound, is received and amplified by a series of stages which, up to the second detector, are similar to the same stages found in present black-and-white television receivers. Thus, there is an R.F. amplifier, a mixer, a high-frequency local oscillator, a series of video I.F. stages, and a conventional second detector. See Fig. 15.11. The same is true of the audio system with its I.F. amplifiers, discriminator, audio amplifiers, and speaker.

The video signal at the output of the second detector consists of the composite color signal, as shown previously in Fig. 15.10H, plus the mixed-high voltages, plus the various synchronizing

pulses. (Inclusion of the mixed-high waveforms with the low-frequency composite signal would be difficult to indicate and hence is not shown.) Part of the signal is applied to a sync separator stage where the sync pulses are divorced from the rest of the signal and then fed to deflecting circuits where they lock-in the sweep oscillators. This, again, does not differ from conventional black-and-white television receiver practice.
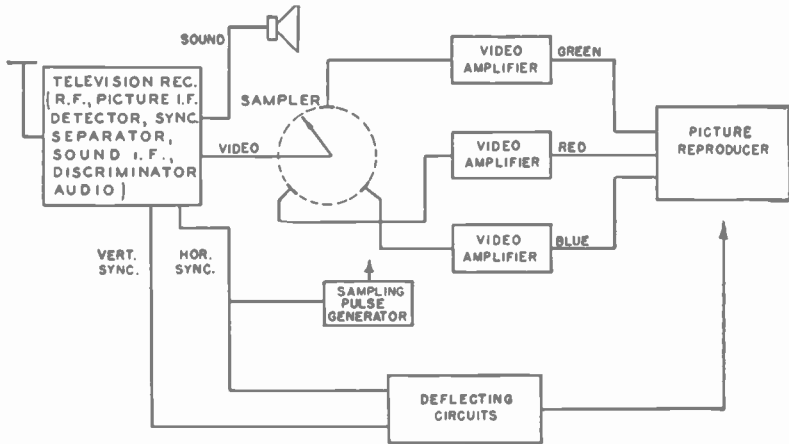
FIG. 15.11. Block diagram of a color television receiver.

The signal from the video second detector is fed to a sampler tube which is similar to the sampler tube employed at the transmitter. Every 0.0877 microsecond, the sampler tube samples the composite signal, producing the narrow pulses shown in Fig. 15.12. The amplitude of each sample will depend upon the strength of the composite wave at that particular instant.

The sampler sends these pulses to each of the video amplifiers and its associated cathode-ray tube in succession. Thus, looking at Fig. 15.12A, the green pulse (taken at a time when the red and blue low-frequency signals are passing through zero, as previously explained) goes to the video amplifier system which is associated with the cathode-ray tube emitting green light; the red pulse goes to the red video amplifier system; and the blue pulse goes to the blue video system. The sequence then repeats

itself, going from green, to red, to blue. Each pulse appears
0.0877 microsecond after the previous pulse; however, for any
one color, pulses appear every 0.263 microsecond. To insure that
the sampler tube sends the series of pulses to the various video
systems in proper sequence, the trailing edge of the horizontal
sync pulses is used to drive both receiver and transmitter sampler
tubes.
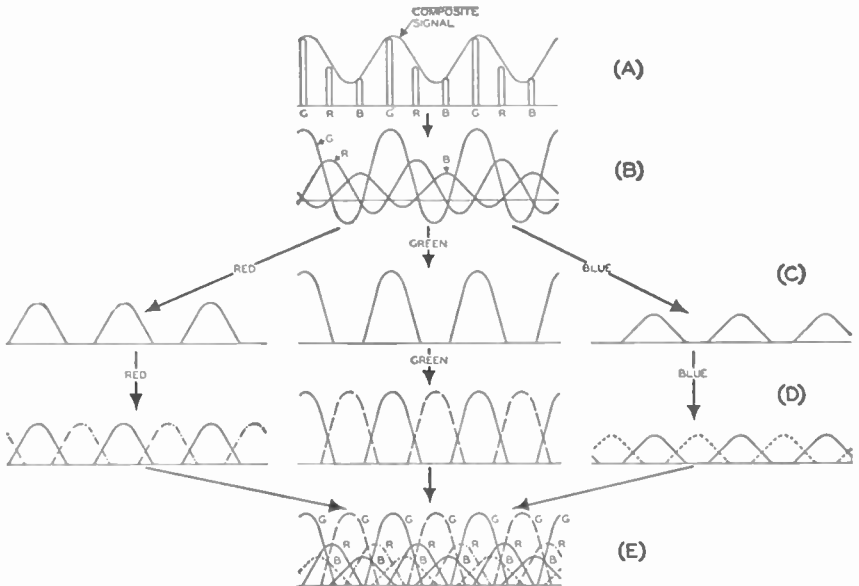
FIG. 15.12. The functioning of the sampling system at the receiving end.

When the three colored pulses pass through their respective
video amplifier systems, each is smoothed out to the sine-wave
form shown in Fig. 15.12B. Note that while all three signals are
shown together in this illustration, only the green signal goes to
the green cathode-ray tube, only the red signal goes to the red
cathode-ray tube, and only the blue signal reaches the blue cath-
ode-ray tube. The image that is produced on each cathode-ray
tube will thus depend upon how much of the scene being sent
by the transmitter contains that particular color. If, for example,
there is a considerable amount of red detail in the scene, with

little blue or green, then the amount of detail visible on each separate image tube will vary accordingly. The light output of each tube is then combined to form the complete picture, to provide the true color shading of the original scene.

In the receiver of Fig. 15.11, the total signal consisting of the sampled low frequency signals of each color plus the mixed-highs has been inserted in the receiver sampler. Hence, when this unit samples portions of the incoming signal, it obtains for each pulse the proper low frequencies for that color plus a combination of the mixed-highs.

Consider carefully what happens to the high frequencies. At the transmitter the high frequency components of each color were combined, first with each other, and then with the low frequency composite signal obtained at the output of the electronic sampler. At the receiver, when the electronic sampler samples the signal, it will obtain not only the particular color wanted, blue, green, or red, but, in addition, it will also receive a combination of the high frequency components of all three colors at the same time. Thus each cathode-ray tube will have its own low frequency color plus essentially the same highs or fine detail. Since each image tube receives the same amount of fine detail, the combination of these three colors in the final image will produce either white, black, or intermediate shades of gray. This is because the combination of the three primary colors, in equal amount, will produce white or its equivalent. Thus, in the foregoing system, the final detail of the image will appear in monochrome, and the larger detail in color.

The "mixed-highs" system is similar to the process of color rotogravure used in printing newspapers and periodicals. To print a color photo, the three primary colors are used, with the addition of a fourth plate which adds the fine detail in black, white, and the intermediate shades of gray to the picture formed by the three primary colors. It has been found that through the use of this fourth plate, the depth, emphasis, and richness of the picture are enhanced. The same results are observed in television.

Another advantage gained by using mixed-highs is due to the poor frequency response of some types of film scanning devices. Some of these scanning devices have an inherently poor high frequency response and it is often necessary to provide high frequency peaking in these circuits. The peaking increases the relative value of the high frequency components, but, at the same time, also raises the level of the noise voltages present in the signal. When the entire 4-mc video signal is sampled, the 3.8-mc sampling frequency beats with the high frequency noise to produce a low frequency component and beats with the low frequency noise to produce a high frequency component. The exchange of noise components would be even if it were not for the fact that the high frequency noise components were peaked before the sampling process. The result is that, after the sampling process, the low frequency noise components are accentuated, giving the image a course-grain appearance.

However, by using the mixed-highs principle, the high frequency components do not pass through the sampler at the transmitter and this annoyance is avoided.

Picture Dot Interlacing and Scanning Sequence. In Fig. 15.12B, the sine waves corresponding to each of the pulse voltages are shown. Because of the d-c component of the pulses, these sine waves extend more above the zero line than below. If we assume that the cathode-ray tube is cut off by the negative portion of these voltages, then only that portion of the sine wave above the zero line is effective in changing the intensity of the cathode-ray tube scanning beam and, consequently, the intensity of the light generated at the screen. We could then disregard the lower portion of the smoothed-out sine wave and consider only the upper portion of the wave. This is done for each of the waves separately in Fig. 15.12C. If we consider the green signal only, it can be seen that a single line scan lays down a series of green dots on its screen. Since the fundamental frequency of these waves or pulses is 3.8 mc, the dots occur at a rate of 3.8 million times per second. On the other two image tubes, the same dot sequence would be occurring, with the dots on these

tubes appearing in the space between the green dots on its tube and with a considerable overlapping of dots. This overlapping can be seen in Fig. 15.12B.

During the next scanning of the *same* line ($\frac{1}{30}$ of a second later), the dots for any color, say, green, are made to fall in between the green dots laid down during the previous scanning of this line. The same, of course, is true of the red and the blue dots. Hence, for any two successive scannings of the same line, all the space is filled up. This is shown in Fig. 15.12D. The solid lines represent the dot sequence during one scanning and the dashed line shows the dot sequence during the second scanning. It is seen that the line would be completely covered with colored dots. When we superimpose the light output of all three tubes, every line is completely filled with picture dots of all three colors. This is shown in Fig. 15.12E.

The dot displacement during the second scanning of the same lines is due to the operation of the electronic sampling circuit. The samples for each scanning line are timed with respect to the horizontal synchronizing pulse for that line.   However, for alternate line scans of the same line, the timing of the sampling pulse is such that samples of any one color are taken at a point midway between samples of the same color for the previous scanning. The same is true for alternate line scans.   In each case, the second samples are taken midway between the first samples resulting in dot interlacing.

Fig. 15.13 brings out more clearly the scanning and interlace pattern employed in the RCA color television system.   Each square represents a dot. Because of the overlapping of dots, each square should be approximately 50 per cent longer than shown.

During the first scanning field, the odd lines are scanned in order. Colored dots are laid down in order along line 1 as shown. Line 3 is scanned next, with the dots displaced so that the dot for any one color falls at a point midway between the same color dots in line 1.   Line 5 is the same as line 1 and line 7 is the same as line 3, etc.   In this manner all of the odd lines of the image are scanned.

During the second field, the even lines are scanned, with the dot pattern for lines 2, 4 and 6 as shown in Fig. 15.13. During the third field, the odd lines are scanned again with the dot displace-
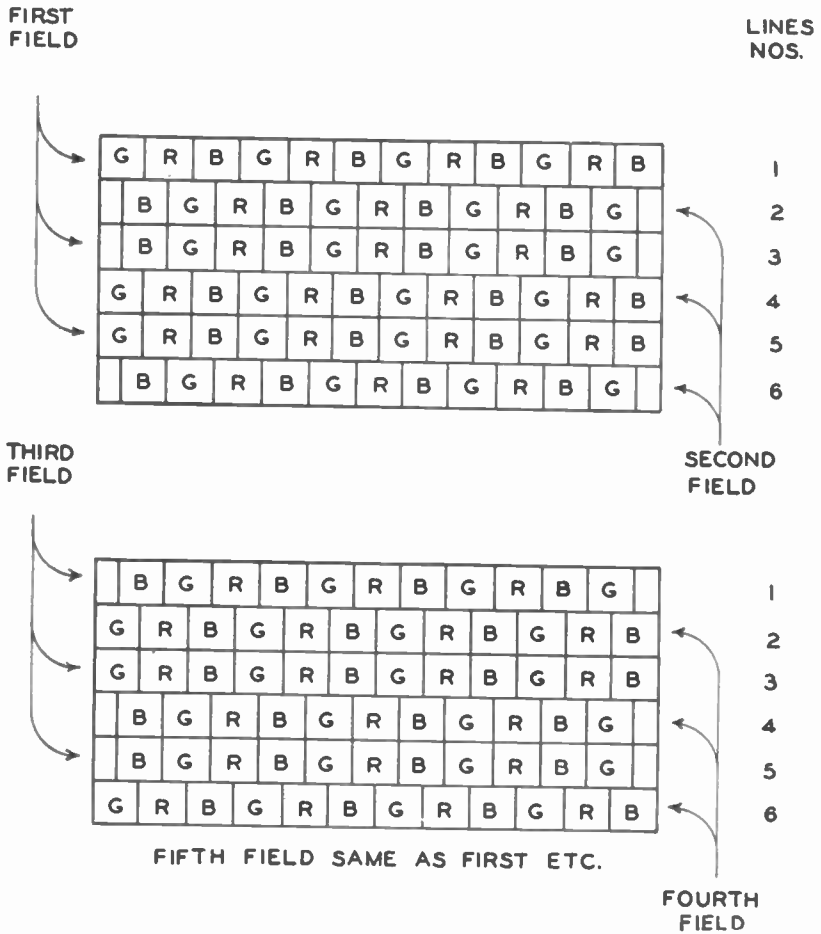
Fig. 15.13. The picture dot interlacing and scanning sequence.

ment such that the dots for any one color falling midway between the same color dots laid down during the previous scanning run of the same line (in this instance, this is during the first scanning field). During the fourth field, the even lines are scanned again

with a similar dot displacement. Each field scanning requires ⅟₆₀ of a second, retaining the same field (and line) frequency currently used in black-and-white sets. To obtain a complete color picture requires 4 field scannings, giving us 15 complete color pictures per second.

RECEPTION WITH BLACK-AND-WHITE RECEIVERS

The signal which is radiated by the color transmitter consists of a composite voltage obtained by combining the low frequency components of each color with the mixed-highs components. The total signal, therefore, possesses all of the information needed to develop a black-and-white image with full resolution. When a black-and-white receiver is tuned to a color broadcast station, the total signal, after the video second detector, is passed through several video amplifiers and then applied to a conventional cathode-ray tube. It is true that there is a 3.8-mc sine wave superimposed on the picture signal as a result of the 3.8-mc sampling frequency at the transmitter. This will produce a dot pattern on the black-and-white image tube in highly colored areas, but the dots are not noticeable at normal viewing distances.

When a color receiver is tuned to a television broadcast station transmitting a black-and-white signal, the picture will appear in black and white with full resolution on the color receiver screen. The successive pulses delivered to the three image tubes will all be of equal magnitude, and, hence, will produce varying intensities of white—which represents a normal black-and-white picture.

COLOR RECEIVERS AND COLOR CONVERTERS

A color receiver requires three image tubes and some method of combining their images to produce the signal final color picture which is viewed by the observer. Fig. 15.14 illustrates one method of combining these tubes using cathode-ray tubes which are similar electrically to present image tubes except that the phosphorescent screen of each is designed to produce either a red,

green, or blue image. These images are then viewed through two dichroic mirrors, the red mirror reflects the light rays streaming from the red cathode-ray tube screen, while permitting the green
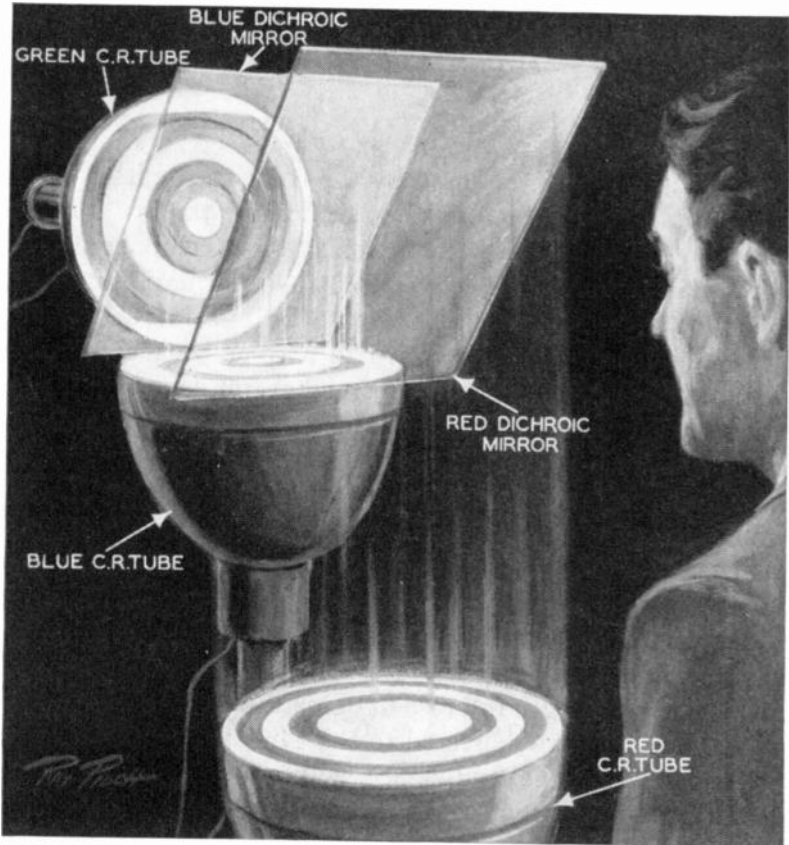
FIG. 15.14. One method of combining three appropriately colored cathode-ray tubes to produce a colored image.

and blue rays to pass. The blue dichroic mirror reflects the blue rays, but permits the green (and all other) rays to pass. An observer, standing in front of the first mirror, thus sees only the combined color pattern of all three tubes.

It is not necessary to restrict the tube arrangement to direct-viewing tubes. Projection systems are also perfectly feasible and

Fig. 15.15 shows the manner in which the projection beams can be combined to form the final enlarged color image.

An important feature of this system is its compatibility with television receivers already on the market. From an examina-
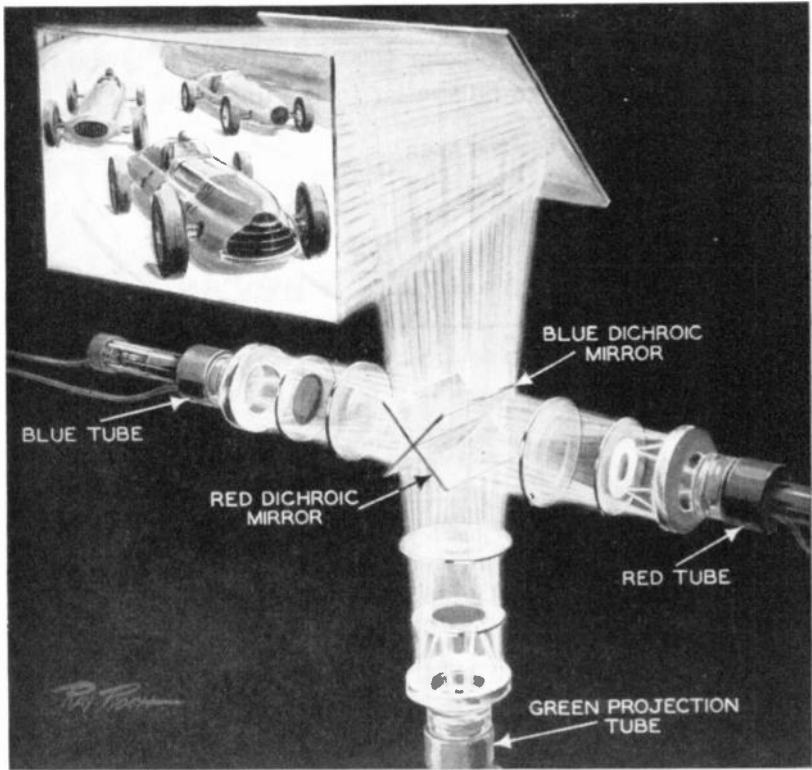
FIG. 15.15. A color television projection system.

tion of Fig. 15.11 it can be seen that to convert a current black-and-white receiver to receive color transmissions with the foregoing system requires the addition of color sampling circuits and three color image tubes. Just how extensive something like this may be is difficult to foretell at this time since there is a very distinct possibility that a single cathode-ray tube using three separate guns will take the place of the three-color image tubes.

Such a tube has been developed experimentally both in this country and in England but has never been manufactured in any quantity.

Two-Color System. It is claimed by RCA that color transmission can be received with a simplified receiver using two colors instead of three. The two colors are blue-green and green-red. A block diagram of a two-color television receiver is shown in Fig. 15.16. It is seen to be similar to the diagram of Fig. 15.11
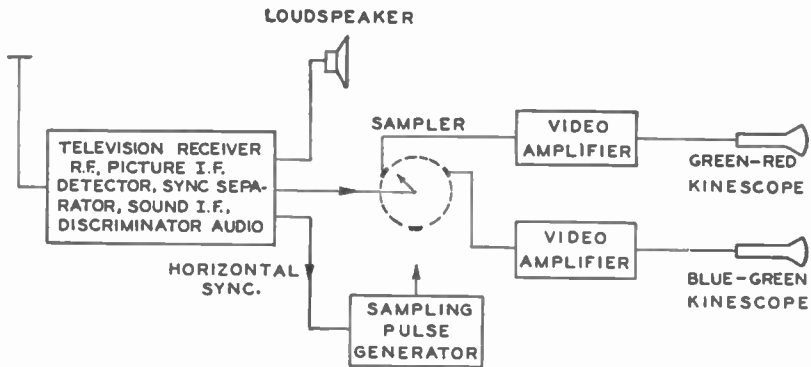
FIG. 15.16. A block diagram of a color television receiver using only two colors.

except that now only two image tubes and two video amplifier systems are required. The sampling method remains essentially the same, although the times when samples are taken of the composite wave are altered.

In Fig. 15.10, the sine waves due to each of the color pulses are shown separately, together with the composite signal. At time 1, the green sine wave is at a maximum and the other two color signals are passing through zero. Hence, if the receiver sampler takes a sample of the composite wave at this instant, it will obtain a pulse of voltage which is governed only by the green signal. This pulse, if the system is operating properly will go into the video amplifiers feeding the green image tube.

By the same reasoning, a pulse sample taken at time 2 will represent the red signal and a pulse sample at time 3 will represent the blue signal. At time 4, the sequence starts over again.

For the two-color television receiver, the same signals as in Fig. 15.10 are shown in Fig. 15.17; however, the instants when samples are taken have now been altered. The composite signal is sampled for blue-green at a time when both blue and green are in a positive direction. This is indicated by the line marked B-G. Similarly, the composite signal is sampled for green-red at a time when both of these components are in a positive direction. This is indicated by the line marked G-R. No sample is taken at the third point.

The two samples are fed to separate video amplifiers and cathode-ray tubes and the final image is formed by combining the light output of both screens. A color converter using a two-color picture-reproducing system is shown in Fig. 15.18. To keep the cost of this color converter as low as possible, the black-and-white image tube already in the receiver is used with a suitable filter placed in front of it. All we require then is a sampling circuit and a second image tube and a suit-

Fig. 15.17. Receiver sampling positions for the two-color system.

able dichroic mirror. If the two-color system is to be used for an inexpensive color television receiver, the two image tubes would possess the proper color phosphors and filters would not be needed.
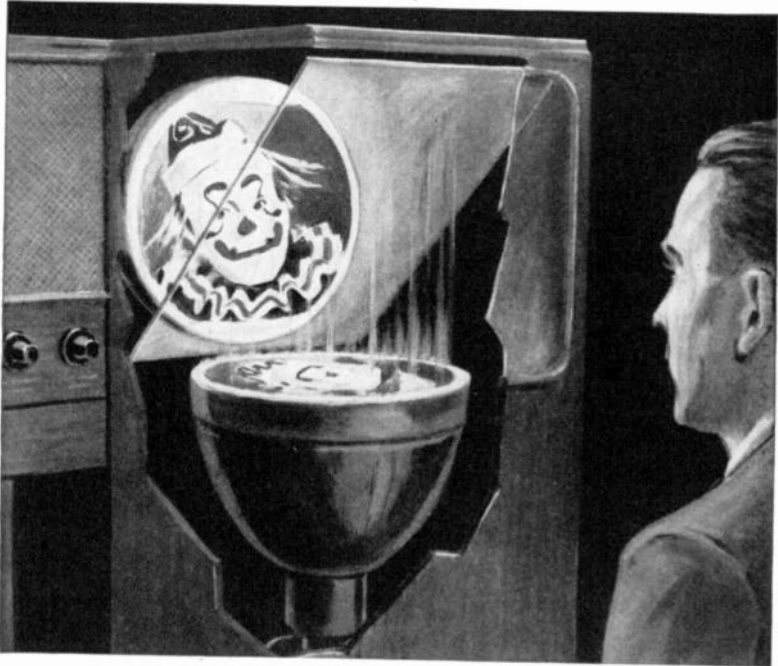
Fig. 15.18. A two-color picture reproducing system.

CTI System

The third proposed color television system is a line sequential system developed by George E. Sleeper, Jr., of Color Television, Incorporated. In this system, the scene to be televisd is focused upon an image orthicon camera tube by means of an appropriate optical system to form three separate color images, side by side. See Fig. 15.19. Each of the lens systems contains filters which permit light of only one primary color (either red, blue, or green) to pass through, and consequently the three color images formed side by side on the camera tube photosensitive surface represent the three primary color components of the televised scene.

The scanning beam in the camera tube starts at the edge of the left-hand color image (shown as red in Fig. 15.19 although it may be any one of the three primary colors) and progressively

moves across the top line of this image. The video signal obtained from this scanning contains all of the information that this section of the red image received.

When the beam reaches the right-hand edge of the red image, it does not immediately commence scanning of the green image. Instead, the two images are separated by a small distance and, as the beam travels across this space, no video signal is generated.
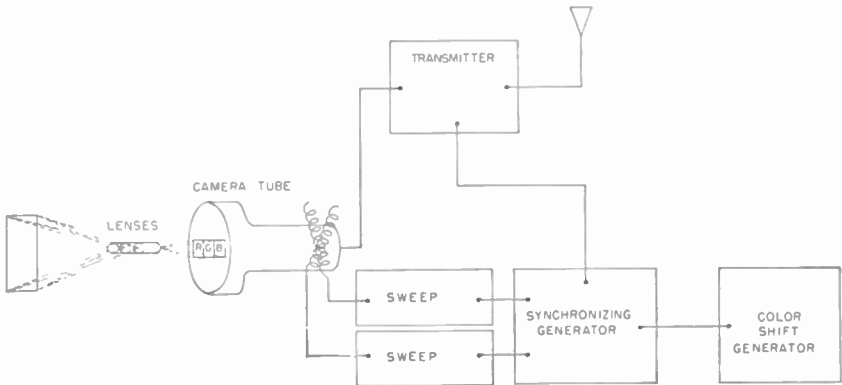
FIG. 15.19. A block diagram of the color television transmitter used in the CTI system.

erated. This is done purposely in order that a 15,750-cycle horizontal sync pulse can be injected into the transmitted signal at this point (plus the usual blanking pulse upon which the sync pulse is mounted).

To this point, then, we have scanned the first line of the red image. The beam, however, is also being subjected to a downward force (the vertical deflection voltage) and hence when it enters the green image, it is in position to scan line 3 of this field. This, of course, is similar to the interlaced scanning employed currently in black-and-white television. The scanning beam now scans line 3 of the green image, sending out a continuous stream of video signals until the right-hand edge of this image is reached. Again, a horizontal sync pulse is injected into the signal while the beam is traversing the distance which separates the green and blue images.

When the blue image is reached, the beam is in position to scan line 5 and this it does. At the completion of the scanning of line 5 in the blue area, the beam is quickly brought back to the left-hand edge of the red image where line 7 may be scanned. See Fig. 15.20. During this retrace interval, another horizontal sync pulse is inserted into the signal being transmitted. The sequence therefore repeats itself, with line 7 scanned in red, line 9 in green, line 11 in blue, line 13 in red, etc. Between any two
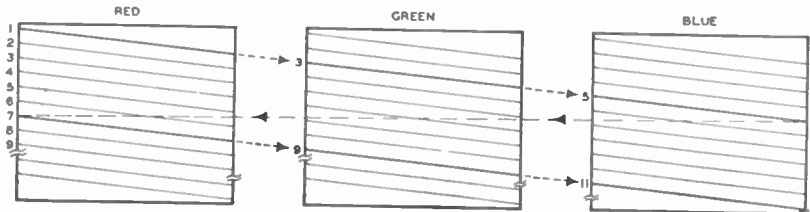
FIG. 15.20. The scanning sequence in the color television camera tube. The odd lines are scanned during one run and the even lines during the next run. The sequence then repeats itself.

color images, 15.750-cycle horizontal sync pulses (with appropriate blanking pulses) are inserted into the signal.

Thus, from this scanning of the three color images we obtain three sets of video signals with three sync pulses. An ordinary black-and-white television set, receiving these signals, would trace out the first received signal (obtained here from the red image) on line 1 (in black-and-white, of course). At the end of line 1, the horizontal sync pulse which was injected into the signal at the transmitter would cause the beam to retrace to line 3. Now the video information obtained from the green area would be traced out. At the end of this line the next sync pulse causes the beam to retrace to line 5 where the video information from the first line of the blue image is traced out. The sequence continues, with line 7 receiving its video detail from the red image, line 9 its detail from the green image, and line 11 its detail from the blue image, etc. At the end of $262\frac{1}{2}$ lines (one field), the beam would retrace upward to the top of the

image and start on the even lines of field II (starting with line 2). At the end of the even field (line 525), the scanning beam would return to line 1 and the sequence would repeat itself.

In the transmitter, the three images are placed side by side, and the scanning beam then moves across the three images in succession. Now in order for the transmitted signal to be receivable by an ordinary black-and-white receiver, we must retain the same line frequency (15,750 cycles) and the same field frequency (60 cycles). To achieve this in the transmitter, the scanning frequency is reduced to a third of its value, i.e., from 15,750 cycles to 5,250 cycles. At the transmitter, then, the scanning beam moves only one-third as fast. However, since we have three images side by side, each line occupies only one-third its normal length and therefore the scanning beam spends only one-third of its time traversing any one image. The result, then, is a series of lines which possess the same frequency (15,750 cycles) we have in the ordinary black-and-white receiver. Further, by injecting synchronizing pulses as the beam travels between color images (at the transmitter), we obtain a video signal which is identical, in all respects, to the video signal currently used with black-and-white transmissions.

Thus, the CTI system is fully compatible with the present standards. In this respect it is similar to the RCA dot sequential system.

For color reception, the three separate primary colors are reproduced in three images, placed side by side on the cathode-ray tube using the same scanning sequence employed at the transmitter. See Fig. 15.21. In the color receiver, the horizontal scanning frequency would be 5,250 cycles per second, just as it is at the transmitter. The sweep circuit is designed so that it responds only to a special notched pulse inserted in the signal just prior to the scanning of the red field. The color receiver does not respond to any of the other horizontal sync pulses. By the same token, an ordinary black-and-white set receiving these signals will not respond to the special notch, but only to the 15,750-cycle sync pulses.

The final color image viewed by an observer is formed by combining the light from the three separate images using a suitable projection system. It is possible to have the three images produced directly in color, using appropriately colored phosphors on the face of the cathode-ray tube, and then combining the three images by using three ordinary projection systems; or the
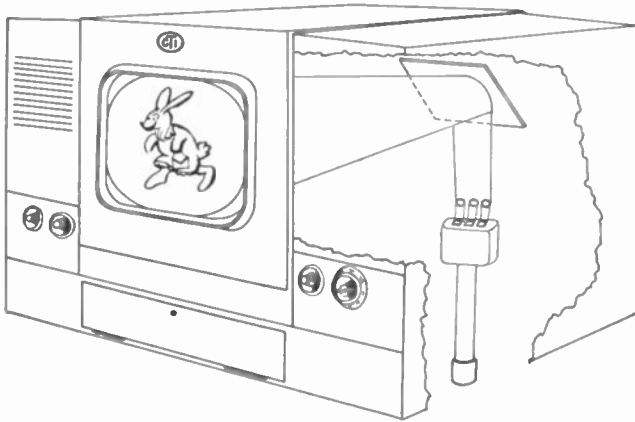
Fig. 15.21. A CTI color television receiver. The light from the three color images formed on the cathode-ray tube is superimposed by a suitable lens system to form the final image.

three images could be reproduced in black-and-white and appropriate color filters placed in the projection system.

The foregoing is an outline of the basic line sequential system devised by CTI. In any commercial use of this system, some modifications would be required. To understand why, consider the following. In the scanning sequence outlined above, at the transmitter, line 1 is scanned on the red image, line 3 on the green image, and line 5 on the blue image. A question that could be asked now is: Following this sequence, would we ever scan the first lines of either the blue or the green images? Since there are 525 lines in a complete image, and 525 is exactly divisible by 3, line 1 would always be scanned in red, line 3 in green, line 5 in blue, etc. Whenever any scene to be televised had one of

the primary colors (or some color close to one of these primary colors) concentrated in one section of the image, this portion would appear on the final composite image once every third line only and consequently present a rather course image structure with poor definition.

In order to prevent this from occurring, the color sequence is modified during the long vertical blanking period between fields

TABLE 15.2. A color shifting sequence designed to have every line scanned in all three colors.

LINE	I	II	III	IV	V	VI	VII
1	RED		GREEN		BLUE		RED
2		BLUE		RED		GREEN	
3	GREEN		BLUE		RED		GREEN
4		RED		GREEN		BLUE	
5	BLUE		RED		GREEN		BLUE
6		GREEN		BLUE		RED	
7	RED		GREEN		BLUE		RED
8		BLUE		RED		GREEN	

FIELD →

when the electron beam is moving from the bottom to the top of the image. One modification, suggested by CTI and shown in Table 15.2, is the color shift arranged to occur only after the evenly numbered fields. Thus, following our previous scanning sequence, field I would be scanned by line 1 in red, line 3 in green, line 5 in blue, etc. Without any modification in scanning sequence, line 2 of field II would be blue, and this is permitted to appear, as indicated in Table 15.2. The remainder of the even lines of field II would then continue in the normal sequence of red, green, blue, red, etc. Thus far, no modification in color sequence has occurred.

Now, if the sequence were permitted to continue, the start of field III would revert back to a scanning of line 1 of the red image. To prevent this, a color shift is incorporated and line 1 of the green image is scanned first, followed by line 3 from the

blue image, line 5 from the red image, etc. Without making any color shift at the end of the last line of field III, line 2 of field IV appears in red, line 4 in green, and so on. The next color shift in the sequence is made at the end of field IV in such a way that line 1 of field V now appears in the third color, namely blue, and the other lines of the pattern follow similarly, so that line 3 will be red, and line 5 green, line 7 red, and so on.

In field VI the even lines appear in such colors as are developed without introducing phase shift, and with the assumed color traces of field V, the even lines of field VI, starting with line 2, will appear in color order green, blue, red, and so on. A color shift is injected following field VI to bring the line colors of field VII to coincide with those of field I. Thus, color shifting occurs after every even field. Note, however, that after a color shift has occurred, the colors follow in the chosen sequence, i.e., red, green, blue.

To achieve the color shifting the notched pulse in the video signal previously mentioned is used. This notch, it will be recalled, indicated to a color television receiver that the next line to be scanned must be in the red image. Thus, if the notch appears after a green field instead of its normal position after a blue field, then a circuit in the color television received would shift the scanning beam so that the next line scanned is in the red image. Green and blue then follow in sequence.

To a black-and-white receiver, the notch is of no consequence and the scanning would merely continue. It makes no difference to this receiver whether the signal it is receiving is line 1 of the red image or line 1 of the blue or green images.

With the foregoing color shifting technique, Table 15.2 reveals that to scan any one line (say line 1) in all three colors requires six successive fields. Since the field rate is 60 fields per second, a complete color picture is obtained at the rate of 10 per second. In the CBS system, the color scanning rate was 24 per second, and in the RCA system, it was 15 per second.

QUESTIONS

Chapter 1

1. Why do television receivers have more panel controls than sound receivers?

2. What is a "Fine Tuning" control? Why is it necessary in most television receivers?

3. What are some of the desirable characteristics than an image should possess? Explain each briefly.

4. Draw the block diagram of a typical television receiver.

5. Of what does a complete television signal consist?

6. State briefly the function of each stage in a television receiver.

7. What is the purpose of synchronizing pulses?

8. Name three types of television cameras. Explain briefly the operation of one of these tubes.

9. Define scanning. What type of scanning is standard today? Why?

10. Define frame frequency, field frequency, and line frequency. Give values for each.

11. What would happen to the receiver image if blanking voltages were not employed in the video signal?

12. Discuss negative and positive picture polarity.

13. How do English and American television signals differ? What effect does this have on the reproduced image? What would happen if an American-made receiver were to receive English television signals?

14. Explain why video signals require wide frequency bands.

15. What effect does the width of the television signal have on the form of the final transmitted signal? Explain.

16. List all the channels currently assigned to television broadcasts, giving frequencies in each instance.

17. What is the visual effect of a loss of high video frequencies? Low video frequencies?

18. Why is F-M employed for sound transmission and A-M for video signal transmission?

19. What relationship exists between flicker and the method employed for scanning?

20. Discuss in detail the motion of the electron beam in interlaced scanning.

21. How is horizontal synchronization maintained while the vertical pulses are active? What is this called?

22. What is the horizontal scanning frequency? The vertical scanning frequency? Explain how each figure is arrived at.

23. What is meant by vestigial side-band transmission? How does this differ from the type of transmission employed in standard broadcast practice?

24. Are relay stations necessary for television transmission? Where are relay stations useful?

25. List the video front-panel controls that are generally used in commercial television receivers. State their function briefly.

26. What are two defects of an Iconoscope? How does the Orthicon overcome these defects?

27. Name two defects of low velocity scanning.

28. Why must amplifiers be included with a camera unit?

29. Draw two lines of a complete video signal including two blanking and sync pulses. Draw the video in positive picture phase.

30. What is an electron multiplier? Where is it used?

31. What is the time, in microseconds, for one complete horizontal line?

32. Explain the difference between camera tubes employing the storage and non-storage principles.

CHAPTER 2

1. Why are antennas more important to television receivers than to standard A-M broadcast receivers?

2. What happens if the same signal is received from several directions? What is this called?

3. What is the importance of the ionosphere?

4. What factors determine whether or not radio waves are returned to earth from the ionosphere?

5. How are television signals sent? Explain.

6. What is the horizon distance for a television antenna mounted atop a tower 450 feet high?

7. How much is the above distance increased if the antenna is raised an additional 100 feet?

8. A receiver is located 30 miles *beyond* the horizon distance computed in Question 6. How high should the receiver antenna be raised to receive signals from this transmitter?

9. What is meant by wave polarization? How does it affect the installation of a television receiving antenna?

10. What are the disadvantages of using any length of wire for the reception of television signals?

11. Indicate the materials required to construct and erect a half-wave dipole antenna.

12. A half-wave antenna is to resonate at 70 mc. What should its overall length be?

13. How are the directional characteristics of antennas obtained?

14. Name and sketch five different types of antennas that could be employed to receive television signals.

15. What precautions must be observed in choosing and installing a transmission line?

16. Name and describe four types of transmission lines.

17. Where could each type of line be used? Give reasons for each choice.

18. Define antenna gain and antenna directivity.

19. Must a signal always be received directly from the transmitter to be useful? Explain.

20. A half-wave dipole antenna designed for 80 mc is to be used on 192 mc. By how much should it be altered?

21. Illustrate a balanced and an unbalanced input system.

CHAPTER 3

1. How are wide-band tuning circuits achieved using conventional tuning circuits?

2. What is the difference in behavior between transformer-coupled tuning circuits using tuned and untuned primaries?

3. Why is the gain low in television circuits?

4. What is the usual purpose for including R.F. amplifiers in receivers?

5. Why are R.F. amplifiers especially useful in television receivers?

6. What desirable characteristics should R.F. amplifier tubes possess? Explain your answers.

7. Illustrate several types of coupling networks used in television receivers.

8. What is the advantage of using an overcoupled transformer in the input circuit and a single-peaked tuner in the plate circuit?

9. Explain the operation of the R.F. circuit shown in Fig. 3.15.

10. Why can triodes be employed as R.F. amplifiers in television receivers? Why are they not used in standard broadcast sets?

11. Explain the origin of all the capacitances associated with an R.F. amplifier.

12. Explain the term "Figure of Merit." Why is it useful?

13. Why is the cathode-lead inductance important in high frequency tubes?

14. Draw the circuit of an amplifier in which the effect of cathode-lead inductance is minimized.

15. Explain what effect a narrow frequency response in the R.F. tuned circuits would have on the reproduced image.

16. What precautions should be noted when constructing an R.F. amplifier for use in a television receiver?

17. What effect would an inoperative R.F. amplifier tube have on the image? Explain your answer.

CHAPTER 4

1. Why are pentagrid converters seldom, if ever, found in television receivers?

2. What is the difference, technically, between a mixer and a converter?

3. Draw the circuit of an ultraudion oscillator.

4. Indicate the differences in circuit between an ultraudion oscillator and a Colpitts oscillator.

5. Explain the purpose of a "Fine Tuning" control.

6. Where is the "Fine Tuning" control placed, electrically, in the circuit? Draw a circuit using this control.

7. Illustrate two methods of coupling the oscillator signal to the mixer.

8. How is the oscillator frequency for each channel obtained, using a single tube? Illustrate your answer.

9. What is the mathematical relationship between the oscillator frequency and the video and audio frequencies?

10. Draw the standard response curve for the I.F. system of a television receiver. Indicate the position of the video carrier.

11. Explain why the video carrier is placed where it is on the video I.F. response characteristic.

12. What basic factors govern the design of an I.F. system?

13. How is the I.F. chosen for a system?

14. What is a spurious response?

15. List and explain two types of spurious responses.

16. Illustrate two methods for separating audio and video I.F. voltages from each other.

17. When are video and audio I.F. signals separated from each other? Why?

18. Why are trap circuits used in video I.F. amplifiers? What would happen if they were not used?

19. In a receiver employing 25.75 mc for the video carrier I.F. and 21.25 mc for the audio carrier I.F., what trap frequencies should be employed? Explain how your answers were obtained.

20. When is the audio signal of the adjacent television channel not important? Why?

21. Draw three types of trap circuits commonly found in television circuits.

22. How are the channels allocated in any given community? Why? Determine which channels have been assigned to your community.

23. Given that the video carrier I.F. is 26.4 mc for a certain receiver. List the oscillator frequencies for each of the thirteen channels.

24. What is meant by A.G.C.? Why is it useful?

25. Explain the operation of a contrast control, both as to its action in the circuit and its effect on the image.

26. Draw the circuits of two different types of I.F. amplifiers.

27. Explain why condenser tuning is seldom found in television I.F. tuned circuits.

28. A video I.F. signal extends from 28.3 mc to 24.3 mc. What effect would attenuation of the frequencies around 28.0 mc have on the image? Around 24.3 mc?

CHAPTER 5

1. Draw the circuit of a television diode detector which will produce a negative picture phase signal.

2. Show how the above circuit can be modified to produce a positive picture phase signal.

3. Explain the difference between positive and negative video signals. What phase must the video signal possess when applied to the grid of the cathode-ray tube? Why?

4. How can a video signal, which is phased positively, be converted to the negative phase? Explain your answer.

5. Besides picture phase, what other precautions must be observed in video detector circuits?

6. To what purposes can the output of the video detector be put?

7. What advantages would be gained by the use of A.G.C. in a television receiver?

8. What portion of the incoming signal is useful in regulating the A.G.C. voltage? Why?

9. Contrast the methods used to obtain A.V.C. in a sound receiver and A.G.C. in a television receiver.

10. Draw the schematic diagram of an A.G.C. circuit.

11. What relationship exists between the polarity of the signal at the video detector output and the number of permissible video amplifiers?

12. Would your answer remain unchanged if the signal is applied to the cathode of the image tube rather than its control grid? Explain.

13. Why is it important to maintain a good frequency response in the coupling network between the video second detector and the video amplifiers?

Chapter 6

1. Why must we modify a high fidelity audio amplifier before it can be used as a video amplifier?

2. Must the full 4.0-mc video signal be used in all television receivers? Explain.

3. What governs the minimum viewing distance of a television screen?

4. What purpose does the d-c component of a television signal serve?

5. What occurs to the image when the d-c component is removed?

6. Why is phase distortion important in television? Why is it unimportant in sound receivers?

7. Explain how base distortion occurs in a television circuit.

8. What particular components are responsible for low frequency phase distortion? Why?

9. What is the effect of high frequency phase distortion?

10. What is the visual effect of low frequency phase distortion?

11. What factors tend to reduce the high frequency amplification of an audio amplifier?

12. Draw the equivalent high and low frequency circuits of an audio amplifier.

13. What is a peaking coil? Why is it useful in video amplifiers?

14. Draw the circuit of a video amplifier containing high frequency compensation.

15. Explain and illustrate the differences between series peaking, shunt peaking and a combination of the two.

16. Why can we disregard all shunting capacitances when designing the low frequency compensation network?

17. Without adding any additional components to an audio amplifier, how can we partially improve its low frequency response? What limitations exist to this method?

18. Draw the circuit of a video amplifier containing low frequency compensation.

19. Specify the various points in an amplifier where low frequency compensation can be applied. Indicate the compensation suggested in each instance.

20. What would be the visual effect of over-peaking? Under-peaking?

21. A video amplifier is to use a single shunt peaking coil. The response is to extend to 4.0 mc. If the load resistor is 2,000 ohms and the total shunting capacity is 20 $\mu\mu f$, what value should the peaking coil have?

22. In the same video amplifier, the coupling capacitor (C_c) has a value of 0.1 μf and the grid resistor of the following stage a value of 250,000 ohms. What value should C_f have in the low frequency compensation network?

23. Explain how the low frequency compensation networks accomplish their purpose.

Chapter 7

1. What is meant by d-c reinsertion? Why is it necessary?

2. Explain the difference between the a-c and the d-c components of a video signal.

3. How is the d-c component removed? Why is it possible to reinsert this voltage?

4. Must a television receiver contain a d-c restorer? Explain.

5. Explain the operation of the grid-leak bias method of d-c reinsertion.

6. What is the brilliancy or brightness control? Where it is situated in the circuit?

7. Explain the need for the brightness control.

8. What is the difference between the brightness and contrast controls?

9. What would happen to the image if the grid-leak d-c reinsertion network has a time constant of 1 microsecond?

10. Draw the schematic circuit of a diode d-c reinsertion network.

11. Explain how the circuit drawn in the previous question operates.

12. Explain what happens when the d-c component of a video signal is removed.

Chapter 8

1. Indicate briefly how a cathode-ray tube differs from a conventional pentode.

2. Which elements of the cathode-ray tube are contained in the first lens system?

3. Explain what occurs to the electron beam in the first lens system.

4. Which elements are contained in the second lens system? What occurs to the electron beam in this section of the electron gun?

5. What is an electric equipotential line?

6. What type of electrodes is employed in the electron gun? Why?

7. Explain, with illustrations, how the deflection plates bend the electron beam.

8. Name all the elements of an electrostatic deflection cathode-ray tube.

9. What is the purpose of an aquadag coating inside the walls of the cathode-ray tube?

10. Why is balanced deflection preferred over unbalanced deflection? List the advantages of each method.

11. Draw the circuit of a balanced electrostatic deflection system.

12. Why are vertical and horizontal centering controls necessary?

13. Show how centering controls are placed in the circuit.

14. Define deflection sensitivity and deflection factor. How can one be converted to the other?

15. Explain what happens when an electron enters a magnetic field.

16. Explain how an electron beam is focused magnetically.

17. Explain how a beam is deflected magnetically. Indicate the placement of the deflection coils at the cathode-ray tube.

18. What is the purpose of the fluorescent screen? What is its composition? What is the difference between fluorescence and phosphorescence?

19. What happens to all the light that is generated at the fluorescent screen?

20. Define image contrast. Why does the scattering of light reduce image contrast?

21. Explain halation briefly.

22. How can reflections inside the cathode-ray tube interfere with the image on the screen?

23. What is the reason for coating the backside of the fluorescent screen with aluminum?

24. What do we mean by sticking potential? When does it occur?

25. What is an ion spot? Why does it occur only in tubes using electromagnetic deflection?

26. Illustrate and explain two methods frequently used to remove ion spots.

27. How are cathode-ray tubes identified? Explain in detail the system used.

28. Why is a flat screen preferable to a curved screen? On which is it easier to keep the beam in focus? Why?

29. Explain the difference between electromagnetic and electrostatic tubes. Illustrate the difference in their internal construction.

30. Draw the circuit for a low-voltage power supply suitable for a television receiver.

31. What differences exist in the choice of components between 60-cycle low-voltage and high-voltage power supplies?

32. Draw the circuit of a 60-cycle high-voltage power supply. Include centering and focus controls for an electrostatic deflection tube.

33. Explain briefly the operation of an R.F. type of high-voltage power supply.

34. Draw the schematic diagram for a suitable R.F. high-voltage power supply.

35. On what principle does the "flyback" type of power supply operate?

36. What is the purpose of placing a damping tube across the horizontal deflection coils?

37. What precautions should be observed when handling cathode-ray tubes? Why?

38. Explain, with illustrations, how a simple lens type of projection system operates.

39. What is the Schmidt optical system? How has it been adapted for television?

40. Why is the Schmidt optical system superior to a simple lens type of projection system?

CHAPTER 9

1. Do the horizontal and vertical synchronizing pulses ever reach the control grid of the cathode-ray tube? Explain.

2. Draw a diagram of a complete video signal indicating where the horizontal synchronizing pulses are located.

3. Illustrate the path taken by all synchronizing pulses in a television receiver.

4. State specifically the action of the horizontal and vertical pulses in controlling the motion of the electron beam.

5. Explain what precautions must be observed before the pulses can be separated from the rest of the video signal.

6. Draw the circuit of a diode clipper. Explain how it operates.

7. Why are pentode or triode clippers more desirable than diode clippers?

8. Draw the circuit of a pentode clipper stage indicating the values to be assigned to the B+ voltage.

9. Why do the blanking voltages last longer than either the vertical or the horizontal pulses? What would happen if the blanking voltages were too short?

10. Explain why serrated vertical pulses are employed. Draw a serrated vertical pulse, indicating its time duration in microseconds.

11. What is an active line? What is the approximate number of active lines per frame? Indicate how your figure was obtained.

12. Indicate the position and time duration of the equalizing pulses.

13. Why are equalizing pulses necessary? Illustrate your answer by means of diagrams.

14. Draw the diagram of a differentiating network and explain its operation.

15. Draw an integrating network and explain its operation.

16. Do the same vertical and equalizing pulses trigger the horizontal oscillator after every field? Explain.

17. Illustrate the action of a vertical pulse in triggering the vertical sweep oscillator.

18. How are saw-tooth deflection voltages developed? What are the limitations of this method?

19. Draw the diagram of a blocking oscillator.

20. Explain the operation of blocking oscillators.

21. To control effectively the sweep oscillator, should the pulse frequency be higher or lower than the oscillator frequency? Why?

22. Draw the circuit of a cathode-coupled multivibrator.

23. Explain briefly how the multivibrator functions.

24. Using Fig. 9.30, explain the effect on the saw-tooth waves developed across C; of increasing the value of R_3, R_4, C_2 and R_1. Consider one component at a time and explain the change in terms of the amplitude and frequency of the saw-tooth waves.

CHAPTER 10

1. List and explain the purpose of every variable resistor and condenser found in the circuit of Fig. 10.1.

2. Draw a low-voltage power supply which would be suitable for the deflection system of Fig. 10.1.

3. If the upper triode section of V_4 (Fig. 10.1) stopped functioning, how would it affect the image?

4. The video signal is reaching the control grid of the cathode-ray tube, but the clipper tube breaks down. What is the effect on the screen?

5. If a vertical line is obtained on the screen when the set it turned on, indicate all the possible points where the trouble could exist. Use Fig. 10.1.

6. What is the purpose of the linearity control in Fig. 10.1?

7. Why are saw-tooth voltage waves not suitable for use with deflection coils?

8. How is the proper deflection voltage for deflection coils developed?

9. Draw the differentiating circuit (with parts values) used in Fig. 10.4. Do the same for the integrating network.

10. What is a damping tube? Why do we use a damping tube only in the horizontal system? What is used in the vertical system to accomplish the same purpose?

11. If a leakage path developed in one of the .005-mfd. condensers which couple the horizontal deflection voltage to the 7JP4, how would this affect the image?

12. Draw the beam-centering system used in Fig. 10.4.

13. List and explain the purpose of every control found in the circuit of Fig. 10.4.

CHAPTER 11

1. Explain the function and operation of the focus, contrast, brilliancy, and fine tuning controls.

2. What controls are generally classified as secondary controls? Where is their position on the television receiver chassis?

3. What type of R.F. tuning system is used in the receiver of Fig. 11.1? Explain how it operates.

4. What is the function of each of the following components in the R.F section of Fig. 11.1: T_1, C_3, C_{10}, C_{15}, L_{80} and C_{14}, R_3, and R_{13}?

5. What would happen if R_6 opened up?

6. Explain why each coil in the oscillator tuning line can be adjusted, yet only four coils in each of the other R.F. tuning lines are provided with a similar adjustment.

7. List all the trap circuits in the video I.F. system, together with their resonant frequencies. Explain how each trap circuit achieves its purpose.

8. Describe the operation of the contrast control of Fig. 11.1.

9. List the high frequency compensating components in the stages following the video second detector. Which are the low frequency compensating components?

10. Explain how the horizontal synchronizing discriminator controls the frequency of the horizontal sweep oscillator.

11. What type of oscillator is used in the vertical synchronizing system? Redraw the circuit so that it assumes a more conventional form.

12. Explain the operation of the horizontal output system, using the proper waveforms.

13. How does a linearity control function?

14. What equipment would be needed to align thoroughly this receiver?

15. What is a marker signal? Why is it useful? How are marker signals generated?

16. Explain in detail the alignment procedure for the trap circuits.

17. Outline the alignment procedure for the video I.F. system.

18. How is the sound I.F. system aligned?

19. By what method is the oscillator adjusted?

20. What adjustments are made in aligning the R.F. amplifier and converter?

21. A receiver is brought in for repair with the complaint that dark bars appear across the screen. It is later determined that this is true only when a signal is being received. What components are at fault and how can they be corrected?

22. What are the proper settings for each of the front panel controls during an alignment?

CHAPTER 12

1. In an A-M wave, where is the intelligence contained? How does this differ from the conditions prevailing in frequency modulation?

2. What is a discriminator? What is the accepted application of this word?

3. What influence does the audio-modulating signal frequency have in the production of an F-M signal?

4. Where do the F.M sidebands obtain their power? Contrast this with the situation existing in an A-M signal.

5. Differentiate between phase modulation, amplitude modulation, and frequency modulation.

6. What is the significance of the 2 to 1 ratio in F-M reception?

5. Describe a method for measuring the amount of ripple in the low-voltage and high-voltage power supplies. The method devised for the high-voltage power supply must be safe.

6. What controls are associated with the horizontal deflection system? Explain the visual result of an improper setting for each control.

7. Explain, in detail, what can cause loss of synchronization.

8. Inspection of a poorly operating television receiver reveals that near-by interference is largely responsible. What steps can be taken to reduce and/or eliminate the effect of such interference?

9. In the receiver described in Chapter 11 it is found that the image contains poor vertical linearity. Which components should be investigated?

10. Which controls are associated with the vertical deflection system? State the visual effect of an improper adjustment of each control (considered separately).

11. How can we distinguish between vertical and horizontal non-linearity?

12. What possible image distortions are due to defects in the video I.F. system?

13. How can the cause of image smearing be traced?

14. In the circuit of Fig. 11.1, what could produce the blurring of fine detail?

15. List the equipment which should be on hand for thoroughly testing a television receiver.

16. What is the visual effect of low-voltage a-c ripple in the deflection systems.

17. What happens when the damping tube becomes inoperative?

18. What visual checks should be made on a television receiver before the actual servicing is begun?

19. What defects could exist in sets employing electromagnetic deflection that could not exist in sets using electrostatic deflection?

20. Outline a procedure for testing cathode-ray tubes.

Chapter 15

1. What advantages are offered by the use of color television?

2. Why is it often difficult to tell the true color of an object under artificial lighting conditions?

3. Name the primary colors. What is their significance?

4. Describe, in detail, how the additive process of color transmission functions in the CBS system.

5. How is the receiver color disc kept in proper position at all times? What would be the result of poor control?

6. Outline the motion of the electron beam and the color disc to obtain an image completely scanned in all colors.

7. Why is the field scanning rate higher in this color television system than in a monochrome (black and white) system?

8. Indicate the significance of the following numbers in the CBS color television system: 24, 144, 72, 48.

9. What changes would have to be made in Table 15.1 if 60 color frames were transmitted per second?

10. What two factors must be observed in controlling the receiver color disc? How is each of these achieved in practice?

11. What are the essential differences between the CBS and the RCA systems of color television?

12. How is an image (or a scene) scanned in the RCA system?

13. Draw a block diagram of the RCA color television transmitter.

14. Explain the operation of the electronic sampler.

15. Why are the high frequency components of the video signal treated differently than the low frequency components?

16. Draw a block diagram of an RCA color television receiver.

17. In what respects does this set differ from a black-and-white television receiver?

18. Explain the picture dot interlacing and scanning sequence at the receiver.

19. RCA claims that color transmissions can be received on a two-color television receiver. Explain.

20. Discuss the adaptability of RCA and CBS systems to the present black-and-white television system.

GLOSSARY OF TELEVISION TERMS

A

Active Lines—In scanning an image, those lines that are responsible for imparting the information of the image. The beam is inactive when moving rapidly from right to left, or from the bottom of the picture to the top.

Amplitude Modulation—The process of varying the amplitude of a carrier in accordance with the amplitude of the intelligence (sound or video) to be broadcast.

Aquadag—A substance composed of graphite in solution. A coating of this substance is usually placed on the inside of a cathode-ray tube to prevent the accumulation of free electrons on the walls of the tube.

Array—A group or combination of two or more antenna elements, functioning as a unit. Antenna arrays are generally designed to provide greater directivity and gain than are available from a single-element antenna.

Aspect Ratio—A term used to denote the ratio of the image width to the image height.

Automatic Frequency Control—A method of automatically maintaining the frequency of an oscillator at a desired value. In television receivers, automatic frequency control is extensively applied to the horizontal sweep oscillator.

Automatic Gain Control (A.G.C.)—A method whereby the overall gain of a television receiver is automatically adjusted to produce a constant output signal for varying input signals.

B

Back Porch—The section of the synchronizing signal extending from the back end of the horizontal sync pulse to the start of the next line.

Band—A group of frequencies having definite upper and lower frequencies.

Bandwidth—The numerical difference between the highest and lowest frequencies passed by an electrical circuit.

Beam—When referring to television, a stream of electrons traveling in a vacuum tube. The tube to which this expression is most generally applied is the image tube.

Bi-directional—A term that applies to the response characteristic of an antenna and signifies that signals may be received from (or transmitted to) two different directions.

Blacker-than-Black Region—The region where the blanking and synchronizing voltages are found in the video signal. The voltages in this region prevent any electrons in the cathode-ray tube from reaching the viewing screen. The result is an absence of light on the screen.

Black Level—The point in the video signal at which the electron beam in the image tube is cut off or prevented from reaching the screen. This point normally occurs at 75% of the maximum amplitude of the signal.

Blanking Pulses—Sharp rises in voltage that bias the viewing tube control grid beyond cut-off. This action, when properly correlated with the brightness control, prevents the electron beam retraces from appearing on the viewing screen.

Blooming—The mushrooming of an electron beam (with consequent defocusing) produced by too high a setting of the brightness control.

Booster Amplifier—An R.F. amplifier which is not an integral part of a television receiver but which is connected to the front end of the set in order to "boost" or raise the strength of the received signal. Booster units usually contain more than one R.F. amplifier.

Brightness Control—A potentiometer control that varies the average or background illumination of the received image. When properly set, this control prevents any beam retraces from appearing on the screen.

Brilliance Control—Another name for the brightness control.

C

Camera Tube—A tube which has the ability to transform incoming light rays into equivalent electrical charges. A scanning beam then utilizes these charges to produce a video signal.

Cathode-ray Tube—A vacuum tube that contains a fluorescent screen at one end. By directing an electron beam at this screen, visible traces are formed and a combination of these gives rise to the reproduced image. Also known as Kinescope (RCA trade name).

Centering Control—A potentiometer which enables the viewer to move the image back and forth or up and down on a screen. Horizontal and vertical centering each requires a separate control.

Channel—The group of frequencies over which the video and audio signals may be transmitted. Each television channel is 6 mc wide.

Clamping Circuit—Another name for a d-c restorer. Clamping circuits in American television receivers maintain the tips of the sync pulses at a common level.

Clipper—A circuit which does not permit the positive (or negative) level of signal to exceed a certain value. The most extensive use of clippers in television receivers is the separation of the sync pulses from the rest of the video signal.

Coaxial Cable—A transmission line in which one conductor (the outer) completely surrounds the other conductor (the inner). The two conductors are separated by air or some other insulator.

Contrast—The ratio between the brightest and darkest portions of an image.

Contrast Control—A potentiometer that permits variations of the intensity of the various elements of an image. May be used to accentuate the highlights and shadows in an image.

Cross-over Area—In an electron gun, a region in the first lens system where the cathode-emitted electrons are brought together under the influence of electric (and sometimes magnetic) fields.

D

Damping Tube—A tube used with magnetic deflecting coils to prevent any transient oscillations from being set up in the coils or the associated circuits.

D-c Reinsertion—The readjusting of the video signal at the image tube to the form it possessed when transmitted by the broadcast station. Passage of the video signal through the a-c coupling networks of the video amplifiers results in the removal of the d-c component of the signal. A d-c restorer circuit just prior to the cathode-ray tube reinserts this lost d-c component.

Deflection—The shifting of the electron beam in a cathode-ray tube away from the center of the screen.

Demodulation—Another name for detection, or obtaining the intelligence contained in a signal from the carrier.

Detail—The smallest or minutest portions of an image that can be distinguished from each other.

Differentiating Circuit—A grouping of components that possess the ability to produce an output voltage proportional to the rate of change of the input signal.

Dipole—An antenna wire, one-half wave length long at the frequency it is to be used. It is usually divided into two equal quarter-wave sections.

Directive Antenna—Any antenna system that tends to receive signals best from one or more but not all directions.

Director—An antenna wire placed in front of a dipole. Its purpose is to sharpen the directivity of the dipole and increase its gain.

Discharge Tube—A tube which is biased to cut-off and therefore non-conducting except when triggered by a positive pulse. A condenser, con-

nected in the plate circuit of the tube, charges when the tube is non-conducting and discharges when the tube is triggered and forced into conduction.

Discriminator—The second detector in an F-M superheterodyne receiver. The frequency variations in the F-M signal are here converted to amplitude variations, suitable to be heard on a loudspeaker.

Driven Element—The wire or wires of an antenna which are connected to the receiver (or transmitter).

E

Electric Field—The region surrounding charged particles. An electric field is set up also whenever a magnetic field varies. Radio waves traveling through space are composed of electric and magnetic fields.

Electromagnetic Deflection—Deflecting an electron beam by applying varying currents to coils mounted on the neck of a cathode-ray tube.

Electromagnetic Deflection Coil—A circular coil placed around the neck of some cathode-ray tubes to cause deflection of the electron beam. Generally enclosed in an iron core known as a yoke.

Electron Gun—The cathode, grid, and cylindrical plates in a cathode-ray tube that produce the electron beam.

Electron Multiplier—A series of anodes used in the Image Dissector camera tube to increase the intensity of the video signal.

Electron Scanning—The periodic deflection of an electron beam across the screen of a cathode-ray tube, following a definite pattern.

Electrostatic Deflection—Deflecting an electron beam by applying varying voltages to plates mounted inside the glass envelope of a cathode-ray tube.

Equalizing Signals—A series of six pulses before and after a serrated vertical pulse. The action of these pulses causes the vertical deflection to start at the same time in each interval.

F

Field Frequency—This term is used in interlaced scanning and refers to the portion of a complete frame when either the even or odd lines are scanned. Requires 1/60 of a second.

Flicker—The variation in brightness that can be seen by the human eye when the images presented on a screen do not follow each other with sufficient rapidity.

Flyback—The rapid retrace motion of an electron beam after every horizontal line from the right- to the left-hand side of the image and after every field, from the bottom to the top of the image.

Folded Dipole—A half-wave antenna consisting of two dipoles in parallel with each other. Connection to the array is made at the center of one of the dipoles.

Fluorescent Screen—The coating located at one end of the cathode-ray tube on which the image is produced.

Focusing Control—The control whereby the electron beam is made to meet the fluorescent screen in a small, well-defined spot.

Frame Frequency—The rate at which a complete image is scanned. This includes both even- and odd-line fields. The rate is 30 frames per second.

Frequency Modulation—A means of transmitting radio intelligence by varying the frequency of the wave.

Front Porch—The portion of the synchronizing signal extending from the end of a line to the start of the horizontal sync pulse.

G

Gamma—The ratio of brightness variation in the reproduced image to the brightness variation in the original scene.

Ghost Image—A second image appearing on the receiver screen, superimposed on the desired signal. These images are caused by reflected rays arriving at the receiving antenna some small time interval after the desired wave.

Ground Wave—A radio wave that travels close to the earth.

Grounded Grid Amplifier—An amplifier in which the control grid is at R.F. ground potential and the signal is fed into the cathode circuit.

H

Halation—A ring or halo of light surrounding a point where the electron beam is impinging and producing a dot of light. The ring is due to multiple reflections between the front and back surfaces of the glass screen.

Height Control—The control whose setting determines the vertical amplitude of the image.

Hold Control—The variable resistor that permits adjustment of the synchronizing oscillator until the latter frequency nearly equals that of the incoming synchronizing pulses.

Horizontal Blanking—The interruption of the electron beam during horizontal retrace.

Horizontal Centering Control—A control that enables the operator to move the television image in a right or left direction across the screen.

Horizontal Line Frequency—The number of horizontal lines per second: 15,750.

Horizontal Resolution—The number of light variations or picture elements along a line which can be distinguished from each other.

Horizontal Retrace—The rapid right to left motion of the electron beam at the end of each line.

I

Iconoscope—An image camera tube that receives the light rays of the scene being televised and converts this energy into electrical charge.

Image Dissector—Another television camera tube that serves the same function as the Iconoscope and Orthicon tubes, but operates differently.

Image Orthicon—A highly sensitive camera tube used extensively for indoor and outdoor telecasting.

Implode—The action of the highly evacuated cathode-ray tube when the glass envelope is suddenly broken. Due to the atmospheric pressure against all sides of the tube, the glass moves inward with tremendous force.

Impulse—A sudden rise and fall of current (or voltage) in an electrical circuit.

Intercarrier System—A system in which the 4.5-mc difference between video and sound carriers is used as the I.F. frequency of the sound system.

Integrating Circuit—A circuit, consisting generally of condensers and resistors, whose output voltage is equal to the sum of a number of input pulses.

Interlaced Scanning—A method whereby an image is scanned first along the odd-numbered lines and then along the even-numbered lines. The result of interlaced scanning is an apparent increase in the rate at which the picture is sent. Flicker, by this means, is reduced to a minimum.

Ion Spot—An area on the fluorescent screen of an electromagnetic deflection image tube which has become desensitized because of a bombardment by ions in the electron beam.

Ion Trap—An arrangement whereby the ions within an electron beam are prevented from bombarding the screen and producing a ion spot.

L

Limiter—The last I.F. stage (or two) in an F-M receiver. The purpose of this stage is to eliminate all amplitude distortion or variation in the F-M signal.

Linearity Control—An adjustment that tends to correct any distortion in the saw-tooth current or voltage waves used for deflection.

Line Scanning Frequency—The rate at which the lines or sections of an image are scanned. Present standards set the rate at 525 horizontal lines for each 1/30 of a second, or 15,750 per second.

M

Marker Pip—An identification pulse which is superimposed over a response curve to indicate the position of a definite frequency.

Monitor—An auxiliary circuit containing a cathode-ray tube upon which appears the image being broadcast by the transmitter. The use of this auxiliary circuit permits the engineers in the station to maintain a continual check of the signal being transmitted.

Monoscope—A television camera tube that contains a fixed pattern within the tube. The tube is used to produce pre-broadcast test patterns for testing and alignment purposes.

Mosaic—The photosensitive surface in an Iconoscope or Orthicon camera tube. It is here that the light rays are transformed into equivalent electrical charges.

Multivibrator—An oscillator used to generate saw-tooth voltage (and current) waves.

N

Negative Picture Modulation—A method of transmitting the television video signal so that all the picture values are reversed. The brightest portions of the image are represented by the least amount of voltage while the dark sections of the image have large voltage (or current) values.

Noise—Undesirable voltages, either generated in the set or received from some external source, which produce a multitude of very small black and white spots over the entire image. These spots are often referred to as "snow."

P

Pairing—An effect in which the lines of one field do not fall exactly between the lines of the next field. When the effect is pronounced, the lines of the two fields fall directly over each other, effectively reducing the vertical definition in half.

Peaking Coil—A coil inserted in the video amplifier circuits for the purpose of improving its high-frequency response.

Pedestal—The level of the video signal at which blanking of the beam occurs.

Period—The time of one complete cycle of an alternating wave.

Persistence of Vision—A phenomenon of the human eye whereby variations in light intensity, occurring sufficiently close, tend to blend into each other and appear continuous.

Phosphor—The fluorescent material coated over the inside surface of the viewing end of a cathode-ray tube.

Pickup Tube—Another name for camera tube.

Picture Elements—The smallest portions of an image that are distinguishable from each other.

Picture Frequency—This term is synomymous with frame frequency.

Positive Picture Modulation—A method of transmitting video signals in which the brightest portions of an image are represented by the most positive voltages. Opposite to negative picture modulation.

Pulse—Another term for impulse and denotes a sudden rise and fall of voltage.

Pulse Repetition Rate—The number of times a pulse reappears each second.

Pulse Width—The time duration of a pulse.

R

Raster—The pattern of a television screen that is traced out by the electron beam. When no image is being received and the brightness control is turned up, the various lines comprising the raster can be plainly seen.

Ratio Detector—A circuit which is capable of converting frequency-modulated signals into equivalent audio signals.

Reactance Tube—A tube which is so connected that it appears as an inductance or capacitance to its circuit.

Reflector—An antenna wire placed behind a dipole and designed to improve the directional characteristics and gain of the dipole.

Relaxation Oscillator—An oscillator through which current flows strongly for part of a period and then ceases to flow entirely for the remainder of the period. Blocking and multivibrator oscillators perform in this manner and hence fall within this category.

Resolution—A term which refers to the smallest detail which can be distinguished or seen separately in a television image. Resolution is generally expressed as the maximum number of alternate black and white lines which can be distinguished in a test pattern.

Response Characteristic—The manner in which a circuit reacts to a set of signals. In an antenna, the response characteristic refers to the

manner in which signals arriving from different directions are received. In a receiver, this same phrase refers to the way certain frequency signals are received and amplified while others are rejected.

Retrace—The return of the electron beam either from the right-hand side of the image to the left-hand side, or from the bottom to the top of the picture.

S

Scanning—The process of breaking down an image into a series of elements or groups of elements and transmitting this information in a logical manner.

Schmidt Optical System—An optical system employing reflectors and a corrective lens to magnify an image produced on a small cathode-ray tube screen.

Secondary Electrons—Electrons that are obtained from a substance because of the intensity with which other electrons (known as primary electrons) are impinging on the surface of this substance. The primary electrons arrive with sufficient force to knock loose one or more secondary electrons.

Separation Circuit—A circuit which will separate signals having different properties, such as amplitude, frequency, etc.

Sequential Color Transmission—The sending of the signals arising from differently colored sections of an image one after the other, in a certain order.

Serrated Vertical Pulse—The manner by which the relatively long vertical pulse is broken up into a series of pulses to permit simultaneous control of vertical and horizontal synchronizing oscillators.

Single Side-band Transmission—See vestigial side-band transmission.

Smear Ghost—Ghost images which follow the desired image so closely that the overall effect is one of smearing.

Spurious Signal Voltages—These are the voltages caused by the secondary emission effects of a mosaic plate.

Staggered Tuning—The peaking or resonating of each of the tuned circuits in an I.F. system to different frequencies. This is done to achieve a broad response.

Synchronizing Pulses—Voltage (and current) waveforms that keep the electron beam at the receiver in step with the camera tube electron beam.

T

Tearing—A synchronizing circuit disruption which causes the displacement of lines from their normal position. The visual effect is as though portions of the image had been physically torn away.

Televise—To train a television camera on a scene and convert the light reaching the camera into equivalent video signals.

Test Pattern—A special chart on which lines and other detail are so arranged as to indicate certain characteristics of the system through which the television signal obtained from this chart passes.

Time Constant—The time required for the voltage or current in a circuit to rise to 63 per cent of its final value or fall to 37 per cent of its initial value.

Time Delay—The time required by a specific voltage or current to travel through a circuit.

Transmission Line—A set of two conductors possessing evenly distributed resistance, capacitance, and inductance and employed for transporting electrical energy from one point in a system to another.

Trigger—To set off or initiate a certain action in an electrical circuit by the application of a pulse of voltage.

U

U.H.F.—An abbreviation for ultra-high frequencies. By definition, these extend from 300 to 3,000 mc.

V

Vertical Blanking—The interval which the electron beam is being shifted from the bottom of the image back to the top and the electron beam is prevented from reaching the screen.

Vertical Centering Control—An adjustment control for moving the image up or down on the viewing screen.

Vertical Resolution—The number of active lines in an image.

Vertical Retrace—The return path of the electron beam during the vertical blanking interval.

Vestigial Side-band Transmission—A method of transmission whereby one set of side bands is eliminated from the modulated transmitted signal.

V.H.F.—Abbreviation for very high frequencies. By definition, these extend from 30 to 300 mc.

Video Amplifiers—Any amplifier having a uniform frequency response over a wide range. Generally this range starts at 20 cycles and extends for several megacycles.

Video Frequency—Any frequency obtained from the scanning by a camera tube. At the present time, the highest value is restricted to 4 megacycles, but it could be higher.

W

Wedge—Those portions of a test pattern containing a series of lines which converge at one end, this end generally positioned at the center of the pattern.

Width—The horizontal dimension of an image. It is generally expressed in inches or feet.

Width Control—The electrical component or circuit that controls the width of the image.

Y

Yoke—The frame upon which is wound the horizontal and vertical deflecting coils.

APPENDIX

ALLOCATION OF TELEVISION CHANNELS

ALABAMA

	V.H.F. Channel No.	U.H.F. Channel No.
Alexander City..	0	17
Andalusia.......	0	26
Auburn........	0	33
Birmingham.....	4, 6, 13	0
Brewton........	0	15
Clanton........	0	27
Decatur........	0	41
Demopolis.....	0	14
Dothan........	0	45
Enterprise......	0	39
Eufaula........	3	0
Florence........	0	43
Gadsden........	0	44
Greenville......	0	43
Huntsville......	0	26
Jasper.........	0	20
Mobile.........	5, 8, 11, 13	0
Montgomery....	7, 10	0
Opelika........	0	31
Selma.........	0	30
Sheffield.......	0	45
Talladega......	0	35
Tuscaloosa.....	0	23
Troy..........	0	21

ARIZONA

	V.H.F. Channel No.	U.H.F. Channel No.
Ajo...........	0	19, 21
Bisbee.........	0	19, 21
Buckeye.......	0	39
Casa Grande....	0	24
Clarkdale......	0	43, 45
Clifton.........	0	30
Coolidge........	0	35, 37
Douglas........	0	15, 17
Flagstaff........	9, 11	14, 16
Ft. Huachuca....	0	38
Ganado........	0	15
Grand Canyon...	0	40
Globe..........	0	22
Halbrook.......	0	27, 29
Hayden........	0	28, 44
Jerome........	0	36
Kingman........	6	29, 35
Mesa..........	0	31, 33
Miami..........	0	26
Morenci........	0	32
McNary........	0	34
Nogales........	0	23, 25
Parker..........	0	38
Phoenix........	2, 4, 5, 8, 12	15, 17
Prescott........	0	23, 25
Safford........	0	36
St. Johns........	0	38
San Simon......	0	40
Superior........	0	42
Tombstone......	0	29
Tucson.........	3, 6, 7, 10	14, 16
Wickenburg.....	0	41
Williams........	0	30
Winslow........	0	18, 20
Yuma..........	9, 13	30, 32, 34

ARKANSAS

	V.H.F. Channel No.	U.H.F. Channel No.
Arkadelphia . .	0	15
Batesville	0	20

ARKANSAS (Cont.)

	V.H.F. Channel No.	U.H.F. Channel No.
Blytheville	0	44
Camden	0	42
Conway	0	24
Crossett	0	26
El Dorado	0	34
Fayetteville	0	31
Forrest City	0	16
Fort Smith	0	16, 18
Harrison	0	26
Helena	0	14
Hope	0	22
Hot Springs	0	44
Jonesboro	0	23, 25
Little Rock	2, 5, 7, 11	0
Magnolia	0	20
Malvern	0	28
Morrilton	0	17
Newport	0	37
Paragould	0	18
Paris	0	39
Pine Bluff	0	38, 40
Pocahontas	0	34
Rogers	0	33
Russellville	0	21
Siloam Springs	0	42
Springdale	0	45
Stuttgart	0	33
Texarkana	6	25, 27
West Helena	0	27

CALIFORNIA

	V.H.F. Channel No.	U.H.F. Channel No.
Alturas	0	24
Arcata	0	30
Arroyo Grande	0	32
Bakersfield	10	14, 16
Banning	0	23
Barstow	0	25
Blythe	0	26
Brawley	0	20
Bridgeport	0	43
Calipatria	0	28
Calexico	0	22
Chico	12	36
Coalinga	0	41
Colton	0	39
Corona	0	35
Crescent City	0	45
Delano	0	38
Dinuba	0	29
El Centro	0	18
Escondido	0	41
Eureka	0	14, 16, 28
Fillmore	0	28
Ft. Bragg	0	24
Fresno	8, 12	15, 17
Grass Valley	0	19
Hanford	0	19
Hollister	0	20
Independence	0	33
Indio	0	31
Inyokern	0	43
Laguna Beach	0	33
Lakeport	0	33
Lancaster	0	45
Lodi	0	21
Lompoc	0	42
Los Angeles	2, 4, 5, 7, 9, 11, 13	0
Merced	0	24
Modesto	0	26
Mojave	0	20
Monterey	0	18
Mt. Shasta	0	23
Napa	0	29
Needles	0	24
Oceanside	0	27
Oroville	0	27
Oxnard	0	22
Placerville	0	34
Pacific Grove	0	45
Palm Springs	0	44
Paso Robles	0	25
Petaluma	0	23
Porterville	0	31
Portola	0	41
Red Bluff	0	25

	V.H.F. Channel No.	U.H.F. Channel No.		V.H.F. Channel No.	U.H.F. Channel No.
Redding	0	18, 42	Cheyenne Wells	0	39
Redlands	0	29	Colorado Springs	0	20, 24
Riverside	0	19, 21	Cortez	0	18
Sacramento	6, 10	38, 40	Craig	0	26
Salinas	0	30	Del Norte	0	33
San Bernardino	0	15, 17	Delta	0	25
San Diego	3, 6, 8	14, 16	Denver	2, 4, 5, 7, 9	0
San Francisco-Oakland	2, 4, 5, 7, 9, 11	0	Durango	0	14
San Luis Obispo	0	21	Ft. Collins	0	33, 35
San Jose	0	35, 37, 39	Ft. Morgan	0	25
Santa Barbara	0	24, 26	Glenwood Springs	0	30, 36
Santa Cruz	0	14, 16	Grand Junction	0	15, 17
Santa Maria	0	44	Greeley	0	29, 31
Santa Paula	0	18	Gunnison	0	19
Santa Rosa	0	17	Hugo	0	36
Scotia	0	37	La Junta	0	16
Sonora	0	32	Lamar	0	19
Stockton	0	42, 44	Leadville	0	32
Susanville	0	22	Limon	0	22
Taft	0	36	Longmont	0	45
Trona	0	40	Las Animas	0	14
Tulare	0	23	Loveland	0	27
Turlock	0	28	Meeker	0	42
Ukiah	0	20	Montrose	0	27
Ventura	0	30	Oak Creek	0	34
Victorville	0	37	Ouray	0	38
Visalia	0	27	Pagosa Springs	0	16
Wasco	0	34	Pueblo	3, 6, 8, 10	0
Watsonville	0	22	Rocky Ford	0	42
Weaverville	0	39	Saguache	0	40
Westwood	0	45	Salida	0	44
Willits	0	43	San Luis	0	23
Willows	0	31	Silvertown	0	29
Yreka	11, 13	0	Springfield	0	25
Yuba City	0	15	Steamboat Springs	0	39
			Sterling	0	34
COLORADO			Trinidad	0	18, 21
			Walden	0	37
Alamosa	12	31	Walsenburg	0	26
Boulder	0	41, 43	Wray	0	38
Burlington	0	15	Yuma	0	17
Canon City	0	28			

CONNECTICUT	V.H.F. Channel No.	U.H.F. Channel No.
Bridgeport......	0	14, 16
Hartford-		
New Britain...	0	30, 32, 34
New Haven.....	6	20, 22
Waterbury......	0	24, 26

DELAWARE	V.H.F. Channel No.	U.H.F. Channel No.
Dover..........	0	47 (c)
Wilmington.....	7	30, 32

DISTRICT OF COLUMBIA	V.H.F. Channel No.	U.H.F. Channel No.
Washington.....	4, 5, 7, 9	33

FLORIDA	V.H.F. Channel No.	U.H.F. Channel No.
Apalachicola.....	0	44
Belle Glade-		
Chosen.......	0	26
Clearwater......	0	43
Crestview.......	0	18
Cross City......	0	24
Daytona Beach..	0	32, 34, 36
De Land........	0	19
Everglades......	0	40
Fort Lauderdale.	0	30, 32
Fort Myers......	0	35, 37
Fort Pierce.....	0	39
Gainesville......	0	14, 16
Hollywood......	0	34
Jacksonville.....	2, 4, 5, 8, 10	0
Key West.......	0	19, 21
Lake City.......	0	26
Lakeland.......	0	33
Lake Worth.....	0	28
Leesburg........	0	27
Marianna.......	0	37
Melbourne......	0	15
Miami..........	2, 4, 5, 8, 10, 12	0
Ocala...........	0	38
Orlando.........	0	21, 23, 25

	V.H.F. Channel No.	U.H.F. Channel No.
Palatka.........	0	40
Palm Beach.....	0	24
Panama City....	0	14, 16
Pensacola.......	0	20, 22, 24
Perry...........	0	22
Plant City......	0	31
Quincy.........	0	19
Sebring.........	0	17
St. Augustine....	0	42, 44
St. Petersburg-	3, 6, 7, 9,	0
Tampa	11, 13	
Sanford.........	0	29
Sarasota........	0	20
Sulphur Springs..	0	45
Tallahassee......	12	28
West Palm Beach	0	14, 16, 18, 22
Winter Haven...	0	41

GEORGIA	V.H.F. Channel No.	U.H.F. Channel No.
Albany.........	0	42
Americus.......	0	20
Athens..........	0	21, 23
Atlanta.........	2, 5, 8, 11	32, 34
Augusta........	6, 12	17
Bainbridge......	9	0
Brunswick......	0	37, 39
Cairo...........	6	0
Cartersville.....	0	39
Cedartown......	0	19
Columbus.......	0	36, 38, 40
Cordele........	13	0
Dalton..........	0	25
Dawson.........	0	25
Douglas.........	0	30
Dublin..........	0	43
Fitzgerald.......	0	27
Gainesville......	0	15
Griffin..........	0	29
Jessup..........	0	35
La Grange......	0	22, 24
Macon..........	0	14, 16, 18
Milledgeville....	0	26
Moultrie........	0	15

	V.H.F. Channel No.	U.H.F. Channel No.		V.H.F. Channel No.	U.H.F. Channel No.
Rome...........	0	42	Soda Springs....	0	37
Savannah.......	3, 9, 11	0	Standpoint......	0	20, 22
Statesboro......	0	19	Twin Falls......	11, 13	16
Thomasville.....	0	32, 34	Wallace.........	0	39
Thomson.......	0	41	Weise...........	0	27, 29
Toccoa.........	0	27			
Valdosta........	0	17	**ILLINOIS**		
Waycross.......	0	21, 23			
			Aurora..........	0	41, 43
IDAHO			Bloomington....	0	26
			Cairo...........	0	15
Aberdeen.......	0	43	Carthage........	10	0
Arco...........	0	28	Centralia........	0	24
Blackfoot.......	0	33	Champaign......	0	15
Boise...........	2, 4, 5, 7	0	Chicago.........	2, 4, 5, 7,	0
Bonners Ferry...	0	31, 33		9, 11, 13	
Buhl...........	0	44	Clinton.........	0	38
Burley..........	0	24	Danville........	0	19
Caldwell........	0	35, 37	Decatur.........	0	34, 36
Cascade.........	0	18	Elgin...........	0	20
Challis.........	0	26	Galesburg.......	0	21
Coeur D'Alene...	9, 12	41, 43	Harrisburg......	0	32
Council.........	0	31	Herrin..........	0	37
Diggs..........	0	39	Jacksonville.....	0	23
Dubois.........	0	31	Joliet..........	0	24
Gooding........	0	22	Kankakee.......	0	30
Grangerville.....	0	45	Kewanee........	0	16
Idaho Falls......	3, 6	19, 21	La Salle.........	0	33
Kellogg Wardner.	0	16	Lincoln.........	0	44
Ketchum........	0	36	Litchfield.......	0	29
Lewiston........	0	32, 34	Metropolis......	0	22
Mackay.........	0	38	Moline-Rock		
Malad City.....	0	45	Island-Dav....	4, 5	42
Montpelier......	0	26	Mt. Carmel.....	0	35
Moscow........	0	21	Mt. Vernon.....	0	27
Mountain Home.	0	39	Peoria..........	6, 12	31
Nampa.........	9, 12	23, 25	Quincy.........	0	18, 30
Orafino.........	0	36	Rockford.......	0	27, 29
Pocatello.......	8, 10	35	Springfield......	3	17
Preston.........	0	15, 17	Sterling.........	0	35
St. Anthony.....	0	41	Urbana.........	0	22
St. Maries.......	0	18	Vandalia........	0	40
Salmon.........	0	15	Waukegan......	0	46 (c)
Shoshone........	0	14			

INDIANA

	V.H.F. Channel No.	U.H.F. Channel No.
Anderson	0	27
Bedford	0	33
Bloomington	10	0
Columbus	0	43
Evansville	0	16, 18, 20
Fort Wayne	0	25, 38
Gary	0	48 (c)
Indianapolis	6, 8, 12	45
Kokomo	0	23
Lafayette	0	37
Logansport	0	21
Marion	0	18
Muncie	0	32
Richmond	0	41
Seymour	0	17
South Bend	0	40, 42
Tell City	3	0
Terre Haute	0	28, 39
Vincennes	0	14

IOWA

	V.H.F. Channel No.	U.H.F. Channel No.
Ames	4	0
Albia	0	34
Algona	10	0
Atlantic	0	32
Boone	0	25
Burlington	0	28
Carroll	0	40
Cedar Rapids	7, 9	0
Centerville	0	26
Chariton	0	41
Charles City	12	0
Cherokee	0	38
Clarinda	0	23
Clinton	0	37
Creston	0	21
Davenport, Rock Island, Moline	4, 5	42
Decorah	3	0
Des Moines	8, 11, 13	0
Dubuque	0	45
Fairfield	0	24

	V.H.F. Channel No.	U.H.F. Channel No.
Fort Dodge	0	17
Fort Madison	0	14
Glenwood	0	28
Iowa City	2	0
Iowa Falls	0	33
Keokuk	0	32
Knoxville	0	43
Marshalltown	0	15
Mason City	0	39
Muscatine	0	40
Newton	0	29
Ottumwa	0	20, 38
Red Oak	0	42
Shenandoah	0	16
Sioux City	2, 5, 9	0
Storm Lake	0	35
Waterloo-Cedar Falls	0	22, 36
Webster City	0	19

KANSAS

	V.H.F. Channel No.	U.H.F. Channel No.
Anthony	0	39
Arkansas City	0	37
Atchison	0	18
Baxter Springs	0	38
Belleville	0	27
Clay Center	0	38
Coffeyville	0	44
Colby	0	26
Concordia	0	34
Dodge City	0	24, 43
El Dorado	0	16
Emporia	0	21
Ft. Scott	0	32
Garden City	9, 11	0
Goodland	0	28
Great Bend	5	14
Hays	0	22
Hutchinson	0	20
Iola	0	41
Junction City	8	0
Kansas City (See Kansas City, Mo.)		

	V.H.F. Channel No.	U.H.F. Channel No.
Kinsley	0	41, 45
Larned	0	30
Lawrence	0	39
Liberal	0	38
Lindsborg	0	42
McPherson	0	28
Manhattan	0	15
Newton	0	31
Norton	0	36
Oberlin	0	33
Osawatomie	0	24
Osborne	0	17
Ottawa	0	26
Phillipsburg	0	44
Pittsburg	0	30
Pratt	0	18
Russell	0	32
Salina	0	40
Scott City	0	31
Sharon Springs	0	21
Syracuse	0	29
Topeka	11, 13	0
Wellington	0	33
Winfield	0	35
Wichita	3, 10, 12	0

KENTUCKY

	V.H.F. Channel No.	U.H.F. Channel No.
Ashland (see West Virginia)		
Bowling Green	0	34
Corbin	0	45
Danville	0	38
Frankfort	0	15
Glasgow	0	40
Hazard	0	23
Henderson	0	41
Hopkinsville	0	36
Lexington	0	19
Louisville	5, 9	29, 31
Madisonville	0	25
Mayfield	0	17
Maysville	0	39
Middlesborough	0	41
Murray	0	39

	V.H.F. Channel No.	U.H.F. Channel No.
Owensboro	0	44
Paducah	12	0
Richmond	0	21
Somerset	0	35
Winchester	0	42
Van Cleve	0	28

LOUISIANA

	V.H.F. Channel No.	U.H.F. Channel No.
Abbeville	0	28
Alexandria	5, 11, 13	0
Bastrop	0	23
Baton Rouge	0	43, 45
Bogalusa	0	26
Crowley	0	17
De Ridder	0	29
Eunice	0	38
Hammond	0	14
Houma	0	24
Jennings	0	31
Lafayette	0	41
Lake Charles	0	23
Minden	0	14
Monroe	0	32, 39
Natchitoches	0	21
New Iberia	0	34
New Orleans	2, 4, 6, 7, 10	0
Oakdale	0	19
Opelousas	0	15
Pineville	0	21
Ruston	0	16
Shreveport	3, 10, 12	0
Tallulah	0	30
Thibodaux	0	32
Winnfield	0	36

MAINE

	V.H.F. Channel No.	U.H.F. Channel No.
Augusta	8, 10	19, 21, 23
Bangor-Old Town	5, 12	36, 42
Biddeford-Saco	0	14, 16
Brunswick	0	44
Calais	2, 7	14, 16, 18

MAINE (Cont.)

	V.H.F. Channel No.	U.H.F. Channel No.
Ft. Kent- St. Francis....	8	15, 17, 19, 21
Houlton........	0	25, 27, 29
Lewiston-Auburn	0	28, 30
Portland........	6, 13	0
Presque Isle.....	0	31, 33, 35
Waterville......	0	32, 34

MARYLAND

	V.H.F. Channel No.	U.H.F. Channel No.
Annapolis.......	0	49 (c)
Baltimore.......	2, 11, 13	14, 16
Cumberland.....	0	39, 44
Frederick.......	0	37
Hagerstown.....	0	35
Salisbury.......	0	43

MASSACHUSETTS

	V.H.F. Channel No.	U.H.F. Channel No.
Barnstable- W. Yarmouth.	0	37
Boston..........	2, 4, 5, 7	0
Brockton........	0	48 (c)
Fall River- New Bedford..	0	19, 21, 23
Lawrence-Lowell- Haverill.......	0	25, 27
Pittsfield........	0	28
Springfield- Holyoke......	0	36, 38
Worcester.......	0	43, 45

MICHIGAN

	V.H.F. Channel No.	U.H.F. Channel No.
Alpena..........	0	39
Ann Arbor......	0	37
Battle Creek....	0	29
Benton Harbor..	0	44
Cadillac.........	0	23
Cheboygan- Mackinaw.....	4	0
Detroit.........	2, 4, 7	24, 27
Escanaba.......	0	25
Flint...........	0	14, 16, 34
Gladstone.......	13	0
Grand Rapids...	7, 12	33, 35
Hancock........	0	16
Harbor Beach...	0	38
Holland.........	0	26
Houghton.......	0	27
Iron Mountain..	7, 9	32, 34
Iron River......	0	14
Ironwood.......	0	30
Ishpeming.......	0	20
Jackson.........	0	20, 22
Kalamazoo......	3	15
Lansing.........	6	45
Ludington.......	0	30
Manistee........	0	27
Manistique.....	0	15
Marquette......	3, 5, 10	18
Midland........	0	28
Muskegon.......	0	17, 19
Petoskey........	0	29, 31
Pontiac.........	0	48 (c)
Port Huron.....	0	46 (c)
Rogers City.....	0	42
Saginaw- Bay City......	0	18, 21, 32
Sault Ste. Marie.	8, 10	14, 16
Tawas City.....	0	25
Traverse City...	0	41, 43
West Branch....	0	36

MINNESOTA

	V.H.F. Channel No.	U.H.F. Channel No.
Albert Lea......	0	24
Alexandria......	0	29
Austin..........	0	16
Bemidji.........	0	22
Brainerd........	0	43
Chisholm.......	0	44
Crookston.......	0	20
Detroit Lakes....	0	27
Duluth-Superior (see Wisconsin)		
Ely............	0	18
Eveleth.........	0	37

	V.H.F. Channel No.	U.H.F. Channel No.		V.H.F. Channel No.	U.H.F. Channel No.
Fairmont	0	26	Kosciusko	0	19
Faribault	0	21	Laurel	0	16
Fergus Falls	0	38	McComb	0	20, 22
Grand Rapids	0	26	Macon	2	0
Hastings	0	40	Meridian	0	36, 38
Hibbing	0	39, 41	Natchez	0	25, 27
International Falls	0	14, 16	Pascagoula	0	28
Little Falls	0	25	Philadelphia	0	34
Mankato	0	44	Picayune	0	44
Marshall	0	20	Starkville	0	28
Minneapolis-St. Paul	2, 4, 5, 7, 9, 11, 13	0	Tupelo	0	22
Montevideo	0	36	Vicksburg	0	35, 37
Moorhead (see Fargo)			West Point	0	32
New Ulm	0	28	Yazoo City	0	41
Northfield	0	14			
Owatonna	0	42	**MISSOURI**		
Pine City	0	31	Cape Girardeau	0	45
Red Wing	0	18	Carrollton	0	40
Rochester	0	32, 34	Carthage	0	25
St. Cloud	0	17, 19	Chillicothe	0	44
Thief River Falls	0	24	Clinton	0	20
Virginia	0	21	Columbia	0	15
Wadena	0	32	De Soto	2	0
Willmar	0	15	Flat River	0	31
Winona	0	38	Fulton	0	33
Worthington	0	23	Hannibal	0	25
			Hermitage	0	23
MISSISSIPPI			Jefferson City	6	43
			Joplin	0	19, 22
Aberdeen	0	15	Kansas City	2, 4, 5, 9	0
Biloxi	0	31, 33	Lebanon	0	27
Brookhaven	0	18	Lexington	0	31
Canton	0	24	Louisiana	0	39
Clarksdale	0	29, 31	Marshall	0	17
Columbia	0	29	Maryville	0	30
Columbus	0	25	Mexico	0	22
Greenville	0	43, 45	Moberly	0	36
Greenwood	0	21	Nevada	0	34
Grenada	0	17	Poplar Bluff	0	21
Gulfport	0	21, 23	Rolla	0	35
Hattiesburg	0	40, 42	St. Joseph	0	35, 37
Jackson	3, 9, 12	0	St. Louis	4, 5, 7, 9, 11, 13	0
			Salem	0	14

MISSOURI (Cont.)

	V.H.F. Channel No.	U.H.F. Channel No.
Sedalia..........	0	29
Sikeston........	0	26
Springfield......	3, 10, 12	0
Van Buren......	0	38
Washington.....	0	19
West Plains.....	0	41

MONTANA

	V.H.F. Channel No.	U.H.F. Channel No.
Anaconda......	0	35, 37
Baker..........	0	19
Big Timber.....	0	24
Billings.........	2, 4, 5, 7	19, 21
Bozeman........	0	14, 16
Broadus........	0	29
Butte..........	2, 4, 5, 7	33, 40
Chester........	0	30
Chinook........	0	25
Choteau........	0	18
Circle..........	0	28
Cut Bank......	0	43, 45
Dillon..........	0	27
Ekalaka........	0	26
Forsyth........	0	32, 39
Fort Benton.....	0	36, 38
Glasgow........	0	18, 20, 22
Glendive........	0	21
Great Falls......	3, 6, 8	26, 28
Hamilton.......	0	44
Hardin.........	0	41, 43
Harlowton......	0	44
Havre..........	9, 11	19, 21, 23
Helena..........	10, 12	0
Hysham........	0	37
Jordan..........	0	30
Kalispell........	0	15
Lewistown......	0	17
Libby..........	0	35, 37
Livingston......	0	32, 34
Malta..........	0	27
Miles City......	3, 6, 10	14, 16, 24
Missoula........	11, 13	17, 19
Paradise........	0	42

	V.H.F. Channel No.	U.H.F. Channel No.
Philipsburg......	0	29
Plentywood.....	0	29, 31, 44
Polson..........	0	27
Red Lodge......	0	29
Roundup........	0	35
Saco............	0	45
Scobey..........	0	41
Shelby..........	0	14, 16
Sidney..........	0	15, 17
Stanford........	0	15
Thompson Falls..	0	25
Virginia City....	0	45
Whitehall.......	0	22
White Sulphur Springs.......	0	20
Wibaux.........	0	40
Winifred........	0	41
Winnett........	0	42
Wolf Point......	0	33

NEBRASKA

	V.H.F. Channel No.	U.H.F. Channel No.
Ainsworth.......	0	38
Alliance.........	0	15, 37
Atkinson........	0	34
Bayard.........	0	42
Beatrice........	0	45
Bridgeport......	0	40
Broken Bow.....	0	16
Columbus.......	0	26
Crawford.......	0	22
Fairbury........	0	43
Falls City.......	0	33
Fremont........	0	36
Gothenburg.....	0	14
Grand Island....	0	35, 37
Hastings........	4	39, 41
Holdredge.......	0	25
Kearney........	0	21, 23
Lexington.......	0	18
Lincoln.........	10, 12	0
McCook........	8, 13	0
Nebraska City...	0	14
Neligh..........	0	17
Norfolk.........	0	15

	V.H.F. Channel No.	U.H.F. Channel No.
North Platte....	2, 5	0
Ogallala.........	0	24
Omaha..........	3, 6, 7	0
O'Neill.........	0	20
Ord............	0	30
Scottsbluff......	0	18, 20
Seward.........	0	24
Sidney..........	0	32
Stanton.........	0	22
Superior........	0	29
Valentine.......	0	28
West Point......	0	44
York...........	0	19

NEVADA

Austin..........	0	29
Battle Mountain.	0	42
Boulder City....	0	18, 22
Caliente........	0	28, 30, 43
Carson City.....	0	30
Elko............	10	15, 17, 91
Ely.............	3, 6	14, 16, 20
Eureka.........	0	40
Fallon..........	0	35
Gerlach.........	0	28
Goldfield........	0	44
Henderson......	0	27, 32
Las Vegas.......	8, 10, 12	14, 16, 41, 45
Lovelock.......	0	25
McDermitt......	0	26
McGill..........	0	23, 25
Mina...........	0	39
Mountain City...	0	34
Overton.........	0	34, 36
Palisade........	0	45
Pioche..........	0	24, 26
Reno...........	3, 13	14, 16
Sparks..........	0	37
Tonopah........	0	18, 21
Wells...........	0	41
Winnemucca....	0	18, 21
Yerington.......	0	23

NEW HAMPSHIRE

	V.H.F. Channel No.	U.H.F. Channel No.
Berlin..........	0	26
Concord........	0	31, 33
Laconia.........	0	35
Littleton-Bethlehem....	0	40
Manchester.....	9	29
Portsmouth.....	0	39, 41

NEW JERSEY

Asbury Park....	0	46 (e)
Atlantic City....	0	23, 25, 27
Newark.........	13	0
New Brunswick..	0	48 (e)
Trenton........	0	15, 17, 41
Vineland........	0	39

NEW MEXICO

Alamogordo.....	0	19, 21
Albuquerque....	2, 4, 5, 7	0
Artesia.........	0	26, 28
Belen...........	0	22, 24
Bernalillo.......	0	20
Carlsbad........	10	22, 24
Carrizoza.......	0	42
Chama..........	0	43
Clayton.........	0	27
Clovis..........	12	14, 16
Dawson.........	0	41
Deming.........	0	23, 25
Farmington.....	0	21
Ft. Summer.....	0	43
Gallup..........	3, 10	17, 19
Hachita........	0	37
Hobbs..........	0	15, 17
Hot Springs.....	0	31, 33
Laguna.........	0	28
Las Cruces......	0	27, 29
Las Vegas.......	0	17
Lordsburg.......	0	43, 45
Los Alamos.....	0	34
Lovington.......	0	30
Magdalena......	0	35

NEW MEXICO (Cont.)

	V.H.F. Channel No.	U.H.F. Channel No.
Park View	0	36
Portales	0	18, 20
Raton	0	35, 37
Roswell	3, 6, 8	34, 36
Roy	0	44
Santa Fe	9, 11, 13	30, 32
Santa Rita	0	20
Santa Rosa	0	25
Silver City	12	18
Socorro	0	14, 16
Taos	0	15
Tucumcari	0	29, 31
Vaughn	0	45
Willard	0	39

NEW YORK

	V.H.F. Channel No.	U.H.F. Channel No.
Albany-Schenectady-Troy	4	42, 44
Auburn	0	18
Batavia	0	36
Binghamton	12	23, 25
Buffalo-Niagara	2, 4, 7	27
Dunkirk	0	31
Elmira-Corning	0	14, 16
Hornell	0	39
Ithaca	0	37
Jamestown	0	17
Malone	0	30
Massena	0	21
Middletown	0	35
New York City-Northeastern N. J.	2, 4, 5, 7, 9, 11	0
Ogdensburg	0	34
Olean	0	19
Oneonta	0	27
Oswego	0	20
Plattsburg	0	32
Poughkeepsie	0	40
Rochester	5	22, 32, 44
Saranac Lake	0	39

	V.H.F. Channel No.	U.H.F. Channel No.
Syracuse	3, 8, 10	0
Tupper Lake	0	19
Utica-Rome	13	33
Watertown	0	41, 43

NORTH CAROLINA

Ahoskie	0	39
Asheville	0	14, 18
Belhaven	0	20
Charlotte	3, 9, 11	0
Durham	0	33, 35
Elizabeth City	0	31
Fayetteville	0	38, 40
Gastonia	0	42
Goldsboro	0	26
Greensboro	2	41, 43, 45
Greenville	0	36
Henderson	0	18
Hendersonville	0	20
Hickory	0	34
High Point	0	23, 25
Jacksonville	0	22
Kannapolis	0	19
Kinston	0	42
Lenoir	0	36
Morehead City	0	45
New Bern	0	32
Raleigh	0	28, 30
Rocky Mount	0	24
Salisbury	0	21
Shelby	0	44
Washington	0	34
Wilmington	5	14, 16
Wilson	0	44
Winston-Salem	6, 13	17

NORTH DAKOTA

Ashley	0	36
Bismarck	5, 7, 12	20, 22
Bottineau	0	32
Bowman	0	43, 45
Carrington	0	17
Cooperstown	0	28
Crosby	0	36, 38

	V.H.F. Channel No.	U.H.F. Channel No.		V.H.F. Channel No.	U.H.F. Channel No.
Devils Lake	0	19	Steubenville	0	22
Dickinson	2, 4, 9	0	Toledo	13	39, 43
Fargo	6, 10, 13	14, 16, 18	Youngstown	0	14, 16, 18
Ft. Yates	0	29	Zanesville	0	15
Grafton	0	26, 30			
Grand Forks	2, 4, 8	33, 35, 39		OKLAHOMA	
Harvey	0	44	Ada	0	20
Hettinger	0	32, 34	Altus	0	16
Jamestown	0	25	Alva	0	23
Kenmore	0	30	Ardmore	0	32
Langdon	0	41, 43	Bartlesville	0	14
Larimore	0	45	Beaver	0	36
Mandan	0	33, 35, 37	Boise City	0	30
Minot	3, 6, 10	16, 18	Chickasha	0	45
Napoleon	0	27	Clinton	0	31
New Rockford	0	15	Duncan	0	35
Oakes	0	40, 42	Durant	0	40
Rolla	0	23	Elk City	0	14
Rugby	0	21	El Reno	0	22
Stanley	0	42	Enid	13	15
Stanton	0	14	Frederick	0	27
Valley City	0	31	Guthrie	0	24
Wahpeton	0	34	Guymon	0	20
Williston	8, 11	23, 25, 27	Hobart	0	25
			Hugo	0	29
	OHIO		Lawton	10	18
Akron	0	25, 36, 38	McAlester	0	34
Canton	0	32, 34	Miami	0	36
Chillicothe	0	37	Muskogee	8	23
Cincinnati	4, 7, 11	22, 24	Norman	0	41
Cleveland	4, 5, 8, 11	40, 42	Okeene	0	29
Columbus	3, 6, 10	0	Oklahoma City	4, 7, 9	0
Dayton	5, 13	14, 16	Okmulgee	0	28
Gallipolis	0	27	Ponca City	0	27
Hamilton-			Seminole	0	43
Middletown	2	34	Shattuck Junc	0	40
Lima	0	28, 30	Shawnee	0	30
Mansfield	0	21, 23	Stillwater	0	17
Marion	0	33, 35	Tulsa	2, 6, 11	0
Newark	0	29	Woodward	0	45
Portsmouth	0	18, 20			
Sandusky-				OREGON	
Fremont	0	17	Albany	0	25
Springfield	0	26, 44	Ashland	0	19, 21

OREGON (Cont.)

	V.H.F. Channel No.	U.H.F. Channel No.
Astoria	0	26
Baker	0	16
Bend	0	28, 35
Burns	0	21, 42
Canyon City	0	14
Condon	0	22
Coquille	0	24, 26
Corvallis	0	23
Enterprise	0	40
Eugene	0	14, 16
Gold Beach	0	40
Grants Pass	0	36, 38
Hepner	0	41, 43
Hood River	0	36
Kinzua	0	18
Klamath Falls	2, 4	32, 34
La Grande	3, 13	0
Lakeview	0	20, 27, 29
McMinnville	0	44
Madras	0	39
Marshfield (Coos Bay)	0	22, 29
Medford	5, 7	15, 17
Newport	0	42
Ontario	0	20
Pendleton	0	24
Portland	3, 6, 8, 10 12	17
Pineville	0	30
Redmond	0	45
Reedsport	0	18
Roseburg	0	31, 33
Salem	0	32, 34
Sprague River	0	41, 43
The Dalles	0	27
Tillamook	0	19, 21
Westfir	0	37

PENNSYLVANIA

	V.H.F. Channel No.	U.H.F. Channel No.
Altoona	0	15
Du Bois	0	43
Easton-Allentown-Beth.	0	19, 21
Emporium	0	33
Erie	12	45
Greensburg	0	48
Harrisburg	0	22, 42
Hazleton	0	38
Johnstown	6, 13	21
Lancaster	4	26, 28
Lebanon	0	24
Lewistown	0	40
Meadville	0	47
New Castle	0	30
Philadelphia	3, 6, 10	44
Pittsburgh	3, 9	24, 26
Reading	0	34, 36
Scranton-Wilkes-Barre	0	31, 45
Uniontown	0	46
Williamsport	0	29
York	0	18, 20

RHODE ISLAND

	V.H.F. Channel No.	U.H.F. Channel No.
Providence	11	15, 17

SOUTH CAROLINA

	V.H.F. Channel No.	U.H.F. Channel No.
Anderson	0	33
Barnwell	0	25
Bennettsville	0	15
Charleston	2, 8, 13	28, 30
Columbia	4, 7, 10	39
Florence	0	27
Georgetown	0	18
Greenville	0	38, 40
Greenwood	0	31
Myrtle Beach	0	37
Orangeburg	0	45
Rockhill	0	29
Seneca	0	35
Spartanburg	0	22, 24
Sumter	0	32
Walterboro	0	34

SOUTH DAKOTA

	V.H.F. Channel No.	U.H.F. Channel No.
Aberdeen	3, 9	26, 30
Belle Fourche	0	20

	V.H.F. Channel No.	U.H.F. Channel No.		V.H.F. Channel No.	U.H.F. Channel No.
Brookings	0	41, 43, 45	Lewisburg	0	29
Buffalo	0	30	Lexington	5	0
Chamberlin	0	23	Memphis	4, 6, 8, 10, 13	0
Custer	0	16			
Deadwood	0	35	Morristown	0	43
Dupree	0	17	Murfreesboro	0	14
Edgemont	0	39, 41	Nashville	2, 4, 7, 11	0
Gettysburg	0	19	Paris	0	19
Hot Springs	0	33	Pulaski	0	38
Huron	0	32, 35	Shelbyville	0	31
Lake Andes	0	27	Springfield	0	23
Lead	0	27	Tullahoma	0	33
McIntosh	0	24	Union City	0	28
Madison	0	37, 39	Winchester	0	18
Martin	0	31			
Mobridge	0	39, 41		TEXAS	
Miller	0	15	Abilene	9	24
Mitchell	4, 8	0	Alice	0	19
Phillip	0	14	Alpine	12	0
Pierre	6, 10	0	Amarillo	2, 4, 5, 7, 10	0
Pine Ridge	0	43, 45			
Rapid City	7, 12	0	Athens	0	41
Sioux Falls	11, 13	14, 16, 18	Austin	0	26, 28, 30
Sisseton	0	44	Ballinger	0	36
Vermillion	0	31, 33	Bay City	0	16, 40
Watertown	0	22, 24	Beaumont-		
White River	0	21	Port Arthur	4, 6	26, 33, 39
Winner	0	42, 44	Beeville	0	25
Yankton	0	25, 29	Big Spring	0	25
			Borger	0	15
	TENNESSEE		Brackettville	0	29
Bristol	0	26	Brady	0	19
Chattanooga	3, 9, 12	0	Breckenridge	0	17
Clarksville	0	42	Brenham	0	19
Cleveland	0	30	Brownfield	0	37
Columbia	0	21	Brownsville	4, 5, 9	0
Cookeville	0	37	Brownwood	0	21
Dyersburg	0	30	Bryan	0	14
Fayetteville	0	16	Cameron	0	32
Harriman	0	17	Canadian	0	28
Humboldt	0	35	Canyon	0	32
Jackson	0	24	Center	0	40
Johnson City	0	16	Childress	0	19
Knoxville	6, 10, 13	0	Clarendon	0	26
Lebanon	0	27			

TEXAS (Cont.)

	V.H.F. Channel No.	U.H.F. Channel No.		V.H.F. Channel No.	U.H.F. Channel No.
Cleburne	0	44	Kingsville	0	17
Coleman	0	43	La Grange	0	43
Colorado City	0	18	Lamesa	0	41
Corpus Christi	6, 10	31, 33	Lampasas	0	35
Cotulla	0	32	Laredo	3, 8	0
Crockett	0	22	Liberty	0	44
Crystal City	0	24	Littlefield	0	39
Cuero	0	20	Livingston	0	42
Dalhart	0	22	Longview	0	30
Dallas	4, 8, 12	0	Lubbock	11, 13	33, 35
Del Rio	0	18	Lufkin	0	35
Denton	0	36	McAllen	0	26
Dumas	0	45	Marfa	0	20, 25
Eagle Lake	0	29	Marshall	0	37
Eagle Pass	0	16	Mexia	0	34
Edinburg	0	21	Midland	0	29
El Campo	0	38	Mineola	0	21
Eldorado	0	33	Mineral Wells	0	42
El Paso	2, 4, 5, 7, 9	41, 44	Monahans	4	19
Falfurrias	0	23	Mount Pleasant	0	33
Ft. Davis	0	14	Nacogdoches	0	28
Ft. Stockton	0	31	Orange	0	18
Ft. Worth	2, 5, 10	0	Odessa	7	21
Fredericksburg	0	22	Ozona	0	45
Galveston	0	21, 24	Palestine	7	0
Graham	0	15	Paris	0	19
Greenville	0	24	Pampa	0	17
Gonzales	0	15	Pearsall	0	34
Hamilton	0	39	Pecos	0	27
Hamlin	0	28	Perryton	0	34
Harlingen	0	14	Plainview	0	23
Haskell	0	30	Presidio	0	16
Henrietta	0	23	Rankin	0	42
Hereford	0	42	Rio Grande	0	29
Hillsboro	0	25	Robstown	0	27
Houston	2, 8, 11, 13	0	Rocksprings	0	20
Huntsville	0	17	Rosenberg	0	36
Jacksonville	0	15	Sabinal	0	44
Jasper	9	0	Sanderson	0	23
Junction	0	27	San Angelo	2, 6	0
Kermit	0	38	San Antonio	4, 5, 7, 9, 12	0
Kerrville	0	17, 31	San Benito	0	34
Kilgore	0	43	San Diego	0	37

	V.H.F. Channel No.	U.H.F. Channel No.		V.H.F. Channel No.	U.H.F. Channel No.
San Marcos	0	45	Loa	0	45
Seguin	0	41	Logan	0	30, 32
Seymour	0	34	Milford	0	32
Shamrock	0	21	Moab	0	20
Sherman	0	14	Monticello	0	23
Sierra Blanca	0	32	Nephi	0	18
Snyder	0	22	Ogden	12	34, 38, 40
Sonora	0	15	Panguitch	0	42
Spur	0	44	Parowan	0	15
Stanford	0	20, 40	Price	11, 13	0
Stephenville	0	29	Provo	0	21, 24
Sterling City	0	16	Richfield	0	22
Sulphur Springs	0	26	St. George	0	38
Sweetwater	12	14, 32	Salina	0	35
Taylor	0	23	Salt Lake City	2, 4, 5, 7, 9	0
Temple	0	37	Tooele	0	27
Terrell	0	38	Vernal	0	33
Texarkana (see Arkansas)					
Tyler	0	45	**VERMONT**		
Uvalde	0	14	Brattleboro	0	18
Van Horn	0	18	Burlington	0	15, 17
Vernon	0	38	Montpelier	3	20, 22
Victoria	0	18	Newport	0	38
Waco	0	16, 18	Rutland	0	37
Waxahachie	0	31	St. Albans	0	24
Weslaco	0	42			
Wichita Falls	3, 6	0	**VIRGINIA**		
			Charlottesville	0	32
UTAH			Covington	0	29
			Danville	0	37
Beaver	0	19	Emporia	0	27
Brigham	0	42	Fredericksburg	0	41, 45
Castle Dale	0	14	Harrisonburg	0	36
Cedar City	5	17	Lexington	0	42
Duchesne	0	31	Lynchburg	0	14, 16
Ephraim	0	28	Martinsville	0	31
Escalante	0	25	Norfolk-Portsmouth-Newport News	4, 10, 12	25, 29
Fillmore	0	37	Norton	0	32
Green River	0	43	Petersburg	0	21
Heber	0	16	Pulaski	0	39
Hurricane	0	21	Richmond	3, 6, 8	15, 17, 19
Hyrum	0	20			
Kanab	0	44			
Lehi	0	44			

VIRGINIA (Cont.)

	V.H.F. Channel No.	U.H.F. Channel No.
Roanoke	7, 10	20, 22
Staunton	0	34
Suffolk	0	23
Waynesboro	0	38
Winchester	0	25

WASHINGTON

Aberdeen	0	22
Bellingham	0	21, 23
Bremerton	0	39, 41
Centralia	0	24
Chehalis	0	28
Colfax	0	28
Colville	0	45
Ellensburg	0	42
Ephrata	0	17
Everett	0	43, 45
Goldendale	0	29
Grand Coulee	0	27
Kennewick	0	26
Longview	0	40
Metaline Falls	0	29
Moses Lake	0	44
Mt. Vernon	0	19
Olympia	0	18
Omak	0	25
Oroville	0	32
Pasco	0	19
Port Angeles	0	32, 34
Pullman	0	30
Puyallup	0	20
Republic	0	40
Ritzville	0	23
Seattle	4, 5, 7, 11	14, 16
Sheldon	0	30
Spokane	2, 4, 5, 7	0
Sunnyside	0	15
Tacoma	9, 13	0
Vancouver	0	38
Walla Walla	6, 8, 10	38
Waterville	0	35
Wenatchee	0	37
Yakima	0	31, 33

WEST VIRGINIA

	V.H.F. Channel No.	U.H.F. Channel No
Beckley	4	0
Bluefield	0	15
Charleston	8, 12	30, 40
Clarksburg	0	17
Elkins	0	23
Fairmont	0	31
Hinton	0	24
Huntington-Ashland	5	25
Martinsburg	0	27
Montgomery	0	34
Parkersburg	0	43, 45
Sutton	0	33
Weston	0	19
Wheeling	7	28, 41

WISCONSIN

Antigo	0	22
Appleton	0	28
Ashland	0	42
Beloit	0	18
Eau Claire	0	27, 29
Fond du Lac	0	21
Green Bay	0	40, 42
Hayward	0	36
Janesville	0	39
Kenosha-Racine	0	32, 34, 36
Ladysmith	0	45
La Crosse	0	41, 43
Madison	0	14, 23, 25
Marshfield	0	35
Medford	0	15
Merrill	0	19
Milwaukee	3, 6, 8, 10	0
Oshkosh	0	16, 31
Prairie du Chien	0	30
Rhinelander	0	39
Rice Lake	0	23
Shawano	0	44
Sheboygan	0	38
Sparta	0	17
Stevens Point	0	24, 26

	V.H.F. Channel No.	U.H.F. Channel No		V.H.F. Channel No.	U.H.F. Channel No.
Superior-Duluth	3, 6, 8, 10, 12	0	Kemmerer	0	23
Warsaw	0	37	Lander	0	16
Whitehall	0	20	Laramie	0	19, 21
Wisconsin Rapids	0	33	Lusk	0	26
			Midwest	0	32, 34
WYOMING			Newcastle	0	23
			Pinedale	0	14
Basin	0	38	Powell	0	27
Buffalo	0	22	Rawlins	0	17
Casper	3, 6, 8	24	Riverton	10	18, 20
Cheyenne	11, 13	14, 16	Rock Springs	0	25
Cody	0	23, 25	Sheridan	9, 11, 13	15, 17
Douglas	0	36	Sundance	0	25
Evanston	0	36	Superior	0	29
Gillette	0	40	Thermopolis	0	45
Green River	0	41	Torrington	0	44
Hanna	0	15	Wheatland	0	28, 30
Jackson	0	44	Worland	0	31, 33

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