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 two years, since the appearance of the first edition, sufficient advances have been made to warrant a complete revision.

The presentation in the revised edition follows exactly the pattern established in the previous edition. 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, is carefully noted.

An entire chapter (No. 13) 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 discussion readily.

The genuine test of how well knowledge has been acquired is in its application to actual 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 four major sections and, from the facts previously presented, the servicing and repairing of the majority of troubles are 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 material presented. 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 acknowledgement is due to the Radio Corporation of America, the Allen B. DuMont Laboratories, Inc., the Rauland Manufacturing Company, the Farnsworth Television and Radio Corporation, the General Electric Company, 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 Morton Whitman, electronic engineer, who spent many hours proofreading the manuscript and offering suggestions on methods of presentation. 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.

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CHAPTER I

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* controls at the front of the receiver is kept as low as possible, generally not more than three or four. One control regulates the background brightness, another permits proper focusing 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.

Besides the three television controls just mentioned, three

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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 addi-
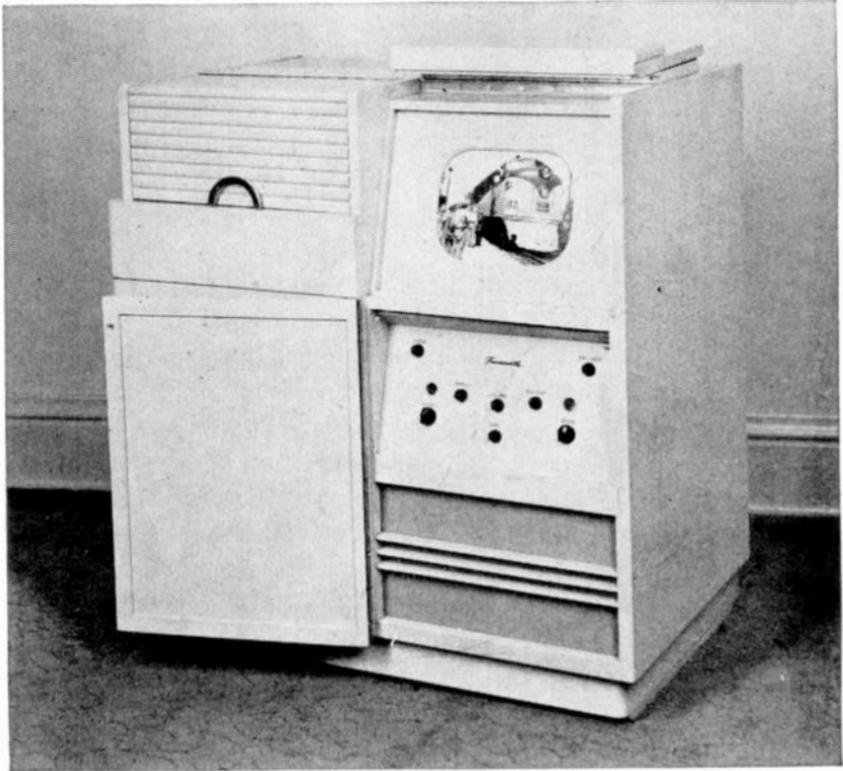
FIG. 1.1. A modern television receiver.

tion 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 per-

mits 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.

Of the remaining two controls that are on the front panel, one is for volume and the other for tone. 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 satis-
factory.

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 am-
plitude-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
with the beam in the camera tube, synchronizing pulses are in-
serted 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 trans-
mitter.   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 cor-
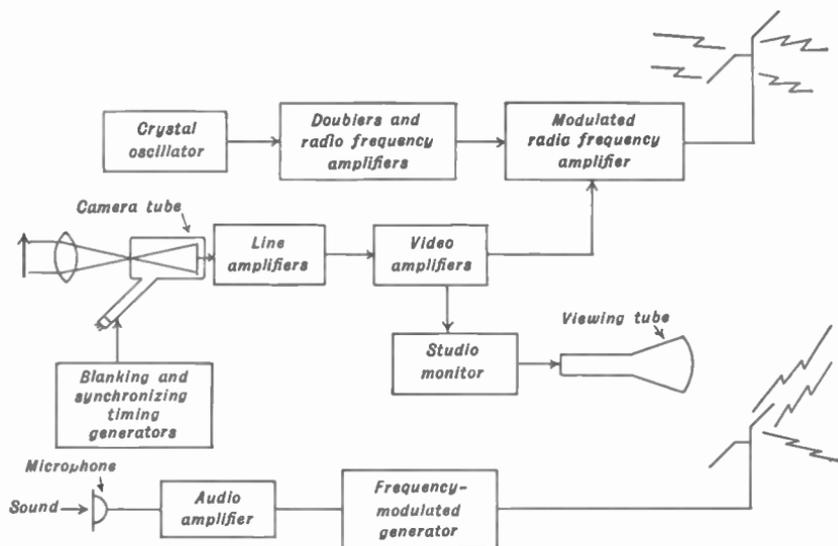
FIG. 1.2. An outline of a modern television transmitter.

respondence 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 televised is kept separate from the video electrical currents. The sound is frequency modulated and sent out by another transmitter at a frequency that lies close to the edge of the band of frequencies utilized by the image signals. So far as the transmitters are concerned, two separate units are necessary; one for the sound, the other for the light rays.

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
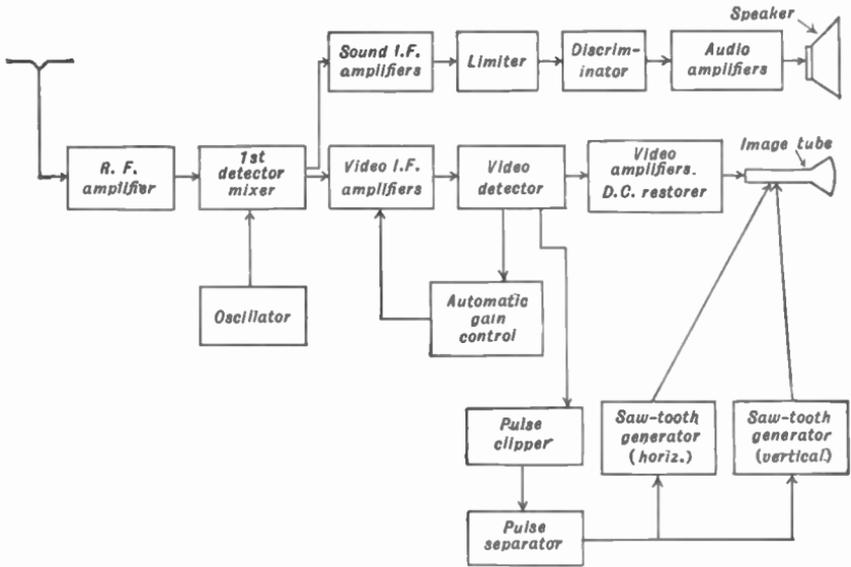I.F. amplifiers.

Fig. 1.3.   A block diagram of the components of commercial television receivers.

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 varia-
tions.   A brief description of the operation of F-M receivers
will be given in Chapter 13.   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 becomes 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, 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 number 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 continuous.

FIG. 1.4. A television studio scene developed from an ordinary negative.

However, if the picture is further and further enlarged, a point is soon reached where the granular structure of the picture does become visible. These grains, then, are the elements 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 television 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 impinging 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-


Courtesy Farnsworth

FIG. 1.5. An Iconoscope camera tube.

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.

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 consists of a thin sheet of mica (an insulator) upon the front of
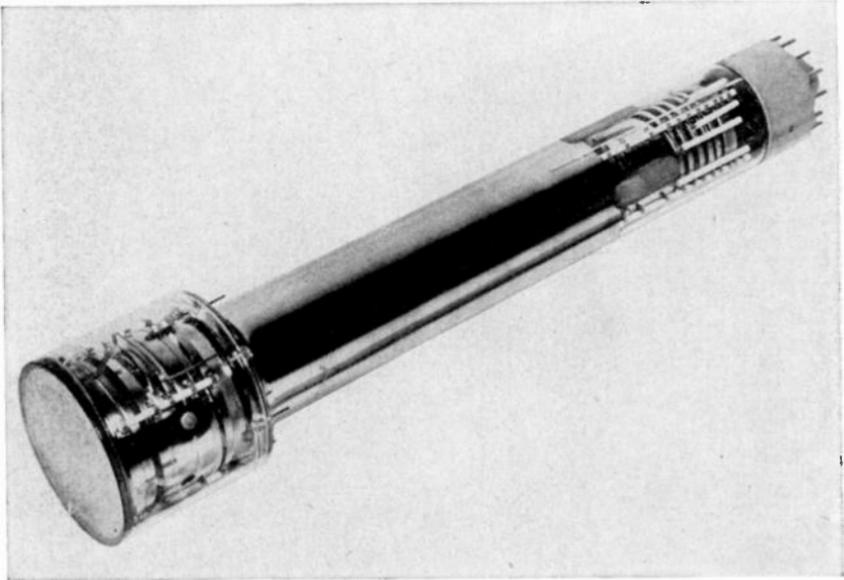
Courtesy RCA

FIG. 1.6. An Image-Orthicon Camera tube.

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 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 glob-
ule forms one separate plate, with the back side of the mica act-
ing as the common second plate for all the globules. The di-
electric is the mica.

The object is focused on the front face of the plate (commonly
called the mosaic). Due to their silver-caesium composition,
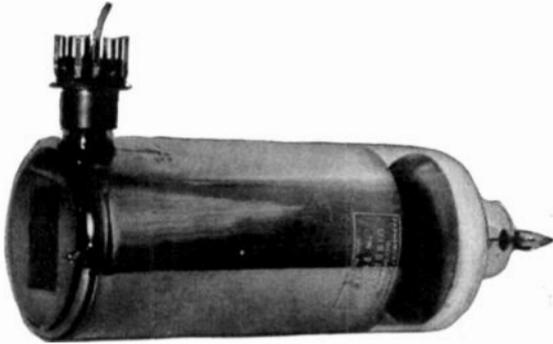the globules emit electrons in proportion to the light intensity

FIG. 1.7.   Farnsworth Image Dissector tube.

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-
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 correspond-
ing photographic process of taking a picture is noteworthy.
With more globules deposited on the mosaic, it should be pos-

sible 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 repro-
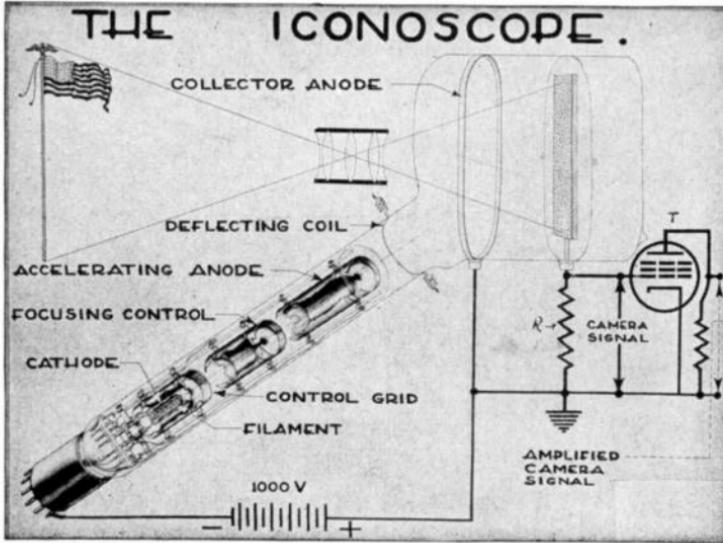

FIG. 1.8. The internal construction of an Iconoscope. The neck of the tube has been purposely enlarged out of proportion with the rest of the drawing to illustrate the construction of the elements of the electron gun.

duction 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 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 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 de-
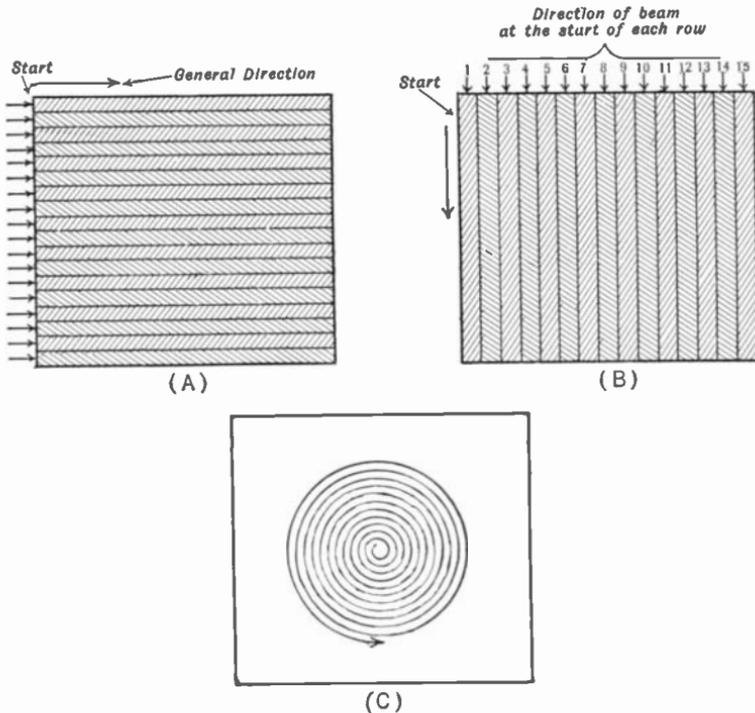

Fig. 1.9.   Three possible methods of scanning an image: Horizontal scanning at (A), vertical scanning at (B) and spiral scanning at (C).

veloped 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 repe-

tition.   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.

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

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
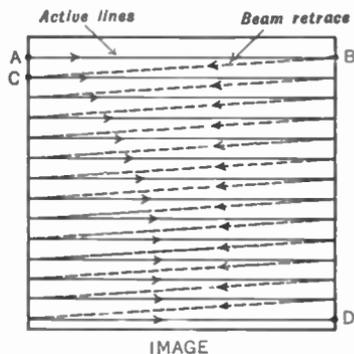
time of the operation of the electron gun located in the neck of the Iconoscope, let us state simply that the horizontal deflection coils can move the electron beams horizontally across the screen from left to right and back again. The vertical deflection coils can cause the beam to move vertically. 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.

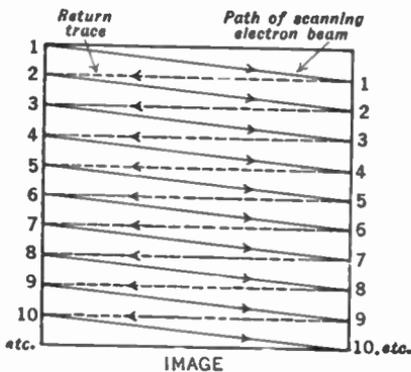In the foregoing type of motion, with the beam moving across the screen slantwise, we have the equivalent of a fast-acting voltage on the horizontal plates quickly forcing the beam straight across, while a slow-acting voltage at the vertical plates is forcing the beam down. The result is pictured in Fig. 1.11. When the beam reaches the end of a line, it is quickly brought 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.

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.

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 saw-tooth wave gen-
erators 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

Fig. 1.12.   A saw-tooth current, as illus-
trated 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.

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 tak-
ing, on the average, about $\frac{1}{50}$ 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 abso-
lute, 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
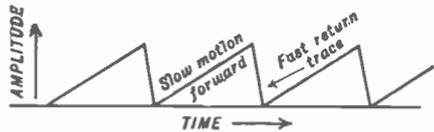rate, flicker is somewhat noticeable, a shutter in the projection

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.
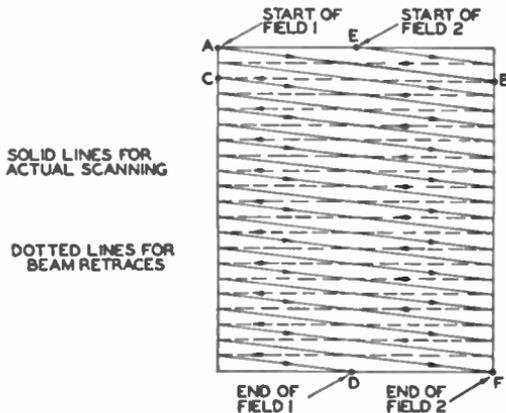

FIG. 1.13. The path of the electron beam in interlaced scanning.

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 $262\frac{1}{2}$ 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 scanning, each frame is broken up into an even-line field and an odd-line field. Each field contains $262\frac{1}{2}$ 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 $262\frac{1}{2}$ lines from its beginning to the start of the next field and, when the beam reaches point E, it has moved through the necessary $262\frac{1}{2}$ 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 $262\frac{1}{2}$ times in going from point A to point D to point E. The remaining $262\frac{1}{2}$ 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 announced 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
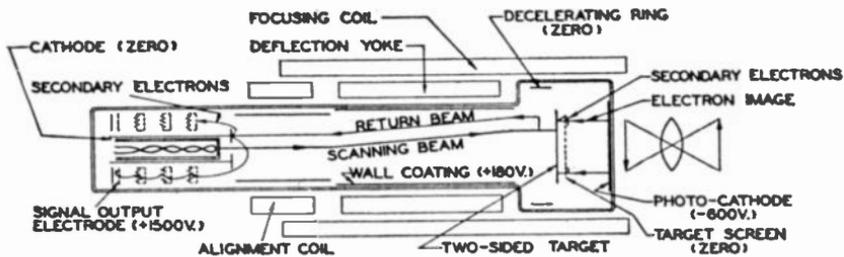emitted from each point in proportion to the incident light intens-

Fig. 1.14.   The internal construction of the Image Orthicon.

ity.   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 density
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 develop a pattern
of positive charges directly proportional to the distribution of
energy in the arriving electron image.   The target is not photo-
sensitive, but is capable of emitting secondary electrons.

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
electron 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 remainedr 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 disappears.

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

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.
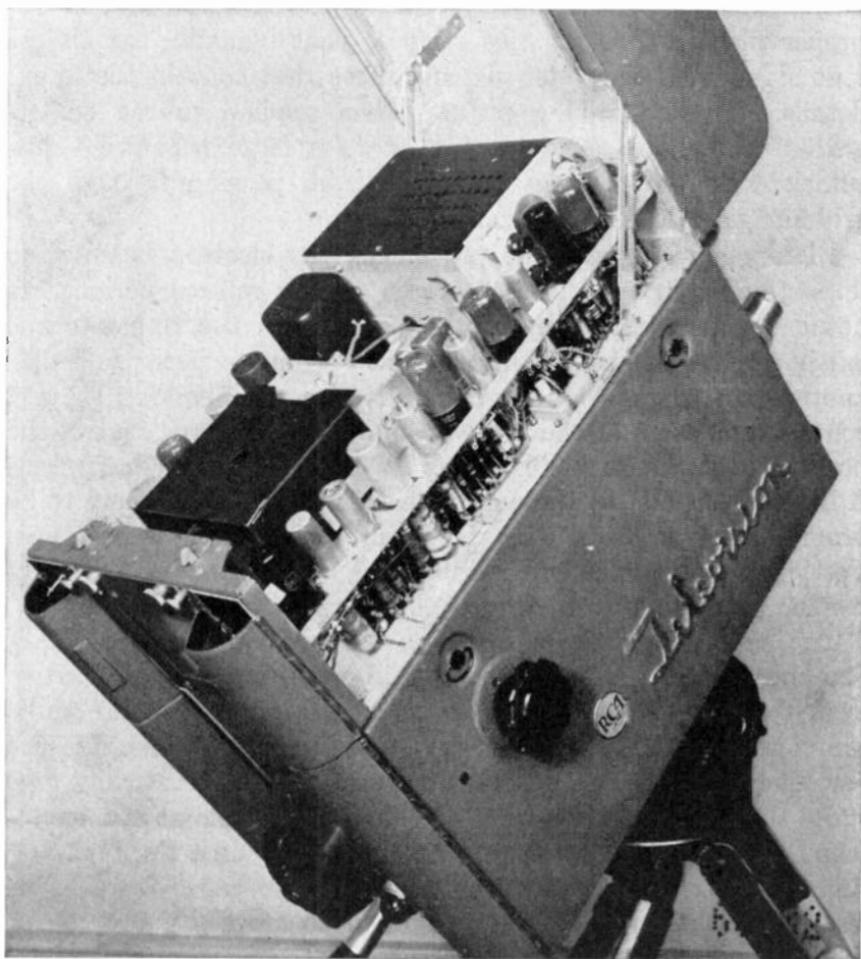

Courtesy NBC

Fig. 1.16.   A television studio camera in action.

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 the long connecting coaxial cables, they would be too small to override the inherent noise in the system by the time the transmitter 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 immediately and then sent into the connecting transmission line.

FIG. 1.17.   Inside view of a Portable Image Orthicon Camera.

Figs. 1.16 and 1.17 illustrate two examples of present-day television 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. 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, 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 instance) 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.

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
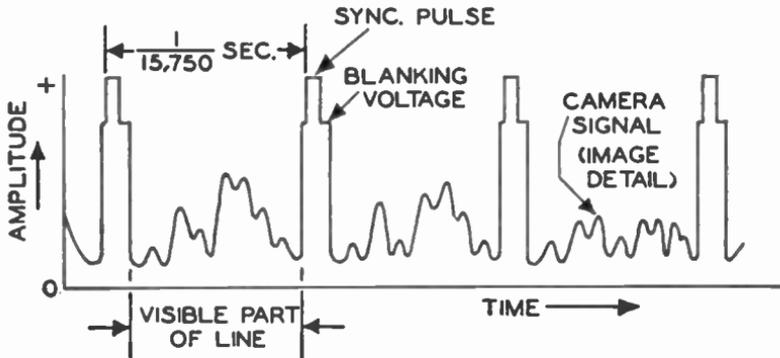

FIG. 1.18. The complete video signal for three scanned lines.

pulse and retrace require a longer period of time than the horizontal triggering and retrace, a longer blanking signal is inserted. As soon as the blanking signal takes hold, the vertical synchroniz-
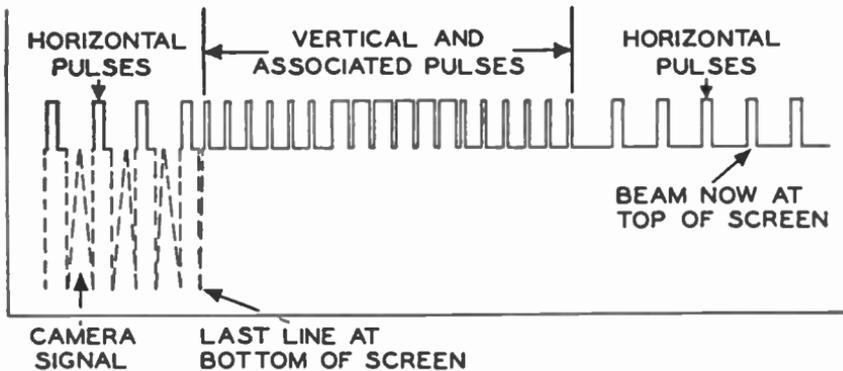

FIG. 1.19. The form of the vertical synchronizing pulses.

ing 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 possible to send both horizontal and vertical pulses at the same time, each being accurately separated at the receiver and transferred 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.
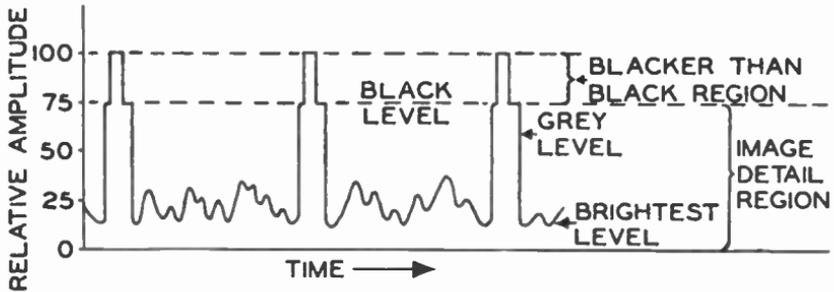

FIG. 1.20. The various proportions of a video signal.

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%) amplitude 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 com-
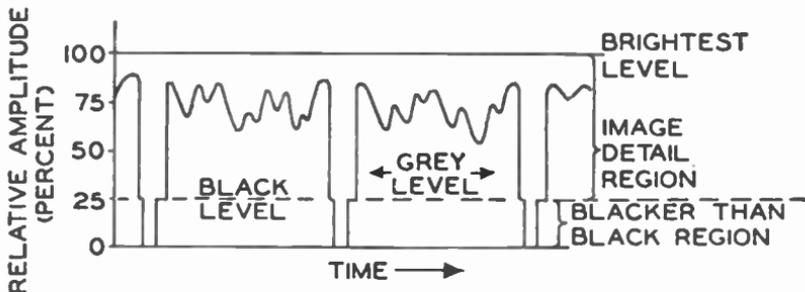

FIG. 1.21. The form of the video signal in positive transmission.

pletely 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 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.
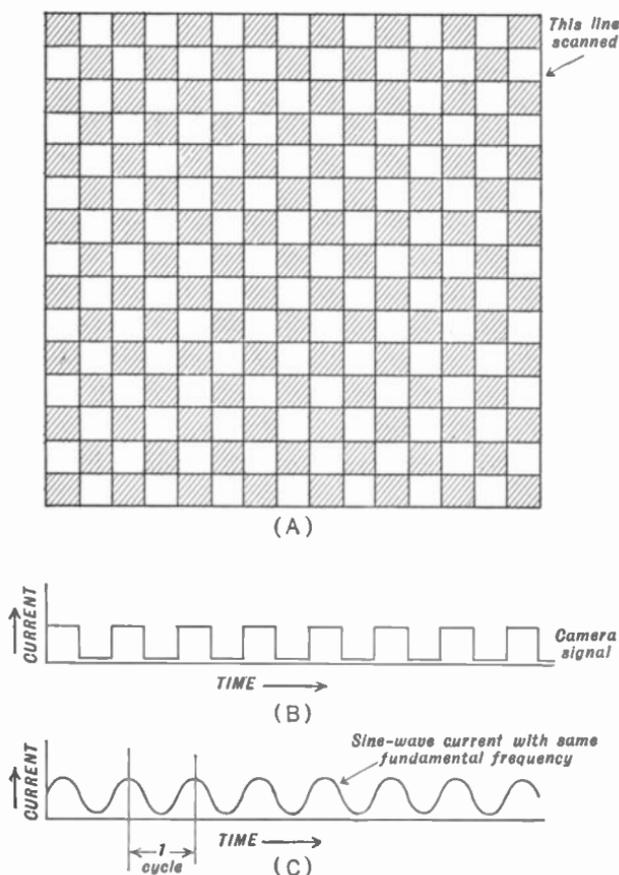

FIG. 1.22.   The basic relationship between the number of elements in an image and the width of the frequency band required.

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 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 carrier frequency is found 1.25 mc above the low-frequency
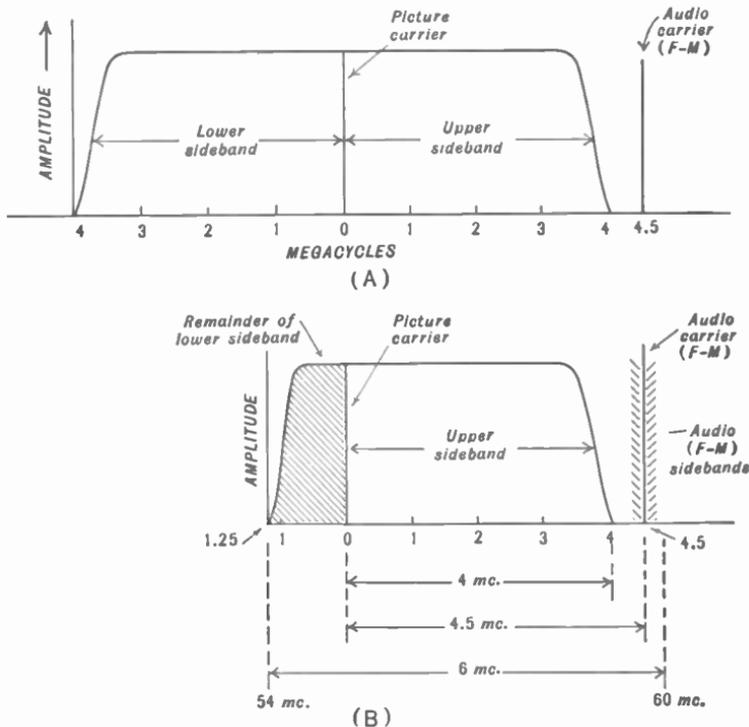

Fig. 1.23.   Double-side band (A) and vestigial-side band (B) transmission of television signals.   Method B is standard in the United States and represents the signal as sent.

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 interaction between the two, such as cross-modulation, which would 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 picture I.F. and video amplifiers, this is not easily attained in practice. 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 alloted space at the high frequencies, from 44 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 frequen-

cies 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. One such relay network already in operation is shown in Fig. 1.24. The main transmitter of station WRGB is located $12\frac{1}{2}$ airline miles from the studio. The programs originating in the studio are beamed to the main transmitter and from that location broadcast to the surrounding countryside. In addition, programs originating in New York City are picked up by the WRGB relay station and also beamed to the main transmitter.

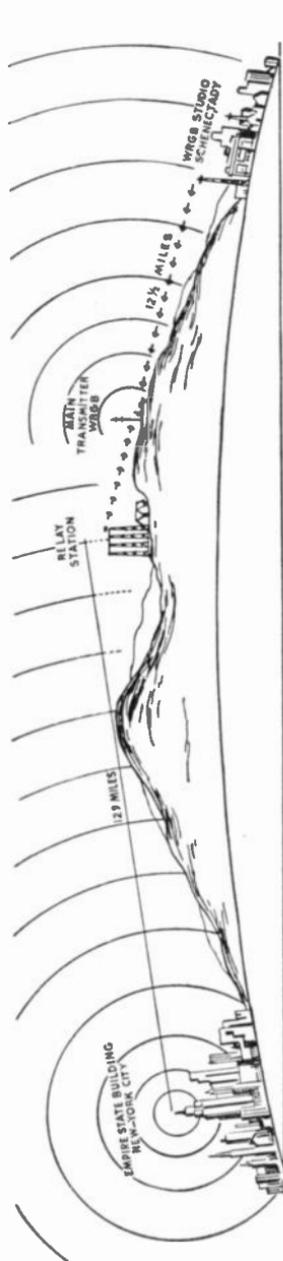Recently the Federal Communications Commission has removed

Fig. 1.24. A relay system in use by WRGB. Programs from New York City and Schenectady are beamed to the main transmitter and then rebroadcast.

the uncertainty regarding the future of the higher frequencies by making definite assignments up to 30,000 mc. While Table 1.1 shows the allocation of specific frequencies, the bands set aside for television are of greatest interest to us. These are numbered 1 through 13 for frequencies up to 216 mc. Each band is 6 mc in width. Others are in the 480 to 920 mc region and have not been given any specific band width. The F.C.C. left the question of band width up to the industry. Nothing will be decided upon until such time as it is felt that commercial television is in a position to utilize these additional frequencies.

For the present, channels 1 to 6 are the most practical and all broadcasting will remain here. Then, as the television art progresses, channels 7 to 13 will also be enveloped. Finally, for television that includes 1,000 or more lines per image, color and other refinements, the region from 480 to 920 is certain to assume greater prominence.

F-M for Audio Transmission. The F.C.C. has further issued regulations to the effect that F-M will be definitely employed for the audio portions of the television signal, and amplitude modulation for the video section 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
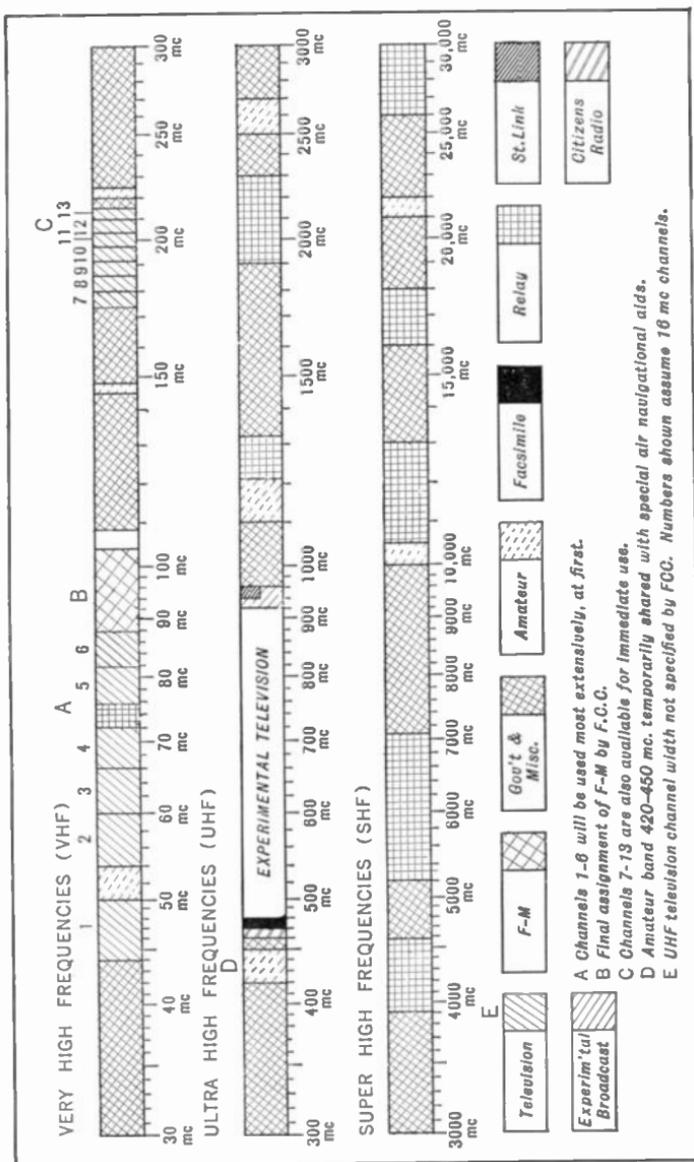
TABLE 1.1

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.

CHAPTER 2

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 difference.

On a television screen, the scanning beam has traveled a small distance by the time the reflected ray arrives at the receiver.
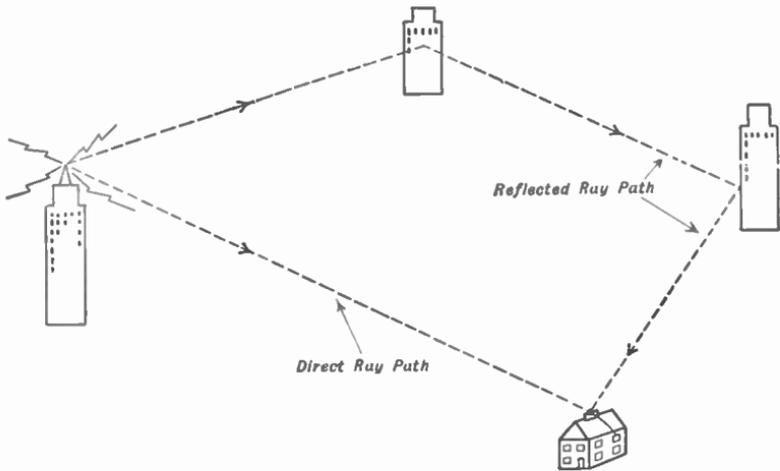
Fig. 2.1. The reflected-ray, along with the direct ray, arrive at the receiving antenna to form double images, called " ghosts."

Hence, the image contained in the reflected ray appears on the screen displaced some small distance from similar detail contained
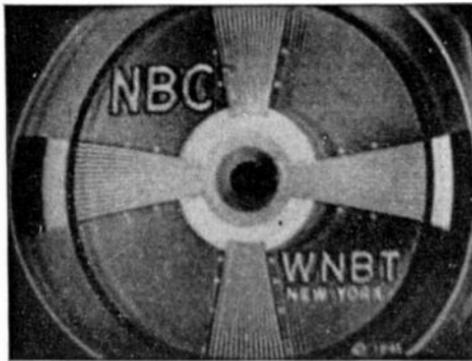

Fig. 2.2. A " ghost " image on a television viewing screen.

in the direct ray. The result is shown in Fig. 2.2. When the effect is pronounced, a complete double image is obtained and the

picture appears blurred.   To correct this condition, it is necessary
to change the position of the antenna until only the direct ray is
received.   The antenna should never be turned to favor the
reflected ray because the action of reflecting surfaces changes
almost daily and there is no certainty that a good signal 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 fre-
quencies 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 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 com-
plete (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 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

THE IONOSPHERE

Small angle

Large angle
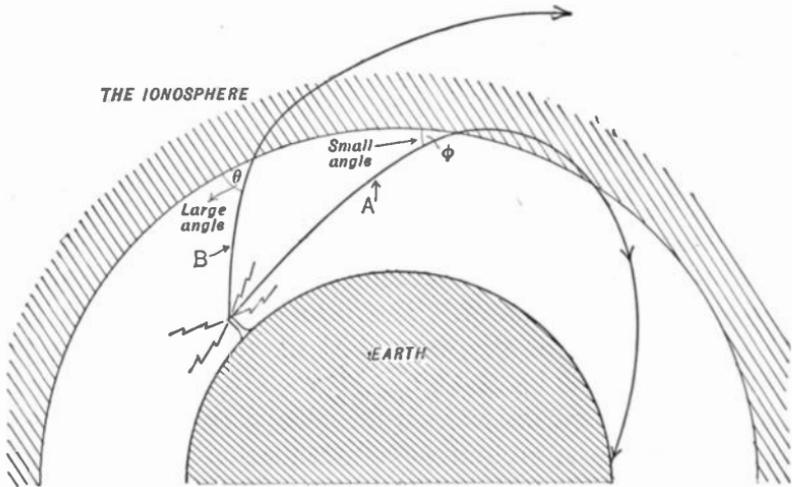
θ

ϕ

A

B

EARTH

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.

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 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.
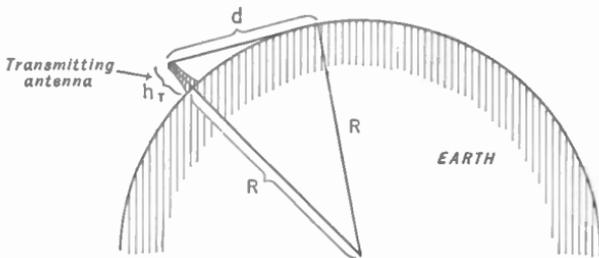

Fig. 2.4.   Illustrating how to compute the line-of-sight distance for high-frequency radio waves.

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 some-
what, it will be assumed that the earth, for that small section
under consideration, is flat.   This gives us a right triangle.
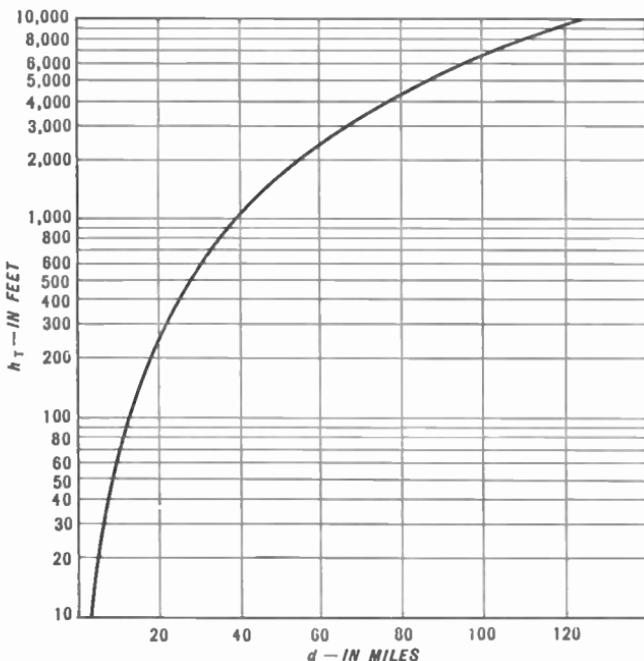
FIG. 2.5.   The relationship between the height of the transmitting antenna (in feet)
and the distance in miles from the antenna that the ray may be received.

From elementary geometry it is possible to write down the follow-
ing 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 pos-

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

sible 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 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 else may have
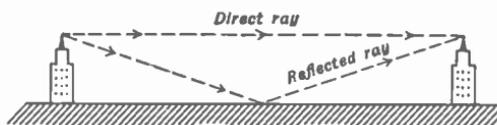

FIG. 2.7. The reflected radio wave, arriving at the receiving antenna after reflection from the earth, may lower the strength of the direct ray considerably.

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 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 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
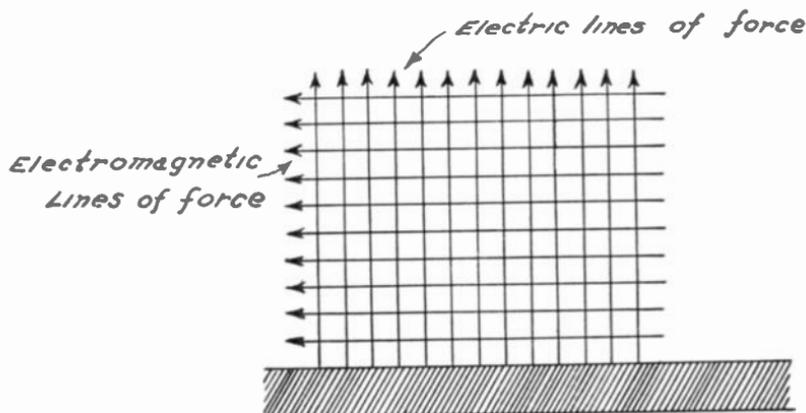

Fig. 2.8. The components of an electromagnetic wave. The wave travels at right angles to these lines of force. In this illustration, direction of travel is forward, out of the paper.

be vertically polarized. A horizontal antenna radiates a horizontally polarized wave. Experience has revealed that the greatest 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.

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 approaching 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.
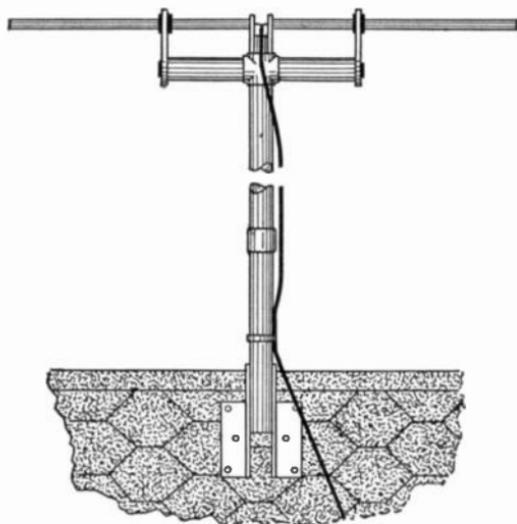

FIG. 2.9. Dipole antenna assembly used extensively for television receivers.

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 determine 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.
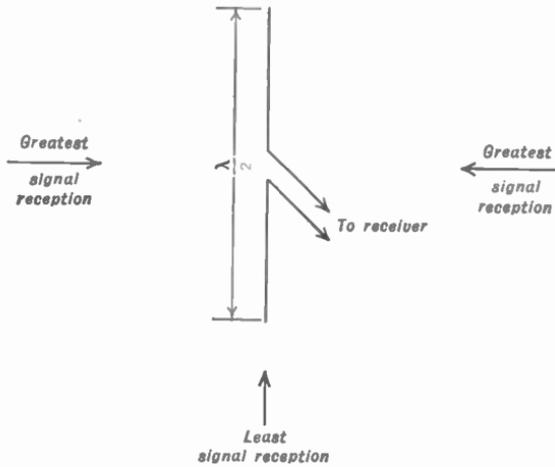
FIG. 2.10A.   Dipole antennas, of the type shown, received signals best from the directions indicated.
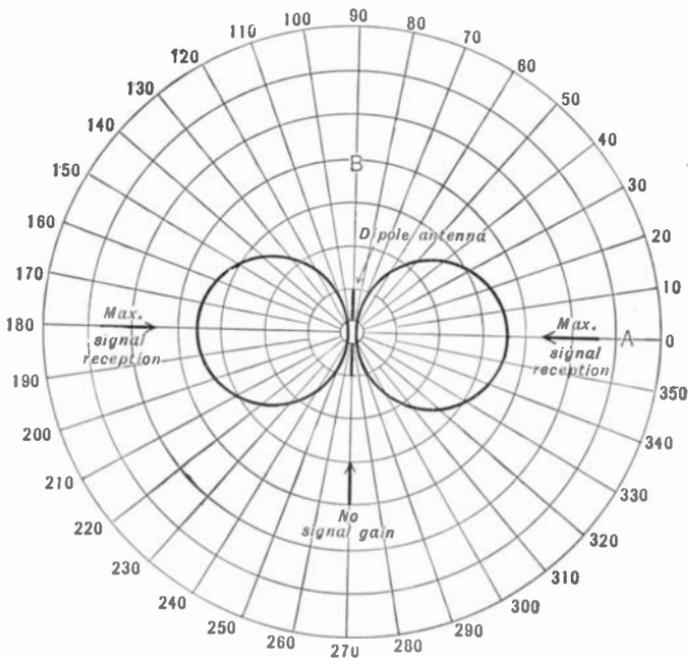

FIG. 2.10B.   The directional response curve of a dipole antenna.

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 44 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 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
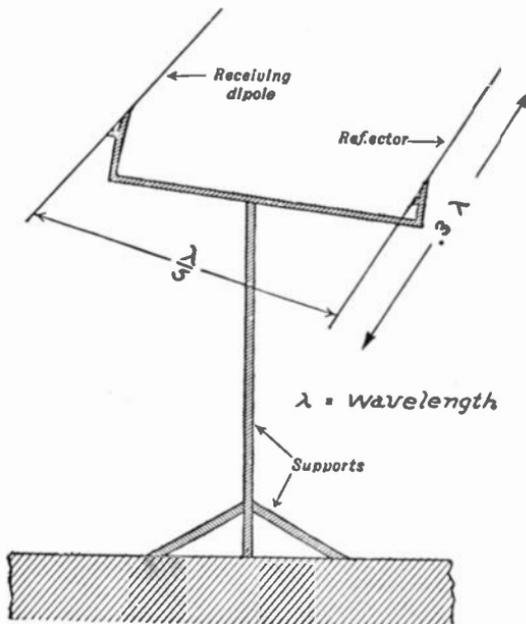
FIG. 2.11. Dipole receiving antenna and reflector. The distance between the reflector and the receiving dipole will be λ/5 at the frequency to which the antenna is cut.

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 ad-

vantageous 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
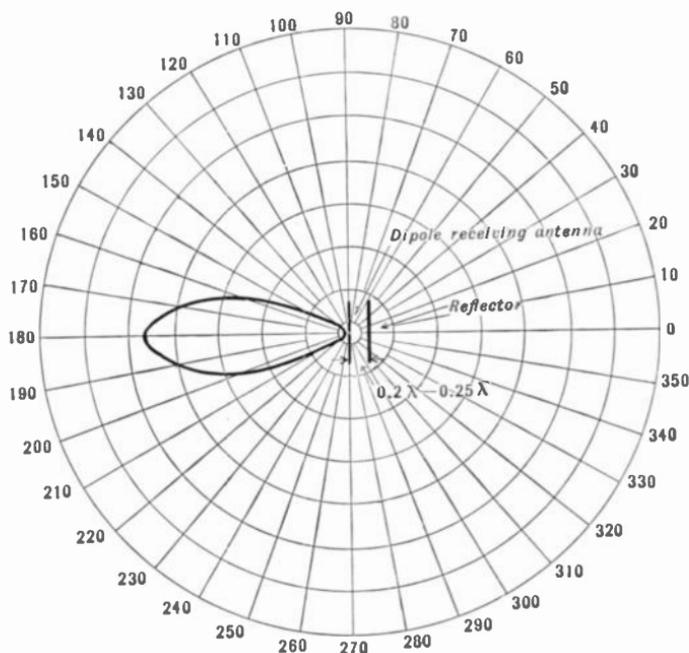
FIG. 2.12.   The directional response curve for a half-wave antenna with a reflector.

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

The two antenna systems described are the most widely used and recommended by television receiver manufacturers.   Other types are found, however, and the more popular of these are

shown in Fig. 2.13. Instructions for calculating their lengths are as follows:

1. *Folded Dipole*, Fig. 2.13A. This consists of two dipole

(A) Folded Dipole

(B) Folded Dipole with Reflector

(C) Cage Antenna

(D) Double-V Antenna

(E) Di-Fan Antenna

FIG. 2.13. Five types of popular antennas.

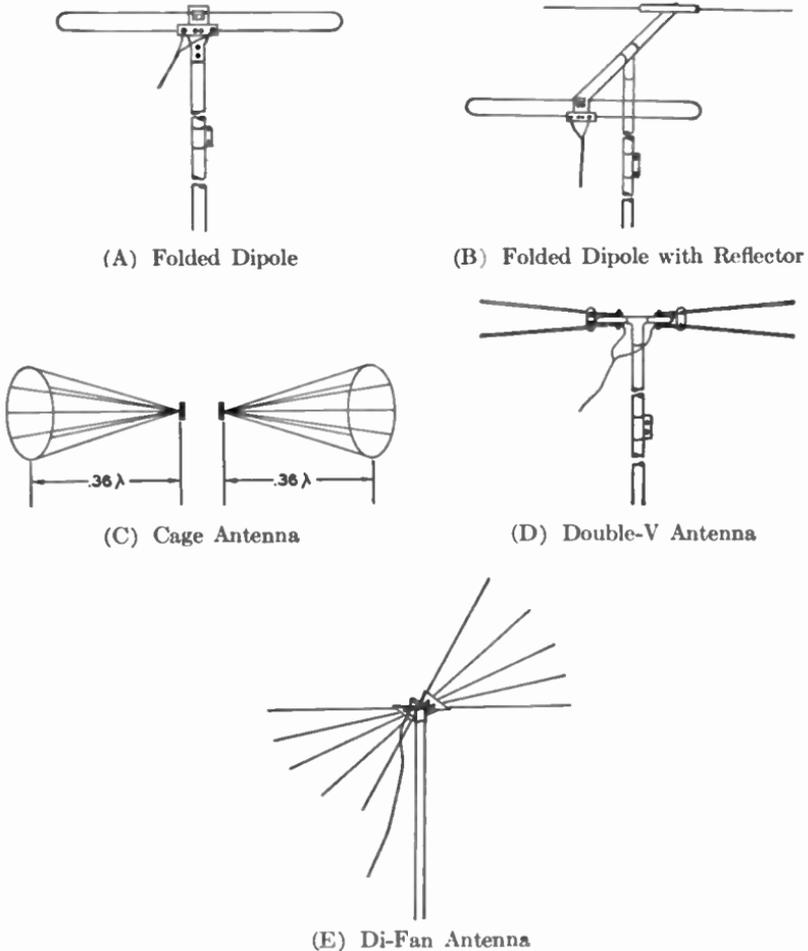antennas connected in parallel with each other. The total, overall length is twice that of a single dipole. The separation between the two sections is approximately 3 inches. The folded

dipole has the same bi-directional pattern as the simple dipole. Its gain, however, is greater.

2. *Folded Dipole with Reflector*, Fig. 2.13B.   The addition of a reflector has the same effect here as with the simple dipole. Reflector spacing and length are identical with the figures previously given for the simple dipole with reflector, Fig. 2.11.

3. *Cage Antenna*, Fig. 2.13C.   A bi-directional characteristic with greater gain than a simple dipole.   Actually, what we have here are 12 dipoles.   The length of each wire, from the center to one end, is $.36\lambda$ at the frequency for which this system is designed.

4. *Double-V Antenna*, Fig. 2.13D.   There are 4 rods or wires in this antenna, each one-quarter wavelength long.   Signals can be received from the front and rear of the array.

5. *The Di-Fan Antenna*, Fig. 2.13E.   Contains 10 wires or rods, 5 to each section of the array.   Excellent broad band response. Each wire is one-quarter wavelength long.

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 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.   However, when we attempt to use the same dipole for a band of frequencies, we find that the 72 ohms 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 higher value which will

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

(C) Twisted pair (Unshielded)   (D) Twisted pair (Shielded)
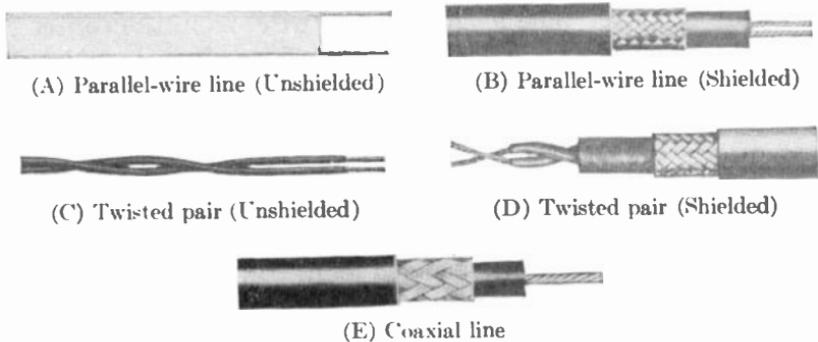
(E) Coaxial line

FIG. 2.14.   Various types of popular transmission lines used for F-M and television installations.

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 transmission 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 consists of 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 is un-
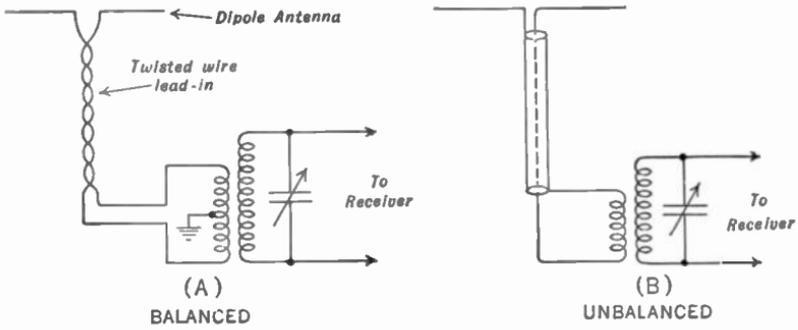
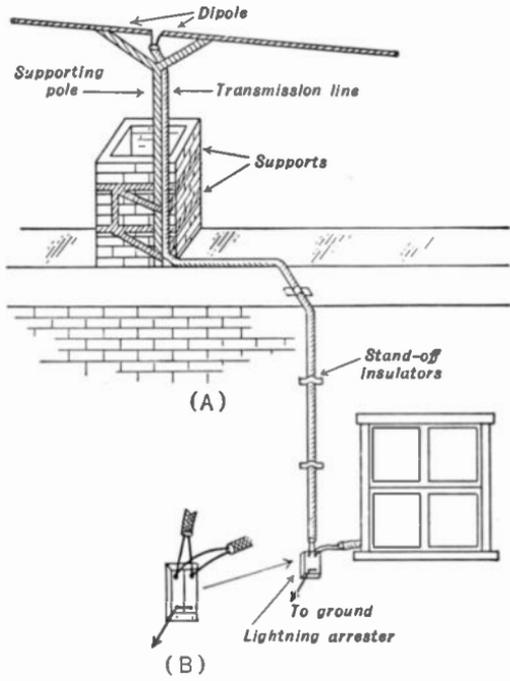FIG. 2.15. Methods of connecting lead-in wires to the input coil of a receiver.

FIG. 2.16. An antenna installation for a television receiver. The ground from the lightning arrester should be as short and direct as possible.

balanced 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 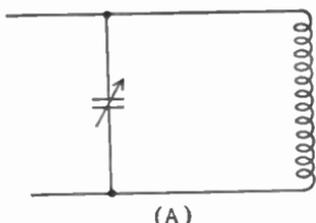response of the tuned receiving circuit should be uniform throughout the 6-mc band and yet be selective enough to discriminate against unwanted image frequencies or stations on adjacent bands. Before the circuits of the R.F. and mixer stages are considered, it will be helpful to discuss wide-band tuning 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 signal 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 impedance 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 a different value of Q. Q, which is the ratio of inductive reactance to coil resistance, may be taken to indicate two things:

64
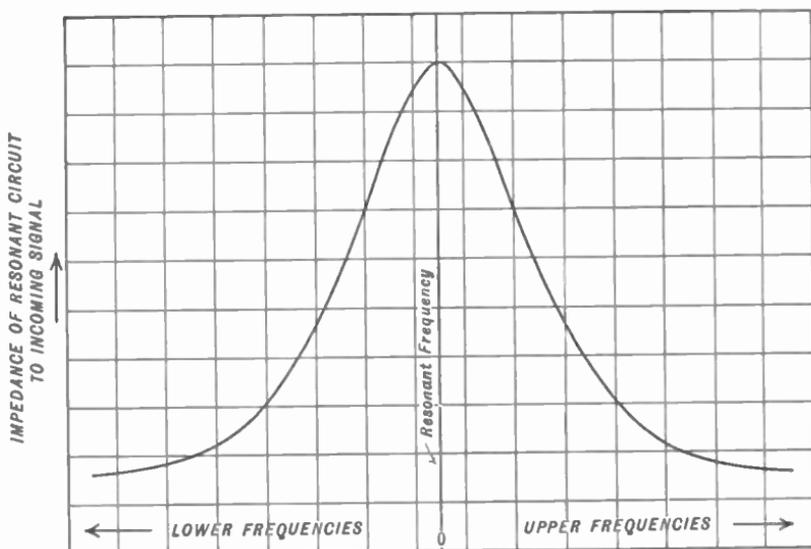
FIG. 3.1B.   The response curve for the tuning circuit shown in Fig. 3.1A.

1. The sharpness of the resonant curve in the region about the resonant frequency. This, of course, is the selectivity of the tuning circuit.
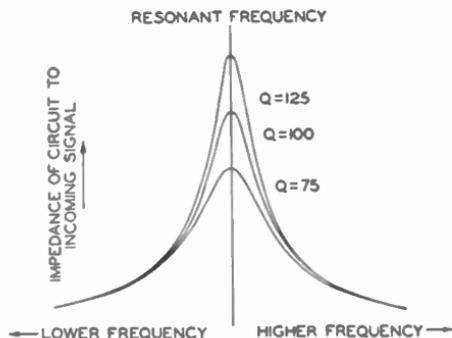
FIG. 3.2.   The variation in the response curve with different values of Q.

2. The amount of voltage that will be developed by the incoming signal across the resonant circuit at resonance.

For any given circuit, the greater its Q value, the more selective

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 desirable. 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 example, would develop a greater voltage across the resonant circuit 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 change but,
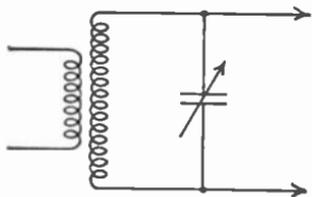
with the advent of high gain tubes, amplification is not too serious a problem.   The emphasis now can be shifted to fidelity, which is especially necessary for the reproduction of images in television receivers.

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

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.
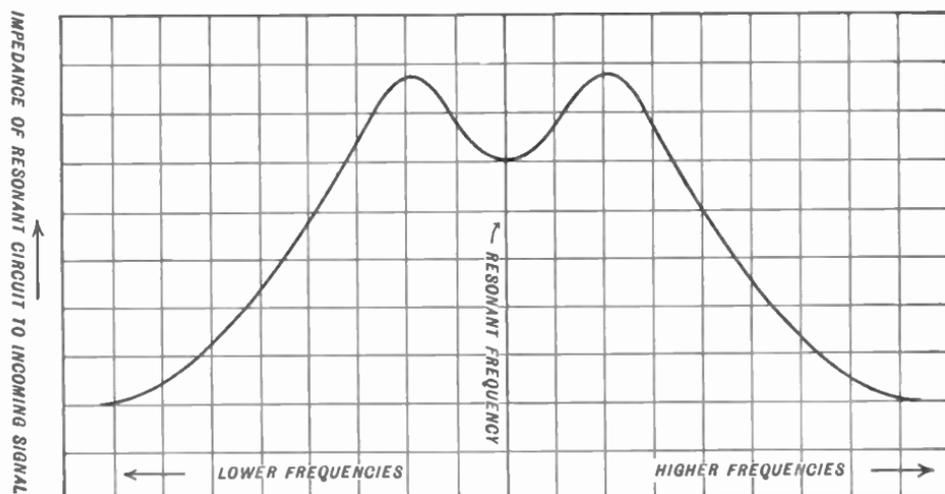
Fig. 3.4. Close coupling between two tuning circuits produces this type of response curve.

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 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 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.
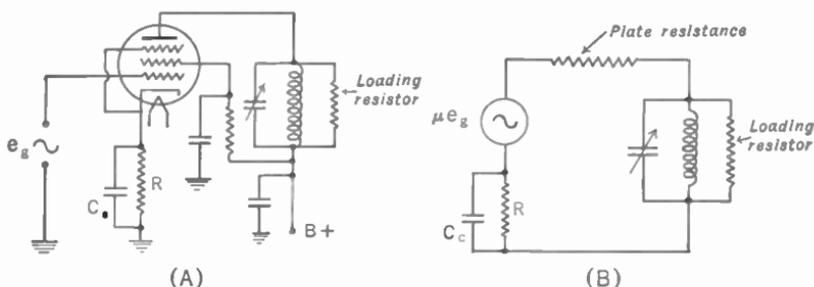
FIG. 3.5.   An amplifier stage (A) and its equivalent circuit (B).

Mathematically, the gain of the pentode stage can be ex-
pressed 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 an 1852 tube, g_m is 9,000 micromhos.   With a plate load of
2,000 ohms, we obtain

$$\text{Gain} = \frac{9,000}{1,000,000} \times 2,000$$

$$= 18.$$

The 9,000 is divided by 1,000,000 to convert it from micromhos
to mhos.

To obtain more amplification per stage, the mutual conduct-
ance of the tube must be increased. g_m, it will be recalled, repre-
sents 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 (1851, 1853) and the miniature tubes, 6J4, 6J5, 6AK5, and 6C4.

As an example, the 1851 has a mutual conductance of 9,000; the 1852 likewise has a g_m of 9,000, and the 1853 has a g_m of 5,000. 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 18 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 greater 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. Secondly, it provides greater discrimination against signals lying in adjacent bands. This is especially applicable for image frequencies. Finally, 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 disturbances are amplified along with the video signal and, if stronger than the received signal, will appear as small white spots on the image screen. The white spots are sometimes referred to as " snow." These small disturbances are also referred to frequently as masking voltages because they tend to override or mask small, weak signals.

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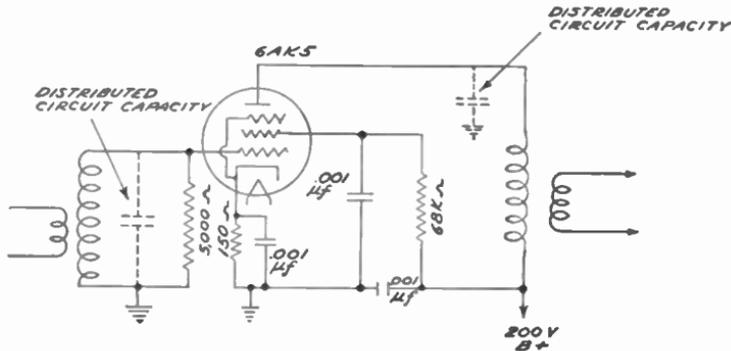
Fig. 3.6. A typical television R.F. amplifier.

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 achieve a fairly uniform response without, at the same time, decreasing the circuit gain too much.

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 movable cores within the coil.   Thereafter a selector
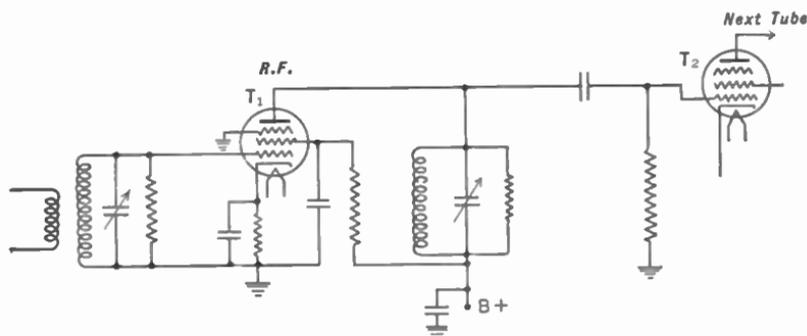
FIG. 3.7.   Another R.F. amplifier stage. One tuned circuit is common to the plate of T_1 and the grid of T_2.

switch or a series of push-buttons enables the operator to choose the desired channel.   Although only one set of coils is shown in these diagrams, there would be similar arrangements for each of the thirteen channels.
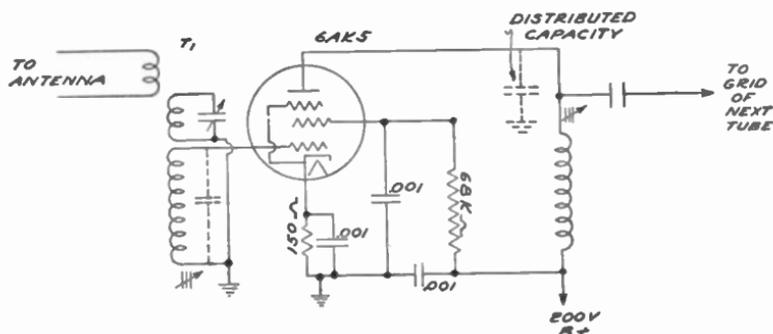
FIG. 3.8.   An R.F. amplifier which combines the response characteristics of grid and plate tuned circuits to obtain a 6-mc overall spread.

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. 3.8.   The primary winding of T_1 is untuned and matches

the transmission line impedance. The grid winding is tuned by the grid input capacity 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 link coupling between the input and grid coils. The combination of these three coils results in a double peak response curve (see Fig. 3.9A). 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. 3.9B. By properly adjusting the peaks of these circuits, we can readily achieve an over-all flat response of 6 mc for the stage (see Fig. 3.9C).

Other methods of coupling between stages in order to achieve a broad bandpass are shown in Fig. 3.10. In Fig. 3.10A, a small capacitor connects the primary and secondary windings. The value of this capacity is low (10 to 20 $\mu\mu$f) and governs the extent of the bandwidth; increasing the capacity increases the bandwidth.
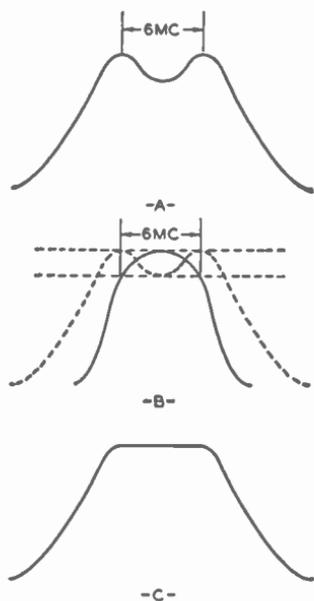
Fig. 3.9. The combination of two tuning circuits to produce a flat-topped overall response. (A) grid-circuit response; (B) plate circuit response; (C) overall response.

In Fig. 3.10B, increased coupling is obtained by means of a tuned circuit. The circuit serves two purposes: (1) It can act as a trap by being tuned to a frequency which we wish to eliminate, such as the frequency of the adjacent channel carrier; (2) it will increase the coupling between the primary and secondary windings. Whether the tuned circuit acts as a condenser or an inductance to the desired signal depends upon whether it is tuned above or below this frequency.

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. 3.11. The transmission line from the antenna is fed directly into the grids of a 6J6 push-pull triode amplifier. To

(A) Mutual Capacity Coupling

(B) Mutual Tuned Circuit
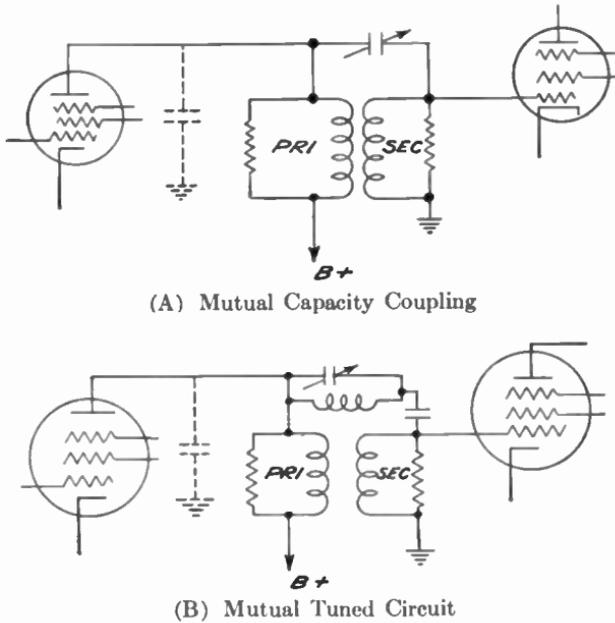
FIG. 3.10.   Several methods of increasing the coupling between two tuned circuits to achieve broad band pass.

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 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
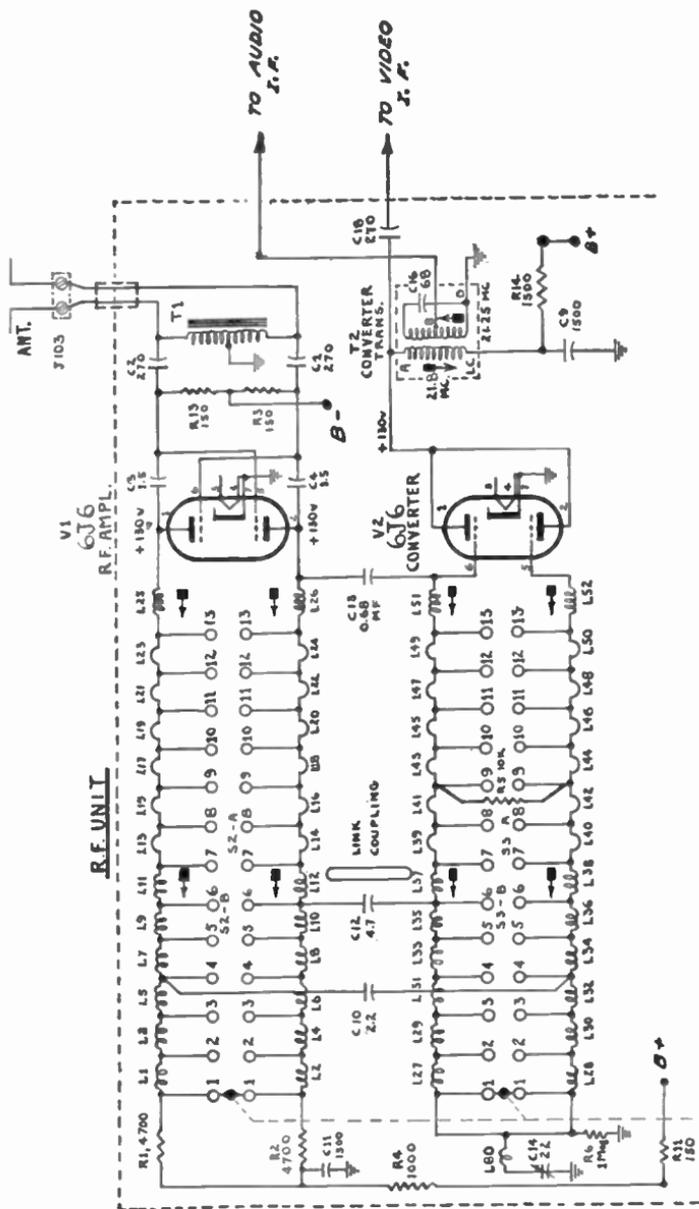
FIG. 3.11. A quarter-wave transmission line used for tuning the R.F. stages of a television receiver.

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 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 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 twofold: 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.

Only pentodes have been used in the R.F. and I.F. stages of conventional sound receivers because of their ability to amplify weak signals more than triodes. 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.

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 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 capacity which shunts the coil includes the interelectrode capacity of the tube. As we make this capacity 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 capacity, 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 20 in these amplifiers.

For the 1853, C_{gk} is equal to 8 $\mu\mu$f, C_{gp} amounts to 0.015 $\mu\mu$f, and the gain of the stage may be taken as 20. The input capacitance, exclusive of C_s, is equal to 8.3 $\mu\mu$f. 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 18.3 $\mu\mu$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. 3.12).

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.

Regular tuning condenser

$C_{ADDED} = C_{gk} + C_s + C_{gp}(1+G)$
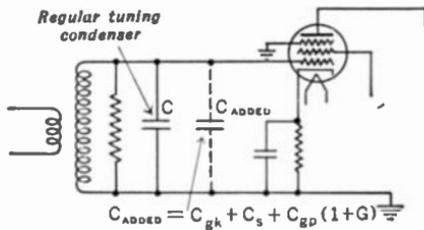
FIG. 3.12. At the higher frequencies, the stray wiring and internal tube capacitances represent an appreciable part of the total circuit capacitance and hence must be included in all computations.

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.

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. 3.13.

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
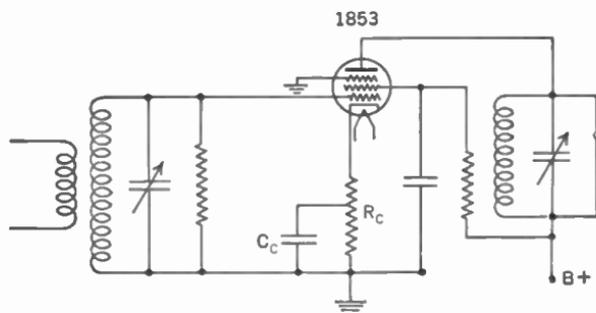
FIG. 3.13.   By leaving R_c, either partially or totally unby-passed, it is possible to minimize the effect of tube capacitance changes with receiver operation.

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

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

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 analagous to inverse feedback, except that the lead-inductance voltage is present even 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.   As 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. 3.14 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 condenser. 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
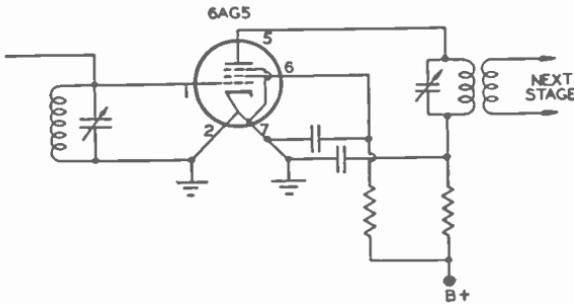
FIG. 3.14.   The use of two cathode wires to eliminate the adverse effect of cathode inductance.

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 manufacturers' 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. 3.14. If anyone 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.

Summary. Essentially, television R.F. amplifiers resemble the familiar A-M radio-frequency amplifier. Differences in frequency and band width clearance are met by low-valued shunt-

ing resistors across the tuned circuits and by smaller coils and capacitances. Special tubes were designed to provide the greater gain necessitated by the poor efficiency of the tuning circuits. The tubes possess high values of mutual conductance and embody carefully constructed internal electrodes which present small capacitances to the outside circuit. Engineering tolerances are more critical, and slight circuit or operating changes cause larger, more noticeable effects.

CHAPTER 4

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

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

*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.

popular combination is a pentode as the mixer, and a triode supplying the oscillator voltage. With the oscillator separate, no trouble is encountered in well-built sets up to the highest frequencies used in television. Recently tubes have been developed which can function satisfactorily as converters at frequencies up to 100 mc. Some manufacturers have incorporated these tubes in their circuits, but many still prefer the separate oscillator, insisting that it results in superior operation.
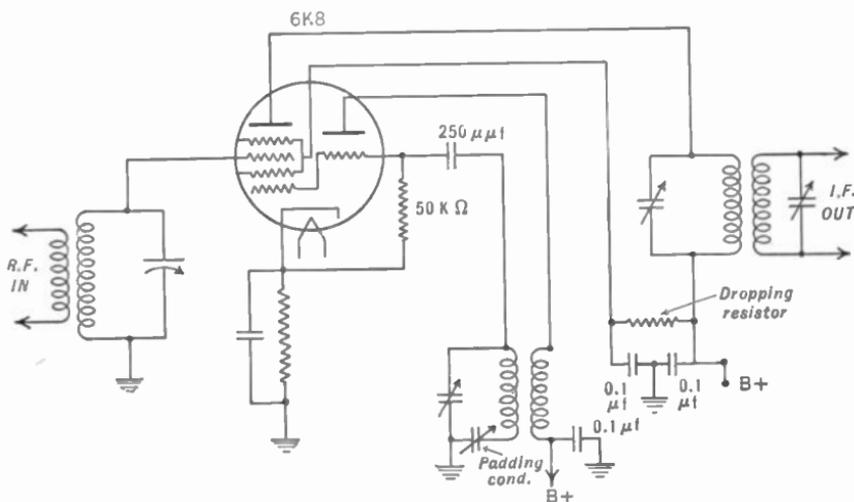
FIG. 4.2. An oscillator and mixer stage, using a 6K8. The oscillator voltage is transferred internally to the mixer section.

Energy from a separate 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 frequency is close to the picture carrier of the station being received by the other sets, the " beat " interference produces relatively large vertical or horizontal bars.
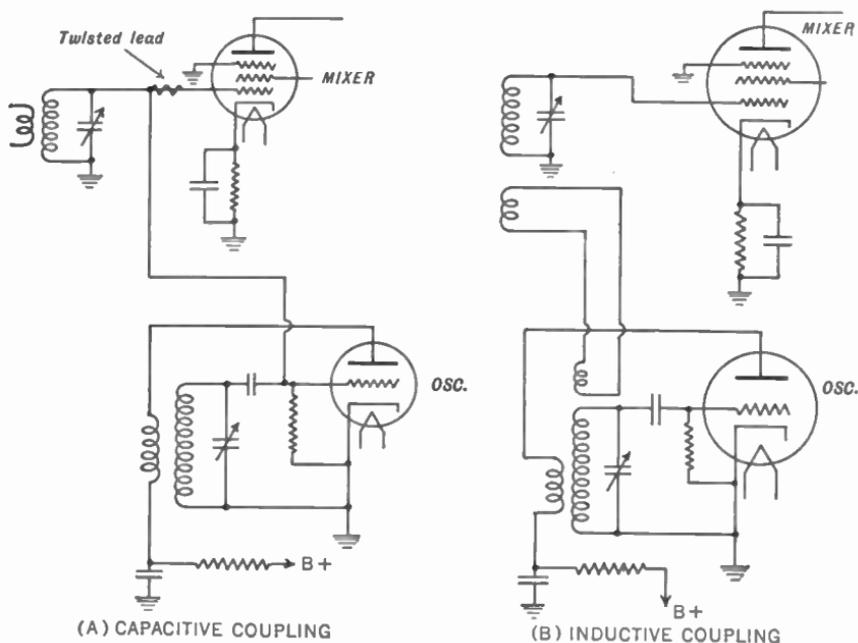
FIG. 4.3.   Coupling energy from the oscillator to the mixer by inductive or capacitive means.

Oscillators. There are three circuits that have been used for the oscillator in the greater majority of sets. These are the familiar Hartley, the tuned-grid tickler oscillator, and the ultraudion, the latter being a modification of the well-known Colpitts. Each is shown in Fig. 4.4.

For multiband operation of these oscillators, it is possible by switching arrangements to change coils, add inductances or capacitances, or both, and in this way obtain the necessary frequency coverage. In Fig. 4.5, the oscillations generated by the 6J5 tube are capacitively coupled to the grid of the 1852. No actual coupling condenser is necessary; it is sufficient merely to

(A) HARTLEY   (B) TUNED-GRID TICKLER   (C) ULTRAUDION

FIG. 4.4. Three basic oscillator circuits used in television receivers.

FIG. 4.5. One possible arrangement for having one oscillator generate many frequencies. Although not shown here, the mixer tube input tuning circuit would likewise have to be changed for each band.

twist a lead from the grid of the triode around the grid lead of the 1852. In the oscillator, L_1 and C_1 determine the lowest frequency, 71 mc, for mixing on the 44- to 50-m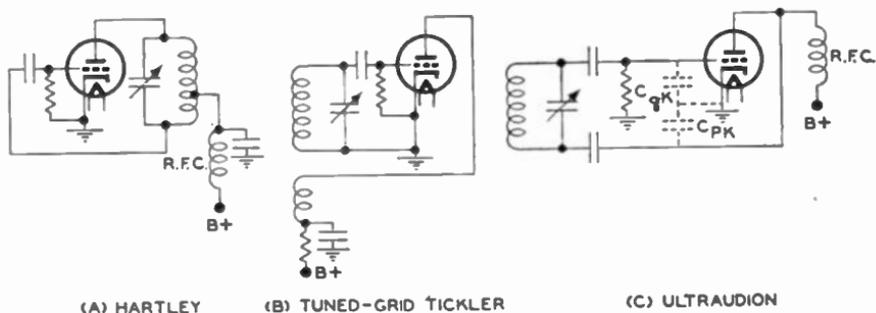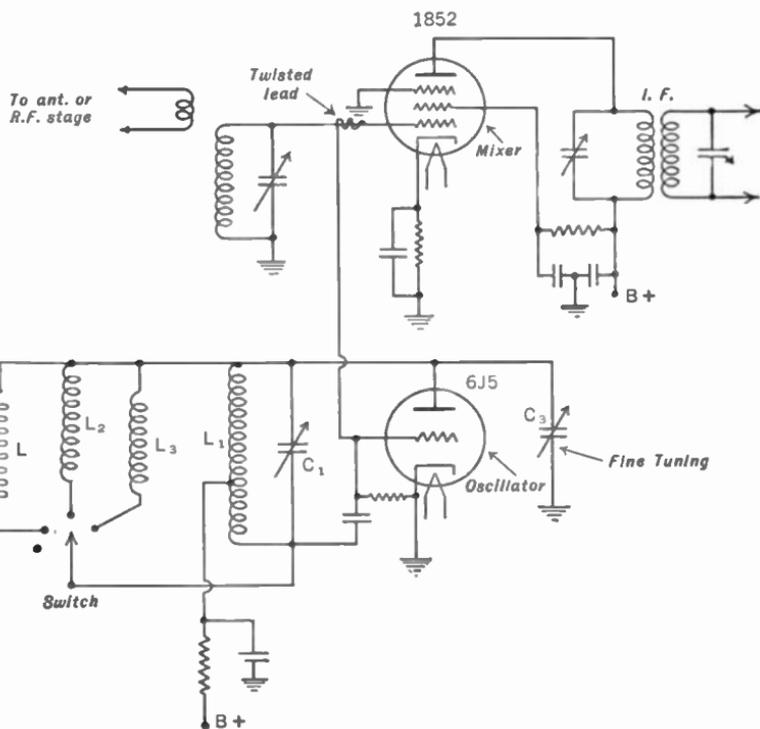c band. For the next higher band, 54 to 60 mc, L_1 and C_1 remain in the circuit, and L is switched in, paralleling L_1 and lowering the total inductance across C_1. To reach still higher, we find L_2 placed in parallel with L_1 for the 60- to 66-mc band. L is now out of the circuit. Finally, L_3 would be switched in for another band. Each coil, when not in use, is completely shorted out, although not indicated here. This arrangement is necessary to prevent the unused inductances from affecting the coils in use.

The condenser C_3, labeled " Fine Tuning," is always in the circuit and permits slight variation of the oscillator frequency on all bands. It will enable the observer to correct for any slight frequency drifting of the oscillator. Oscillator frequency change, or drift, may be brought about by fluctuations in the B+ voltage, variations in inductance and capacitance values in the tuning circuit, or aging of the tube. Any 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.

Another possible oscillator circuit is shown in Fig. 4.6. Direct inductive coupling is used to transfer the oscillator voltage to the mixer tube. Coils for each band of frequencies are wound on one form, each form placed in a separate shielded compartment to minimize reaction between coils in use and those that are not used. In the schematic, a separate coil and condenser are brought in for each band, which is perhaps a little more costly than the previous method. Again, a fine tuning control is used, common to all bands.

The placement of the coil windings on this form follows a definite pattern. To prevent oscillator radiations from reaching the antenna coil, L_1 and L_4 are placed as far apart as possible. In addition, L_2 is tuned to the incoming signals only and acts as a transferring coil between L_1 and L_3. Hence, even if the oscillations from L_4 did reach L_2, very little of its voltage would be developed here because of the difference in frequency.
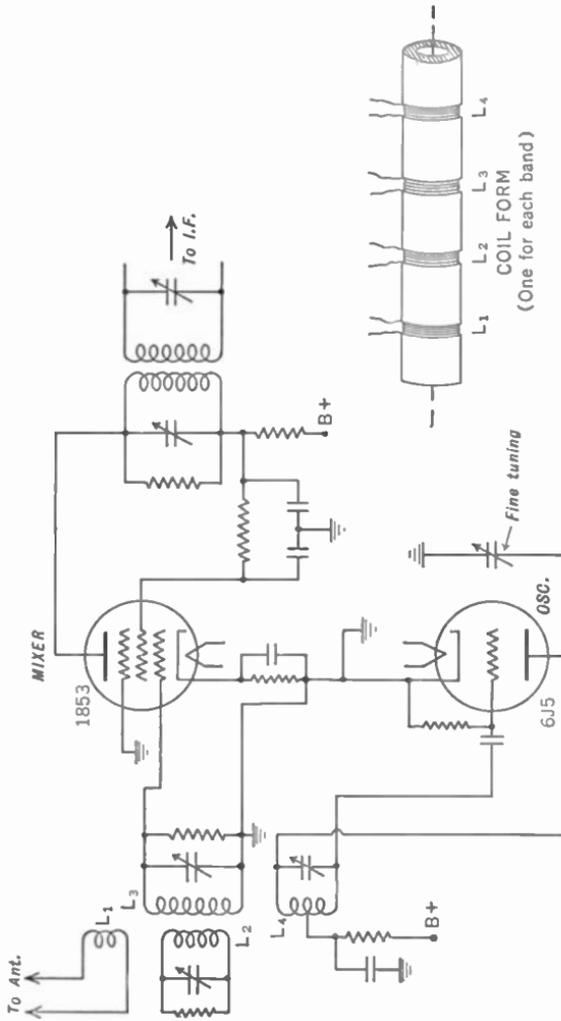
Fig. 4.6. In this oscillator and mixer circuit, coupling between the 6J5 and the 1853 is accomplished by winding all the coils on one form.

Just as important as the circuit layout and resonant circuit designs 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 1, 44 to 50 mc, the video carrier would be at 45.25 mc. (The remnants of the other side band are from 44.00 to 45.25 mc, but these are useless and rapidly attenuated in the circuits.) From the video carrier, the picture side bands extend for 4 mc up to 49.25 mc. The audio carrier would then be located at 49.75 mc.

Now suppose that the oscillator frequency is 71.00 mc. In the mixer tube, the 44- to 50-mc signals would combine with the oscillator frequency to form the following I.F. signals:

1. For the video, the I.F. will range from 21.75 mc to 25.75 mc. This is the difference between 71 mc and 45.25 to 49.25 mc. Actually, the I.F. generated will extend to 27 mc. However, the vestigial side band remnants are from 25.75 mc to 27 mc and are not desired. The I.F. bandpass 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 side band are permitted to remain because of the difficulties en-

countered in attempting to separate the lower side band entirely from the upper side band without affecting the phase or amplitude characteristics of the desired upper side band.   At the receiver, the remaining or vestigial lower side band 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 side band and the remnants of the lower side band.   The higher video
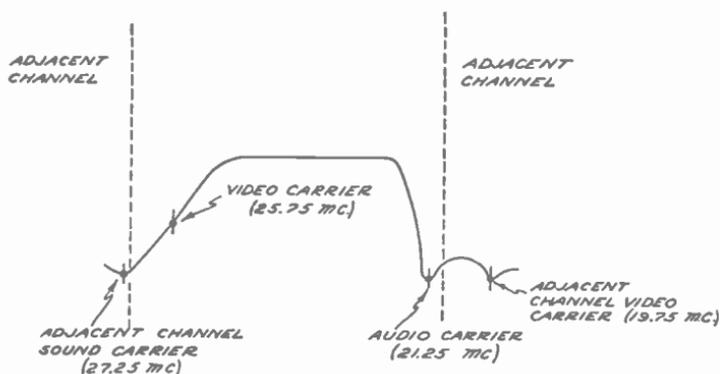
Fig. 4.7.   The recommended overall video I.F. response curve.

frequencies are present only in the upper side band, having been eliminated from the lower side band.   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. 4.7 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 side bands, receive half the amplification accorded those higher frequencies for which there is only one side band.   The over-all result is an equal response for both the low and the high video frequencies.

The characteristic shown in Fig. 4.7 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 sensitivity of the receiver.

Indicated, too, in Fig. 4.7 are the frequencies which are attenuated 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 the difficulty in stabilizing a high-frequency oscillator. Any tendency on the part of the oscillator to wander (change frequency) will cause detuning at the I.F. stages. In the sound I.F. stages, for example, the band width 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 variations that generally occur in the oscillator. But these variations must be kept small, as can be readily appreciated. The fine tuning control 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 important 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 15.75 mc. This means that its band pass extends from 15.75 mc to 11.75 mc. Further, suppose the set is tuned to the 44–50 mc television channel, No. 1. With the I.F. value specified, the local oscillator would be operating at 45.25 mc plus 15.75 mc or 61.00 mc. If a powerful station is, at the same time, operating in the 76–82 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 15.75 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 lower television band, 44–88 mc, this requires an I.F. value in excess of 22 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 incoming 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., and which is slightly greater than the entire band. In the low-frequency television band, this would be 44 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 bandwidth 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 recommended by the RMA 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 Audio Signals.   It is common practice to separate the audio and video I.F. signals immediately beyond the mixer, although there are some systems which permit these signals to remain together through more stages. The separation of these closely spaced signals, when this does occur, is accomplished by means of simple tuned circuits. In Fig. 4.8, the transfer occurs in the plate circuit of the 6J6 mixer. All the difference frequency currents (video and audio) pass through the tuned coil in the plate circuit of the mixer stage. Coupled to this coil is a resonant circuit tuned to the audio I.F. center value, in

this instance 21.25 mc.   This latter coil is connected into the grid circuit of the first audio I.F. stage, thus feeding the induced audio signal to the audio system.
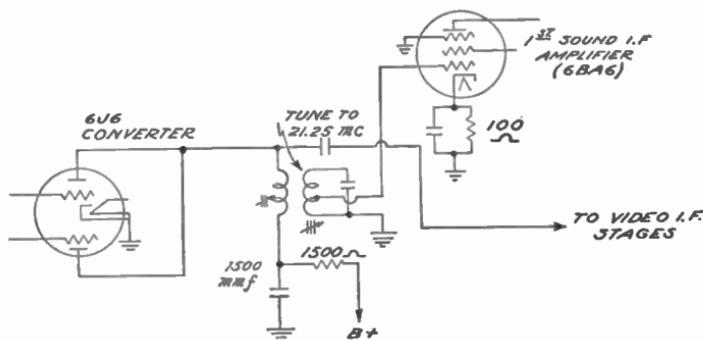
FIG. 4.8.   One method of separating the audio and video I.F. signals.

Another method of transfer is illustrated in Fig. 4.9.   Two tuned circuits are connected in series in the plate circuit of the mixer.   The top resonant circuit covers the video I.F. range, and
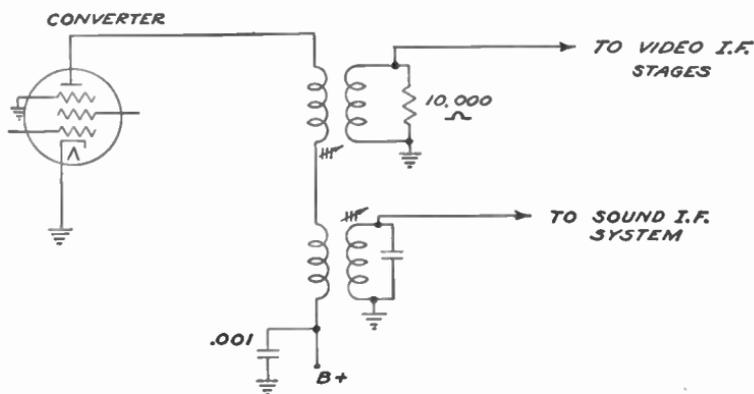
FIG. 4.9.   Another means of separating the sound and video I.F. signals.

the other resonant circuit is tuned to the audio I.F. signal.   Both currents 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 audio I.F.   The energy in each coil will then transfer to its respective system.

Note that in each of these circuits we are merely removing some of the audio I.F. energy, but not all.   Hence, provision must be made at some later point in the video I.F. amplifiers to completely suppress or eliminate whatever remains of the audio I.F. signal.

For the audio I.F. stages, the filtering needed is not extensive. The audio I.F. transformers have a uniform response of at most 300 kc.   Since the video signal extends for 4 mc, very little will penetrate the audio amplifiers.   In addition, the method of audio frequency modulation is inherently opposed to the amplitude-modulated picture signal.   In F-M receivers, limiters form part of the I.F. system, and these stages are carefully adjusted to eliminate any amplitude variations in all signals passing through. Hence, any video signal reaching the limiter tube would be suppressed automatically.   With these two factors guarding the audio system, the filtering problem is materially reduced.

Video I.F. Amplifiers.   A video amplifier employing a wide bandpass filter is given in Fig. 4.10. L_1,C_1 and L_2,C_2 form the video tuning circuit.   There is no inductive coupling between L_1 and L_2, the signal being transferred by means of the coupling condenser C_c.   The parallel resonant circuit of C_3 and L_3 is the audio-rejector filter.   In alignment, L_1,C_1 and L_2,C_2 are each separately adjusted until desired spread is obtained.   The curve is actually a composite, the resultant of the separate curves of L_1,C_1 and L_2,C_2.   Sometimes a slight dip appears in the curve due to an overextension of the center resonant frequencies of the two tuning circuits.   The dip may be straightened out either by slowly bringing the centers of the resonant curves of L_1,C_1 and L_2,C_2 closer together, or by compensation in some other stage. In general, it is much better engineering practice to try to obtain the proper response curve in each stage separately rather than to have one stage overpeaked at some point in order to compensate for an excessive loss in some other stage.   Resistors R_1 and R_2 are shunted across each circuit to widen and flatten the curve.
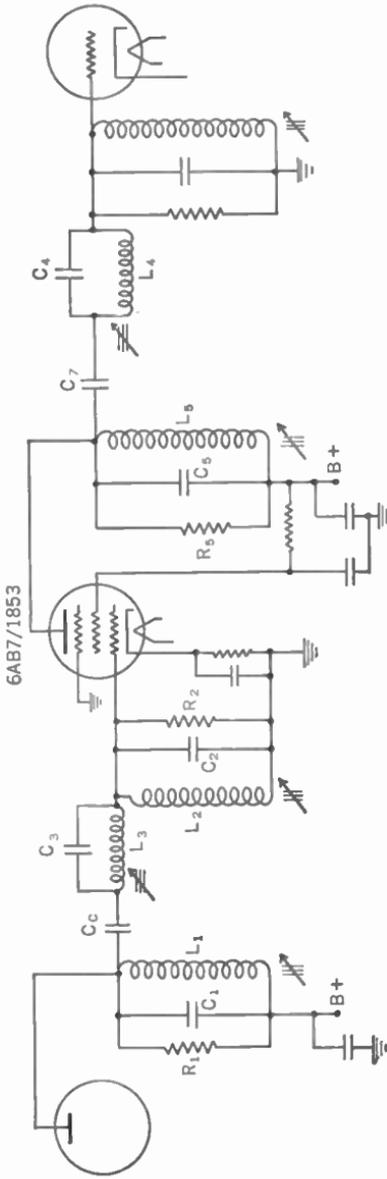
Fig. 4.10.   A typical video I.F. amplifier.

The audio-rejector filter consists of L_3 and C_3. This is a sharply tuned circuit with no artificial damping resistor and is resonant at 21.25 mc. Its purpose is to prevent audio signals from penetrating deeper into the video I.F. system. A high impedance is presented to 21.25 mc and hence most of this audio voltage is lost across this resonant filter. All video frequencies are above 21.25 mc and L_3, C_3 appear to them merely as a capacitive reactance. If the trap were broadly tuned, it would interfere with and absorb some of the higher video frequencies. Usually only one such audio rejector circuit is incorporated into the amplifiers.

The series rejector L_4 and C_4 in the next I.F. stage, Fig. 4.10, is not tuned to 21.25 mc, but to 27.25 mc. To understand the need for this filter, let us consider two adjacent television frequency bands as, for example, the 60- to 66-mc band and the 66- to 72-mc channels. Our receiver is tuned, let us say, to the 66–72 mc channel. The audio carrier in the 66- to 72-mc band is at 71.75 mc and, when this beats against the oscillator frequency of 93 mc, the 21.25 I.F. audio value is obtained, which is desired. However, with a powerful carrier being broadcast by a station on the adjacent television channel, it is entirely possible that some of this signal will reach the grid of the mixer tube of a receiver tuned to the 66–72 mc channel. Of particular interest, in this case, is the audio carrier of the adjacent 60- to 66-mc band, which is at 65.75 mc and, if received, will mix with the 93-mc oscillator frequency signal to produce a difference frequency of 27.25 mc. This frequency is very close to the 25.75 mc of the video amplifier bandpass circuit and could easily filter through, causing interference in the reproduced image. To eliminate this possibility, this second series rejector circuit is tuned to 27.25 mc.

It will be noted that the 27.25 audio signal of the adjacent television band is obtained only when two bands closely follow each other. Thus, the two adjacent 44- to 50-mc and 54- to 60-mc bands would not give rise to a similar situation because the audio signal of the 44- to 50-mc band occurs at 49.75 mc. If this should beat with the 81.00-mc oscillator of the 54- to 60-mc band, an I.F. of 31.25 mc would be obtained and would be

attenuated rapidly by the ordinary tuning circuits. No special
rejector filters would be required.

Tuning on all these coils is accomplished by altering the mov-
able core position within the coil. The inductance changes
directly with the amount of core within the form. The capaci-
tance necessary to resonate with the inductance is kept as small
as possible. In this way a large L/C ratio is obtained, which in
turn means greater gain for the stage. In many sets, the resonat-
ing capacitance across the coil is obtained from the sum of the

Represented by tube and stray wiring capacitances

FIG. 4.11. When an R.F. or I.F. tuning circuit does not contain a visible condenser,
advantage is being taken of the tube or stray wiring capacities that are always present.

interelectrode and stray wiring capacitances. One example of
this is illustrated in Fig. 4.11.

The preceding paragraphs have dealt with one type of I.F.
amplifier circuit. Another type, used by some receiver manu-
facturers, is given in Fig. 4.12. The familiar transformer coupling
is used between stages, but inserted in series with the grid lead is a
rejector trap, tuned to one of the two rejection frequencies, 21.25
or 27.25 mc. The first video I.F. amplifier might have the 21.25-
mc trap, the next stage the 27.25-mc trap. Inspection of the
diagram reveals that a third coil, inductively coupled to the first
I.F. transformer, conducts the 21.25-mc audio carrier to the first
audio I.F. stage.

Another method of eliminating unwanted audio frequencies
in the video I.F. stages is obtained by inserting the tuned rejector
trap in the cathode leg of the I.F. amplifier (see Fig. 4.13).
The audio I.F. voltage developed across the trap will function as a

negative feedback or degenerative voltage, opposing any audio I.F. signal at the grid of the tube. The elimination of the audio signals using this method is not as complete as can be obtained
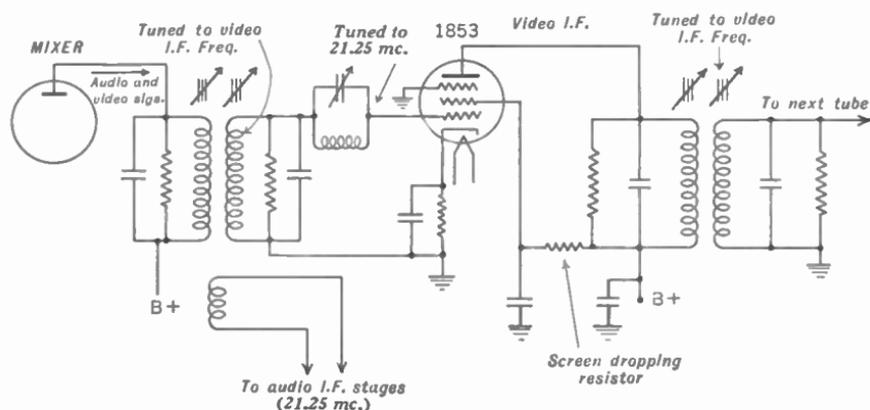

FIG. 4.12. Another widely found video I.F. amplifier.

with the other methods described, but it is sufficient for most practical purposes.

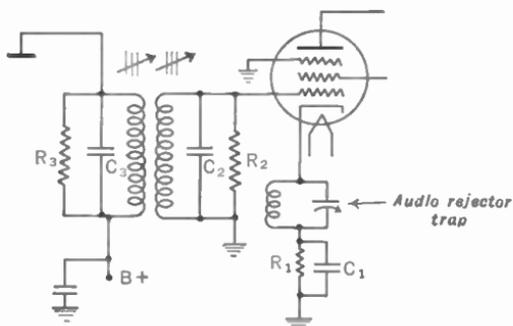Finally, we can use absorption traps, such as we find in the RCA

FIG. 4.13. In this circuit the audio rejector trap is placed in the cathode leg of the I.F. amplifier. It then functions as a degenerative amplifier at the frequency of the trap.

television receivers (see Fig. 4.14). The coil to which the trap circuit is coupled is tuned to accept the video I.F. The trap is tuned to the frequency which is to be suppressed, say 21.25 mc.

At this frequency, the presence of the trap causes the video coil
(L) to offer a very low impedance to any 21.25 mc currents that
may be contained in the video I.F. signal.   As a result, very little
of the 21.25 mc voltage appears across L_1 and correspondingly
little of this voltage reaches the next amplifier.

The traps generally have movable cores and are aligned together
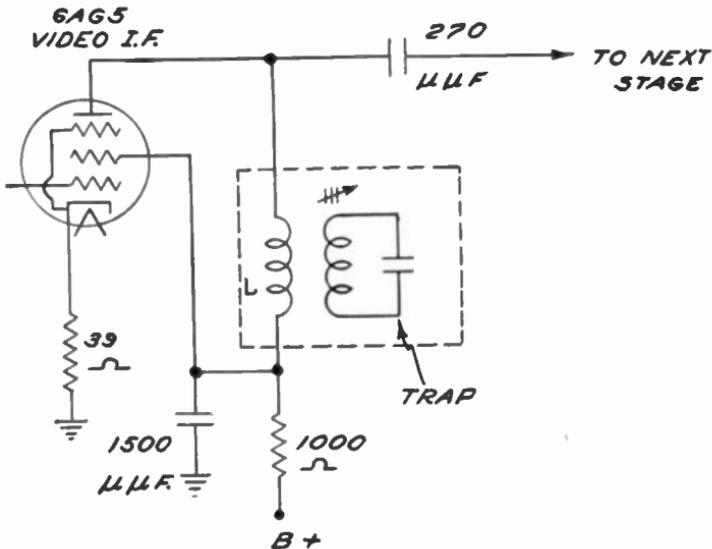with the video amplifiers every time these amplifiers are serviced.

FIG. 4.14.   An absorption trap.

The best guide to any adjustments necessary for alignment will be
obtained from the servicing instructions that the manufacturer
issues with the set.   A general alignment procedure for such units
will be found in Chapter 11.

The trap circuits discussed in the preceding paragraphs were set
to eliminate either the sound I.F. carrier of the same channel or
the sound carrier of the next lower adjacent channel.   There are
some receivers which include still a third trap for the picture
carrier of the next higher adjacent channel.   Thus, suppose we
have a receiver employing a 25.75-mc video I.F. and tuned to the
60–66 mc channel.   For this channel, the local oscillator is set for

$61.25 + 25.75$ mc or 87 mc. The picture carrier of the next higher adjacent channel, 66–72 mc, is at 67.25 mc. If this should appear at the grid of the mixer tube and mix with the 87-mc oscillator signal, a difference frequency of 19.75 mc would be generated. Interference could be produced by 19.75 mc at the screen if it were received in sufficient strength. To prevent this from occurring, a trap tuned to 19.75 is sometimes included in the video I.F. systems.

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. Trap No. 1 is never omitted from the receiver.

The numerous references to interference from adjacent channel stations may puzzle those readers who are aware that the operation of stations on adjacent channels in the same community is expressly forbidden by the F.C.C. regulations. There is, however, a need for such traps. The metropolitan districts throughout the United States have been arranged according to sales rank (by the 1940 census) and assigned television channels. Each channel, starting with the lowest one, 44–50 mc, has been assigned a number and these are listed in the table in the appendix. Those cities which are located close to each other have been assigned alternate channels. Thus, New York City is given channels No. 2, 4, 5, 7, 9, 11, and 13; Philadelphia receives channels 3, 6, 10, and 12. For any receiver located between these cities there exists the possibility of adjacent channel interference and it is expressly for this reason that television receivers contain adjacent channel traps.

Adjacent channels are defined as those channels which follow each other without any frequency separation. Therefore, 44–50 mc and 54–60 mc, even though they do follow each other, are not considered as adjacent channels because of the 4-mc

difference between 50 and 54 mc.   The same is true of the 66–72 mc and 76–82 mc channels.

Gain per Stage.   Due to the loading that is necessary with the video I.F. amplifiers, high voltage gain per stage is not possible.   With specially designed tubes, perhaps of the 1800 series, the average gain is about 15–20 per stage.   Consequently, more stages are required than with the ordinary broadcast amplitude-modulated receiver.   Some low-priced television sets sacrifice band width for increased gain and employ only three I.F. stages. In more expensive sets, the wider band widths mean more stages, perhaps as many as five.   Assuming a gain of 15 per stage, a total of five stages would increase the strength of the I.F. input voltage by $15 \times 15 \times 15 \times 15 \times 15$, or approximately 750,000 times. This amplification is necessary if the input signals received at the antenna are to be increased to the required 2 to 5 volts at the detector.

Automatic Gain Control.   The biasing arrangements in the circuits investigated in this chapter have been conventional, i.e., cathode bias.   If automatic gain control (A.G.C.) is used in the receiver, the grid circuit will have to be modified slightly, as shown in Fig. 4.15.   Condenser C_4 is inserted between the tuning circuit and ground in order not to short-circuit the A.G.C. voltage. C_4 also completes the path for the signal voltage of the tuning circuit to grid and ground.   A.G.C. in television sets is closely related to A.V.C. in sound receivers.   Its purpose in the video amplifiers is to vary their gain in such a manner that the reproduced image on the screen is kept at the level established by the observer.   The observer fixes the desired level by the manual contrast control.   Once the control is set, the A.G.C. operates to maintain the image at this level.   Some receivers contain no A.G.C., and the contrast control is the only governing factor. In the next few paragraphs, the manner in which the contrast control functions will be explained.   A.G.C. systems are discussed in the next chapter for they are generally developed at the second detector and an understanding of the operation of these detectors is necessary.

Fig. 4.15. A video I.F. amplifier with provision for the insertion of A.G.C. voltage.

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.   If the image is made intense, the difference between the bright and dark portions of the picture will increase, i.e., the contrast between them becomes greater.   On the other hand, lowering the setting of the control causes the intensity of the brighter sections of the image to decrease, and the contrast ratio is lowered.   The dark level of the screen, where details are no longer distinguishable from each other, is relatively fixed.   Thus, the contrast control is concerned mainly with increasing or decreasing the intensity of the brighter sections of the image.   In a room completely dark, too great an advancement of the contrast control will provide the image with improper shading and prove annoying.   The picture becomes more or less distorted.   In a bright room, a greater amount of contrast may be necessary to counterbalance the illumination of the room itself.

Manual control of the strength of the output video voltage may be readily accomplished by varying the gain of one or more stages.   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 control 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. 4.16, a section of the I.F. amplifiers of a receiver is shown.   Each tube is provided with one fixed resistor for minimum fixed bias while the 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 condensers by-passing these resistors.
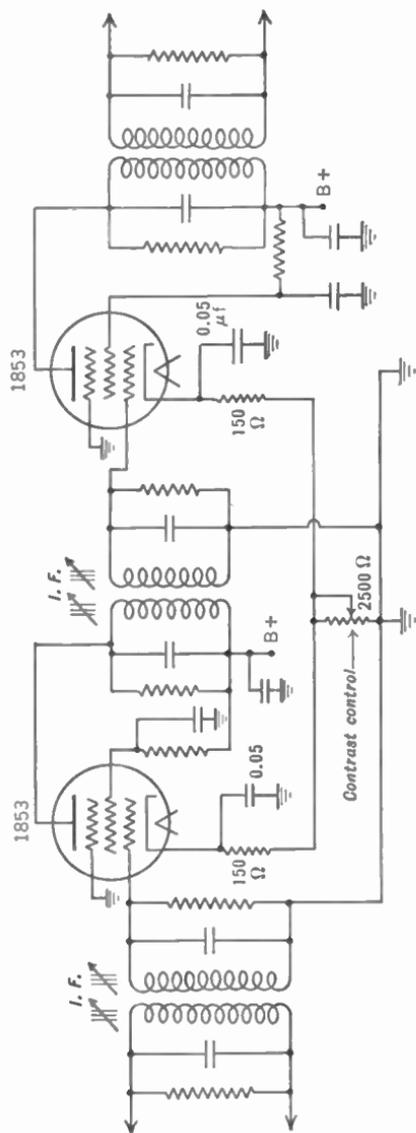
FIG. 4.16.   One method of varying the gain of a stage.   The potentiometer is called the contrast control.

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. 4.17.   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.   Extended cut-off tubes are the only ones that permit satisfactory variation of d-c
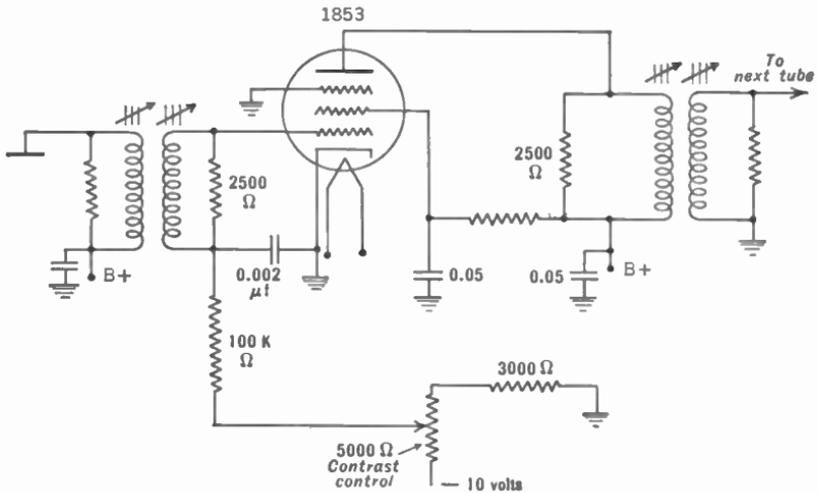
Fig. 4.17.   Another method for varying the gain of the set.

bias over wide limits without too much distortion, and they are always used.   As a general rule, when a receiver contains automatic gain control in addition to the preceding manual gain control, the designer will incorporate the contrast control into the A.G.C. network.

It may be well to reiterate the difference between A.G.C. and the contrast control.   The A.G.C. may be considered as a variable bias applied to several tubes in the receiver in order to control their amplification.   The purpose of the A.G.C. is to automatically maintain a steady signal level at the input of the image tube. The contrast control, on the other hand, determines the operating point for the tube.   It provides a steady d-c potential between

the grid and the cathode which, once set, will not fluctuate. It is around this operating point that the signal and A.G.C. variations act. In a way, the A.G.C. may be considered as a correcting voltage, which adds sufficient additional voltage to the grid bias of a tube to carry out its function of keeping the image intensity constant.

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 as shown in Fig. 5.1 is typical. The demodulated video signal
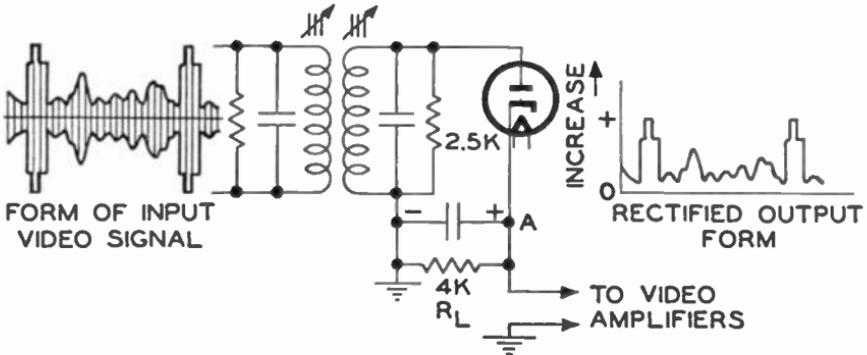

FORM OF INPUT VIDEO SIGNAL

RECTIFIED OUTPUT FORM

TO VIDEO AMPLIFIERS

Fig. 5.1. A diode detector for a television receiver.

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 each other and either one may be used. Instead of a half-wave

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rectifier it is also possible to use the full-wave arrangement shown in Fig. 5.2 with a 6H6 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 systems, negative picture transmission is standard. This means that the
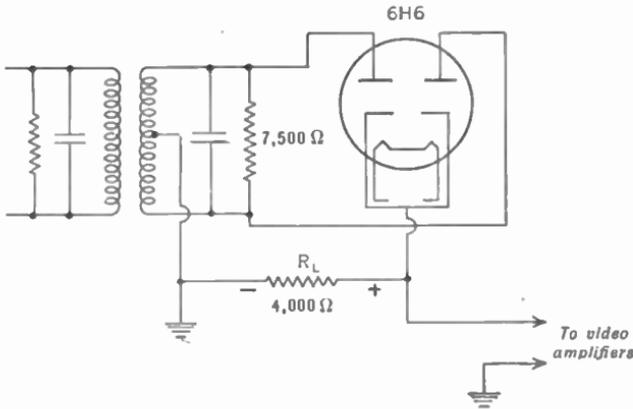

FIG. 5.2.   A full-wave detector.

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.
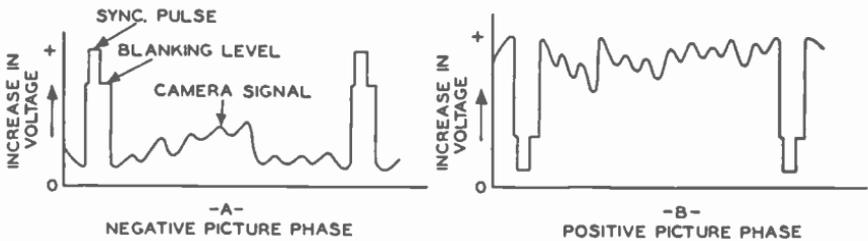

FIG. 5.3.   Rectified video signals may be obtained from the output of the detector in either one of the two forms shown, depending upon how the detector is connected.

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-
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
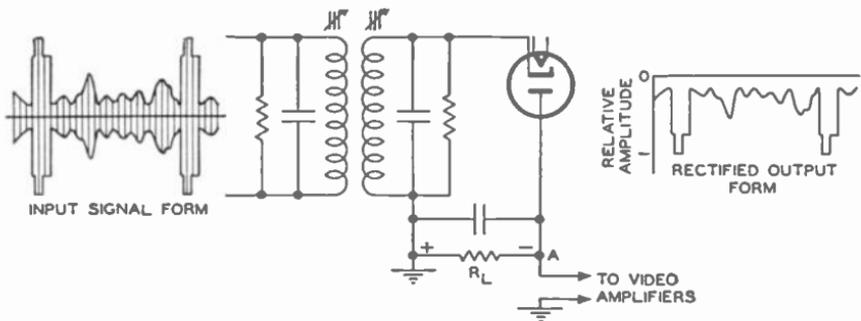a bright spot will appear on the fluorescent screen.   For the

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.

blanking 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,
have the property of reversing by $180°$ the polarity of any signal
sent through them.   (This will be proved in Chapter 6.)   Thus, if
the video signal had a positive picture phase at the diode load re-
sistor, 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 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.
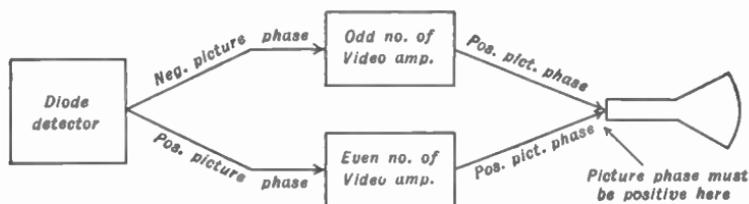

FIG. 5.5. An illustration of why the number of video amplifiers after the detector is dependent upon the polarity of the signal obtained from the detector.

Detector Filtering and Peaking. The frequencies present in the detector circuit include the I.F. values, 21.25 mc to 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 mc to 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 mc to 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 Figure 5.6. 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 due to 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 equivalent of an actual condenser of 10–15 $\mu\mu f$. The two coils, L_1 and
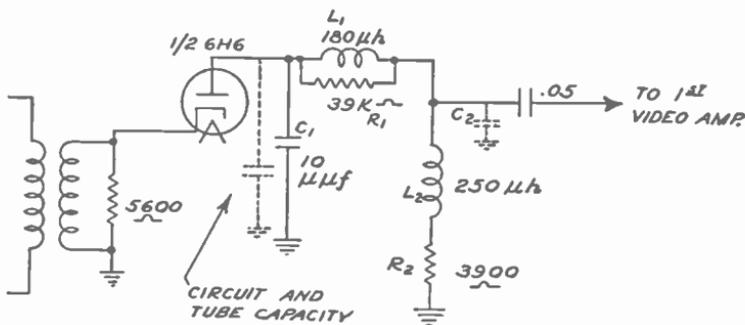

FIG. 5.6.   A video detector circuit with a low-pass filter and load resistor.

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 due to a natural resonant circuit formed by the coil and its inherent capacitance. The detector load resistor is R_2, 3900 ohms.

The output of the second detector, Fig. 5.6, 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 to actually 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 capacity 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.

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 selected 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. 5.7, 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 back to the R.F. and I.F. stages, but rather an average voltage that depends upon the carrier level. If the audio variations were

sent back to the preceding tubes, all musical passages, for example, would 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 car-
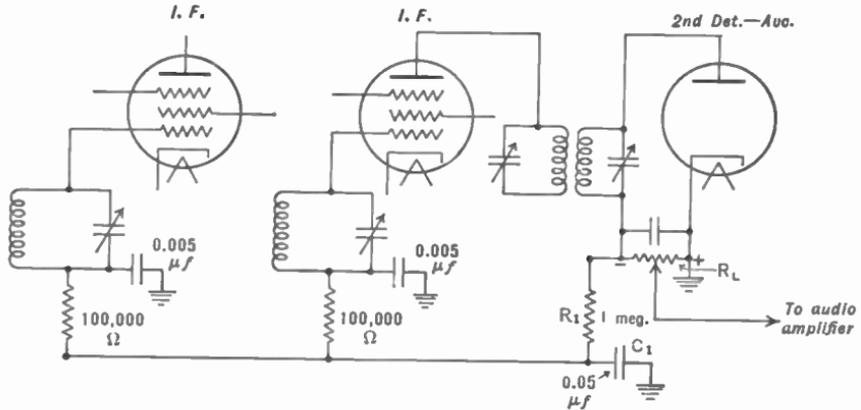

FIG. 5.7. A conventional A.V.C. circuit found in present sound receivers.

rier signal. The incoming signal both before and after rectification by the diode detector is shown in Fig. 5.8. The detector output consists of a pulsating d-c voltage that contains
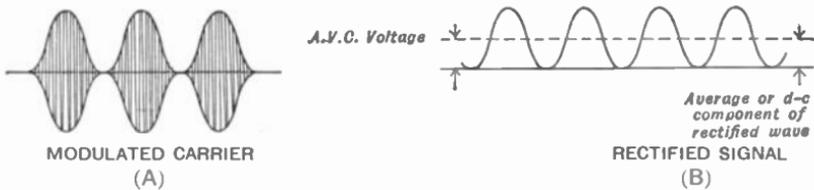

FIG. 5.8. The A.V.C. voltage developed across R_L represents the average value of the incoming wave.

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. 5.9 where different levels of carrier signals are shown, all having the same audio component.   The d-c voltage is then fed to the various controlled I.F. and R.F. stages.
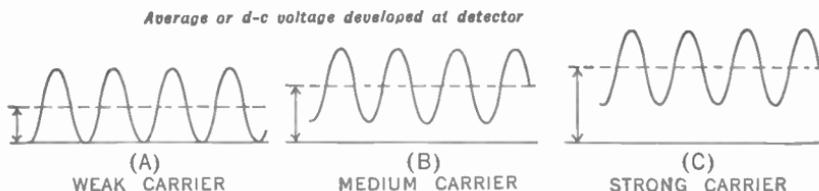

Fig. 5.9.   These diagrams illustrate how the A.V.C. voltage is dependent upon the strength of the incoming signal, and not its modulation.

The purpose of the filter condenser C_1 and resistor R_1 of Fig. 5.7 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. 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
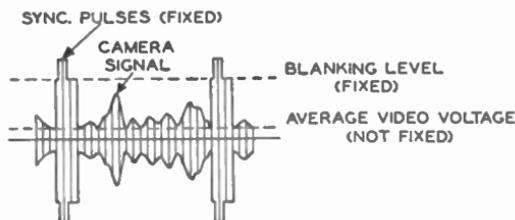

Fig. 5.10.   An amplitude-modulated television signal.   Only the fixed voltage levels are suitable for A.G.C. control since only these voltages vary directly with signal strength.

Fig. 5.10 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. The simple arrangement shown in Fig. 5.11 is found in several G.E. sets. One half of the 6H6 is used for the video detector and the other half for the A.G.C. In the A.G.C. circuit, we find R_1, R_2, R_3, R_4, and R_5 with the 0.05-μf condenser connected between R_4 and R_5. Since the detector half of the 6H6 does not enter into the operation of the gain control circuit, it may be disregarded.

The modulated video signal is applied to the plate and cathode of the diode, and current will flow whenever the plate becomes positive. The path of the current is from cathode to plate through R_4, R_2, and R_3 back to the cathode by way of the secondary of the I.F. transformer. As a result of the current flow, a voltage will be developed across R_4 with the polarity indicated. Since the incoming video signal has a negative picture phase (see Fig. 5.3), the plate reaches its greatest positive value with the application of the blanking and synchronizing pulses. The largest current flows at this moment and develops the greatest voltage across R_4. The portion of the signal representing the bright sections of the image drives the diode plate only slightly positive, resulting in a relatively small amount of current flow.

The voltage that is developed across R_4 represents the A.G.C. voltage. It is applied from the negative end of the resistor to
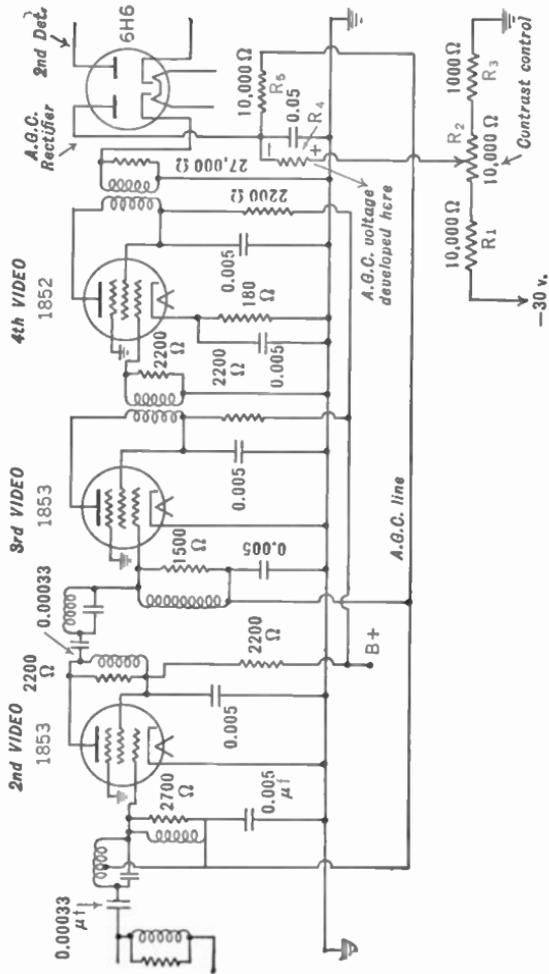
Fig. 5.11. A simple method of obtaining A.G.C., employed in G.E. sets.

the grids of the tubes to be controlled through the filter composed of R_5 and the 0.05-μf condenser. The filter has a relatively long time constant ($T = RC = 0.0005$ sec), existing for about 10 horizontal lines. With this time constant, the 0.05-μf condenser, which is effectively across R_4, charges to the peak value of the voltage across the resistor and retains this charge for a relatively long time. However, as explained above, the peak voltage across R_4 is determined by the synchronizing pulses of the video signal. Hence, the condenser charges to this peak voltage and then discharges so slowly that the rapid variations due to the smaller image voltages are ineffective and never reach the grids of the controlled tubes. Only changes in the level of the synchronizing pulses will affect the preceding tubes. This is the desired action because, with constant carrier signal strength, the peak pulse voltages are also constant. With no signal arriving at the receiver, no voltage is developed across R_4.

The plate of the A.G.C. diode and the grids of the controlled tubes are negatively biased by a voltage obtained from the negative side of the power supply. This voltage is in addition to the negative A.G.C. voltage and represents the minimum fixed bias on the tubes. There is -30 volts between the end of R_1 and the grounded side of R_3. Approximately 13 volts are dropped across R_1, leaving the remaining 17 volts for R_2 and R_3. Rotation of the center arm of R_2 will permit adjustment of the amount of negative voltage placed on the diode plate and on the controlled tubes' grids. In this way the amount of A.G.C. voltage fed back to the grids can be controlled. In addition, the d-c negative bias of the grids may be altered, resulting in more or less gain for the video signal passing through the set. With greater gain, a stronger video signal is applied to the grid of the picture tube and a greater degree of contrast is obtained. Contrast, it will be recalled, is the ratio of the intensity of the bright sections of the image to its dark sections. Within limits, more contrast is desirable; beyond this, as with too much volume in a sound receiver, distortion results. Potentiometer R_2 controls the gain which controls contrast of the image at the view-

ing screen.   Hence it is called the contrast control.   It is available on the front panel for the observer to adjust to his liking.

To prevent distortion as the amount of negative bias applied to the controlled tubes increases, variable-mu tubes are preferred in the regulated stages.   This arrangement is found in television receivers just as much as in sound sets.
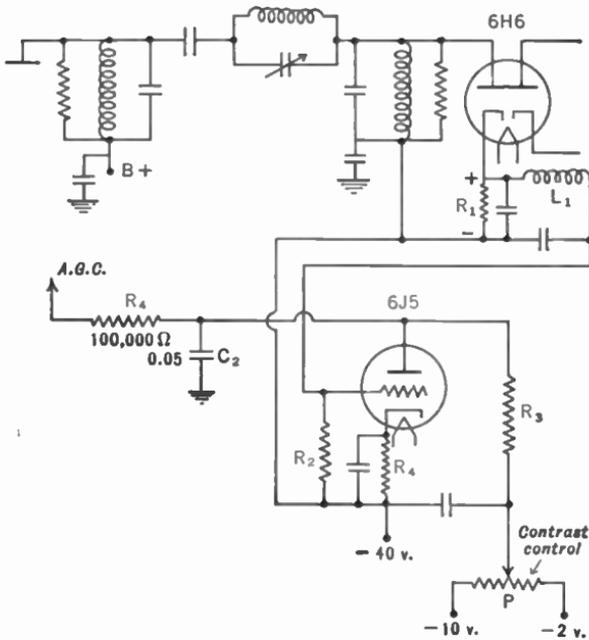

FIG. 5.12.   An alternative method of obtaining A.G.C.

A more elaborate circuit for obtaining the A.G.C. voltage is given in Fig. 5.12.   One half of the 6H6 rectifies the video signal, which appears across R_1 with the polarity shown.   The video signal, at this point, has a negative picture phase.   The voltage across R_1 is then brought to the grid of the 6J5 from L_1 and appears across R_2.   Voltage variations at the grid causes similar changes in the plate current and, because this current must flow through R_3, a varying voltage drop is developed here. The line to the grids of the controlled tubes is connected to the

6J5 plate. In this way the voltage variations at R_3 are delivered to those tubes.

The method of making the plate of the 6J5 tube more positive than the cathode is a little unusual. By placing a small negative voltage on the plate and a larger negative voltage on the cathode, the plate becomes more positive than the cathode and attracts the electrons that are emitted by this element. Electrons, although negative in charge, react to voltage differences. The plate is positive, by comparison, and they are attracted to it.

The negative voltages are placed on the elements of the tube because the A.G.C. line connects directly from the plate of the 6J5 to the grids of the controlled tubes. If a positive voltage were placed at the 6J5 plate, the grids of the controlled tube would likewise be affected by this voltage, which is undesirable. Hence the negative voltage. The contrast control, P, varies the amount of negative voltage on the controlled grids and this voltage is independent of any A.G.C. voltage developed across R_3. It is well to keep in mind that only the variable voltage developed across R_3 is the A.G.C. voltage, whereas the variable resistor, P, sets the fixed operating bias for the controlled tubes. Any d-c voltage developed across R_3 is added to the operating bias. R_4 and C_2 form a filter with a relatively long time constant in order to prevent any picture element variations from reaching the grids of the controlled tubes. Only the synchronizing pulses determine the voltage across C_2 and only this will reach the grids. The action is similar to that of the 0.05-μf condenser in Fig. 5.11.

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 band width 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

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 dis-tinguish 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 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.
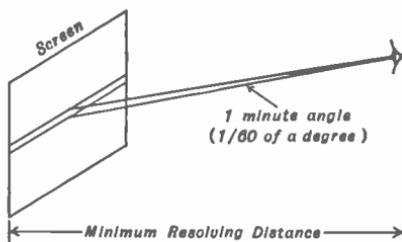

FIG. 6.1. The power of the human eye to resolve or separate two objects that are closely spaced depends upon the dis-tance from the eye to the objects. If the objects subtend a 1 minute angle at the eye, they may be seen separately.

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 illus-trated 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 band widths 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 character-
istic 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.

To ascertain what loss of response at the low frequencies would
mean, let us examine in some detail the camera signal, for it
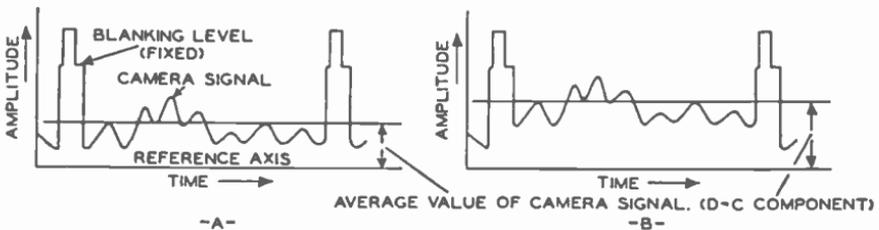contains the information of the picture.   In Fig. 6.2 there is a

Fig. 6.2.   The height of the camera signal variations above the reference axis rep-
resents 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.

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 blank-
ing pulses of the video signal, there is another component, re-
ferred 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 variations of
Fig. 6.2A as compared with the average of the a-c portion of the

signal of Fig. 6.2B. That of B is the greater of the two. This average value represents the background illumination 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 variations 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 background will convey the impression of daylight, sunshine and clear weather. With a darker background, one obtains the opposite impression.

At the transmitter, the d-c component may be inserted manually by an operator viewing the scene from a monitor, or automatically by using the average current derived from the viewing tube, where this is possible. If the latter cannot be accomplished, the light from the scene is allowed to fall onto a photoelectric 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 present 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

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

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.
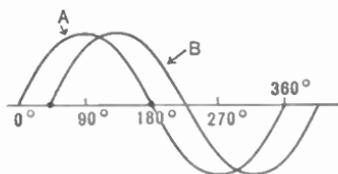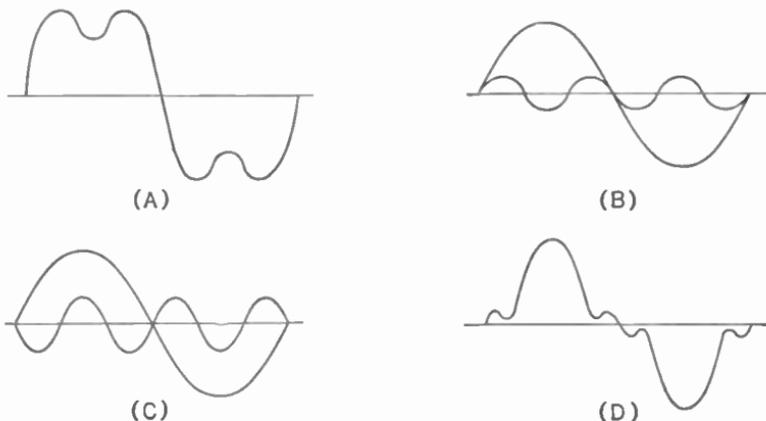

Fig. 6.4.   The effect of phase distortion in changing the shape of a wave.   The composite wave at (A) can be broken down into the two waves at (B).   If these two component waves change their relative phases, then (D) shows one result.   There may be other combinations than the ones shown.

Phase distortion is produced when the time or angle relationship of electric waves to each other changes 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 assumes 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 illustrated, let us see how the circuits found in video amplifiers may 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 amplifiers. 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 simplification 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 accomplished 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 oppo-

sition 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 radio-man 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.

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
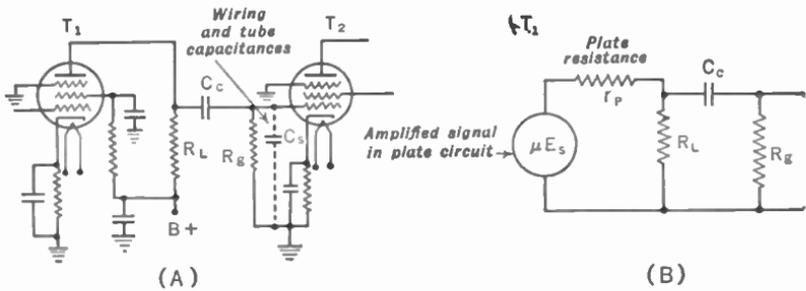

Fig. 6.5.   A resistance-coupled amplifier (A) and its low frequency equivalent circuit (B).

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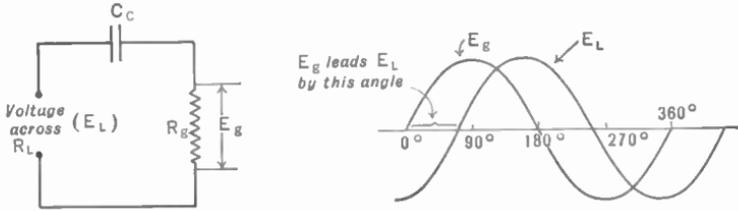

FIG. 6.6. At the low frequencies, E_g is out of phase with E_L because of the coupling condenser C_C.

The lowest frequency will have the greatest phase angle introduced while it is travelling from the output of the tube to the input of the next stage. As the frequency rises, the phase difference becomes less, gradually reaching zero. This characteristic
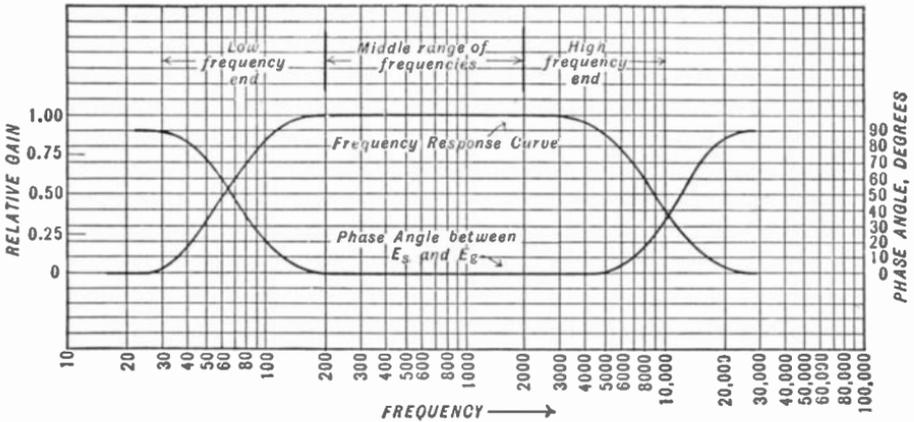

FIG. 6.7. The frequency and phase response of an ordinary resistance-coupled amplifier.

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, 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
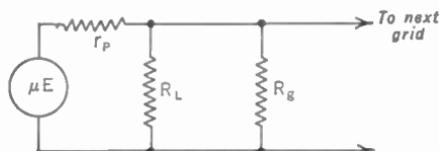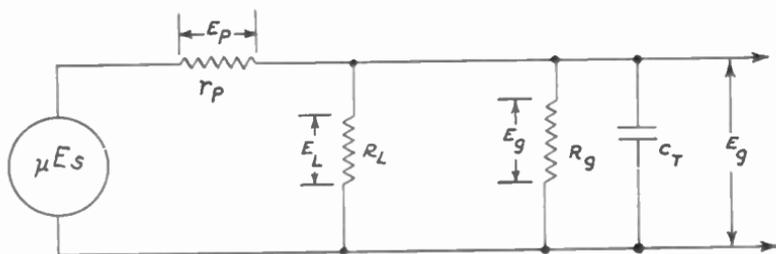

FIG. 6.9. The equivalent circuit, at the high frequencies, of the resistance-capacitance coupled amplifier of Fig. 6.5.

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 band width 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 frequency 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 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_T is less and it does not begin to destroy the
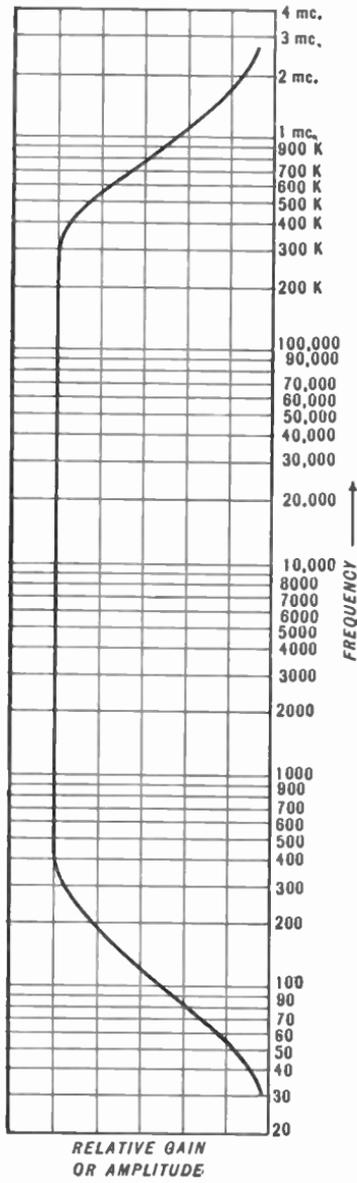
FIG. 6.10. Increase in the frequency response of a resistance-coupled amplifier with decrease in shunting capacity.

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 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.
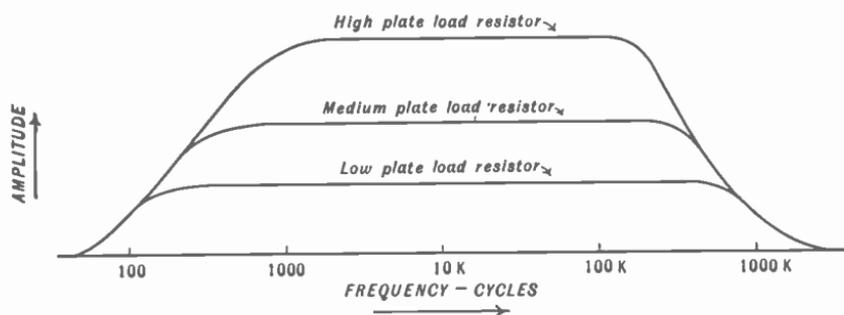

FIG. 6.11.   By lowering the plate load resistor, it is possible to increase the extent of the flat portion of the response curve.

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_T 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_T and the curve remains flat. If too much peaking is resorted to, the curve will rise sharply near the 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.

(A)
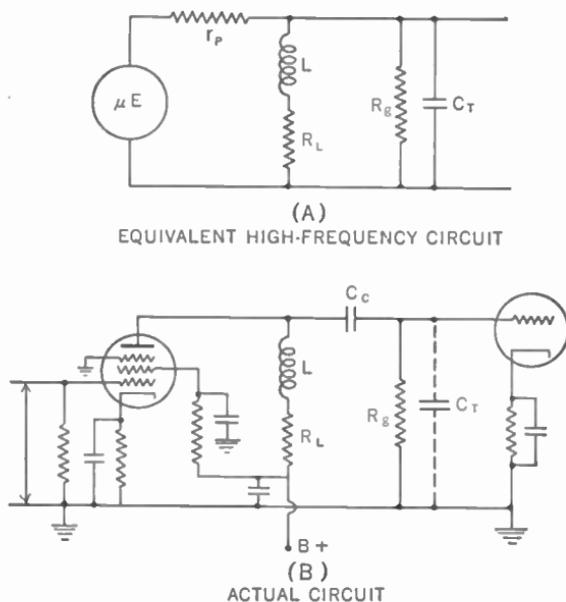EQUIVALENT HIGH-FREQUENCY CIRCUIT

(B)
ACTUAL CIRCUIT

FIG. 6.12.   High-frequency compensation for an r-c amplifier.

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.

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
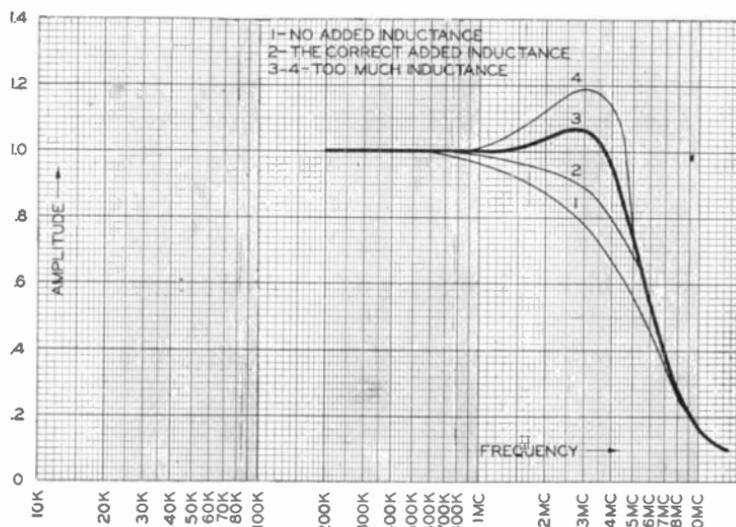

FIG. 6.13. The effect on amplifier response of the insertion of various amounts of peaking inductance in the plate load.

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
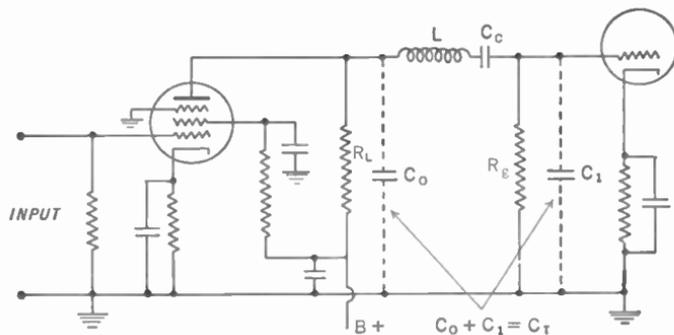

FIG. 6.14. High-frequency compensation by means of a series peaking coil.

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.

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

$$R_L = \frac{1.8}{2\pi f C_t} \ (C_t = C_1 + C_0)$$

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

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

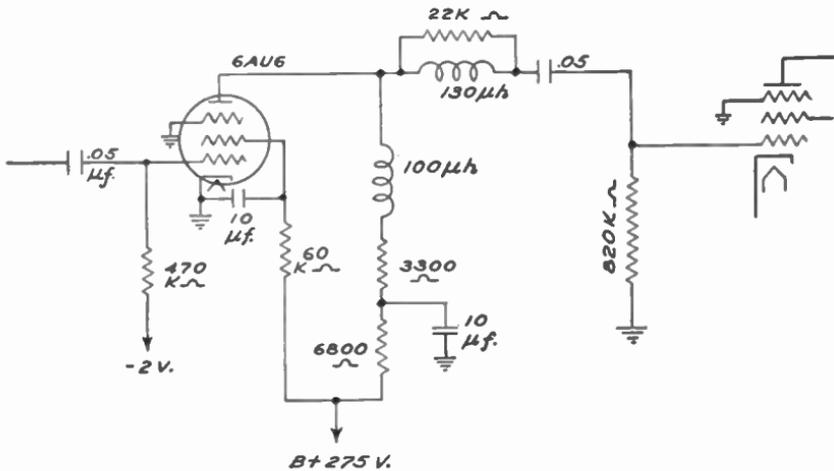f is the highest frequency it is desired to have the amplifier pass.

FIG. 6.15.   A video amplifier employing series and shunt peaking.

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 $X_c = \dfrac{1}{2\pi f C}$, 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 back-
ground 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 con-
denser 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 in-
creased 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 oscilla-
tions or motor boating from feedback between stages by way of
the power supply.

The value of C_f in Figure 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.

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}
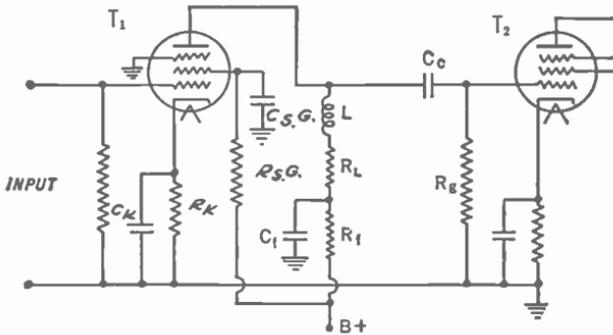

FIG. 6.16.   Low-frequency compensation (R_f, C_f) of an r-c amplifier.

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 high-frequency compensating components are chosen first. These include R_L, L_s and L_c. Next, the low-frequency compensating 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
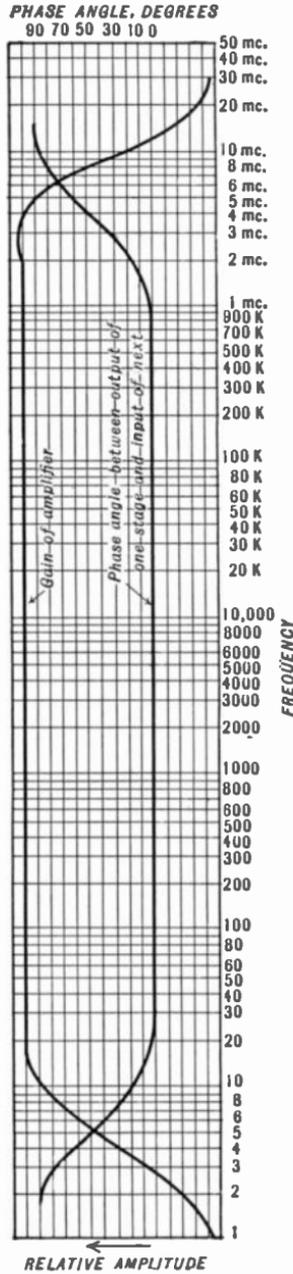
PHASE ANGLE, DEGREES

FIG. 6.17.   The frequency response of a fully compensated resistance-coupled amplifier.   An amplifier of this type is shown in Fig. 6.16.

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 constant in each instance (as $C_f \times R_f$, $R_{sg} \times C_{sg}$, and $R_k \times C_k$) 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
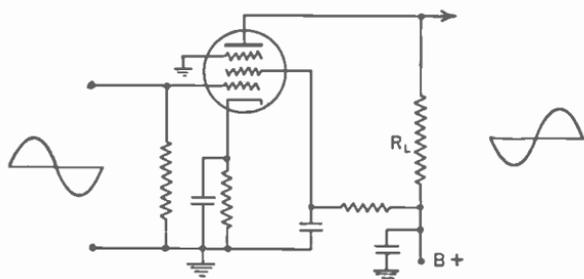

Fig. 6.18.   The input and output voltages of a tube showing the 180° phase reversal.

plotted in Fig. 6.17. The number of such stages required between 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 signal 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, and blanking and synchronizing impulses. The form of the signal at the output of the video detector is shown in Fig. 7.1A.
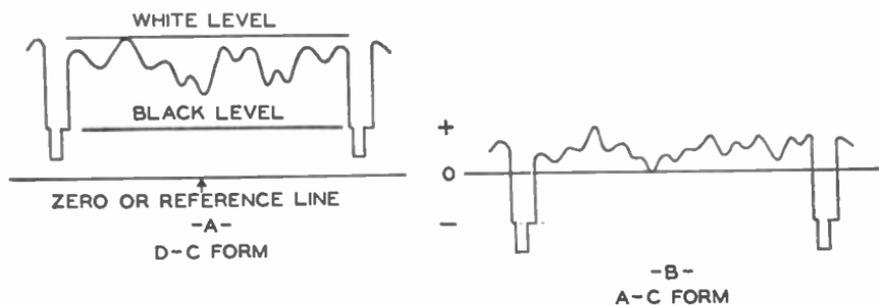

FIG. 7.1. The d-c and a-c forms of a television video signal.

However, when this signal is sent through a resistance-capacitance coupled amplifier, the condenser prevents any d-c from passing, and only the a-c component, with the blanking and synchronizing pulses, continue through the system. The video signal with the d-c component removed, is shown in Fig. 7.1B. In its a-c form, note that part of the signal is above the zero line, part below. Previously the entire signal was completely on one side of the zero line, held there by the d-c component. Like any other a-c signal, its average value, when measured with a d-c meter, is zero. There is as much *area* above the reference line as below.

A comparison is made in Fig. 7.2 further to demonstrate the difference between the a-c and d-c forms of a video signal representing three degrees of light intensity; namely, white, dark, and

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grey.   It is seen that the blanking levels and their corresponding
synchronizing pulses no longer are lined up as they were when
the d-c component was present.

It may be asked how the image would appear if these signals
were applied (in their a-c form) to the grid of the cathode-ray
tube.   First, the average brightness or the background illumina-
tion would be incorrect, since this is determined by the d-c
component of the signal.   The reproduced picture might have the
correct contrast between the various picture elements, but the
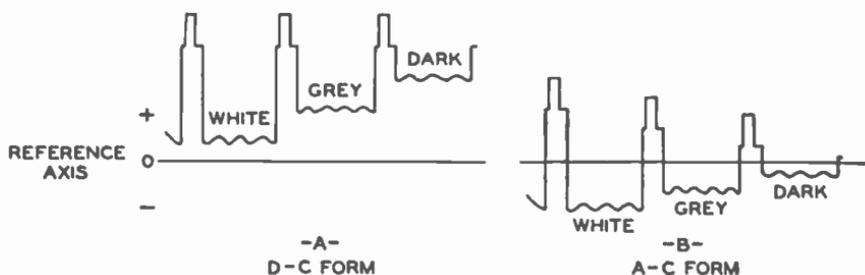background shading would be incorrect.   An example may make

FIG. 7.2.   A-c and d-c forms of a video signal.

this distinction clearer.   Imagine a scene where a great deal of
dark color predominates.   The actors are wearing dark clothes
and the objects (chairs, tables, etc.) are likewise dark in shade.
The scene is set in a brightly lighted room and the background
illumination is high.   If the d-c component is removed, however,
the scene as observed on the screen at the receiver would appear
much darker because now you, as the observer, would tend to
visualize an average illumination based only on the various shades
of the people, their clothing, and the objects in the picture.   It all
relates to the previously mentioned fact that the same people
(and objects) can be placed against a bright background or a dark
one; the a-c video signal variations in both cases remain es-
sentially the same.   Only the d-c components of the two scenes
would differ.

Secondly, with the removal of the d-c component, we find that

the blanking and synchronizing pulses are no longer lined up. Their function, it will be recalled, is to drive the grid of the picture tube to cut-off in order that no beam retraces are visible.   In their a-c form, this will not always happen since some blanking pulses are less negative with respect to the reference line than others.   With the same fixed bias on the picture tube grid, many pulses would not be sufficiently negative to cause cut-off. As a result, some retraces would be visible, a definitely undesirable situation.

The d-c component acts as the average value of the signal and represents, for each scene, the average background illumination. The a-c voltages vary above or below this average value, depending upon whether they represent elements that are darker or brighter than the background illumination.   With this fixed reference point, black, or grey, or white, or any one color is always reproduced by the *same illumination*.   With the d-c component removed, we have no information as to its absolute value, and what is black (or any other color) in one instance, may not be black (or any other color) at another point.

Finally, with the d-c component in the video signal, all the blanking and synchronizing pulses are on the same level.   With the correct fixed bias applied to the grid, all these pulses automatically drive the cathode-ray tube control grid beyond cut-off. With the direct current absent, the pulses assume various levels (see Fig. 7.2) and each now requires a different bias on the grid of the cathode-ray tube in order to blank out the beam.   For manual control, this is obviously impossible.

It might be suggested that all retraces could be eliminated by raising the picture tube grid bias to so high a value that every pulse, no matter how slightly negative it may be, drives the grid to cut-off.   But what would be the result?   By referring to Fig. 7.2, where the three signals (white, grey, and dark) are shown in their a-c form, we see that this would require making the grid so highly negative that even the relatively small pulse associated with a dark line would drive it to cut-off.   But if this is done, those portions of the white line and grey line signals that

extend farther below the zero axis than the end of the dark signal pulse would be lost.

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 properly operate the television receiver, 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. 7.1A 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 variations and the pulses. As the scene becomes darker, these two components move closer together (see Fig. 7.2).

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
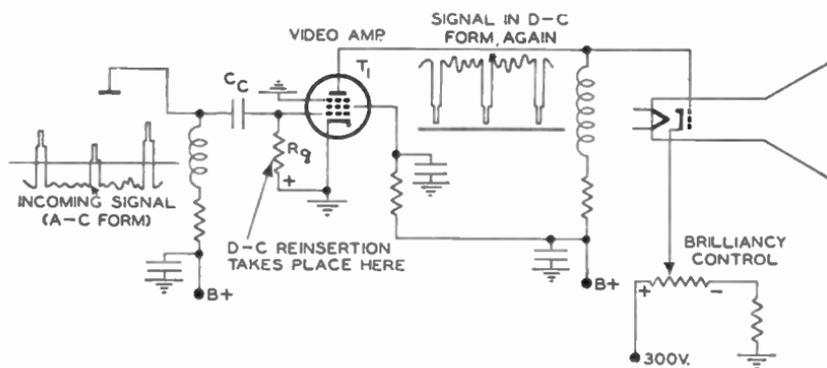

FIG. 7.3.   A simple d-c reinsertion circuit. The bias developed across R_g varies with the incoming signal.

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. 7.3.   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 signal

* The name " d-c reinsertion " circuit is common throughout the television field.   However, sometimes the name of " clamping " circuit is also heard. Both refer to the same thing and may be used interchangeably.

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. 7.3. 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 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. 7.3. One further point should be kept in mind throughout this entire process.   The bias developed across R_g does not vary each instant,
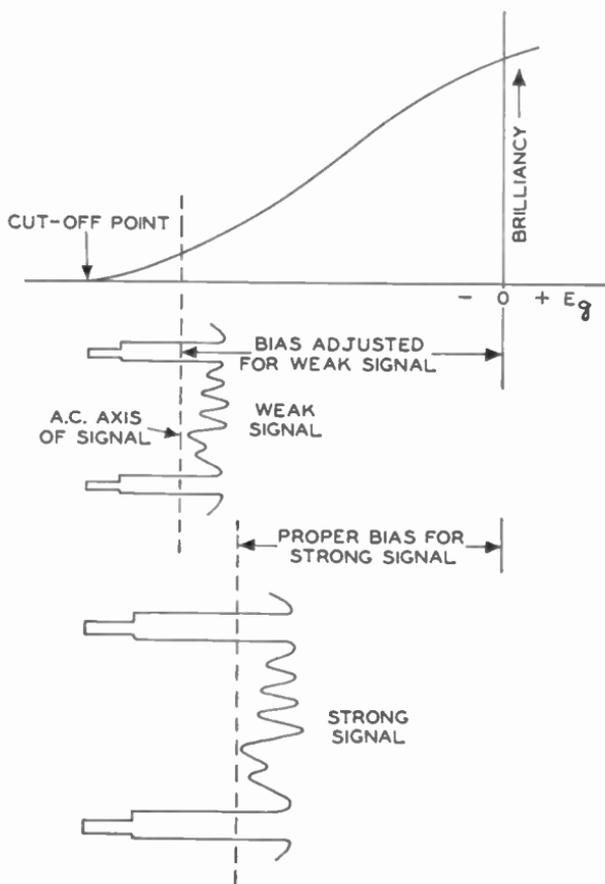

Fig. 7.4.   Illustrating why the brilliancy control must be adjusted to suit the incoming signal.

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 $\frac{1}{16,000}$ of a second.

The output of T_1, shown in Fig. 7.3, is applied directly to the control grid of the cathode-ray tube. Direct coupling is necessary since a condenser would remove the d-c component just inserted. At the grid of the cathode-ray tube, a fixed bias between 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, requires 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. 7.4. 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 connected into the bias circuit, brought out to the front panel, and called the brilliancy or brightness control. By its use, the observer 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 visible. 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 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.   Inspection of Fig. 7.3 will reveal that with this particular method of d-c reinsertion, a large positive voltage is applied to the cathode of the picture tube to counterbalance the large positive voltage on the grid, which is connected directly to the plate of the video amplifier.   The position of the movable arm permits the correct position to be obtained.

The foregoing method of d-c reinsertion is simply attained and produces good results.   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. 7.5).   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 synchro-
nizing pulses are below the zero line. When applied to points 1
and 2, the signal will cause point 1 to become negative with re-
spect 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,
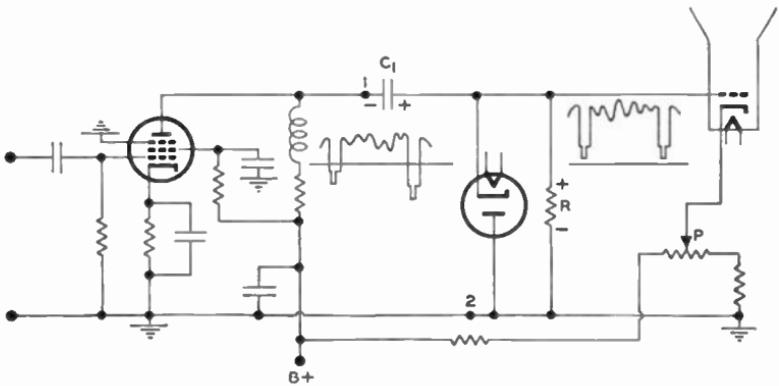or when point 2 is positive with respect to point 1.

Fig. 7.5.   D-c reinsertion with a diode.

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. 7.5. 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 ampli-
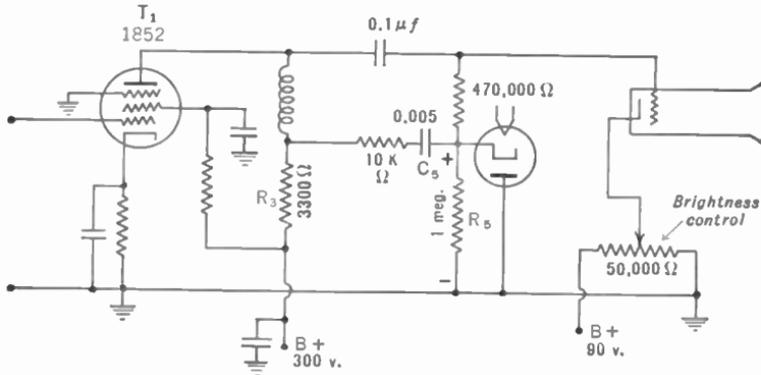

FIG. 7.6.   A d-c reinsertion circuit that has been employed in commercial receivers.

tude 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 has been used in some RCA television sets.   The circuit, given in Fig. 7.6, 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.

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 mater-
ial 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

FIG. 8.1. Cathode and heater
construction for a cathode-ray
television tube.

sharp, narrow beam that finally impinges on the fluorescent
screen in a small round point.

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 elec-
trons 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 repelled 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
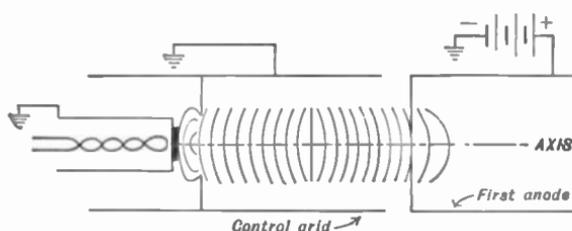
FIG. 8.2.   The first lens system of a television viewing tube.

the surrounding regions. To be sure, the farther away we get from the anode, the weaker the strength of the field. With zero 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 influenced by the distance from the first anode and the control

grid. Cathode-ray tube design engineers use such field distribution 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 proven 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.
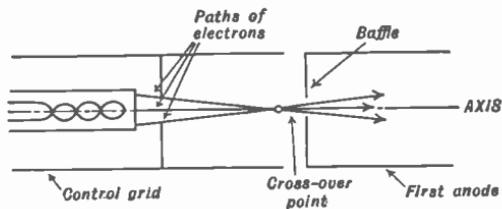

Fig. 8.3. A simplified diagram of the cross-over point in the first lens system. The two subsequent electronic lens systems are designed with this cross-over area serving as the starting point.

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
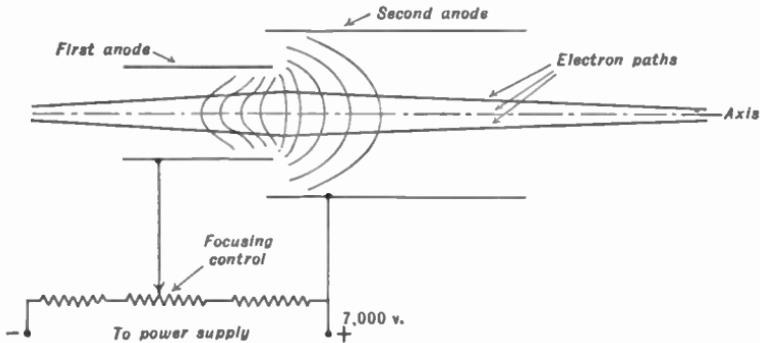

FIG. 8.4. The second lens system. Focusing of the electron beam at the viewing screen is accomplished by varying the voltage at the first anode.

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.

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 equipotential 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 convex equipotential lines force the electrons to converge to a greater extent than the concave lines cause the electrons to diverge. 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
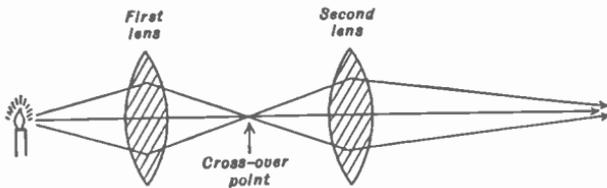

Fig. 8.5.   The glass lenses used in focusing light rays illustrate the similarity between light wave and electron beam focusing.

determine the amount and the point at which the focusing takes place. In present-day cathode-ray tubes, the ratio of the first to the second anode voltages ranges from 3 to 1 to 6 to 1.

In order that the electron beam leaving the cross-over point shall not diverge too greatly, a baffle is placed at the opening of 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. 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. 8.6. 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.

The reason for the defocusing action may be explained as follows: The electron beam, once it leaves the second anode, is
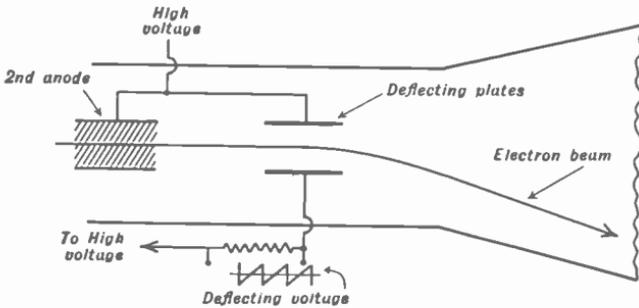

FIG. 8.6.   Deflection of electron beams.   This unbalanced method, while simple in construction, does not always give a clearly defined beam on all parts of the fluorescent screen.

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. 8.7. 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 volt-

age 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 to permit an unobstructed sweep of the electron beam through the necessary angles.
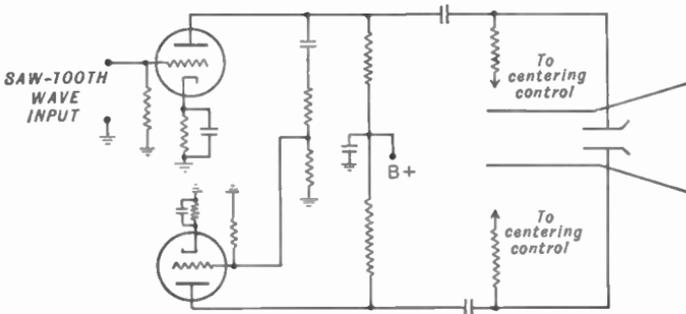

Fig. 8.7. A balanced deflection system.

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, deflec-

tion is used, some manufacturers omit the separate cylindrical second anode and use the coating to perform this function, too. Tests have proven 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. 8.26 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 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 sensitivity, 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 sensitivity 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 hori-
zontal 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.
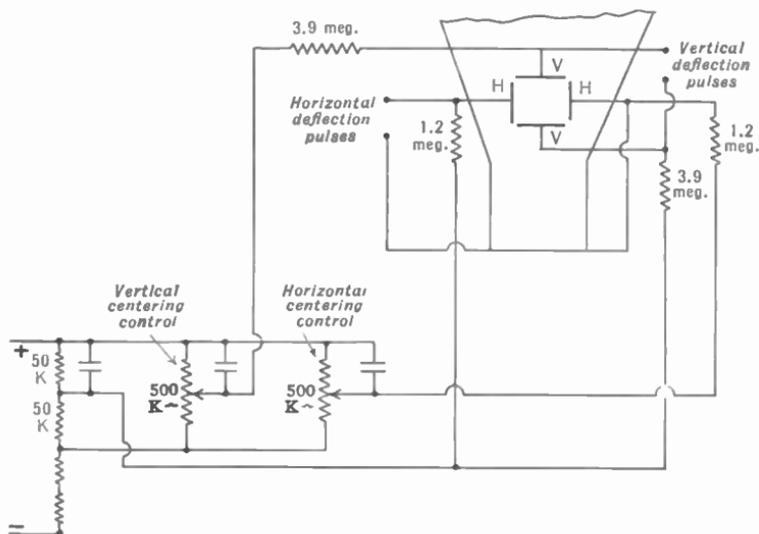

Fig. 8.8.   Vertical and horizontal centering controls.

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 potentiometers 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 potentiometer arms, however, will make one plate more positive than the other of either set and bend the electron beam in the desired 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 voltages 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
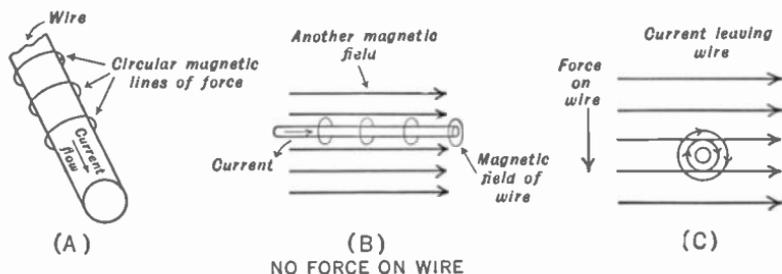carrying a current has a circular magnetic field set up around

FIG. 8.9.   The action of a wire carrying current when placed in a magnetic field.

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 mag-
netic force. Above the wire the lines of both fields add, whereas
underneath the wire they oppose and tend to cancel. Experi-
ment 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
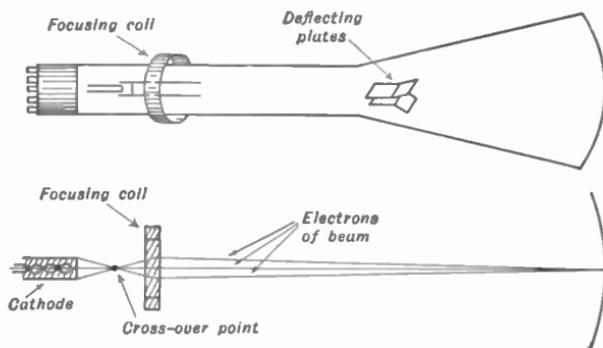angle to the flux lines, a force will be brought to bear on them and
their path will be altered.

FIG. 8.10.   Magnetic focusing.

It is well to reiterate that for an electron to react with a mag-
netic 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
described electrostatically controlled tubes; it still converges
electrons to the cross-over point. From this point, the elec-
trons 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
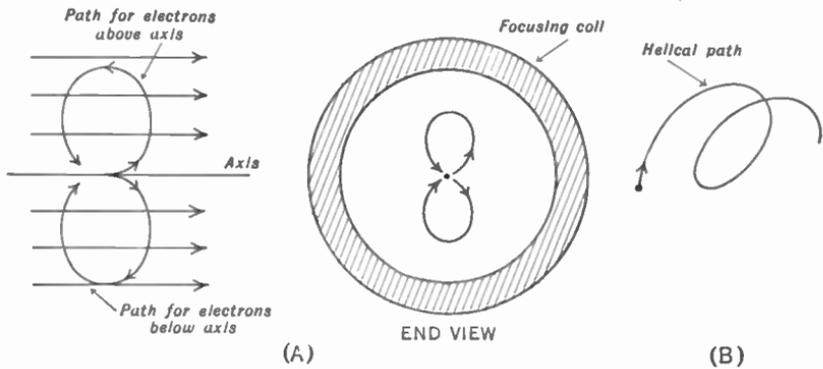field can be more easily understood if it is recalled that the re-

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).

sulting 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.

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.

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 mag-

netic 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 and adjusted for best results. The electron beam is thus subjected 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 comprising one set. These are connected in series in order to obtain 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, 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 current 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, sweeping out the desired pattern.

The reader should not become confused by the seemingly different 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
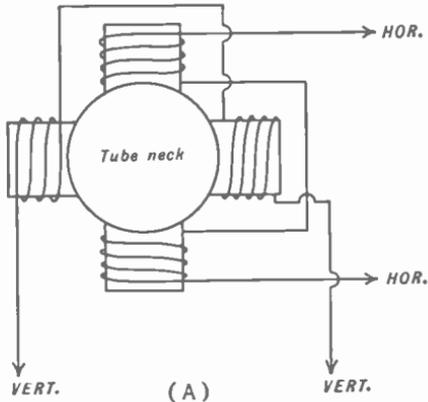

FIG. 8.12(A). Electromagnetic deflection coil. This represents the physical placement of the windings.
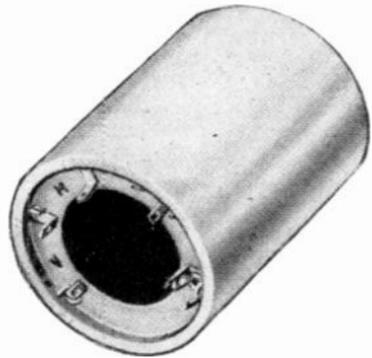
FIG. 8.12(B). Deflection yoke form.

axis. Their forward motion, given to them by the positive first anode, and sometimes by an intensifier ring, keep 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 focusing 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 retained. This is shown in Fig. 8.13. 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. 8.14.   In this case, correction may be accomplished by rotating the yoke until the image is again properly positioned.
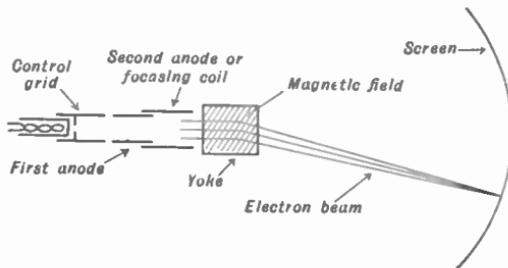

Fig. 8.13.   Deflection by magnetic means.

All sets using magnetic deflection are provided with two centering controls, one for the vertical coils and one for the horizontal coils.   These controls permit the adjustment of the electron beam until it hits the very center of the screen when no deflecting currents are applied to the yoke.   A small d-c current is sent through the coils and serves to alter the course of the electron beam until it is centered on the screen.   The amount of current is controlled by potentiometers.   More detailed information on circuit connections is given in Chapter 10.

Cathode-Ray Tube Screens.   Everything that has been done on 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.

It has been generally established, by this time, that the most widely acceptable screen for television is one which emits white light when excited by an electron beam.   This does not exclude screens emitting light of other colors, for some of these have

Courtesy NBC.

FIG. 8.14. Incorrectly positioned image due to improper placement of deflecting coil yoke.

been and are being used. However, black and white images are less fatiguing for the eyes, especially for long sustained viewing periods. Again, the wide acceptance of the already familiar motion picture also played an important part in the choice of this set of color values.

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 luminescence. 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 phosphor-
escent screens, and indeed the crystalline substances used for
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

RMA Designa- tion—Substance	Activator	Fluorescent Color	Phosphorescence (seconds)
P1—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
P11—Zinc sulphide	Silver with a nickel quencher	Blue	Very short 10μ sec.

TABLE 8.1.   The most common phosphores used for oscilloscopes, television re-
ceivers and radar equipment.

common phosphors in use in oscilloscopes, television receivers and
radar equipment is shown in Table 8.1.   For television, a com-
bination 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 Figure
8.15.

    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.
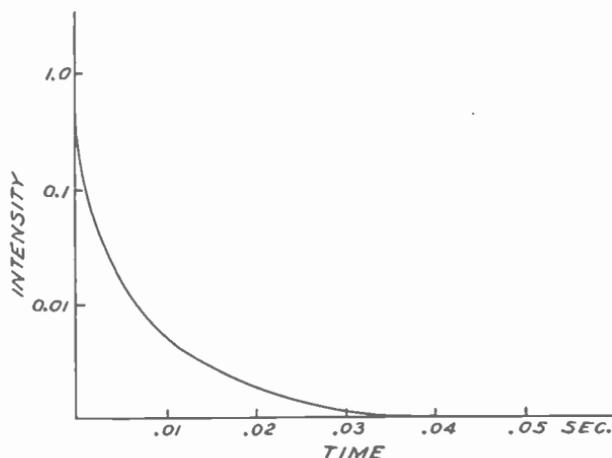
30% reaches the observer.

FIG. 8.15.   A persistence curve for zinc sulphide, commonly used in P4 television screens.

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 reflected 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. 8.16).   The light rays which leave the fluorescent crystals at the inner surface of the tube face travel into the glass and are re-fracted.   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
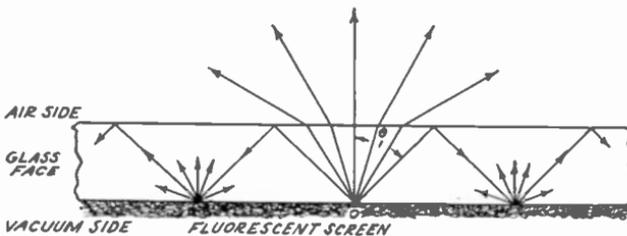

Fig. 8.16.   Illustration of how reflections between the two sides of the glass can cause halation.

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 areas, one of which is being 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 between 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. 8.17.   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.   A good portion of the image is useless because of the optical distortion introduced by the screen curvature.   A flat-face 10-inch tube seems much more preferable than a 20-inch curved screen.
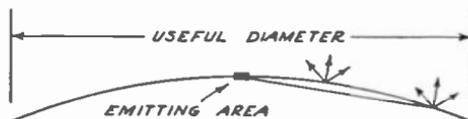

Fig. 8.17.   Diffusion effects in nonflat screen.

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. 8.18 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. 8.18, 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
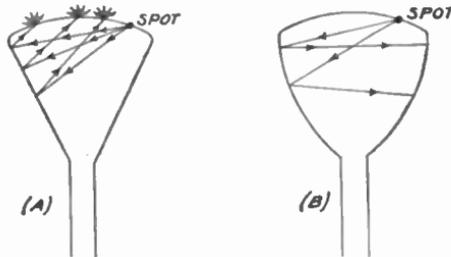

FIG. 8.18.   The shape of the tube bulb can reduce internal reflections.

permit the electrons in the scanning beam to reach the fluorescent crystals.   It will prevent, however, any of the light which is gen-
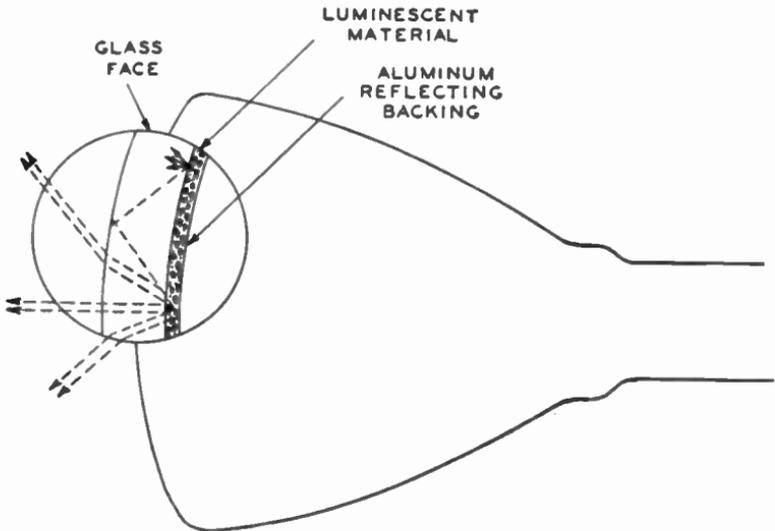

FIG. 8.19.   An aluminum backing over the fluorescent screen prevents light from traveling back into the tube.

erated by the screen crystals from traveling back into the tube. This is shown in Fig. 8.19.   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, the detail contrast is not
noticeably affected since it is governed primarily by halation, and
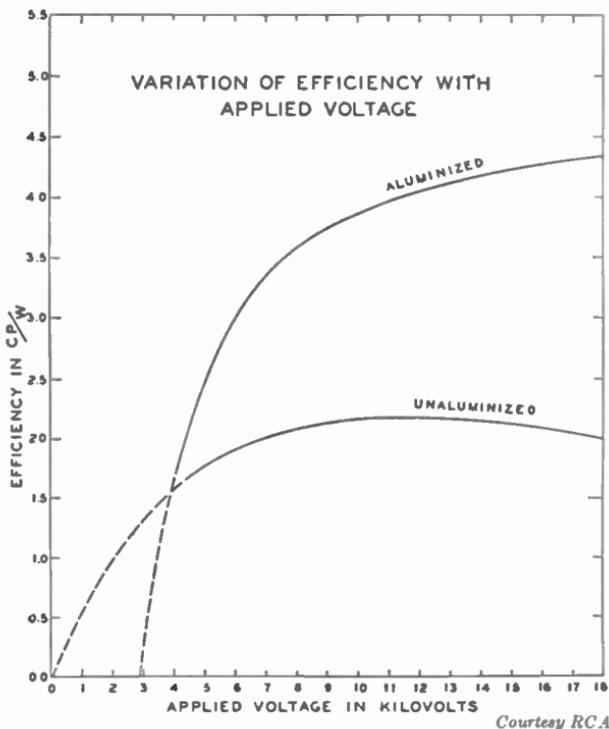the addition of the aluminum layer does not affect this.

FIG. 8.20.   Variation in efficiency of aluminized and unaluminized screens.

The metal film is extremely thin, being on the order of
3500×10^{-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. 8.20,
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-
trating the layer decreases their efficiency below that of similar
electrons in tubes not possessing this layer.   The poorer ef-

ficiency 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
employs 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 traveling 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 considera-
tion, ions and electrons receive similar treatment.

There are several methods in current use for preventing the ions
from reaching the screen.   First there is the bent electron gun, as
shown in Fig. 8.21.   The cathode, when heated, will emit ions
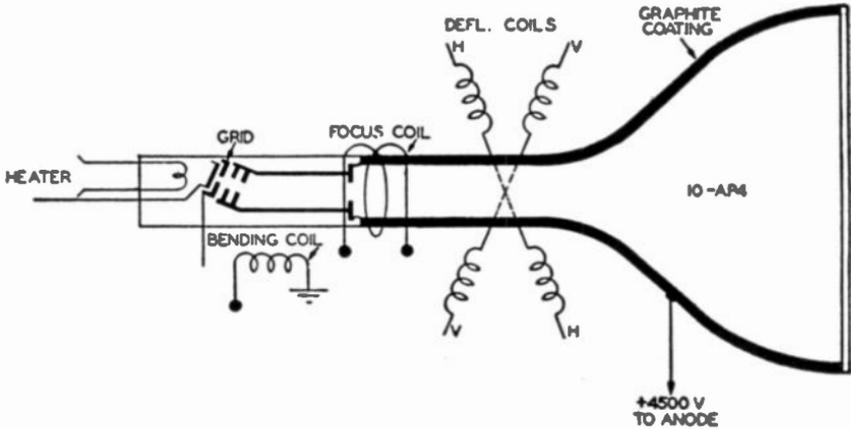and electrons and these will be accelerated to the first and second

FIG. 8.21.   Cathode-ray tube using a bent electron gun and magnetic field to elim-
inate ion spotting of tube face.

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 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 tube is a commercial tube which em-
ploys this type of ion trap.

There is still another method of eliminating the ions, and this

type of electron gun is shown in Fig. 8.22.   The electrons and ions are emitted from the electron gun and travel forward.   Immediately beyond the control grid a positive electrode is inserted which is designed to attract both the electrons and negative ions. A magnetic field, however, produced by external coils, will bend the electrons back to the central axis of the tube without noticeably affecting the ions.   In this manner the two are separated and the ions prevented from reaching the fluorescent screen. This type is used in RCA television receivers.
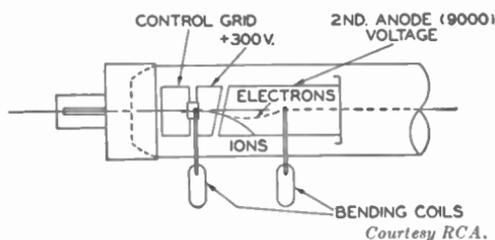

FIG. 8.22.   An ion trap used in 10BP4 tubes.

In the adjustment of the television receiver the position of the bending coils for the ion trap is at the end of the tube neck, close to the tube base.   The set is turned on and the coils moved about until the scanning raster or image is brightest.   The coil clamps are then tightened securely.

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,

$$\text{depth of penetration} = \frac{K(Ve)2}{m}$$

where K = constant, dependent upon the material used (i.e., aluminum),

   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.

Most current tubes which have screens greater than 7 inches in diameter use electromagnetic deflection. The advantage lies in the simpler construction of the tube and the shorter tube lengths possible. If we were to use electrostatic deflection in a tube having the length of the electromagnetic deflection tubes, it would be necessary to develop comparatively large deflection voltages. However, with electromagnetic deflection, the necessary deflection currents can be generated in a single power amplifier. The trend, of late, has also been to replace electrostatic focusing with magnetic focusing, thus resulting in a tube with a very simple internal construction.

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. 8.23. 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 that are required on a cathode-ray tube, the base contains eleven pins. Practically all tubes with screens of 5 inches or greater employ an 11- or 12- or 14-pin socket, while some smaller tubes, 3-inch, etc., use 7-pin sockets.

The use of colloidal graphite or aquadag has been mentioned before. Fig. 8.24 illustrates the location of this coating which acts as either a return circuit for secondary electrons knocked off the fluorescent screen, a second anode, or both. In large tubes an external cap connection to this coating is provided; in smaller tubes it is attached internally to the second anode.

Many larger screen tubes incorporate one additional element not present in the 5-inch tube. The new element is a second grid, located just beyond the control grid. It is constructed in

(A)

RMA BASING
(B)
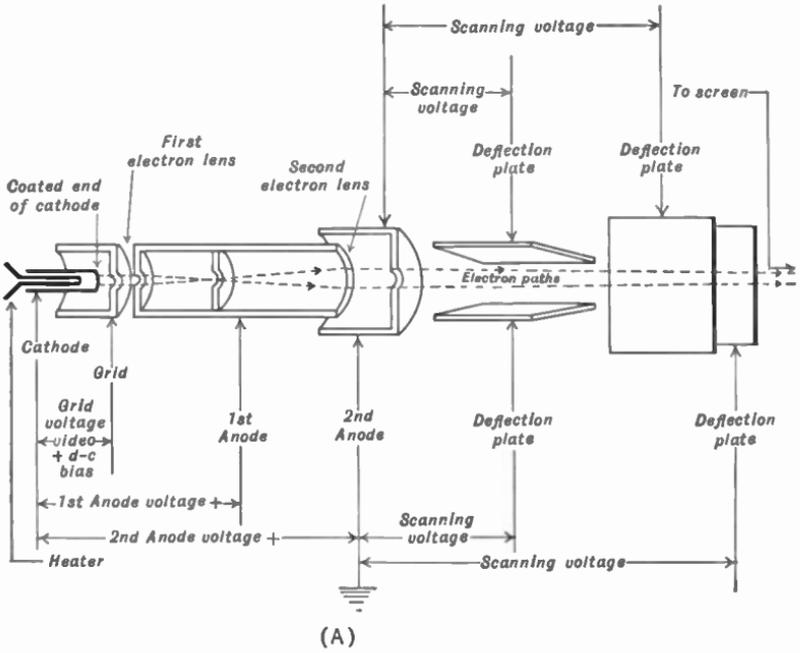
Courtesy Sylvania Electric Products Corp.

FIG. 8.23.   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).

the form of a baffle, as shown in Fig. 8.25. A positive voltage
of about 250 volts is placed on this grid, known variously as
Grid #2, or the accelerating grid. The introduction of this grid
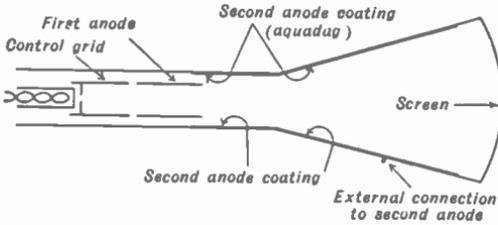acts to increase the number of electrons reaching the cross-over

Fig. 8.24. Many cathode-ray tubes utilize the
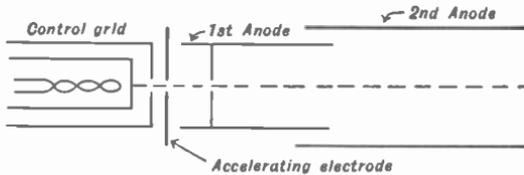conducting coating for a second-anode instead of a
metallic cylinder.

Fig. 8.25. The addition of an accelerating elec-
trode, as shown above, produces a relatively stable
cross-over point.

Fig. 8.26. Large RCA tele-
vision tube. The RCA trade
name for these tubes is
Kinescope.

point, and the position of this point becomes more independent of
changes in the first anode or control grid voltages.

A large television tube, the 9AP4, which is constructed with
an accelerating grid and an extended second anode is shown in
Fig. 8.26.

When the deflecting and focusing functions of a tube are ac-
complished magnetically, the internal structure is modified
accordingly. Thus, Fig. 8.24 would represent a tube which

utilized electromagnetic deflection and electrostatic focusing. To employ electromagnetic focusing, we would retain essentially the same elements shown in Fig. 8.24. However, there would now be a fixed positive voltage applied to the first anode, in place
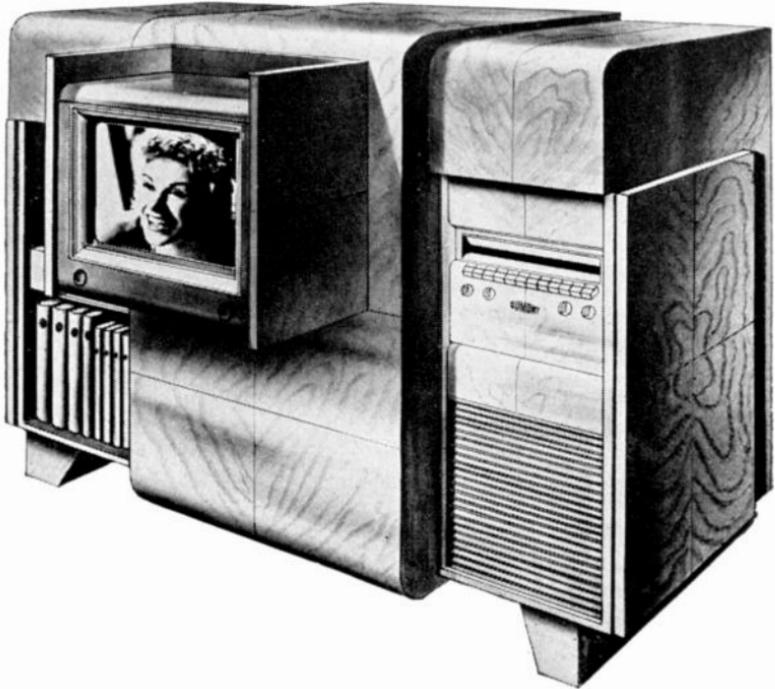

FIG. 8.26A.   A DuMont television receiver employing a 20-inch direct-viewing tube. When not in use, the tube is tilted back into the cabinet.

of the variable voltage when electrostatic focusing is used.   Some tube manufacturers use the first anode as the accelerating electrode, with its voltage considerably lower than if it were being used for electrostatic focusing.

Large cathode-ray tubes, manufactured by DuMont Laboratories, Inc., have a slightly different structure from the tubes just described, which are RCA manufactured.   An intensifier ring or coating is placed near the fluorescent screen and operated at a higher voltage than even the second anode.   The purpose of

this electrode is contained in its name, namely to intensify (by acceleration) the action of the electron beam at the screen. The width of the intensifier ring varies with the tube type. An example of narrow rings is shown in Fig. 8.27, for a 14-inch tube.
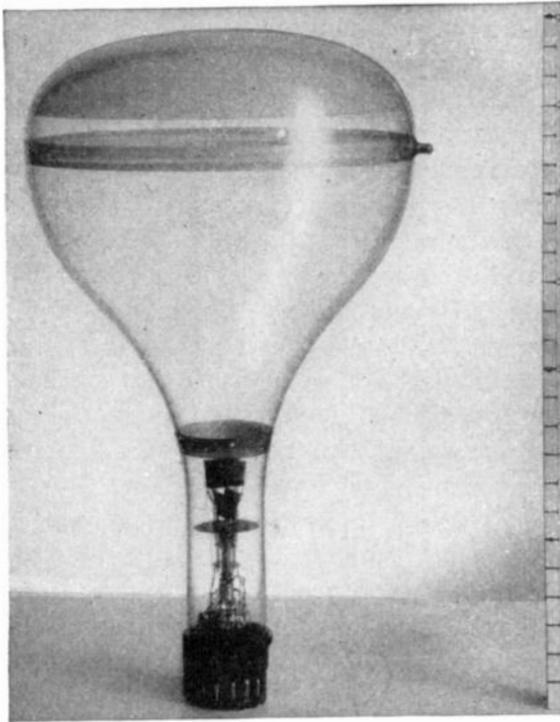

FIG. 8.27. DuMont 14-inch television reproducing tube. Note the intensifier ring placed near the screen.

In connection with the intensifier ring, it should be added that a definite advantage is obtained by placing the ring at a higher potential than the second anode or the deflection plates. Besides imparting greater speed to the electrons, it permits the deflection voltages to bend the electron beam while the electrons are still in a relatively low-voltage point of the tube. It requires less voltage, for example, to deflect electrons when they are travelling at lower velocities than when they are moving more rapidly. In

the DuMont type of tube, the greater acceleration does not affect the electrons until they have already been deflected. The result — strong intensity and smaller deflecting voltages.

It is difficult to state definitely that the preceding discussion covers all the different types of television cathode-ray tubes that are available on the market. Undoubtedly variations and combinations of the above features will be encountered. With the explanation as a guide, however, no trouble should be encountered in determining the function of any added electrodes.

Curvature of Television Screens. The viewing screen of many television tubes is curved for two reasons. First, there is the matter of air pressure. Using the value of 15 pounds per square inch as the atmospheric pressure, a 12-inch tube, which has a screen area of 113 square inches ($\pi r^2 = 3.14 \times 6 \times 6 = 113$), has 1,695 pounds force on it. This is almost $\frac{7}{8}$ of a ton. A flat glass plate would have to be quite thick, perhaps 0.5 inch, in order to withstand this force By curving the surface of the screen, a greater weight can be safely accommodated with a much thinner screen.

Secondly, it is easier to keep a beam in focus on a curved surface than on a flat screen. To see why, refer to the illustration in Fig. 8.28. The path of the focused end of the electron beam, as it sweeps back and forth across the screen,' is the arc of a circle which has the end of its radius placed near the second lens system. The glass screen is curved to fit this arc, and the electron beam is in focus at all points. With a flat screen, the arc and the screen touch at only one point, the center. At all other points, the glass plate is beyond the line where the electrons focus. This means that when the beam finally does strike the screen, the electrons have already begun to diverge, or spread out, and no longer form a sharp well-defined point.

The distinct advantage that a flat screen possesses over a curved screen is found in the proportioning of the figures and objects in the image. With a curved surface, the curvature tends to distort the relative features of people and objects (much as a curved mirror would) and interferes with the full enjoyment

of the picture.   Only at the center of the screen do the figures appear as they should.   A flat screen does not have this limitation.   However, recent advances in the methods of manufacturing cathode-ray tubes now permit flat screen tubes to be constructed easily and economically.

For flat screen construction, the electron beam is made very narrow.   In this way the electrons in the beam, even if they
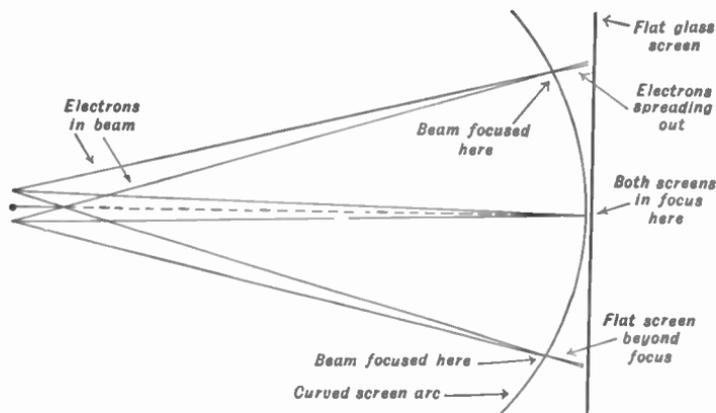

Fig. 8.28.   The reason for electron beam defocusing on flat screens.

spread out slightly, are still close enough to produce a small round spot.

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 sensitivity, factor, etc.

With the preceding rules as a guide, the 14AP4 tube would be approximately 14 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 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 10,000 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 10,000 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 would then take its familiar form as in Fig. 8.29.   The filter choke is the usual 30 henrys and the electrolytic condensers are rated at 30 μf, 500 volts.   For the
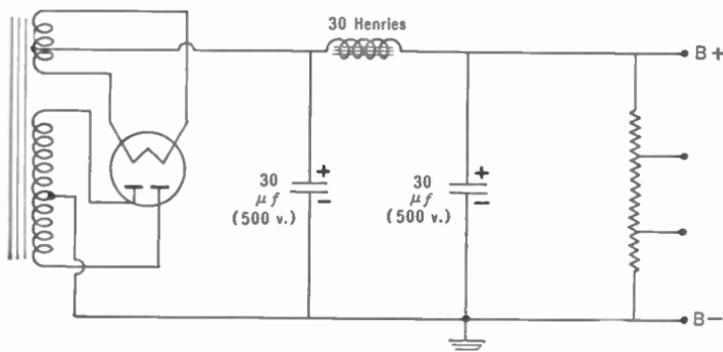

FIG. 8.29.   A low-voltage power supply.

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.

The second power supply, that for the high-voltage circuits of the image tube, is designed 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 volt-
ages, 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 con-
densers and small chokes, as in low-powered units. The con-
densers 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 induct-
ance, because the current flowing is small and fine wire can be
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 resist-
ance 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 re-
sistors in series, each with $\frac{1}{2}$ 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 arcing 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 positioning controls.
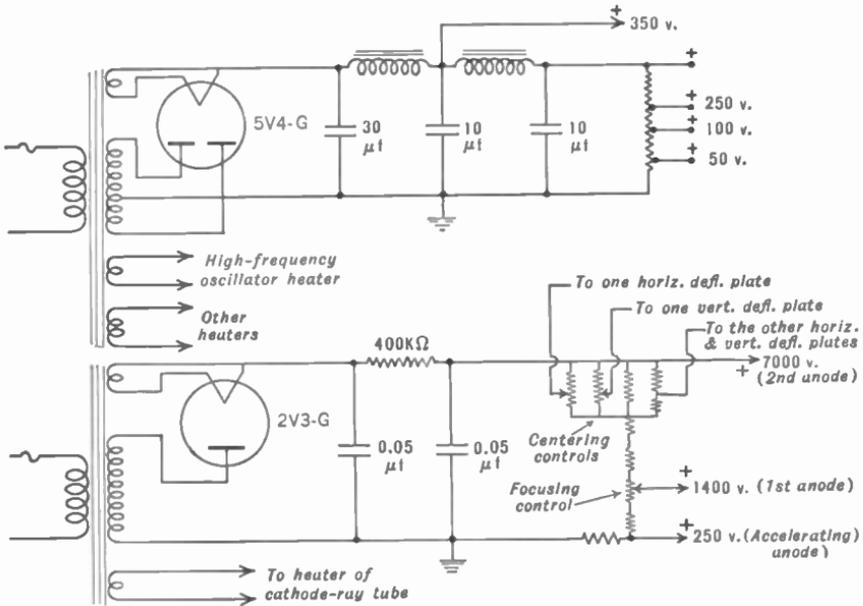

FIG. 8.30.   A complete power supply for a television receiver.

Commercial Power Supply.   An example of the power supplies typical of commercial receivers is shown in Fig. 8.30.   A 2V3-G is operated as a half-wave rectifier to develop the high voltage (7,000 volts) necessary for the second anode.   The bleeder resistor combination includes the centering controls and a 2-megohm potentiometer for focusing.   Two additional potentiometers have been provided to permit centering, but would only be inserted if deflection plates (instead of coils) were used. The centering resistors must be at a potential near that of the second anode.   If they are placed at some lower voltage, the electron beam will suffer a retarding effect when travelling between the second anode and the deflection plates.

In the diagram given in Fig. 8.30, the lowest point of the high-voltage power unit is grounded, but this is not always the case. In many power units, this bottom end of the supply is attached to the highest voltage point of the low-voltage unit. In that event, all the voltage values given for the larger unit would have to be raised by a figure equal to the highest voltage of the low-powered unit. For example, in Fig. 8.30, this would mean attaching the bottom end of the high-voltage unit (after disconnecting the ground connection), to the $+350$ volt terminal of the low voltage unit. Under these conditions, each voltage point in the 2V3-G rectifier system would be 350 volts *higher* above the ground than is now indicated.

The reason why something like this might be done is to be found at the cathode-ray tube. Here the low-voltage and the high-voltage systems meet, so to speak, at the brightness potentiometer, which varies the cathode to control grid potential. If both power supplies were grounded at their low voltage points, the cathode of the viewing tube would also have to be grounded. For brightness control, the grid must be placed at a negative potential with respect to the cathode. But with a direct connection between the output video amplifier plate and the control grid of the picture tube (as sometimes found), a negative voltage on the grid is not feasible. Hence the necessity for raising the cathode potential to some positive voltage in order that the control grid may also be positive with respect to ground, but negative with respect to the cathode.

The foregoing example is merely one illustration of why the high-voltage unit may not always be grounded. Others will arise from time to time. However, whether the unit is grounded directly or not makes absolutely no difference in its operation. Within itself, the rectifying action is complete. The lowest potential point of a rectifier unit is still the lowest point in that system. What it may be with respect to ground will depend upon how it is connected in the circuit.

For larger cathode-ray tubes, where the deflection is accomplished magnetically, centering controls are placed in series with

the deflecting coils. A power supply of this type will be illustrated when horizontal and vertical synchronizing circuits are developed.

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 increases, too, but at a much greater rate. The use of projection tubes, which require voltages as high as
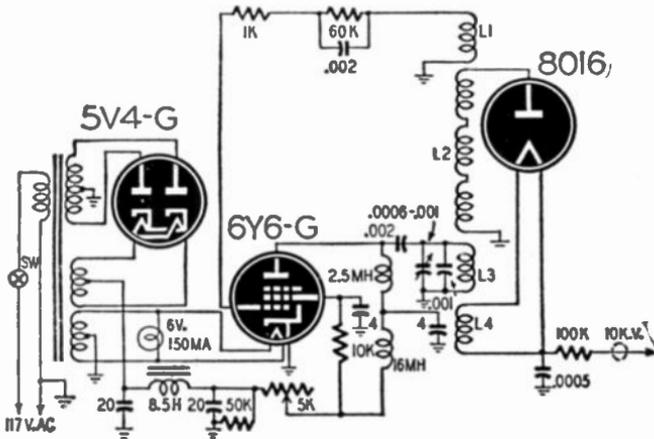

Fig. 8.31. An R.F. power supply. The filament of the 8016 rectifier also operates on R.F.

27,000 volts, would, if the previous conventional design were followed, lead to a unit that was far out of proportion with the rest of the set. In an effort to evolve a more suitable solution, research was directed toward other avenues of approach. From these investigations, 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 obtained. The other unit obtains its voltage from the inductive kick-back of the horizontal deflection coils.

The first type of R.F. power supply is shown schematically in Fig. 8.31. A 5V4-G full-wave rectifier operating from the

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
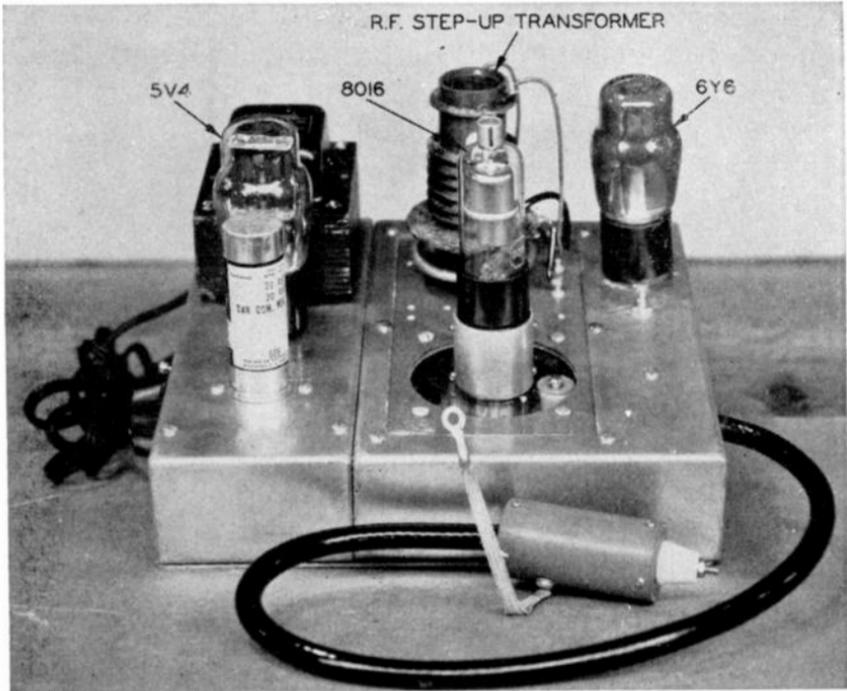

Fig. 8.32A.   The entire R.F. power supply.

coil, L_2, which contains more turns that 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.

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. 8.32A; in Fig. 8.32B the high-voltage step-up transformer is shown separately.

The   Inductive   "Kick-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

$$e_L = - L \frac{di}{dt}$$

FIG. 8.32B.   The   high-voltage step-up transformer.

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. 8.33.   The horizontal discharge tube, V120B. is actuated by a positive pulse applied to its grid and
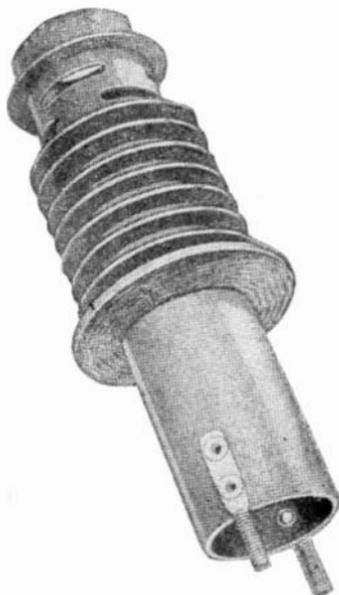
Courtesy RCA.

Fig. 8.33.   A circuit schematic of an "inductive kick" or reaction type of high voltage power supply.

discharges condenser C179, 680 $\mu\mu$f.   At the end of the positive pulse, the discharge tube lapses back into cut-off and the condenser C179 starts to charge for the next cycle again.   The deflection waveform produced by C179, R210 and R187 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 rapid retrace.   The output tube, V126, 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.

In order to properly interpret the action which occurs in this circuit, the following relationships within the horizontal scanning interval must be known.   A complete horizontal scanning cycle is 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. 8.34C.   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 resonant frequency of the system; this is about 75 kilocycles in order to insure a sufficiently short retrace period. Note that the system is shocked into oscillation by this sudden cut-off of plate current.   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 trans-

former, 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 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.   Note that now the
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 dissi-
pated.   Very little energy was lost during the first half cycle of
retrace because the damping tube was non-conductive and the
circuit was low loss.   When, after this first half cycle, the damping
tube does begin to conduct, it places such a heavy load across the
deflection coil that it is prevented from oscillating further.   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 produce a linear trace motion of the
electron beam.

The waveforms in Fig. 8.34 illustrate graphically the action
within the circuit.   Fig. 8.34A shows the voltage applied to the
grid of the horizontal output tube.   In Fig. 8.34B 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
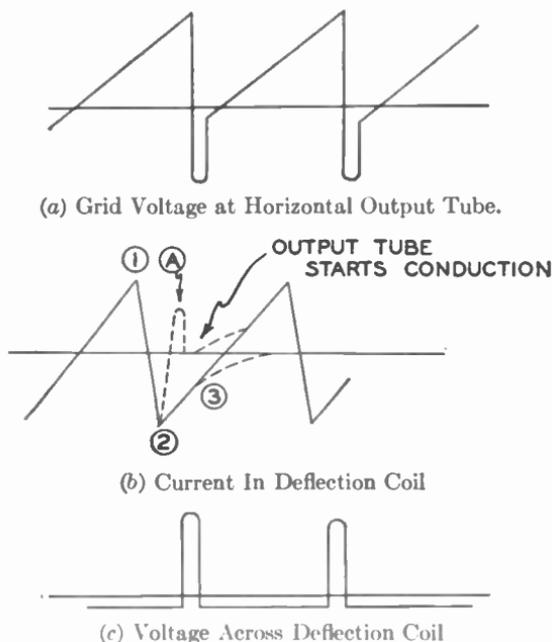

(a) Grid Voltage at Horizontal Output Tube.

(b) Current In Deflection Coil

(c) Voltage Across Deflection Coil

FIG. 8.34.   The various current and voltage relationship in the horizontal deflection output circuit.

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 were not present.   As it is, the diode begins 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 R209, the diode load resistor, and amounts to about 75 volts.   This, then, is the reason one end of R209 is labeled $+275$ 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.   Condensers C186 and C188 charge to $+350$ volts and they maintain the B$+$ on the plate of the 6BG6G tube when the 5V4G tube is not conducting.

The voltage across C186 varies due to the charging by the deflection coil kickback and the discharging through the output tube.   The rise and fall of this voltage is equivalent to an a-c ripple in the B$+$ supply reaching the horizontal output tube. L201 and C188 form a phase-shifting network and, by shifting the phase of this ripple, it is possible to alter the tube's characteristics.   L201 is variable and can provide small improvements in linearity.   Adjustment of the inductance of L201 causes the second quarter of the picture to stretch and the first quarter to crowd.

Additional controls in this circuit include L196 (width control) and R187, the horizontal drive control.   L196 is shunted across the secondary winding of the horizontal output transformer and can vary the output of this transformer and hence the picture width.

R187 controls the ratio of high peaking and saw-tooth voltage on the grid of the output tube and thus also controls the width of the picture.   Adjustment of R187 may require adjustment of L196.   Actually, in operation, R187 increases picture width, crowds the right side of the image and stretches the left side. L196 increases picture width and stretches the right side of the image slightly.   The two controls thus interact and adjustment of one generally requires adjustment of the other.

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, transferred to the secondary and rectified by the 8016 diode. Since the frequency is 15,750 cycles per second, sufficient filtering is provided by a single 500 $\mu\mu$f condenser. The 9,000 volts generated is fed to the second anode (aquadag coating) of the cathode-ray tube.

Safety Measures in Television Receivers. The servicing of television receivers is sometimes difficult because of the number and complexity of the circuits and the presence of extremely high voltages that are necessary for the operation of the set. A 12-inch tube has approximately 10,000 volts on its second anode; any bodily contact with this high voltage may prove fatal to the serviceman.

All well-designed television receivers are provided with inter-lock switches which automatically open the circuit when the back cover of the set is removed. In addition, it is advisable to remove the high-voltage power supply fuse before doing any repair work on the chassis. Due to the use of two separate power supplies, removal of the high-voltage power unit fuse still permits measurements to be taken on the low-voltage sections of the receiver. It may occasionally be found that, while two distinct filtering units are employed, all the plate voltages for the rectifier tubes are taken off one power transformer. In this case, only one fuse would be used for the set and it could not be removed when making low-voltage measurements. An effective way of eliminating the very high voltages without interference to the low-voltage power supply is obtained by unsoldering the plate lead of the high-voltage rectifier tube and taping this open end with some friction tape. It is never recommended (or even advisable) to make voltage checks on the high-voltage power unit. Any faults that may exist will always be brought to light by the simple method of resistance measurement.

When television receivers are installed in a home, a good, permanent ground connection must be made before the power cord is inserted into an outlet. This will protect the user against electrical shock if the insulation on the high-voltage winding of the power transformer should accidentally break down and permit contact to be made with the iron core.

The amount of current that the human body can safely carry without loss of life varies with many factors. It will depend upon:

1. The frequency of the current.
2. The resistance of the body at that particular moment.
3. The paths that the current takes through the body.

A high frequency current is less hazardous than the same amount of current at a low frequency. On the other hand, a burn obtained from a low frequency current will generally heal faster than one received from the high frequency currents. Burns of the latter type have been known to linger for weeks before completely healing.

The most critical frequencies are those up to 200 cycles. At this level 100 ma are considered dangerous. The exception is direct current. The latter may be taken up to 150 ma. The resistance of the body can never be predicted or regulated. It depends upon such things as the amount of salt in the body, the physical condition of the organs, and the amount of moisture on the skin. It may be as high as 500,000 ohms or as low as 5,000. Finally, the current will be easier to withstand if none of it passes through the heart. Servicemen frequently report that a shock obtained through the right arm leaves them less upset or shaken than one entering the left arm.

In servicing or installation work, the cathode-ray tube must be carefully handled. The tube is highly evacuated and the stress on the glass envelope is high. For example, it was previously computed that a 12-inch tube has $\frac{7}{8}$ of a ton acting on the screen alone. Should the tube break, injury may be caused to anyone in the immediate vicinity. When placing the tube into its socket, do not use excessive force. The action should

proceed smoothly with only a moderate amount of pressure. If the tube appears to stick, investigate and remove the cause of the trouble.   Do not, at any time, scratch or strike the glass envelope, for this may weaken the tube sufficiently at that point to cause it to break.   In all receivers, a sheet of plate glass is placed in front of direct viewing screens to protect the tube from having any objects fall on it, or to shield the observer if the tube should explode.   Never remove this glass.

Projection Cathode-Ray Tubes.   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 eye strain 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 9-inch models and finally arriving at the 14- 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 20 inches probably 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 several projection methods for producing larger images have been designed.

Perhaps the most obvious method of attacking the problem is to place several lenses in front of the cathode-ray viewing screen and project the image onto a larger screen.   That this proves unsatisfactory is due to the low transmission efficiency of the intervening lenses.   Much of the image illumination is reflected from the lens surface, still more lost within the optical

system itself, so that finally only a small proportion of the original amount reaches the larger screen.

To increase the illumination available at the translucent screen, the image formed on the cathode-ray tube surface is made more intense. Because the transmission efficiency of the optical syst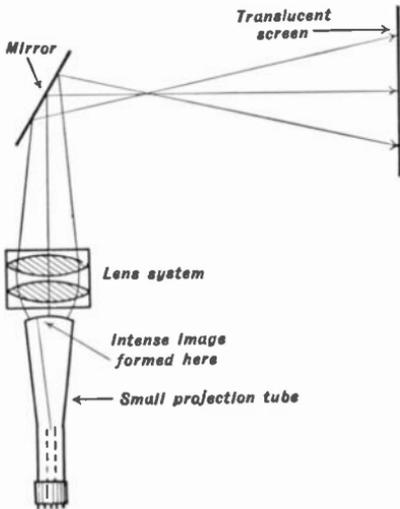em is only on the order of 5 to 10 per cent, the light output at the cathode-ray tube had to be increased 10 to 20 times. Changes were required in the electron gun to provide greater acceleration and a more sharply defined electron beam at the screen. Voltages used range as high as 30,000 volts, in some instances even more. The crossover point in the electrical system of the electron gun is made smaller, narrower, more clearly outlined. Finally, even the composition of the fluorescent material must be altered, for the energy dissipated grows in proportion to the increased accelerating voltages on the anodes.

Fig. 8.35.   Projection system to obtain large images.

Now, this type of cathode-ray tube, designed especially for projection purposes, may be employed as indicated in Fig. 8.35. From a small 3 by 4 inch image formed on the fluorescent screen of this tube, we can obtain satisfactory reflected images as large as 12 by 16 inches or even 16 by 20. For convenience, the translucent screen required slides down into the television cabinet when the set is not in use. A typical receiver might appear as shown in Fig. 8.36.

The comparison between a projection type cathode-ray tube and an ordinary 15-inch, direct-viewing tube in Fig. 8.37 emphasizes the large difference in space required in the receiver cabinet. The projection tube is a more compact unit, more

Courtesy RCA

FIG. 8.36. A large screen (20 × 16″) receiver. The image from a small projection-type tube is enlarged to permit comfortable viewing by many people.

Courtesy Rauland Corp.

(A)　　　　　　　　　　　　　(B)
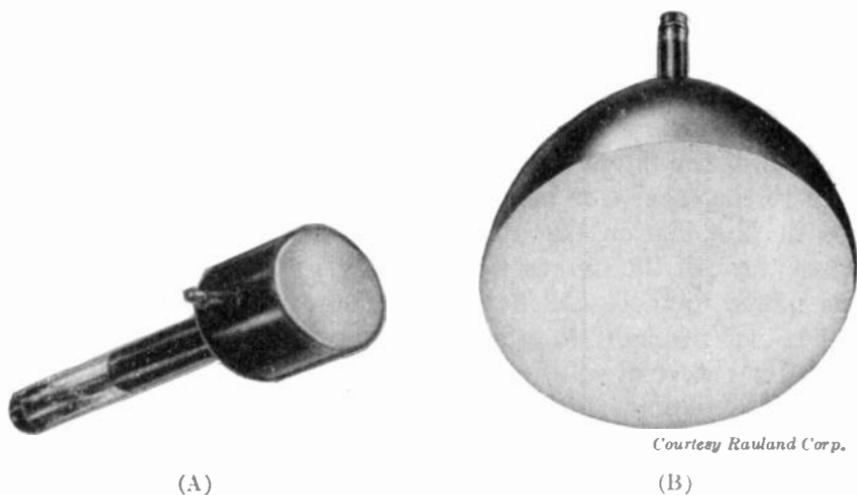
FIG. 8.37. A—Projection type cathode-ray tube. B—A direct viewing 15″ tele-vision tube.

easily placed.   The only difficulty with these latter tubes is the greatly increased accelerating voltages needed, in this case, 25,000 volts.   Compare this with the approximately 12,000 volts used on the 15-inch tube.   It cannot be too greatly emphasized that extreme care should be exercised whenever these receivers are serviced.

A modification of the preceding tube is the projection tube in Fig. 8.38.   In this illustration, the screen is so positioned that

Courtesy Rauland Corp.

Fig. 8.38.   A " front-surface " projection tube.   Enlarged images having sizes up to 24 × 18 inches may be obtained.

the light for observation is obtained directly from the same side on which the exciting electrons impinge.   In this respect, it could be labeled as a front-surface projection tube, which differs from the ordinary cathode-ray tube where the electrons strike one side of the fluorescent screen and the light must then penetrate to the other side before it is visible to the observer.   The loss in illumination energy caused by making the light rays travel through the fluorescent material is neatly side-stepped in this newer method.   In both types, of course, the light must still travel through the glass envelope containing the tube to reach the observer.

In construction, the tube slightly resembles the Iconoscope. The electron gun assembly is placed at an angle to the axis of the tube in order that the electrons can impinge on the fluorescent screen and still not have the gun interfere with the outgoing light rays.   The screen within the tube is circular, with a 4-

inch diameter; 30,000 volts imparts sufficient velocity to the beam to develop a highly intense image. A " big-brother " of this tube, Fig. 8.39, is designed for theatre use and is capable of giving pictures 20 by 15 feet. The actual screen in the tube itself is $7\frac{1}{2}$ inches in diameter.

Courtesy Rauland Corp.

FIG. 8.39.   Projection tube for theatre use.   Similar in construction to the tube in Fig. 8.38.

The Schmidt Principle in Television.   Recently, progress has been made in still another direction, different from any of the foregoing conventional methods. The newer system is based on the so-called Schmidt principle, which was originally developed for astronomical telescopes. The high efficiency of this system is due mostly to the fact that fewer reflecting surfaces are utilized. It is this greater efficiency that has attracted the attention of television set engineers.

As first designed for the telescope, the system consisted of a correcting glass lens, a large spherical reflecting surface or mirror, and a photographic plate (see Fig. 8.40). As the light rays from the distant stars entered the telescope, they were reflected by the spherical mirror onto a small photographic plate. The desired objective was to concentrate as much light at the photographic plate as possible to form a bright, clear image of the distant constellations.

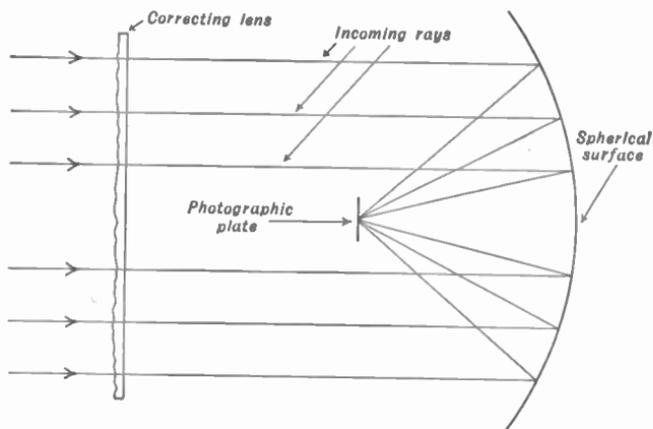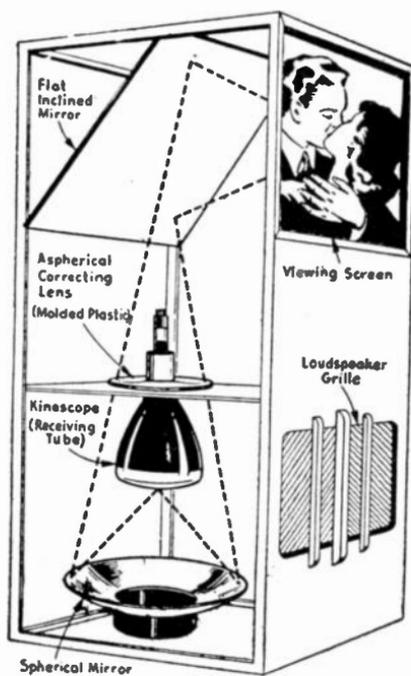Due to the inherent spherical aberration of a spherical reflect-

FIG. 8.40.   Original arrangement of the Schmidt lens system.

Courtesy RCA

FIG. 8.41.   An adaptation of the Schmidt system for home television receivers.

ing surface, a correcting lens had to be inserted. This is shown
in Fig. 8.40. Spherical aberration, a form of optical distortion,
arises when all the light rays striking a spherical surface do not
come to a sharp focus on the central axis.

There are several modifications of the Schmidt principle for
television projection systems. In Fig. 8.41, a projection-type
cathode-ray tube is placed near, and along, the central axis of
the spherical mirror or reflecting surface. A brilliantly illumi-
nated image is formed on the tube's fluorescent screen and then
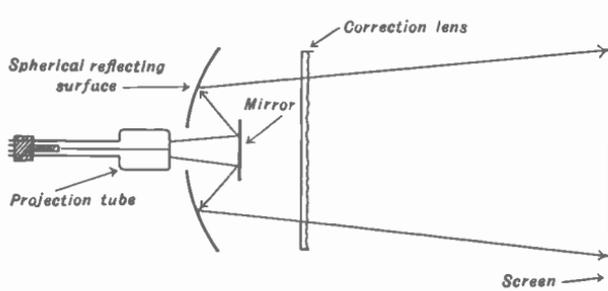
FIG. 8.42.   Second variation of Schmidt optical system.

transmitted by the spherical mirror to the large viewing screen.
An intervening lens corrects the spherical aberration caused by
the reflecting mirror and a clear image is obtained on the screen.
RCA uses a large adaptation of this apparatus for theatre demon-
strations. For home receivers, the design shown in Fig. 8.41
would be suitable.

Another way of using the same principle is given in Fig. 8.42.
This time the projection cathode-ray tube is located behind the
spherical reflecting surface. In order to have the light rays
reach the surface for further transmission to the large viewing
screen, a mirror receives the light from the cathode-ray fluorescent
screen and then reflects the rays toward the spherical surface. As
before, a correction lens is incorporated into the system.

It has been found that the amount of projected light reaching
the final viewing screen using this system was increased eight-
fold over the simple lens projection method of Fig. 8.35. The

greatest drawback to the use of this method arises from the
difficulty of keeping the large spherical surface (which may be
either metallic or silvered glass) clean and free of dust deposits,
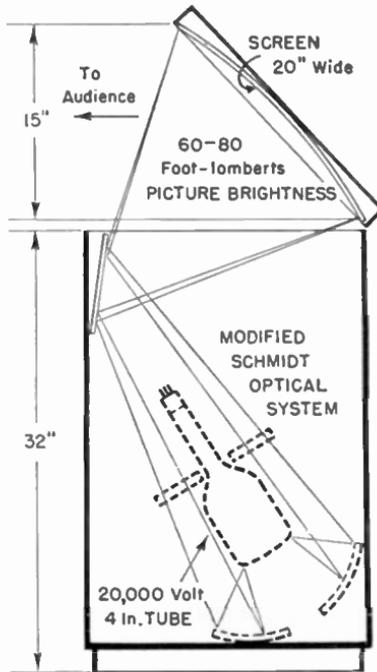which mar the final image and reduce the transmission efficiency
of the system.

Fig. 8.43.   The optical system in the Philco projection receiver.

A modification of the preceding Schmidt optical system (see
Fig. 8.40) has also been used in Philco projection receivers (see
Fig. 8.43).   The light or beam from a 4-inch projection tube is
reflected from a plane mirror inside the front of the cabinet onto
the inclined high-gain specular screen on the underside of the
lifted cabinet lid.   The picture that is developed is 15 by 20
inches in size, with a brightness of 60 to 80 foot-lamberts.   Such a
picture can be viewed comfortably in a lighted room, with all
window shades open and sunlight pouring in.

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.

CHAPTER 9

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 mosaic of the Iconoscope. 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

From Video detector → Synch. clipper

HORIZONTAL SECTION

High-pass filter → Oscillator (15,750∼) → Saw-tooth wave developed here → Amp. → To horiz. deflecting plates or coils

VERTICAL SECTION

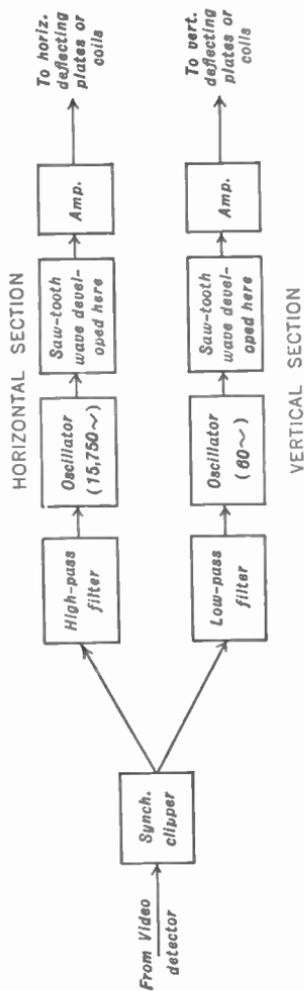Low-pass filter → Oscillator (60∼) → Saw-tooth wave developed here → Amp. → To vert. deflecting plates or coils

FIG. 9.1. A block diagram of the entire synchronizing section of a television receiver.

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 I.F. amplifiers 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 either from the output of the second detector or the plate circuit of the first video amplifier. At these points, the signal has 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 vertical 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.

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.
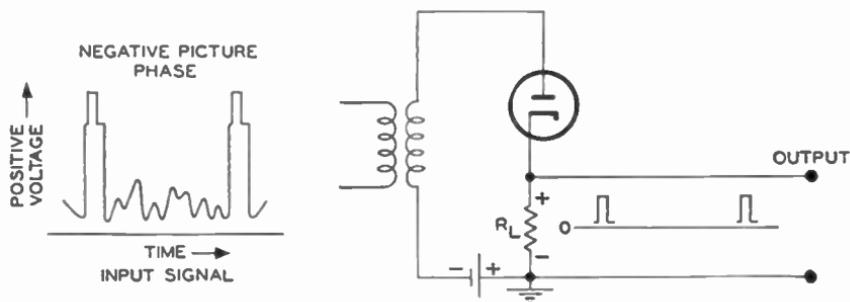

FIG. 9.2.   A diode clipper.   This operates with input signals having negative phases.

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.
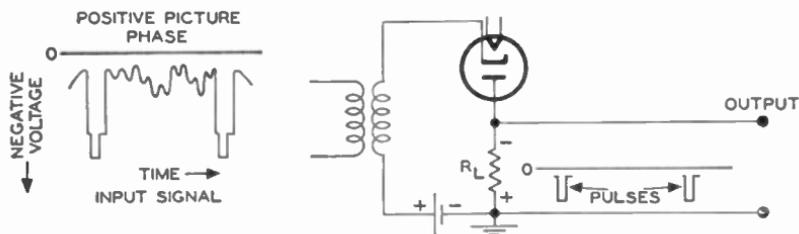
FIG. 9.3.   An inverted diode clipper, suitable for input signals having a positive picture phase.

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,
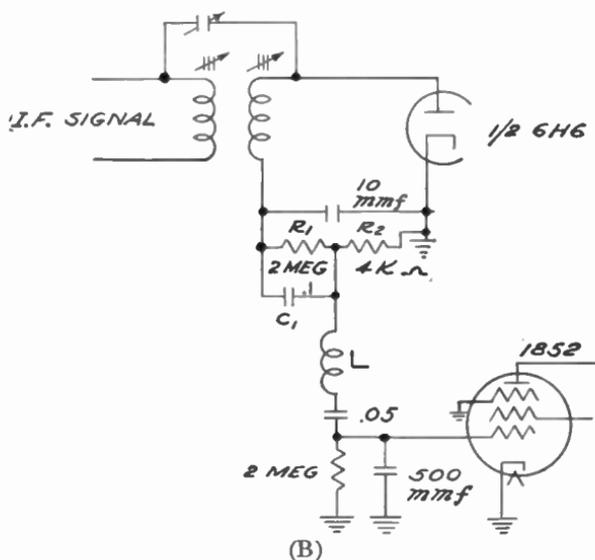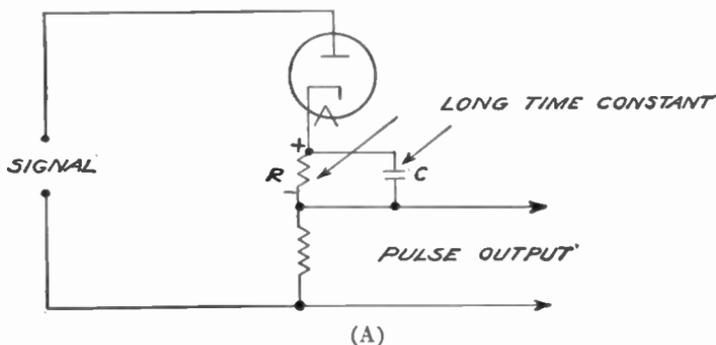

(A)

(B)

Fig. 9.4A–9.4B.   (A) Fundamental diode clipper circuit.   (B) The commercial application.

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.

Triode and Pentode Clippers. The chief disadvantage of using a diode clipper is in the loss in amplitude that results. Amplification is desirable and it is for this reason that we find triodes and pentodes (of the sharp cut-off type) used more frequently. The same method is applicable to both and is illustrated by the simple circuits of Fig. 9.5. Each tube has zero bias with no signal acting on its grid. When a signal is applied, the positive voltage causes the grid to become positive. Electrons will then flow in this circuit, charging the coupling condenser. R_g has a

high value, and the charge on C_c will leak off slowly, causing a fairly steady bias voltage to develop across the grid resistor. The electron current flow is from grid to ground, which means that the top end of R_g becomes negative with respect to ground and the cathode, which is also grounded. The biasing voltage of R_g developed in this manner prevents plate current from flowing except on the most positive points of the incoming wave, the synchronizing pulses. An amplified plate current, responding under the action of these pulses, develops voltages of the same
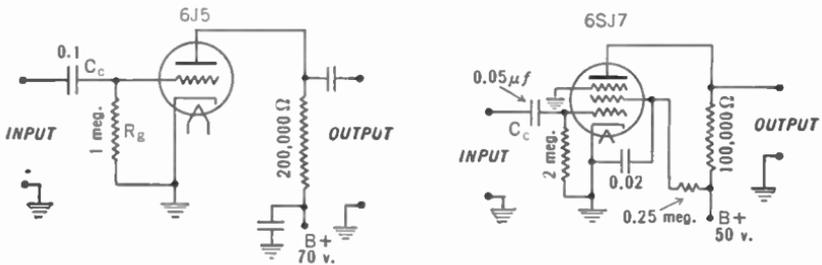
FIG. 9.5. Triode and pentode pulse clippers.

form across the plate load resistor. The input for the following stage is then obtained, as indicated.

The operation of the grid condenser and resistor is actually very similar to the d-c restoring action described in Chapter 7. If the input signal is in the a-c form, the action of C_c and R_g will result in the pulses becoming aligned again. The reader may be puzzled about this point because, in the previous description, the entire video signal (pulses and all) was obtained in the plate circuit; now only the pulses are obtained. The answer is to be found in the value of R_g. In the previously described d-c restoring circuits, R_g was generally around 500,000 ohms. Here it has a higher value, starting at 1 megohm and extending upward to 3 megohms in some sets. This increased value of resistance places most of the signal beyond plate current cut-off, with only the pulses causing current flow. The difference in these two situations is shown by the two curves in Fig. 9.6. With the same

amount of signal voltage acting on each grid, the same amount of current will generally flow. However, since one circuit has a larger resistor than the other, the negative voltage developed across this grid resistor will be larger, placing the operating point of the tube farther into the negative region.

The action in which the operating point of the tube is altered with various values of R_g is not new to radio circuits. It is well
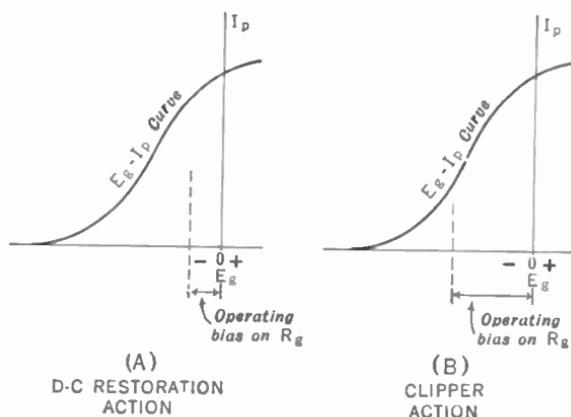

FIG. 9.6.   Illustrating how the operating bias of a clipper tube is determined by the size of the input resistor and condenser.

known that, if the d-c bias for a tube is obtained from a resistor inserted in the cathode leg of a tube, the operating point for this tube may be changed by using other values of resistance.

It becomes possible, with the foregoing arrangements, to feed either a d-c or an a-c video signal into the circuit input and obtain the required pulses at the output load resistor. One point must, however, be kept in mind. Only a negative picture phase video signal will do for triodes and pentodes.

A commercial application, using one triode section of a 6F8G, is shown in Fig. 9.7. The video signal input is obtained from the plate circuit of the first video amplifier and applied through the 0.02 μf condenser to the grid of the clipper. The output of the clipper is then connected to both the vertical and horizontal saw-

tooth wave generators.   In tracing this circuit from the second
detector, it will be noticed that a positive picture phase is applied
to the input of the first video amplifier in order to obtain the
necessary negative picture signal at the clipper input.   The other
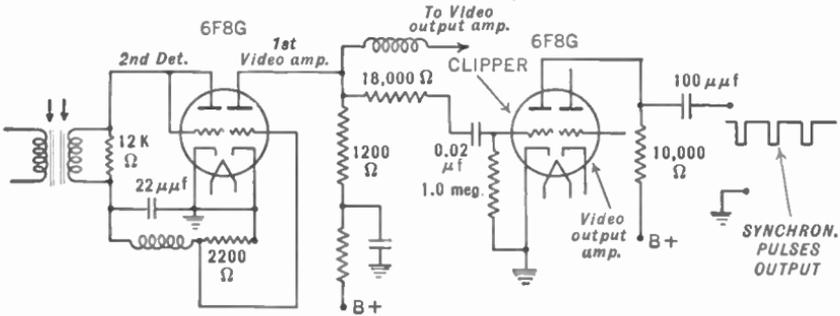half of the 6F8G functions as the final or output video amplifier.

Fig. 9.7.   A commercial triode clipper.

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 ac-
complishing 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 pre-
cedes 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 fre-
quency is considerably less than that of the horizontal pulses and
it is because of this fact that they can be separated with compara-
tive ease.

With the preceding ideas in mind, let us closely examine the
construction of the video signal with its synchronizing pulses.
In Fig. 9.8 several lines of an image are shown, complete with
the detail information, blanking voltages, and horizontal syn-
chronizing pulses. The blanking and synchronizing voltages
occupy approximately 20 to 25 per cent of the total signal am-
plitude. 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 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.
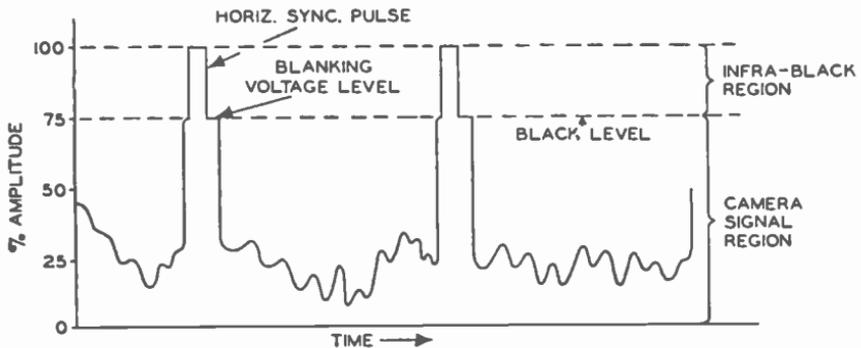

FIG. 9.8.   A video signal with its synchronizing (horizontal) pulses.

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 voltages shown in Fig. 9.9. At the bottom of the image, a long vertical pulse is inserted into the signal. This controls the vertical synchronizing oscillator and forces the beam to be brought back to the top of the screen. No provision is made in the signal, 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 broken up into smaller intervals and now both actions can occur simul-

taneously.   The vertical synchronizing pulse, in the modified form, is shown in Fig. 9.10 and is known as a serrated vertical pulse.
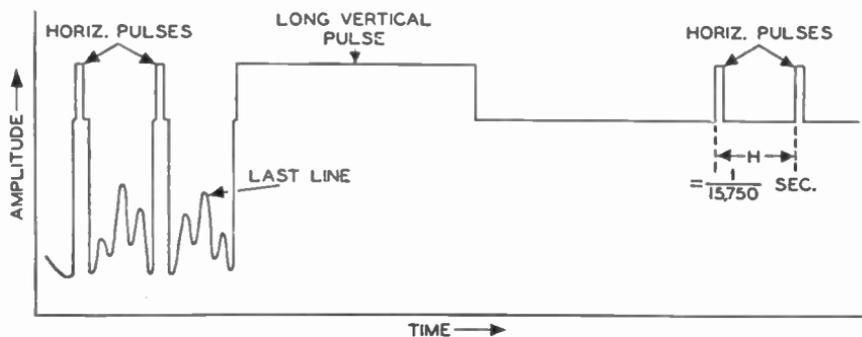

FIG. 9.9.   The basic form of the vertical synchronizing pulse

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
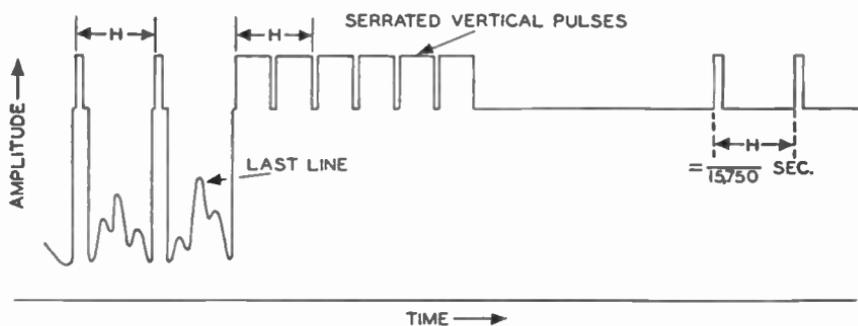

FIG. 9.10.   The serrated vertical synchronizing pulse.

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. 9.10.

Due to the fact that an odd number of lines is used for scanning, 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 $262\frac{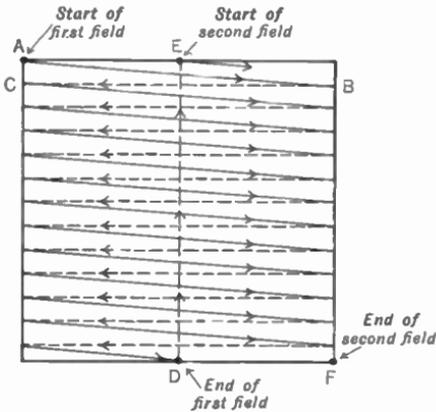1}{2}$ lines from the beginning of its field to the *start* of the next. This is important and has not been overly stressed before.   In Fig. 9.11, reprinted from Chapter 1, the notation is made that the end of the visible portion of each field occurs at the bottom of the image. However, the actual end 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 inserted.

Fig. 9.11.   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.

Point D, we can see, occurs during the middle of a horizontal 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 employing this particular method of scanning were explained in Chapter 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 approximately 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 F.C.C. regulations specify that the beam shall be blanked out for 1,250 microseconds between fields while the
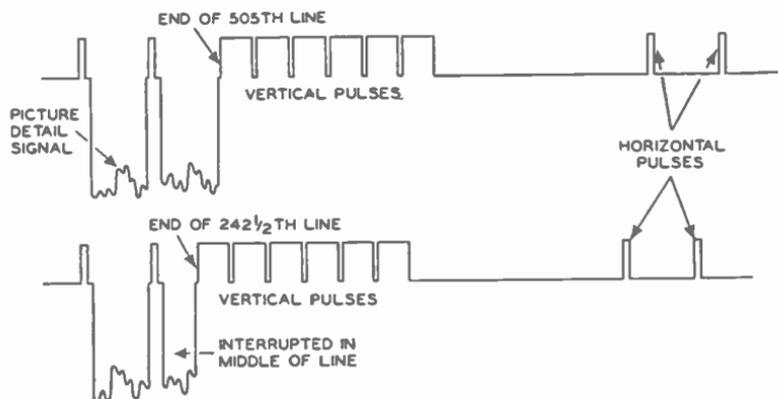

FIG. 9.12.   The form of the video signal at the end of $242\frac{1}{2}$ and 505 lines.   The equalizing pulses are not shown here.

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.   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 com-

pleted 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. 9.12. 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
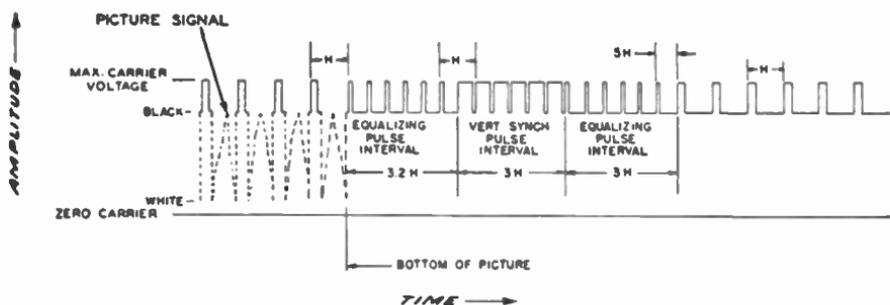

Fig. 9.13.   The position of the equalizing impulses in the video signal.

equalizing pulses is inserted into the signal immediately before and after the vertical synchronizing pulses. These equalizing pulses, shown in Fig. 9.13, 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.

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 $262\frac{1}{2}$ 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 compared in Fig. 9.14. 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
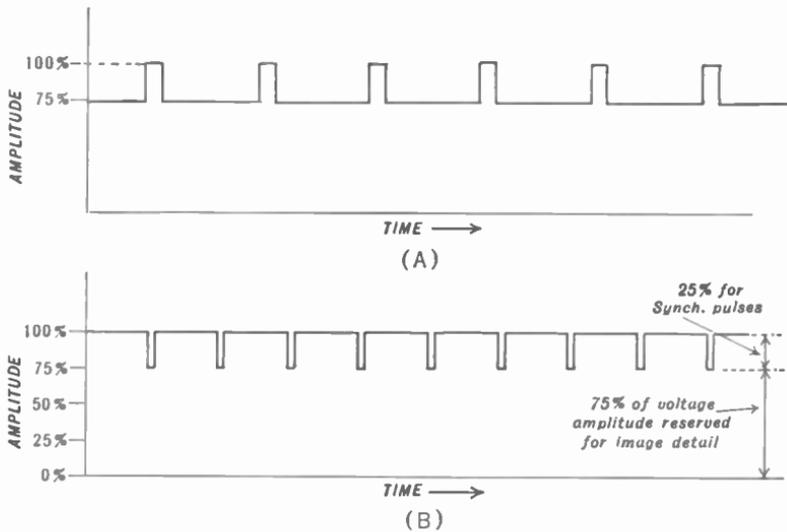being received.

FIG. 9.14.   A comparison of the waveforms of horizontal (A) and vertical (B)
pulses.

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
form slightly so that they are suitable for controlling the fre-
quency 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. 9.15, 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 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. 9.15.
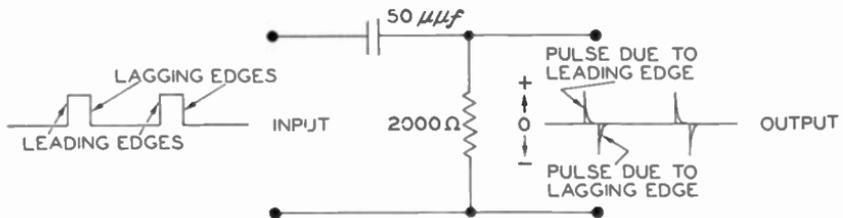

FIG. 9.15. A high-pass filter and its effect on the horizontal synchronizing pulses.

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 frequency 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. 9.16 are shown the input wave and the output
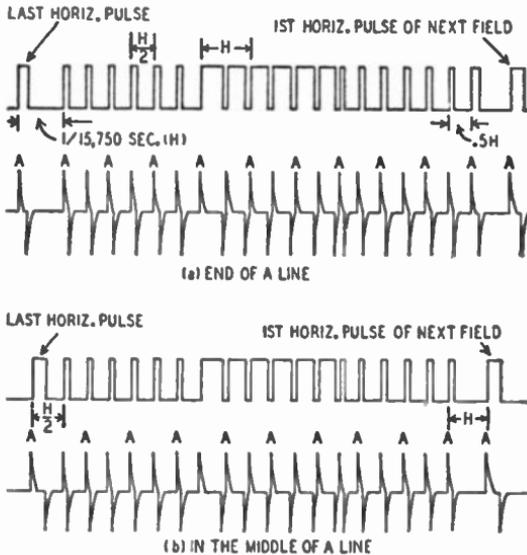

FIG. 9.16. Conditions during vertical pulses. The pips labeled " A " control the horizontal sweep oscillator.

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 indicated 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. 9.16A occur only when the vertical pulses are inserted at the end of a line. Fig. 9.16B 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. 9.16A. 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. 9.17.   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 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

Fig. 9.17. A low-pass filter. The con-
denser combines (or integrates) all the ser-
rated vertical pulses until the output voltage
rises to the necessary level where the vertical
synch oscillator will react.

the higher frequency pulses affecting the operation of the vertical
synchronizing generator.   Fig. 9.18 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.
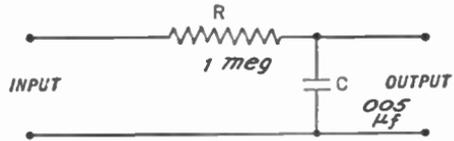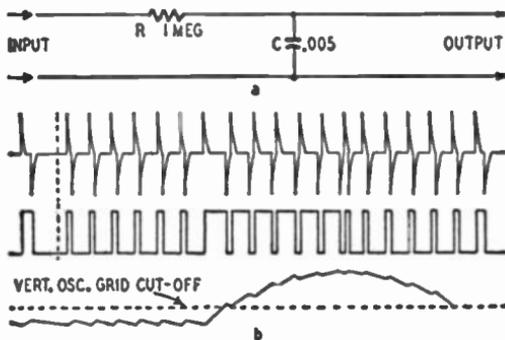

Fig. 9.18.   (a) Low-pass filter for separating the vertical and horizontal pulses;
(b) the waveform of the rise in voltage across the condenser due to vertical pulses.

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. 9.18.   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
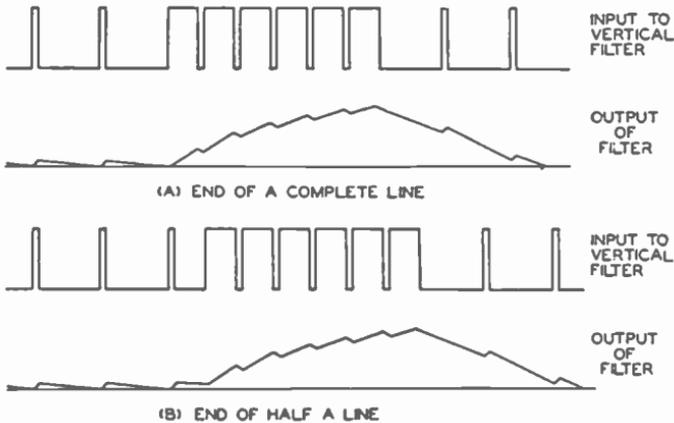

Fig. 9.18A. The difference in voltage conditions before a vertical pulse when no equalizing pulses are used.

Fig. 9.18A is shown the build-up of vertical deflecting voltage across the output of the vertical filter, once for the vertical pulse 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. 9.18A, 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. 9.18A 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.

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. 9.18).   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. 9.15 and 9.18, 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 syn-

chronizing 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.
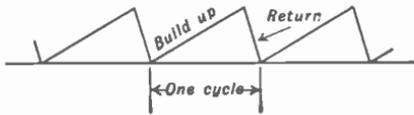

Fig. 9.19.   A saw-tooth wave. Either the voltage or the current may assume this form.

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. 9.19. 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 supply) 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 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. 9.20A). 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 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 practice, 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. 9.20A.

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
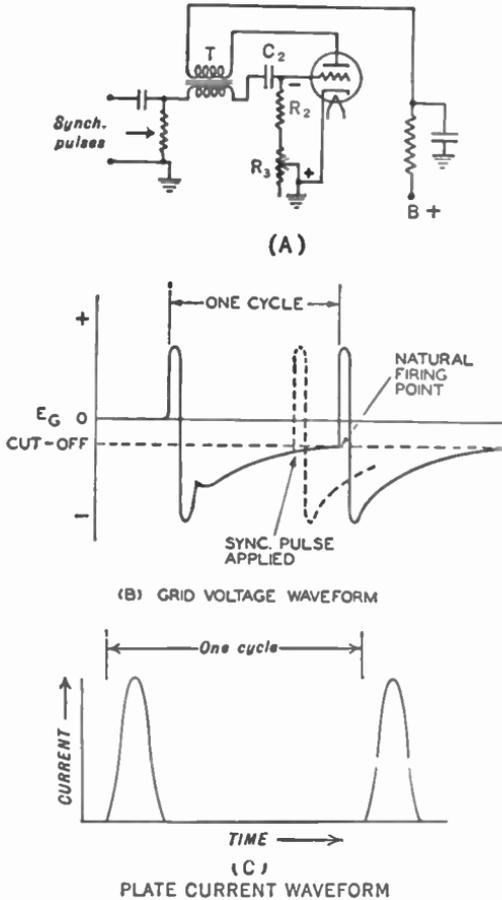

(A)

(B) GRID VOLTAGE WAVEFORM

(C)
PLATE CURRENT WAVEFORM

FIG. 9.20. A blocking oscillator (A). The grid voltage variations are illustrated at (B) while the form of the plate current is given at (C).

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. 9.20B. 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. 9.20B. 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. 9.20B. 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 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. 9.22.   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. 9.19: 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. 9.21.   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
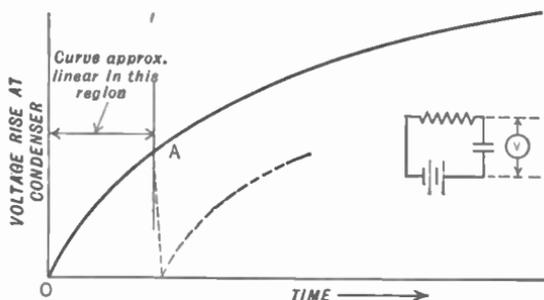

FIG. 9.21. The manner in which a voltage across a condenser increases when a potential is applied through a series resistor.

in Fig. 9.22. 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
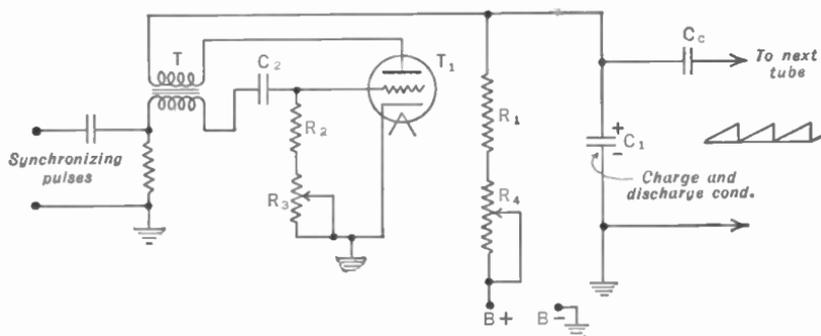

FIG. 9.22. A simple method of obtaining a saw-tooth voltage from a condenser. This voltage, when applied across the cathode-ray deflecting plates, will control the action of the election beam in the desired manner.

every cycle. During the remainder of the time, the grid is negatively biased beyond cutoff, and no current flows in the plate circuit.

Throughout the time when no plate current is flowing, condenser 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. 9.22.

When plate current does start to flow, it is only for a very short period, and during this time the resistance of the tube becomes very low.   Condenser C_1, which is actually in parallel with the tube, then quickly discharges through this low resistance 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 developing 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."

RCA in many of its television receivers, uses an extra tube to discharge the saw-tooth voltage generating condenser. The circuit, shown in Fig. 9.23, is basically as simple as the preceding
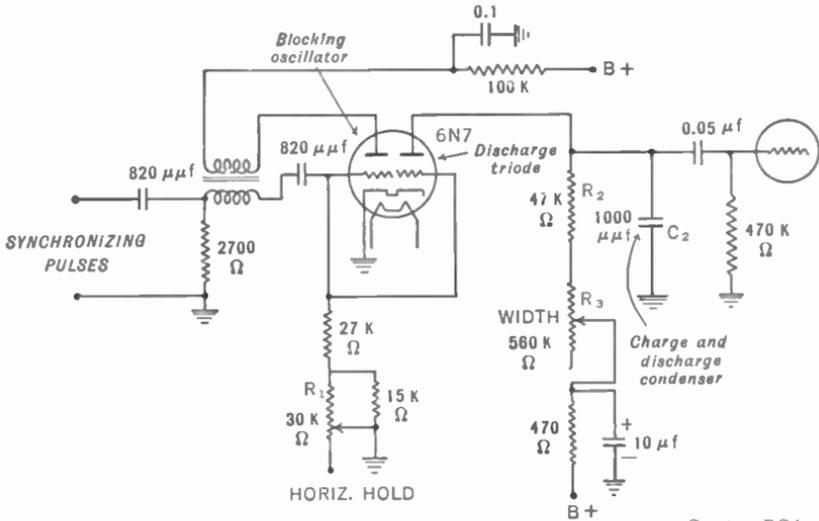
Fig. 9.23. A commercial circuit used for obtaining saw-tooth voltages in television receivers.

method. A 6N7 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. 9.23, a single tube need not be used for the dual functions of blocking oscillator and discharge tube. 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 resistance-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. 9.24. Due 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
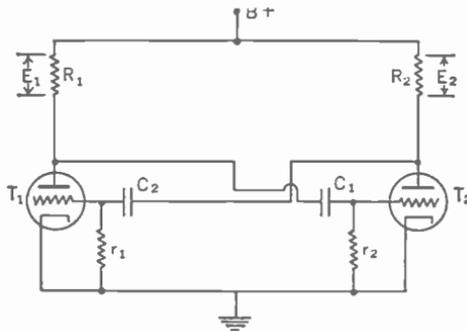

Fig. 9.24.   The fundamental multivibrator circuit.

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
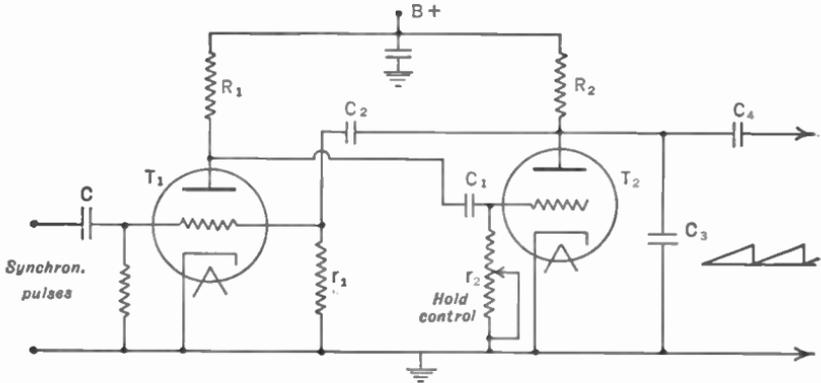

FIG. 9.25. How a multivibrator may be connected to control the charging and discharging of a condenser to derive saw-tooth waves.

the first tube which is cut-off. When the first tube is again permitted to conduct, the second tube is driven into non-conduction. 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. 9.25 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 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. 9.25

60 cycles	15,750 cycles
T_1 — ½6SN7, 6N7, 6F8	T_1 — ½6SN7, 6N7, 6F8
T_2 — ½6SN7, 6N7, 6F8	T_2 — ½6SN7, 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. 9.25 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. 9.26.   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 multi-vibrator 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
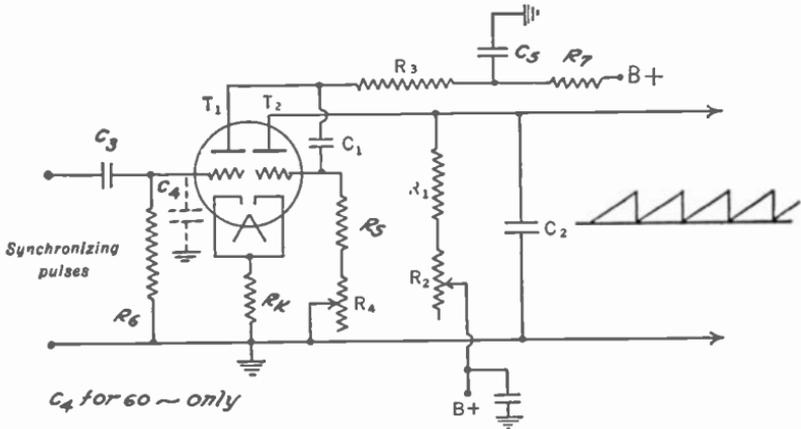

FIG. 9.26.   Another widely used form of multivibrator.   This is known as a cathode-coupled multivibrator.

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 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. 9.26

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 multi-

vibrator.   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
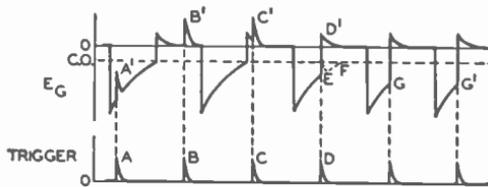
FIG. 9.27.   Illustrating how the incoming pulses lock-in the synchronizing oscillators.

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. 9.27 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 unable 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 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 14).   To prevent this form of image distortion, several 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.   One such system is analyzed in Chapter 11.

We have now completed a description of each of the components of an ordinary television synchronizing section.   In the next chapter two commercial synchronizing sections are examined in detail to illustrate how the various components are combined to form an integrated unit.
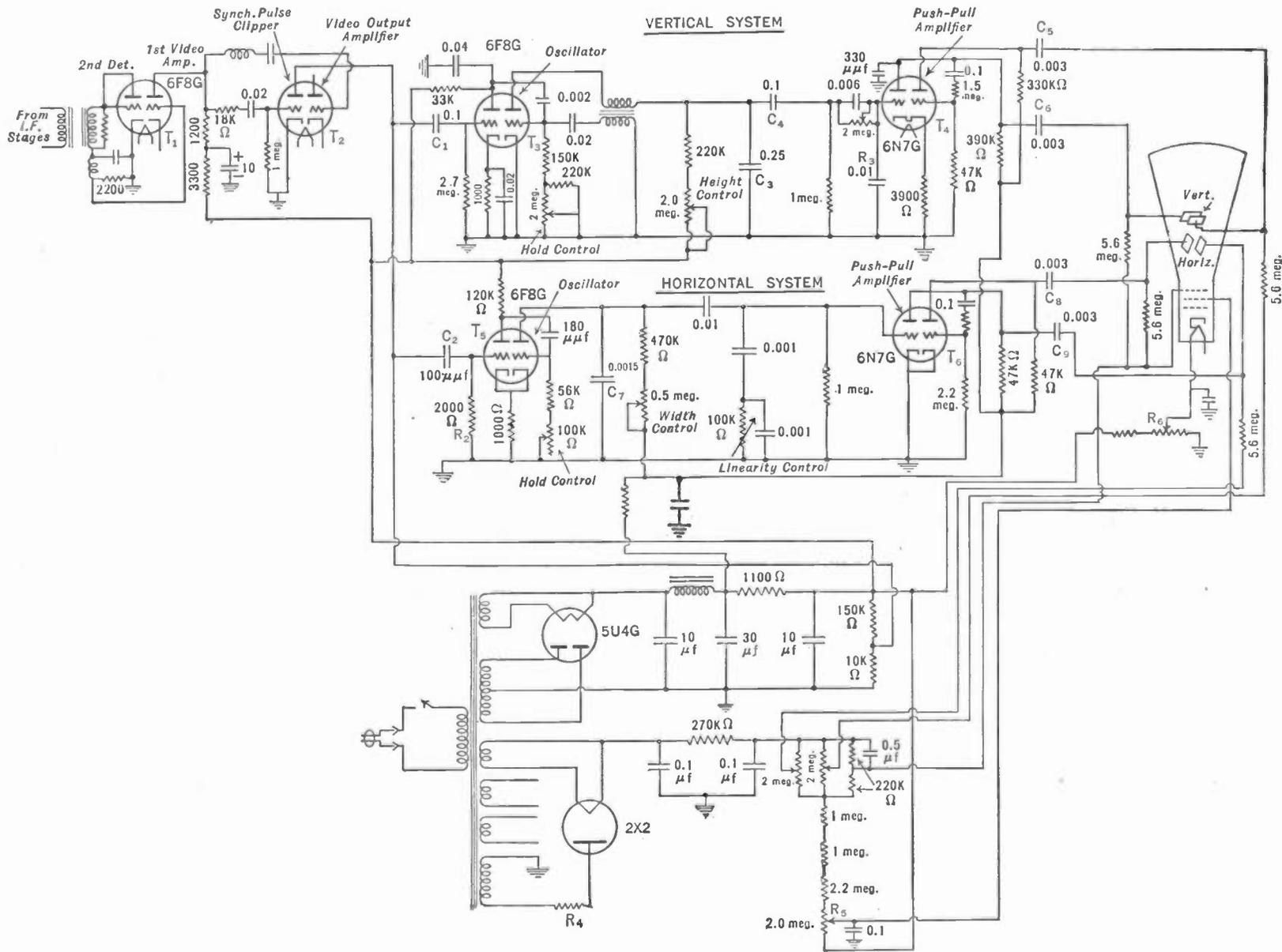
CHAPTER 10

DEFLECTING SYSTEMS

An Electrostatic Deflecting System. The schematic of an electrostatic deflecting system is shown in Fig. 10.1. It has been altered slightly for the sake of clearness and simplicity but, beyond a very few changes, remains essentially as designed by the manufacturer.

The video signal at the output of the detector is fed to the second triode of the 6F8G tube (T_1) for amplification. This tube is the first video amplifier. The synchronizing pulse clipper, which is one triode of a second 6F8G (T_2), obtains its input signal voltage from the plate of the first video amplifier. The second triode section of T_2 is the first video output amplifier (not shown here).

The 18,000-ohm resistor and the 0.02-μf condenser couple the the video signal into the grid of T_2, across the 1-megohm resistor. The 0.02-μf condenser prevents the positive plate voltage at the first video amplifier from reaching T_2. It also combines with the 1-megohm resistor to eliminate everything but the synchronizing pulses from the applied video signal. This action has been described in a preceding paragraph where, it will be remembered, a condenser and resistor combination of this type developed the operating grid-leak bias for the tube. There is no other form of bias on the tube. In the present circuit, the 0.02-μf condenser with the 1-megohm resistor have a relatively long time constant and only the large positive synchronizing pulses will determine this bias. Plate current flows only at these pulses, the remainder of the signal never bringing the grid voltage beyond the cut-off point. The tube thus clips off the

FIG. 10.1. A complete electrostatic deflecting system.

synchronizing pulses and discards the rest of the signal. It is from this action that the tube derives its name.

In order to have the pulses possess the necessary positive voltage at the clipper input (negative picture phase), the output of the detector T_1 in this instance must be in the positive picture phase. Inspection of the diagram will reveal that this is the case. If there had been no intervening amplifier, and if the output of the detector had been connected directly to the clipper, then a negative picture phase signal output from the detector would have been required. In any situation, it is merely necessary to remember that passage of the video signal through an amplifier will reverse its phase by 180°.

The output of the clipper stage is fed to both the vertical and horizontal deflecting oscillators. The method for separating the low-frequency vertical pulses from the higher-frequency horizontal pulses is to employ the proper combination of resistors and condensers in each circuit. In the vertical system, the 0.04-μf condenser and the 33,000-ohm resistor in the plate lead of one triode section of the 6F8-G tube respond to the longer vertical pulses. For the horizontal system, C_2 (100 $\mu\mu$f) and R_2 (2,000 ohms) combine to form a low-time-constant circuit.

The first section of T_3 receives the negative vertical pulse, amplifies it, reverses its polarity so that it is positive, and applies it to the blocking oscillator, which is the second triode section of T_3. Note that this reversal is necessary because only positive pulses will control the blocking oscillator, and the pulse at the output of the clipper is negative (positive picture phase). The 0.002-μf condenser couples the output of the first triode of T_3 to the second triode.

C_3, a 0.25-μf condenser, is the charge and discharge saw-tooth generator. When the blocking oscillator tube is non-conductive, C_3 charges through the height control potentiometer (2 megohms) and a 220,000-ohm plate load resistor. The voltage variations of C_3 are transmitted to T_4, a duo-triode amplifier. A portion of the output voltage of the first triode of T_4 is fed to the second triode, and in this manner a balanced push-pull arrangement is

obtained. Condensers C_5 and C_6 transmit the vertical deflecting saw-tooth voltages to the plates of the cathode-ray tube.

The variable resistor R_3 is known 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_3 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 nonlinearity by a special control. Good results are obtained in this manner and one stage of amplification following the charge-and-discharge condenser is usually sufficient.

The vertical linearity control is part of a filter composed of the 0.006-μf condenser, the 0.01-μf condenser, and the 2-megohm variable resistor (R_3). In some circuits the cathode resistor is variable and acts as the linearity control whereas in other circuits in which small screens are employed, no linearity control is provided.

The horizontal synchronizing oscillator T_5 is a multivibrator circuit, the output of which controls C_7, the charge and discharge condenser. The variable resistor of 500,000 ohms controls the charging rate of C_7 and is therefore the width adjustment. T_6 serves the same function here as T_4, and the output deflecting voltage is connected to the cathode-ray tube plates through condensers C_8 and C_9. A 100,000-ohm variable resistor acts as the horizontal linearity control.

Power Supply. In the power supply, one transformer is used for the rectifier plate windings of the low voltage and also of the

high voltage unit.   A 5U4G rectifies the low voltage and a 2X2 does the same for the high voltage.   Resistor R_4 in the plate lead is inserted to prevent an excessive current that could prove injurious to the tube.   This might occur if some component in the unit became shorted.

Little need be said about the unit because it is conventional and follows the description given in Chapter 8.   Two 2-megohm potentiometers provide beam centering adjustment, while an additional 2-megohm resistor is employed for focusing.   The current drawn by this high-voltage power supply is very small and a resistor instead of a choke is inserted for filtering.   The bleeder resistors are of the small carbon type, with a 1-watt dissipation rating.   Note that in this high-voltage unit, the negative end of the bleeder resistor string does not connect to ground, but rather to the positive terminal of the low-voltage power supply.   In this way it reaches the cathode-ray tube through the brightness control R_6.   The $B-$ lead of the high-voltage supply could have been attached directly to the viewing-tube cathode, but it could not have been directly grounded, because the cathode is at ground potential only when the movable arm of R_6 is at the grounded end of that control.   This can be traced out in Fig. 10.1.   At all other settings of the R_6 potentiometer arm, the cathode is above ground.   Hence a direct connection from the $B-$ terminal of the high-voltage unit to ground is impossible.

Another reason for not grounding the negative end of this supply is due to the position of the focus control.   This potentiometer connects to the first anode of the cathode-ray tube and must be several hundred volts more positive than the cathode. It is at this potential in this unit because the negative end of the high-voltage supply connects to the positive end of the low-voltage unit.   The cathode of the viewing tube is attached to the brightness control which is less positive than the focusing resistor.

The preceding description will hold for many of the power units found in television receivers.   In some perhaps the $B-$

end of the high-voltage unit is so arranged that it can be directly
attached to the ground, whereas in others, like the above, this
will not be possible.   The arrangement depends on the circuit
design.

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 volt-
age 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 electro-
magnetic 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

FIG. 10.4. A complete electromagnetic deflecting system:

shown in Fig. 10.2C.   A voltage of this type, when placed across
the deflecting coils will give a saw-tooth current, and the mag-
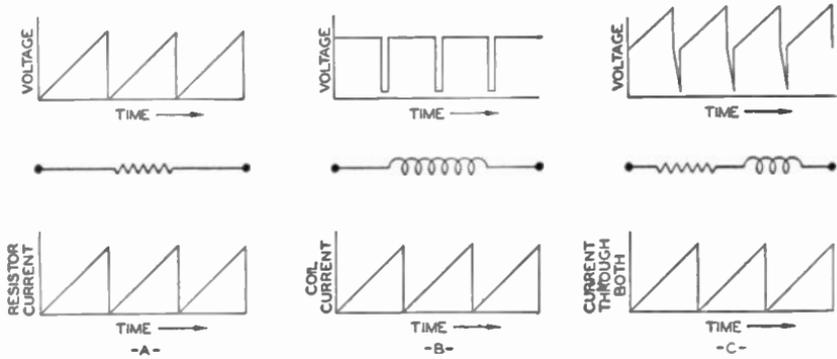netic flux, varying in like manner, will force the electron beam

FIG. 10.2.   By applying the voltage shown above each electrical component, the
saw-tooth waves shown underneath are obtained.

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 re-
sultant wave will be closer in form
to Fig. 10.2B.   On the other hand,
if the resistance predominates,
then the resultant wave will re-
semble 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

FIG. 10.3.   A common method for
generating deflecting voltages suitable
for application to deflecting coils.

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 condenser 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 given in Fig. 10.4. The synchronizing signal is obtained at the output of the second detector and applied to one triode portion of T_1 (6N7). This tube has no fixed bias of its own, the operating point being determined by the pulse level of the incoming signal. As previously explained, the grid coupling condenser is charged by each pulse and then slowly discharged through the 1-megohm grid resistor. With the low plate voltage of the tube (33 volts), plate current is permitted to flow only at the most positive portions of the video signal, which is assumed by the synchronizing pulses in this case. The signal at the input of T_1 must be in the negative picture phase.

The output of the first synchronizing separator, or clipper, is then amplified by the second triode section of T_1 and relayed to T_2, a pentode (6Y6G). This tube is the second synchronizing separator, where any unwanted video voltage that may have passed through the first separator is suppressed. Note that here again the pulses are positive at the control grid. The plate

is operated at an extremely low voltage (7 volts) to aid in the separation. In this design there is an unusually large number of stages (3) devoted to separating the synchronizing pulses from the rest of the signal.

After T_2, separation of the vertical and horizontal pulses takes place. For the horizontal pulses, we have the low-time-constant circuit connecting the horizontal synchronizing triode portion of T_3 and the horizontal oscillator (150-$\mu\mu$f condenser and a 270-ohm resistor). For the vertical pulses there is a three-stage low-pass filter composed of three 8,200-ohm resistors and three 0.005-μf condensers.

Turning our attention first to the vertical deflecting system, we find that T_6 serves as the vertical blocking oscillator. The vertical pulse from T_3 is sent through the low-pass filter composed of three 8,200-ohm resistors in series, by-passed by three 0.005-μf condensers. The filter eliminates any high frequency horizontal pulses that may be present. The 1.2-megohm variable resistor in the grid lead controls the natural frequency of the oscillator and hence is the vertical hold control. It is adjusted until the blocking oscillator is locked in by the incoming positive pulses.

In this receiver a separate tube, the second triode of T_6, controls the discharging of condenser C_1. The grid of the discharge tube is directly connected to the blocking oscillator grid and follows its voltage variations. Once in every cycle a sharp positive voltage appears on these grids, both tubes become conducting, and C_1 discharges rapidly through T_6. The input for T_7 is obtained from across the series combination of C_1 and R_1 and provides the necessary peaked voltage form of Fig. 10.2. When applied across the deflecting coils, the voltage will generate the necessary saw-tooth wave of current. The charging rate of C_1 can be varied by the 2.7-megohm resistor in the plate circuit of the second triode of T_6. This resistor would be the height control.

The vertical output amplifier, a 6J5, receives the vertical voltage wave, increases its amplitude, and then applies it to the

vertical deflecting coils through an output transformer. A variable resistor of 5,600 ohms is inserted in the cathode leg of T_7 to provide a vertical linearity control.

In the secondary circuit of T_7, there are two resistors and a condenser, R_2, R_3, and C_2. The function of R_3 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 deflecting 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 eliminate it entirely when the movable arm is at the tap. A similar arrangement is found in the horizontal deflecting circuit (resistor R_4).
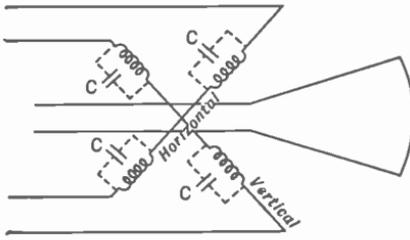
Fig. 10.5. The distributed capacity inherent in deflecting coils.

Condenser C_2 and resistor R_2 are employed 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 capacity between turns, and the inductance of the coils, in conjunction with this distributed capacitance, form a parallel resonant circuit (see Fig. 10.5). Every $\frac{1}{60}$ of a second, a sharp pulse of current flows in the circuit and, if one of the 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 current arrives at the coils and the beam, after the pulse, is at the upper side of the screen.

By inserting a simple R-C 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 amplitude of the oscillations can be decreased if a relatively low resist-

ance is placed across the circuit. The action resembles the loading of the input tuning circuits in the R.F. and I.F. stages. In Fig. 10.4, R_5 placed in parallel with one of the vertical deflecting coils (there are two connected in series) is also used for damping any oscillations generated at this point. In addition, the 6J5 output triode is across the vertical deflecting coils, and 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 more stringent measures be taken to eliminate these unwanted oscillations.

The horizontal deflecting system, starting with tube T_4, parallels the vertical deflecting system in all but two respects. One is the type of saw-tooth deflecting voltage that is generated, and the other concerns the damping circuit. Let us analyze each one.

Condenser C_3, in the plate circuit of the second triode of T_4, is the charge and discharge condenser that generates saw-tooth waves of voltage. This form of voltage, it was previously shown, when applied across a coil containing inductance and resistance, would not develop the necessary saw-tooth current wave that is needed to deflect the electron beam. Hence, in this case, it would appear that the circuit as designed is not suitable. However, let us carry the analysis one step further. The horizontal coils do not possess very much inductance (about 2 mh.) and depend upon a large current, rather than upon a large number of turns, to generate a strong magnetic flux. Hence a 6L6 power amplifier with a step-down transformer is utilized to develop this large current.

Now the inductive reactance of the horizontal deflecting coils is essentially placed in series with the plate resistance of the 6L6 through the action of the transformer. The equivalent circuit is shown in Fig. 10.6. Since the coils have a small inductance, their inductive reactance is not very great, and the plate resistance of the 6L6, which is quite high, predominates. Thus, for a circuit which is essentially resistive, a saw-tooth voltage can cause

a saw-tooth current to flow. This is the reason why it is un-
necessary to place a resistor in series with the discharge con-
denser in order to obtain the peaked wave. A condenser will
suffice, and that is all that is used in Fig. 10.4. However, if the
inductive reactance of the horizontal deflecting coils had been
greater, or if a triode with a low plate resistance had been used
instead of a pentode, the peaked wave of Fig. 10.2 would have
been necessary. In comparison to the inductance of the hori-

zontal coils, the vertical coils have 45
mh. of inductance.

The second difference between the
two deflecting sections of this receiver
is found in the horizontal damping
tube T_8. An ordinary R-C parallel
damping circuit at this point would
not be satisfactory for several reasons.
First, the R-C circuit would prevent
very large voltages from being built up
across the coils because of its damping
effect and because large voltages are

Fig. 10.6. An equivalent cir-
cuit of the horizontal deflecting
coils and the associated output
tube.

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. Secondly, it
has been found that an R-C filter at this place would lengthen the
return time of the beam, an undesirable feature.

A more efficient circuit is required to prevent oscillations
from affecting the action of the beam. A diode is quite often
used. In the circuit of Fig. 10.4 a 5V4G is shunted across the
secondary of the output transformer, with its plates connected
in parallel, and its cathodes likewise. The tube presents a low
resistance path whenever the plates become positive and cur-
rent flows through it. On the negative half of the transient
waves, the plates are negative, the tube non-conductive, and its
resistance infinite. The damping, therefore, is done when the
plates are positive and enough energy is absorbed to prevent
any transient oscillations from existing too long. When the

5V4G is non-conducting, the necessary high voltages may be built up across the coils to swing the beam back to the left-hand side of the screen.

The power units in this receiver are simply constructed and require no special explanation. A 5U4G operates as a full-wave rectifier in the low-voltage unit, while a 2V3G is utilized in the high-voltage unit. The 6,800 volts in the 2V3G supply are connected directly to the second anode of the 12-inch viewing tube to provide the necessary focusing and accelerating action. Another receiver employing electromagnetic deflection is described in 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:

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. Thirteen channels are covered, with an F-M sound system. The various oscillator frequencies for each of the thirteen channels are as follows:

Channel Number	Channel Freq. Mc	Picture Carrier Freq. Mc	Sound Carrier Freq. Mc	Receiver R.F. Osc. Freq. Mc
1	44–50	45.25	49.75	71
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
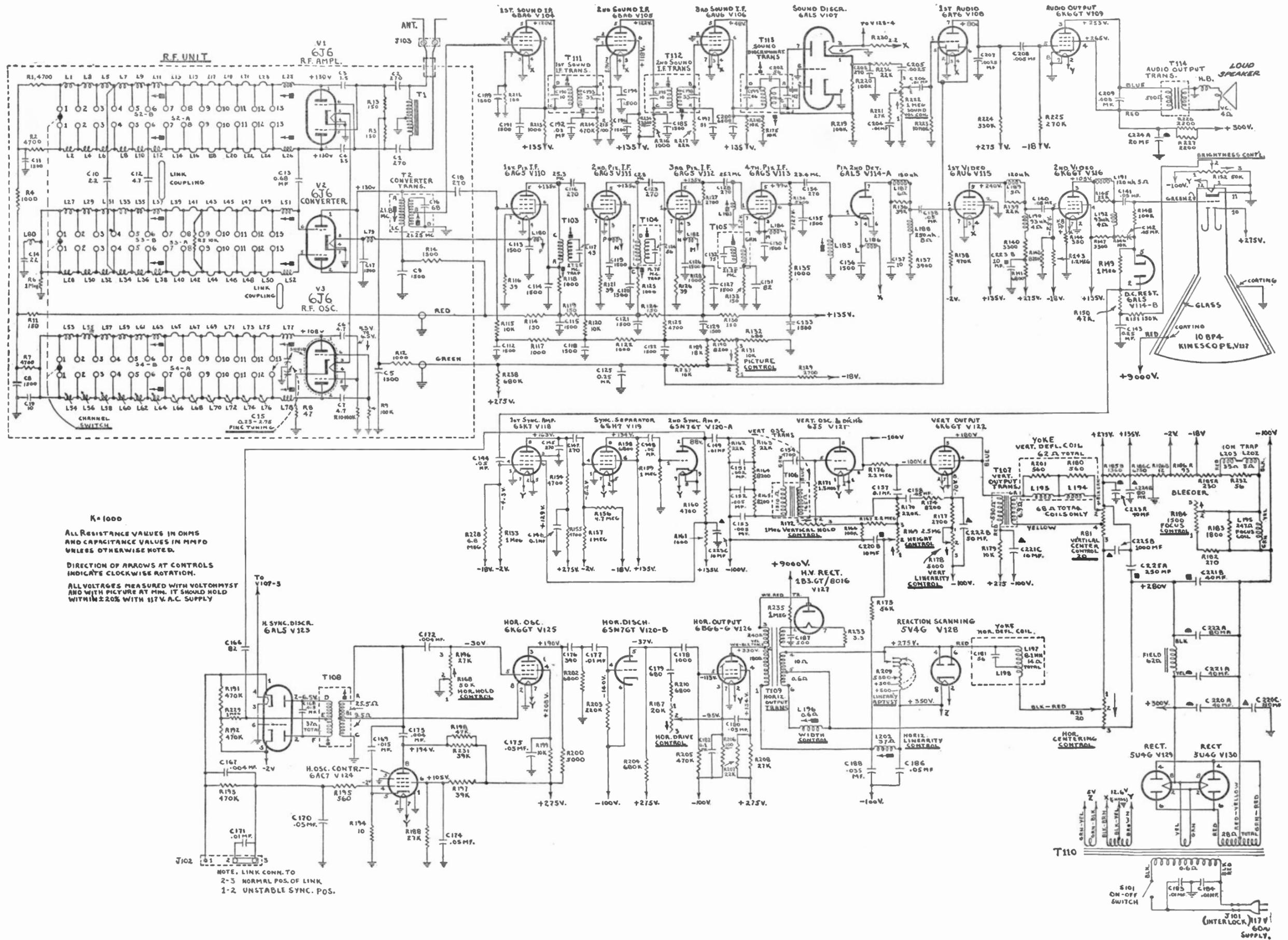
FIG. 11.1. The complete schematic diagram of the RCA 630-TS model television receiver.

Operating controls, those on the front panel, are (see Fig. 11.2):

Channel selector⎫
Fine tuning   ⎬ .... Dual control knobs

Picture (contrast)   ⎫
Sound volume and on-off switch⎬ .... Dual control knobs

Horizontal hold⎫
Vertical hold   ⎬ .... Dual control knobs

Brightness.................................... Single knob

Courtesy RCA
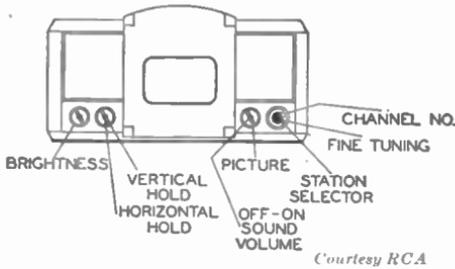
FIG. 11.2.   The front panel operating controls of the RCA table television receiver.

The non-operating controls, those which are mounted on the rear of the chassis, include:

Horizontal centering
Vertical centering
Width
Height
Horizontal linearity
Vertical linearity
Horizontal drive
Horizontal oscillator frequency
Horizontal oscillator phase
Focus
Focus coil
Ion trap coil
Deflection coil

The purpose and use of each of the controls will become evident as the analysis of the circuit proceeds.
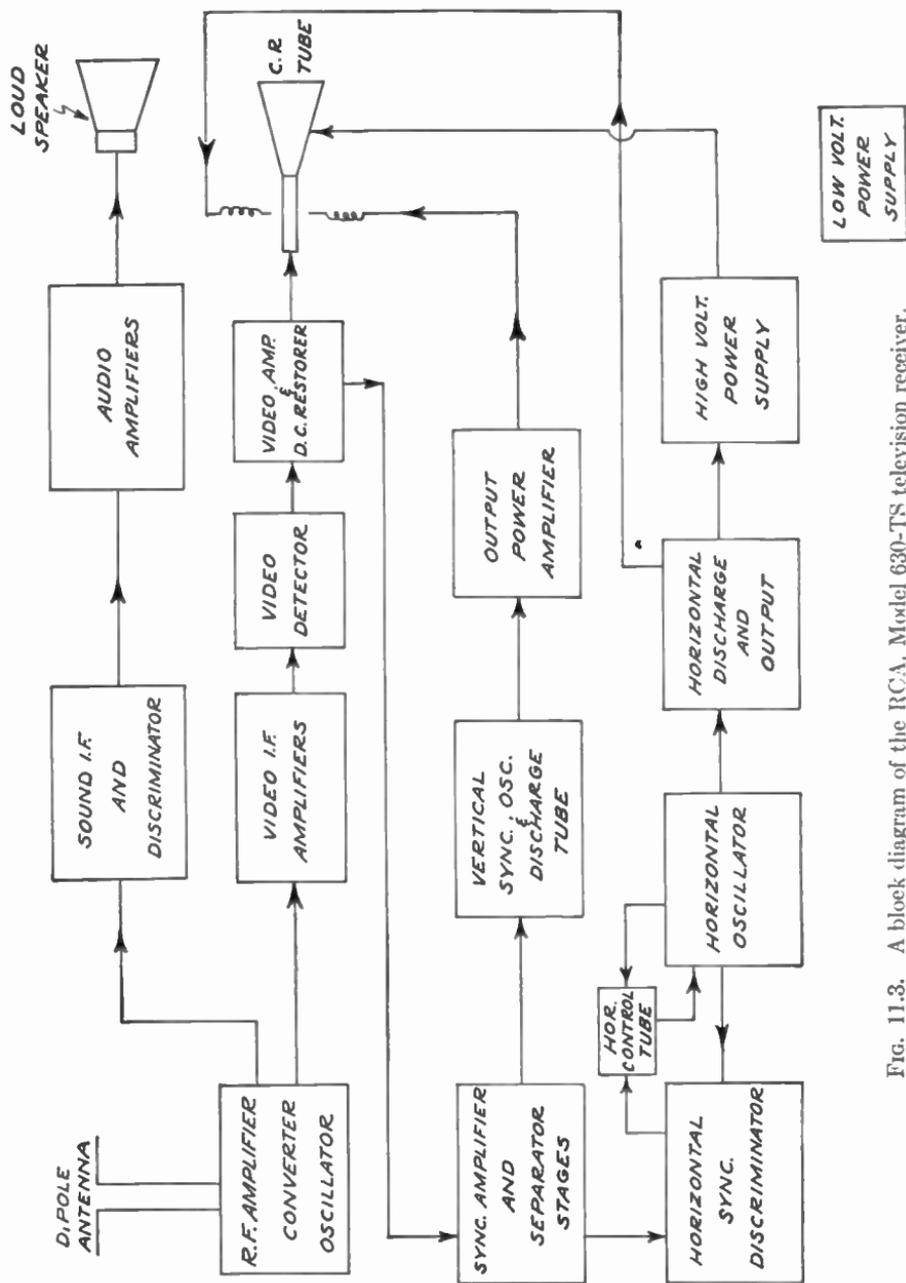
Fig. 11.3. A block diagram of the RCA, Model 630-TS television receiver.

A block diagram of the receiver is shown in Fig. 11.3. Each block indicates the stages which are contained in its section, together with the tubes. The sequence of stages is very similar to the diagram of Fig. 1.3, Chapter 1, with the addition of a phase-synchronized, horizontal-sweep oscillator and a fly-back type of high-voltage power unit. It is, in fact, due to these new stages that we have the horizontal drive and horizontal oscillator phase controls. In this receiver, the 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. When this occurs, it lasts for a few seconds and then is automatically locked-in again. In most instances, the effect of the horizontal hold control on the front panel is negligible and could have been shifted to the rear of the chassis.

The full 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 in order to understand completely the various conclusions reached.

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 providing 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. amplifier 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 triode introduces less noise

than the pentode and is, therefore, especially desirable in the R.F. and mixer stages.   However, until their adaptation to high-frequency use, triodes proved impractical because of their poor amplification, high internal losses and tendency to oscillate.

The 13-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 13 series inductances in each section of the line.   Coils L25 and L26 provide the proper inductance to tune the circuit to the highest television channel, 210–216 mc.   Iron-core slugs in L25 and L26 permit adjustment of each coil.   L13 to L23 on one side of the line, and L14 to L24 on the other side of the line are fixed sections which are added in series to L25 and L26 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 L13 to L24 is a small non-adjustable silver strap between the switch contacts.   Each strap is cut to represent a 6-mc change in frequency. Coils L11 and L12 bridge the gap between 174 mc and 88 mc. For the 6 lower television channels, L1 to L9 and L2 to L10 are used.   These coils are constructed in the form of a figure eight.

The Converter.   The grid circuit of the push-pull 6J6 converter is similar to the plate circuit of the R.F. amplifier.   The signal is transferred between the two circuits by means of C10, C12, C13, 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.

L80 and C14 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 8 lower channels in order to achieve the proper band width, 6.0 mc.   In the 5 highest channels the necessary band width can be obtained without resort to this artificial loading.   As we raise the frequency of the resonant circuit, the 6.0-mc band width 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 band pass 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 C15.   The adjustment is approximately ± 300 kc on channel 1; this increases to approximately ± 750 kc on channel 13.   The oscillator signal is coupled to the converter 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.

AUDIO SYSTEM

The sound system contains three I.F. amplifiers, a Foster-Seeley type of discriminator and two stages of audio amplification. The sound discriminator band width 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 13.

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 loud-speaker. 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 converter, 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 local mixing
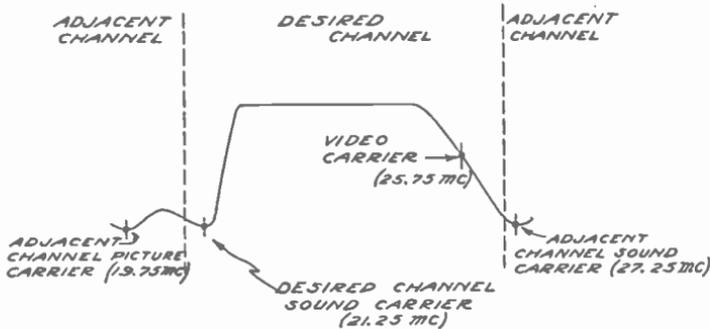
FIG. 11.4. The receiver over all video I.F. response curve.

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.

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 T103; be-
tween the second and third video I.F. stages, the shunting re-
sistor is a 4,700-ohm grid-leak
resistor, etc. Fig. 11.5 shows
the relative gains and selectivi-
ties of each coil and the manner
in which they combine to pro-
duce the desired overall char-
acteristic. The sharp cut-off
at 21.25 mc is due to the sound
traps in the video system
tuned to this frequency.
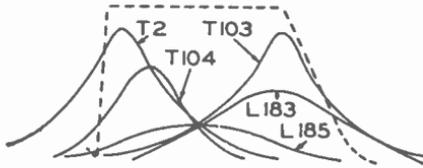
FIG. 11.5. The relative gains and selec-
tivities of each coil video I.F. system.
The effects of the traps are not shown.

The various video I.F. transformers are peaked to the following
frequencies:

T2 (primary)..............................21.8 mc
T103 (primary)............................25.3 mc
T104 (primary)............................22.3 mc
L183......................................25.2 mc
L185......................................23.4 mc

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
T105 located in the cathode leg of the fourth I.F. amplifier, V113.

The traps in T103 and T104 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 double-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 T103 or T104 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

F-A   *F*   *F+A*
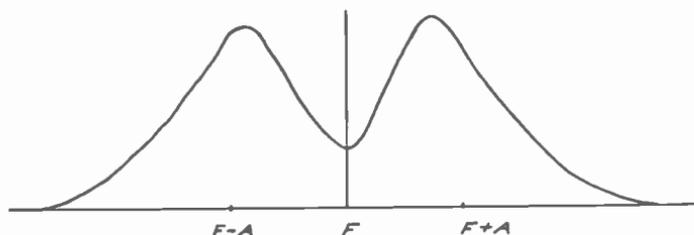
Fig. 11.6.   The double-humped response of two closely coupled coils.

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.

The final trap is in the cathode circuit of the fourth video I.F. amplifier V113 and is tuned to the accompanying sound carrier I.F. The primary of T105 forms a series resonant circuit with C131 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 straight-forward 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
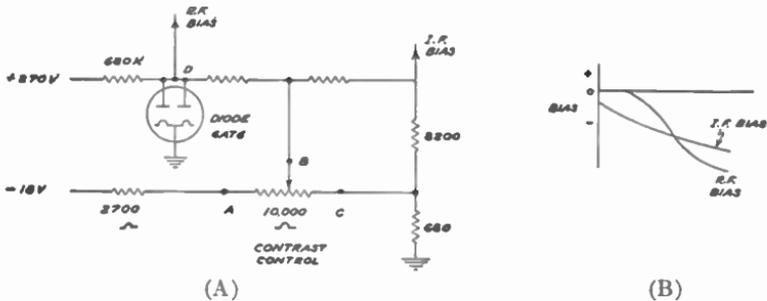
FIG. 11.7.   (A) The contrast control circuit in the receiver.   (B) The variation in
R.F. and I.F. grid voltage due to this control.

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 see that
the duo-diode sections of the 6AT6, 1st audio tube (V108), 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 approxi-
mately -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 potential. 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 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 supplies 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.
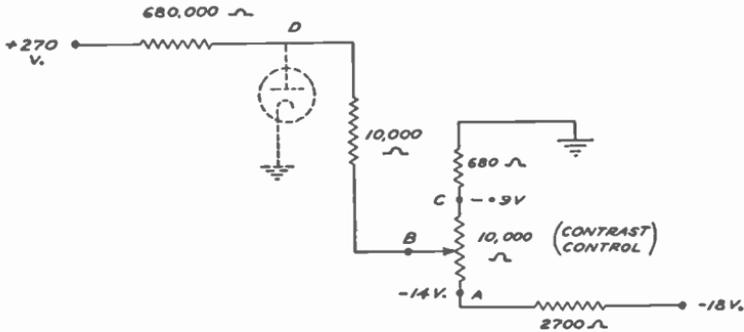

FIG. 11.8.   A simplified diagram of the contrast control circuit.

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 cathode-ray tube. The diode load resistor R137 is 3,900 ohms. The circuit is fully compensated, employing both series and shunt peaking, with L187 and L188. The 39,000-ohm resistor across L187 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 L189, L190, L191, etc. The low-frequency compensating components are the decoupling networks between the lower end of the load resistors and the power supply: for example, C223B (10-μf electrolytic condenser) and R141 (6,800-ohm dropping resistor) in the plate circuit of V115.

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 r-c 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. There is, of course, no objection to this method, although it is customary to achieve this separation at the second detector. 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 V118, is in the negative direction. To remove completely any remaining blanking and video portions of the signal, the signal is amplified by the 6SK7 (V118) and applied to the grid of the following 6SH7 with the synchronizing pulses in the positive direction. The synchroniz-

ing 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 6SK7 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 R163, R164, R165, C151, C152 and C153 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 C158 is charging through R169 and R170. When the synchronizing pulse arrives, it drives V121 into conduction and C158 discharges through the secondary winding of T106 and 6J5 tube.   The current in T106 induces a positive voltage on the grid of the 6J5, which further reduces the plate resistance of the tube and permits C158 to discharge even faster.

The sequence follows the pattern of operation of all such blocking oscillators and the waveform developed across C158 and R174 is shown in Fig. 11.9. This type of waveform is obtained from peaking circuits (C158 in series with R174) and, when applied to a coil, will produce a saw-tooth current. Adjustment of R169 will vary the amplitude of the deflection voltage and is, of course, the height control.

The circuit, in its present form, appears to bear no resemblance to charge and discharge circuits previously discussed in Chapter 10. However, by a rearrangement of the components, the similarity is readily apparent (see Fig. 11.10).

Fig. 11.9.   The shape of the deflection voltage wave at the input to the vertical output amplifier.

To develop sufficient driving power, the output of the 6J5 is applied between the grid and cathode of the 6K6 power amplifier. In the cathode leg of this amplifier, a variable resistor functions as the vertical linearity control. Variation of resistance in the cathode leg has the effect of producing slight variations in the
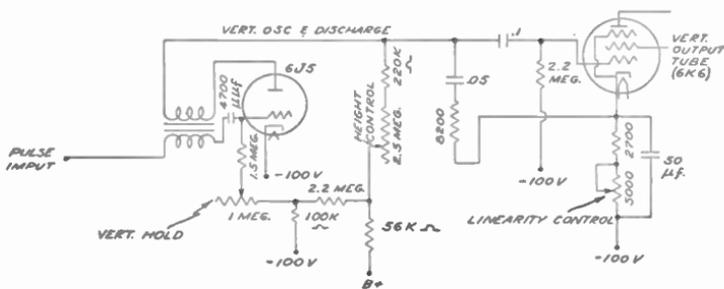
Fig. 11.10.   The vertical oscillator and discharge circuit, rearranged to more conventional form.

shape of the saw-tooth wave by shifting the operating 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 V121 plate and require adjustment of the linearity control. The 6K6 is matched to the vertical deflecting coils by means of T107. 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 is a marked departure from conventional methods. It is 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 V125 (6K6) and it is conventional in form. The oscillator coil (secondary of T108) is closely coupled to the primary winding. The primary winding is center-tapped and tuned by means of C168. Since each diode is connected across half of the primary coil T108, each receives voltages which are equal in amplitude but opposite in phase. Resistor R229 is common to both tubes and the oppositely phased voltages appear across here.

The horizontal synchronizing pulse is transferred to R229 from the second synchronizing amplifier by means of C166 ($82\mu\mu f$) and this pulse will add to each of the sine-wave voltages. If the horizontal oscillator is at the frequency of the incoming pulses, then the condition shown in Fig. 11.11A will be true. The synchronizing pulse will add in the same direction to both sine waves; but, if the pulse arrives when both waves are passing through zero, there will be no change in circuit conditions. The incoming synchronizing pulse is placed across R229 and combines with the sine-wave voltage from each half of the primary coil (T108) to form the driving voltage for each diode. If the pulses arrive when the sine-wave voltage across T108 is zero, then each diode will receive the same pulse voltage and the same amount of rectified voltage will ap-

Fig. 11.11. Illustrating how the horizontal synchronizing discriminator separates.

pear across the diode load resistors R191 and R192. 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 R191 and R192 at this moment is that there is no sine-wave voltage and each tube receives the same synchronizing pulse voltage from R229.

Suppose, however, that the pulse arrives at some other instant. Two such situations are shown in Fig. 11.11B and C. In Fig. 11.11B, 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 R191 than across R192. The average voltage, over one cycle, will be positive and this, fed to V124, will make its grid more positive. On the other hand, if we consider the situation of Fig. 11.11C, we

see that R192 will receive the greater voltage and that, on the average, the voltage from the combination will be negative. The effect on V124 obviously will be different in each instance. It is seen, therefore, that the double-diode arrangement of V123 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 in the Hartley oscillator.

The d-c voltage developed in the phase discriminator, together with a fixed negative biasing voltage (-2 volts) is applied through C167, R193, C171, and R195 to the grid of a reactance tube, V124. This tube is so connected that its plate current is 90° out of phase with the voltage across it and consequently it appears as a reactance. Since it is connected directly across the tuning coil of the Hartley oscillator, changes in plate current of the reactance tube will cause changes in the frequency of the oscillator and so act to force it back into line with 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 for.

C167 and C170 form a voltage divider to attenuate rapid changes in d-c from the phase discriminator such as are produced by the vertical synchronizing pulses or noise. If any phase modulation is present in the transmitted synchronizing pulses, it may be necessary to sacrifice some noise immunity to compensate for this phase modulation in the transmitted synchronizing pulses. The phase discriminator will follow these variations in the pulses, but the voltage divider arrangement will remove this information just as effectively as the other unwanted disturbances. The elimination of this information will produce a horizontal displacement of portions of the image. If we remove the shorting link from across C171 and place it across terminals 1 and 2, we connect it in parallel with C167 and the speed of response is increased by several times.

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 V125, 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. 11.12A. The peak-to-peak voltage on the grid of V125 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 C176 and R202, producing the wave shown in Fig. 11.12B. 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 V126 falls to cathode potential and C179 discharges rapidly. However, the conduction period is quite short and C179 does not discharge completely due to R187 and R210, both of which are in series with C179. When V120-B becomes non-conducting again, its plate voltage rises quickly to a value determined by the charge remaining on C179. 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 (V126) via C178.

Horizontal-Deflection and High-Voltage Circuits. This receiver is one of the first to use the recently developed system of

(a) Plate of Horizontal Oscillator 225 Volts peak-to-peak.

(b) Input to Horizontal discharge tube 100 volts peak-to-peak.
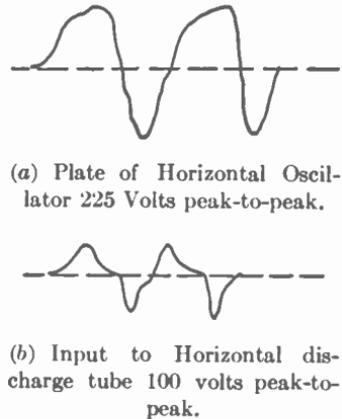
FIG. 11.12. The various waveforms in the horizontal oscillator and discharge circuit.

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 deflection
transformer and the deflecting voltage from the discharge tube is
applied to its grid.   The function of V128, 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 8 and the reader
is referred there.

There are two adjustments for the picture width, R187 and
L196.   Both are necessary because, although their adjustment
alters the width of the image, they perform other functions.
R187 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 control
increases picture width, crowds the right side of the picture and
stretches the left side.   L196 varies the output and hence the
picture width by shunting a portion of the secondary winding of
T109.   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 ap-
plied 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
capacity 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 cathode-ray
tube are low and are supplied by the low-voltage power supply.
In this manner, the high voltage (9,000 volts) is actually de-

creased 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 R152, the brightness control. This control is connected

into the d-c restorer circuits, but has no affect upon its circuit because the d-c potential introduced by this control reaches the two elements of the d-c restorer in equal strength.
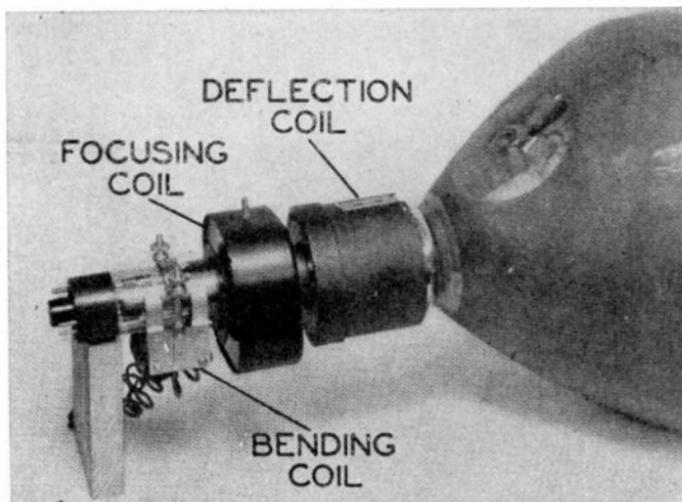
Fig. 11.13.   The placement of the deflection, focusing and bending coils on the neck of a cathode-ray tube.

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 ad-

justments 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. Due to the wide band widths 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 selector switch, 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 instantly. To keep the image on the screen stationary, a small portion of the 60-cycle sweep frequency is fed to the horizontal
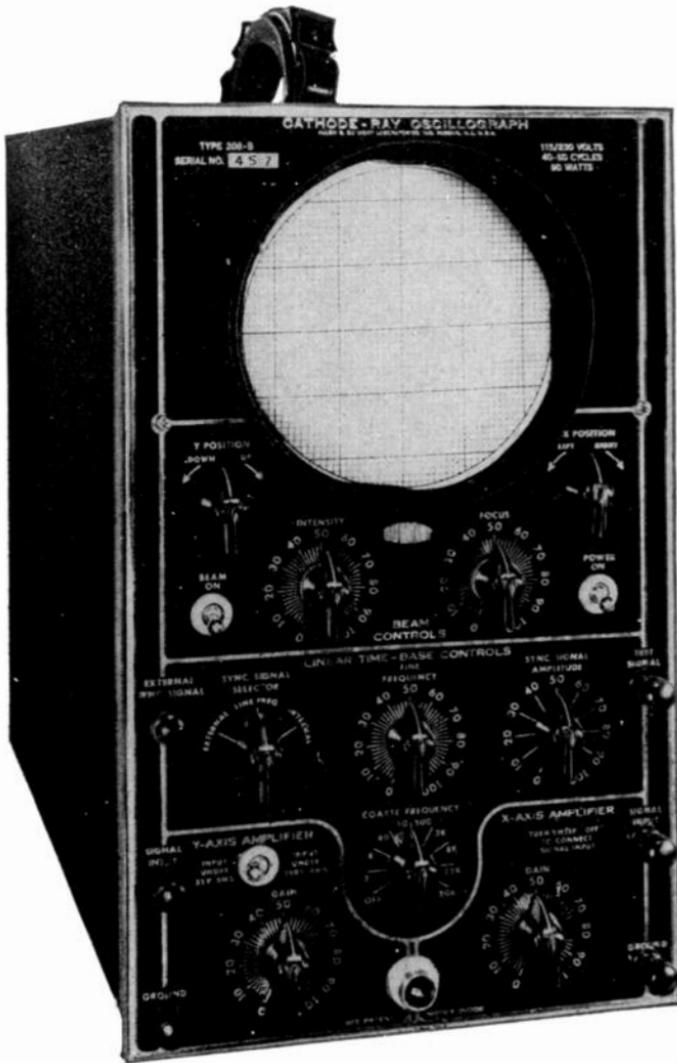
FIG. 11.14.   A modern service oscilloscope.

amplifier (through the external synchronizing posts) of the oscilloscope for synchronization.

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

Courtesy U.S. Television

FIG. 11.15.   A signal generator covering the F-M and television bands.

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 band-pass 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.

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 band-pass 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.
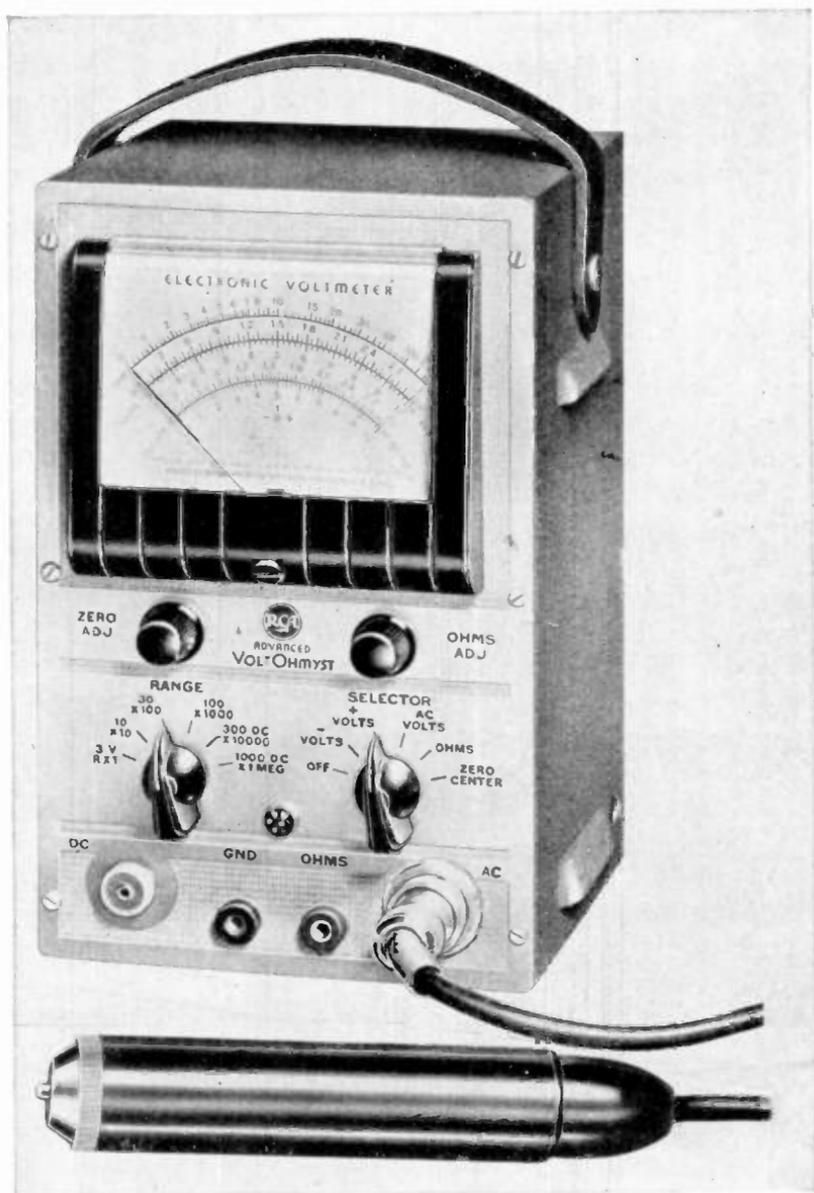
FIG. 11.16. A vacuum-tube voltmeter capable of measuring voltages with frequencies up to 200 mc.

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 mc 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 indicated 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 indicator that super-imposes the two signals on the I.F. being swept out (16 to 30 mc). The indication of the marker points in the visible pattern is either a slight wiggle or else a dip in the curve at these two points. Fig. 11.17 shows how these marker points appear. The difference in the manner in which the points are indicated is due to the method used in the sweep signal generator to develop these marker points.

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 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. The frequency of this second oscillator should be accurately set to one of the end frequencies, either 21.75 or 25.75 mc. The
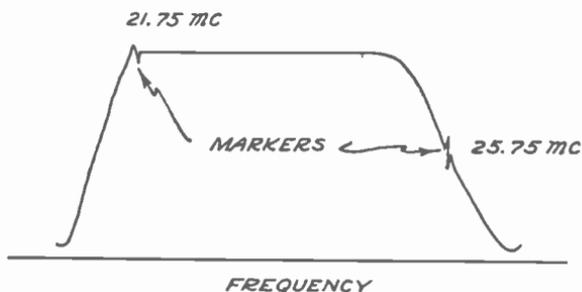
FIG. 11.17. The use of marker points for definitely indicating a frequency on a response curve.

indication on the screen curve will appear as a wiggle, at the center of which is a thin, black line. Mark this point on the oscilloscope screen with a pen or crayon, or even by means of a very thin strip of adhesive tape. None of these will mar the screen in any way. Now change this second generator to the other marker frequency and make the same mark at the other end of the visible response curve. It is even feasible to make only one mark on the screen surface, and let the marker oscillator show the position of the other marker point by remaining connected in the circuit and tuned to the other frequency. One precaution that must be observed with this latter method is not to alter the setting of the oscilloscope horizontal gain control, once it has been set. Any change would invalidate the pen marks made on the screen. Enough horizontal gain should be provided before the marks are made on the screen to take care of the resulting pattern on the

screen, whether the signal has passed through one I.F. amplifier or all. A little experimentation will readily indicate the best setting of the horizontal amplifier gain control. It is also 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 several 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 converter 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 converter tube. The vacuum-tube voltmeter

is placed across the video second-detector load resistor, or R137. Set the generator to each of the following frequencies and tune each specified adjustment for *minimum* indication on the meter.

T104... 19.75 mc
(Adjacent Channel Video Carrier Trap)

T2 (top).. 21.25 mc
(Accompanying Sound Trap)

T105 (top).. 21.25 mc
(Same as preceding trap)

T103 (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:

T2 (bottom)... 21.8 mc
(Converter Output)

T103 (bottom)....................................... 25.3 mc
(1st Video I.F.)

T104 (bottom)....................................... 22.3 mc
(2nd Video I.F.)

L183 (top of chassis)................................ 25.2 mc
(3rd Video I.F.)

L185 (top of chassis)................................ 23.4 mc
(4th Video I.F.)

If any of the transformers (T2, T103, and T104) require any appreciable adjustment, it is advisable to re-check 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 $1,000\text{-}\mu\mu\text{f}$

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 (L185) for maximum response.   Shift the signal generator to the grid of the third I.F. amplifier.   Remove the shunting capacitor 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.
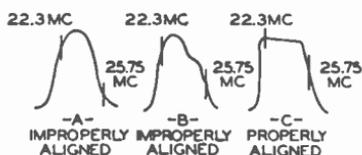
Fig. 11.18.   The form of the video I.F. response curve for proper and improper alignment.

The entire video I.F. system is now adjusted.   An over-all check should be run, with the sweep oscillator connected to one of the triode grids of the converter.   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 R137.   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 frequencies.   If any slight adjustments are required, they are made with the sweep generator on so that the effect on the over-all 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 over-all video I.F. response curve when the circuit is improperly aligned is indicated in Fig. 11.18A 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 13 before continuing.)

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 R219 and R220 join. Now detune the secondary winding of T113 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 (R219 and R220) 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 R220. This places it across both load resistors. Adjust the secondary of T113 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 slowly move 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 (T113) 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 cross-over point. The cross-over point should be located midway between the upper and lower peaks. We can use the sweep generator to see the entire curve at one time and determine whether both of the foregoing condi-
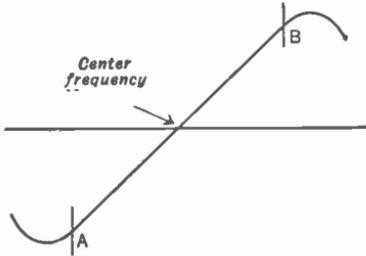
Fig. 11.19.   Discriminator charac-
teristic curve.

tions 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 band width 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 R220 and ground. The pattern that is obtained should be shown in Fig. 11.19. If the curve is not symmetrical or the linear portion sufficiently long, both trimmers of T113 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 13, 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 receiver, there are two normal sound I.F. amplifiers, V104 and V105, and one limiter, V106. V105, 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, R217.   It is suggested that a
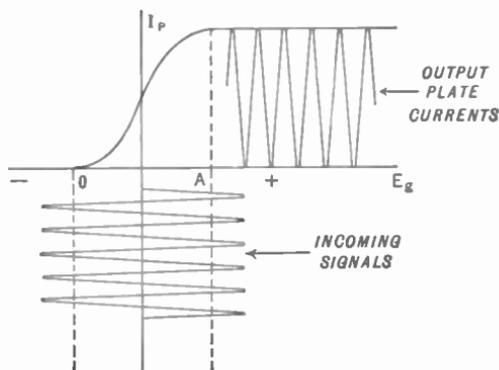
Fig. 11.20.   The characteristic curve for a limiter.   As long as the incoming signal extends beyond O–A, the output will be free of amplitude modulation.

33,000-ohm isolating resistor be placed in series with the oscilloscope lead that connects to the top of R217.   (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 T112 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 V104 and adjust T111 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 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 discussion, the various stages can be separately aligned and so the R.F. and converter stages are taken first.

21.25 mc.

Marker wiggle here

FIG. 11.21.   The shape of the response curve and the position of the marker frequency when aligning the F.M., I.F. stages.

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
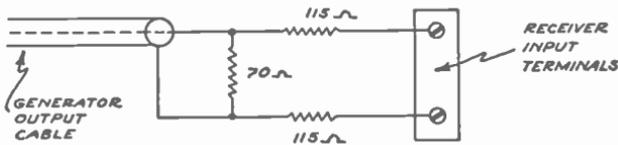
Fig. 11.22.   A simple method of matching the impedance of the generator cable to the receiver input.

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 L80 and R6 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
L25, L26, L51 and L52 for an approximately 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 re-
sponse 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 re-
quirement on one or more of the
high-frequency channels, it will be
necessary to readjust L25, L26, L51,
and L52 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 fre-
quency television band and we now adjust L11, L12, L37, and L38
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 1, each time making the neces-
sary 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, L11,

Fig. 11.23.   The R.F. response
characteristics of the RCA receiver.

L12, L37, and L38 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.
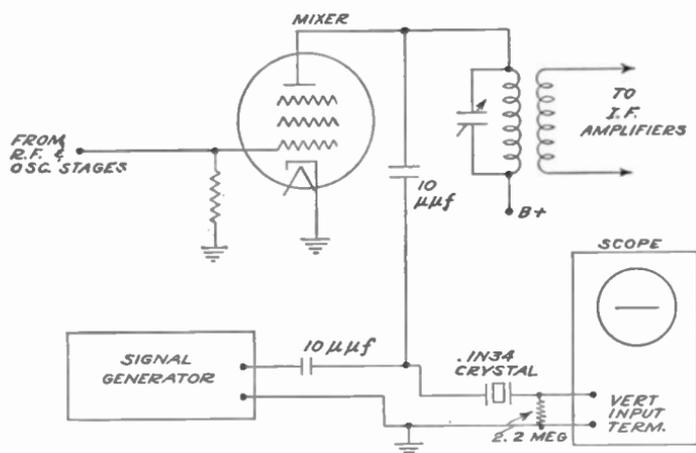
Fig. 11.24.   A means of checking and aligning the receiver oscillator frequency. The oscillator signal is taken from the plate circuit of the mixer in order not to disturb the oscillator operation.

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 1. 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 L77 and L78 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 appropriate value. The proper oscillator coil to be adjusted for each channel can be obtained from the complete circuit schematic diagram. For example, adjust L76 for channel 12, L74 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

COLOR TELEVISION

Introduction. Emphasis throughout the preceding chapters has been devoted entirely to the underlying principles of transmission and reception of so-called black and white images. With 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. While 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 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 most radio 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 operation since the middle 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, to date, 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 on the basis of these inadequacies, plus the desire to bring the American public the best possible system, that the F.C.C. has recently refused to establish a set of regulations for color television. The opinion has been to permit further experimentation in the

laboratories and in the field before any choice is made. The experimentation is carried out in the allotted frequencies of 480–920 mc.

Advantages of Colored Images. The advantages of color television lie in its greater naturalness. Our environment contains many varieties of color and it is only natural that the same life-like qualities should be desired in television. Color in an image heightens the contrast between elements, brightens the highlights, deepens the shadows and seems to add a third dimension to an otherwise flat reproduction. It is interesting to note that more detail appeared to be present in colored images containing less lines than corresponding black and white pictures. This is the actual testimony of ordinary observers. Only on close inspection does the increased line spacing become apparent. Perhaps many readers have noticed the remarkable differences between technicolor films and the ordinary motion pictures. The same results are observed with television.

Color Television Systems. In this country, there are two systems of color television on which any extensive work is being done. One is the sequential, additive method used by the Columbia Broadcasting System; the other is the simultaneous method developed by RCA. At the present time, each is important because each possesses certain advantages and neither has been chosen officially by the Federal Communications Commission. An analysis of each system follows in the following paragraphs.

CBS System

The phrase " sequential, additive method of color transmission " represents the heart of the CBS system. A thorough understanding of what this phrase implies 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, due to

the limitations of the human eye and the fact that the colors produced by the prism blend into each other, we can count only seven fairly distinct colors. Upon closer inspection of this color distribution, additional 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 infra-red 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 reason 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 light, the object appeared blue, then it 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: these lamps have an excess of red light and a deficiency of blue light. 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 which 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.

While red, blue, and green would give us all the colors we might need, practical considerations and limitations govern the final choice of the actual colored filters chosen. It has been found, for example, that certain filters do not transmit as much light as others somewhat differently composed. Another limitation resides in the fluorescent material coating the cathode-ray viewing screen. These have their own color characteristics, which must be chosen with regard toward color reproduction and decay time of the fluorescent illumination. And, finally, the use of purely colored filters would give us a range of colors far greater than we might ordinarily desire. Thus, while we may work on the assumption that pure red, green, and blue filters are being utilized, actually some modifications exist. However, for the purposes of understanding the operation of color television transmitting (and receiving) systems, these assumptions will not invalidate any of the statements made. It is merely a case of noting the practical limitations that exist.

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. And because the result is determined by the addition of these colors, the term additive is attached to this method. Another significance to the word additive rests on the fact that by using the complements of the primary colors (blue-green, magenta, and yellow) we may evolve the same derived shades by a subtraction method. Subtraction of colors is used to a great extent in photography, but never in television.

The action of the three filters in breaking down or analyzing

a scene is a logical process. The light intensity reaching the camera tube must first pass through an intervening filter disc. 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 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 charge and transmitted through the connected electrical circuits. The same reasoning holds for the next, or red, filter. Hence we see that, through the use of properly synchronized filters, any scene being televised is analyzed into these three component 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. This is not a disadvantage, however, for we never need this sharp division in practice.

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.

Due to the importance of correctly synchronizing the rotation of the filter disc at the receiver with the disc at the transmitter,
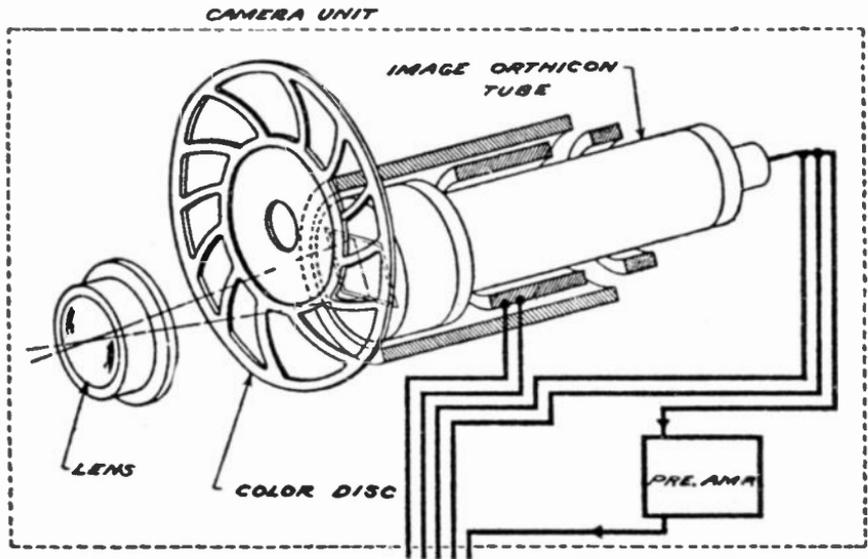
FIG. 12.1. The incoming light rays are filtered by the color disc before reaching the camera tube.

the receiver disc is driven by an induction motor. Synchronization is accomplished by using part of the vertical sweep frequency 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. Poor operation in this system would result in incorrect color values given to the various sections of the image.

Color Filters. A color filter disc used in CBS transmitters and receivers is shown in Fig. 12.1. At the studio, either an Image Dissector or an Image Orthicon camera tube is used to receive the light rays from the scene being televised. See Fig. 12.2. The

camera tubes differ slightly from the conventional form in that they are now more sensitive to the three colors used in the filters; 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
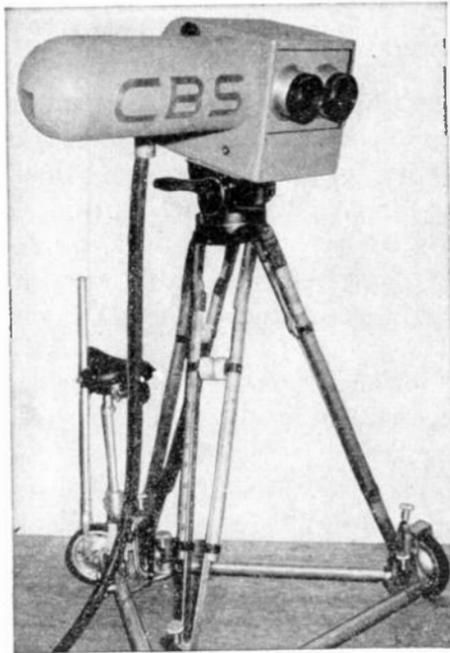
Courtesy CBS

FIG. 12.2. A color live pick-up camera using an Orthicon tube.

electron beam or scanning aperture within the camera tube. The color disc of course 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 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 ($262\frac{1}{2}$ 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 beam again scans the mosaic plate, this time across the $262\frac{1}{2}$ lines not included in the last 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 $262\frac{1}{2}$ 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 period all the odd lines were scanned with the red filter in position. During the next period, the even lines were scanned with the blue filter in front of the camera tube. Finally, at the third run, the green filter intercepted all the light arriving at the mosaic. In this latter run, the odd lines were again scanned. Thus each color was obtained at the mosaic, but only for half the lines, or 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 period. 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, 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 the even lines will be scanned. The complete sequence up to this point is given as follows:

Period	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.
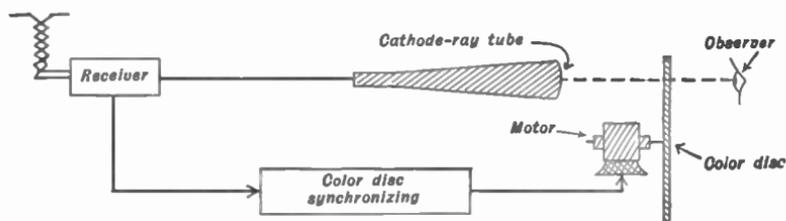
FIG. 12.3. CBS basic color receiver.

At the receiver 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 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 ordinary 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 band width, the number of scanning lines would have to be decreased.   It was felt however, that anything less than 525 lines would not produce the desired results and it was decided to retain the same number of lines (525) and increase the band width.   Since the band width is directly proportional to the scanning rate, we find that a band close to 16 mc wide is required for the transmission of color images in this system.

Since $\frac{1}{144}$ of a second is required to scan one field, or one-half of 525 lines, $\frac{1}{72}$ of a second is needed for a complete image or frame.   Hence, we have 72 complete images 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 12.1 shows the sequence of the various fields, with 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, or $\frac{1}{24}$ 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 over each 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

TABLE 12.1. A TABLE OF THE COLOR SEQUENCES AND THEIR TIME DURATION IN THE CBS SYSTEM OF COLOR TELEVISION

	Image scanned once with every color $\frac{1}{48}$ 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
COLOR OF FILTER	Red	Blue	Green	Red	Blue	Green	Red	Blue

etc. ⟶

Complete color sequence ($\frac{1}{24}$ sec.)

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 break up occurs unless this precaution is observed and is one 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 the above 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.

It has been suggested that the field repetition rate be raised from its present value of 144 to 180. This means 60 color frames per second. It is feared that when the present screen illuminations are increased flicker will become noticeable, since flicker depends upon the brightness of the image. An increase to 180 fields per second, however, would mean that a band 18 mc wide would be required to accommodate the signal, and the additional frequency spread is undesirable. The F.C.C., in many of its decisions concerning television in general and color television in particular, has stressed the importance of two factors.

1. The development of low-cost receivers.

2. The evolution of a system of transmitting color television over as narrow a channel as possible.

They have further emphasized that narrowing the band width should not be at the expense of picture brightness, picture detail, color fidelity, or other features of television performance.

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. Likewise, the position of a similar

color disc in front of the camera tube at the studio decreases the sensitivity there.

Transmitter Components. The block diagram of the main transmitter components is shown in Fig. 12.4. All of the electronic units in the transmitter receive their power from a line power source of 120 volts, 144 cycles per second — the same frequency as the color field frequency. This is purposely done to avoid any hum components which might produce a loss of line interlacing in the synchronizing signal and scanning tube circuits. This effect was found to occur when the ordinary 60-cycle power lines were used. Driving the 144-cycle frequency converter with a 60-cycle synchronous motor assures that the 144-cycle power is synchronous with the local 60-cycle power, and permits the use of ordinary 60-cycle synchronous drive motors where required in the system.

The most important unit in the transmitter is the synchronizing signal generator. It furnishes all of the timing pulses required in a television system. These pulses are: the horizontal and vertical blanking and synchronizing pulses and the color pulses, the latter for maintaining disc synchronization and phasing at the receiver and the transmitter.

Following the signal generator are the isolation amplifiers which serve as matching units between the generator and the various circuits which receive the output of the generator. It is important that nothing disturb the operation of the synchronizing signal generator since any slight shift in frequency of the generated pulses will disrupt the image in the receiver. The isolation amplifier section consists essentially of 75-ohm cathode-follower output stages.

The vertical and horizontal scanning amplifiers receive the driving pulses from the synchronizing signal isolation amplifier and develop the proper saw-tooth deflection voltages or current which are needed at the camera tube to control the motion of the scanning electron beam.

Within the camera housing unit we find the tube, its associated voltage-regulated power supplies and the video pre-amplifiers.
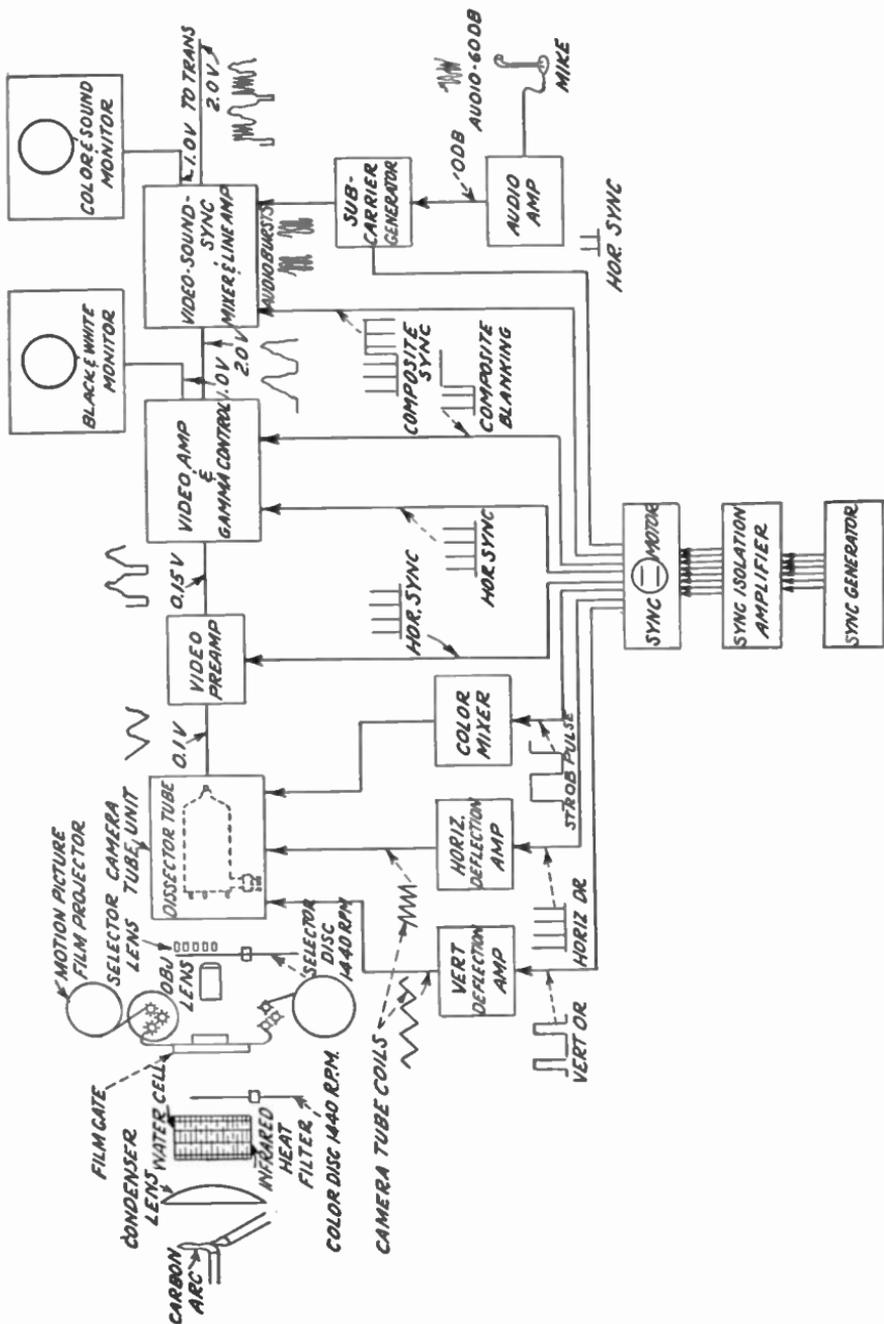
Fig. 12.4. Block diagram of the CBS color television transmission equipment for color film. In live studio work, an iconoscope camera tube would be used.

The levels of the video voltages noted in Fig. 12.4 are those which are obtained for the Farnsworth Image Dissector tube. The output levels for the signal voltages from each of the three color fields are individually controlled in order to compensate for any differences that may arise between them. In addition, the individual controls are useful in altering the various signal voltage relationships to produce special scenic and artistic effects in the final image.

The video signal is now passed through successive amplifiers where the appropriate blanking and synchronizing pulses are combined with the video signal to form the complete television signal with its picture information and controlling pulses. The signal obtained from the camera represents only the picture detail; the blanking and synchronizing pulses must be inserted at the appropriate points to fashion the complete or composite signal.

Sound Transmission. One interesting feature of the CBS color system is its method of sound transmission. In black and white television, the sound carrier is located just beyond the high-frequency edge of the upper video sideband. This position is satisfactory in practice, but it does possess the disadvantage of extending the band width required by the television signal. An alternate method of sending the sound signal is to transmit it during those periods or intervals when the camera signal is blanked out and the beam is swinging from the right-hand side of the screen to the left-hand side in position for the next line. At the end of each horizontal line, the beam is blanked out and the synchronizing pulse applied. At the termination of the synchronizing pulse, the audio signal is inserted in the form of a short burst of a 4.75-mc frequency-modulated signal (see Fig. 12.4). The signal extends the full amplitude of the video signal and lasts for 8 per cent of the horizontal scanning period. At the end of this burst, the blanking voltage is removed and the video detail of the following line is traced out on the screen. These bursts continue at the end of each line and throughout the serrated vertical pulse interval. At the receiver, the bursts of F-M are separated from the carrier wave and passed on to the

audio section of the receiver where they are converted into sound.
When we utilize the sound in this manner, we do not require any
more frequency space than that needed by the video carrier and
its upper sideband.

The sound signal is discontinuous in nature, but this produces
no audible effect so long as the bursts of energy are transmitted
sufficiently close to each other.   We might, if we wish, compare
this situation with the rotating blades of a fan.   When the blades
are rotating fast enough, they appear to form one continuous ring
of metal all around the path of rotation.   The same is true of the
F-M bursts.

It is not at all obvious, but it can be proven mathematically,
that the maximum distortionless audio frequency which can be
transmitted with these bursts of energy is restricted to not more
than one half the line-scanning frequency.   It is possible, of
course, to use a higher audio frequency than this, but the result
is highly distorted.   It has been suggested by those who have
used this system that it is best not to attempt to reach the highest
frequency permissible, but to use a somewhat lower value.

To determine the line-scanning frequency, we note that one
field requires 1/144 seconds, or there are 144 fields per second.
Since each field contains $262\frac{1}{2}$ lines, the total number of lines per
second is $262\frac{1}{2}$ times 144 or 37,789 lines.   Hence, the line
scanning frequency is 37.789 kc and one-half this value is ap-
proximately 19 kc.   This is more than we require and hence full
fidelity can be obtained with this method of sound transmission.

The sound bursts occupy the full amplitude of the television
signal.   Within the receiver it is necessary to include special
blanking signals to prevent the appearance of these audio signals
on the viewing tubes.

Color Disc Synchronization.   In the CBS color system, syn-
chronization 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: first it must keep the disc rotating at the same speed as
the disc in the studio camera; and, second, it 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 given in Fig. 12.5 could be employed. While this circuit may not be precisely the circuit used in the latest 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 6F8 tube. After this voltage is amplified, it is applied through a 0.1-μf condenser to the grid of the second triode of the 6F8. In addition, a 144-cycle voltage, developed in a generator mounted on the rotating shaft of the color disc, is also 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, 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
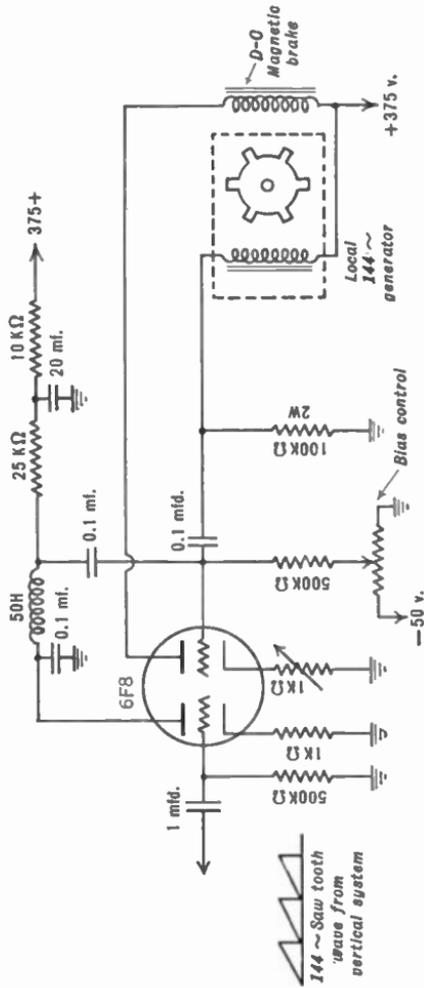
FIG. 12.5. Color disc speed synchronizing circuit.

reason. Whatever the cause, the disc is improperly phased and the above 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. These indicating pulses occur after the vertical synchronizing wave and hence do not interfere with the action. Horizontal synchronization is maintained because every fourth leading edge of the additional series of pulses will trigger the horizontal oscillator at the correct instant. Thus, the remainder of the receiver operates normally. Synchronizing signals for the other two colors are unchanged (see Fig. 12.6). One further change has been made in the CBS television signal. By making the time constants of the vertical signal integrating circuits sufficiently short, it was possible to eliminate the equalizing pulses. Hence, in the composite signal shown in Fig. 12.6, we find only the serrated vertical pulses. A serrated waveform is still employed, but it now consists of long pulses at double line frequency interspersed between short pulses, also at double line frequency. This break-up of the vertical pulses permits horizontal synchronization to be maintained without interfering with the vertical timing networks.

In the receiver, the 150-kc (approx.) identifying pulse is separated from the other pulses by a tuned circuit (see L_1 and C_1, Fig. 12.7). This 150-kc signal is then fed to the grid of a pentode while, at the same time, a mechanical rotating cam (contractor) alters the voltages on the screen grid at the rate of 48 cycles per second. Electrically, we have the effect of mixing the 150-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 volt-
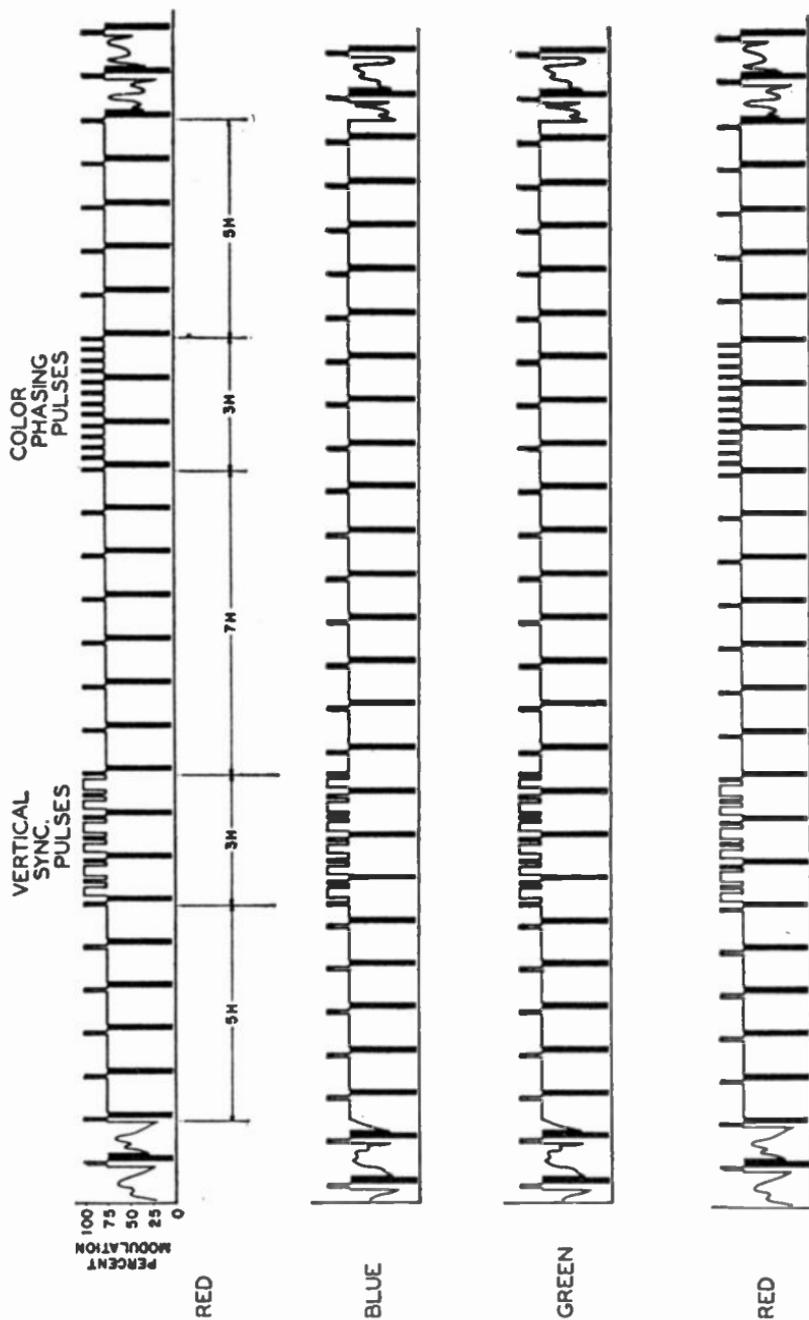
FIG. 12.6. Synchronizing pulses in the CBS color system showing the portion of the color identifying signal in the red field.

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FIG. 12.7. A color-disc synchronizing and phasing circuit.

Courtesy I.R.E.

age results when the color disc is not presenting the proper filter to the fluorescent viewing screen.

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 150-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 revolution, 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 reason the screen voltage is varied at a rate of 48 times per second (equivalent to a 48-cycle pulse) is due to 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 150-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 150-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. 12.8. 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

The RCA system of color television differs from the CBS system in that all three color signals are transmitted simultaneously and consequently are present at all times. For this reason the RCA method is referred to as the simultaneous system. As we shall see, three separate carriers are employed, requiring three distinct sets of circuits at the transmitter. At the receiver, however, the
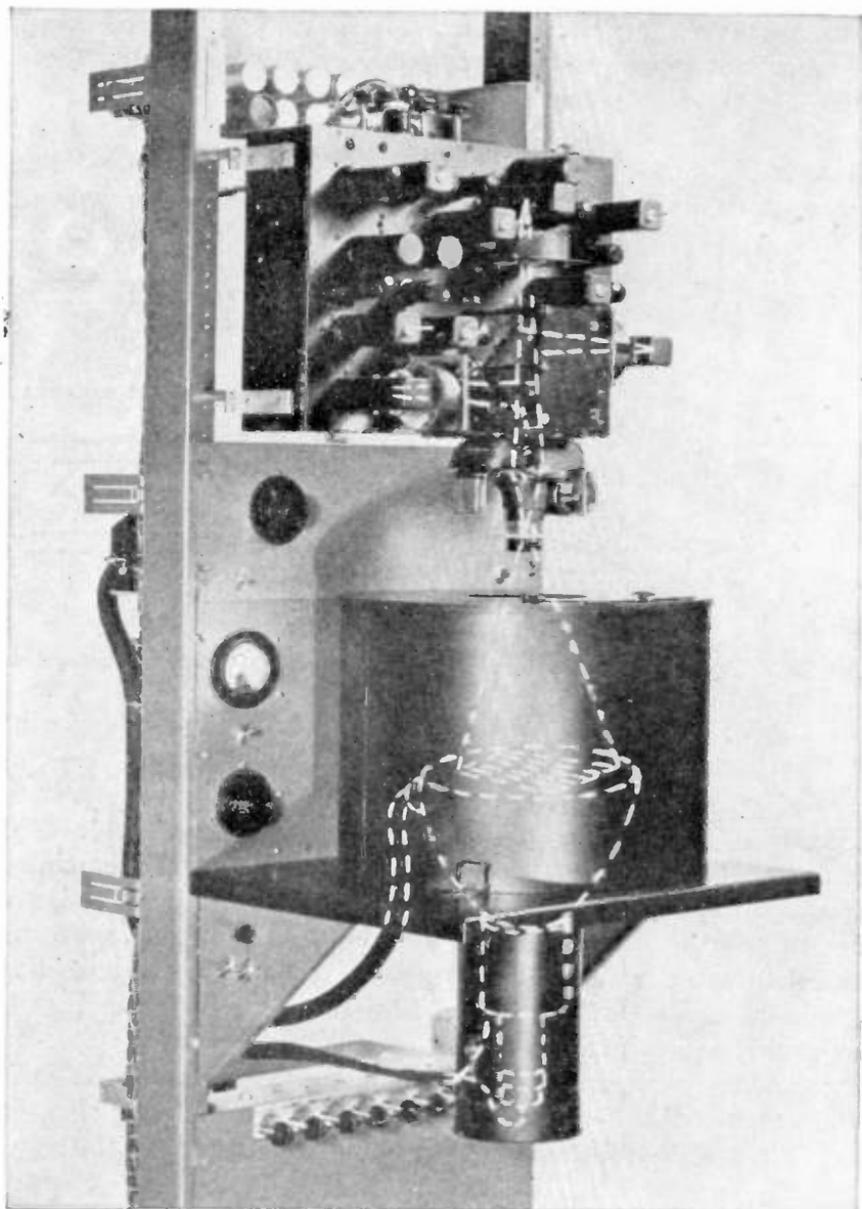
FIG. 12.10. The physical appearance of the color film scanning unit.
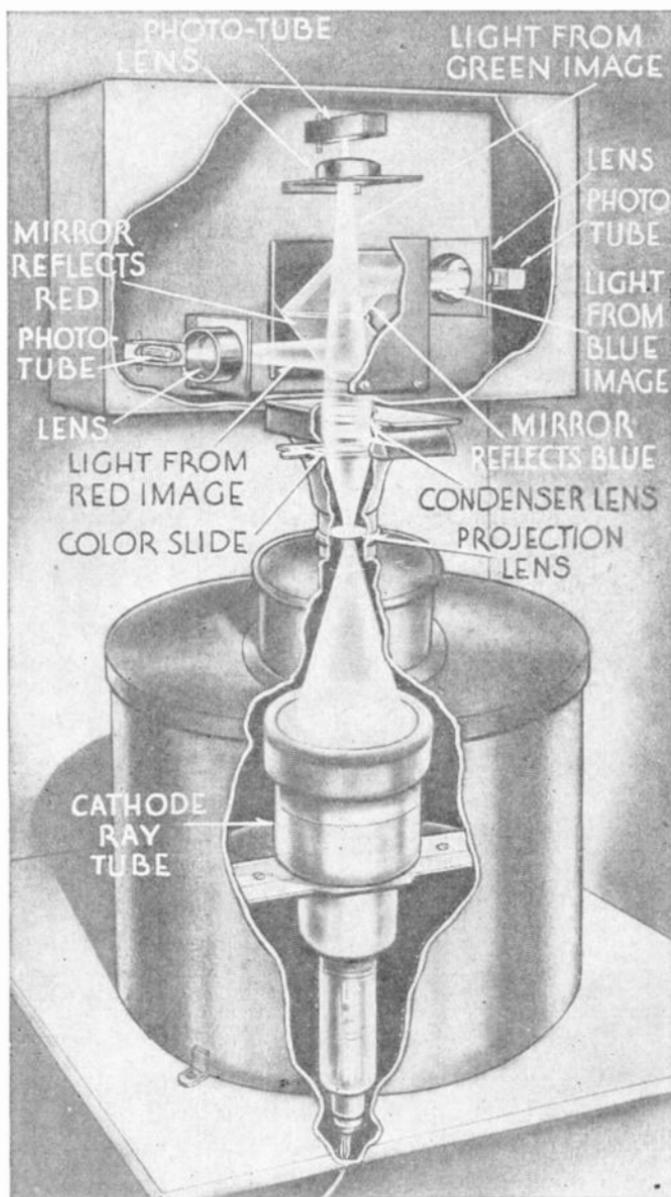
FIG. 12.11. An internal view of the film Scanner.

each colored portion of the received light to its particular photo-
cell.   The sequence from this point is identical to what has already
been described.

At the receiver, the three adjacent carriers are received by the
same R.F. and I.F. circuits.   At the video second detector they
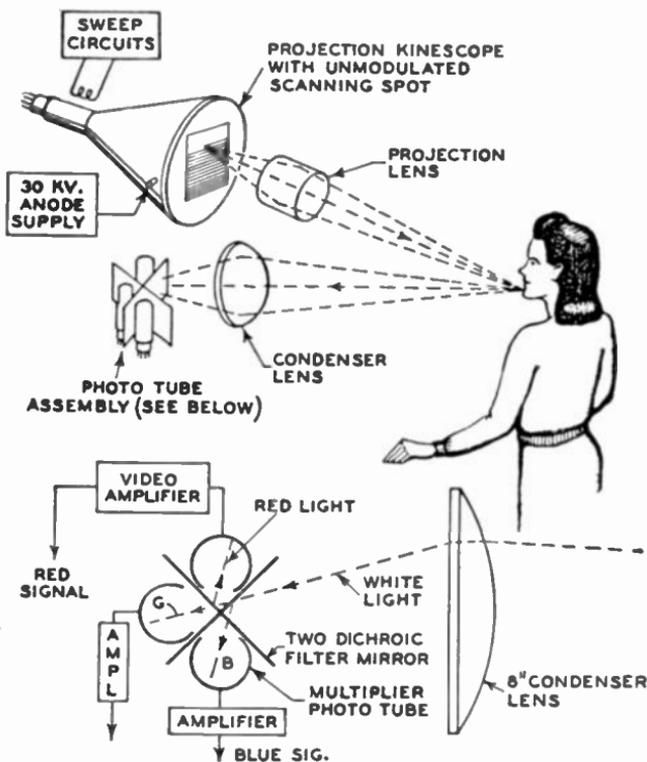
FIG. 12.12.   Adapting the RCA color system for studio use.

are separated and applied to different projection cathode-ray
tubes.   Light from each tube is then focused through the proper
green, red, or blue filters and projected onto a 15-by-20-inch
translucent screen.   The formation of the complete image is
shown in Fig. 12.13A and B.

Each of the three transmitted images, red, blue, and green,

contain the same number of lines, namely, 525. In addition, the horizontal and vertical scanning rates are the same as current commercial black and white television. Due to this similarity
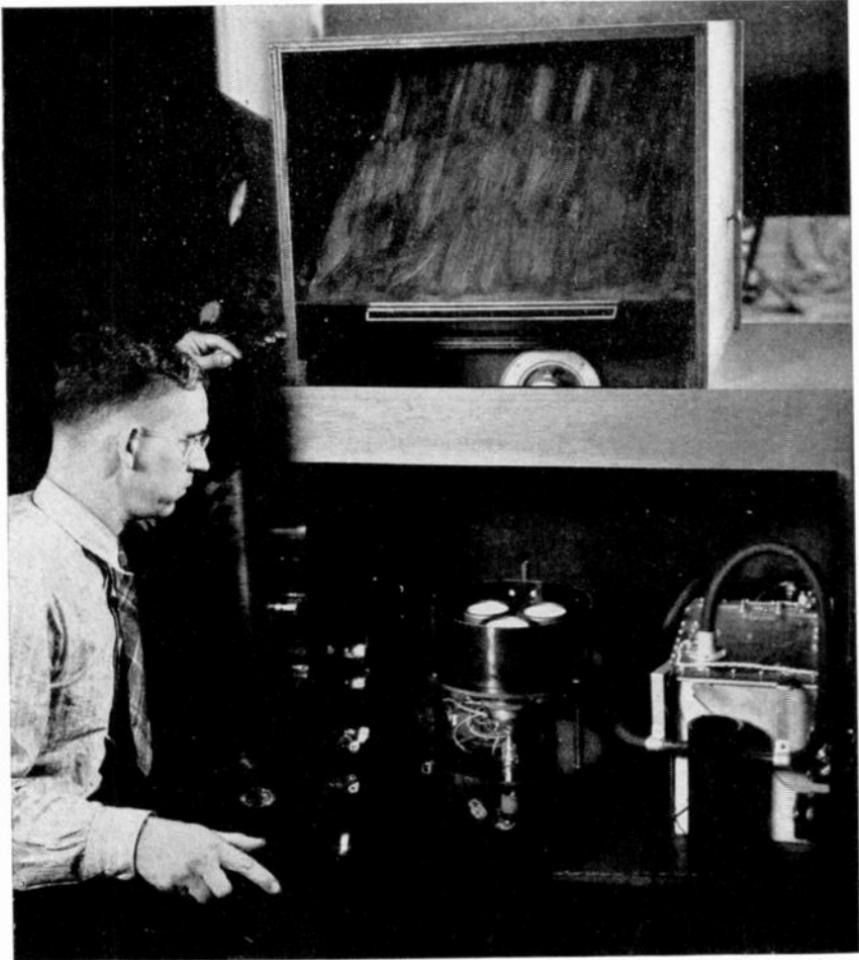
FIG. 12.13A. Rear view of the RCA television receiver.

of characteristics, any broadcasts from color stations utilizing the simultaneous system can be received clearly on the existing black and white receivers by the addition of an easily installed radio-
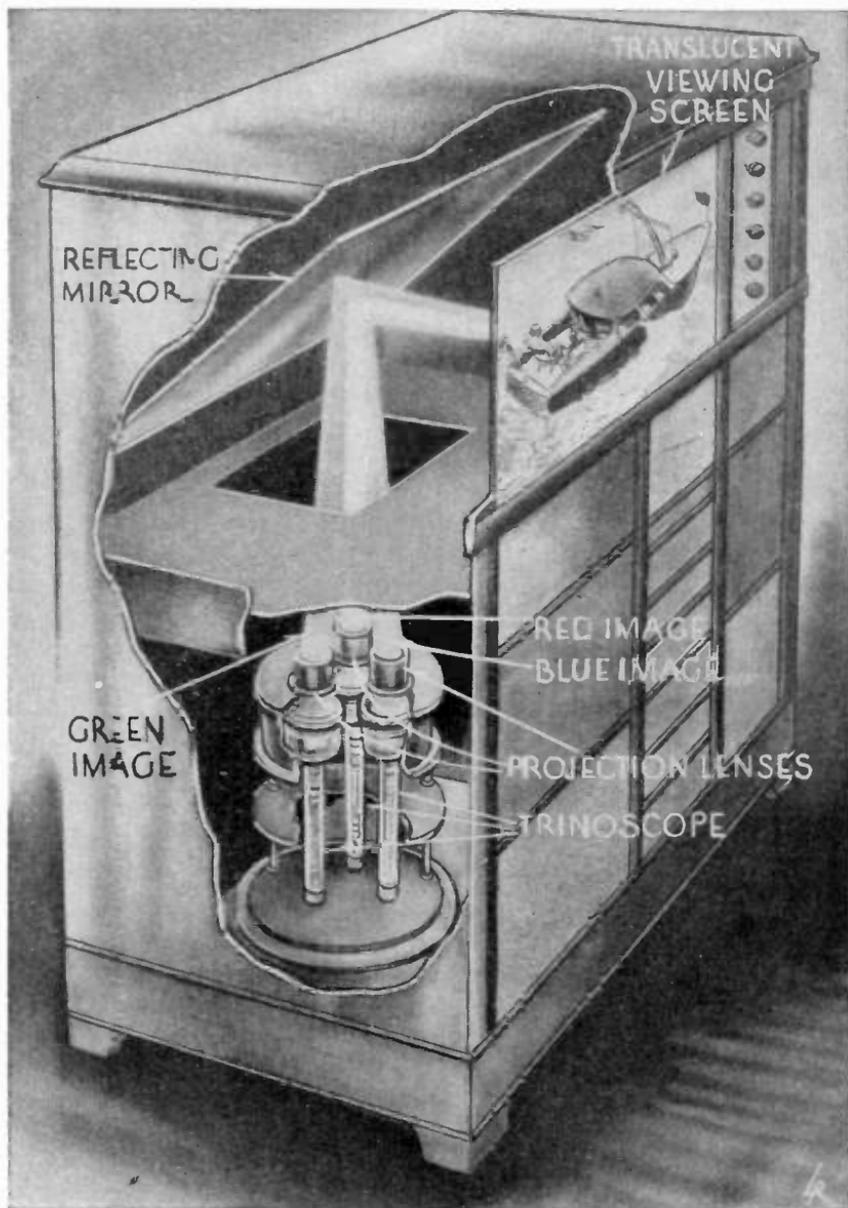
Courtesy RCA

FIG. 12.13B.   The transposition of the three colored images to form the final picture.

frequency converter. No other modifications within the set are necessary.

The converter will permit present-day television sets to receive color television programs and reproduce them in black and white even when transmitted on the ultra-high frequencies. In this manner, existing receivers will not be made obsolete by the introduction of color television.

The RCA system transmits the three colors simultaneously and three carriers must be used. The carrier which contains the
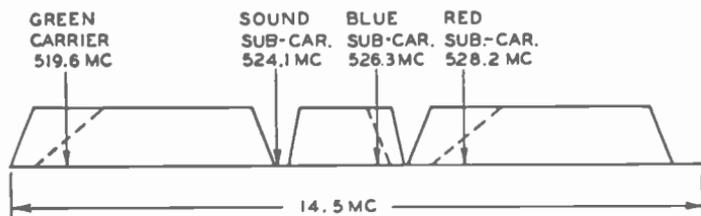
FIG. 12.14. The position of the R.F. video and sound carriers in a channel 14.5 mc wide.

signal due to the green portion of the image is known as the main carrier; the carrier waves of the remaining two colors, and sound, are known as sub-carriers. This is merely an arbitrary designation and does not signify that there is any essential difference between the signals.

The arrangement of the three carriers in the frequency spectrum is shown in Fig. 12.14. The green carrier is lowest in frequency, with its upper side extending for 4 mc above its carrier. Just beyond the edge of the green video signal we find the frequency-modulated sound signal associated with this broadcast. If we were to stop now, we would have the equivalent of a black and white transmission. Since the signal contained in the green carrier (with its sideband) is the entire signal, any receiver not equipped for color would merely have to receive this carrier and its sound in order to produce a complete black and white image on the screen.

The carrier containing the blue color information of the scene

is located above the sound carrier. Concerning this blue carrier, two items are of interest. First, the carrier and the lower sideband are used, with only a vestige of the upper sideband remaining. The preference for the lower sideband is due to the desire to position the blue carrier as far from the sound carrier as possible to minimize cross-modulation. Second, the extent of the lower sideband is limited to approximately 1.5 mc. It has been found that the human eye can resolve considerably less detail in a blue image than in a green or red image. The inclusion of detail beyond that required by the observer is a waste of valuable frequency space. The use of 1.5 mc of the blue sideband is a recognition of these limitations.

The red sub-carrier, together with one of its sidebands, is placed at the upper end of the channel. It is possible to use either sideband in this instance, although the one shown in Fig. 12.14 is the upper one. A full 4 mc is employed, although again some modification is possible because of the relative insensitivity of the human eye to fine detail in the red section of the visible spectrum. For the three color carriers and the sound, an over-all channel width of 14 to 15 mc is required.

" MIXED-HIGHS SYSTEM "

The desirability of as narrow a band width as possible has been continually stressed by the F.C.C. The CBS proposal requires a band 16 to 18 mc wide. The system just described needs 15 mc. Now another proposal has been advanced by RCA which decreases the band required to 12.5 mc, while still maintaining substantially as much definition as before. The name assigned to this system is " mixed-highs " because of the manner in which it functions (see Fig. 12.15). Each of the video color channels receives its signals through the selective mirrors as noted previously. However, the high video frequencies of each of the color chains are separated from the rest of their signals, combined with each other and then transmitted over the green channel. The high video signals are those possessing frequencies above 2 mc. Frequencies from $0 - 2$ mc are considered as containing the

larger detail of the image.   The red and blue channels, devoid of
the higher video currents, transmit only the low frequencies on
narrow sidebands.   The green carrier still maintains a full side-
band, 4 mc, containing the green lows and the three mixed high
video frequencies.
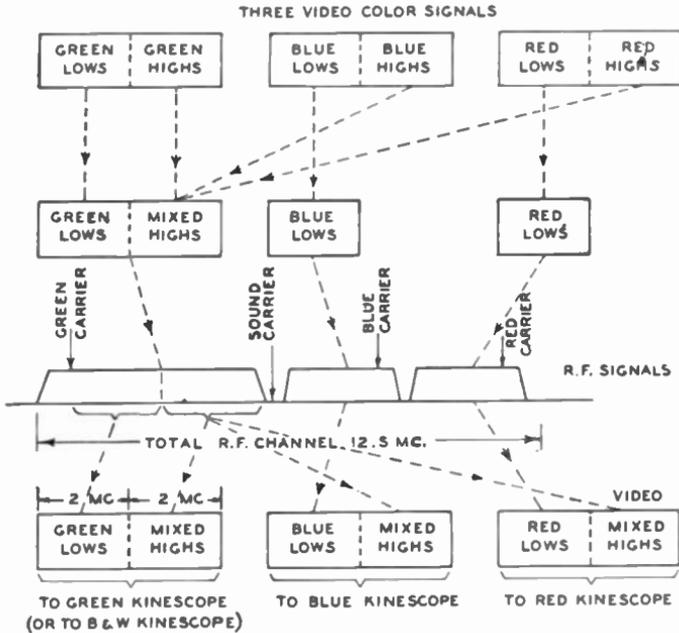
Fig. 12.15.   The " mixed-highs " system of simultaneous color television.

At the receiver, the lows of each channel are received separately,
whereas the highs of the green channel are distributed in like
measure to each receiving system.   The signals in each channel
then activate their particular cathode-ray tube and the light from
the three tubes are combined for the final image.

Consider carefully what happens to the highs.   Each cathode-
ray tube will produce the same highs or fine detail on its screen
and the combination of these three colors in the final image will
produce either white, black, or intermediate shades of grey.   This
is true because the combination of the three primary colors, in

equal amount, will produce white or its equivalent. Thus we see that in the " mixed-highs " system, the fine detail of the image will appear in monochrome, and the larger objects will be in color.

The " mixed-highs " system is similar to the process of color rotogravure as 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 is black. This fourth plate adds black, white, and the intermediate shades of grey to the image 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 increased. The same results are observed in television. In demonstrations of the " mixed-highs " system with the other simultaneous system, no difference between the two was noted.

Comparison of the CBS and RCA Systems

A recent ruling by the Federal Communications Commission has made it evident that there will be no definite standards established for color television until there is conclusive evidence that color television receivers can be placed in the home as completely finished products. The two systems discussed above differ considerably from each other. In order to fully appreciate how these two systems measure up, the following comparisons are made.

Band Width. The difference in band width requirements of the two systems is clearly evident from an inspection of Fig. 12.16. The 6-mc band of the black and white receiver appears first in the illustration. Below, in Fig. 12.16B and C, we have the band that is required by the CBS sequential color system, depending upon whether 180 fields are sent in one second or 144, the 144 being the present rate. In Fig. 12.16D, we have the band width required by the RCA simultaneous system, using three channels, each complete in itself. Finally, in Fig. 12.16E, the spread of the RCA simultaneous system using the " mixed-highs " modification.

Band widths for CBS signals using 144 and 180 fields per second are both shown because it is believed that when image intensities exceed values of 50 foot-lamberts flicker will be
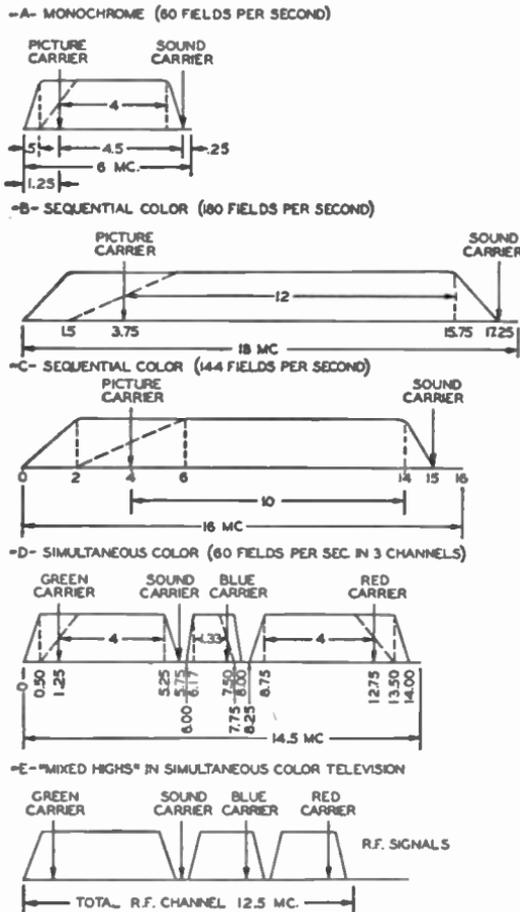
FIG. 12.16. A comparison of the band width required in each of the television systems.

noticeable.   The present field rate is 144, but to overcome the flicker, 180 fields per second will be required.   In presenting a series of related images on a screen, we try to reach a rate where the blending of one image into the next is accomplished without

flicker.   Rates from 50 to 60 fields per second are satisfactory with present screen brightnesses or illumination, but there is good reason to believe that when and if the screen intensity is made greater, flicker will be evident.

In the CBS sequential system, the three color fields follow each other on the screen.   However (and this is important) they 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.   In black and white image reception, that section of the image due to one field remains while the next successive field is traced out.   The two do not interfere with each other.   Hence, phosphors with slower decay characteristics can be used, materially aiding the suppression of flicker.   In the sequential color system, the light decay must occur more rapidly.   This accounts for the use of a field repetition rate of 144, and it is felt that even higher rates may be necessary when the brightness of the screen becomes greater. The field repetition rate often suggested is 180 or, what is the same thing, 60 color frames per second.   Since the width of the channel varies directly with the number of fields per second, 180 fields per second would require a channel three times wider than the 6 mc being used in the present black and white system.

From the comparison chart it is evident that the " mixed-highs " simultaneous system possesses the advantage of band width, since it requires only 12.5 mc.   Furthermore, the simultaneous system is less subject to flicker effects, even though this is not an inherent property but merely a function of the phosphors used.

In connection with band width, it should be noted that, in the simultaneous system, the amount of detail that is included with each color can be modified to suit the physical needs of the human eye.   Thus, in the blue field, where the eye is less sensitive to detail, we can use a narrower band.   To accomplish the same effect in the sequential system would require different scanning rates for each color field.   While this is not impossible, it is impractical and not likely to occur.

Received Picture Brightness. In a receiver designed for the sequential system, all the picture information is recorded on one cathode-ray tube screen. In the simultaneous system, there are three light sources and the final projected image will be approximately three times as bright. Further, through the use of colored phosphors, it is possible to obtain images which are still more intense.

Adapability to Present Systems. One of the great deterrents to the start of black and white television has been the hue and cry raised by those who claimed that color television would make all present sets obsolete. To this, the RCA simultaneous system has an answer in the fact that monochrome receivers can, by means of an additional converter, receive in black and white, images which are being sent in color. This has already been discussed. The sequential system cannot be made to fit in with the present black and white system; at least, this has not been done so far.

It is highly desirable to establish monochrome and color television systems which are complementary. In this manner there would never arise the question of obsolescence.

Equipment Requirement. An important consideration in the design of any electronic equipment for public use is the factor of cost. In the sequential system, there is one channel through which all signals travel. In the simultaneous system, there must be three separate channels in the transmitter and in the receiver. There is no reason to believe however, that the difference between the two will be in the ratio of 3 to 1. In the receiver, for example, it is possible to use one R.F. stage, one mixer, and one I.F. system before the separation of the signals occurs. In this manner the cost can be kept considerably below the 3 to 1 ratio.

In the sequential receiver, we find the added cost of a filter disc and a synchronous motor plus several stages which are required to maintain the disc synchronization. None of these is present in the simultaneous system, so it would be rather difficult to determine whether receiver costs of one would be greater than the other. At the transmitter, however, there seems to be little doubt of the greater cost of the simultaneous system equipment.

The F.C.C. has recently refused to standardize the color system advanced by CBS on the grounds that there have not been sufficient operating data accumulated to warrant such standardization.   The opinion voiced by most receiver manufacturers is that, for the present, black and white television images will be more than satisfactory and extensive plans have been made to swing into full production.   Color television, it is expected, will make its appearance on the American scene sometime about 1950.

A Concluding Thought.   Color television, although it contains many advantages that would be welcomed by the public, must be delayed for a short while.   The reasons have been stated earlier in the chapter.   It is difficult to foretell at this particular moment what the system finally evolved will be like.   If the present trend continues, the essential components have been given in this chapter.   If not, then we must bide our time until the answer is revealed.   But, as in everything else, the future can only be built up on the past, and the basic principles will remain unaltered.

CHAPTER 13

FREQUENCY MODULATION[1]

General Outline. Frequency modulation, although only a new-comer 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 proven 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 handling the much higher peak (or surge) power. Naturally, this requirement materially increases the cost of the station. In

[1] 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.

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 side bands 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. 13.1A. 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. 13.1B. 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 causes the band width of the station to increase. Hence all
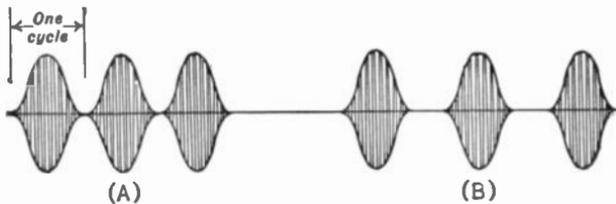
FIG. 13.1. Amplitude-modulated waves. (A) 100% modulation, (B) overmodulation.

commercial 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. 13.2. The property of constant amplitude makes the frequency-modu-
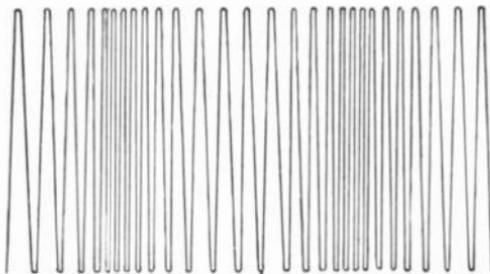
FIG. 13.2. Frequency-modulated wave. The changing spacing between cycles indicates different modulating frequency intensities.

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, smoothes any irregularities in the amplitude of the incoming signal and by this process eliminates the interference.

, The frequency band width 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 output 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 frequency 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 relationship 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
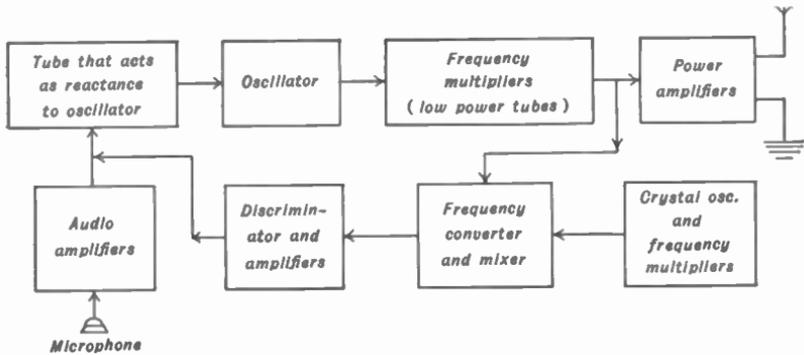
FIG. 13.3.   Crosby System or Reactance-tube method of producing F-M waves.

Figs. 13.3 and 13.4.   In Fig. 13.3 we have the reactance-tube,
or Crosby, system, whereas in Fig. 13.4 we have the Armstrong
method of frequency-modulated transmission.   Although both
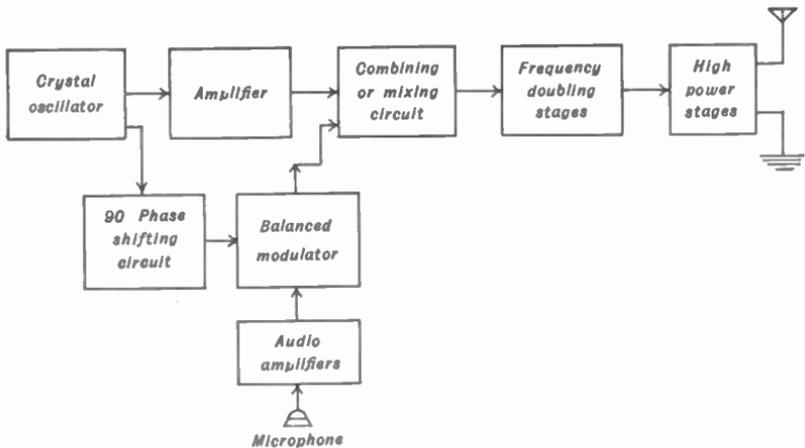
FIG. 13.4.   Armstrong System of Frequency Modulation.

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. 13.3. 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 something 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. 13.4. 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 appear at the

output of the stage. These sidebands, when recombined 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. 13.5 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 band width 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
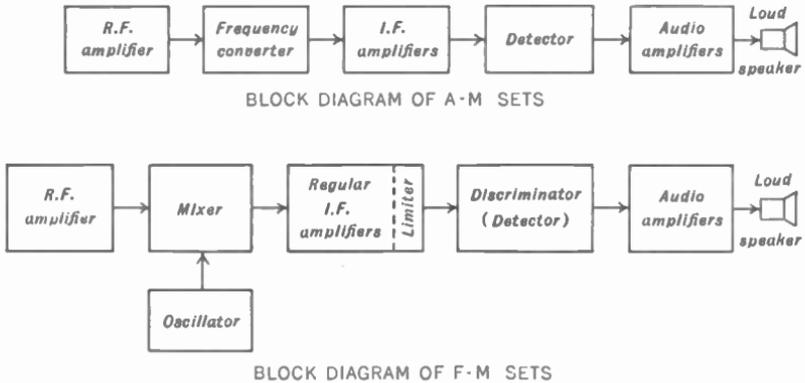
Fig. 13.5.   A comparison of the block diagrams of A-M and F-M receivers.

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 mechanical 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 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.
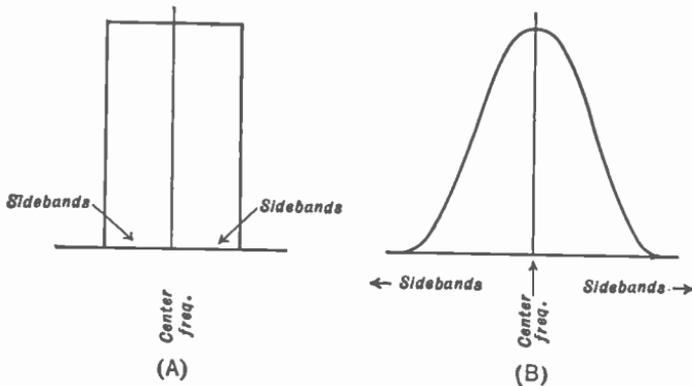
Fig. 13.6. Receiver response curves. (A) is the ideal curve, (B) a typical practical result.

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. 13.6A. With such a characteristic, each frequency within the signal would

receive uniform amplification. Such a happy situation, how-
ever, is seldom encountered in practice. The more usual state
of affairs is illustrated by the curve of Fig. 13.6B. 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 the limiter
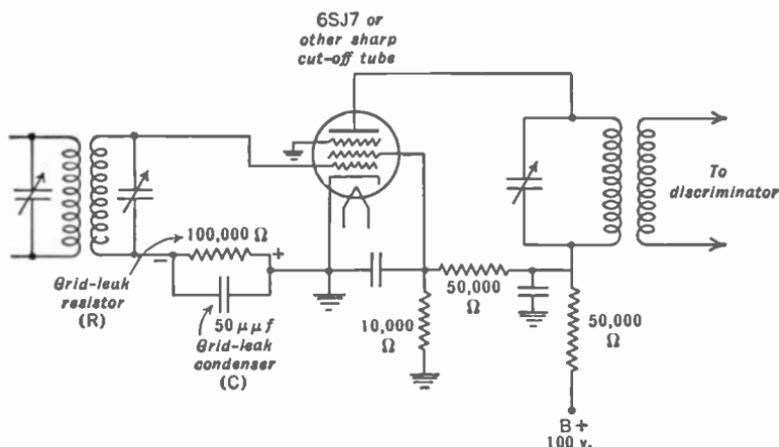
FIG. 13.7. A familiar limiter stage circuit.

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. 13.7. 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, 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 in-
terference affects the amplitude
of the radio signal more than its
frequency.   By the simple de-
vice of smoothing out the am-
plitude differences of the incom-
ing waves (without affecting
their fundamental frequency),
we eliminate the noise or inter-
ference.   This is one reason for
the extensive use of F-M.

A limiter characteristic curve
is shown in Fig. 13.8.   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 demon-
strated graphically.   The curve OAB in Fig. 13.9 is the relation-
ship 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.

Fig. 13.8.   The characteristic curve for
a limiter.

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. This means that any noise and amplitude distortion contained in this signal will be amplified and reproduced in the plate circuit
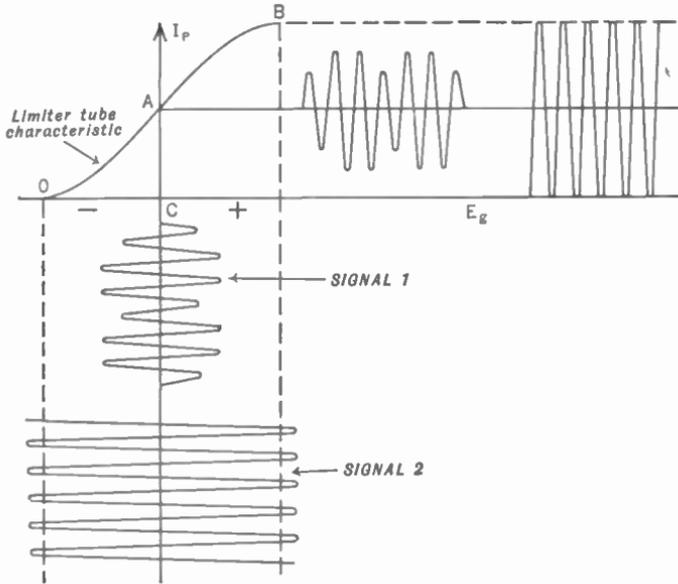
FIG. 13.9. These curves illustrate that the incoming signal must reach a certain amplitude before the limiter stage will saturate.

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 de-

signed 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 band-pass 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. 13.7). 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. 13.7. 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.

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 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. 13.10, and their characteristic curve is given in Fig. 13.11. 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 frequencies is the elementary parallel (or series) resonant circuit. As is 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
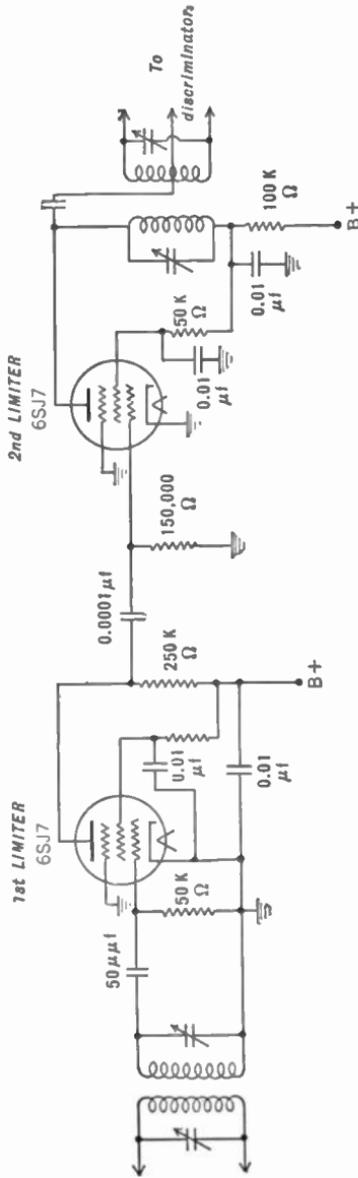
Fig. 13.10. A dual limiter circuit.

two resonant circuits in an arrangement as shown in Fig. 13.12. 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.
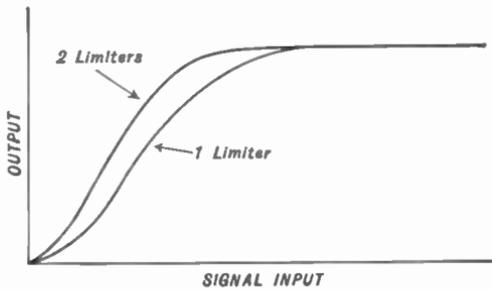
FIG. 13.11. A comparison of limiter characteristic curves for single and dual stages.

In order to determine the frequencies to which L_2 and L_3 must be tuned, it should be recalled that when an audio-modulating 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
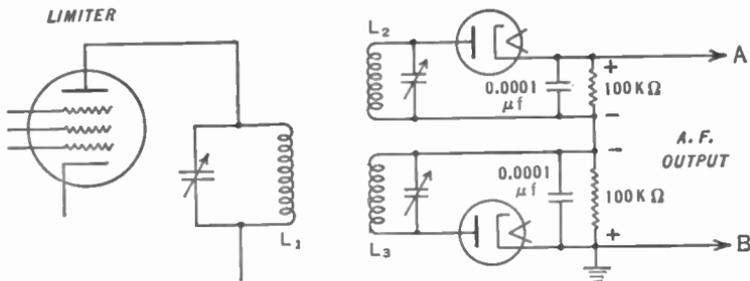
FIG. 13.12. A simple discriminator circuit.

increase the frequency, say by 40 kc, while the maximum negative section would decrease the carrier frequency by the same amount. At intermediate points, less voltage would cause correspondingly 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 8.15 mc to 8.35 mc (with 8.25 as the mean or carrier frequency), L_2 might be peaked to 8.15 mc, and L_3 would be peaked to 8.35 mc. The response curves would then appear as in Fig. 13.13.
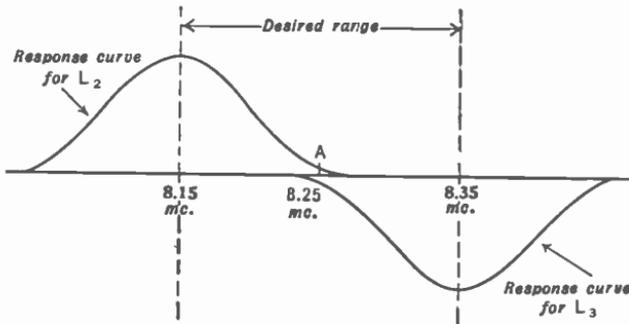
Fig. 13.13. The overall response curve for the discriminator of Fig. 13.12.

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. 13.12.

At the center frequency, point A of Fig. 13.13, the two voltages 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 over-all resultant curve shown in Fig. 13.14. This is the familiar S-shaped curve of all frequency discriminators and shows how the output voltage 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 8.31 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 8.19 mc, the output voltage is indi-

cated by point 2. Notice that all frequencies below 8.25 mc result in positive output voltages, whereas all those above 8.25 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.

The useful·portion of this discriminator characteristic curve is the linear portion included between the two maximum points,
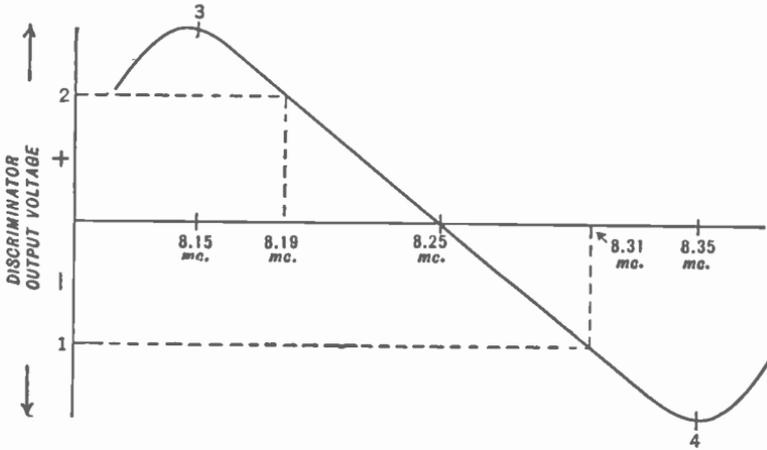
Fig. 13.14.   The resultant S shaped discriminator characteristic curve obtained by adding the two separate curves of Fig. 13.13.

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 tendency 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. 13.14 beyond points 3 and 4 are completely disregarded. The frequency of the output 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 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
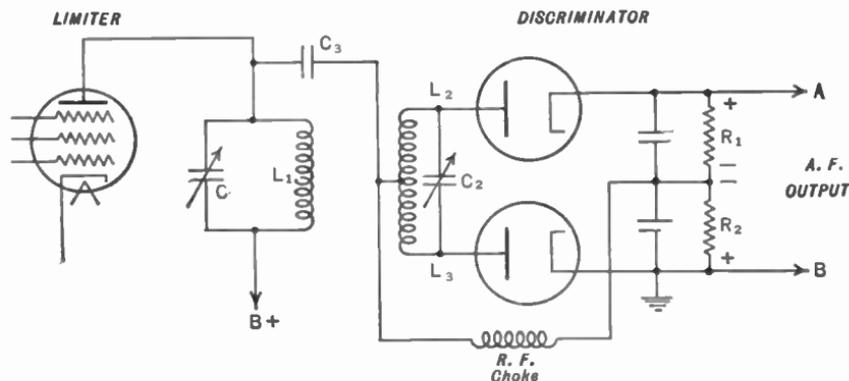
FIG. 13.15. A common discriminator in today's F-M receivers.

the same as the present-day discriminator of Fig. 13.15. 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 appear-

ing 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 an incoming signal. For frequencies above resonance, the inductive reactance of the secondary circuit predominates whereas,
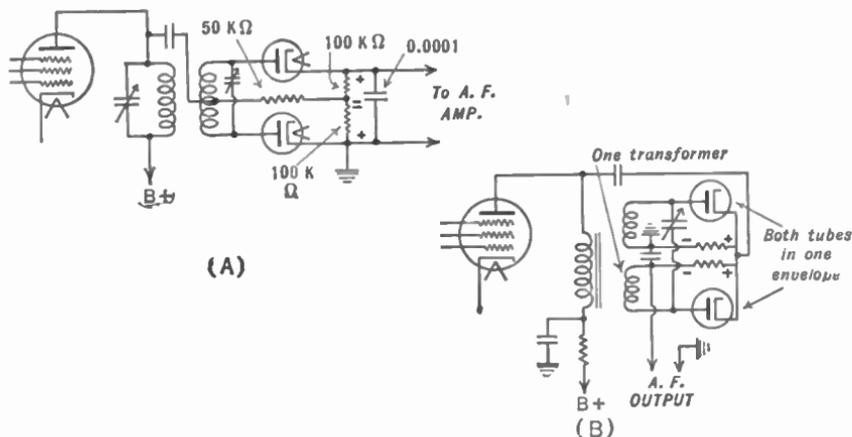
Fig. 13.16. Two additional discriminator circuits found in use. The arrangement in (B) has the advantage of placing both cathodes at the same potential. This permits use of duo-diodes with one common cathode.

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. 13.14 is obtained for this discriminator.

There are many variations of this discriminator schematic, two of the more common ones being given in Fig. 13.16A and B. The output terminals for each type are clearly indicated. They connect to the following audio amplifiers. The discriminator of Fig. 13.16B is used in General Electric television receivers. 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. Two such detectors have been developed and their 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. 13.15, 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 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
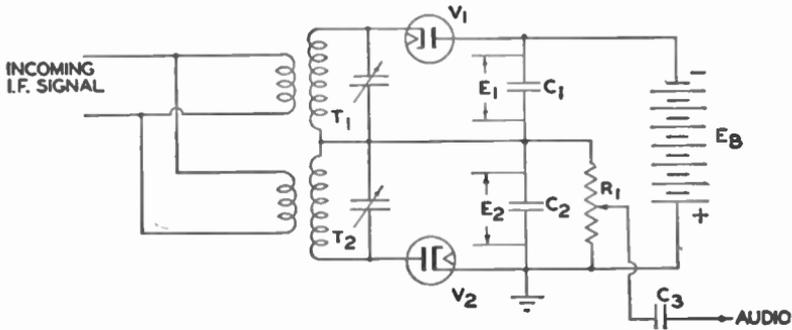
FIG. 13.17.   Preliminary form of the ratio detector.

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. 13.17. In this form, the detector is similar to the detector of Fig. 13.12, 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. 13.18.

It uses the phase-shifting properties of the discriminator of Fig. 13.15. 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 (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
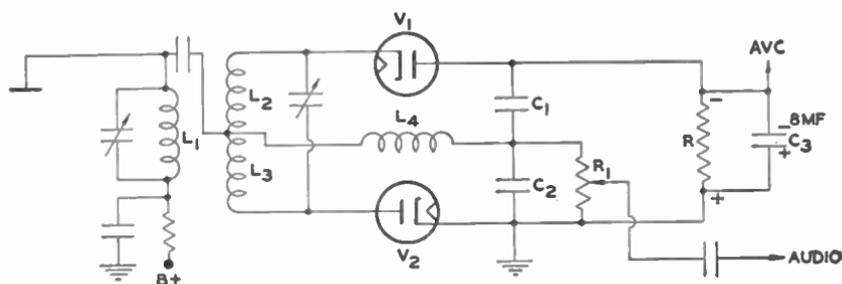
Fig. 13.18.   Practical form of the ratio detector.

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. 13.18.

The Philco Single-Stage F-M Detector.   In addition to the preceding two types of F-M detectors, there is still a third unit which utilizes a locked-in oscillator.

The basic circuit is shown in Fig. 13.19.   The tube, which was specially designed for this purpose, is a heptode.   The cathode and the first two grids serve as an electron-coupled oscillator with grid 2 as the plate.   Grids 2 and 4 are connected together; but, since grid 2 is at I.F. ground potential, connecting grid 4 to it does not make this latter grid the oscillator plate.   The input I.F. signal is fed in at grid 3, while the feedback or quadrature circuit

is connected to the plate of the tube.   Both the oscillator and the
quadrature circuits are resonant to the I.F.   In order to insure
the proper kind of feedback, the quadrature circuit is damped with
a relatively low resistor (4,700 ohms) so as to have a band width
which is roughly six times that required by the F-M signal.

Since the oscillator grid is closest to the cathode, it will exert
the greatest influence over the flow of electrons.   The oscillator
functions class C and hence permits electrons to flow past grid 1
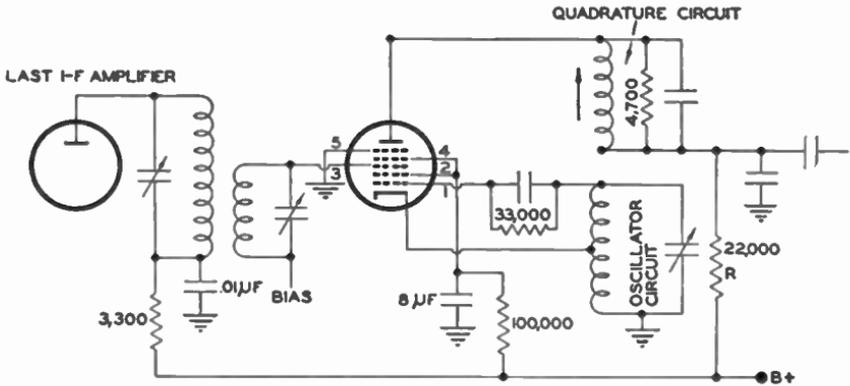
FIG. 13.19.   The Philco single-stage F-M detector.

only in short pulses.   Throughout the remainder of its cycle the
grid is biased beyond cut-off.   The second controlling element in
the tube is grid 3.   Its voltage will determine how much of the
pulse passed by the first control grid reaches the plate.   There are
thus two controlling factors over the amount of plate current that
flows to the quadrature circuit.   As we shall see presently, it is
through this dual control that the circuit is able to function.

The basic operation of the circuit depends upon the fact that
the pulses of current that the oscillator grid permits to flow are
further modified in magnitude by the second (or signal) control
grid 3.   If, at some instant, the potential of grid 3 is more
positive than its normal value, an increased plate current will
flow through the quadrature coil.   Conversely, if grid 3 is more
negative, less than average current will flow.   Through the

interaction of the oscillator and the quadrature coils, the change in current will alter the frequency of the oscillator. From the oscillator frequency variation, F-M demodulation occurs. Essentially, then, lock-in between the oscillator and the frequency variations of the incoming F-M signal must occur.

The circuit consists of three main sections: the oscillator, the quadrature circuit, and the second control grid (3) where the incoming signal voltage is applied. The oscillator is a free-running Hartley, designed to generate a frequency equal to the center frequency of the I.F. band. This is in the absence of any signal voltage. However, should a signal appear (assume for the moment that it is not modulated), then the oscillator will adjust itself so as to lock-in with the signal. Throughout the lock-in range, the frequency of the oscillator and the signal is identical.

The lock-in of the oscillator (so that it follows the frequency variations of the incoming signal) is brought about by the transfer of energy (coupling) between the oscillator coil and the quadrature coil. The quadrature coil is designed so that its impedance does not appreciably change over the range of frequencies of the incoming signal. To insure this, the coil is made to possess a band width approximately six times that which is actually required. This is the reason for the low-valued damping resistor (4,700 ohms).

The quadrature coil is inductively coupled to the oscillator and any change in plate current in the quadrature circuit will immediately be reflected into the oscillator. The reflected impedance consists of two parts, a resistive component and a reactive component. The resistive loading remains constant because of the low-valued resistor. The reactive component, however, will vary directly with the plate current. It is this reflected component which causes the oscillator frequency to vary. It is important that only the reactive feedback vary, otherwise the amplitude of the oscillator signal will fluctuate giving us an additional A-M component which is not part of the original signal.

The incoming signal controls the flow of plate current and this, in turn, through the quadrature circuit, affects the oscillator

frequency and causes it to lock-in with the incoming signal. The oscillator frequency is thus kept the same as the signal.

The control of the plate current by signal grid 3 is illustrated in Fig. 13.20. In A the incoming signal has the same frequency as the oscillator and the pulse of current passes through the tube when the signal grid is going through zero. Under this condition
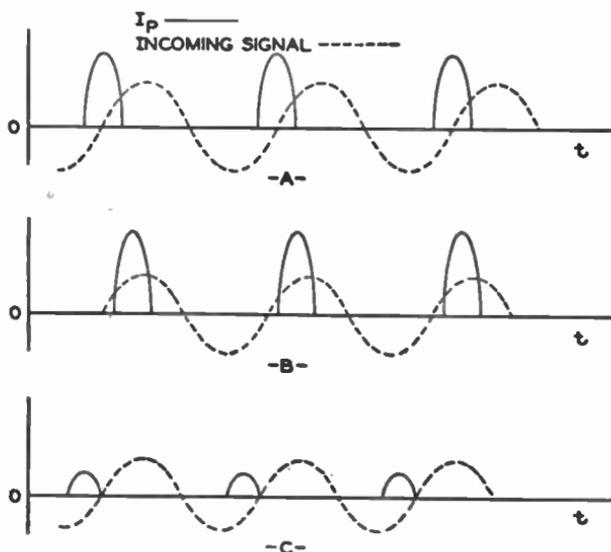
FIG. 13.20. Interaction between the signal voltage and the oscillator pulses to regulate the oscillator frequency. In (A) the two signals are identical; in (B) and (C) the signal frequency is either slightly higher or lower than the oscillator.

the two frequencies are locked together and the average plate current (of the pulses) is such as to maintain this condition. If, upon application of the signal, the exact phase reationship between the signal and the oscillator pulses is not as shown in Fig. 13.20A, then the average value of the plate current will change sufficiently to swing the oscillator into line. Thereafter, the two are locked in synchronization and the situation shown in Fig. 13.20A prevails.

When the signal frequency changes frequency with modulation, the phase of the signal voltage (with respect to the pulses of plate

current) changes, either increasing or decreasing the average value of the current. This change, reflected into the oscillator circuit, appropriately increases or decreases its frequency to the new value. When the new frequency is reached, the phase between signal voltage and oscillator is again as shown in Fig. 13.20A.

Now the question is: How do these variations in oscillator frequency bring about demodulation of an F-M signal? Simply this — the average value of the current over any cycle is directly proportional to the peak value of the fundamental component of
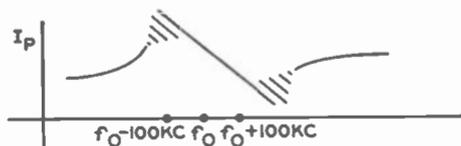
Fig. 13.21. The response characteristic of the Philco F.M. detector. The dashed lines at each end of the curve shows what occurs when the oscillator slips out of lock-in.

the pulse. (A pulse will contain a strong fundamental and many weaker harmonics. The fundamental, of course, is the oscillator frequency.) Now, if the signal frequency changes, so will the oscillator frequency. This means a change in the number of current pulses per second and, from this, a different average plate current. Thus, plate current will vary with frequency and the circuit is designed so that the current varies in a linear manner (see Fig. 13.21). By placing a resistor in the plate lead, R of Fig. 13.19, we can obtain the audio voltage and tap off from here for the audio amplifiers that follow.

Note that the entire action will hold only so long as the oscillator is locked-in with the incoming signal. If the signal voltage is too small (below one-half volt for full 75-kc deviation) or the signal frequency shift too large, then the oscillator will slip out of control and return to its free-running frequency. An advantage of the requirement of a minimum voltage for control of the oscillator is the elimination of interstation noise which is common with the conventional limiter-discriminator arrangement. Its

disadvantage is the loss of control that may occur with weak signals.   However, weak signals tend to be noisy (even with F-M) and therefore the loss may not be too disadvantageous.   With sufficient strength, amplitude variations in the signal do not cause changes in the average plate current.   What happens is that with a change in signal amplitude, the oscillator phase re-adjusts itself slightly to maintain the plate current required for that frequency.

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."
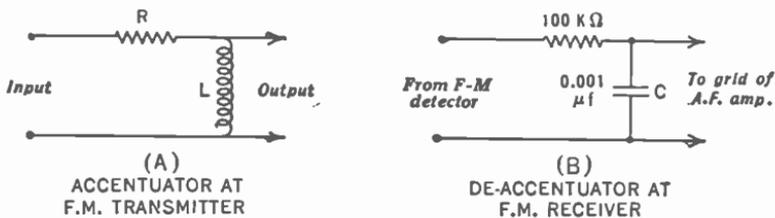
Fɪɢ. 13.22.   Two circuits that help maintain the fidelity of the higher audio fre-quencies in F-M systems.

It was required because the greatest audio frequency noise is generated in the transmitter at the higher frequencies, from 5 kc up.   Since the audio signals in this higher range have less ampli-tude 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. 13.22A. 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 rela-tionship between the various frequencies is to be maintained. Hence, a de-emphasis network is inserted between the discrimini-nator output and the first audio amplifier.   The circuit shown is in Fig. 13.22B.   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.

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

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.
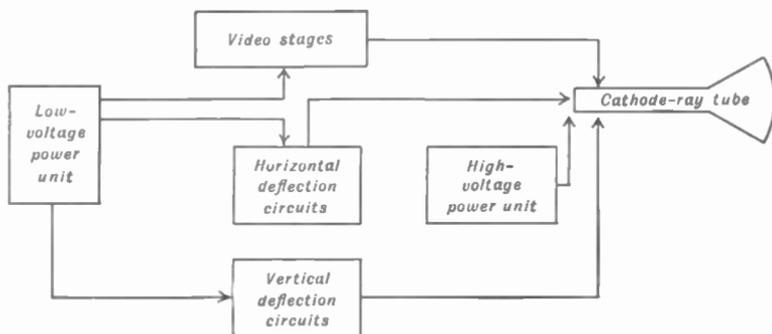
FIG. 14.1. Functional block diagram of the major circuits in a television receiver.

Servicing Divisions of Television Receivers.   When the action of the cathode-ray viewing tube is analyzed, it is found to be the recipient of voltages from four different sections of the receiver. A television receiver has been arranged in block form (Fig. 14.1) to emphasize these divisions.   They include:

1. The horizontal deflection circuits.
2. The vertical deflection circuits.
3. The video circuits.
4. The power supply — both high- and low-voltage units.

Although the final image, as seen on the viewing screen, represents a combination of these four voltages, each voltage has certain definite characteristics that enable an experienced viewer

to identify the particular section at fault. This is the line of attack that the author has found most useful and will be described in detail in the paragraphs to follow. To begin our discussion, let us quickly review each of the four divisions and its action at the cathode-ray tube. The sound section of the receiver will be brought in wherever any of its defects affect the image. Otherwise, trouble shooting at that point is quite comparable to present methods of servicing which are touched on briefly at the end of the chapter.

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 best and most reliable indication that the high-voltage power supply unit is inoperative is the total absence of any light or illumination on the viewing screen of the cathode-ray tube. When this condition is encountered, the trouble may lie either in the high-voltage power unit or in the low-voltage supply. Check the low-voltage supply by noting whether any hum or other audio sounds are heard in the loudspeaker. Pulling out an audio amplifier tube should produce a click at the speaker if the low-voltage supply is functioning.

If the low-voltage power supply is operating, a failure in any section of the high-voltage power supply would still prevent the image tube from functioning. The heater of this tube may be emitting electrons (because its power comes from the 110-volt power transformer) but with no accelerating voltages, no electron beam is formed. The most critical components in the high-voltage supply are the rectifier tube and the filter condenser. Both can be checked by replacement. If the unit is still in-

operative, check the voltages in the circuits driving the high-voltage supply.

While an absence of any light on the screen is a definite indication of trouble in the high-voltage supply, the general indication that this unit is operating satisfactorily is almost as positive. For, with all the high potentials applied to the tube, a trace or even just a bright spot will appear on the screen. Adjusting the focusing control should cause the beam to come to a sharp point. So long as this indication is evident, it can be assumed that the high-voltage unit is in satisfactory operating condition.

The indication of proper operation of the low-voltage power unit, as it directly affects the cathode-ray tube, can be determined by rotating the brightness control. This control, it will be recalled, varies the bias on the control grid of the viewing tube and hence determines the intensity of the impinging electron beam. A clockwise rotation (on most receivers) of this knob will cause the beam illumination to increase; a counter-clockwise rotation has the opposite effect.

Satisfactory results from the preceding test indicate that the operation of the low-power unit, so far as the viewing tube is concerned, is not at fault. However, it must be kept in mind that almost every other circuit in the receiver is likewise affected by the low-voltage power supply. It can happen, for example, that the B+ low-voltage circuit is broken or inoperative in some other branch of the receiver and still be satisfactory at the viewing tube. Hence this possibility should be kept in mind when making checks on other stages. Nevertheless, as a rough indication, the action of the brightness control can be relied upon. Generally, low-voltage power failure in other sections of the receiver will make itself evident in one of the ways soon to be mentioned, and the radio serviceman can locate it.

One point of special importance concerns the use of voltmeters in actually checking the voltages at their source — namely, the power supplies. The extremely high voltages of the large power unit make the testing of this unit quite dangerous and it is best

not to attempt the measurement of these voltages which can cause serious injuries to the serviceman if anything should go wrong. The use of an ohmmeter to check the continuity of the wiring in this circuit is a much safer method and should reveal the
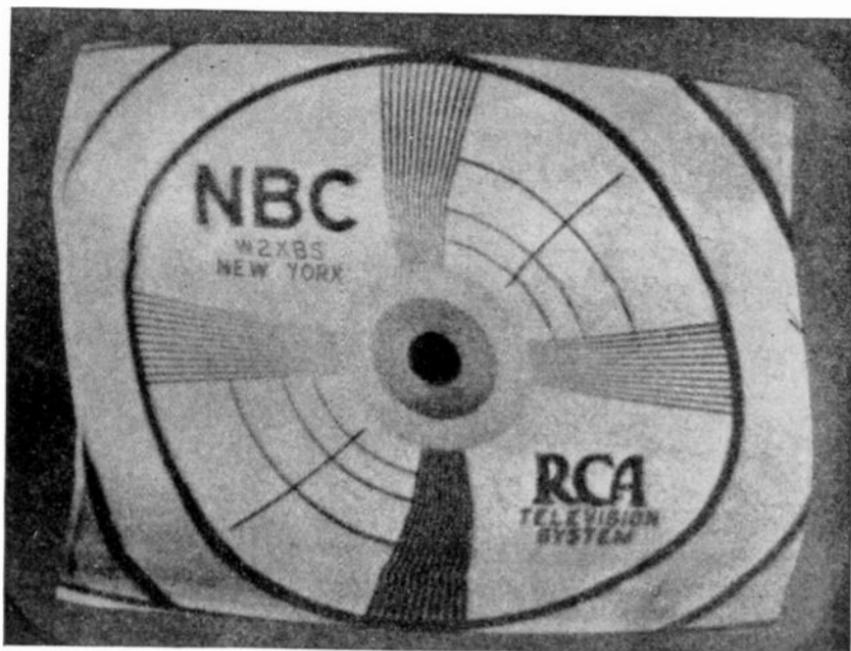
FIG. 14.2.   Distortion due to ripple in horizontal deflection system.

cause of any trouble which might exist in the high-voltage power supply. It is necessary, of course, that the serviceman make sure that all power is off before he attempts making the continuity check.

The lower voltage values present no greater problem than the serviceman encounters daily in his work on ordinary sound receivers. A good practice, when working on the low-power unit,

is to disconnect the high-voltage section entirely. This does not effect the taking of low-voltage measurements and reduces the possibility of injury to the serviceman. In most receivers, simply pulling out the tube in the high-voltage unit is all that is necessary.
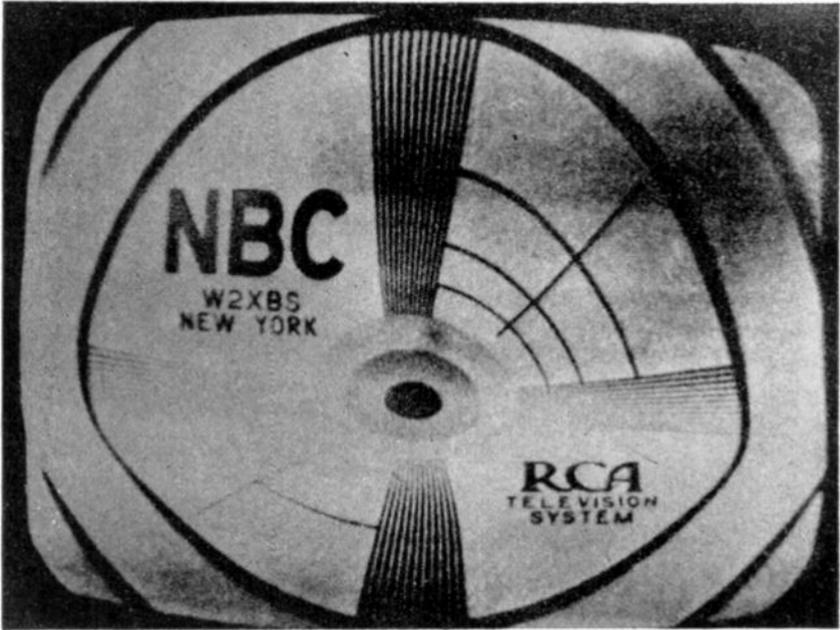
Courtesy RCA

Fig. 14.3. Unfiltered A.C. ripple in vertical deflection amplifiers.

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 con-

denser, and (2) too great a load on the unit, due perhaps to some partial short circuit elsewhere in the receiver. The latter 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 re-

FIG. 14.4.   A large percentage of ripple voltage in the video amplifiers.

duced 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. 14.2, 14.3, or 14.4, depending upon which circuit is affected. The first of these defects, Fig. 14.2, 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. 14.3 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. This latter effect is also observed when one of the high-voltage filter condensers becomes open.

Sound 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 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 interference. When the system is properly aligned, a slight adjustment 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. 14.5 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 disappear. Distortion from the power supply is steadier in intensity. Tuning the set to another station does not alter the position of the bands. And, while on the subject of image dis-

FIG. 14.5. The visual result when sound voltages reach the cathode-ray tube.

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.

In the usual course of events, a certain amount of weaving is permissible in a picture. This is due to some residual hum or ripple in the power supply and will not generally prove annoying. Most times, this slight weaving is apparent only upon close examination of the picture. Like hum in sound receivers, a level is soon reached where it is easier (and cheaper) to tolerate the ripple than to attempt to add more filter sections to remove it entirely.

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 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 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.

Horizontal Deflection Circuits. The next section of the receiver that we shall consider is the horizontal deflection circuit.* A block diagram of a typical horizontal deflection system of a

* There is no particular significance to the order in which these sections are being discussed, merely one of convenience in explanation.

television receiver is given in Fig. 14.6, 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 contained in the incoming signal keeps 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
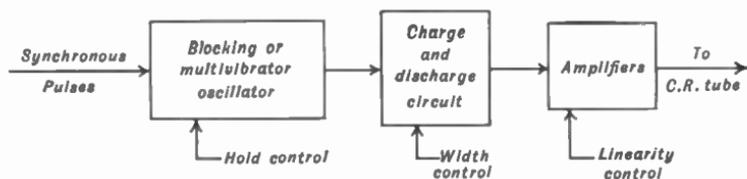
FIG. 14.6.   Block diagram of horizontal deflection system, together with the controls associated with each section.

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.

The most positive indication of the complete failure of horizontal deflection circuits is the appearance of merely a vertical line on the screen of the viewing tube. With no horizontal deflection voltage, the electron beam is subject only to the vertical deflection amplifiers. To localize the stage at fault in the hori-

zontal deflection system, signal tracing with an oscilloscope is the most rapid method.

Starting at the deflecting oscillator, place the leads from the oscilloscope vertical amplifiers across the output of the saw-tooth wave generating circuit. Two appropriate points in this stage are indicated in the diagram of Fig. 14.7. If the stage is producing the necessary deflection voltages, these waves will appear on the oscilloscope viewing tube. In running the test, it
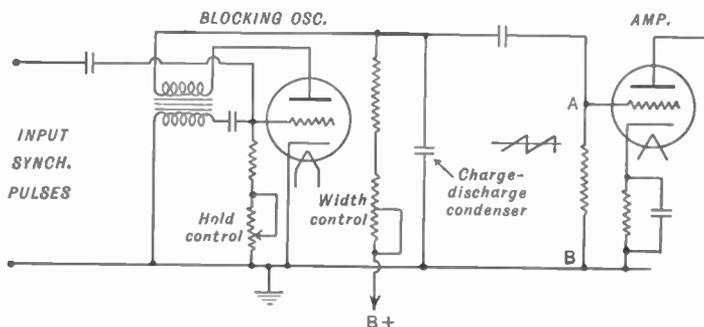
FIG. 14.7. Testing points to determine the shape of the generated saw-tooth waves.

should be kept in mind that the testing oscilloscope is essentially a voltage indicating instrument. It illustrates only the shape of the deflecting voltage. For magnetic deflection coils, the current, not the voltage, is of a saw-tooth shape. The latter assumes the peculiar shape of Fig. 14.8, this form having been derived in Chapter 9. For a correct interpretation of the observed pattern in the oscilloscope's screen, the serviceman should first become familiar with the circuit under test to determine whether a saw-tooth voltage or the voltage of Fig. 14.8 should be produced.

If the deflecting oscillator is operating normally, the following amplifier should be checked for output wave form. In the same manner, by moving from stage to stage toward the viewing tube,

little trouble should be encountered in locating the defect. The check may be run with or without the incoming signal synchronizing pulses, since the deflection oscillators of all television receivers are capable of generating oscillations at their natural frequency. The incoming synchronizing pulses merely alter this frequency to a value determined at the transmitter camera tube. If the receiver deflection oscillator is incapable of operating at its own natural period, the synchronizing pulses will seldom be

FIG. 14.8. Voltage wave shapes required at the electromagnetic coils to produce saw-tooth shaped currents.

capable of forcing a pulse through. For correct operation, then, it is first necessary for the deflection oscillator to operate at its own frequency, irrespective of the synchronizing pulses.

The frequency of the deflection oscillator must be close to the frequency of the pulses if it is to be synchronized. The natural frequency of the horizontal oscillator depends upon the value of one or more condensers and resistors in the circuit and, since these components are subject to change, the frequency generated may also vary. To correct any slight variation, one of the frequency-determining components (generally a resistor) is made variable. This is labeled the hold control. Within limits, variation of this resistor value will compensate for any change in the deflection oscillator frequency. As a result, the frequency of the oscillator returns to the correct value, or to a point where the synchronizing pulses may take control.

Loss of Synchronization. Loss of horizontal synchronization is indicated when the picture either has sections " torn away " (as in Fig. 14.9) or assumes the distorted appearance of Fig.

14.10.   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
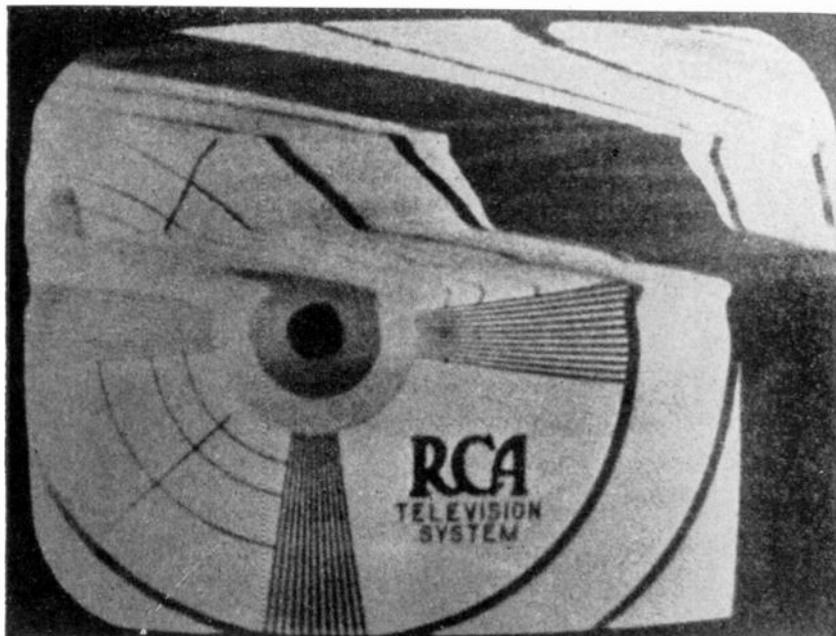
Courtesy RCA

FIG. 14.9.   Improper adjustment of horizontal hold control.

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. 14.11.
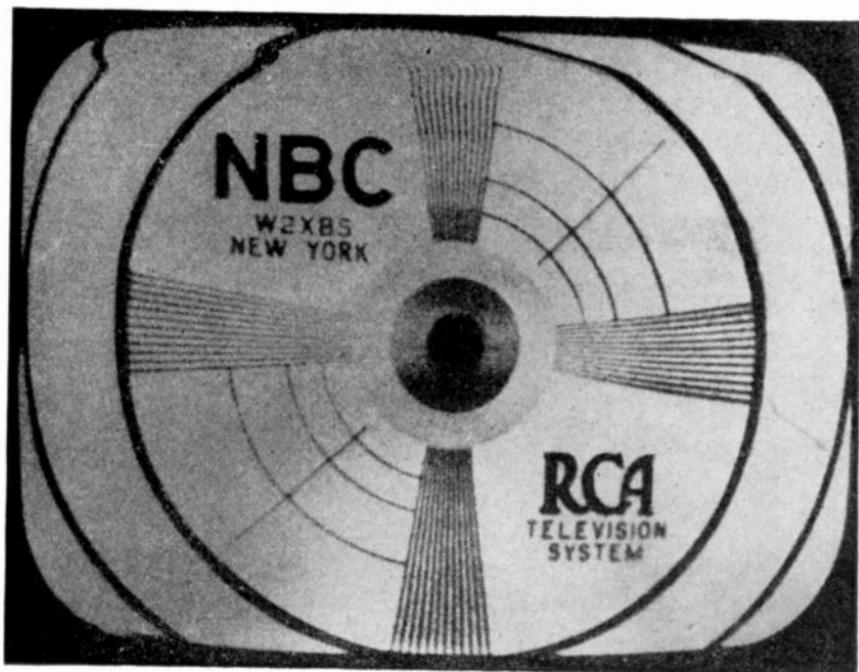
<div align="right">*Courtesy RCA*</div>

FIG. 14.10.   A result of unstable horizontal synchronization.

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. 14.12 shows the grid voltage
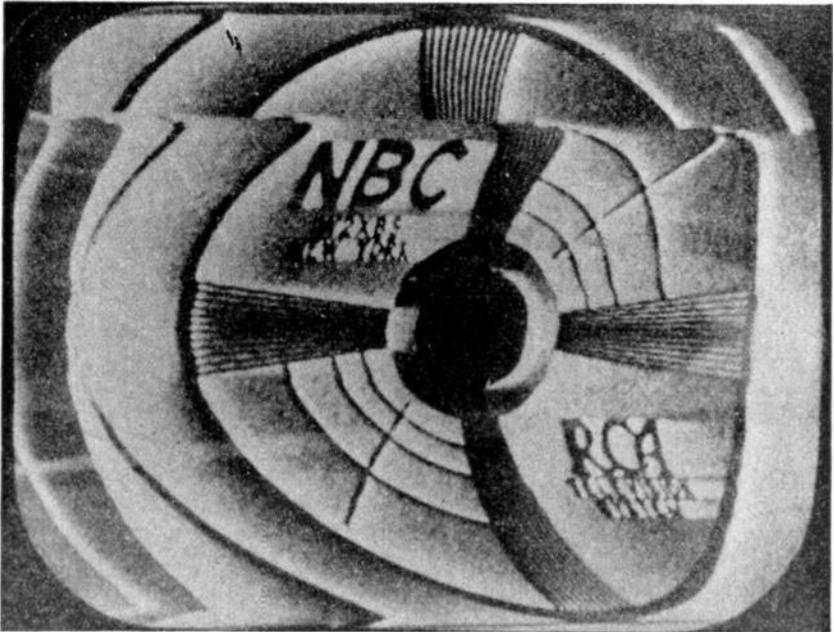
Fig. 14.11.   Distortion due to a very powerful signal.

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
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 condenser 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
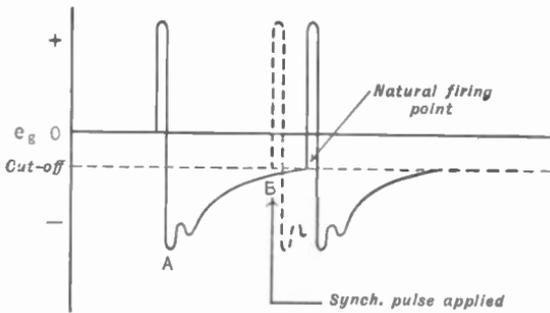
Fig. 14.12.   Output wave form of blocking oscillator.   The synchronizing pulse at B controls the frequency of this generator.

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 the curve of Fig. 14.12 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 re-

ception 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 occur. 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 many 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 placed in series with the charge and discharge condenser (see Fig. 14.7) 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 substitution 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
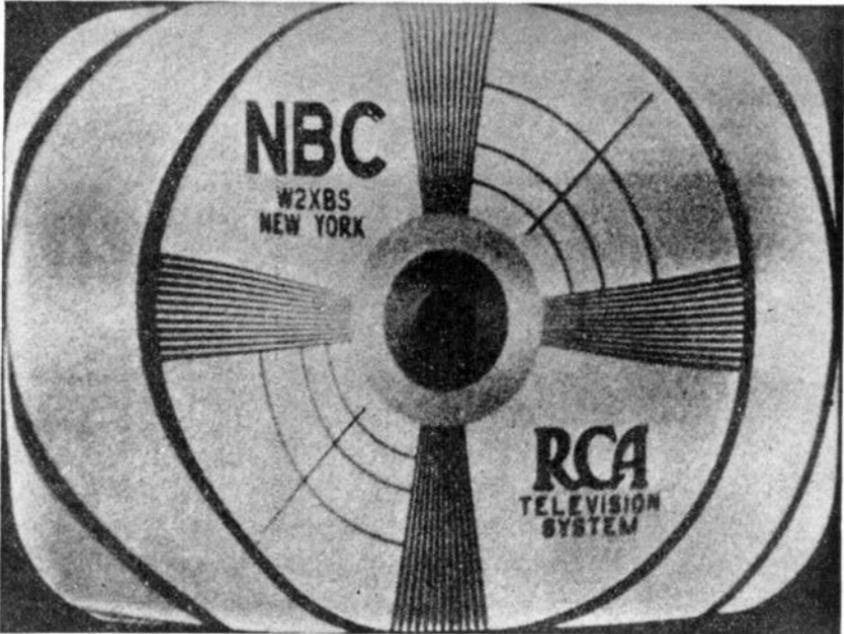
FIG. 14.13.   Horizontal deflection with non-linear saw-tooth waves.   Note the
relative crowding at the right-hand side of the image.

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. 14.13 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. 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. 14.14.   As noted previously, the 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.
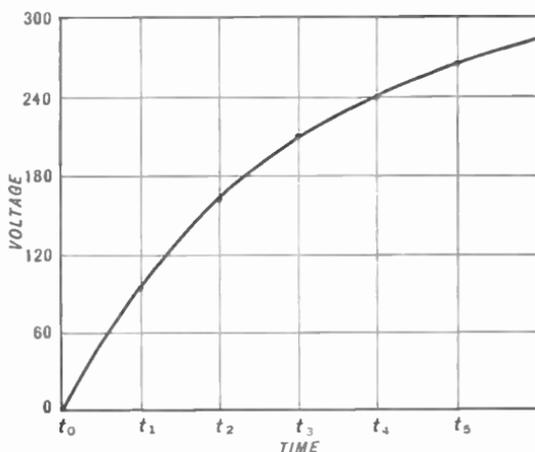
Fig. 14.14. Charging curve for a condenser.

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. 14.14 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).

Uneven Edges of Images. Distortions of the reproduced image that cause the vertical edges to be uneven are generally due to two main reasons, a-c ripple or unequal deflecting voltages in the horizontal deflection system. Ripple, as we have shown in Fig. 14.2, causes the image to weave slowly from side to side, much in the manner that a sine wave will drift across the face of an oscilloscope if the deflecting system is not properly synchronized because the ripple disturbance refuses to lock in with the image synchronization voltages and its phase keeps changing. When the ripple has a frequency of 60 cycles, the pattern of Fig. 14.2 is observed. Note that the curvature at the edge of the image represents one cycle of a sine wave laid on its side. If the ripple voltage frequency is doubled to 120 cycles (as, for example, from a full-wave rectifier) then the number of " bends " is similarly doubled. Fig. 14.15 illustrates the difference in the two patterns.

The best answer to the problem of ripple in any circuit is to trace its path from the power supply with the aid of an oscilloscope. Although the rectified output voltage of a power supply appears to be the most logical source of trouble, this is not always the case. Stray fields from transformers not completely shielded

can cause as much interference as a poorly filtered power unit. Observe the wave form of the saw-tooth waves (again with an oscilloscope) at the various stages and, in this way, isolate the amplifier where the distortion arises. Once this is done, the task becomes one of testing the individual parts of the stage to
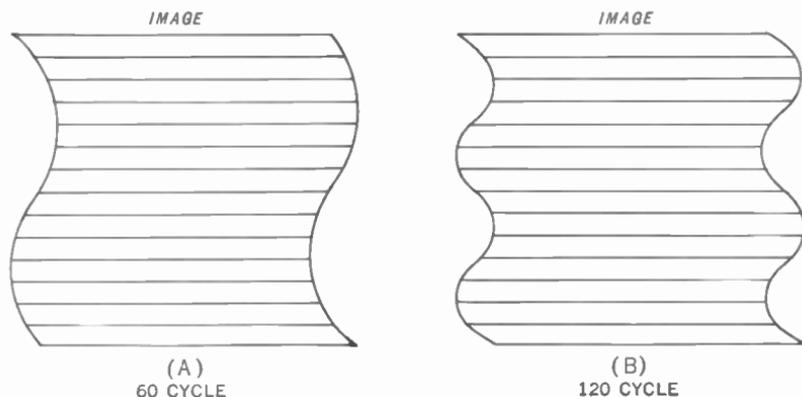
Fig. 14.15. Effects of 60- and 120-cycle ripple in the horizontal deflection system on the reproduced pattern.

localize the source. The oscilloscope is stressed so frequently because of its immediate indication, at any point, of the shape of the wave present. All other meters prove quite ineffectual in this respect.

It would be helpful to compare Fig. 14.2 with Fig. 14.3 in order to differentiate between ripple in the horizontal deflecting system and the same defect in the vertical deflecting system. More information will be given on such distortion in the discussion on vertical deflection circuits.

A second defect that can result in unequal widths of the image at various points is due to varying amplitudes in the generated saw-tooth voltages. The visible effect, as observed on the screen, is that some sections of the image spread out while other sections appear to contract. The difference between this form of distortion

and that due to ripple is best seen from the comparison made in Fig. 14.16. Again, the best method of locating the circuit element responsible is through the use of the oscilloscope in tracing the signal from the generating oscillator to the deflection plates or coils. The indication of uneven amplitude is shown on the oscilloscope, as in Fig. 14.17.

To avoid confusion in differentiating between the effects of non-linearity in the saw-tooth wave and those effects arising from ripple, the following points should prove helpful:
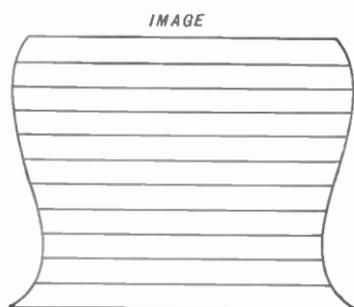
FIG. 14.16. Resultant pattern arising from uneven horizontal deflection voltage amplitudes.

FIG. 14.17. A type of saw-tooth voltage variation that would cause patterns similar to that of Fig. 14.16.

1. Compression of the picture will take place generally at the extreme right-hand side of the image (horizontal system), or at the very bottom of the image (vertical system) if the deflecting wave is non-linear.

2. Ripple causes alternate expansion and compression of the elements in an image. The ripple pattern is seldom stationary, weaving slowly from side to side, or up and down.

3. Distortion due to the non-linearity of the deflecting wave remains fixed on the image.

4. Variation of the linearity control will affect the compressed portion of the image if the deflecting voltage is at fault. It will not appreciably alter distortion due to ripple.

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 on the negative part of the oscillation cycle and absorbs as much energy as possible during this interval. As a result of the absorption, the interfering wave rapidly dies out. Generally only the horizontal coils have a damping tube, while a simple resistor and condenser in series damp out any oscillations in the vertical deflecting coils. The reason is to be found in the higher frequency of the horizontal deflection voltages and their ability to generate more readily frequencies close to the resonant frequency of the coils.

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. 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 Deflecting System. Due to the similarity of the two deflecting systems, many of the same defects arise in both. The only difference in the present case is that now the image is affected in a vertical direction. Because of this similarity, detailed descriptions will be required only when the defect is peculiar to the vertical circuits.

Complete failure removes all vertical motion of the electron beam. The result is merely a thin horizontal line on the viewing screen, due to the horizontal deflecting voltages. Loss of action by both sections will allow the beam to remain stationary at the

center of the screen. The receiver must not be permitted to remain in this condition for any appreciable length of time or the fluorescent crystals at this point will become inactive. The visual consequence is a blank spot in any image that may later be traced on the screen.

Tubes are the source of the greatest number of failures in deflecting circuits. It is good policy to check them first. If further testing is indicated, signal tracing with an oscilloscope is perhaps the most efficient method for localizing troubles. Start at the blocking or multivibrator oscillator and progress by stages toward the picture tube end of the receiver. The form of the a-c voltages can be observed on the oscilloscope screen. Where these begin to differ from the required pattern will be the point to check for defective components. A voltage or resistance test will then single out the exact part. This sequence of tracing troubles in television systems is logical for it enables the service-man to observe the action at each individual stage. Every component is being tested under dynamic operation, which is the only condition in which we are interested.

Vertical Hold Control. Analogous to the horizontal hold control, the vertical hold control is capable of varying the frequency of the vertical oscillator. Again, the generator frequency must remain stable, otherwise loss of vertical synchronizing action will result. As before, the visual consequence of a loss of synchronization is picture slippage across the screen. Fig. 14.18 is a typical image observed under these conditions. Rotation of the hold control will eliminate this slipping, unless other defects exist.

Height Control. Electrically associated with the charge and discharge condenser (and resistor) is the vertical height control. On direct viewing screens a mask or frame is placed over the cathode-ray tube. The image size then is increased in the horizontal and vertical directions until the image completely fills this rectangle. See Fig. 1.1, Chapter 1. Anything less represents improper operation. Inability to reach the desired dimensions

means that the correct voltage amplitudes are not being developed in the deflection circuits. The most common reason for the failure of the circuit to develop the necessary voltage swing is usually to be found at the tube — in this case the output amplifier tube. Check here first. If the tube is satisfactory, use an
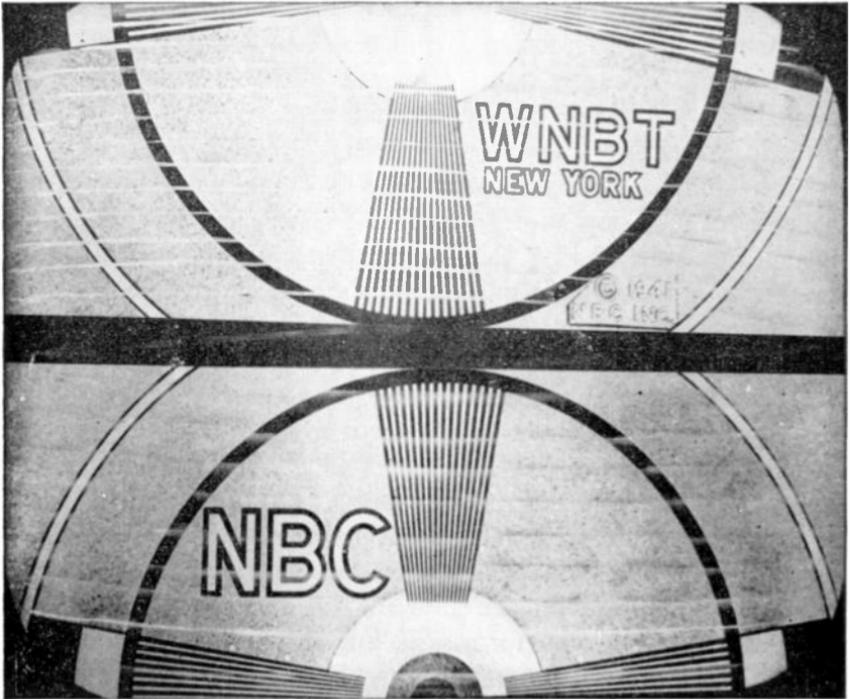
Fig. 14.18. Incorrect setting of vertical hold control. This picture was retouched slightly to bring out the loss in interlacing that generally accompanies this condition.

oscilloscope to determine the relative amplitude of the signals at the input and output of each amplifier. Open coupling resistors, improper cathode bias voltages, shorted condensers, almost anything that can affect the correct operation of an amplifier can be responsible. The suggestion of checking relative amplitudes of

the signal at various points will be helpful in locating the stage that is not operating properly.

Uneven Image Distribution. Crowding of the image either at the top or the bottom of the scene can be traced to either (1) improper setting of the vertical linearity control, or (2) a defective charge and discharge condenser or its associated resistor.

To service the first defect, adjust the linearity control to the point where the saw-tooth wave again assumes its proper form. However, the linearity control can be effective only when the charge and discharge circuit is operating normally. In electrostatic deflection tubes, a saw-tooth voltage is required. On the other hand, with electromagnetic deflection, the current must be of the saw-tooth form. The voltage, for the latter case, is far from having this shape, being highly peaked. See Fig. 14.8. To develop this type of wave, a simple condenser is insufficient, but a series combination of a condenser and resistor proves satisfactory. Failure of either one of these components will interfere with the generation of the necessary peaked wave. The result on the screen is a crowding or overlapping of the lines in the image.

As noted, correction of the crowding at either end of the image should first be attempted by rotation of the vertical linearity control. If the crowding still persists, connect an oscilloscope across the various input circuits in the deflection system and observe the voltage waveform. Follow the synchronizing pulses through each amplifier of the vertical deflection system of the receiver until the wave form departs from the required pattern.

While crowding together of the detail at either the top or bottom of the image is due to one of the preceding defects, alternate spreading and crowding of the image is a result of hum in the vertical deflection system. Fig. 14.19A illustrates the effect on the image when 60-cycle hum or ripple is present. With 120-cycle ripple, such as that obtained with full-wave rectification, twice as many points of spreading and compression are observed. A comparison of the two is made in Fig. 14.19.

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 num-

(A)   (B)
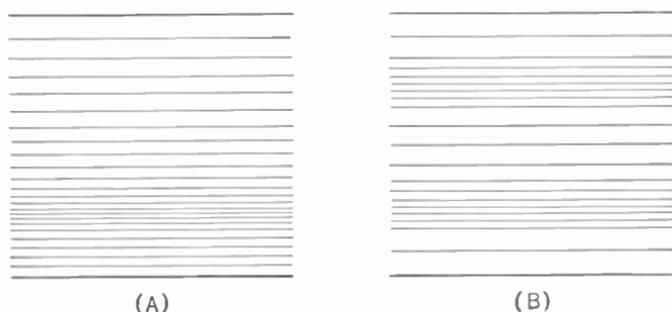
Fig. 14.19.   60-cycle (A) and 120-cycle (B) ripple in the vertical deflection system appears at viewing screen as shown above.

ber 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 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 System. 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 system. This includes all of the R.F., I.F., and video voltage amplifiers that deal directly with the image signal. If the arrangements of these stages are recalled, and their functions understood, very little trouble should be encountered in interpreting and localizing defects in the video system. A few of the more frequent troubles are described in the succeeding paragraphs and, from these, the television serviceman should be able to trace other defects not given. The secret of successful trouble shooting of television receivers lies in the correct interpretation of the visual images viewed on the screen.

As before, it will save much time when servicing television equipment, to repeat again that the greatest number of defects are due to poorly functioning or inoperative tubes. Hence, when the trouble has been definitely traced to one stage, test the tube first. Only when this is proved good should the service-man look further for defective components.

Ripple reaching the video amplifiers will produce one or two (60- or 120-cycle currents) wide, dark bands horizontally across the screen. Fig. 14.4 shows the result of severe a-c ripple in the video amplifiers; most cases encountered will cause less pronounced darkening. It is evident upon inspection of this image

that the vertical and horizontal deflection stages are operating properly because the image is steady and correctly interlaced at those points where the a-c ripple does not obscure observation of the image. Should the a-c ripple affect the deflection circuits in addition, then a resultant pattern will be obtained that is a combination of Figs. 14.2, 14.3, and 14.4.

With a pronounced ripple in the video amplifiers, the chances are good that the speaker will also indicate hum. Check the filter condensers in the low-voltage power supply. With experience, the serviceman may actually be able to indicate which filter condenser is defective merely by observing the intensity of the ripple effect on the screen. The input filter condensers (those nearest the rectifier) are more instrumental in eliminating the effects of ripple than the output filter condensers. Hence an open input filter condenser causes the ripple percentage to be larger, with a greater resultant darkening.

Sound modulation is quite similar to the effect of ripple in the video system. Actually, of course, hum is merely low-frequency sound. However, with increase in frequency, more dark bands appear across the screen. Fig. 14.5 is typical of the appearance of sound modulation reaching the viewing tube. The reason for sound in the video amplifiers can almost always be traced to poor alignment. A simple illustration will indicate why.

Suppose the receiver is tuned to the 44- to 50-mc band. For this band we know that the oscillator should be at 58 mc. With this frequency, the 49.75-mc sound carrier mixes with the 58-mc heterodyning oscillator to give the 8.25-mc sound I.F. frequency. The set is now operating properly. If any sound voltage should reach the I.F. video stages, the 8.25-mc trap immediately eliminates this interference.

However, suppose the oscillator is incorrectly set, or it has drifted to another frequency, say 60 mc. Now let us analyze what has occurred. The 60-mc, beating with the 49.75-mc sound carrier, generates a 10.25-mc intermediate frequency and this falls exactly at the middle of the video I.F. band. There are no

rejection filters for this frequency and hence there is nothing to eliminate the incoming sound voltages. As a consequence, sound interference reaches the viewing tube.

Ordinarily, an adjusted setting of the fine tuning control corrects the oscillator and places the sound and video I.F. frequencies at their proper place. But, when the change in the oscillator frequency is too great or the tuned circuits are completely out of alignment, even the fine tuning control proves useless. Under these conditions, realignment with a signal generator is the accepted servicing procedure.

A less rigorous alignment, but one that may prove satisfactory when signal generators are not immediately available, may be accomplished by adjusting for the appearance and elimination of sound interference bands across the face of the viewing tube. The first step in the procedure is to tune in a television station. Since the sound bands at the viewing screen are being used as our indication, the heterodyning oscillator frequency is set as high as possible and then gradually lowered to the point where the sound interference bands disappear.

To increase the oscillator to its highest frequency (for the particular band in question), place the fine tuning condenser at its lowest value (plates completely unmeshed). Then adjust the trimmer screw on either the oscillator coil or condenser (whichever is variable) until the sound interference bars are quite evident on the viewing screen. The oscillator is now functioning at the point where the sound causes the greatest distortion.

Start turning the trimmer adjustment of the oscillator coil or condenser until the sound bars just disappear. Stop here and adjust the fine tuning control for best indication on the viewing screen. Sound reception may be judged by ear. For each band, the different trimmers may be altered in turn until the set is completely aligned. It is important, in this visual method, to keep the sound tone, as well as the image, clear and sharp. We are assuming in the discussion that the I.F. stages are in correct alignment.

Loss of Image Detail. In the descriptions that were advanced for the design of the video amplifiers, emphasis was given to the high- and low-frequency compensating networks inserted into these stages. With the additional components, it was possible to extend the flat frequency response of the amplifier up to 4 or 5 mc

Fig. 14.20. Distortion due to poor high-frequency response of video amplifiers.

at the high end and down to 10 or 20 cycles at the low end. The higher frequencies contain the fine image detail whereas the background shading and large objects are determined by the lower frequencies.

If something should occur in the circuits that would tend to affect the amplifier response at either the high or the low fre-

quencies, the reproduced image at the viewing screen must suffer accordingly. Loss of the higher frequencies tends to blur the fine detail (Fig. 14.20) while loss or phase shift at the low frequencies affects both the background shading and the larger objects in the image. The observed result of the loss of flat, low-
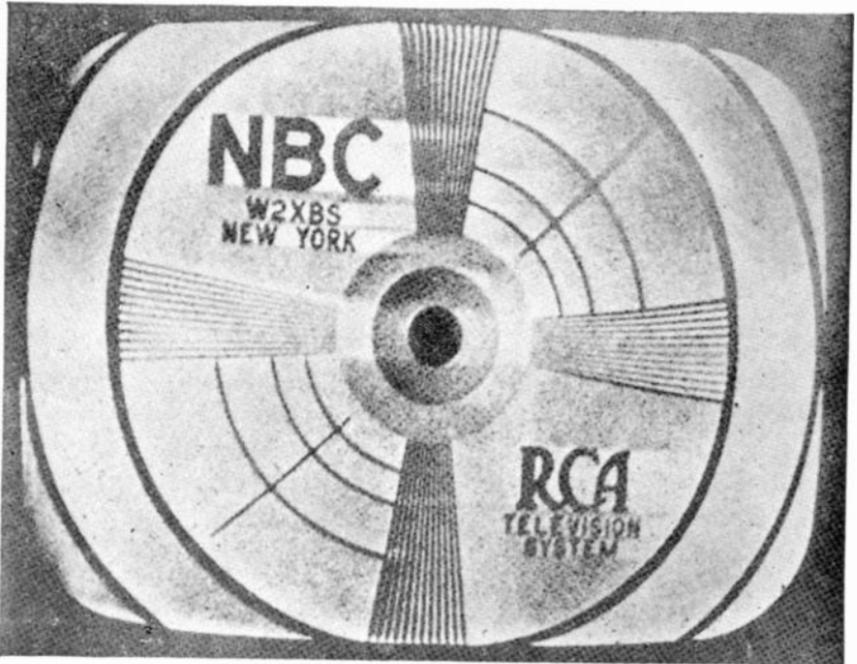
Courtesy RCA

Fig. 14.21. A visual indication of poor low-frequency response in video system.

frequency response is indicated in Fig. 14.21 by the uneven background shading and the smearing of large objects.

Defective low-frequency compensation circuit components in the video amplifier stages are generally responsible for poor low frequency response. Check such parts as by-pass condensers, load resistors, and cathode resistors for defective operation. Special attention should be given to any low-frequency compen-

sating networks (see Chapter 6) to determine whether they are operating properly. In most cases, only the video amplifiers (those that follow the 2nd detector) need be investigated. The R.F. and I.F. stages may affect the high-frequency response, but they seldom influence the low frequencies unless the receiver requires alignment. In the latter case, other defects, such as sound interference bands on the screen, or poor tone quality, will also be present.

Loss of fine detail due to poor high frequency response may arise from:

1. Open or shorted peaking inductances in the video amplifiers.

2. Too narrow response of the R.F. and I.F. coupling circuits.

If the response curve is not flat over its entire range in the I.F. circuits, a quick visual alignment check will indicate it. The sound will generally not be affected by poor high-frequency response in the video I.F. amplifiers because the F-M sound is separated from the image voltages at the mixer. But if the poor response is due to the misalignment of the R.F. stages, then the sound is also distorted. This distinction is helpful in determining whether the poor response arises in the R.F. or I.F. stages. Unfortunately, there is no quick way of distinguishing whether poor video response is arising in the video I.F. stages or the video amplifiers. Individual checking is necessary.

In testing the small peaking inductances, an ordinary ohmmeter may prove useless because of the extremely low ohmic resistance of these coils. Perhaps a better indication can be derived by a dynamic test. With the receiver operating, short out the suspected peaking inductance and observe the change on the viewing screen. If the coil is defective, no great change will occur, while if it is in good working condition, the image becomes blurred. By checking all such inductances, a defective unit can be isolated.

Poor image reception is not always indicative of a defective receiver. The trouble may very well lie at the antenna or some other outside source. The mere fact that the sound is coming

GLOSSARY OF TELEVISION TERMS

A

Aspect Ratio — A term used to denote the ratio of the image width to the image height.

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.

B

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.

Blanking Pulses — Sharp rises in voltage that bias the viewing tube control grid beyond cut-off. This action, when properly synchronized with brightness control, prevents the electron beam retraces from appearing on the viewing screen.

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.

C

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).

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

Directive Antenna — Any antenna system that tends to receive signals best from one or more directions, but not all.

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.

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.

E

Electric Field — The region surrounding charged particles. An electric field is set up also whenever a magnetic field varies. Radio waves travelling through space are composed of electric and magnetic fields.

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.

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.

Electron-Multiplier — A series of anodes used in the Image Dissector camera tube to increase the intensity of the video signal.

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 $\frac{1}{60}$ of a second.

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.

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.

Frequency Modulation. — A means of transmitting radio intelligence by varying the frequency of the wave.

G

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.

H

Hold Control — The variable resistor that permits adjustment of the syn-

chronizing oscillator until the latter frequency nearly equals that of the
incoming synchronizing pulses.

Horizontal Centering Control — A control that enables the operator to move
the television image back and forth across the screen.

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.

Impulse — A sudden rise and fall of current (or voltage) in an electrical
circuit.

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.

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 $\frac{1}{30}$ of a second, or 15,750 per second.

M

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 cur-
rent) 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.

P

Picture Frequency — This term is synonymous with frame frequency.

Positive Picture Modulation — In this method of transmitting television

video signals, the picture values are represented by corresponding voltages or currents.   Opposite to negative picture modulation.

Picture Elements — The separate photosensitive globules or groups of globules that combine to form an image.   At the receiver, the picture elements are the many light emitting particles of the fluorescent screen.

R

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.

Synchronizing Pulses — Voltage (and current) wave forms that keep the electron beam at the receiver in step with the camera tube electron beam.

Serrated Vertical Pulse — The method is used to break up the relatively long vertical pulse into a series of pulses to permit simultaneous control of vertical and horizontal synchronizing oscillators.

Spurious Signal Voltages — These are the voltages caused by the secondary emission effects of a mosaic plate.

V

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.

Vertical Centering Control — An adjustment control for moving the image up or down on the viewing screen.

Vestigial Side-Band Transmission — A method of transmission whereby one set of side-bands is eliminated from the modulated transmitted signal.

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.

Y

Yoke — A magnetic metallic frame of high permeability for the horizontal and vertical deflecting coils.

APPENDIX

Metropolitan District (U.S. Census 1940)	Sales Rank	Population	Channel Numbers
Akron	35	349,705	11
Albany Schenectady Troy	23	431,575	2, 4, 7, 9, 11
Allentown Bethlehem Easton	43	325,142	(8)
Altoona	111	114,094	9
Amarillo	136	53,463	2, 4, 5, 7
Asheville	132	76,324	5, 7, 12
Atlanta	25	442,294	2, 5, 8, 11
Atlantic City	83	100,096	(8)
Augusta, Ga.	135	87,809	6, 12
Austin	106	106,193	8, 10, 12
Baltimore	13	1,046,692	2, 11, 13
Beaumont Port Arthur	90	138,608	3, 6, 8, 10
Binghamton	75	145,156	12
Birmingham	42	407,851	4, 9, 13
Boston	5	2,350,514	2, 4, 9, 7, 13
Bridgeport, Conn	53	216,621	(1)
Buffalo Niagara	14	857,719	4, 7, 9, 13
Canton, O.	63	200,352	(1)
Cedar Rapids	115	73,219	7, 11
Charleston, S.C.	127	98,711	7, 10, 13
Charleston, W.Va.	88	136,332	7, 11, 13
Charlotte	99	112,986	3, 9, 11
Chattanooga	76	193,215	3, 6, 10, 12
Chicago	2	4,499,126	2, 4, 5, 7, 9, 11, 13
Cincinnati	16	789,309	2, 4, 7, 11
Cleveland	9	1,214,943	2, 4, 5, 7, 9
Columbia	117	89,555	2, 4, 8
Columbus, Ga.	133	92,475	3, 12
Columbus, O.	29	365,796	3, 6, 8, 10

431

Metropolitan District (U.S. Census 1940)	Sales Rank	Population	Channel Numbers
Corpus Christi	121	70,677	3, 6, 8, 10
Dallas	27	376,548	4, 8, 12
Davenport } Rock Island } Moline }	67	174,995	2, 4, 5, 9
Dayton	44	1,513	5, 13
Decatur	122	65,764	2
Denver	26	384,372	2, 4, 5, 7, 9
Des Moines	59	183,973	2, 4, 5, 9
Detroit	6	2,295,867	2, 4, 5, 7, 9
Duluth-Superior	72	157,098	3, 6, 8, 10
Durham	139	68,683	4, 7
El Paso	105	115,801	2, 4, 5, 7
Erie	95	134,039	12
Evansville, Ind.	93	141,614	2, 11
Fall River } New Bedford }	55	272,648	(1)
Flint	64	188,554	11
Fort Wayne	81	134,385	2, 4, 7, 9
Fort Worth	51	207,677	2, 5, 10
Fresno	79	97,504	2, 4, 5, 7
Galveston	131	71,677	9, 11, 13
Grand Rapids	57	209,873	7, 9
Greensboro	130	73,055	2, 10
Hamilton } Middletown }	110	112,686	9
Harrisburg	70	173,367	8
Hartford } New Britain }	20	502,193	8, 10
Houston	21	510,397	2, 4, 5, 7
Huntington, W. Va. } Ashland, Ky. }	92	170,979	5
Indianapolis	24	455,357	3, 6, 8, 10, 12
Jackson	128	88,003	2, 4, 5, 7
Jacksonville	66	195,619	2, 4, 6, 8
Johnstown, Pa.	100	151,781	13
Kalamazoo	112	77,213	3
Kansas City, Mo. } Kansas City, Kans. }	17	634,093	2, 4, 5, 9
Knoxville	87	151,829	2, 4, 8, 11
Lancaster	91	132,027	(4)
Lansing	94	110,356	6
Lincoln	109	88,191	10, 12
Little Rock	98	126,724	3, 6, 8, 10

Metropolitan District (*U.S. Census 1940*)	*Sales Rank*	*Population*	*Channel Numbers*
Los Angeles....................	3	2,904,596	2, 4, 5, 7, 9, 11, 13
Louisville.....................	33	434,408	5, 9
Lowell........................			
Lawrence......................	45	334,969	6
Haverhill......................			
Macon........................	137	74,830	4, 7, 10
Madison.......................	101	78,349	9
Manchester....................	118	81,932	(1)
Memphis......................	37	332,477	2, 4, 5, 7, 9
Miami........................	38	250,537	2, 4, 5, 7
Milwaukee.....................	15	790,336	3, 6, 8, 10
Minneapolis....................	11	911,077	2, 4, 5, 7, 9
St. Paul.......................			
Mobile........................	119	144,906	3, 5, 9, 11
Montgomery...................	126	93,697	6, 10
Nashville......................	56	241,769	4, 5, 7, 9
New Haven....................	39	308,228	(6)
New Orleans...................	31	540,030	2, 4, 6, 7, 10
New York.....................	1	11,690,520	2, 4, 5, 7, 9, 11, 13
Northeastern New Jersey........			
Norfolk.......................			
Portsmouth....................	47	330,396	4, 7, 11, 13
Newport News.................			
Oklahoma City.................	52	221,229	2, 4, 5, 9
Omaha........................	40	287,269	3, 6, 7
Council Bluffs.................			
Peoria........................	69	162,566	3, 6, 12
Philadelphia...................	4	2,898,644	3, 6, 10, 12
Phoenix.......................	84	121,828	2, 4, 5, 7
Pittsburgh....................	8	1,994,060	3, 6, 8, 10
Portland, Maine................	89	106,566	3, 8
Portland, Oregon..............	22	406,406	3, 6, 8, 10, 12
Providence, R.I................	18	711,500	11
Pueblo........................	140	62,039	3, 6, 8, 10
Racine........................	97	135,075	(1)
Kenosha.......................			
Reading.......................	73	175,355	(5)
Richmond.....................	48	245,674	3, 6, 8, 10
Roanoke......................	104	110,593	5, 9, 12
Rochester.....................	28	411,970	2, 6, 11
Rockford......................	102	105,259	12
Sacramento....................	54	158,999	3, 6, 10
Saginaw.......................	77	153,388	3, 8, 13
Bay City......................			

Metropolitan District (U.S. Census 1940)	Sales Rank	Population	Channel Numbers
St. Joseph	129	86,991	13
St. Louis	10	1,367,977	4, 5, 7, 9, 13
Salt Lake City	58	204,488	2, 4, 5, 7, 9
San Antonio	50	319,010	2, 4, 5, 7, 9
San Diego	49	256,268	3, 6, 8, 10
San Francisco / Oakland	7	1,428,525	2, 4, 5, 7, 9, 11
San Jose	78	129,367	13
Savannah	114	117,970	3, 5, 9, 11
Scranton / Wilkes-Barre	30	629,581	11(1)
Seattle	19	452,639	2, 5, 7, 11
Shreveport	96	112,225	2, 4, 6, 8
Sioux City	107	87,791	4, 9, 11, 13
South Bend	80	147,022	(1)
Spokane	71	141,370	2, 4, 5, 7, 9
Springfield, Ill.	103	89,484	8, 10
Springfield, Mass. / Holyoke	32	394,623	3(1)
Springfield, Mo.	134	70,514	2, 4, 5, 9
Springfield, O.	125	77,406	(1)
Stockton	108	79,337	8
Syracuse	46	258,352	5, 8, 10
Tacoma	74	156,018	4, 9, 13
Tampa / St. Petersburg	61	209,693	2, 4, 5, 7
Terre Haute	116	83,370	4
Toledo	34	341,663	13
Topeka	123	77,749	7, 11
Trenton	60	200,128	(1)
Tulsa	65	188,562	3, 6, 8, 10
Utica / Rome	68	197,128	3, 13
Waco	138	71,114	3, 6, 9, 11
Washington	12	907,816	4, 5, 7, 9
Waterbury	85	144,822	12
Waterloo	120	67,050	3, 6, 13
Wheeling	82	196,340	12
Wichita	86	127,308	2, 4, 5, 9
Wilmington	62	188,974	(7)
Winston-Salem	124	109,833	6, 8
Worcester	41	306,194	5
York	113	92,627	(1)
Youngstown	36	372,428	13

QUESTIONS

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 that 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 live 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 would 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. 3.11.

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 a Hartley oscillator.

4. Indicate the differences in circuit between a straight Hartley ocsillator and an electron-coupled Hartley.

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 phase 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 2000 ohms and the total shunting capacity is 20 mmf, what value should the peaking coil have?

22. In the same video amplifier, the coupling capacitor (C_c) has a value of 0.1 mf 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 is it 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 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. 9.22, 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. In Fig. 10.1, why is the negative end of the high-voltage power supply connected to the positive end of the low-voltage power supply?

2. If a leakage path developed in C_8 of Fig. 10.1, what would happen to the electron beam? Explain your answer.

3. If the right-hand triode section of T_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 is 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. Explain why a single condenser is sufficient to develop the deflection voltage in the horizontal sweep system, whereas a condenser and resistor are needed in the vertical system of Fig. 10.4.

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. 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 ratio higher in a 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 12.1 if 60 color frames were transmitted per second?

10. How is the sound transmitted in the CBS color television system? How does this differ from the method of transmission currently in use in black-and-white television?

11. Outline briefly the transmitter components used in the CBS television system.

12. What two factors must be observed in controlling the receiver color disc? How is each of these achieved in practice?

13. What are the essential differences between the CBS and the RCA systems of color television?

14. How is an image (or a scene) scanned in the RCA system?

15. Show how the three carriers used in the RCA system are arranged in frequency.

16. Why is the signal containing the blue portion of the image smaller in frequency range than either of the other two carriers? What other modifications could be made?

17. Explain how the " Mixed-Highs " system operate?

18. Draw a diagram illustrating the " Mixed-Highs " system. Why is this system more desirable than the RCA system?

19. Compare the CBS and RCA systems according to band width. Include illustrations.

20. Discuss the adaptability of RCA and CBS systems to the present black-and-white television system.

Chapter 13

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?

7. Why is oscillator stability so important in a high frequency receiver?

8. What purpose do the I.F. amplifiers serve in a superheterodyne?

9. What advantages are obtained through the use of an I.F. amplifier?

10. Why are limiters necessary in F-M receivers?

11. Do all F-M receivers require limiters? Explain.

12. What advantage do double limiters possess over single limiters?

13. Explain the operation of a grid-leak bias limiter.

14. In what other circuits in radio do we find grid-leak bias?

15. What effect does the use of lowered voltages have on tube operation?

16. Contrast the purpose of an A-M detector with an F-M detector. State clearly why each should differ.

17. Draw the schematic diagram of an early type of discriminator which employed two secondary windings.

18. Explain the operation of the circuit drawn for Question 17.

19. Would the foregoing discriminator function if one of the diodes became inoperatve? Give the reasons for your answer.

20. Draw the circuit of a modified discriminator (Foster-Seeley type) widely used today.

21. Draw the circuit of a ratio detector.

22. Explain briefly the operation of a ratio detector.

23. Draw the circuit diagram for the Philco F-M detector.

24. What is the purpose of a quadrature circuit in the Philco circuit?

25. Explain the operation of the Philco F-M detector.

26. What is a reactance tube? Does this differ in physical characteristics from any other tube? Explain.

27. What is the Armstrong System o. generating frequency modulation? Why is it useful?

28. Draw a block diagram of the basic Armstrong System. Explain the function of each stage.

Chapter 14

1. List the servicing divisions of a television receiver and give the reasons for your choice.

2. What indications would be obtained if each of the following defects occurred? (Consider each one separately.)

　　a. No vertical deflection voltage.

　　b. No low voltage.

　　c. The R.F. amplifier tube filaments burned out.

　　d. The clipper tube became inoperative.

　　e. The horizontal deflection yoke opened up.

　　f. A coupling condenser in the video amplifier system shorted out.

　　g. The control grids of all video I.F. amplifier tubes become grounded.

　　h. Too strong a signal is received.

3. Describe the power supply system found in current television receivers.

4. What is the visual effect of low-voltage a-c ripple in the video amplifiers? How do we distinguish between this effect and that obtained when sound voltages reached the cathode-ray tube?

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.

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