TELEVISION RADIO ELECTRONICS

UNITED TELEVISION LABORATORIES

INCORPORATED

LOUISVILLE, KENTUCKY

ASSIGNMENT 100

COLOR TELEVISION

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It is customary for the normal human being, unless he is color blind, to see everyday scenes in full color. It is only natural, therefore, that television, which is a process of reproducing scenes at remote points, would have an ultimate goal of color reproduction. The full color reproduction of scenes via television has certain definite advantages over the normal black and white, or monochrome reproductions, as it is often termed. In the monochrome system only the black, white, and intermediate shades of gray appear in the reproduced scene. While the reproduced scene indicates the outline, shading, etc., of the original scene, it does not impart the life-like properties of the original scene.

Color television increases the contrast and definition of the reproduced picture and adds an apparent dimension or depth to the reproduced scene which is more attractive than the monochrome image. The latter factor results because the various areas of shadow can be more faithfully reproduced and the apparent increase in definition results from the property of the human eye. Viewing tests have indicated that a color television scene having fewer picture elements than a similar black and white scene will appear to have better definition to the average viewer. Following this same line of reasoning it should be evident that a color scene with an equal number of picture elements will have an apparent higher degree of definition than a similar black and white scene.

The television receiving and transmitting equipment which has been considered previously in this Training Program has been designed exclusively for use with the black and white television system. The equipment used for color television incorporates many circuits which are identical with those used in black and white television systems. However, additional arrangements must be included for the colored reproduction of scenes, necessitating a more complex arrangement.

Properties of Light

Before going into the principles of color television, it will first be necessary to study further the properties of light and to also determine how this light affects the observer so as to leave the impression of color. The nature of light and properties of the human eye have been considered is some detail in Assignments 64 and 66. These subjects should be reviewed before proceeding with this assignment.

As explained previously, light is a form of electromagnetic radiation, the same as an ordinary radio wave except that the frequencies extend to such high values that the wavelength becomes extremely short. For this reason, it is more common to refer to the wavelength of light than to refer to the frequency of the light waves. When considering radio waves it is customary to measure wavelength in meters; however, the wavelength of light is much too short to measure in meters. Two units have been developed for use in measuring the wavelength of light.

The first of these units, which has been mentioned previously, is the Angstrom Unit. The Angstrom unit may be defined as:

One Angstrom unit = 1×10^{-10} meters

In other words, one Angstrom unit is equal to one ten millionth of a millimeter.

The wavelength of visible light covers the range from 4000 to 7000 Angstrom units. The position of these wavelengths in the electromagnetic frequency spectrum is shown in Figure 1. Inspection of this figure will show that the standard radio broadcast band falls within the range of 187.5 meters to 545 meters. To establish a better mental picture of the relationship of the wavelengths of the radio frequency signal in the broadcast band to the wavelengths of visible light, it will be of value to obtain the ratio of the wavelength of the longest radio wave in the broadcast band to the longest visible light wave. The first step is to convert the light wavelength in Angstrom units to wavelengths in terms of meters. Thus:

7000 A = 7000×10^{-10} meters.

The ratio of the wavelength of the radio wave to the wavelength of the light wave may then be expressed as follows:

$$\frac{\text{radio wavelength}}{\text{light wavelength}} = \frac{545}{7000 \times 10^{-10}} = .078 \times 10^{10} = 780{,}000{,}000 \text{ approx.}$$

From the foregoing example, it can be seen that the radio wavelength at the lower end of the broadcast band is 780,000,000 times longer than the longest wavelength of visible light. This example should illustrate very clearly the fact that the wavelength of light is exceedingly short.

There is another unit used for expressing light wavelength that is becoming popular. This unit is called the millimicron. This term consists of a combination of two units with which we are already familiar. These consist of the mil which means one thousandth part of, or 10^{-3}, and the micro which means the one millionth part of, or 1×10^{-6}. To be more explicit, the term micron means one millionth part of one meter, thus the term means one thousandth part of one millionth part of one meter. Expressed in powers of ten, then one millimicron = 10^{-9} meters.

Thus it can be seen that the term millimicron is ten times as large a unit as the term Angstrom unit since the Angstrom unit is 10^{-10} meter. To convert from Angstrom units to millimicrons it is only necessary to divide by 10; or to convert from millimicrons to Angstrom units it is only necessary to multiply by 10. To illustrate this let us consider the wavelength of 7000 Angstrom units, (red light). To convert this to millimicrons it is only necessary to divide by 10. Consequently, red light represents 700 millimicrons. Similarly, blue light which has a wavelength of 500 millimicrons can be expressed in Angstrom units by multiplying the 500 by 10. In other words, blue light has a wavelength of 5000 Angstrom units.

Light waves can be:

(a) radiated
(b) reflected
(c) absorbed
(d) refracted

The light waves which are normally encountered in everyday life undergo all of these conditions. Devices which radiate light waves are called light sources. The principle source of light in the solar system is, of course, the sun. There are, however, many other sources of light; for example, the candle, electric light, etc.

Everyone is also familiar with reflection of light. When light waves strike any object other than a solid black object, reflections of the waves occur. As a matter of fact, this is the method whereby we "see" most objects, since the majority of objects do not act as light sources themselves.

Most of the light waves which fall on an object and are not reflected are absorbed. In this respect the energy contained in the light wave is converted into heat energy on the surface of the material. It is the process of reflection and absorption coupled with the property of the eye which enables us to see colors. This will be dealt with in more detail presently. The color filters used with color television equipment also operate on the principle of absorption, for example, a red filter will absorb all light except red which it allows to pass through.

Refraction of light waves has been dealt with in some detail in the assignment on projection television receivers. In this assignment it was pointed out that as light waves travel through a medium which has a density that differs from that of air, the light waves will be bent or refracted. It is upon the principle of refraction that lenses such as those used in ordinary eye glasses, telescopes, television cameras, etc., operate.

Color Vision

Let us now consider the properties of the eye that produce the sensation that we know as color. White light, such as sunlight, contains all of the frequencies within the range of visible light shown in Figure 1, (4000 to 7000 Angstrom units). As long as these frequencies are present in the proper amount the appearance of the light is white. On the other hand if a light source emits only a few of the frequencies within the visible spectrum, then to the observer, the sensation of color is produced. For example, if the emitted light consists of only a light frequency with a wavelength of 7000 Angstrom units, or a small band of frequencies in the vicinity of 7000 Angstrom units, the sensation produced is a color we describe as red. Similarly, light waves with wavelengths of approximately 5000 Angstrom units produce the sensation of blue.

The exact manner in which sensations of the various types of colors are produced, when the rods and cones of the retina of the eye are struck by light waves of various frequencies, is not known. However for our discussion, it will be sufficient to merely state that the various color sensations are produced by light waves of different frequencies.

When the Associate considers the extremely short wavelength of the various colors of light the thought may occur that these figures are purely theoretical and could not have been substantiated. This is, however, far from the truth. It will be recalled that very effective means have been devised for measuring the wavelength of radio waves, for example, the Lecher wires. Similarly, very effective and very exact means have been devised for measuring the wavelength of the light waves of various colors.

The preceding explanation of the manner in which the sensation of color is produced appears satisfactory as far as the consideration of an actual light emitting source is concerned. However, suppose that a white light falls upon a colored object. The question arises; "Why does a red object, for example, appear red to the observer under the condition that white light is falling upon that object?" The answer to this question comes about through the light frequency absorption properties of certain materials. For example, if an object appears red when white light is falling upon it, that object is absorbing all frequencies except those contained in the red region. Thus in the case cited, only the light waves with wavelengths in the vicinity of 7000 Angstrom units are reflected from the colored object and all light waves with wavelengths outside of this range are absorbed. The light waves reflected from the object which have wavelengths of approximately 7000 Angstrom units produce the sensation of red when they strike the retina of the eye. Similarly when an object which is exposed to white light appears blue to the observer, it follows that all frequencies, except the band of frequencies that produce the sensation of blue to the observer, are absorbed by the blue object and the "blue frequencies" are being reflected.

Figure 2 is a chart which includes only the frequency spectrum of visible light. Although this drawing indicates that the color sensations produced by the eye change abruptly from one to the other at certain critical wavelengths, the actual case is that a gradual change takes place. For example, as the wavelength of the light is varied from red to orange, the color gradually changes from red to orange rather than abruptly from red to orange. Similarly orange gradually changes to yellow, etc.

Pigments

In our early training, probably in the third or fourth grade, we were told that the primary colors are red, yellow, and blue. At that time our experience was primarily limited to mixing water color paints to produce various colors. For example, we found that by mixing red and yellow pigments together an orange color was produced. Similarly by mixing yellow and blue paints together, a green color or mixture was produced. Furthermore, at that time we were more concerned with the results obtained rather than with an explanation concerning the reason for these conditions.

Before considering how it is possible for two colors of paint to produce a third color, let us consider in a little greater detail the process which is used. Note particularly that the mixing of paint does not involve the mixture of light sources. A paint, dye, or any other material which will cause an object to have the appearance of a certain color is called a pigment. Thus, in our grade school experiments, we were mixing pigments. The effect produced by mixing pigments is different from the effect produced by mixing light sources.

To explain the phenomenon of a third color being produced by the mixture of two other colors of pigments we must consider in more detail the reflection and absorption properties of a pigment. The first impression is likely to lead one to believe that a yellow pigment, for example, reflects only the frequencies of light producing the sensation of color called yellow and absorbs all other frequencies of light completely. Actually a yellow pigment reflects a band of frequencies in the vicinity of yellow. If the intensity of reflection of the various wavelengths of light from a yellow pigment is plotted, the graph will appear somewhat as shown in Figure 3(A). An analysis of this figure should show clearly that the yellow pigment produces the greatest degree of reflection for frequencies whose wavelengths fall in the region of yellow light. However, other frequencies are also reflected to a lesser degree. It will be noted that frequencies corresponding to green are reflected quite well from the yellow pigment. However, since the reflection for the frequencies in the region of yellow is greatest, this pigment gives the impression of yellow to the observer.

The reflection characteristics of another type of pigment is shown in Figure 3(B). This pigment reflects frequencies in the region of blue more predominantly than other frequencies; however, it will be noted that the green frequencies are also reflected to a fairly large degree from this pigment.

Now let us consider the condition which occurs when the two pigments whose reflection characteristics are indicated by Figure 3(A) and Figure 3(B) are mixed together. The reflection characteristics of the mixture are indicated in the graph of Figure 3(C). Since the yellow pigment, as indicated in Figure 3(A), and the blue pigment, as indicated in Figure 3(B), have considerable green reflecting properties, a combination of the two pigments in a predominant green reflecting property. In other words, the mixture reflects green to a greater degree than it does either blue or yellow. Thus the mixed pigments appear green to the observer. Let us stress the fact once more. The reason that the mixture appears green is that the frequencies in the vicinity of green are reflected to a greater degree than are the frequencies outside this portion of the spectrum.

To demonstrate the effect of mixing various pigments, a very simple apparatus is often employed. This apparatus is called a color disc and is illustrated in Figure 4. The color disc consists of a disc which may be rotated. Near the rim of the disc are three slots where slips of paper or plastic of the three primary colors may be inserted. As the disc is rotated the persistence of vision of the eye produces the same effect as if the actual colors were mixed. As for example, if only the yellow and blue colors are placed in the slots on the rim and the disc is rotated at a high speed, it will appear to the eye that a green rim is present around the disc. Similarly, if red and blue colors are rotated, the rim will appear to be purple, and yellow and red colors will cause the rim to appear orange. The secondary colors produced by the combination of any two colors are indicated in Figure 4 between the primary colors. If the three primary pigment colors of blue, yellow, and red are inserted in the color disc and rotated, the appearance of the rim will be gray approaching black. Thus it can be seen that the color disc may be used very effectively to demonstrate the result of mixtures of pigments.

Mixing Lights

Let us now consider the effect of mixing various colors of emitted light. Notice in this case that we are not concerned with reflected light but are dealing with light from light sources. For example, a mixture of yellow light and blue light will cause the eye to produce the color sensation we know as gray. Notice that the effects of mixing pigments and mixing lights are different. In the case of yellow and blue pigments, the reflected spectrums are broad enough that a relatively large amount of green light is reflected from each. When the two pigments are mixed, the amount of green light reflected, predominates and the sensation of green is produced by the eye. However, in the case of the transmission of two frequencies of light, namely blue and yellow, the blue light waves and the yellow light waves are actually transmitted to the eye of the observer. Notice that in this case there is no green light being transmitted to the observer, consequently the sensation of green is not produced by the eye. When these two colors of light strike the retina of the eye the sensation of gray is produced.

There are four primary colors used in the transmission of light. These are; red, yellow, blue, and green. By the proper combination of these various colored lights, all colors can be produced. However, as will be shown presently, by employing only red, blue, and green lights in the proper proportion, all of the colors may be produced.

Let us first consider an arrangement wherein the four primary light colors may be combined. Such an arrangement is shown in Figure 5 which is a colored light disc. In an experimental setup this disc may be arranged so that any or all of the four primary colors of light can be made to fall upon the eye of the observer. If more than one color of light is being emitted and the disc is rotated, the effect of a mixture of light will be produced by the persistance of vision of the eye.

If only red light wavelengths are transmitted to the eye, it will appear that a red rim is present on the disc as the disc is rotated rapidly. This also holds true for any of the primary light colors shown in Figure 5. For example, a green light will appear green. On the other hand, if two or more frequencies of light are transmitted, colors that are not actually present appear to be present to the observer. For example, when red and blue wavelengths of light are transmitted and the disc is rotated, the observer sees a red-blue color, or what is more commonly called purple. Similarly, if blue and green are transmitted the color appears as a blue-green mixture to the observer. Also if red and yellow are transmitted, the observer sees this as orange. To summarize the action of the light disc when two colors are used, the effect produced by any two lights is indicated by the color shown between these two lights. Notice for example, that shown between the green and yellow light is green-yellow. This indicates that if only the green and yellow lights are used the effect of green-yellow will be produced.

If the colors shown opposite to each other in Figure 5 are transmitted in the proper proportion, the result is a gray appearance to the observer. Another phenomenon which is particularly interesting is the fact that if the wavelengths corresponding to the four colors red, blue, green, and yellow are transmitted in proper proportion, the result is an apparent white light. Contrast this condition to the one shown for the pigment disc in which the combination of the primary colors produced an apparent black condition.

The colors shown opposite to each other in the drawing of Figure 5, are said to be complimentary colors. As stated, the general tendency when combining complimentary colors of light is to produce a gray. An exception to this, however, is the case when the complimentary colors red and green are combined. If these two colors of light are mixed in the proper proportion, the sensation of yellow light is produced by the eye. Notice that a red and green light produce the sensation of yellow. Also by the proper combination of red and green, an orange color may also be produced. If the effect of the phenomenon just outlined is considered, it should be apparent that a color disc could be designed which would produce all of the required shades through the use of only three colors. These three colors are blue, red, and green. A yellow light is not actually needed to produce the sensation of yellow colors since this can be produced by a proper combination of red and green.

To date no satisfactory explanation has been found for the phenomenon that the sensation of a color is produced by the eye when the eye is struck by mixtures of other colors of light. Thus we are limited to observing the facts and are unable to present a reason for their occurrence.

The foregoing explanation has indicated that all of the required colors can be produced by employing a combination of three of the primary colors. These colors are red, blue, and green. By properly combining these colors any color including white can be produced. From this it should be evident that a television system could be designed which would reproduce scenes in full color provided the three primary colors of red, blue, and green are successfully reproduced.

The light disc illustrated in Figure 5 illustrates one other important fact which should be clear before proceeding with the basic color television system. This is the fact that the properties of persistence of vision of the eye causes an additive effect to occur. For example, if the red, blue, and green lights on the disc are placed in rapid motion, the colors will appear to blend together and fuse into a white color. Notice that at any one time there is only one light present at a point. This light might be red, green, or blue, depending upon the position of the disc. However, the persistence of vision characteristic of the eye produce an effect exactly as if all three colors were present at the same place at the same instant. Thus it is obvious that the effect of the eye is additive. If the observer focuses his vision on a point on the light disc as it is rotating, first a red light will pass that point, then a blue light, and then a green light will pass that point. However, the observer does not see a flash of red, and a flash of blue, and a flash of green. Instead the three effects are additive and the observer sees white light. From this it should be apparent that if first the red portions of a television scene were reproduced, then the blue portions reproduced, and then the green portions reproduced, at a rapid enough rate, the sensation produced by the eye would be that of a full color reproduction of the original scene. The color television systems in use today are based upon the additive process described.

A Basic Color Television System

To obtain a basic concept of how color television can be accomplished, assume that a color filter is placed in front of the camera pickup tube, and that a similar filter is mounted in front of the picture tube of the receiver in such a way so that the reproduced scene must be viewed through the filter. Let us assume that red filters are in position in front of the camera tube and the receiver picture tube as the operation takes place. With this condition only the light from red portions of the scene can get to the sensitized plate in the camera tube. Thus a video signal corresponding to the red portions of the televised scene is generated by the camera tube, and the "red" video signal may be transmitted. This video signal causes the intensity of the electron beam in the picture tube of the receiver to vary in proportion to the "red" video signal being transmitted and since a red filter is present in front of the receiver at this instant, the observer sees the red portion of the picture.

Let us assume that at the next instant the filter at the transmitter and the filter at the receiver are changed to a green color. In this case only the green portions of the scene can get through the filter to the camera tube, and the video signal then transmitted corresponds to the green portions of the televised scene. This video signal then varies the intensity of the beam at the receiver in accordance with the green information transmitted and since the green filter is present in front of the receiver the observer sees the green portion of the reproduced scene.

Finally blue filters are placed in front of the camera tube and the receiver picture tube. Thus the blue portions of the television scene are transmitted. Furthermore, at the receiver the blue portion of the picture are seen since the blue filters are in front of the receiver. Notice that first the red portions of the scene were reproduced, then the green portions of the scene were reproduced, and finally the blue portions of the scene were reproduced. However, if these changes in color are made at a rapid enough rate, the additive effect mentioned previously will occur and the effect of all colors can be produced. For example, the correct portions of the scene will appear white by the addition of the red, green, and blue. Similarly, a yellow portion of the scene will be produced by the addition of the colors red and green in the proper proportion. If the information which has been presented previously is clearly understood, it can be seen that any color present in the original scene can be reproduced by this method.

To convert the basic color television system just described into a practical one it is only necessary to arrange the system so that the filters at the receiver and the transmitter are changed at the proper instants and the video information is, of course, transmitted properly.

The basic system which has been described is sometimes called a sequential color television system because the information corresponding to one color is transmitted, then the next color, then the next color, etc.

Another basic system that presents a practical method for color television is called the simultaneous color television system. With the simultaneous system the camera equipment employs three photosensitive surfaces on which the red, green, and blue areas of the scene are focused by means of lenses and appropriate filters. The three photosensitive surfaces are scanned simultaneously and three independent video outputs corresponding to the red, green, and blue components of the scene are generated. These three video signals are transmitted on separate channels using separate transmitters for each color. At the receiver the incoming signals are fed to a common mixer circuit where the local oscillator beats with the incoming frequencies to produce three picture i-f signals.

The three video i-f signals in the receiver are amplified through three independent i-f channels. Each video i-f channel has it's own detector which is followed by a conventional video amplifier. The outputs of the video amplifiers go to three picture tubes. The picture tube which is fed the signal from the "red i-f" channel has in front of it a red filter, the one fed from the "blue i-f" channel has a blue filter in front of it, and the third picture tube which is fed from the "green i-f" channel has a green filter in front of it. The combination of the three picture tubes is sometimes referred to as a triniscope. The images present on the three picture tubes are brought to focus (through the filters mentioned) on the same surface. In this way the three colored scenes are combined and are seen simultaneously. In this manner full color reproduction is obtainable.

The basic simultaneous color television system has the advantage that no moving parts are required, (the filters remain in place all the time). The disadvantage of this arrangement is however, that a large number of circuits are required for its operation.

A problem that arises in connection with both the simultaneous and sequential color television systems concerns the bandwidth required for satisfactory transmission. The Federal Communications Commission has assigned a 6 mc channel for use in transmitting monochrome television pictures. Both the sound and picture information must be included in the 6 mc channel. However, the basic television systems which have been explained would require a bandwidth from 12 to 15 mc if the present black and white line and frame frequencies are maintained. Such a wide bandwidth cannot be tolerated if a larger number of television stations are permitted to go into service.

There is one other important factor to consider in the choice of a color television system. This is the fact that it is highly desirable to use the same standards for both systems. If this is done, an ordinary television receiver can pick up the program from a station transmitting a color television system. Of course in this case the reproduced picture will appear as a black and white scene. Similarly, a color television receiver could be used to pick up a "black and white" television signal transmitted by a television station. When the black and white and colored television systems will permit this type of operation, the systems are said to be <u>compatible</u>.

In view of the desirable factors for a color television system it should be apparent that the basic systems are not applicable without modifications. However, it will be of value to consider these systems in more detail to obtain a more thorough understanding of the underlying principles of color television.

Sequential Color Transmission

A system employing sequential color transmission was developed by the Columbia Broadcasting System. As already explained in sequential color transmission only one color at a time is transmitted. In order to better understand the principles of operation of this system refer to Figure 6. The color disc shown in this figure is placed between the camera and the scene so that at any instant of time only one particular color can get through to the photosensitive surface of the camera pick-up tube. Red, blue, and green colored filters are arranged around the edge of the disc and the disc is rotated in front of the camera by a motor. As the disc rotates the filters are brought in front of the camera so that the colors are transmitted one at a time.

Assume first that a red filter of the color disc is in front of the camera. The picture output of the camera then contains only red picture information. This output is fed to a video amplifier similar in construction to an ordinary video amplifier with the exception that the bandwidth has been increased. The increased high-frequency response of the video amplifier is necessary as a result of the increased rate of scanning needed to avoid objectionable flicker. In the conventional black and white television system complete scanning of a field occurs in 1/60th of a second. In comparison, for the sequential color television system one field is scanned in 1/44th of a second. This increased scanning rate causes an increase in the video frequencies generated and the actual bandwidth of the video amplifier approaches 16 mc, if the amount of flicker in the color television system is to be approximately the same as for the standard black and white system.

With reference to Figure 6, it is seen that the motor driving the color disc is synchronized from the synchronizing generator. Synchronizing signals are also transmitted so that the color disc used at the receivers will be in exact synchronization with the disc at the transmitter. Unless this requirement is met, the colors reproduced would be meaningless.

As mentioned previously, the three color filters are brought in front of the camera in sequence as the color disc rotates so that video signals corresponding to the other colors are transmitted. Thus we see that at any instant of time the output of the video amplifier of Figure 6 contains only the video signals corresponding to a particular color. The output of the video amplifier is later combined with the composite sync and blanking signals. From there the total output is fed to a conventional television transmitter which has been modified to accommodate the increased bandwidth.

A block diagram of a receiver suitable for use in a sequential color television system is shown in Figure 7. Inspection of this drawing should show that the mixer, oscillator, picture i-f, detector, and video amplifiers are no different from the ones of the conventional black and white receivers. However, it will be found that the bandwidth of all of the circuits is such that picture frequencies up to 16 mc can be handled. The output signal from the video amplifier is fed to a single picture tube similar to the picture tube used in the standard black and white television receivers.

In Figure 7 the output of the detector is also fed to a sync separator circuit. Here synchronizing signals are removed from the rest of the video information and used for synchronizing the deflection circuits of the picture tube. Also synchronizing signals are obtained for application to the motor that drives the color disc. In this way the color disc at the receiver will be in exact step with the color disc at the transmitter. The reproduced scene is viewed through the revolving color disc and the filters in the disc allow successive red, green, and blue portions of the picture to reach the eye of the observer. The additive process of the eye converts these separate flashes of colored scenes into the full-color reproduced scene.

One of the major problems in the sequential color television system is presented by the motor and color disc arrangement at the receiver. The disc must be rotated at a high rate of speed and must be maintained in exact synchronization with the disc at the transmitter. If a relatively large picture tube is used, the disc itself becomes somewhat bulky and it is difficult to attain the required speed of rotation without a great degree of vibration.

As mentioned previously, the use of the existing standard field and line rates for sequential color television system results in a great deal of flicker. For this reason, it has been found necessary to increase the field frequency and the frequency of 144 cps has been used experimentally. However, if the increased field frequency of 144 cps is employed and the same line frequency as used in the monochrome system is used the excessive bandwidth mentioned results. In an attempt to produce satisfactory color television with the sequential system the number of horizontal lines per frame have been reduced to 405, the field frequency of 144 cps is employed, and since interlaced scanning is used the line frequency is 29,160. This produces a sequential color system with a 6 mc bandwidth. The resolution which can be achieved in this system is however, considerably less than that produced in the standard black and white system since the number of picture elements which may be accommodated is less than one-half those in the black and white system.

The low value of resolution produced in this system which has been developed by Columbia Broadcasting System is, however, compensated for to a certain degree by employing efficient peaking circuits in the video amplifiers so that the full bandwidth characteristics are employed. Also as mentioned previously, the fact that the reproduced scene is in color compensates to a certain degree for the loss in detail. This effect is, however, present in all color systems.

Even with the high field frequency of 144 cps a certain amount of flicker is noted when the scenes being televised are relatively bright. Since this system provides a means of transmitting the color television signal in a 6 mc bandwidth, it is a forward step over the system explained previously. There is one disadvantage to this system and that is, it is not compatible. In other words, the color transmission from a television station could not be received on an ordinary receiver and produce a black and white reproduction; similarly, a color television receiver using this system cannot receive the signal from a "black and white" television station. It is of course possible to design the sweep circuits in the receivers so that, through a switching arrangement, either the line frequencies for the black and white system or for the color system could be employed. It is also possible to manufacture an adapter so that after the sweep frequencies have been changed, the black and white receiver can be used for color reproduction.

The Simultaneous Color System

The simultaneous system which was developed by RCA disposes of the mechanical color discs but introduces a large number of electronic circuits. However the simultaneous color system has certain advantages that cannot be overlooked. First of all the three colors are transmitted at the same time and therefore the number of lines and the number of fields need not be changed from those employed in the black and white system. This can be seen by considering the reasons for changing the standards for the sequential scanning system. Here it is necessary to change the scanning rate in order to reduce objectionable flicker. This flicker was brought about by the sequential method of presenting color pictures. By this is meant that only one color was transmitted at a time. Unless the scanning rate is increased the effects of one color of the picture will begin fading before presentation of the other two colors have been completed. In the case where simultaneous transmission of the colors occurs this is not the case because all colors are transmitted simultaneously.

The fact that the number of lines, fields, etc., remain unchanged in the simultaneous color system is a decided advantage, since this presents the possibility that a standard black and white receiver can be used to pick up color transmission, even though the picture will appear in black and white.

A basic diagram showing the principles of simultaneous color television is shown in Figure 8. This arrangement is used for transmitting a film program and serves to illustrate the general principles in a simpler manner than would be the case for a studio camera. It will be noted in this figure that a kinescope or picture tube is employed. However, it should be emphasized that no picture is present on this tube. The deflection circuits are employed so that the beam traces out the normal scanning raster. However, a special screen material is employed on this kinescope having a very short persistence so that only a single spot of light is present at any particular instant of time. This is the purpose of the kinescope, to produce a spot of light which is used to scan the film so that the information on the film can be converted into electrical information. To accomplish these results it is necessary to employ the same general principle as in a conventional television system. In other words, only a very small part of the scene on the film is converted into an electrical pulse at any instant.

The spot of light from the kinescope is caused to pass through the film through the action of the projection lens illustrated. The intensity of the light which passes through the film will vary in proportion to the picture on the film. If color film is used the color of the light which passes through the film will be in accordance with the color of the particular portion of the film being scanned at that instant.

It will be noted that the remaining portion of the diagram of Figure 8 consists of a condenser lens, a special mirror, and three photocells. The light passing through the film is collected by the condenser lens and caused to fall upon the special mirror. The mirror used in this case is a color sensitive mirror. If the light striking the front surface of the mirror is red, it will be reflected to the photocell labeled red as shown. However, if the light is any color but red it will pass through this surface of the mirror. If the light has blue characteristics it will be reflected from the surface of the second portion of the mirror onto the photocell labelled blue. The green portions of the light will, however, pass entirely through the mirror and fall on the photocell labeled green. In this way the three primary colors of light are separated.

The photocells shown are of the multiplier type producing relatively strong output signals. These signals are fed to three independent video channels and from there to separate modulators. Finally three separate transmitters are modulated and the resultant energy transmitted at three different carrier frequencies.

The Simultaneous Color Television Receiver

A block diagram of a television receiver for use with the simultaneous color system is shown in Figure 9. The incoming signals that contain the green, blue, and red picture information and sound information are amplified by a common r-f amplifier. These signals are fed to a mixer stage where the local oscillator signal mixes with these r-f signals producing the four i-f signals in the plate circuit of the mixer stage. These signals consist of the sound i-f frequencies, the green picture i-f frequencies, the blue picture i-f frequencies, and the red picture i-f frequencies. The picture frequencies are amplified by independent video i-f amplifiers as shown in Figure 9. In addition a separate sound i-f amplifier is shown for the sound i-f frequencies. However, it is possible to take the sound i-f frequencies through the green video i-f amplifier.

As shown in the figure, separate detectors and video amplifiers are used for each picture tube. The sync separater circuit is only taken from the video amplifier handling the green picture signals and is done in the conventional manner. That is, the composite signal appearing at the output of the video amplifier is fed to a sync separator circuit where the synchronizing signals are removed from the balance of the composite signal. The output of the sync separator then goes to a conventional deflection circuit which is not shown in the block diagram. The output of the deflection circuit goes to deflection coils connected in parallel. Since there are three picture tubes involved in this system, it follows that three sets of deflection coils are required. These deflection coils are usually connected in a parallel combination and independent centering controls are provided for each set of coils.

The images produced on the three picture tubes are focused, one on top of the other, on a viewing screen where the various colors of light are mixed to produce the full color reproduction. It is also possible to use a special mirror arrangement as illustrated in Figure 7 so that the three picture tubes may be viewed directly to produce the full color.

As already mentioned the simultaneous color television system may be used to receive black and white pictures. This may be understood by reference to Figure 9. If the blue video i-f amplifier and the red video i-f amplifier together with the associated components are removed, a conventional television receiver remains and if the picture tube used does not have a green filter the reproduced scene will appear black and white to the observer.

Sequential Line Color Television System

In the sequential color television system explained previously, it will be noted that the color changes take place at the field rate. That is, first a complete field is scanned in one color, then the filter is changed and the next field is scanned in the second color, etc. It should be apparent that it would be possible to develop a color television system in which the subsequent lines are scanned in different colors. Such a system has been developed by Color Television Incorporated.

Figure 10 illustrates the operation of the sequential line system. Three separate lens systems, each containing a primary color filter, are employed in the camera and project the three color images of the scene on the photo cathode of an image orthicon tube. As shown in Figure 10, these images lie side by side. The scanning beam in the image orthicon tube traces across the three electron images on the target as illustrated in Figure 10. The actual scanning rate is 5250 cps, but since the three images are scanned for each excursion of the scanning beam the line rate produced is 15,750 cps. It should be obvious also that the information present in the lines follows in the sequence of red, green, and blue. As indicated in Figure 10, there is a space present between the various images. Standard synchronizing pulses may be transmitted as the beam covers this area so that the signal may be used with the standard black and white receiver.

In the receiver used with this system, three.images are formed side by side on the face of the picture tube. The scanning sequence in the receiver is the same as that employed in the camera. The three images so produced are focused on a viewing screen or viewing mirror by means of three separate optical systems and appropriate filters. The additive process of the eye converts this multiple image into a full-color reproduction. It is also possible to employ special phosphors on the screen of the picture tube to produce the required three colors instead of using filters.

One of the chief advantages of this system is the fact that the scanning frequencies used are identical with those used in the black and white system and this color signal can be received on a standard receiver and reproduced as a black and white picture. The composite video signal must be modified slightly however, for use with this system although the modification will not effect the standard black and white receiver. Since 525 (the number of lines) is divisible by three, the result is that the same lines on the scene, will be produced in the same color in each case. This is an undesirable condition since it tends to produce a scene which is rather coarse. To eliminate this condition it is possible to transmit a notched pulse during the vertical blanking interval which changes the point at which the scanning beam starts on the image. In this way one particular area of the scene will be scanned only on every third field, thus producing better detail.

Sequential Dot Color Television System

In the first sequential system which has been explained, the color sequence was varied at a field rate. That is an entire field was scanned in one color, then the next color, etc. In the color system which has just been described, the color sequence occurred at the line frequency or, in other words, a line was scanned in one color, then the next line was scanned in the next color, etc. In a system proposed by the Radio Corporation of America, each line is effectively broken up into small areas, or dots, of color and the information from these colored dots transmitted in sequence. This system is compatible. That is the color transmitted signal can be reproduced on a standard receiver as a black and white picture, and the bandwidth required is 6 mc.

Before taking up the block diagram of the sequential dot color television system, it will be necessary to illustrate the principles upon which the system functions. To develop an insight into the working principles refer to Figure 11. In this drawing are shown three sets of pulses with different amplitudes. The repetition rate of the three sets of pulses is identical. Suppose that we use the pulses of Figure 11(A) as a video signal application to the grid circuit of a receiver picture tube. Providing that these pulses are a multiple of the horizontal line frequency a series of dots will be generated on the picture tube screen. A dot is generated for each positive excursion of the waveform. For example when the positive excursion marked 1 of Figure 11(A) occurs a bright dot will appear on the picture tube screen. Similarly other dots will appear on the positive excursions labelled two and three. Since waveform (A) is a continuous waveform generating an endless chain of positive pulses, the whole screen will be filled with a series of dots.

Suppose next that waveform (B) of Figure 11 is applied in place of waveform (A). What effect will this have upon the reproduced information as seen on the face of the cathode-ray tube? Since waveform (A) and waveform (B) are identical in repetition rate the position of the dots formed by each waveform will be identical also. However since the amplitude of the waveforms are not alike, the intensity of the dots as seen on the picture tube screen will be different for the two waveforms. It should not be hard to visualize that waveform (A) of Figure 11 will produce brighter dots than waveform (B) since the amplitude of waveform (A) is the greatest. Thus by varying the amplitude of the waveform we can change the intensity of the dots as seen on the screen. Thus in going from waveform (A), (B), and through (C) of Figure 11, the illumination of the screen will change from a high to a low light level.

The foregoing behavior of the varying amplitude pulses suggests a method of color television but before we consider the system for color transmission, let us consider the possibility of using the principle associated with Figure 11 for producing a black and white picture.

The basic block diagram for such a television system is shown in Figure 12. This television receiver is identical to a conventional television receiver with the exception of the pulse generator.

In Figure 12 it is seen that the detector output feeds the composite video signal to the pulse generator and also to the sync separation circuits. The applications of the composite video signal to the sync separation circuit is conventional and requires no explanation. However, the application of the composite video signal to the pulse generator is new in principle. The purpose of this arrangement is to cause the pulse generator to produce pulses, the amplitude of which are proportional to the amplitude of the video signal.

To better understand the operating principles consider the following. The pulse generator without an input signal from the detector generates series of pulses of constant amplitude and with a shape similar to those shown in Figure 11. As the signal from the video detector is applied, the amplitude of these pulses changes in proportion to the amplitude of the video information. Thus the signal from the pulse generator, which is fed to a conventional video amplifier, has amplitude proportional to the picture information. These pulses vary the beam intensity of the picture tube in the conventional manner. The recurrence rate of these pulses is great compared to the time of one horizontal line. To be more specific let us assume that the pulses from the pulse generator occur at the rate of 4,000,000 per second. Then the number of pulses generated during the time of one horizontal line will be approximately:

$$\text{Number of pulses} = \frac{4{,}000{,}000}{15{,}750} = 254$$

This is the approximate number of pulses that will be generated during one horizontal line. This means that the picture will take the appearance as in the normal television receiver with the exception that it will be generated in the form of a series of dots of varying intensities, rather than a solid line of variable intensity as in the case of the conventional black and white receiver.

At first such an arrangement may not appear to offer any advantage whatsoever over the more conventional television system. The advantage of the system of Figure 12 over the conventional system may be seen by reference to Figure 13. In this figure waveform (A) represents the pulse generator output without input signal and waveform (B) represents the output of the detector of Figure 12 and is, therefore, the signal applied to the input of the pulse generator. With an input signal applied to the pulse generator, the output of this generator changes to waveform (C) of Figure 13. It should be evident that the output of the pulse generator is proportional to the amplitude of the video signal of waveform (B) of Figure 13.

Before considering waveform (C) further, let us consider the effect produced if waveform (B) were applied directly to the grid-to-cathode circuit of a conventional picture tube. Notice that the sides of waveform

(B) are not vertical. Rather they have considerable slope and will cause the picture to change gradually from black to white during the occurrence of the pulse rather than abruptly from black to white. This gives the appearance of poor definition since the change from black to white is not rapid. Consider next the action of waveform (C) as applied to a picture tube. Here the pulses have nearly vertical sides and therefore when a pulse occurs the picture changes very rapidly from black to white. This gives the appearance of sharper definition than that produced by the application of waveform (B) of Figure 13 to the picture tube. Since the amplitude of the pulse of waveform (C) is proportional to the amplitude of waveform (B), a true scene will be reproduced except the definition will be improved.

In Figure 13 an ideal case is represented since the pulses from the pulse generator occur at exactly the correct time. In the case where a pulse from the input signal did not coincide with a pulse from the pulse generator, then the advantages of the system would be lost. This results from the fact that a pulse from the input signal could occur at a time when no pulse is present from the pulse generator. This undesirable condition can be corrected by having a high pulse repetition rate. For example, if a large number of pulses occur during the time of one horizontal line then it follows that between pulses of Figure 13(B), for example, that a large number of pulses from the pulse generator could occur. With a large number of pulses it is possible to always have pulses occurring from the pulse generator at approximately the right time.

In summarizing the preceding discussion it should be evident that the over-all performance is to artificially improve the definition of the system. The sequential dot system of color television is based upon these principles. In order to produce colored pictures, however, three independently acting pulse generators must be employed.

To obtain a general idea of the working principles of the actual system refer to the waveforms of Figure 14. Waveforms (A), (B), and (C) of this figure represent the outputs of three pulse generators similar to the one shown in the block diagram of Figure 12. The receiver circuits are so arranged that waveform (A) is made to vary in amplitude in proportion to the amplitude of the green picture information at the output of the receiver second detector. Similarly waveforms (B) and (C) are made to vary in amplitude in proportion to the amplitude of the blue and red picture information. This system could be arranged in a workable fashion by employing the circuit of Figure 9. With reference to this circuit a pulse generator, would be inserted between the detector and video amplifier of each section of the receiver. However, if such a method is used the over-all bandwidth of the system will be as great as ever and hence the requirements of limiting the bandwidth to 6 mc will not have been met. However, by means of an electronic switching arrangement, it is possible to switch rapidly from one signal to another so as to give the appearance of continuous pulses of green, blue, and red picture information.

Block Diagram Of Color Television Transmitter

The basic block diagram of the sequential dot color television system transmitting equipment is shown in Figure 15. The color camera shown in block form employs an arrangment similar to the color television camera shown in Figure 8. As a matter of fact, the film camera shown in Figure 8 could be used with the system shown in Figure 15. If it is desired to use an image orthicon camera, an arrangement is employed for three image orthicon tubes and a special mirror arrangement is used to break up the color in the scene into the three primary colors for application to the three image orthicon tubes. In this way three independent color outputs are obtained. The three independent video output signals corresponding to the three primary colors are fed to the three low-pass filters as shown. These filters are used so that video frequencies in excess of 2 mc are not passed.

The output signal from the low-pass filters are then applied to the sampler circuit. The sampler circuit consists of an electronic switch combined with a pulse generator. The amplitude of the pulses obtained from the output of the sampler is varied in proportion to the amplitude of the applied video signals. That is, the electronic sampler first causes these pulses to be in proportion to the amplitude of the green signal, then the red signal, and then the blue signal. In this manner the pulses obtained from the sampler vary in amplitude in direct proportion to the intensity of the various light components of the original scene. The sampler chooses between the three colors of the video signal at a rapid rate thereby causing the output signal to change from one color to another many times during the time of one line. In this manner adder number 1 contains pulses corresponding to the green, blue, and red picture information from the television camera.

The blanking and synchronizing signals from the sync generator are also applied to adder number 1 where they are combined with the video information to produce the composite video signal. In addition to combining the output of the sampler and the synchronizing generator the high-frequency components of the video signal are also combined with the signal in adder number 1. It will be noted that the three output signals from the color camera are passed through low-pass filters which will not allow frequencies in excess of 2 mc to pass. However, the output signals from the camera are also applied to adder number 2. Here the three components are combined and pass through the bandpass filter. This filter will allow only signals whose frequencies range between 2 mc and 4 mc to pass. Thus, the high-frequency components of the three video signals are combined and applied to adder number 1. This combination of the high-frequency components of the three color video signals is often referred to as the mixed-high component. It would seem that the mixing of these high-frequency components would result in a deterioration of picture detail. However, this is used to increase the detail of the picture. To understand this statement, let us consider very briefly the full color reproduction of pictures by the printing process.

In color printing it is customary to produce full-color reproduction through the use of the three primary colors and a fourth plate which prints the black, white, and gray colors. It has been found that through the use of this fourth plate, the detail of the reproduced picture is improved. In other words, the fine detail is reproduced in black, white, and intermediate colors of gray, while the larger areas are produced in color. These same results have been observed in television and it is for this reason that the high-frequency signals are combined. It will be recalled, that the mixture of the three primary colors of light produce white light and shades of white ranging through gray, depending upon the amount of each color of light contained in the mixture. Thus the high-frequency components, which correspond to the fine detail in the scene, are combined and will be reproduced as fine white and black detail.

After the mixed-highs have been combined with the sampler signal and the synchronizing signals in adder number 1 the output signal is coupled to the low-pass filter. This circuit is so arranged that no frequencies higher than 4 mc will be passed for application to the modulator of the transmitter. Thus the transmitted signal will occupy no more bandwidth than the limit set forth by the Federal Communications Commission.

To briefly summarize this system, the sampler breaks up each line into a large number of pulses or dots, and the amplitude of these dots is proportional in sequency to the green, red, and blue information along the line. The high-frequency components of the three video signals are also combined so that the transmitted information is in the form of pulses, which will produce dots corresponding to the various colors and also will have fine detail in black and white.

Let us now determine the manner in which these signals are converted into color in a receiver designed for use with this system.

Block Diagram of the Sequential Dot Color Television Receiver

Figure 16 shows the basic block diagram of a television receiver suitable for use with the sequential dot color system. The r-f amplifier, mixer, oscillator, video i-f amplifier, and detector are identical to those used in a conventional black and white television receiver. The output of the detector feeds a sync separator which in turn feeds the conventional deflection circuits for the three picture tubes required in the color system. The horizontal synchronizing pulses are used to synchronize the sampling pulse generator in the receiver with the sampling pulse generator at the transmitter. The sampling pulse generator produces pulses similar to those shown in Figure 14.

It should be noted that the sampler of the circuit of Figure 16 is synchronized with the sampler of the transmitter. In other words, when the sampler at the transmitter is receiving a pulse from the red camera the sampler in the receiver is applying the signal to the red video amplifier. Similarly, when the sampler in the transmitter is receiving a signal from the blue camera, the sampler in the receiver is applying the signal to the blue video amplifier.

Since the video signal is applied from the detector to the sampler circuit, the output pulses from the sampler are made to vary in amplitude in proportion to the video signal shown in Figure 13. For example, the green signal information at the output of the detector causes the pulses applied to the green video amplifier to vary in amplitude in proportion to the green picture information. Similarly, the blue picture information in the output of the second detector varies the amplitude of the pulses applied to the blue video amplifier.

The pulses from the three video amplifiers vary the intensity of the beams of their respective picture tubes in proportion to the amplitude of the pulses. Thus reproduced scenes are produced on the three picture tubes in series of dots as explained in connection with the black and white receiver of Figure 12. However, the intensity variations on one picture tube are in proportion to the green component of the video signal, the variations of another tube are in proportion to the red picture information, and the intensity variations on the third tube is in proportion to the blue picture information. A series of color sensitive mirrors or lenses and color filters may be used for viewing the three picture tubes so that the additive processes of the eye combine these three color scenes into a full-color reproduction of the original scene.

The Block diagrams of Figures 15 and 16 would seem to indicate that the sampler is a mechanical switch. Actually, however, it is an electronic circuit used for switching rapidly from one circuit to another. It is possible to use a number of frequencies for the sampler and sampling frequencies of 3.8 mc have been employed in an experimental setup.

Present State of Color Television

At the time of this writing standards have not been adopted for color television. The Federal Communications Commission has been holding hearings for many months concerning color television. The various companies who are interested have demonstrated their systems to the FCC and the advantages and disadvantages of the various systems have been studied. It is generally conceded that it will be highly desirable, if the color television system and the black and white system are compatable. In this way the existing television receivers can be used to receive monochrome reproduction of colored transmissions. Another factor which is considered highly important is the cost of modification which must be performed on existing receivers to convert them into color receivers. In this respect the CBS sequential field system seems to be superior to the RCA dot sequential system. However, the reduced definition of the CBS color television system may prove to be too great a disadvantage. While the dot sequential system is, theoretically, capable of producing a colored reproduction with a high degree of definition the demonstrations have not, at the time of this writing, lived up to expectations.

The line sequential system which has been developed by Color Television Incorporated is the newest system and has not been demonstrated before the FCC at the time of this writing.

The choice of the color television system is a very vital one as far as television industry is concerned. In the first place the FCC has held up issuance of any further television station permits until this choice has been decided upon. The reason for this is the fact that the present twelve channels definitely do not provide enough frequency allocation for nationwide coverage in television. For this reason it is desirable to place television stations in the higher frequency spectrums. The color television stations will also be placed in this region and the FCC cannot determine the proper placement of the various services until the channel width requirements of the color television systems have been determined. If it can be definitely established that color television can be successfully handled in a 6 mc bandwidth, it will then be possible for the FCC to make channel assignments for the higher frequency stations and permit the resumption of the black and white television station construction. Until this decision has been made, however, the construction of television stations is at a standstill.

On the other side of the picture, however, is the fact that the FCC wishes to be absolutely positive in its choice concerning the color television system. Once a system has been adopted and many receivers manufactured for use with this system, it will be very difficult to change the standards. For this reason it is evident that the correct decision must be made in the first place. One other fact is that many developements are taking place which might, very shortly cause any color system which has been adopted to be obsolete. For example, special color television picture tubes are being experimented upon, which, if successful, may greatly simplify the subject of color television.

Test Questions

Be sure to number your Answer Sheet Assignment 100.
Place your Name and Associate Number on every Answer Sheet.
Send in your answers for this assignment immediately after you finish them. This will give you the greatest possible benefit from our personal grading service.

1. How many Angstrom units are there in one millimicron?

2. (a) What are the three primary colors of pigments?
   (b) What two primary colors of pigments must be mixed to produce green?

3. What is the approximate range of wavelengths of visible light?

4. (a) What are the four primary colors of light?
   (b) What three colors of light can be combined to produce all of the colors?

5. In the sequential field color television system (CBS system) is it necessary for the color disc at the receiver to be synchronized with the color disc at the camera? Why?

6. In the sequential field color television system, why is it necessary to use a higher field frequency than that used in the standard black and white system?

7. In the sequential line color television system the scanning beam moves across the entire image at a rate of 5250 cps. The line frequency in this case is, however, 15,750. Explain how this occurs.

8. In the sequential dot color television system why are the high-frequency components of the video signal mixed together and added to the output of the sampler?

9. What controls the amplitude of the output signal from the pulse generator in the sequential dot system?

10. What is meant by compatability? Explain why this factor is important.

ELECTROMAGNETIC FREQUENCY SPECTRUM

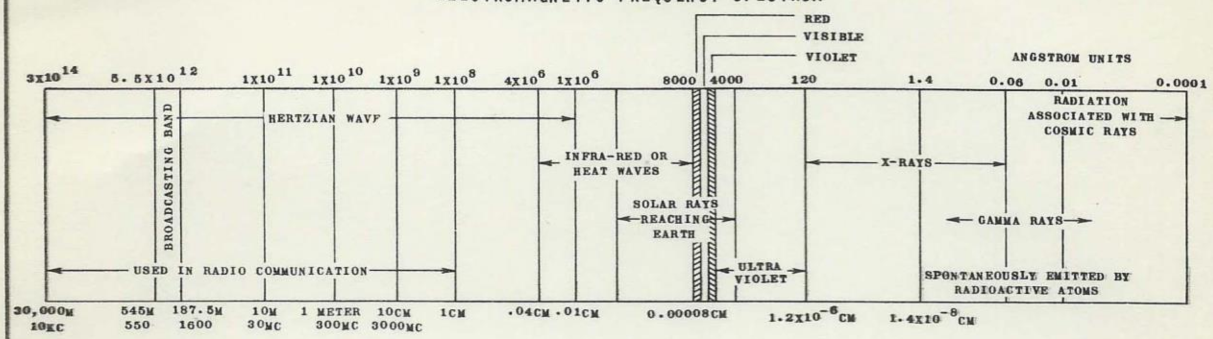
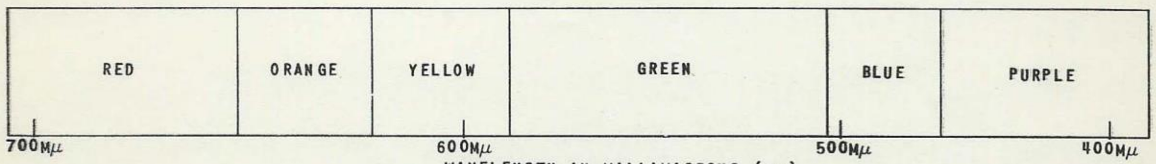


FIGURE I

VISIBLE LIGHT



WAVELENGTH IN MILLIMICRONS (Mμ)

FIGURE 2

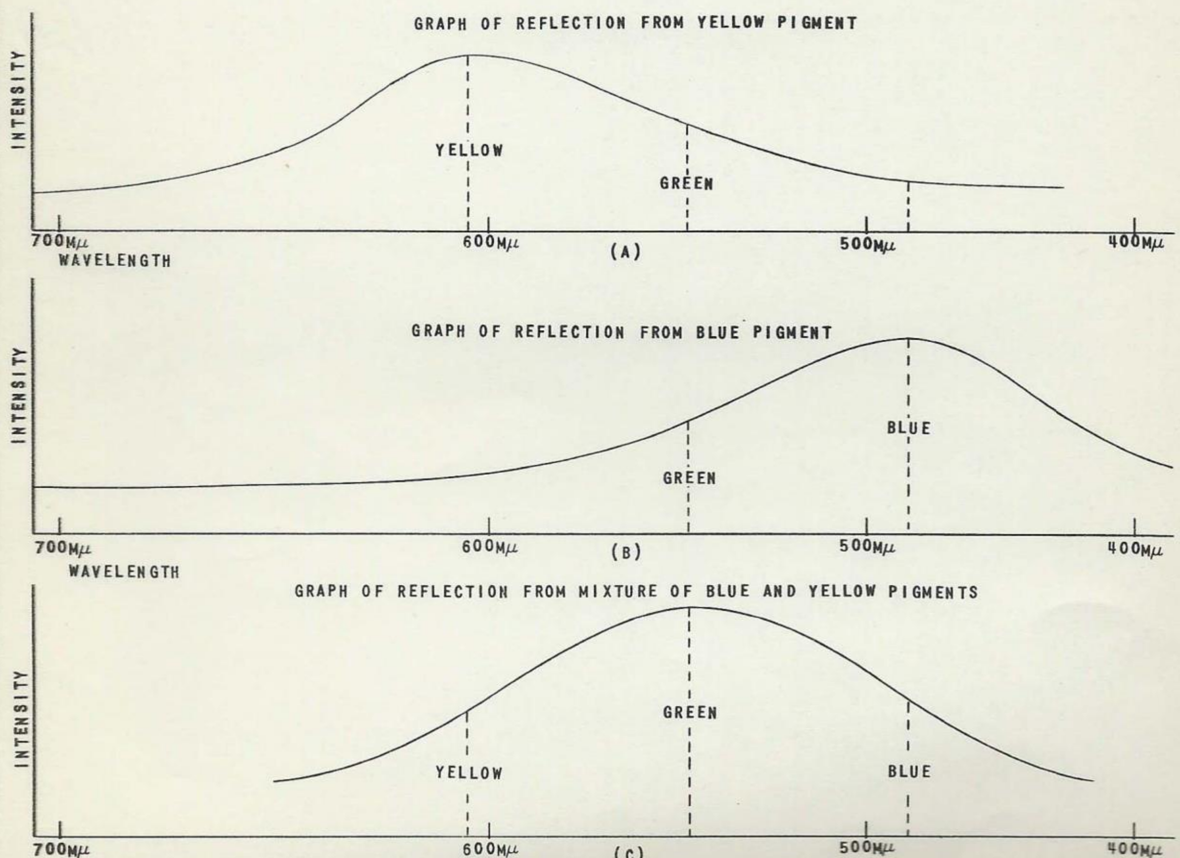


FIGURE 3

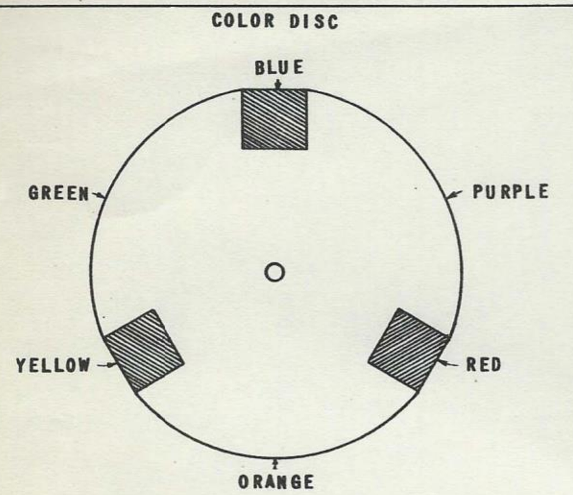


FIGURE 4

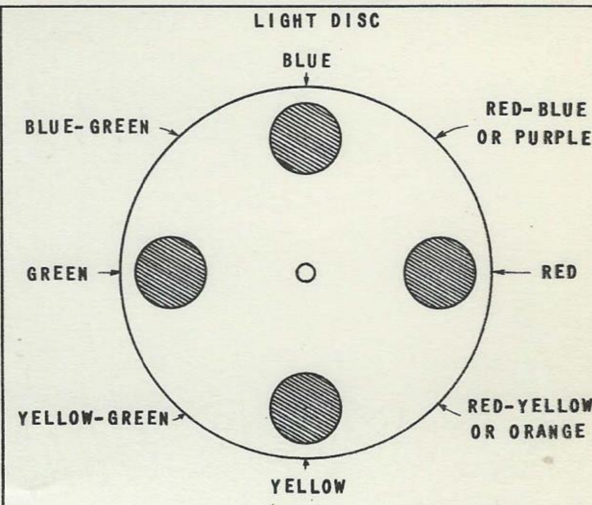


FIGURE 5

BLOCK DIAGRAM OF SEQUENTIAL COLOR TELEVISION PICKUP

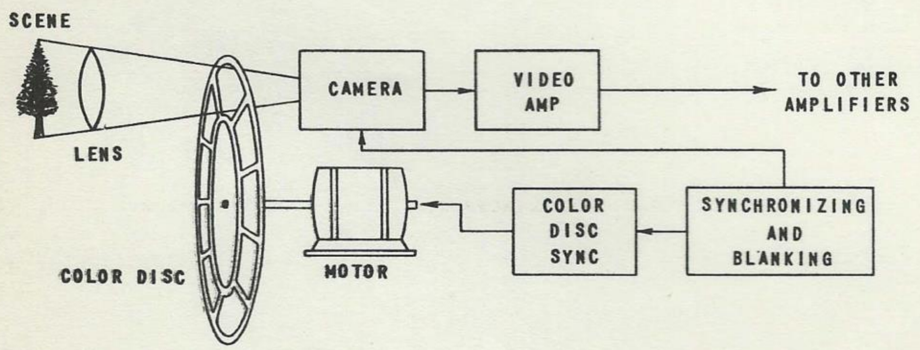


FIGURE 6

BLOCK DIAGRAM OF SEQUENTIAL COLOR TELEVISION SCANNER

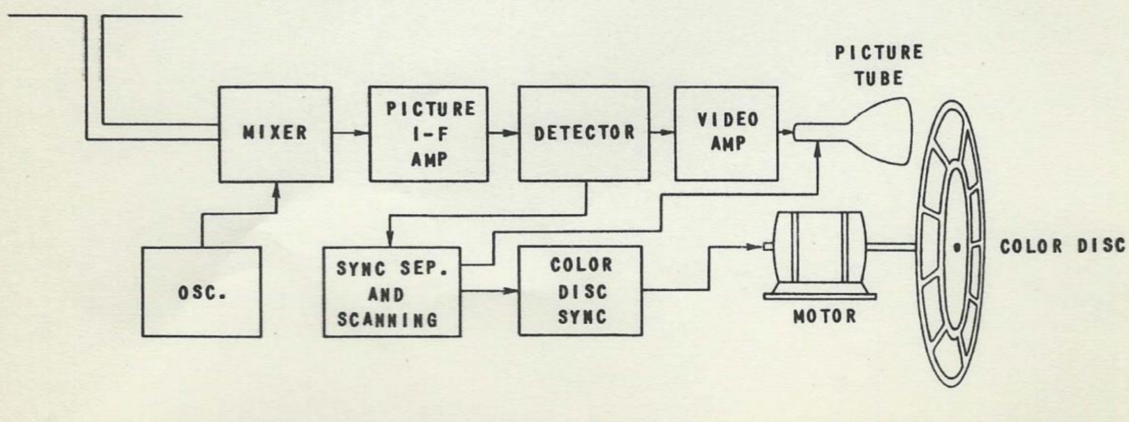


FIGURE 7

DIAGRAM OF THE COLOR-FILM SCANNER

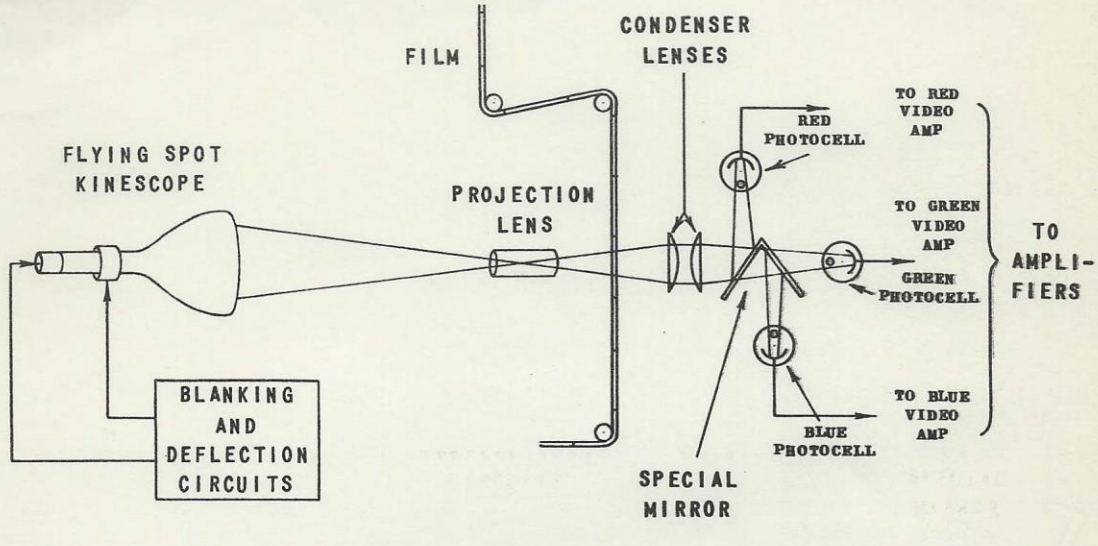


FIGURE 8

BLOCK DIAGRAM OF SIMULTANEOUS COLOR TELEVISION RECEIVER

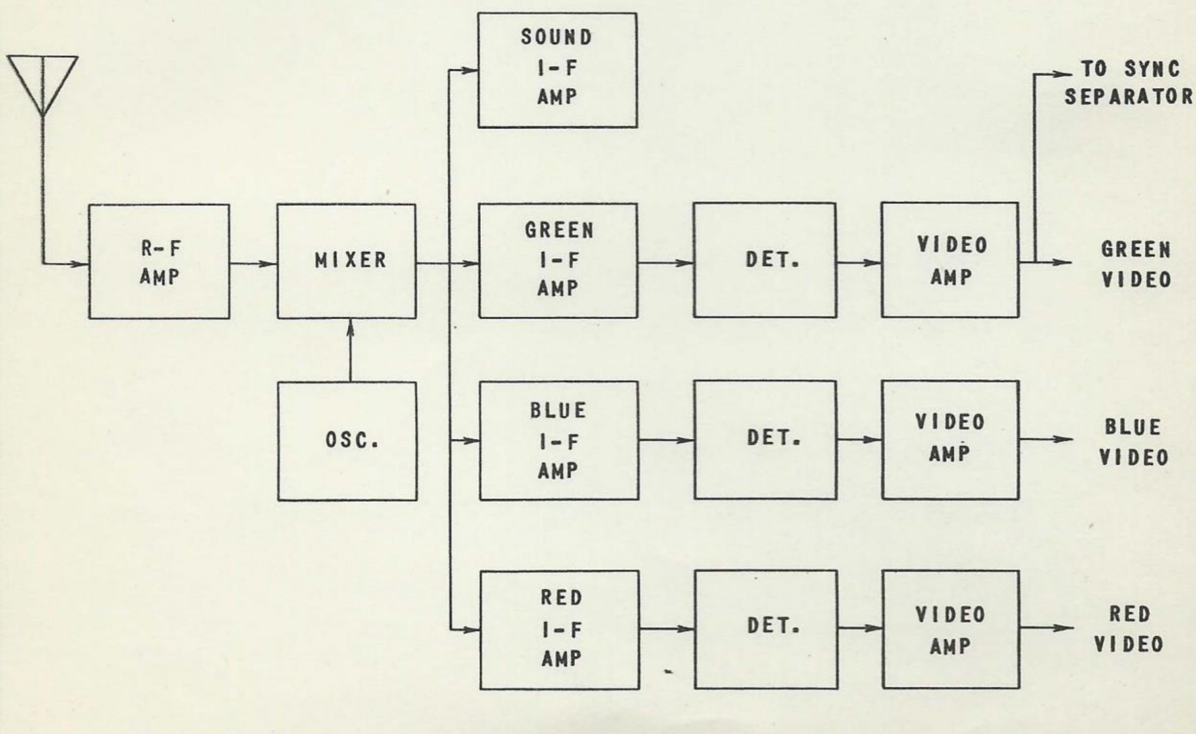


FIGURE 9

SEQUENTIAL LINE COLOR TELEVISION SYSTEM

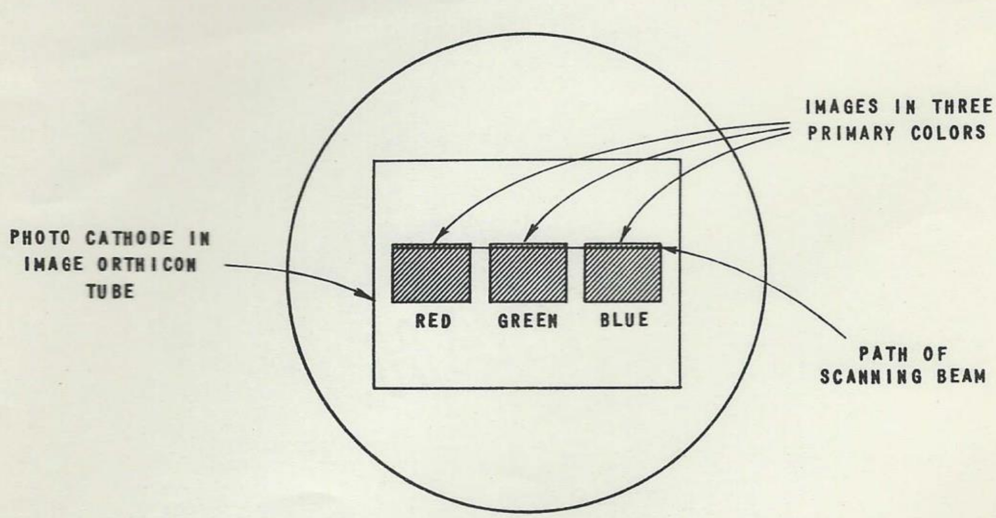


FIGURE 10

VIDEO SIGNAL WHICH WOULD PRODUCE DOTS

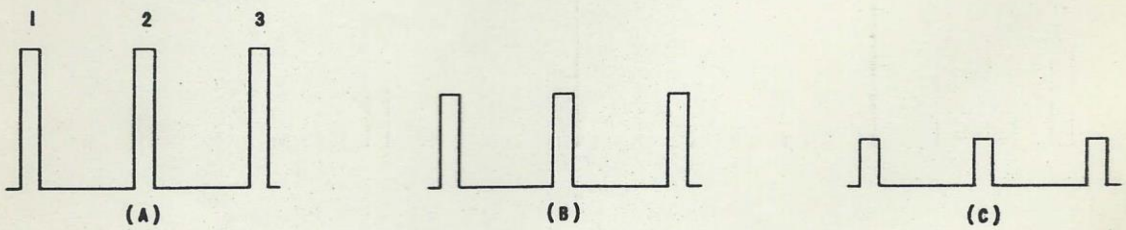


FIGURE 11

BLOCK DIAGRAM ILLUSTRATING DOT SYSTEM FOR BLACK AND WHITE RECEIVER

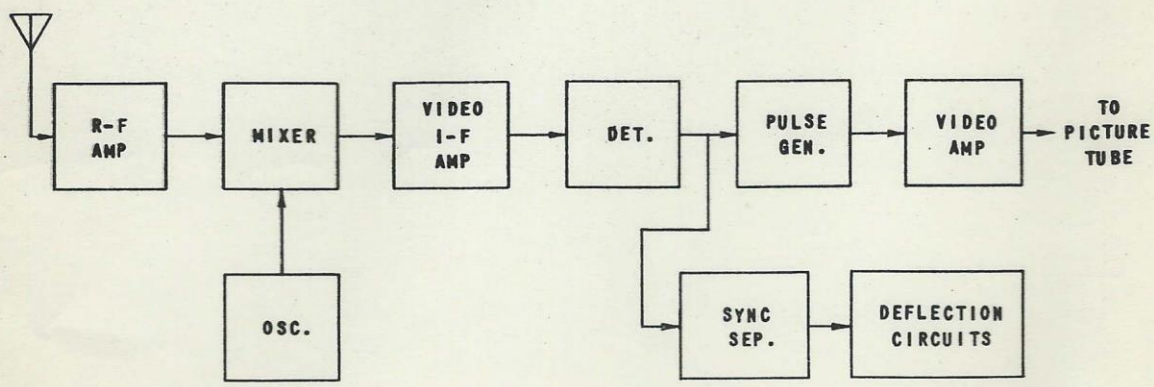


FIGURE 12

ILLUSTRATING MANNER IN WHICH DOT SYSTEM CAN IMPROVE DEFINITION OF BLACK AND WHITE PICTURES

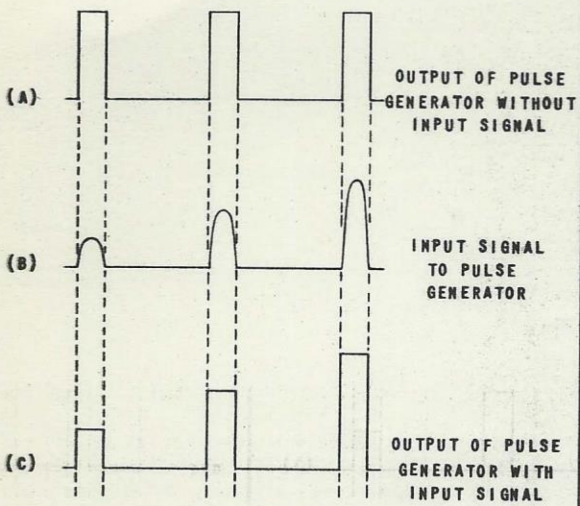


FIGURE 13

WAVEFORMS FOR SEQUENTIAL DOT COLOR TELEVISION SYSTEM

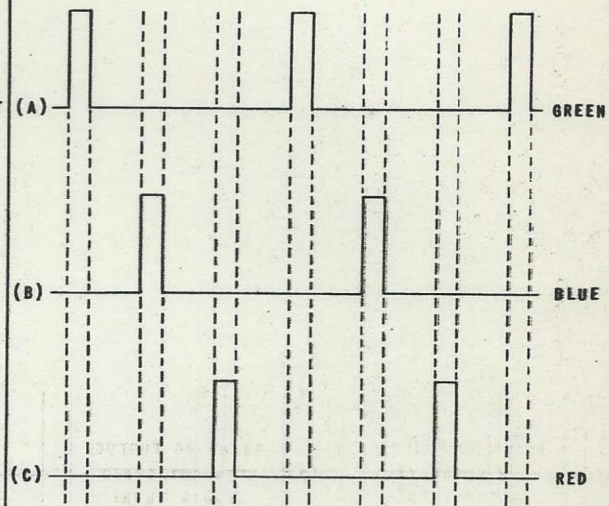


FIGURE 14

BLOCK DIAGRAM OF SEQUENTIAL DOT COLOR TELEVISION TRANSMISSION SYSTEM

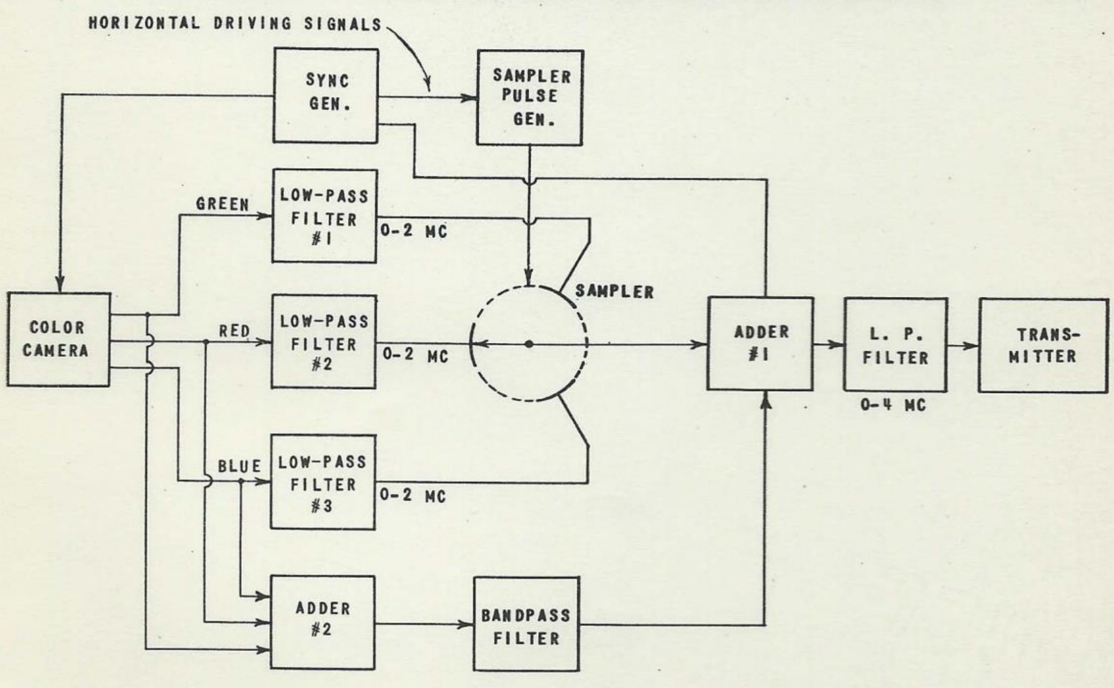


FIGURE 15

BLOCK DIAGRAM OF SEQUENTIAL DOT COLOR TELEVISION RECEIVER

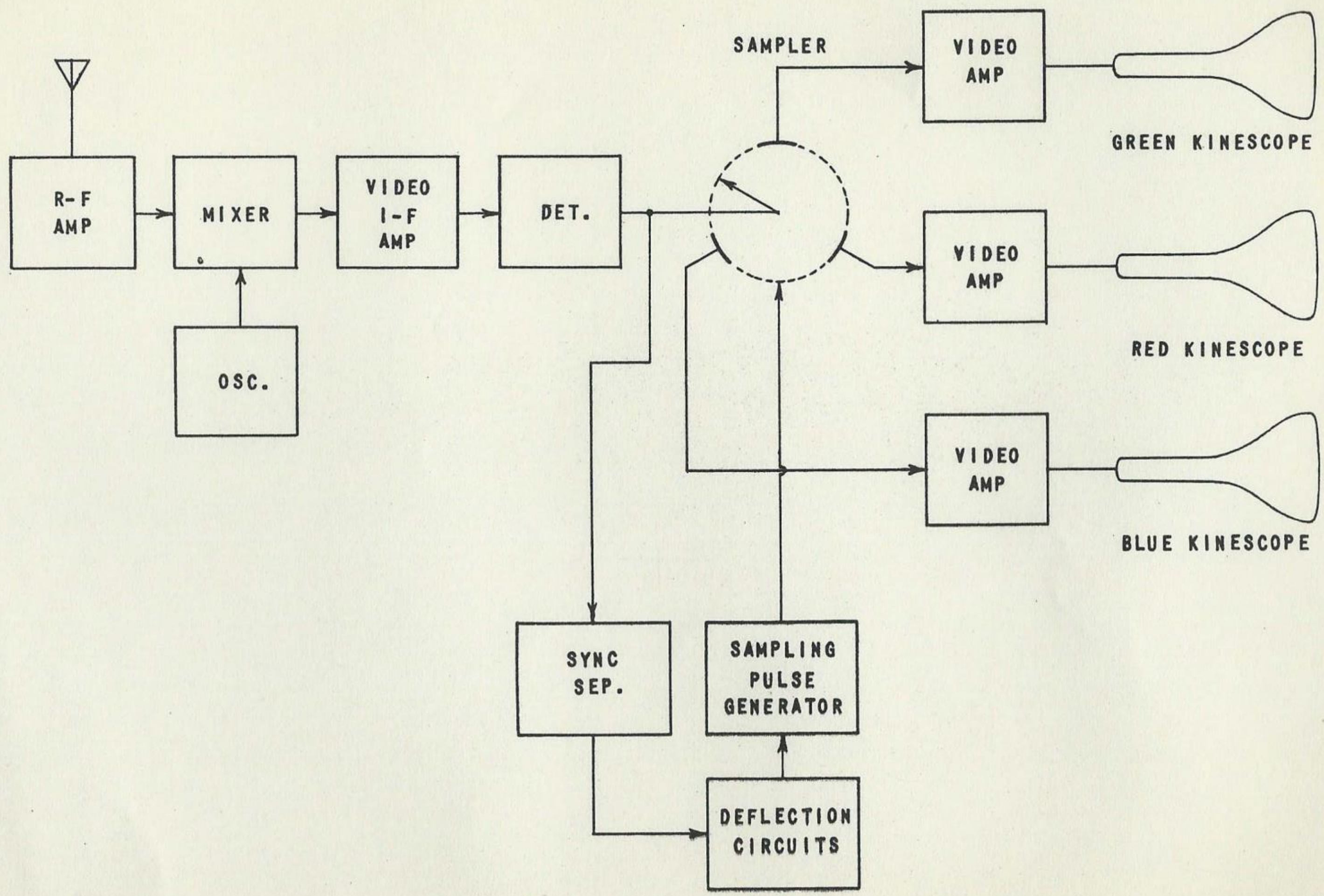


FIGURE 16