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Color Television

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COLOR TELEVISION FUNDAMENTALS

MILTON S. KIVER

*Author, "Television Simplified,"
"FM Simplified," etc.*

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COLOR TELEVISION FUNDAMENTALS

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PREFACE

The transition from black-and-white to color television is another phase in the engineering development of this relatively new, yet firmly established, form of communication. Color television is today at about the same point of development as its black-and-white predecessor was back in 1945-1946. However, because of the enormous working knowledge that the industry has already amassed and the striking visual appeal of colored images to the viewer, we can reasonably expect substantial progress in both picture presentation and set distribution in the immediate future.

To the technicians who are now engaged in television work and to those who are just entering, a full working knowledge of color and color television is of the utmost importance if the many opportunities in this field are to remain available to them. It is the purpose of *Color Television Fundamentals* to provide this knowledge within a single integrated text.

The book is written so that anyone who is familiar with radio and black-and-white television will have no difficulty in following the various discussions. All circuit explanations employ the highly successful step-by-step approach, starting with the simplest facts and proceeding gradually to the more complex. No mathematics of any difficulty is used in the text.

The initial chapter begins with a general discussion of light and color and ties these in with the special color-vision properties of the human eye. In Chapter 2, the principles of the modern NTSC color system (which is FCC-approved) are discussed. It is shown how we are able to fit a full color video signal into the same channel that is currently being utilized by black-and-white signals. In this same discussion, it is demonstrated how the NTSC color system is so fashioned that it takes full advantage of the color characteristics of the human eye.

In the third chapter, a full color receiver is discussed, but only in block diagram form. Thereafter, chapter by chapter, every circuit is carefully analyzed as to both purpose and operation. The discussion

follows the path of the signal, from antenna to loudspeaker and picture tube.

In the next-to-last chapter, two commercial color television receivers are fully analyzed, including the manner in which they are aligned. Finally, in the last chapter, a complete servicing procedure for color television receivers is given in detail.

Additional information (including a mathematical discussion) is available in an extensive appendix for those who desire it.

Every recent advance in the field up to the time of writing has been included. In this way the reader is assured of a text that will bring him up to date on the status of color television.

The book can be used in technical junior colleges, technical institutes, and high schools, or for home study. The approach is kept as practical as possible, designed for those who will work with color television receivers in production, installation, or repair. Questions are included for each chapter, for use by an instructor to test the progress of a student or as a form of self-test for those studying alone.

The author wishes to extend his appreciation to Paul Eckstein and Harold Adler of the Lion Manufacturing Company, to the Radio Corporation of America, to Admiral Corporation, to Motorola, Inc., and to Simpson Electrical Company for the data and material which they graciously provided. The author is also indebted to William Stocklin of *Radio & Television News* for his cooperation in making available numerous illustrations used in the text.

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CHAPTER 1

COLOR FUNDAMENTALS FOR TV SERVICEMEN

Color forms one of the most intimate contacts in our everyday life—we wear colored clothes, we use colored objects, we live in colored houses, and we eat colored food. Yet, in spite of this close contact with color, most people have only a casual knowledge of the nature of color or of color mixing. To the television technician, color possesses added significance because of its application in color television. For a full understanding of the operation of color-television receivers, it is essential that certain basic facts concerning the physical basis of color be known, and it is the purpose of this chapter to review this information.

PRINCIPLES OF COLOR

In 1666, Sir Isaac Newton discovered that when a beam of sunlight is made to pass through a glass prism, the emerging beam of light consists not of sunlight but instead of a continuous spectrum of colors ranging from violet at one end to red at the other (see Fig. 1).

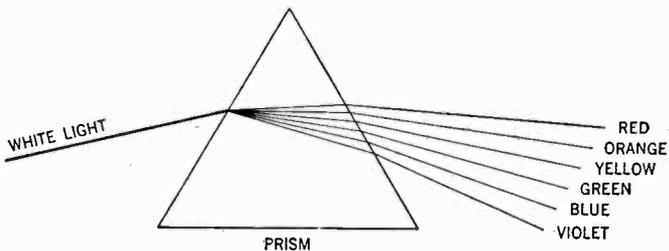


FIG. 1. White light, when passed through a glass prism, breaks down into the colors of the spectrum.

The spectrum may be broadly divided into six regions: violet, blue, green, yellow, orange, and red. From the scale which appears in Fig. 2 it is seen that

Violet	extends from 400 to 450
Blue	extends from 450 to 500
Green	extends from 500 to 570
Yellow	extends from 570 to 590
Orange	extends from 590 to 610
Red	extends from 610 to 700

When the spectrum is viewed in full color it can be seen that no color ends abruptly at a specific point, but rather that each color slowly blends into the next.* The above figures are accepted generally as representing the band limits of the various colors, although some variations will be found in the literature.

The numbers in Fig. 2 are not arbitrarily chosen; rather they represent the wavelengths of the various colors. Physicists have discovered

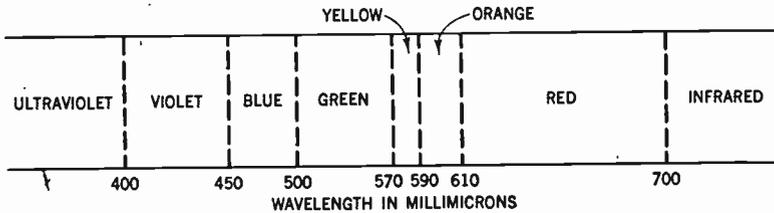


FIG. 2. The broad color regions of the visible spectrum.

that light rays possess the same basic structure as radio waves, television waves, or X rays. All of these are electromagnetic waves, traveling through space with a velocity of approximately 186,000 miles per second. The length of each wave varies inversely with frequency, being extremely long at low frequencies (i.e., 60 cycles) and extremely short at the light frequencies.

A chart of the electromagnetic spectrum is shown in Fig. 3. At a frequency of 10 cycles, one wavelength has the phenomenally large value of 6,000 miles! As the frequency rises to the AM broadcast band, one wavelength decreases to about 2,000 ft. At the television frequency of 200 Mc, one full wavelength is now only slightly under 5 ft. Finally, when we get to light waves, where the frequency is in the neighborhood of 100 million million or 100 trillion cycles per second, the associated wavelength becomes inconceivably small, on the order of 400 billionths to 700 billionths of a meter. For the sake of convenience, the latter

* The dotted lines in Fig. 2 are included to indicate roughly where each color ends, but actually no sharp line of demarcation exists.

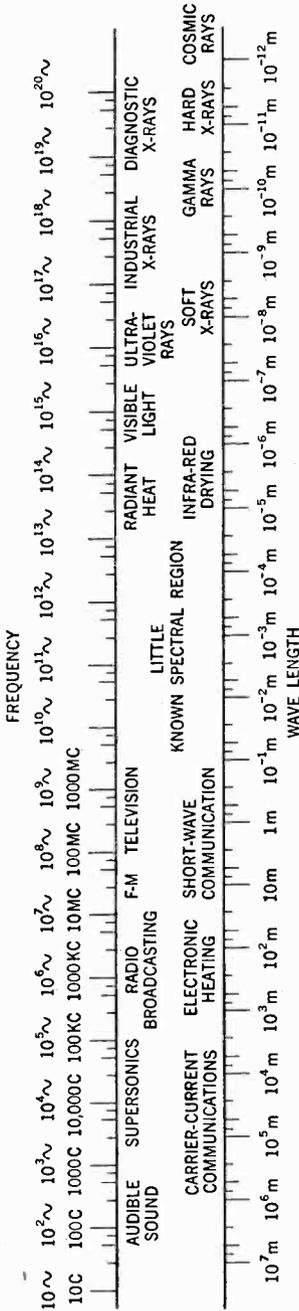


Fig. 3. The electromagnetic spectrum covering a frequency range from 10 cycles to 10²⁰ cycles. (10²⁰ = 100,000,000,000,000,000,000.)

wavelengths are commonly expressed by a much smaller unit called the millimicron, abbreviated mμ. The micron is defined as one millionth of a meter (i.e., one millionth of 39.37 in.) and the millimicron is one thousandth of one micron, or one billionth of a meter.

The significance of the numbers listed just below the color spectrum chart in Fig. 2 may now be appreciated. They represent the wavelengths of the various colors in millimicrons. Thus, violet extends from 400 to 450 mμ in length, blue from 450 to 500 mμ in length, etc. It is much more convenient to use this notation than to say 400 billionths of a meter, etc.

COLOR MIXTURES

Anyone who has ever experimented with projector lamps has discovered that when differently colored lights from several projectors are combined, the resultant color seen by an observer will differ in hue from any of the projected lights. Thus, for example, yellow can be formed by combining red and green light; white light can be produced by combining red, green, and blue. The color of the light formed will appear to the eye as a complete color and the eye will be unable to distinguish the various components of the mixture that united to form the new color.

This method of color formation is illustrated in Fig. 4. Two circles of colored light are projected onto a screen and positioned so that they overlap to some extent. Within the

overlapping region, a new color will be produced by the addition of color A and color B. Where the circles of light do not overlap, each light will retain its original color. If a third circle of light is added, as shown in Fig. 5, then additional colors can be obtained. These are:

- Color A
- Color B
- Color C
- Color D (formed from A and B)
- Color E (formed from A and C)
- Color F (formed from B and C)
- Color G (formed from A, B, and C)

and each would differ from the other. In the areas where the circles of light overlapped, the eye would not be able to distinguish each of the colors forming the mixture, but instead would see the final color produced. Furthermore, as we varied the relative intensities of colors A, B, and C, we would see that colors D, E, F, and G would vary in shade.

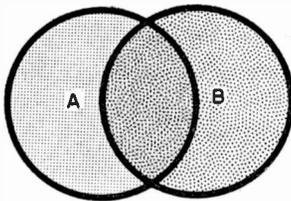


FIG. 4. A new color is formed between color A and color B as a result of mixing color A and color B.

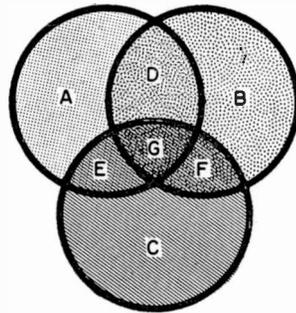


FIG. 5. Three colored lights, when mixed together, can produce a greater range of different colors than two mixing colors can.

The number of different colors that can be formed by the use of three colored lights will depend upon the colors chosen. Experience has indicated that the colors red, blue, and green, when combined with each other in various proportions, will produce a wider range (or gamut) of colors than any other combination of three colors. Note, however, that if we used four different colors in our mixing process, we could produce

an even greater number of different colors. With the addition of more and more colors to our mixing scheme, the reproducible range would widen somewhat. Obviously, however, a line must be drawn and the use of three colors has been standardized. The three colors chosen, red, green, and blue, are thus referred to as the "primary" colors although use of the word primary has been widely misinterpreted to mean that red, green, and blue will, in various combinations, reproduce *all* colors. This is only true in a special instance, as we shall see.

The reason why three primaries were chosen, in preference to four, probably stems from the theory that the eye behaves as though it contains three sets of nerves with each set of nerves responsive to a different portion of the visible spectrum. Thus, one set of nerves has its greatest sensitivity in the blue region, another set is most sensitive in the green region, and the third set is most sensitive to red. Whether or not three sets of nerves actually exist has never been definitely established. However, the eye reacts as though such a condition does exist, and it is reasonable to work on the assumption that it does.

The theory which serves to explain the ability of the human eye to distinguish various colors can also be employed to explain color blindness. In the eye of a color-blind person, all of the nerves, or retinal cones, as they are called, react in the same way to all colors. Hence, when colored light is viewed by these people, all three sets of nerves are similarly stimulated and the same result is obtained as though equal amounts of red, green, and blue light were intermixed. The color seen would be white or some intermediate shade of gray. These people can distinguish between dark and light, but no more.

There are also people whose retinal cones differ sufficiently to see some of the colors, but not all. These people are known as partially color blind. Perhaps the best-known instance of this is green and red color blindness. In the eyes of these people green or red appears gray. Fortunately, however, over 90 per cent of the population have normal vision and are able to distinguish between all of the spectrum colors.

For many years it was believed that the ability of the human eye to see color was the same whether the area viewed was large or small. This has only recently been found to be untrue, and the NTSC color television system is specifically designed to take advantage of this modified eye behavior. This point will be amplified later in this chapter and again when the principles of the NTSC color system are discussed.

COLORIMETRY

The science of determining the components of any color mixture is known as colorimetry. For example, suppose we have light of a certain color and we want to find out how much red, green, and blue it contains so that we can reproduce light of this color any time we wish. In essence, the procedure is as follows: The unknown sample is projected on one side of a translucent screen and a circle containing known amounts of the primary colors red, blue, and green is placed on the screen next to the sample. The amount of light from each primary color is now adjusted (say, by a rheostat) until the sample and the circle containing the three primary colors match perfectly. The sample can now be specified in terms of known amounts of red, blue, and green.

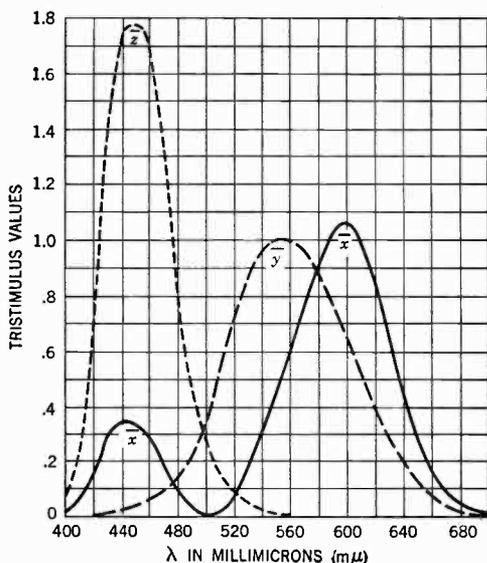
There are some colors that no combination of red, blue, and green will match. However, a match may be achieved by taking one of the primary components and combining it with the unknown color. The two remaining components in the right-hand circle can be made to match the combination of the unknown color and the added primary.

By following this approach, *all* colors can be designated in terms of the three primary colors. Note, however, that it is only in this sense that we are able to state that the three primary colors will match any given color. If we restrict ourselves to matching colors by using red, green, and blue and not adding any of these to the unknown color, then we *cannot* say that these three primary colors will reproduce all colors.

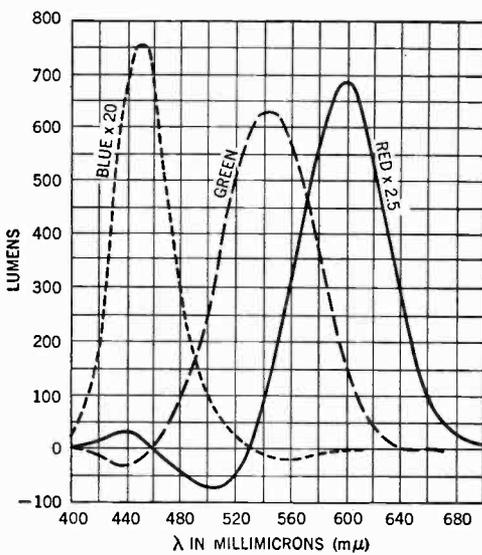
When one of the primary colors has to be added to the unknown sample in order to achieve a match, the amount of that primary color required is considered a negative quantity.

Figure 6A contains an experimental set of color-mixture curves giving the number of lumens of light of three primaries (red—650 m μ , green—530 m μ , blue—460 m μ) required to match 1 watt of radiant energy for any color from 400 to 680 m μ . Note that each curve at some point drops below the zero line, indicating that for colors in this region, this primary must be added to the unknown sample to achieve a color match with the two remaining primaries. As an example, if we wish to match a color having a frequency of 500 m μ (this is in the blue-green region) we add 175 lumens* of red light to the sample to be matched.

* The lumen values of red and blue in Fig. 6A must be multiplied by the amounts indicated on each curve.



(B)



(A)

FIG. 6. (A) Color-mixture curves giving the number of lumens of three primaries required to match one watt of radiant power having the indicated wavelength. (B) Standard ICI color-mixture curves giving the amount of the three ICI primaries required to color-match a unit amount of radiant power at each wavelength. (\bar{x} is equivalent to red curve of Fig. 6A; \bar{y} is equivalent to green curve; and \bar{z} is equivalent to blue curve.)

Then, by combining a mixture of 2,000 lumens of blue light and 240 lumens of green light, a color match can be achieved. The red light that had to be added to the unknown sample is considered as a negative quantity.

Red, green, and blue are the colors that can match (or produce) the widest range of different colors without using any negative components. This means that we can develop more colors by combinations of red, green, and blue—without adding any of these three colors to the unknown—than by combination of any other three colors.

It will be found that any set of three primary colors we choose will require negative values at some wavelengths if we wish to reproduce the entire range of visible colors. For the purposes of simplifying color-mixing computations, an International Commission on Illumination standardized in 1931 the set of color-mixture curves shown in Fig. 6B. All negative values have been eliminated, but this was achieved only by using fictitious red, green, and blue primaries—primaries that cannot be obtained in practice. It is possible, however, to employ this data to obtain the mixing curves for any other set of primaries, real or fictitious, and for this reason the curves in Fig. 6B are useful.

The use of the words red, green, and blue in the preceding discussion will help the reader visualize the approximate colors that are being chosen as primaries. However, it is undoubtedly apparent that there is a wide variety of reds, greens, and blues that may be chosen, since the words red, green, and blue represent regions of color rather than specific colors. Blue, for example, extends from 450 to 500 $m\mu$, and any frequency within this region will appear blue to an observer. The same situation exists for red and for green.

The primary colors chosen by the ICI committee are red = 700.0 $m\mu$, green = 546.1 $m\mu$, and blue = 435.8 $m\mu$.

CHROMATICITY CHART

A diagram which is more convenient to use for color mixing than the curves in Fig. 6B is the tongue-shaped (or horseshoe-shaped) curve shown in Fig. 7. This is known as a chromaticity chart and presents the same information as the former diagram. Indeed, one set of curves can be derived from the other. We are, in other words, using the same values in both diagrams but arranging them in different form.

The positions of the various spectrum colors from violet at 400 $m\mu$ to red at 700 $m\mu$ are indicated around the curve. Any point not actually on the solid-line curve but within the diagram represents not a pure

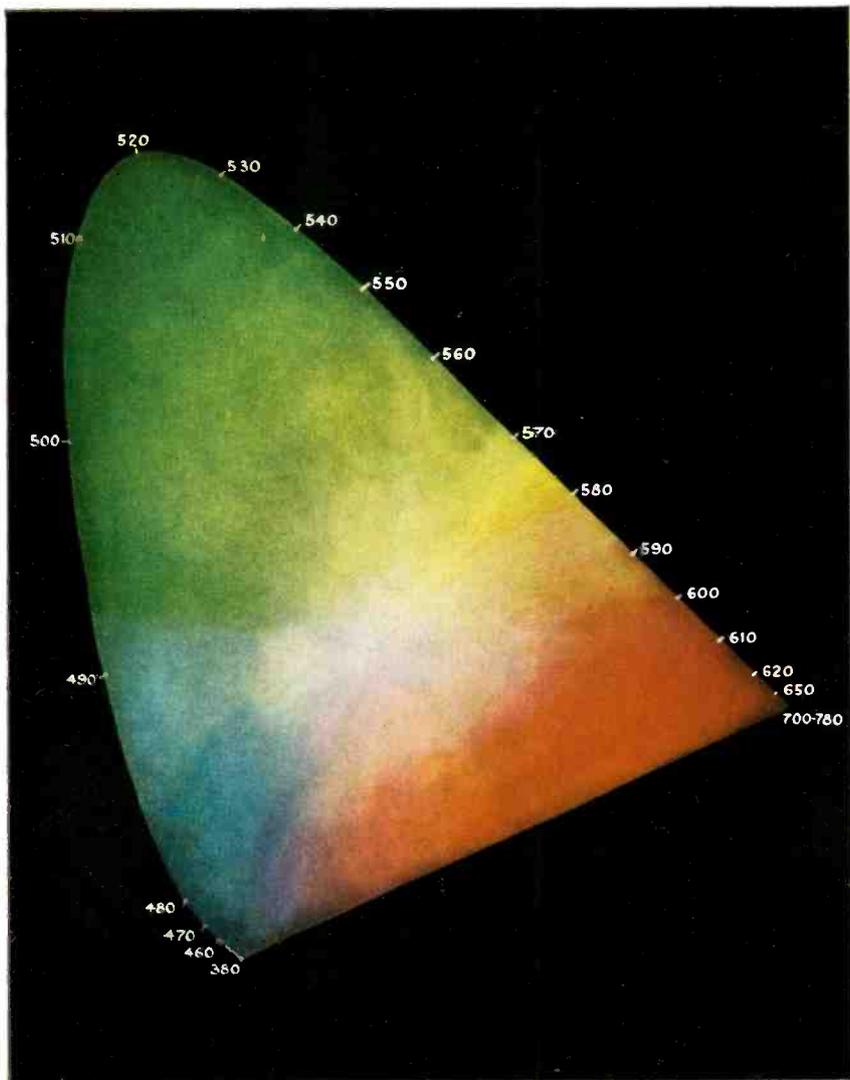


PLATE I. Hue and saturation values for red, green, blue, and their color mixtures. (RCA.)

The author is indebted to the RCA Service Company for permission to use Plates I through XV.

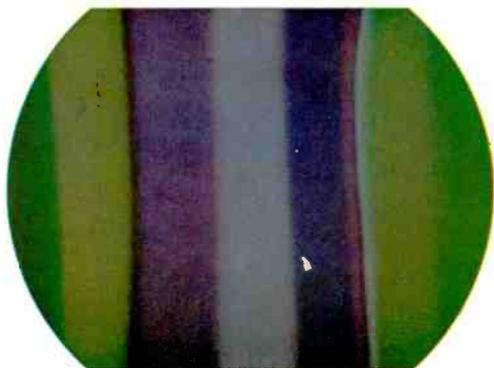


PLATE II. Color bars with the *I* component missing. (RCA.)

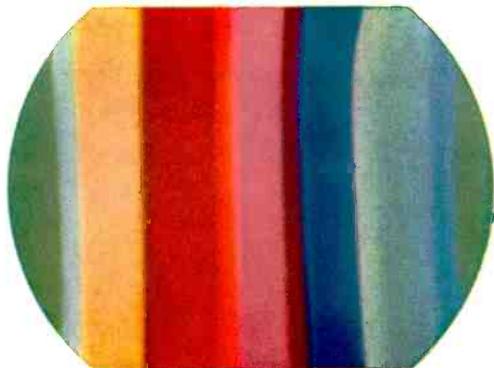


PLATE III. Color bars with an insufficient amount of *Y* delay. (RCA.)



PLATE IV. Color bars with the brightness component (*Y*) missing. (RCA.)

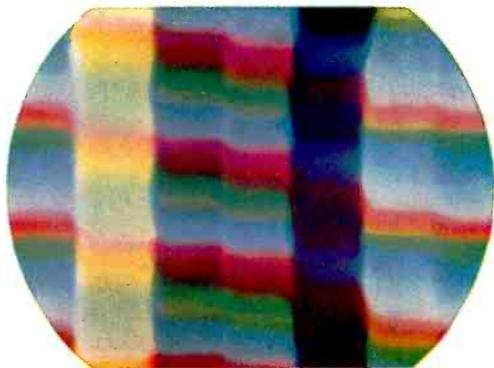


PLATE V. A color-bar pattern out of color sync. (RCA.)



PLATE VI. Normal appearance of color bars 100 per cent saturated. (RCA.)

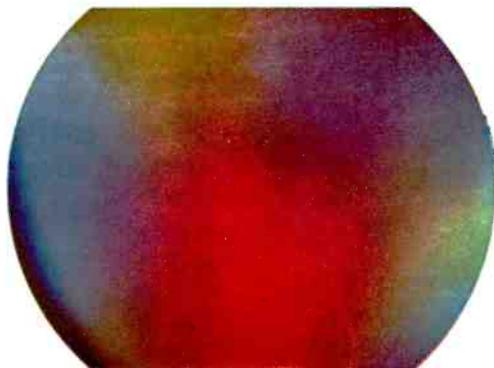


PLATE VII. A red screen with poor purity. When the purity is good, the red color is spread uniformly over the screen. (RCA.)

*a quiet red screen first
over entire surface*



PLATE VIII. Normal appearance of color flower image. (RCA.)

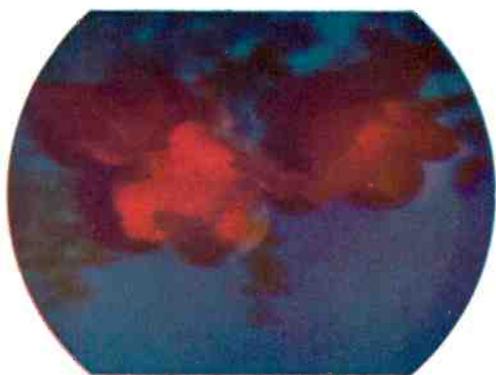


PLATE IX. The flower image with the Y component missing. (RCA.)



PLATE X. The flower image with the Q component missing. Note how little difference this makes. (RCA.)



PLATE XI. The flower image with the I component missing. Note how much more evident this loss is than the loss of the Q component. (RCA.)



PLATE XII. The flower picture with the red video signal missing. (RCA.)



PLATE XIII. The flower picture with the green video signal missing. (RCA.)

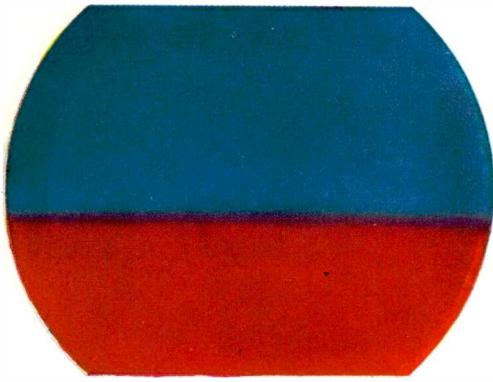


PLATE XIV. Hum in the I section of the receiver. (RCA.)

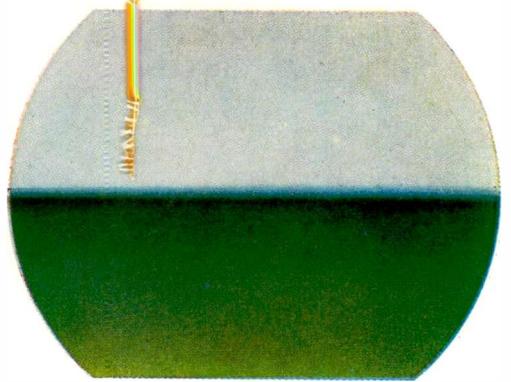


PLATE XV. Hum in the Q section of the receiver. (RCA.)

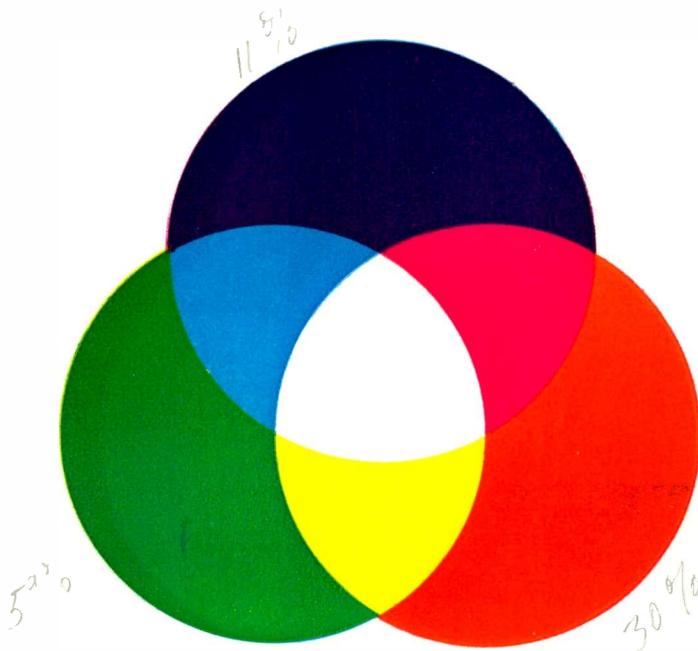


PLATE XVI. Addition of colors.

spectrum color but some mixture of spectrum colors. Since white is such a mixture, it, too, lies within this diagram; specifically, at point C. This particular point was chosen at the ICI convention in England and is generally referred to as "illuminant C." Actually, of course, there is no specific white light, since sunlight, skylight, and daylight are all forms of white light and yet the components of each differ consider-

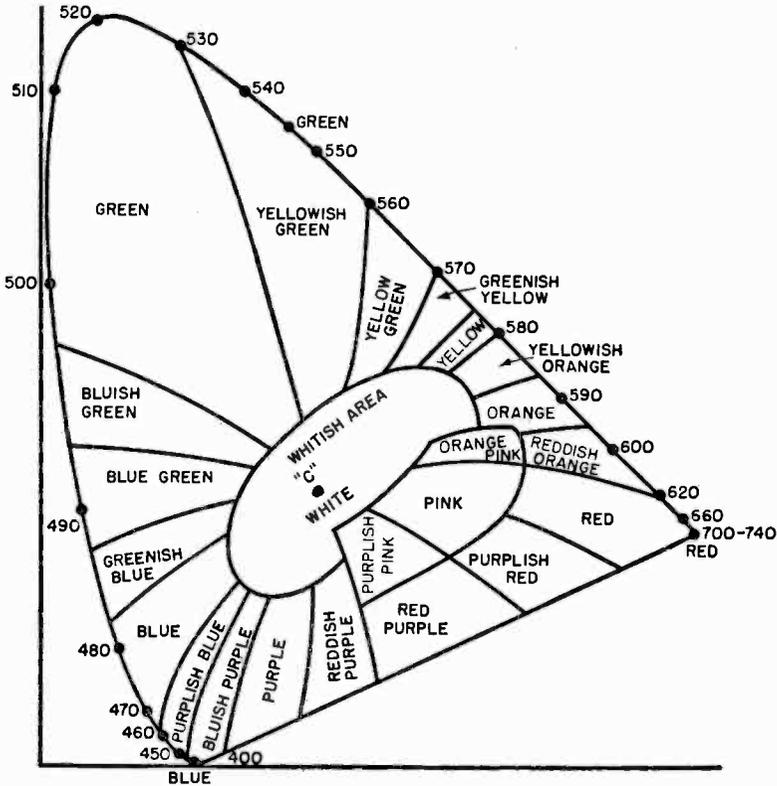


FIG. 7. A chromaticity diagram, useful for color mixing. See text for details.

ably. The color quality of a conventional black-and-white television receiver tube is represented by some point in the central region of the diagram about point C.

(When Fig. 7 is viewed in full color it is seen that the color changes gradually from point to point.* The deepest and most intense colors are obtained at the outer edge of the diagram. Here we find the real deep red, deep blue, and deep green shades which we actually see very seldom in everyday life. More familiar are the lighter colors, ap-

* See Plate I.

pearing as we move in toward the center. These are the pastels such as pink, light green, and pale blue. Finally at the center come the whites with point *C* as the reference white, or for our purpose here, the "whitest" white. Actually this is a rather nebulous shade, entirely arbitrary in value and simply chosen for certain conveniences.)

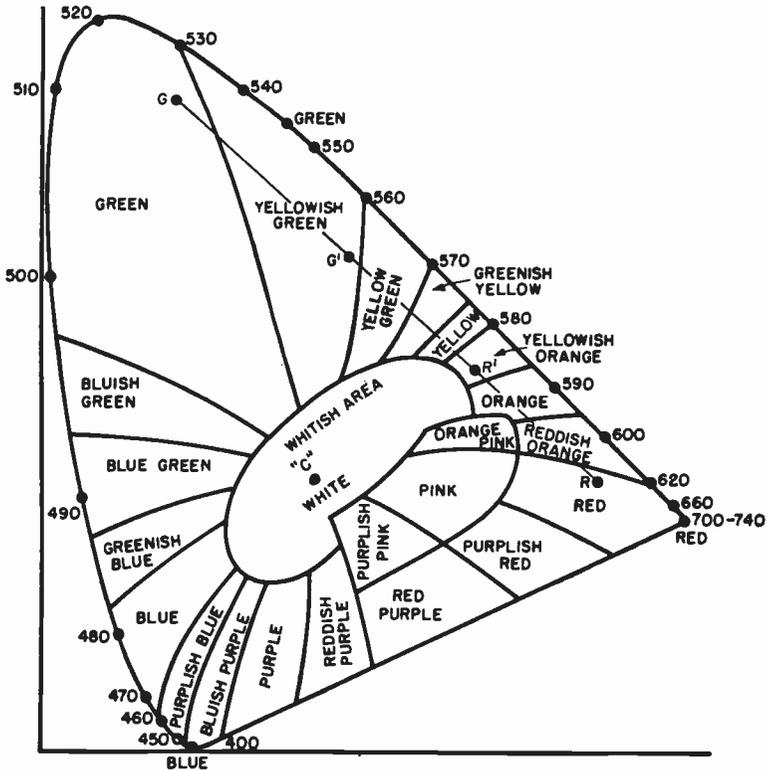


Fig. 8. The line drawn between points *R* and *G* passes through all the colors that can be obtained by mixing these two shades of red and green.

The chromaticity chart lends itself readily to color mixing, because a straight line joining any two points on the curve will indicate all the different color variations that can be obtained by combining these two colors additively. Thus, consider a line drawn connecting points *R* and *G* representing certain shades of red and green respectively (see Fig. 8). If there is more red light than green light, the exact point representing the new color will lie on the line but be closer to *R* than *G*. Point *R'* might be such a color. On the other hand, if a greater percentage of

green light is employed, color will still lie on the line connecting R and G , but now be closer to G than to R . Point G' might be such a color. This same line of reasoning can be carried out for any two colors on the chart.

On the screen of a three-gun tricolor picture tube, we can carry out the same experiment by turning off the blue gun and permitting only the electron beams from the green and red guns to reach the phosphor-dot screen. As one beam, say that from the red gun, is made more intense the resultant color on the screen shifts closer to red. On the other hand, if the red gun is turned down and the green gun beam is turned up, the resultant color takes on more and more of the greenish cast. When both guns are producing beams of equal intensity, yellow will be seen.

Point C , in the central region of this diagram, is taken to represent white or daylight. If we draw a line between point C and any point around the curve, we have a mixture of white light and a particular spectrum color. Thus, in Fig. 9, a line connects point C and green at $545\text{ m}\mu$, indicating a mixture of white light and spectrum green. If the amount of white light is zero, then the pure spectrum green will be produced. As white light is added, the hue of the screen changes and the point representing this mixture moves along the line toward point C . We might consider this as diluting the green, causing it to become lighter and lighter in shade.

It is possible to specify the purity of a color by its distance from point C . Thus, consider point B in Fig. 9. This is halfway along the line between point C (white) and point A ($545\text{ m}\mu$ -green). Thus, point B represents a mixture of green diluted 50 per cent with white light, and we can say that the purity of this color is 50 per cent. Had the distance between point C and point B been 75 per cent of the total distance between point C and point A , we would have stated that the purity of the color at point B was 75 per cent. By moving point B closer and closer to the spectrum curve, the purity of the color it represents increases until it becomes 100 per cent at the curve—point A . Moving point B closer to point C decreases its purity. At point C , the purity is said to be zero.

In place of purity, the word saturation is frequently employed. Any point located on the tongue-shaped curve is said to be completely saturated. As we leave the curve and approach point C , more and more white light is added to the color and it becomes less saturated, or, what is the same thing, more desaturated. At point C the saturation is zero.

In connection with saturation, the word hue is frequently heard. Hue

represents color, such as red, green, and orange. It is associated with color wavelength, and when we call a certain color green or orange or red, we are specifying its hue. Thus, hue refers to the basic color, as it appears to us, while saturation tells us how deep the color is. If the color is highly saturated, we say that it is a deep color, such as deep red, or deep green. If it contains a considerable amount of white light,

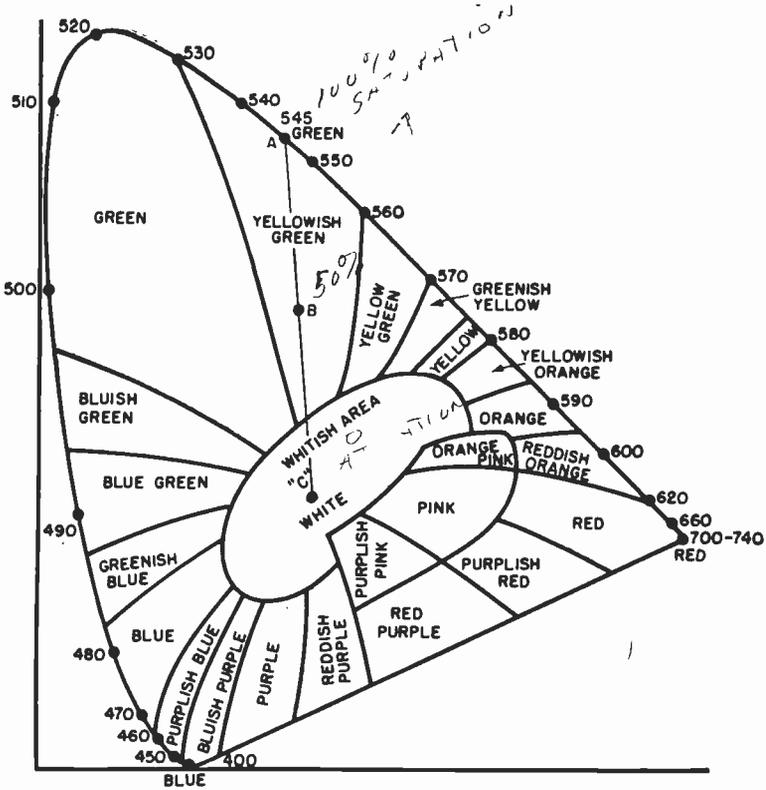


FIG. 9. When moving from A to C the green becomes less and less saturated, or lighter in intensity.

we say it appears faded, as a faded red or a faded green. Hue and saturation are psychological terms representing the observer's impression of a color, and hence they cannot be defined as precisely as wavelength or purity.

If we take the tongue-shaped curve of Fig. 7 and draw a straight line connecting 400 $m\mu$ at one end and 700-740 $m\mu$ at the other end, we obtain a series of colors which are combinations of red and blue in

various proportions. These are the purples or magentas, ranging from reddish purple to purplish red. It can be seen that this line completes the bottom end of the curve of Fig. 7. This line should not be considered in the same sense as the rest of the curve. It does not contain any spectrum colors but only combinations obtained from mixing spectrum colors. Because of this, the region at the back end of this

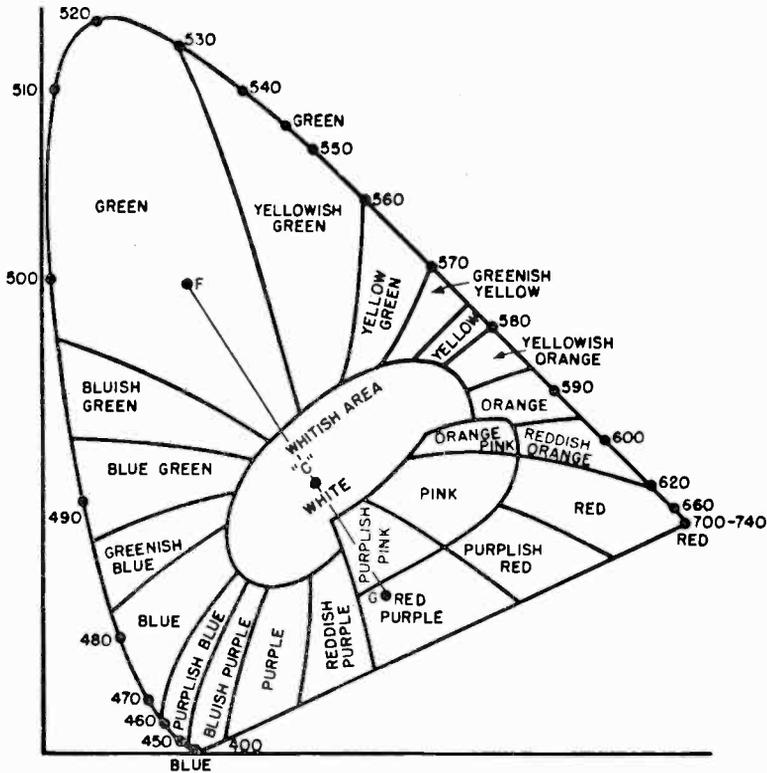


FIG. 10. Colors F and G will produce white when mixed in the proper proportions; they are said to be complementary.

tongue-shaped curve is known as the *region of nonspectral colors*. The boundaries of this region are obtained by drawing a dotted line from point C to 400 mμ and from point C to 700 mμ. The remainder of the diagram above these dotted lines is known as the *region of spectral colors*. The entire diagram is known as the *domain of real colors* because they are reproducible.

One further term used in connection with this diagram is comple-

mentary color. Any two colors which when mixed together form white are known as complementary colors. Thus, in Fig. 10, the line connecting point F with point G passes through point C ; hence the colors at F and G are said to be complementary to each other.

We have previously seen that a line drawn between two points representing two different colors contains all the combinations that can be

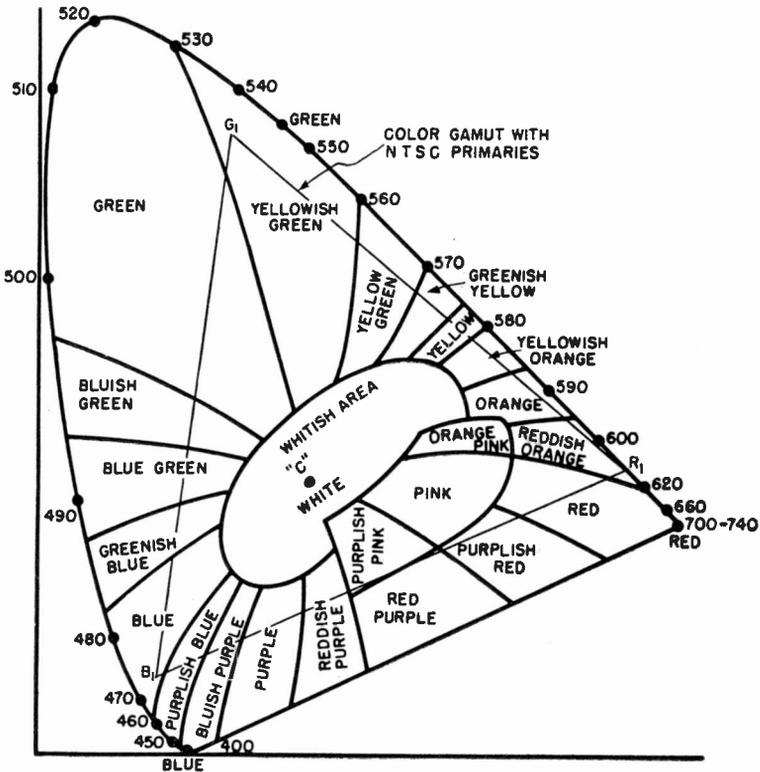


FIG. 11. The colors shown within the triangle are reproducible on a color TV screen.

derived using those two colors. If, now, we wish to determine what range, or gamut, of colors can be obtained from any three given colors (say R_1 , G_1 , and B_1), we would draw connecting lines to each of the colors (see Fig. 11). The result is a triangle. We can produce any color within this triangle by various combinations of the three colors, R_1 , G_1 , and B_1 .

In television we desire to be able to reproduce as many of the colors represented within the tongue-shaped diagram as possible. It has been

determined that the three primaries which would permit the greatest range of colors to be obtained are colors of wavelengths 700, 520, and 400 m μ . These are deep red, green, and deep blue. Note that colors not included within any triangle so formed will not be reproduced by *any* combination of the three primary colors chosen.

(This, of course, brings us back again to the statement made previously, that three primary colors cannot reproduce *all* colors simply by adding the three primary colors together. However, by adding one of the primary colors to the color to be matched, all colors can be reproduced. In color television, of course, only those colors which can be produced by adding the primaries together can be considered, this being the only practical approach possible.)

The choice of suitable primary colors for television depends principally upon the type of color phosphors that can be obtained for the receiver picture tube. Originally it was felt that the color picture would be traced out on a black-and-white screen and then the light passed through a color filter to present the observer with the "color" image. This was the method employed in the CBS system and in the early forms of the RCA system. However, with the development of a color tube, phosphors were employed which emitted colored light directly, leading to a system physically less cumbersome and optically more efficient.

Extensive work is being done on evolving phosphors which will provide as wide a gamut of colors as possible. In recent tubes, a willemite phosphor ($\text{Zn}_2\text{SiO}_4 \cdot \text{Mn}$) was used for the green, a sulfide phosphor ($\text{ZnS} \cdot \text{Ag}$) for the blue, and a third phosphor, $\text{Zn}_3(\text{PO}_4)_2 \cdot \text{Mn}$, for the red. In Fig. 11, these primaries form the solid-line triangle, and they are seen to produce a fairly wide range of colors. Note that this encompasses less area than the triangle formed by using color primaries of 700, 520, and 400 m μ mentioned above. However, the range is still wholly satisfactory.

When the NTSC system of color television was under development, a considerable amount of research was done on how much color the average human eye really sees. This work, in conjunction with other data which has appeared from time to time, brought forth several very interesting facts.

1. The theory that vision is a three-color process is true only when the object viewed is relatively large. On a television screen, this condition would refer to those objects which are produced by video frequencies of 0 to 0.5 Mc.

2. For medium-sized objects, say those produced by 0.5- to 1.5-Mc

video frequencies on a television screen, only two primary colors are needed. Blues and yellows are among the first colors to lose their color and become indistinguishable from gray within this range.

3. For very fine detail, say those reproduced by video frequencies of 1.5 to 4.0 Mc, all people with normal vision are color blind. In other words, only shades of brightness are seen.

The conclusion to be drawn from the foregoing is that 4-Mc color is not necessary. All we require is color up to 1.5 Mc. And even within this range, we need all three colors only to 0.5 Mc and only two primaries for the color signal extending from 0.5 to 1.5 Mc. In the formation of the NTSC signal, these facts were put to use by employing one color signal called the Q signal, with a range of 0 to 0.5 Mc and a second color signal, called the I signal, with a bandpass of 0 to 1.5 Mc. The rest of the video picture, containing all of the fine detail, is reproduced in black-and-white by a monochrome signal, and the eye is none the wiser. As a matter of fact, a full-color television signal consists of a 0- to 4-Mc monochrome video signal (just as we have in black-and-white broadcasting) plus a color subcarrier containing the I and Q color signals mentioned previously. It has been truly said that the NTSC system is a "colored" television system.

THE SUBTRACTIVE METHOD OF COLOR MIXING

Instead of producing colors by addition, as discussed above, we can employ a method of subtraction. Thus, suppose a white beam of light is passed through a piece of red-colored glass. An observer, viewing this beam after it has passed through the glass, would see only red light. The glass in this instance has absorbed all of the light components except red and consequently only red is visible on the other side.

The colored glass need not absorb all colors except its own. In most instances the glass will transmit a band of colors and the color of the glass will be determined by the strength of those color components that do pass through. Thus, green glass will absorb most strongly in the red and violet regions, while permitting yellow, orange, green, and some blue to pass. The blue, yellow, and orange are absorbed to a greater extent than green and this accounts for the predominantly green appearance of the glass. Further accentuation of the green is obtained because blue with yellow and blue with orange combine to yield green, too.

By the same token, yellow-colored glass will ordinarily pass orange,

yellow, red, and green, absorbing only violet and blue to any appreciable extent. Here the color is yellow because of the small loss suffered by the yellow portion of the spectrum light and also because green with orange and green with red produce a resultant orange hue.

Purple glass may pose a problem to the reader because of the fact that purple is not a spectrum color. Hence purple cannot be obtained by eliminating all colors of white light except purple. Yet we have all seen purple glass. When the light that passes through a piece of purple glass is analyzed, it is found that red and violet are present, but very little green, blue, or yellow. The combination of red and violet produces purple. This was previously noted in connection with Fig. 7.

Note, then, that in forming colors by the subtractive method, we remove the colors from the incident light (usually this is white light) and produce the desired color from what remains.

The subtractive process of color formation is largely employed in making paints and inks. To make paint, for example, we mix a fine powder into a liquid vehicle, generally linseed oil. When light enters the paint suspension, it has to pass through these thousands of very fine powder particles. If the particles are colored, they act as tiny filters, absorbing all but the desired color. This absorption occurs when the light enters the paint suspension and when it leaves. The color of the paint is thus determined by what light frequencies are permitted to pass through the suspended particles.

When two or more colored pigments are combined in a paint, the resulting color will be determined by what light is permitted to pass through both sets of particles. Thus, suppose we mix blue paint and yellow paint. The blue paint will absorb strongly red, orange, and yellow. The yellow paint will strongly absorb blue and violet rays. The only rays, therefore, that are not strongly absorbed are the green rays, and consequently the color of the paint will be green. By altering the proportions of the blue and yellow paints we can vary the shade of green.

In printing, colored inks are obtained in the same manner. The particles are dyed to the desired color and dissolved in a transparent liquid. Light passing through this solution must pass through the colored particles where all but the desired color (or range of colors) are removed. On striking the paper surface on which the ink is coated, the light is reflected back through the ink again. Thus, what we see is the light which has not been absorbed.

In the three-color printing process, the inks are transparent and printed over each other. Each ink permits only a certain range of colors

to pass through, and the resultant color that reaches the viewer is the color which has not been removed after passage through the various inks.

Subtractive Primaries. Since the subtractive method of forming various colors differs from the additive, red, green, and blue would not be suitable as subtractive primaries. The subtractive primaries commonly used are blue, red, and yellow. Another way of naming these subtractive primaries is by the colors they absorb or remove from white light passing through them. Thus, for the blue primary the name *minus-red* or *cyan* is used. If white light falls on this subtractive filter, red is removed and a mixture of blue-green is permitted to pass. Thus it would be more correct to call the first subtractive primary bluish green rather than just blue.

For the second subtractive primary, red, the name *minus-green* or *magenta* is used. This subtractive filter removes green from white light and transmits red and blue rays. Here again a more correct designation would be reddish blue or magenta rather than the more common name of red.

Finally, for the yellow primary, the alternate name *minus-blue* is used. White light falling on this subtractive filter has blue removed from it, while red and green are permitted to pass. The red and green combine to form yellow in the observer's eye.

Possibly the common names of blue, red, and yellow arose because of the fact that many materials used for the subtractive process vary so far from the ideal colors that they appear as blue, red, and yellow to most observers. Actually, as we have seen, the true subtractive primaries are bluish green, magenta, and yellow.

One further word concerning the subtractive primaries. If we consider these not for the light they permit to pass but for the light they absorb (i.e., minus-red, minus-green, and minus-blue), then we can clearly see that the same basic colors are employed in both the additive and subtractive methods. In the additive system, red, green, and blue are added in various quantities to form the desired hue; in the subtractive system, red, green, and blue are subtracted in differing amounts to form whatever hue is desired. Regarded in this manner, the reader should have little difficulty following the formation of colors in either system.

QUESTIONS

1. What general colors are distinguishable in a color spectrum obtained when sunlight is passed through a prism? Include the wavelengths of these colors.

2. What is a millimicron? How many millimicrons in an inch?
3. What three primary colors are employed in additive light mixing?
4. What advantage would four primary colors possess over three? Why are three primaries used more frequently than four?
5. Under what conditions is it true that all colors can be designated in terms of three primary colors?
6. What is a chromaticity chart and what purpose does it serve?
7. What colors are found near the edges of the chromaticity chart? What colors are found near the center?
8. Explain the meanings of hue, saturation, and purity. Use the chromaticity chart in your explanation.
9. What general colors on the chromaticity chart are not found in the spectrum of light?
10. How would you determine the complement of a certain color, say blue, using the chromaticity diagram?
11. Does the normal eye see color equally well in large as well as small areas? Explain.
12. How does the subtractive method of color mixing differ from the additive method?
13. Give an example of subtractive color mixing using specific colors.
14. What are the subtractive primaries? Contrast these with the additive primaries.

CHAPTER 2

THE NTSC COLOR TELEVISION SYSTEM

What is already being called the miracle of the 20th century, color television, is in the initial stages of mass production, and the days to come will be some of the most hectic that the television industry has ever known.

Perhaps the most striking feature of this system to the service technician is the fact that a high-quality color-television signal can be fitted into the same spectrum space now occupied by a black-and-white (or monochrome) signal. To make this feat even more astounding, not only

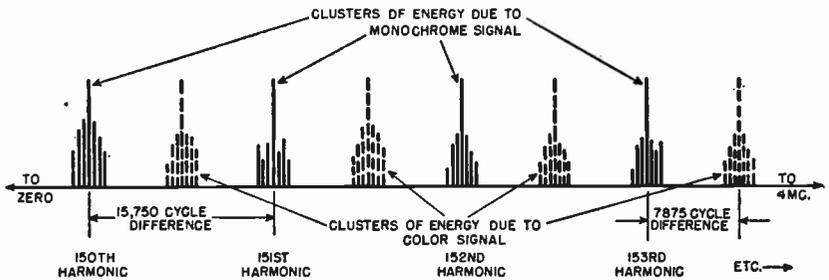


FIG. 1. The color information is inserted in the gaps between the monochrome signal.

do we have the color signal, but we have in no way disturbed the already existing monochrome signal.

How is all this possible? It is all possible because of the nature of a television signal. When we say that a television signal extends from 0 to 4.0 Mc, we do not mean that it occupies every cycle of that 4.0 Mc. In other words, the energy is not spread continuously from one end of the band to the other; rather it exists in the form of bundles or clusters of energy, each separated from the group above and below it by a frequency of 15,750 cycles. This is illustrated in Fig. 1, where a section of the spectrum of a video signal is shown. Gathered around each

harmonic are a number of sidebands caused by the vertical scanning of the image and hence each of these sidebands is separated from its neighbor by 60 cycles. The spread of these latter sidebands is quite restricted, and, to all intents and purposes, the spectrum space between harmonics of 15,750 cycles is empty. There is thus no reason why this empty space could not be utilized for the color portion of the signal, and here, indeed, is where this information is placed. The process of fitting one video signal in among the empty spaces of another video signal is known as interleaving. The two signals thus can be said to occupy the same general band, although they never come in contact with each other and do not, within limits, interfere with each other.

THE MONOCHROME SIGNAL

The black-and-white or monochrome portion of the total color signal is equivalent in all respects to present black-and-white signals. It is formed by taking 59 per cent of the signal coming from the green camera tube, 30 per cent of the signal developed by the red camera tube, and 11 per cent of the signal output of the blue camera tube. Mathematically,

$$Y = 0.59G + 0.30R + 0.11B$$

where Y = monochrome signal*

G = green signal

R = red signal

B = blue signal

This particular combination was chosen because it closely follows the color sensitivity of the human eye. That is, if you take equal amounts of green, red, and blue light energy and superimpose the rays from these lights on the screen, you will see white. However, if you then look at each light separately, the green appears to be twice as bright as the red and six to ten times as bright as the blue. This is because the eye is more sensitive to green than to red and more sensitive to red than to blue. Recognition of this fact led to the above equation.

To repeat, then, the monochrome signal is composed of 59 per cent of the voltage appearing at the output of the green camera tube, 30 per cent of the voltage produced by the red camera tube, and 11 per cent of the voltage from the blue camera tube. All video frequencies from 0 to 4 Mc are contained in these voltages.

* This notation is widely used by the industry.

Alternate names for the monochrome signal are *luminance signal* and *brightness signal*. These terms perhaps indicate more clearly the action of this signal. Every monochrome video signal contains nothing but the variations in amplitude of the picture signal and these amplitude variations, at the picture tube, produce changes in light intensity at the screen.

THE COLOR SIGNAL

The second component of the television signal is the color signal itself. This, we have just seen, is interleaved with the black-and-white signal. To determine what information this portion of the total signal must carry, let us first see how the eye reacts to color, since it is the eye, after all, for which the color image is formed.

Investigations of the color characteristics of the human eye have revealed useful information. To reproduce essentially all the colors which the eye normally sees we require only three primary colors. These are red, blue, and green. The proportion in which these colors are mixed will determine the color produced; when all three are used in the proper proportion, white will be produced.

The average human eye requires these three primaries only for relatively large areas or objects. When the size of the area or object decreases, several things happen. Probably the most important change that takes place is that it becomes more difficult for the eye to distinguish between various colors. For example, blue and green are often confused with each other, as are brown and crimson. Blue tends to look like gray, and yellow also becomes indistinguishable from gray. Reds remain fairly distinct, but all colors tend to lose some of their vividness. Thus, where the eye formerly required three primary colors, now it finds that it can get by very well with only two. That is, these two will, in different combinations with each other, provide the range of colors that the eye needs or can see.

Finally, when the detail becomes very small, all that the eye can discern are changes in brightness; colors cannot be distinguished from gray, and to all intents and purposes the eye is color blind.

These properties of the eye are well put to use in the NTSC color system. For example, only the larger detail is colored; the fine detail is rendered in black-and-white. Secondly, as we shall see later, even the color information sent is regulated according to bandwidth. That is, the larger objects receive more of the green, red, and blue than the medium-sized objects.

The color signal takes the form of a carrier and an associated set of sidebands. The color carrier is more commonly known as a *subcarrier*, possibly because the word carrier is reserved for the RF signal which the station transmits. The subcarrier frequency is approximately 3.58 Mc. This represents a figure which is the product of approximately 7,875 cycles multiplied by 455. Since 7,875 is one-half of 15,750, if we use an odd multiple (i.e., 1, 3, 5, etc.) of 7,875 as a carrier, it will fall midway between the harmonics of 15,750 cycles. If we used even multiples of 7,875, we would end up with 15,750 or one of its harmonics, and this would place the color signal at the same points (throughout the band) as those occupied by the black-and-white signal (refer back to Fig. 1). By taking an *odd* multiple of 7,875, we cause the second signal to fall in between the bundles of energy produced by the first signal, and the two do not interfere.

Application of the interleaving principle enables us to provide a full-color signal in the same bandpass formerly occupied only by the monochrome signal. However, this benefit would be of no avail if a second condition of compatibility were not also satisfied, namely, that the added color signal not develop strongly visible interference patterns on the screens of non-color receivers. Fortunately this requirement too was satisfied.

As simple proof of this latter fact, consider a video signal (in this case, a sine wave) whose frequency is 47,250 cycles. This is the third harmonic of 15,750 cycles. During the scanning of line 1, three complete cycles are applied to the grid of the picture tube. While the cycles themselves are shown in Fig. 2A, actually each negative half-cycle would produce a dark area and each positive half-cycle would produce a light area. However, for ease in presentation, the sine-wave cycles are shown.

Now, every horizontal line will contain the same three cycles, and when line 1 is scanned during the next frame (actually line 526), the original pattern is reinforced, because the beam will react as it did for line 1 of the previous frame.

Consider now a video signal whose frequency is an odd multiple of one-half the line frequency (23,625 cycles, for instance). During one line scan only $1\frac{1}{2}$ cycles of this wave will be traced out on the screen. During the next line (line 3 in interlaced scanning) the pattern shown in Fig. 2B will be traced out. This is a continuation of the pattern for line 1, but since we start line 3 from the point where we left off on line 1, the pattern in this second tracing is 180° out of phase with the pattern on line 1. On the third tracing (line 5) we return to the same

pattern as line 1, and on the fourth tracing (line 7) we obtain the same pattern as line 3.

Thus, every other scanned line reverses the pattern, and when line 526 (which is line 1 of frame 2) is placed over line 1 of the previous frame, the two patterns will be opposite in phase and will nullify each other.

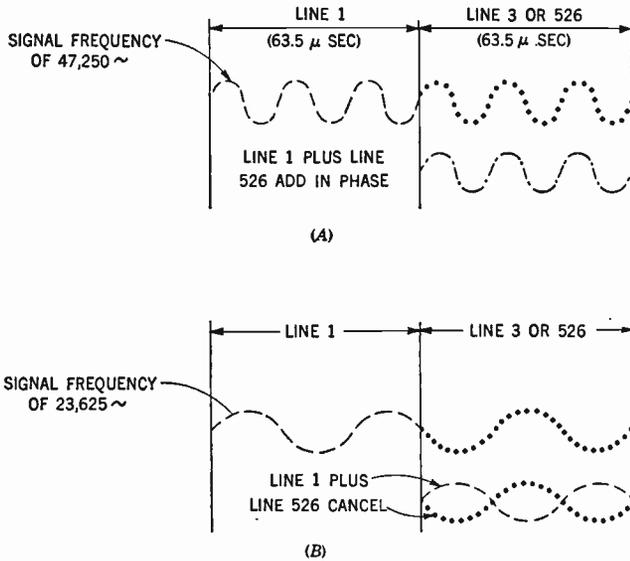


FIG. 2. Cancellation of coloring information. (A) Even harmonics of half the line-scanning frequency reinforce each other on successive scanings of the same line. (B) Odd harmonics cancel out.

While the nullification on a picture screen cannot be as complete as it can be using sine waves, still a significant cancellation does occur and the visibility of the resultant interference pattern in a properly designed and adjusted receiver is quite low.

COMPOSITION OF THE COLOR SIGNAL

Now that we know where the color signal can be placed in the spectrum of a television signal, the next task is to determine what information is required to form a color picture and then to impart this information to the carrier.

Every color in a scene to be televised has three characteristics. The first to strike the viewer is its hue, which is the color itself, green or

yellow or blue, etc. The second characteristic is its (saturation), which governs the intensity of the color, i.e., whether the green is a deep green or a pale green, whether the yellow is a strong yellow or a pale canary yellow. A color which is not fully saturated contains a greater proportion of white light in its mixture than a color which is saturated. In the scanning of a pale yellow, we obtain greater amounts of blue (which adds to the red and green, from which the yellow is basically derived, to form the white required to desaturate the yellow) than we would find in a strong yellow. This means that when pale yellow is being sent, there is more blue signal voltage present than when a stronger, more saturated yellow is being sent.

The third characteristic of any color is its (brightness), or the amount of light which is reaching the camera from that particular color. This, in turn, is governed by the amount of light on the scene plus the ability of the colored surfaces to reflect the light.

In the transmission of any color image, information concerning all of these three characteristics must be included. In addition we also have a monochrome signal to send, and this, we know, tells us what the brightness of the scene is at every point. We remember that

$$Y = 0.59G + 0.30R + 0.11B$$

Now, since brightness information is carried by the monochrome signal, we can eliminate any brightness information contained in the color signal. To do this, we take a portion of the brightness signal, pass it through an amplifier and invert it. If we call the brightness signal Y initially, then after the passage through the amplifier, it becomes $-Y$. This is then combined with each of the three colors to produce $G - Y$, $R - Y$, and $B - Y$ signals. Once this is done, it turns out that instead of requiring all three color-difference signals, all we really need are two, say $R - Y$ and $B - Y$, and the brightness, or Y , signal. This is so because G information is already present in the Y or brightness signal, since the latter contains voltages from all three colors. Hence, if we send along only $R - Y$ and $B - Y$ in the color signal to the receiver, we can use these to obtain the $G - Y$ information we need.

The logic of this procedure becomes evident when it is recalled that only three expressions are needed when three unknowns are involved. The unknowns here are hue, brightness, and saturation. The three expressions are $R - Y$, $B - Y$ and Y .

(For those readers who would like to see mathematical proof of this, a simple analysis is given at the end of this chapter.)

Thus, we now have only two items of color information to send, and

somehow the 3.58-Mc color subcarrier must be modulated by both the $R - Y$ and $B - Y$ voltages without conflict.

The best solution to this problem, designers found, was to take the $B - Y$ and $R - Y$ signals and apply each to a separate modulator (see Fig. 3). At the same time, 3.58-Mc carriers were also applied to each modulator, but with one carrier 90° out of phase with the other. After the carriers were amplitude-modulated, they were combined to form one resultant carrier.

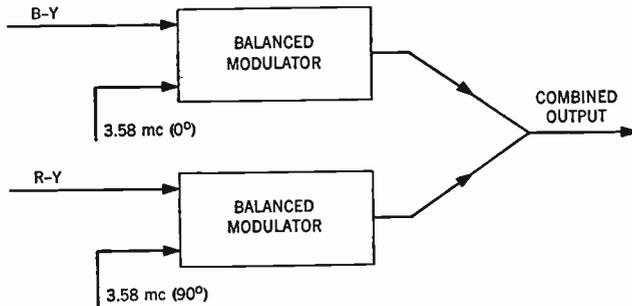


FIG. 3. The basic modulation method used to send two color signals on one subcarrier.

The foregoing action is best illustrated by means of vectors. We know that the two 3.58-Mc carriers are 90° out of phase with each other. Two sine waves (which is what the carriers are) that differ by 90° can be drawn as shown in Fig. 4A or by means of vectors as in

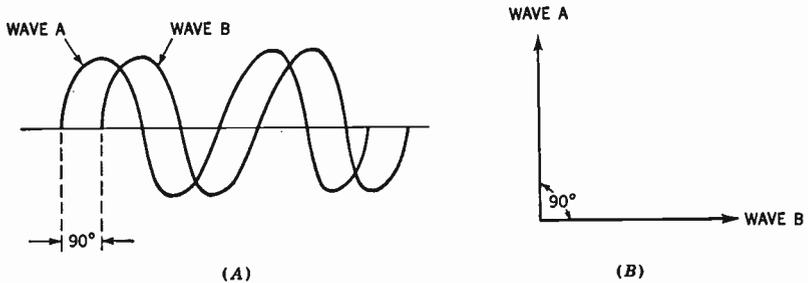


FIG. 4. (A) Two sine waves 90° out of phase with each other. (B) Equivalent vectors also 90° out of phase.

Fig. 4B. Both diagrams are equivalent, but the vector shorthand provides us with a clearer picture of the over-all action. In the present discussion no extensive knowledge of vectors is required other than the

fact that here they represent alternating voltages. When the vectors are drawn at a specific angle to each other, it means that the alternating voltages they represent differ in phase by that number of degrees.

In Fig. 5A the vector labeled $B - Y$ represents the $B - Y$ modulated carrier; the $R - Y$ vector represents the carrier modulated by the $R - Y$ voltage. When these voltages or signals are combined, a resultant is formed. If the $R - Y$ and $B - Y$ signals are equally strong, the resultant will occupy the position shown in Fig. 5B. If the $B - Y$ signal is pre-

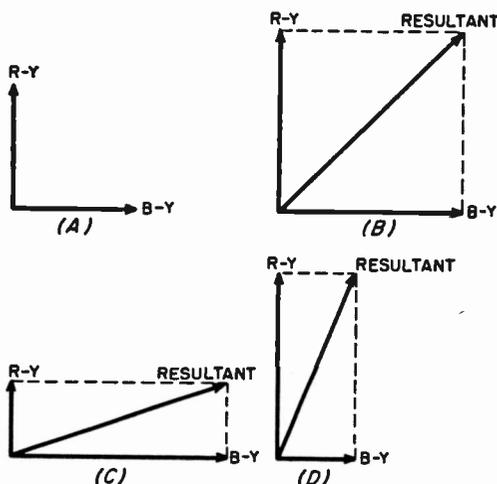


FIG. 5. The angular position and amplitude of the resultant carrier for various amplitudes of $B - Y$ and $R - Y$. (A) The $B - Y$ and $R - Y$ vectors. (B) The resultant when $B - Y$ and $R - Y$ are equal. (C) The resultant when $B - Y$ is stronger than $R - Y$. (D) The resultant when $R - Y$ is stronger than $B - Y$.

dominant, the resultant will be drawn closer to it (see Fig. 5C). On the other hand, if the $R - Y$ signal is the stronger, the position of the resultant vector will shift toward it (see Fig. 5D).

Thus, we can see that the phase angle of the resultant is governed by the stronger vector. Since $B - Y$ and $R - Y$ represent color information of a video picture, the angle of the resultant will vary as the color varies. This is one clue to the nature of the color signal. Another clue is furnished by the fact that the amplitude of $R - Y$ and $B - Y$ indicates the strength (or intensity, hence saturation) of the color detail. Both of these points will be referred to again presently.

Note that the $B - Y$ and $R - Y$ signals amplitude-modulate their separate carriers prior to the addition, and so each modulated signal

possesses a 3.58-Mc carrier and a series of sidebands (like every AM signal). When the resultant is formed, the sidebands are brought along with it.

If we pause now and reconstruct our total color signal, here is what we find. First, there is the Y , or monochrome, signal, and it extends over the entire video-frequency range from 0 to 4.0 Mc. Second, there is a color subcarrier with a frequency of 3.58 Mc. This subcarrier is modulated by the $R - Y$ and $B - Y$ signals, and the modulation intelligence is contained in a series of sidebands that stretch above and below 3.58 Mc. Just how far above and below is dependent on the band of frequencies contained in the $R - Y$ and $B - Y$ modulating voltages.

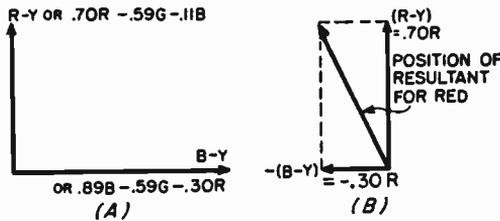


FIG. 6. How color determines the position of a resultant vector. (A) Equations showing compositions of $B - Y$ and $R - Y$. (B) Position of resultant when only red color is being sent. See text for details.

It has been determined that the eye is perfectly satisfied with the color image that is produced if we include color information only up to 1.5 Mc while the portion of the image from 1.5 Mc to 4.0 Mc is rendered in black-and-white. Hence the sideband frequencies of the color modulating voltages (so far, called $R - Y$ and $B - Y$) need extend only from 0 to 1.5 Mc. Furthermore, we can even modify this set of conditions somewhat because the three primary colors are required only for large objects or areas, say those produced by video frequencies up to 0.5 Mc.

For medium-sized objects, say those produced by video frequencies from 0.5 to 1.5 Mc, only two primary colors need be employed.

In other words, to take advantage of this situation, we need two color signals, one of which has a bandpass only up to 0.5 Mc, while the other has a bandpass of 0 to 1.5 Mc. The next problem then is to determine what the composition of each of these two color signals is.

To appreciate the answer to this, let us return to the vector diagram showing the $R - Y$ and $B - Y$ signals. This is redrawn in Fig. 6A and

to the diagram we have added the equivalent expression for Y , namely, $0.59G + 0.30R + 0.11B$. Then

$$\begin{aligned} R - Y &= R - 0.59G - 0.30R - 0.11B \\ &= 0.70R - 0.59G - 0.11B \end{aligned}$$

and

$$\begin{aligned} B - Y &= B - 0.59G - 0.30R - 0.11B \\ &= 0.89B - 0.59G - 0.30R \end{aligned}$$

This means that the $R - Y$ and $B - Y$ vectors contain R , G , and B voltages in the proportions shown.

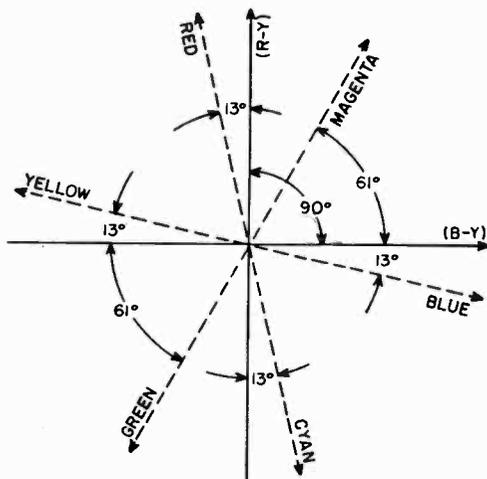


FIG. 7. The phase of the resultant color subcarrier is governed by the color sent.

Now, let us suppose that the color camera is scanning a scene containing only red. No green or blue voltages are present, and the $R - Y$ signal becomes simply $0.70R$, while the $B - Y$ signal reduces to $-0.30R$. This set of conditions and the position of the resultant vector are shown in Fig. 6B. In other words, this is the position the vector would occupy when red only was being sent.

By following the same process, we can obtain the position that the resultant vector occupies when only green is being sent, or blue or any other color formed by combining these three colors in any combination. A number of colors are shown in Fig. 7, and we see, perhaps more clearly than before, how the phase of the resultant color subcarrier

changes as the color to be transmitted varies. This, of course, brings us back to a statement previously made: The phase angle of the resultant will be governed by the coloring of the picture. Furthermore, the amplitude (or length) of the vector will determine how intense (i.e., saturated) the colors are.

With this information in mind, let us return to our original problem: Which of the two color voltages modulating the color subcarrier should have a wide bandpass (i.e., up to 1.5 Mc) and which should have the narrower (0.5 Mc) bandpass? The answer is not $R - Y$ and $B - Y$, but other voltages not far from them. Figure 8 shows where the 0.5-Mc

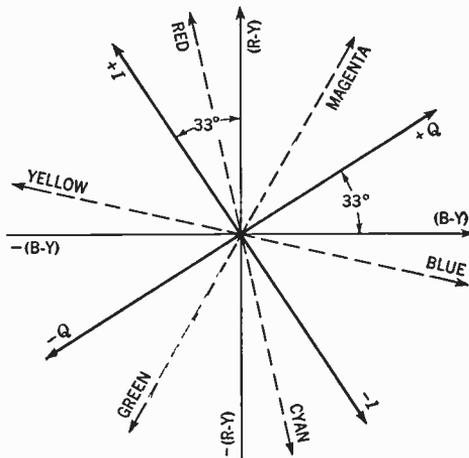


FIG. 8. The positions of the I and Q signals with respect to $R - Y$ and $B - Y$.

bandpass signal was found to be. Let us call this the Q signal. It is between $B - Y$ and $R - Y$, but decidedly closer to $B - Y$ (33° from it).

The second signal, called the I signal, is placed 90° away from the Q signal, and it is provided with voltages whose frequencies extend up to 1.5 Mc. Note that it is quite close to the $R - Y$ vector.

Thus, where before we had $R - Y$ and $B - Y$ voltages modulating the color subcarrier, we now substitute I and Q signals. Of these two signals, it is the I which possesses frequencies to 1.5 and the Q which is given frequencies only up to 0.5 Mc.

At this point, the reader may wonder why the I and Q signals are better suited for use as the color signals than their predecessors, the $R - Y$ and $B - Y$ voltages. Here is the answer to this.

It has been shown that by various combinations of the $B - Y$ and $R - Y$ vectors, every color could be represented by a certain angular position on the diagram. Actually, another way of looking at this is to consider $R - Y$ and $B - Y$ as two signals which, with the proper polarity, produce a resultant at any point around the full 360° of the

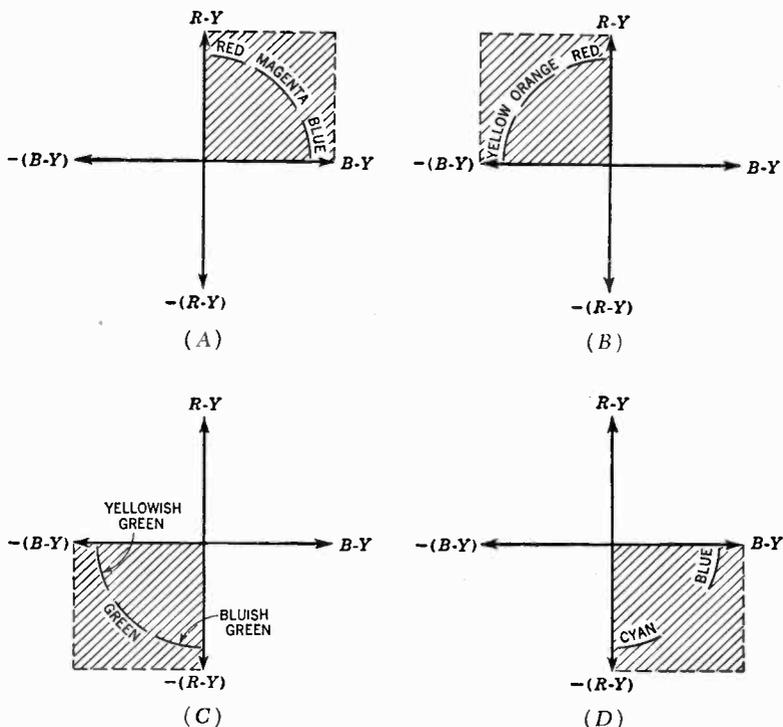


FIG. 9. (A) When $B - Y$ and $R - Y$ are both positive, the resultant vector falls in shaded region only. Colors produced extend from red through magenta to blue. (B) When $B - Y$ is negative and $R - Y$ is positive, the resultant vector falls in shaded area only. Colors produced range from red through orange to yellow. (C) When both $R - Y$ and $B - Y$ are negative, the resultant vector falls in shaded area. Colors range from yellowish green to green to blue-green. (D) When $R - Y$ is negative and $B - Y$ is positive, vector falls in shaded area shown. Colors range from bluish green (cyan) to blue.

diagram. For example, when the $B - Y$ vector and the $R - Y$ vector are both positive, then we can cover every angular position in the shaded area shown in Fig. 9A. When the $B - Y$ vector is negative and the $R - Y$ vector is positive, the resultant vector will fall at some point in the shaded area of Fig. 9B. When both the $R - Y$ and $B - Y$ vectors

are negative, the resultant vector falls into the shaded region of Fig. 9C. Finally, when the $B - Y$ vector is positive in value and the $R - Y$ vector is negative, the resultant falls in section shown in Fig. 9D.

To repeat, then, by suitable combinations of the $R - Y$ and $B - Y$ voltages (or vectors), we can produce any of the three primary colors, red, green, and blue, or any colors formed by combinations of these colors. This, in the final analysis, is what the color phase vector diagram indicates.

Consider, now, the I and Q signals or vectors. They, too, are at right angles to each other, and by combining I and Q signals in various polarities we can reproduce any color represented around the color phase diagram. Thus, whether we use $R - Y$ and $B - Y$ or I and Q for our color signals, we get precisely the same results. Why, then, switch from $R - Y$ and $B - Y$ to I and Q ?

The answer is to be found in the eye characteristics which were mentioned previously. Up to 500 kc all three primary colors are required, and so the signals we use must be capable of producing a resultant vector to occupy any angular position on the color phase vector diagram. This condition is satisfied by both I and Q vectors, since the bandpass of the Q signal extends from 0 to 500 kc and that of the I signal from 0 to 1.5 Mc. Had we used the $R - Y$ and $B - Y$ signals and permitted both of these to possess frequencies up to 500 kc and beyond, the same results would have been achieved.

From 500 kc to 1.5 Mc, the color perceptiveness of the eye is modified and we actually require only two so-called primaries. Neither of these primaries, however, is red, green, or blue; orange-red and blue-green are used. These primaries can be obtained by using a vector positioned 33° ahead of the $R - Y$ vector. This is the position of the I vector, and for color video frequencies from 500 kc to 1.5 Mc, we operate along the positive and negative segments of this line. When the I value is positive, the color produced is in the orange-red region of the color phase vector diagram. When the I value is negative, the color produced falls in the blue-green region. Only these colors and variations of them can be produced in the region from 500 kc to 1.5 Mc, since in this range no Q signal is present.

Thus, the choice of the I and Q vectors really rests on the choice of the I vector designed to conform to the characteristics of the human eye in the medium-sized detail region. The Q vector is then simply chosen to be 90° from the I vector in order to enable us to reproduce the full range of colors for frequencies below 500 kc.

With these questions answered, we are now in a position to consider the color signal in all its aspects.

1. There is a monochrome signal with components that extend from 0 to 4 Mc. This is the *Y* signal.

2. The color subcarrier frequency is set at 3.58 Mc (actually 3.579545 Mc).

3. This color subcarrier is modulated by two color signals called the *I* and *Q* signals.

4. The *Q* signal has color video frequencies that extend from 0 to 500 kc, or 0.5 Mc. Because of this, upper and lower sidebands of the *Q* signal are retained.

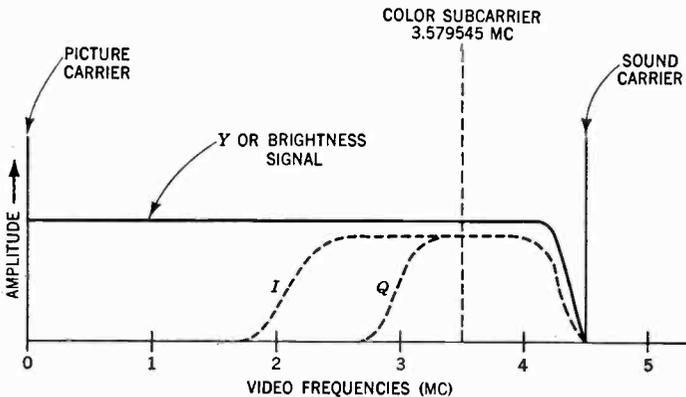


FIG. 10. Distribution of the color video signal in its pass band.

5. The *I* signal has color video frequencies that extend from 0 to 1.5 Mc. When this modulates the color subcarrier, upper and lower sidebands are formed. The lower sidebands then extend down to about 2.1 Mc. If the full upper sideband were permitted to exist, it would extend all the way up to $3.58 + 1.5$, or 5.08 Mc. Obviously this would prevent the use of a 6.0-Mc over-all band for the television signal (video and sound). To avoid this spilling over beyond the limits of the already established channels, the upper sideband of the *I* signal is limited to about 0.6 Mc. This brings the upper sideband of the *I* signal to 4.2 Mc. The video pass band then ends rather sharply at 4.5 Mc (see Fig. 10).

There is one further fact that is of importance in the make-up of a color-television signal and this concerns the color subcarrier. We know that the 3.58-Mc carrier is modulated by the two *I* and *Q* color signals. In conventional modulation methods both the carrier and the side-

bands are present when the signal is finally sent out over the air. The intelligence (or modulation) is contained in the sidebands, and that is actually all that we are interested in. However, the carrier is sent along because it is required in the receiver to reverse the modulation process and re-create the original modulating voltages.

In the NTSC color system, the color subcarrier is not sent along with its sidebands (after the latter have been formed). Instead, it is suppressed by using a balanced modulator. This particular practice is followed for two reasons. First, by suppressing the color subcarrier, we reduce the formation of a 920-kc beat note between it and the 4.5-Mc sound carrier which is also part of every television broadcast. This 920-kc note would appear as a series of interference lines on the face of the picture tube. It is true that the color sidebands are present and that they can (and do) beat with the 4.5-Mc sound carrier to produce similar low-frequency beat notes. However, in any signal the carrier usually contains far more energy than any of its sidebands, and so when we suppress the carrier, we are, in effect, suppressing the chief source of this interference. Whatever other interference may be produced by some of the stronger sidebands near 3.58 Mc can be more easily dealt with by using traps in the IF system. This will be seen when we examine the circuitry of a receiver.

The second reason for using this suppressed-carrier method is that it leads to an automatic removal of the entire color signal when the scene that is televised is to be sent wholly as a black-and-white signal. When this occurs, I and Q drop down to zero and since the balanced modulators suppress the carrier, no color signal at all is developed. After all, why have a useless color carrier when no color information is to be sent?

With these advantages of carrier suppression comes one disadvantage. When the color sidebands reach the color section of the receiver, a carrier must be reinserted in order to permit detection to take place. One might suppose that all we need for this is an oscillator operating at 3.58 Mc. This is one requirement; a second and vitally important consideration is the phase of this reinserted carrier. Remember that back at the transmitter, attention was given to the phase of I and Q as they were introduced into the modulator. If the same relative phase is not maintained in the reinserted carrier, the colors obtained at the output of the color circuits will not possess the proper hue.

To provide information concerning the frequency and phase of the missing color subcarrier, a color burst is sent along with the signal. This burst follows each horizontal pulse and is located on the back porch of each blanking pedestal (see Fig. 11). It contains a minimum of 8

cycles of the subcarrier, and it is phased in step with the color subcarrier used at the station. In the receiver this burst is used to lock in the frequency and phase of a 3.58-Mc oscillator, and thus we are assured at all times that the reinserted carrier will do its job correctly when it recombines with the color sidebands.

The position of the color burst on the back porch of each horizontal sync pulse ensures that it will not be seen on the screen of either color

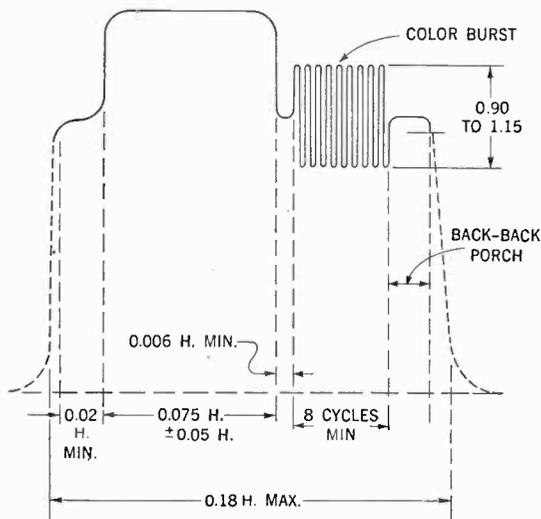


FIG. 11. The color burst is located on the back porch of every horizontal sync pulse.

or monochrome television receivers, since the screen is ordinarily blacked out during this retrace interval. If the burst were to be placed at a lower level, it would produce undesirable spurious picture-tube light, especially on those sets which do not contain special horizontal blanking signals.

The burst does not appear during the vertical serrated pulses or after the equalizing pulses. It was found that the 3.58-Mc oscillator in the receiver remains in synchronism during this brief interval when no burst signal is being received. Upon the reappearance of the horizontal sync pulses and the accompanying color burst at the end of the vertical pulse interval, control of the 3.58-Mc receiver oscillator is smoothly resumed.

FURTHER ASPECTS OF THE NTSC COLOR STANDARDS

The choice of a suitable frequency for the color subcarrier represented a compromise between several opposing considerations. If the

subcarrier is placed high in the video band, any interference pattern which it might develop on a monochrome screen would be less visible because (1) the spots produced are fine-grained and (2) the gain of the video circuits themselves is more likely to be down at this end of the pass band and thus serve to attenuate the subcarrier signal.

On the other hand, the color subcarrier possesses sidebands (as we have seen), and if we place the subcarrier too high in the video pass band, the frequency range of the sidebands will be restricted. This in turn will limit the amount of detail which can be presented in color, and the point where color rendition becomes unsatisfactory is reached quite rapidly. The color subcarrier frequency chosen is 3.579545 Mc, and it is felt that this represents the best compromise.

In the foregoing discussion we have used 15,750 cycles as the line-scanning rate and 7,875 cycles as one-half the line-scanning rate. In the color standards adopted by the FCC, the line-scanning rate is given as $15,734.264 \pm 0.047$ cps. Furthermore, the vertical scanning frequency is still kept at $2/525$ the horizontal scanning frequency. Hence, the actual value of the vertical scanning frequency in the color standards becomes $2/525 \times 15,734.264$, or 59.94 cycles.

Why was this change made? The sound carrier which accompanies every television signal is situated 4.5 Mc above the video carrier. In a color-television signal the color subcarrier is at 3.58 Mc, and the interaction of this signal with the sound carrier will produce a 920-kc interference beat when both signals pass through the video second detector. This interference can be made less objectionable if its frequency can somehow be made an odd multiple of one-half the line-scanning rate; in other words, if the principle of frequency interleaving is applied to it in the same way that it was applied to the choice of a color subcarrier.

There are two possible approaches to this problem. We can change the separation between the video carrier and the sound carrier from 4.5 to 4.5045 Mc. The latter figure is the 572d harmonic of 7,875 cycles. In other words, it is an even harmonic of 7,875 cycles. The color subcarrier, we know, is an odd harmonic. The difference between 3.579545 and 4.5045 Mc would also be an odd harmonic of 7,875, and so we would be applying the principle of frequency interleaving to the beat, thereby reducing the visibility of whatever patterns it might produce on the screen of a monochrome or a color receiver.

This solution was considered and then dropped because it was found that a number of existing monochrome receivers would be unable to obtain proper sound reception if the sound carrier was shifted 4,500 cycles beyond its present position.

The second approach to the problem was to leave the sound carrier where it is, but to position the color subcarrier so that the beat fre-

quency produced by the interaction of these two signals does become an odd multiple of one-half the line-scanning frequency. However, when we move the color subcarrier, we must change the line-scanning frequency in order to retain frequency interlace.

With these conditions, the new horizontal line-scanning frequency is so chosen that the sound-carrier separation of 4.5 Mc is the 286th harmonic of the new line rate. Thus

$$\begin{aligned} f_h &= \frac{4.5 \times 10^6}{286} \\ &= 15,734.264 \text{ cps} \end{aligned}$$

The color subcarrier frequency is then chosen equal to 455 times one-half of 15,734.264.

$$\begin{aligned} f_{\text{color}} &= \frac{455 \times 15,734.264}{2} \\ &= 3.579545 \text{ Mc} \end{aligned}$$

The difference or beat between 3.579545 and 4.5 Mc is 0.920455 Mc and this turns out to be the 117th harmonic of one-half the line-scanning frequency. Thus frequency interlace is still retained.

Finally, the field frequency must be altered to maintain its relative position with respect to the line frequency. That is, the vertical scanning frequency is equal to $2/525$ the horizontal scanning frequency. Hence,

$$\begin{aligned} f_v &= \frac{2 \times 15,734.264}{525} \\ &= 59.94 \text{ cps} \end{aligned}$$

These new horizontal and vertical scanning frequencies are so close to the 15,750 cycles and 60 cycles employed with monochrome transmission that no difficulty is experienced in locking these sets into synchronism with the incoming signals.

It was mentioned earlier in this chapter that we need only $R - Y$ and $B - Y$ to give us $G - Y$. Here is proof of this.

We have already seen that

$$Y = 0.59G + 0.30R + 0.11B$$

With this in mind,

$$\begin{aligned} R - Y &= R - (0.59G + 0.30R + 0.11B) \\ &= 0.70R - 0.59G - 0.11B \end{aligned}$$

By the same method,

$$\begin{aligned} B - Y &= B - (0.59G + 0.30R + 0.11B) \\ &= 0.89B - 0.59G - 0.30R \end{aligned}$$

Also,

$$\begin{aligned} G - Y &= G - (0.59G + 0.30R + 0.11B) \\ &= 0.41G - 0.30R - 0.11B \end{aligned}$$

Now we shall see that if we take $0.51(R - Y)$, add it to $0.19(B - Y)$, and then invert the resultant signal, we will obtain $G - Y$. This will prove that with $R - Y$ and $B - Y$ we can get $G - Y$.

$$\begin{aligned} 0.51(R - Y) &= 0.51(0.70R - 0.59G - 0.11B) \\ &= 0.36R - 0.30G - 0.056B \end{aligned}$$

and

$$\begin{aligned} 0.19(B - Y) &= 0.19(0.89B - 0.30R - 0.59G) \\ &= 0.17B - 0.057R - 0.11G \end{aligned}$$

Adding the two equations together gives us

$$\begin{aligned} 0.51(R - Y) + 0.19(B - Y) &= 0.36R - 0.30G - 0.056B + 0.17B - 0.057R - 0.11G \\ &= -0.41G + 0.30R + 0.11B \end{aligned}$$

This is equal to $-(G - Y)$, as shown above. Hence if we invert the equation, we obtain

$$G - Y = 0.41G - 0.30R - 0.11B$$

Thus we have shown mathematically that adding the proper proportions of the $R - Y$ and $B - Y$ signals and inverting the resultant signal gives us $G - Y$. Then $R - Y$ and $B - Y$ are sufficient for full-color reproduction.

QUESTIONS

1. When we say that a television signal extends from 0 to 4.0 Mc, do we mean that it occupies every cycle of the 4.0 Mc? Explain.
2. How is it possible to transmit a full color signal in the same space occupied by a monochrome signal?
3. What proportions of red, green, and blue signals are employed to form the monochrome signal? Why were these particular values chosen?
4. List several alternate names for a black-and-white signal.
5. How is the color information carried by a video signal?
6. Why is it that a color signal does not produce strong interference patterns on the screen of a black-and-white receiver tuned to the color signal?
7. Every color in a scene to be broadcast possesses three characteristics. Name them and explain each briefly.
8. What information does the monochrome signal carry? The color subcarrier and its sidebands?

9. In what form does the color signal carry each of its components?
10. What do we mean by $R - Y$ and $B - Y$ signals? Why is $G - Y$ not required in the transmitted signal?
11. Why are I and Q signals better suited to color rendition than $R - Y$ and $B - Y$?
12. What is the video bandpass of the Q signal? Of the I signal?
13. Illustrate by means of a diagram the positions of the color subcarrier and its sidebands in the 6-Mc bandwidth of a video channel.
14. Why is the color subcarrier suppressed at the transmitter?
15. How is information concerning the frequency and phase of the missing subcarrier supplied to the receiver?
16. Why were the line-scanning and frame-scanning rates altered slightly for color signals?
17. Why does a misadjusted monochrome receiver develop a 920-kc beat on its screen when receiving a color broadcast? Does this represent a defect in the receiver? Explain.

CHAPTER 3

THE THREE-GUN COLOR RECEIVER IN BLOCK FORM

In the previous chapter we developed the principles of the NTSC color television system. In this and succeeding chapters we will examine first the general form of a suitable receiver and then delve more deeply into it, replacing each of the block sections by specific circuits.

Much of the internal circuitry of color television receivers depends upon the type of picture tube used. Thus you will find circuits in sets using the three-gun picture tube that would not be found in receivers utilizing a single-gun picture tube. And, of course, the reverse situation would also be true; i.e., there would be stages in a single-gun picture-tube receiver that have no actual counterpart in the three-gun set. Since the three-gun tube is the one that set manufacturers turned to first, let us start our receiver analysis with it.

A master block diagram of an NTSC color television receiver using a three-gun picture tube is shown in Fig. 1. Ten general blocks are indicated, with three of the blocks totally shaded and one of the blocks partially shaded. If we disregard the three totally shaded blocks, then what we have is the block diagram of a black-and-white, or monochrome, receiver. Thus, much of a color television receiver would be familiar to anyone who already understands how monochrome receivers function. This is certainly of considerable assistance and should do much to dispel any doubt the reader may have had concerning his ability to understand the circuitry of color television receivers.

The picture-tube block is shown partially shaded, to indicate that while portions of the circuit represented by this block are new, still much of it is familiar to black-and-white practice.

The three blocks in Fig. 1 which are fully shaded represent circuits which have no counterpart in monochrome receivers. Two of these blocks, labeled Color Sync and Chrominance Circuits, are concerned with the color signal and what must be done to this signal to make it

suitable for application to a three-gun picture tube. The third block, labeled Convergence Section, has actually very little to do with the color signal itself. The purpose of this section is to maintain the electron beams in the picture tube in proper focus and in proper relationship to each other at all points over the screen. Just why this is necessary will be noted when we come to a more detailed description of these circuits.

Let us now consider each block in turn, starting at the antenna.

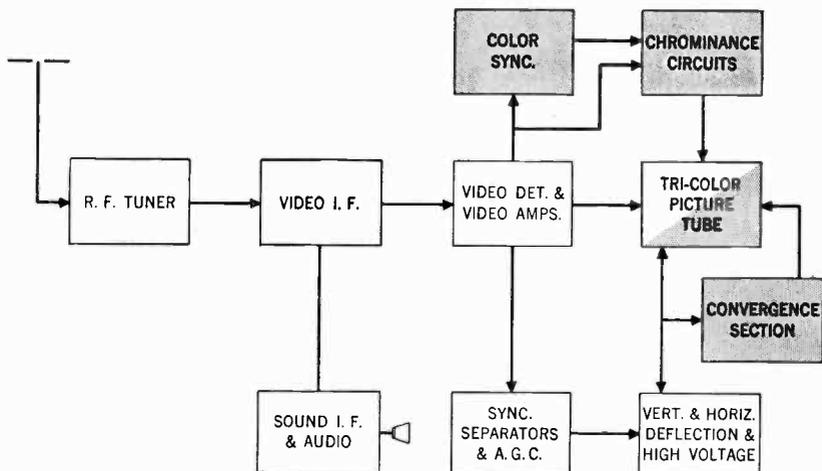


FIG. 1. Master block diagram of a color television receiver using a three-gun picture tube.

RADIO-FREQUENCY SECTION

The signals captured by the antenna are received by an RF tuner which is similar in all respects to the tuners employed in black-and-white receivers. That is, it is capable of receiving VHF signals on channels 2 to 13 and perhaps UHF signals from channels 14 to 82. In the VHF band an RF amplifier is present, together with an oscillator and mixer. For UHF reception either the signal is converted down to VHF (and then treated like any other VHF signal) or the video IF signal is produced directly.

VIDEO INTERMEDIATE-FREQUENCY SYSTEM

The tuner is followed by a video IF system (Fig. 2), which is somewhat more extensive than the video IF systems of monochrome sets in that it usually contains more stages and its bandpass is somewhat

wider. Also, more care must be taken in alignment to see that the response curve possesses the proper shape. However, the layout of the stages, their circuits, and the use of traps follow the practice established in monochrome receivers. That is, the video IF section amplifies only the frequencies of the signal being received, at the same time attenuating other signals that may be present but outside the frequency range of the received signal (usually including adjacent-channel signals).

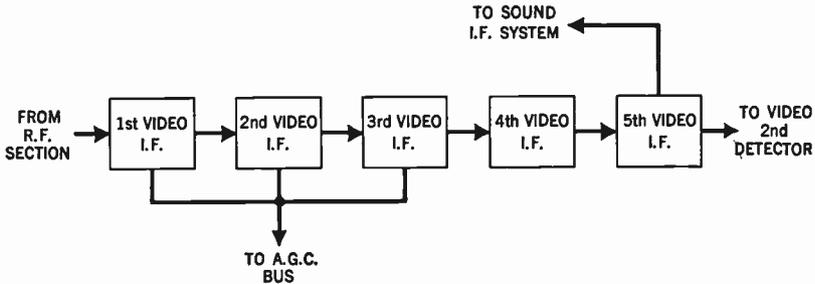


FIG. 2. Block diagram of the video IF channel.

An AGC voltage is applied to the first few video IF amplifiers as well as to the RF amplifier.

The sound take-off point in Fig. 2 is shown connecting to the end of the video IF system rather than to the second detector or beyond. This might lead you to believe that a split-sound system is employed rather than an intercarrier system. This is not the case. An intercarrier system is employed, and the reason for positioning the sound take-off in the video IF system stems from a desire to prevent undesirable interaction between the sound carrier and the color subcarrier. The two signals are separated by 920 kc (4.5 – 3.58 Mc), and unless the sound carrier is kept properly attenuated, a 920-kc beat will be produced in the video, second detector. The effect on the picture-tube screen will be the appearance of rather heavy dark bars. To minimize such interaction, the sound carrier is separated from the video signal at the plate of the last IF stage. This permits the set designer to adjust all the following circuits so that the response to the sound carrier or to any 4.5-Mc beat which it may produce (after detection) is as low as possible.

SOUND SYSTEM

In the sound system, the sound and monochrome video carriers are mixed in a germanium crystal diode, producing a 4.5-Mc beat note that

contains the sound intelligence of the broadcast. This is followed by several sound IF amplifiers, an FM detector, and then two audio amplifiers (see Fig. 3), as in monochrome receivers.

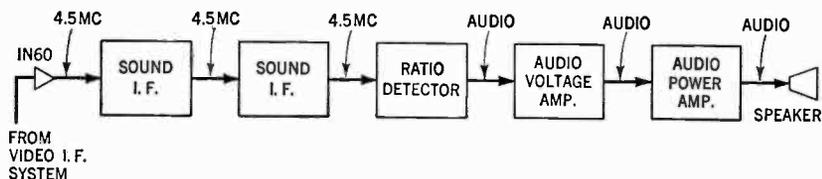


FIG. 3. Block diagram of the sound system of a color television receiver.

VIDEO CHANNEL

Returning to the video channel, both the black-and-white and the color signals are extracted from the picture carrier at the video detector. (Remember that while the color sidebands have their own subcarrier, they still form part of the over-all video signal. So far as the picture carrier is concerned, color signals occupy the same relative position as any monochrome frequency.) The combined signals, after the detector, are applied to a video amplifier. At the plate of this stage, portions of the signal are shunted to the sync separator and AGC

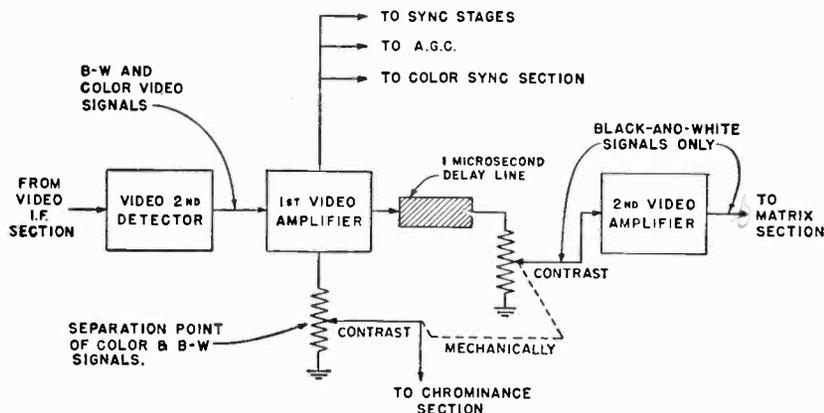


FIG. 4. Video-amplifier-section block diagram.

stages and to a color sync section (see Fig. 4). At the same time, another portion of the signal is taken from the cathode circuit of this tube and applied to the chrominance or color section of the receiver.

The first video amplifier is seen to be a very important junction, or routing point, in the color television receiver. Coming into this stage (from the detector) is a normal black-and-white signal with its familiar horizontal and vertical sync pulses. Also present is an interleaved color signal. The portion of the total signal which is shunted or diverted to the sync separator and AGC stages is designed to provide these stages with the information they need in order to carry out their functions. Thus the sync separator has to be given horizontal and vertical sync pulses so that it may pass these on to the vertical and horizontal sweep systems. Without these pulses, any picture that might be produced would be scrambled.

By the same token, the AGC section must be provided with a representative portion of the incoming signal, in order that it may "know" how strong the signal is and, from this, how much control voltage it must develop.

The color sync section is "interested" solely in the color burst which is present on the back porch of every horizontal sync pulse. The chrominance section, on the other hand, "desires" the color signal which is interleaved with the monochrome signal. The circuits are set up so that each gets only what it "desires." This we shall see in a moment.

Still remaining is the monochrome, or black-and-white, signal and this is taken from the plate of the first video amplifier and applied to the grid of the second video amplifier through a 1.0- μ sec time-delay network. This latter is needed so that when the luminance and color signals meet again later in the adder or matrix section, they will be in time-step with each other. The color signals pass through narrow band-pass filters in the chrominance system, and this serves to delay them. By inserting an equivalent delay line in the path of the luminance signal, we keep all segments of the video signal in step with each other.

Two contrast controls are shown in Fig. 4, one in the cathode leg of the first video amplifier, the other at the input to the second video amplifier. The units are mechanically ganged together so that the proper relationship is maintained between the monochrome and color signals for all settings of the contrast controls.

The video signal is amplified by a second video amplifier and then fed to the adder (or matrix) section. Here it combines with the various *I* and *Q* color (or color-minus-brightness) signals to produce the proper amounts of red, green, and blue voltages.

CHROMINANCE SECTION

The functions of the chrominance section are, first, to extract the color sidebands, second, to attenuate all the remaining sections of the signal, and, third, to demodulate the color signals so that the original color intelligence or voltages are reobtained (refer to Fig. 5).

A portion of the total video signal is obtained from the cathode of the first video amplifier and fed to a bandpass amplifier. Beyond this stage is a bandpass filter which permits signals of approximately 2.1 to 5.0 Mc to pass, while other frequencies are attenuated (see Fig. 6). In this way we tend to eliminate all monochrome signals below 2.1 Mc. The color information, of course, resides between 2.1 and 4.2 Mc of the video signal.

The bandpass amplifier receives other voltages in addition to the video signal.

The screen grid of the tube, for example, receives a negative pulse from the horizontal deflection transformer. This is designed to key the tube off while the color-burst signal (on the back porch of each horizontal sync pulse) is passing through the circuit. This prevents the color-burst voltage from reaching the DC restorers at the output of the chrominance channel and incorrectly shading the background in the color picture. The color-burst signal is designed principally for the color synchronization section of the receiver.

The control-grid circuit of the bandpass amplifier also operates in conjunction with a color-killer tube. This killer tube biases the bandpass amplifier to cutoff when a black-and-white signal alone is being received. However, when a color signal is present, the color burst just mentioned keeps the color-killer tube cut off, and this in turn releases the bandpass amplifier so that it will pass color signals to the following color demodulators.

The end of the bandpass filter is terminated in a chroma-control potentiometer. This control regulates the amount of color signal reaching the picture tube, and hence determines the saturation with which the colors are seen. In action it may be compared to the contrast control; note, however, that there is a master contrast control that regulates the intensity of both the monochrome and color portions of the image simultaneously. The chroma control might be considered as an adjunct to the master contrast control, concerned only with the color portion of the picture.

Beyond the bandpass filter, the color signal is fed in equal measure

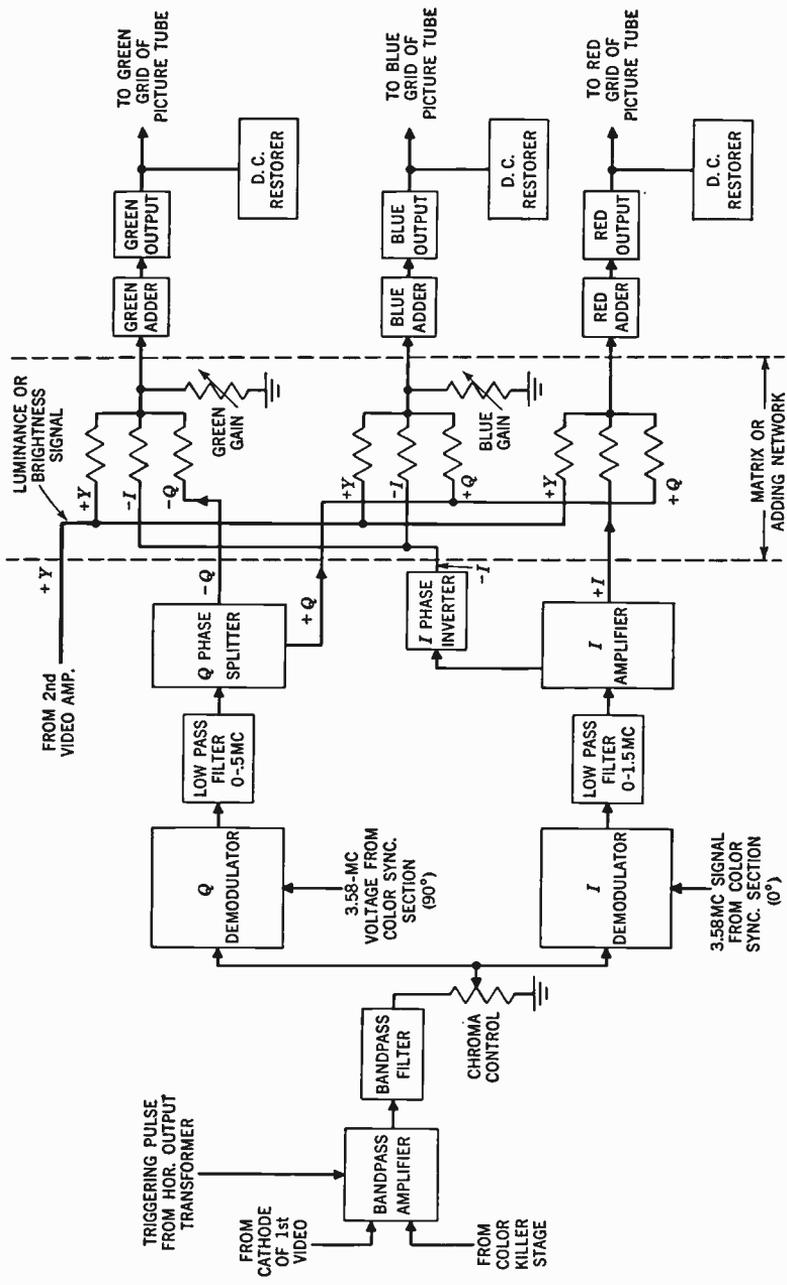


Fig. 5. The chrominance section of a color television receiver.

to two demodulators (i.e., detectors). One is called the *Q* demodulator, the other the *I* demodulator. The incoming signal goes to the No. 1 grids of these tubes. At the same time color subcarrier voltages of about 30 volts peak to peak are applied to the No. 3 grids (the suppressor grids). Both color subcarrier voltages possess the same frequency, but one is 90° out of phase with the other. This is in accordance with the formation of the *I* and *Q* signals at the transmitter. The

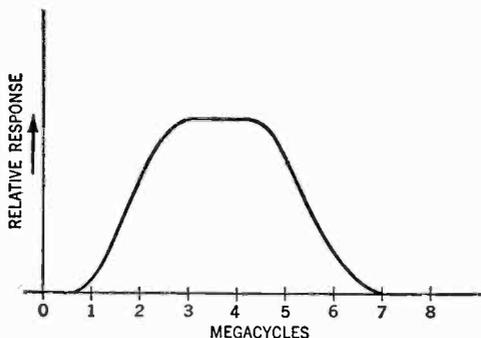


FIG. 6. Bandpass filter response.

beating of this inserted carrier with the *I* and *Q* sidebands re-creates the original color signals at the demodulator outputs.

(The reader will note that the same names of *I* and *Q* refer to the color video signals themselves, before modulation, and to the subcarrier sidebands after modulation. In the receiver, the *I* and *Q* signals exist as sidebands of the 3.58-Mc subcarrier until the signal reaches the color demodulators. Thereafter, they appear as video voltages with frequencies from 0 to 0.5 or 1.5 Mc, as the case may be.)

The signals from the demodulators now pass through low-pass filters designed, first, to remove the color subcarrier frequency (3.579545 Mc) and the sideband frequencies and, second, to limit the *I* and *Q* signal bandwidths to the values assigned to them at the transmitter. Thus the output of the *Q* demodulator goes through a 0- to 0.5-Mc low-pass filter, while the output of the *I* demodulator passes through a 0- to 1.5-Mc low-pass filter. The *Q* signal is applied to an amplifier from which positive and negative output voltages are available. The *I* signal goes first to one amplifier which provides one polarity output and then to a second amplifier from which the opposite polarity output voltage is obtained. (The reader will recognize that one tube could provide both positive and negative *I* voltages, if desired.)

All the I and Q voltages, in proper amplitude and polarity, together with the luminance signal, combine in a series of fixed resistive networks to produce the desired red, green, and blue color signals. After this, each signal is passed through one more amplifier, and then each is applied to a separate control grid of a three-gun color tube. Included, too, in this final arrangement are three DC restorers, one each for the red, green, and blue signals.

At this point we might pause and answer a question that many readers may wonder about: "How can you obtain the required red, green, and blue signals by combining I , Q , and Y (luminance) signals?" The proof requires the solution of several simple mathematical equations. If mathematics is not your forte, then you may skip the following discussion and simply accept the statements given above. However, for those who would like to see how the mixing is accomplished, the mathematical proof follows.

The I signal, from NTSC specifications, is defined as

$$I = -0.27(B - Y) + 0.74(R - Y)$$

where B = blue signal

R = red signal

Y = monochrome signal

The Q signal is similarly defined as consisting of

$$Q = 0.41(B - Y) + 0.48(R - Y)$$

These may be looked upon as two simultaneous equations that we wish to solve for $B - Y$ and $R - Y$. Here is how we do this. First, let us write the equations down.

$$\begin{aligned} Q &= 0.41(B - Y) + 0.48(R - Y) \\ I &= -0.27(B - Y) + 0.74(R - Y) \end{aligned}$$

To solve for $R - Y$, let us multiply the entire Q equation by 0.27 and multiply the entire I equation by 0.41. Doing this gives us

$$\begin{aligned} 0.27Q &= (0.27)(0.41)(B - Y) + (0.27)(0.48)(R - Y) \\ 0.41I &= -(0.27)(0.41)(B - Y) + (0.41)(0.74)(R - Y) \end{aligned}$$

Adding these two equations gives us

$$\begin{aligned} 0.27Q + 0.41I &= (0.27)(0.48)(R - Y) + (0.41)(0.74)(R - Y) \\ &= 0.13(R - Y) + 0.30(R - Y) \\ &= 0.43(R - Y) \end{aligned}$$

Hence

$$\begin{aligned} R - Y &= \frac{0.27}{0.43} Q + \frac{0.41}{0.43} I \\ &= 0.62Q + 0.96I \end{aligned}$$

Thus, if we take 0.62 of the Q signal (with positive polarity) and 0.96 of the I signal (with positive polarity) and mix them together, we obtain a red-minus-brightness signal, or $R - Y$.

By taking the same I and Q equations, and solving for $B - Y$ instead of $R - Y$, we obtain the following result:

$$B - Y = -1.1I + 1.7Q$$

Still to be obtained is a $G - Y$ signal and this was shown in the previous chapter to be

$$G - Y = -0.51(R - Y) - 0.19(B - Y)$$

or, substituting the equivalent I and Q expressions just given,

$$\begin{aligned} G - Y &= -0.51(0.62Q + 0.96I) - 0.19(1.1I + 1.7Q) \\ &= -0.64Q - 0.28I \end{aligned}$$

To each of these color-minus-brightness quantities ($R - Y$, $B - Y$, and $G - Y$) we add Y from the monochrome channel (i.e., the second video amplifier) to obtain R , B , and G , the color signals we seek. These are then amplified and fed to their respective grids of the three-gun picture tube.

COLOR SYNCHRONIZATION SECTION

A portion of the signal at the plate of the first video amplifier goes to a stage known as a burst amplifier. This stage is the input amplifier for a special section of the receiver known as the color synchronization section (see Fig. 7). It is the purpose of this section to utilize the color burst which is sent along with the horizontal sync pulses to develop in the receiver a local subcarrier possessing the proper frequency and phase. This is necessary because the color signal, when broadcast from the transmitter, does not possess a color subcarrier. All it possesses are the color sidebands. To properly demodulate the color signal, the carrier must be reinserted and this is one of the principal functions of the color synchronization section.

In order to reinsert the missing carrier properly, the receiver must be

given some information concerning the frequency and the phase of the missing carrier. This information is provided in the form of a burst of approximately 8 cycles of the color subcarrier which appears on the

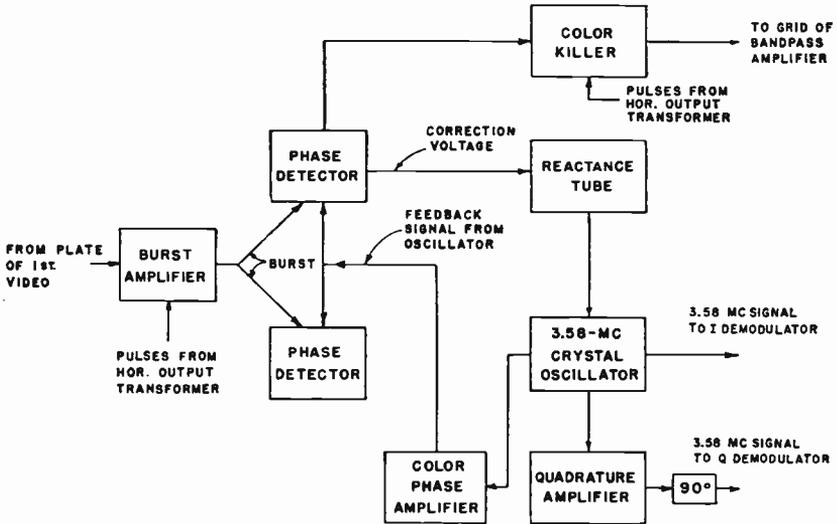


FIG. 7. Color-synchronization-channel block diagram.

back porch of each horizontal synchronizing pulse in the composite signal (see Fig. 8).

The burst amplifier is normally kept cut off except during horizontal retrace when it is keyed or triggered into conduction. In this way, all

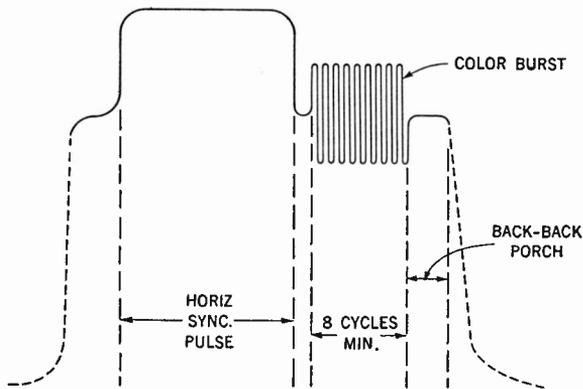


FIG. 8. The color burst on the back porch of each horizontal sync pulse.

but the desired burst is prevented from passing through this tube. The signal, at the output of the burst amplifier, is fed to a phase detector. The phase detector also receives a sample of the signal generated by a 3.58-Mc crystal oscillator. The two signals are compared with each other and any difference in frequency and phase leads to the development of a correction voltage which is applied to a reactance tube. The latter stage, being connected across the oscillator tuning circuit, causes its frequency and phase to change enough to bring the oscillator in line with the received burst.

Output for the *I* demodulator is obtained directly from the oscillator, while a succeeding quadrature amplifier supplies a signal 90° out of phase with the *I* signal. This is fed to the *Q* demodulator. This quadrature relationship is required because the *I* and *Q* signals were originally 90° out of phase with each other when the color subcarrier was modulated at the transmitter.

An alternate approach to the development of a suitable 3.58-Mc subcarrier can be achieved by means of a crystal ringing circuit. This system uses a quartz crystal which, when excited by the color burst at the start of each horizontal line, will continue to "ring" or oscillate at its natural frequency (here 3.58 Mc) for the duration of one horizontal line at least. The burst from the burst amplifier activates the quartz crystal, which, because of its extremely high *Q*, continues to oscillate with very little decrease in amplitude until the next burst arrives. A capacitor trimmer in series with the crystal can change its resonant frequency by several hundred cycles and thus compensate for normal crystal tolerances.

The stage following the crystal is an amplifier stage and the stage beyond that is generally a limiter to smooth out variations in output of the ringing circuit (see Fig. 9). Output from the limiter may be used as one of the 3.58-Mc driving voltages for the *I* or *Q* demodulators, while the same output, passed through a 90° phase-shift network, will provide the reference voltage for the other demodulator.

Note this distinction between these two circuits: in the crystal ringing circuit, no oscillations are generated when no color bursts are being received (i.e., when a black-and-white signal is reaching the receiver). On the other hand, in the automatic phase-detector system, a 3.58-Mc voltage is always being developed, even when the color burst is not present.

A color-killer tube is contained in both types of color sync systems. Its purpose is to prevent signals from passing through the chrominance section when no color signal is being received. This is done to prevent

the appearance of spurious color specks on a black-and-white picture.

Much of the remaining section of the color television receiver is very similar to the same circuits in black-and-white television receivers. The AGC stage, for example, is generally of the keyed variety, receiving a suitable video signal at its control grid and a positive triggering pulse from the horizontal output transformer. The AGC voltage that develops, then, is governed by the amplitude of the sync pulses in the incoming signal.

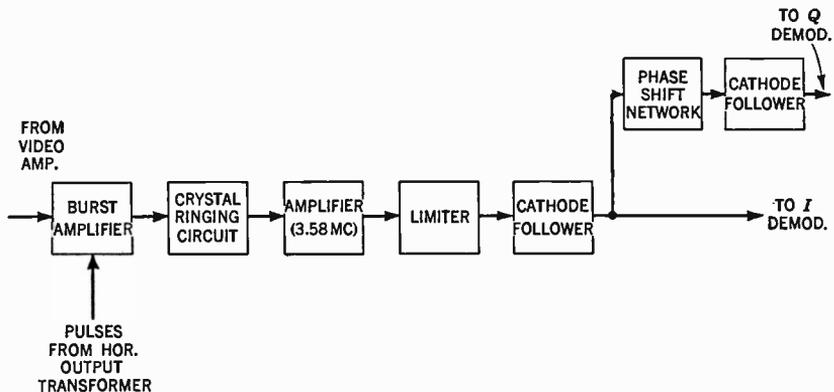


FIG. 9. A crystal ringing circuit for developing a 3.58-Mc signal for use in the *I* and *Q* demodulators.

The sync-separator system receives a portion of the composite video signal and then acts to divorce the sync pulses from the rest of the signal. At the output of the sync-separator section, the sync pulses are fed to the vertical and horizontal deflection systems through appropriate integrating and differentiating networks.

A block diagram of the two deflection systems and the high-voltage section is shown in Fig. 10. For the most part the vertical and horizontal oscillators and output amplifiers follow established practice. Thus the vertical system uses a blocking oscillator and an output amplifier. The horizontal system possesses an AFC network, a controlled horizontal oscillator, an output amplifier, and a damper tube. A special focus rectifier operates off the horizontal output transformer to develop the 5,000 to 8,000 volts required by the focus electrode on the three-gun color picture tube.

The accelerating voltage for the picture tube is 25,000 volts, and this

is obtained by employing one or more high-voltage rectifier tubes. In addition, regulation of this voltage is desirable to prevent variations in scanning linearity, brightness, and most important of all, picture color. A gaseous shunt regulator tube is one common method employed to stabilize the high voltage. During an all-black picture the regulator absorbs the entire load; during an all-white picture the picture tube takes the load and the regulator does very little.

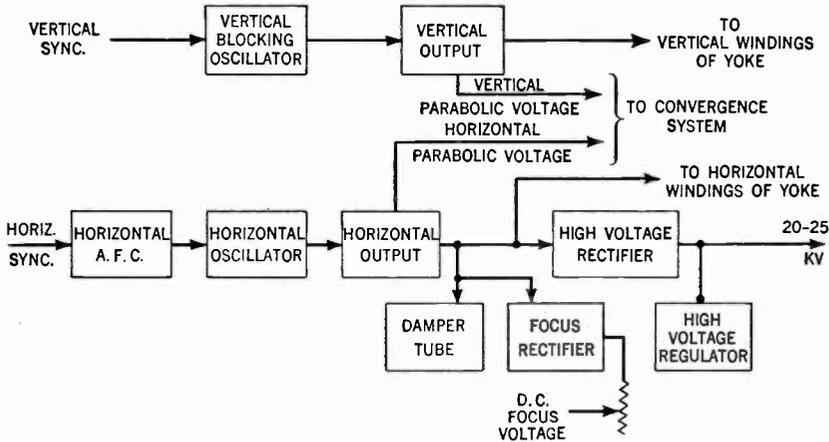


FIG. 10. Arrangement of the vertical and horizontal stages and the high-voltage system.

There is one additional feature of this receiver that requires some explanation, and that concerns the special voltages that are obtained from the vertical and horizontal output amplifiers and sent to a convergence section. Here these voltages are appropriately combined and then applied to special converging coils mounted on the neck of the picture tube.

The need for this additional circuitry stems from the fact that the surfaces of the fluorescent screen and its associated mask in the picture tube do not possess a truly spherical curvature. As a result, electron beams which may be properly coordinated at the center of the screen would, if not corrected, lose this coordination at points away from the center. It is the function of the above-mentioned voltages to vary the scanning angle of each beam so that each follows the actual curvature of the screen. The process is known as convergence, and a more intensive analysis is made of this feature in Chap. 7.

QUESTIONS

1. Draw a block diagram of a color television receiver using a three-gun picture tube.
2. Which sections of the color block diagram would not be found in a monochrome receiver? Explain why in each instance.
3. What precautions must be observed with respect to sound take-off from the video system?
4. List all of the sections in the receiver to which a portion of the detected video signal must be fed.
5. What portion of the incoming signal is the color sync section specifically interested in? How does it use this information?
6. Trace the path of the monochrome portion of a color video signal from the second detector to the picture tube.
7. What is the function of the chrominance section of the receiver?
8. Trace the path of the video signal through this section.
9. Where is the bandpass amplifier found and what does it do?
10. Distinguish between the action of the contrast and chroma controls.
11. How is the color signal demodulated?
12. Where are the demodulated color signals recombined with the brightness signal? What would be the visual result if the brightness signal never reached this point and only the color signals traveled on to the picture tube?
13. Where is the burst amplifier found and what does it do?
14. Describe briefly two methods of developing suitable 3.58-Mc subcarrier signals.
15. What do you suppose would happen if a 3.585-Mc subcarrier signal were generated in place of the desired 3.58-Mc signal? What would happen if *no* 3.58-Mc signal appeared?
16. What is a color-killer stage and what purpose does it serve?
17. Why are special convergence circuits required in the color receiver? Is this a feature of the NTSC system? Explain.

CHAPTER 4

THREE-GUN RECEIVER CIRCUITS: PART 1

In the previous chapter we examined in some detail the block diagram of a color television receiver designed to operate with a three-gun color picture tube. Now we are ready to consider the actual circuits which each of the blocks represented.

RADIO-FREQUENCY TUNER

The introduction of color in no way alters or modifies the RF section of the television receiver. Thus the RF amplifier should still possess high gain and low noise; the oscillator must still provide a signal which, when mixed with the incoming signal, will produce the desired difference or video IF frequencies. For the reception of VHF signals, either a turret tuner or a continuously variable device is employed. For UHF reception continuous tuning is currently the most common method, although there is also available an 82-channel turret tuner.

Over-all tuner selectivity remains at 6 Mc for color receivers, although the limitations on permissible amplitude variations are now more restricted. For example, in monochrome receiver tuners it is not unusual to find variations in amplitude (for the top of the response curve) ranging as high as 30 per cent (3 db) or more (see Fig. 1A). This is acceptable because it does not noticeably affect picture quality. In color receivers there is more involved than just picture quality. There are also the color sidebands and the color burst to consider. A 3-db attenuation of the color burst could lead to the total loss of color, particularly if this 3-db tuner attenuation is combined with other losses elsewhere in the receiver or in the antenna system. For best results, the maximum attenuation across the 6-Mc spread should not exceed 10 per cent (1 db) (see Fig. 1B).

A typical VHF tuner and its circuit are shown in Fig. 2. Cascode amplifiers are common in the RF stage, although some manufacturers

favor single high-frequency miniature pentodes. The oscillator tube is invariably a triode, usually half of the mixer tube. The latter may be another triode (i.e., half of a 6J6) or pentode (half of a 6U8). This arrangement requires only two tubes for the entire tuner section, resulting in a compact and economical assembly.

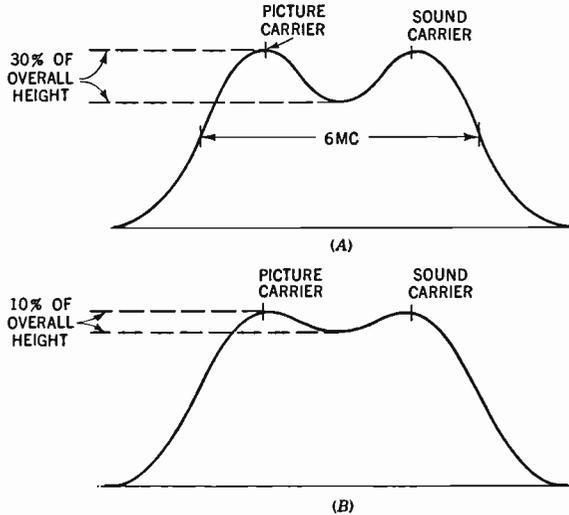


FIG. 1. (A) In monochrome receivers, it is not unusual to find variations along the top of the RF response curve ranging as high as 30 per cent. (B) For color television, the variation should not exceed 10 per cent.

In the tuner shown in Fig. 2, the cascode RF amplifier uses a 6BZ7 duo-triode. One section of a 6J6 serves as the mixer, while the other section functions as the oscillator. Balanced 300-ohm and unbalanced 75-ohm (coaxial line) input impedances are provided by a center-tapped primary winding, L101A. All signals must pass through M101, a high-pass filter designed to attenuate all signals below the lowest VHF channel, 2.

Secondary winding L101B is tuned by the input capacitance (of the first triode unit) in series with alignment trimmer C105. Loading of L101B by R101 provides the required bandpass, particularly on the lower VHF channels. AGC bias is applied to the first triode of V101 through decoupling resistor R102.

Direct coupling is used between the first triode plate and the second triode cathode. This is normal in cascode circuits. With cathode feed to the second triode, C103 is used to place the grid at RF ground po-

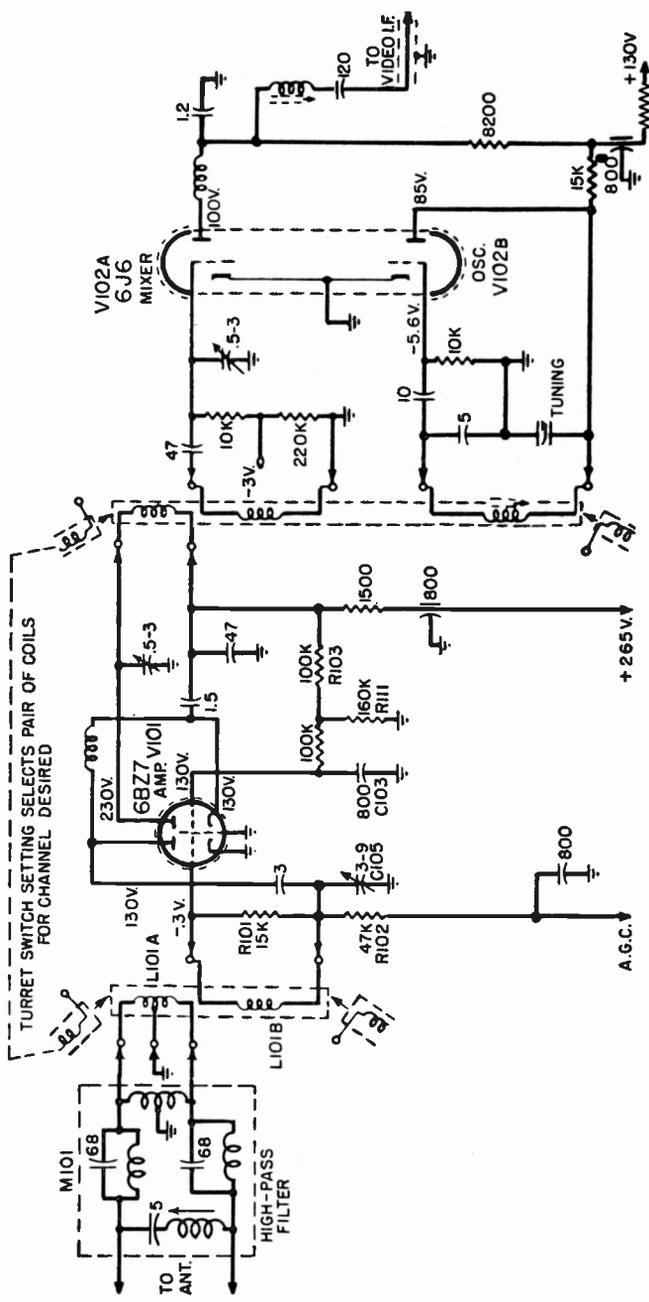


FIG. 2. Typical RF tuner used with color TV receiver. This is a turret-type unit for VHF only; however, combination VHF-UHF models are used also.

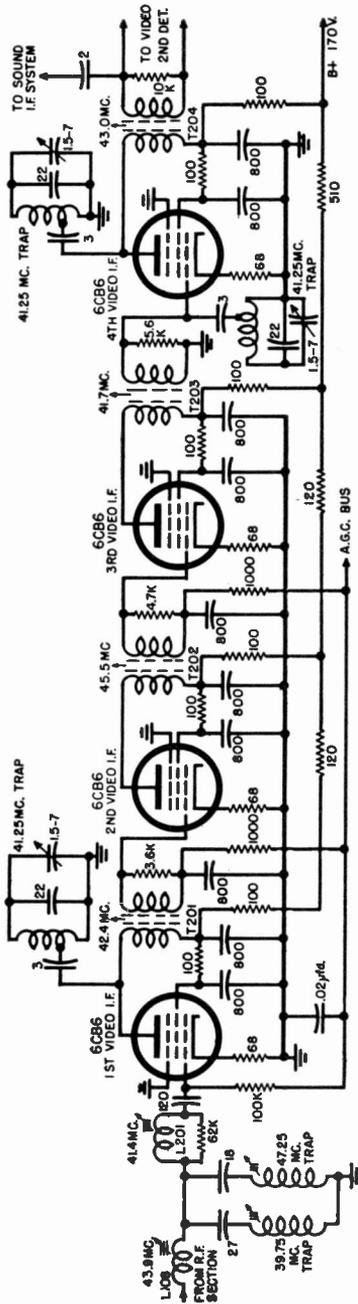


FIG. 3. The video IF circuits of one color TV receiver. Four stages are used here to assure a wider and more uniform bandpass than for black-and-white sets.

tential. Since the two triode sections of V101 are in series across a common plate supply, the cathode of the second triode is positive with respect to chassis ground. A divider across the B+, consisting of R103 and R111, places the grid (of the second triode) at a sufficiently positive potential (with respect to its cathode) for proper operating bias.

The signal at the plate of the second triode of V101 is inductively coupled into the grid circuit of the mixer. At the same time a voltage from the oscillator is similarly brought into the mixer circuit. The mixer combines both signals to produce the desired IF and then transfers this voltage to the following IF stages.

The oscillator is of the ultraudion variety with a front-panel fine-tuning control.

VIDEO INTERMEDIATE-FREQUENCY SECTION

The video IF section follows the RF tuner. This will contain four and sometimes five separate stages (see Fig. 3). In the conventional black-and-white television receiver, three IF stages are most frequently used, although four stages are found in some sets. The increased number of IF stages in the color set stems in part from the wider bandpass

required (4.2 Mc) and in part from the greater precautions that must be taken to ensure that the response will possess the correct form.

The desired response curve for the video IF section is shown in Fig. 4. Of particular interest is the care with which the high-frequency end of the curve must be shaped so that it provides the proper amplification for the color subcarrier and its sidebands. Note that the curve is flat up to approximately 41.65 Mc, after which it falls off quite sharply. The

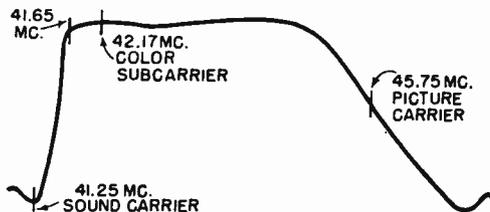


FIG. 4. Video IF response curve of a color TV receiver. Note the steep slope of the curve between 41.25 and 41.65 Mc.

steep decline is needed to prevent the sound carrier from receiving too much amplification. Should this occur, it would produce a 920-kc beat note at the video second detector and this, in turn, would appear on the screen as an interference pattern. Furthermore, too much sound voltage at the detector will produce a fine-grained 4.5-Mc pattern on the screen or sound bars or both. The latter effect, of course, is common to all television receivers, whether black-and-white or color. The 920-kc interference, however, arises only when a color signal is being received.

Video IF systems in color receivers follow the same practice as black-and-white receivers insofar as interstage coupling is concerned. The most common coupling methods consist of bifilar coils or single-wound coils or both. For example, the circuit of Fig. 3 uses bifilar coils predominantly (T201, T202, T203, and T204), but two of the tuned circuits are single-wound coils (L108 and L201). The interstage coils are stagger-tuned, ranging from a low frequency of 41.4 Mc to a high frequency of 45.5 Mc. Also present are five shunt traps, three tuned to the sound IF signal of 41.25 Mc, one to the video carrier frequency (39.75 Mc) of the adjacent higher channel, and one to the sound carrier frequency (47.25 Mc) of the adjacent lower channel.

A number of sets resort to complex-coupling circuits in one or more IF stages in order to achieve suitable attenuation at certain trap frequencies, such as the adjacent-channel video carrier, adjacent-channel sound carrier, and the sound carrier of the channel being received.

In one color receiver (Fig. 5A) a bridged-T circuit is inserted be-

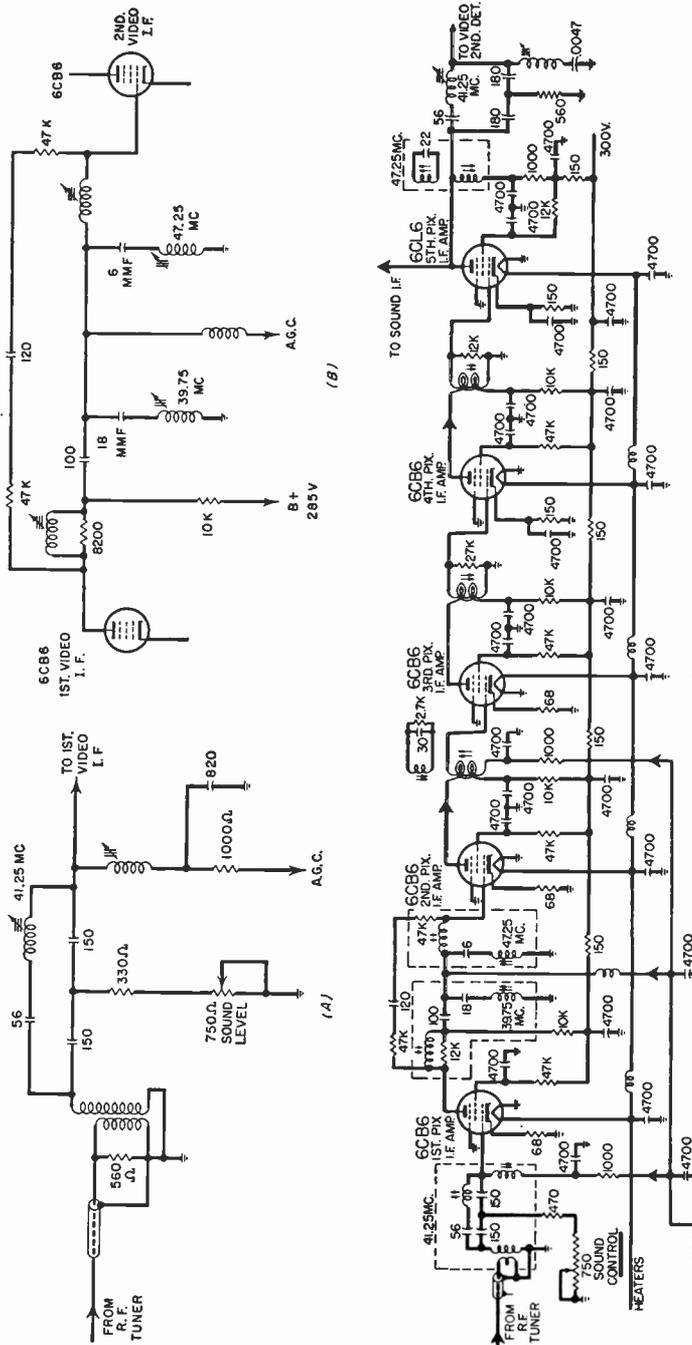


FIG. 5. (A) A bridged-T network between the RF tuner and first video IF amplifier. (B) A more elaborate coupling network combining a bridged-T circuit with an M-derived bandpass filter. (C) The complete schematic for the video IF system.

tween the tuner and the first video IF amplifier. The network contains a trap tuned to the accompanying sound carrier, 41.25 Mc. In order to reduce interference from this source (i.e., cross modulation) the sound carrier is attenuated as soon as possible in the IF amplifier. (The signal is not removed completely, however, since enough must be available for the sound system. The latter ties into the video system at a subsequent point.)

A more elaborate bridged-T network, combined with an M-derived bandpass circuit, is employed between the first and second IF stages (see Fig. 5B). This contains two rejection traps, one tuned to 39.75 Mc (video carrier of adjacent higher channel), the other tuned to 47.25 Mc (sound carrier of adjacent lower channel). Finally, a second complex-coupling network is found between the final IF stage and the video second detector. This, too, contains two traps, one for the accompanying sound carrier at 41.25 Mc and one for 47.25 Mc.

The complete schematic for this video IF system is shown in Fig. 5C.

A bridged-T filter is an efficient attenuating network for a specific frequency. Its basic form is indicated in Fig. 6A and B, and it is seen to consist of an inductance, two capacitances, and a resistance. L_1 , C_1 , and C_2 form a parallel-resonant circuit which is tuned to the frequency to be rejected. If R_1 is properly chosen, an attenuation ratio on the order of 50 to 1 is attainable.

The operation of this circuit can perhaps be understood by comparing its present form with an equivalent electrical diagram (Fig. 6C). At the resonant frequency of L_1 , C_1 , and C_2 , the impedance Z_1 in the equivalent diagram will have a negative value. If, now, we make R_1 equal to Z_1 , the shunting impedance to the design frequency will be zero and this signal will be bypassed to ground. For all other frequencies the network offers little attenuation, and they can proceed unaffected through the circuit.

An M-derived filter is a special form of filter which achieves a desired action with fewer components than simple T or pi filters.

The sound take-off in the circuit of Fig. 5C occurs at the plate of the final video IF amplifier. This does not necessarily denote a split-sound type of receiver, but stems from a desire on the part of the set designer to avoid any appreciable interaction between the color subcarrier and the sound carrier that could produce (by mixing) a 920-kc beat note. The sound carrier is permitted to remain with the video signal up to the plate of the final video IF amplifier; then it is diverted to a germanium crystal where it mixes with the video carrier to produce a 4.5-

Mc signal. In the meantime, the monochrome and color subcarrier signals proceed to the video second detector and are demodulated.

By this arrangement we can permit enough of the sound signal to reach the sound system, yet impose sufficient additional attenuation between the sound take-off point and the video detector to prevent a 920-kc beat signal from appearing beyond the detector.

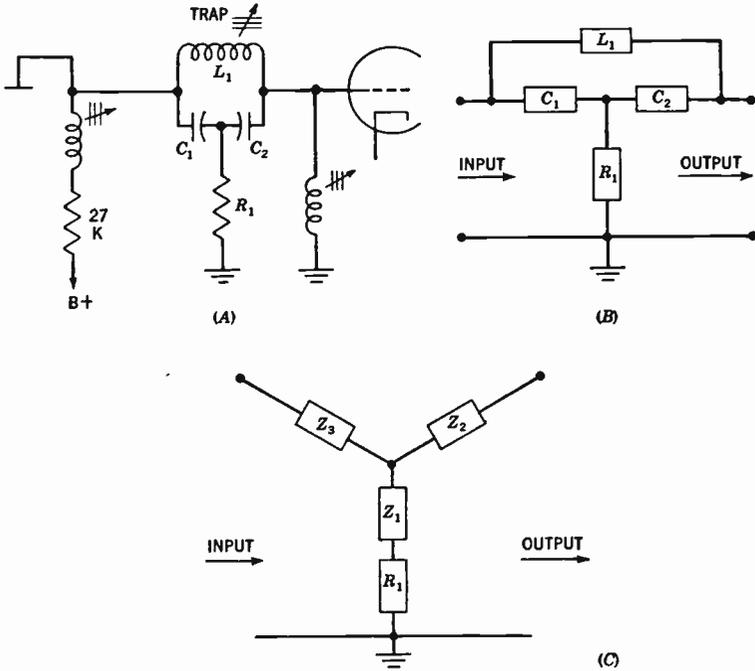


FIG. 6. (A) A bridged-T network. (B) The same circuit in block form. (C) An equivalent electrical network.

Automatic gain control is applied to the first two or three video IF stages in the same manner that it is applied in monochrome receivers (and for the same reason). The RF amplifier also receives a portion of the same AGC voltage.

SOUND CHANNEL

As indicated above, the sound signal is diverted from the video path in the plate circuit of the final video IF amplifier. This signal is then mixed with a portion of the video carrier in a germanium diode to pro-

pentode section. Both signals remain together only in the triode, because at the grid of the pentode a portion of the signal is diverted to a bandpass amplifier, which is the input stage to the chrominance section of the receiver. Hence, separation of the monochrome and color signals might be said to occur at the output of the triode video amplifier.

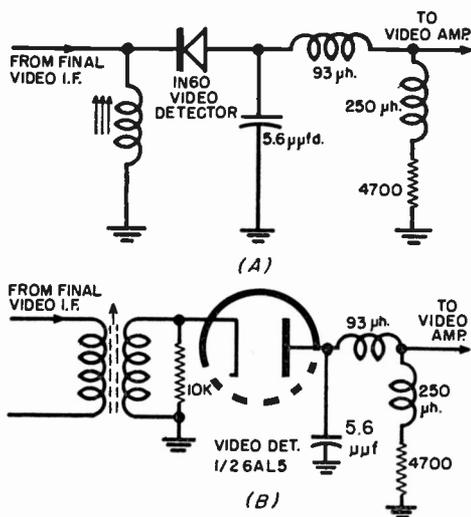


FIG. 8. Two types of video second detectors found in color TV sets. (A) Germanium diode. (B) Diode vacuum tube (one half of a 6AL5).

The second video amplifier in Fig. 9 deals solely with the monochrome portion of the total color signal. This fact is further accentuated by the 3.58-Mc series trap which is present in the plate circuit of this

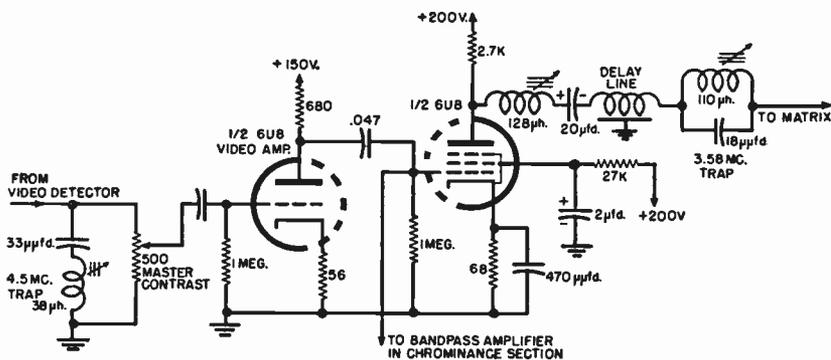


FIG. 9. A video amplifier circuit using a triode-pentode tube.

stage. The trap attenuates any 3.58-Mc color subcarrier voltage which may be present here, in order to prevent it from reaching the picture-tube screen and producing a visible interference pattern. The presence of the 3.58-Mc trap limits the response of the luminance or monochrome channel to a somewhat lower value, usually to 3.0 or 3.2 Mc. Since most present-day monochrome receivers operate within this bandwidth in both their IF and video amplifier systems, any loss of detail will be no more apparent on color sets than it is on black-and-white sets.

At this point the reader may wonder why a special 3.58-Mc trap is required when, in fact, no 3.58-Mc color subcarrier is being sent with the signal. The answer rests in the fact that while it is true that at no time is there any voltage at precisely the 3.58-Mc frequency, the phase excursions of the color signal cause the carrier to move back and forth from frequencies above 3.58 Mc to frequencies below 3.58 Mc. Furthermore, most of the color energy is concentrated in the sidebands around the 3.58-Mc frequency and if we remove the bulk of this energy with a trap, we minimize any tendency of the color signal to produce interference patterns on the screen.

Another fact to remember is this: the frequency of the color subcarrier (and, hence, the frequency of its sidebands) was purposely chosen so that all this energy would fall midway between the clusters of energy of the monochrome signal. Any color signal reaching the screen of a monochrome receiver will tend at least partially to cancel itself out on successive frames so that its visibility is reduced. The same action occurs in a color set when the color signal reaches the screen via the luminance channel. Hence, the combination of the 3.58-Mc trap with the frequency-interlace principle acts to reduce the visibility of any interference pattern from this source to a considerable degree.

In the circuit of Fig. 9 the luminance signal is finally applied to the matrix section, where it combines with suitable *I* and *Q* signals to provide us with the original red, green, and blue voltages.

Two additional representative video amplifier systems are shown in Fig. 10A and B. The first circuit (Fig. 10A) employs a 1N60 crystal diode for the video second detector. The output of this stage is fed to a 6CL6 video amplifier. Here both chroma and monochrome signals are amplified. The monochrome signal is then transferred to a second video amplifier and from this stage to the matrix network. The chroma signal is taken from the cathode circuit of the first video amplifier and transferred to the bandpass amplifier which stands at the head of the chrominance section.

ing that both signals will be varied in equal amount. This is needed to maintain the proper voltage relationship between the two signals.

A 4.5-Mc trap in the cathode leg of the first video amplifier attenuates any 4.5-Mc voltage that may develop in the video detector through the beating of the video and sound carriers.

The final video detector and amplifier circuit are shown in Fig. 10B. The detector stage is formed by using half of a 6BK7 duo-triode. Grid and plate are tied together to have the triode function as a diode. The second triode section of the 6BK7 is operated as a cathode follower, thereby permitting a number of circuits to obtain their signals from the detector without imposing any capacitive loading on this stage.

The plate circuit of the cathode follower provides signal voltages for the sync separator, AGC, and color-burst amplifiers. The cathode of the same tube contains a 500-ohm contrast potentiometer which provides adjustable signals for both a luminance amplifier and a bandpass amplifier.

The brightness or luminance signal is amplified by a single triode stage and then passed through a 1.0- μ sec delay line that is terminated in the matrix network. There are no special traps in this circuit, but the design is such that response falls off rapidly beyond 3.2 MC, attenuating any color subcarrier and 4.5-Mc voltages that might be present.

CHROMINANCE SECTION

We have now followed the full video signal (containing both black-and-white and color components) from the antenna to the video second detector. After detection, we have the 0- to 4-Mc black-and-white signal plus the color information. The latter is present as sidebands of the 3.58-Mc color subcarrier, which means that the color signal will require additional detection (or demodulation) before we can use it for application to the color picture tube. Thus, detection in a color receiver is a two-step process. First we remove the carrier which brought the full signal to the receiver. Then we must remove the color subcarrier so that the color video frequencies which it possesses may be made available. (It is important to keep this distinction in mind.)

The black-and-white portion of the full signal is amplified by one or two video stages and then transferred to the matrix. While this is happening, the color subcarrier and its sidebands are diverted to the chrominance section of the receiver (see Fig. 11). This section is concerned only with the color portion of the signal and it consists basically of a bandpass amplifier, separate *I* and *Q* demodulators, and *I* and *Q*

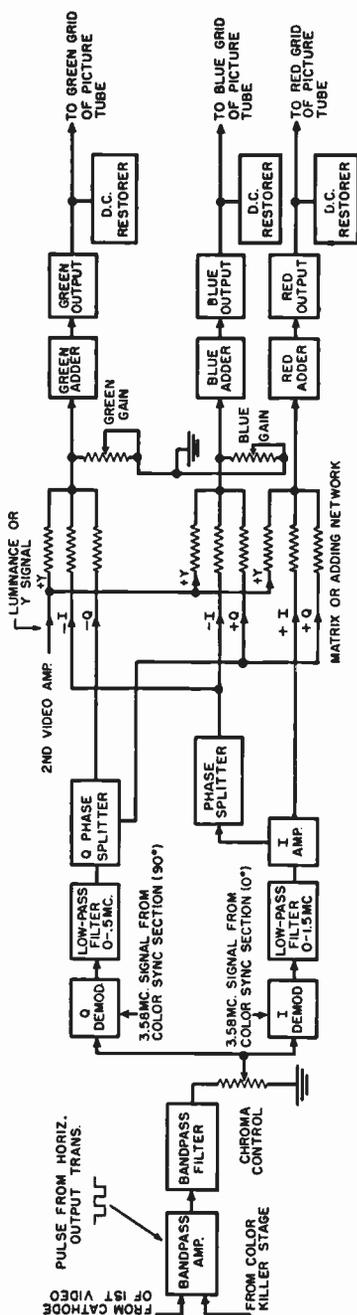


FIG. 11. Block diagram of the chrominance section of a color television receiver. The exact circuitry will vary from set to set.

amplifiers and phase splitters. The output of the system is fed to a matrix network, where, in combination with the monochrome or Y signal, we reobtain red, green, and blue voltages which are then applied to the proper control grids of a three-gun color tube.

The complete circuit of the chrominance section of a television receiver is shown in Fig. 12A and B. The incoming signal, which contains both chrominance and luminance components, is applied to the grid of the bandpass amplifier (Fig. 12A). This tube will permit the signals to pass at all times except during the horizontal retrace period when the tube is keyed to cutoff by a negative voltage pulse obtained from a winding on the horizontal output transformer. The pulse is applied to the screen grid of the bandpass amplifier by a 0.01- μ f capacitor. The tube is keyed out during the color-burst interval in order to avoid unbalance in the color background, produced when the DC restorers clamp onto the color burst rather than on the tips of the sync pulses. Note that only the color burst is removed; the horizontal sync pulse is permitted to pass through the stage.

The grid of this bandpass amplifier also operates in conjunction with a color-killer stage. This latter stage (not shown in the diagram) biases the bandpass amplifier to cutoff when no color

signal is being received. However, when a color signal is active, the color-killer stage removes its bias and the bandpass amplifier is able to function normally. In this way we avoid having spurious signals pass through the inactive color system and produce random colors on the screen.

A filter in the plate circuit of the bandpass amplifier has a bandwidth of approximately 2.4 to 5.0 Mc (see Fig. 14). This restricts what the circuit will pass to that portion of the total signal containing the color frequencies. The rest of the signal, containing only monochrome or luminance voltage, is largely attenuated.

A chroma control terminates the filter, and with it the set viewer can adjust the depth or saturation of the colors in the picture. The need for such adjustment may arise because of the level of the surrounding light in the room, because of the personal preference of the viewer, or because of variations in the color circuits of the receiver. The control is not a critical one and may be varied over a considerable range without overly distorting the tonal value of the picture.

From the chroma control, the signal is fed in equal measure to the control grids of the *I* and *Q* demodulators (Fig. 12A). At the same time both tubes receive a 3.58-Mc signal at their suppressor grids. This represents the missing color subcarrier and is needed in the demodulator to reproduce the original *I* and *Q* color video signals properly. The 3.58-Mc signal which the *I* demodulator tube receives is 90° out of phase with the 3.58-Mc voltage applied to the *Q* demodulator. This is required since the *I* and *Q* sidebands themselves are 90° out of phase with each other.

How Color Demodulators Operate. Note that both demodulators receive the same color signal; therefore, it is in their subsequent interaction with the 3.58-Mc subcarrier that the *I* and *Q* components are separated from each other. To see how this comes about, let us examine demodulator action more fully. The analysis can be made using either demodulator, since both operate similarly.

The 3.58-Mc subcarrier is applied to the suppressor grid of the demodulator and, because of its amplitude, functions as a gating pulse which permits the tube to conduct on positive half-cycles and to cut off on negative half-cycles. In the absence, then, of any color signal the plate current of the tube will consist of a series of half-cycle pulses possessing an average value. This is shown in Fig. 13A.

In the next portion of the illustration, Fig. 13B, a color signal is present on the control grid. This signal is in phase with the subcarrier, with the result that on the positive half-cycles, when the tube con-

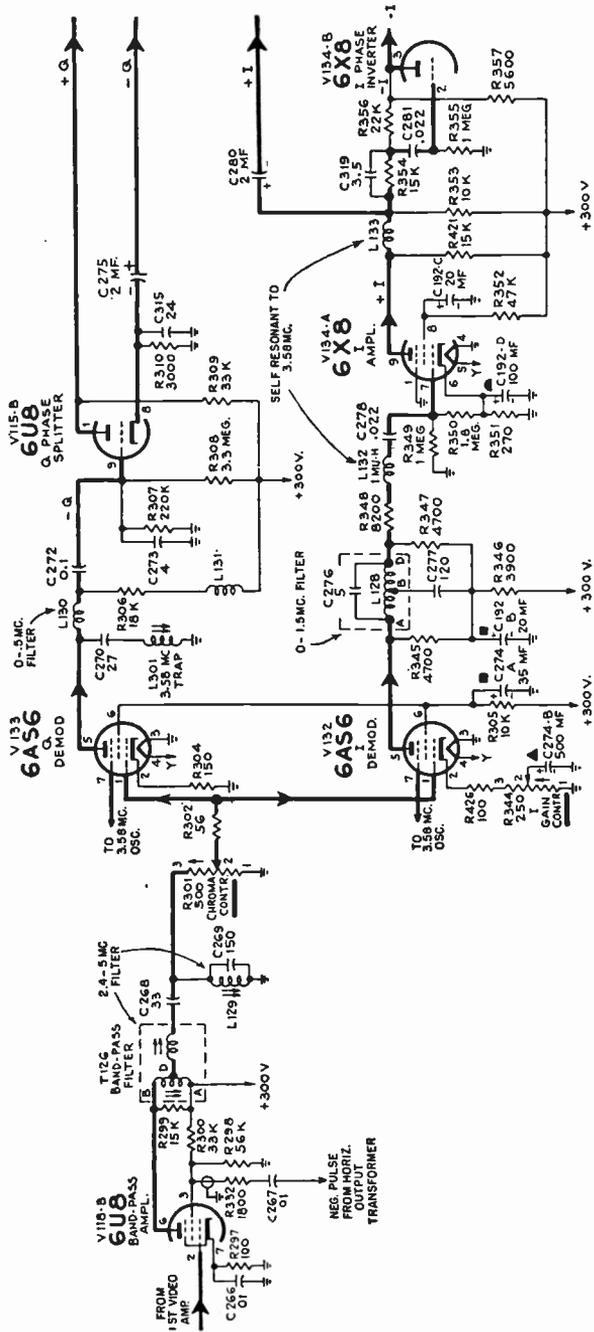


FIG. 12A. A portion of the chrominance section of a color TV receiver. Included are the bandpass, I and Q demodulators, Q phase splitter, I amplifier, and I phase inverter. See Fig. 12B for remainder of diagram.

ducts, it does so more heavily than in the absence of this color signal. As a result, the average plate current rises. The amount of increase will be governed by the amplitude of the input signal. The increase in plate current will develop an output voltage of negative polarity; negative, that is, with respect to the no-signal condition.

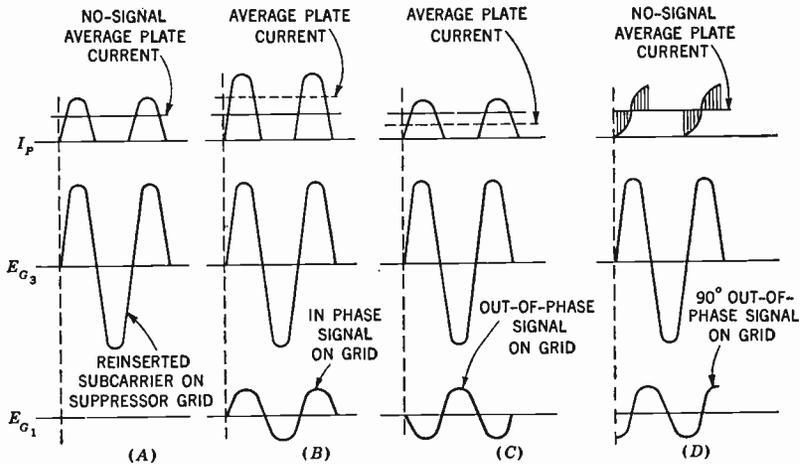


FIG. 13. How the demodulators of Fig. 12A operate. See text for further details.

In Fig. 13C, the color signal has a phase opposite to that of the subcarrier. Thus when the subcarrier is positive, the control grid will be driven negative and the average value of plate current through the tube will be less than the no-signal condition of Fig. 13A. An output voltage of opposite polarity will be produced; (i.e., positive with respect to the no-signal condition).

Thus we see that the output voltage will vary from its static no-signal value a maximum amount in one direction when the input signal is in phase and a maximum amount in the opposite direction when the input signal is 180° out of phase.

The situation depicted by Fig. 13B and C is representative of the demodulator where the inserted subcarrier assumes the phase of the missing subcarrier. The color sidebands for this subcarrier can either be in phase with it or 180° out of phase. This, of course, is the action in amplitude modulation, and it will be recalled from Chap. 2 that each color subcarrier is amplitude-modulated by the I or Q signal with which it combines.

Now let us turn to Fig. 13D where the color signal is 90° out of

phase with the subcarrier. This will happen when the I color sidebands are applied to the Q demodulator (or when the Q color signal is fed to the I demodulator). In this case the signal on the control grid is both negative and positive during the period of conduction and hence causes an approximately equal decrease and increase in plate current. The net result is zero change, and therefore no output voltage is developed when the input signal is 90° out of phase with the 3.58-Mc subcarrier. Likewise, no output would be developed when the input signal is 270° out of phase. It is due to this action that we are able to successfully separate the I and Q color sidebands from each other. Each tube responds only to those incoming color signals which are in phase with the 3.58-Mc subcarrier present on its own suppressor grid.

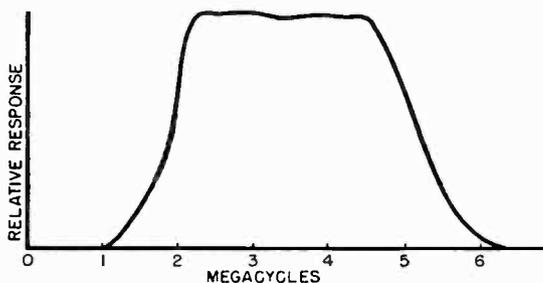


FIG. 14. Response of the bandpass filter in the plate circuit of the bandpass amplifier of Fig. 12A.

It may be noted in passing that while pentodes have been used as demodulators in the circuit diagrams thus far shown, actually any tube from a diode up may be successfully employed for this function. As a matter of fact, in some of the systems analyzed in subsequent chapters such tubes are used, and additional explanation will be given where needed.

I, Q Systems. In the diagram in Fig. 12A the detected Q signal appears at the plate of V133 and is passed through a 0- to 0.5-Mc filter before being applied to a Q phase splitter. The latter stage then supplies negative (at its cathode) and positive (at its plate) Q signals necessary for the matrixing network into which the signals are fed.

The 3.58-Mc color subcarrier signal is not required beyond the demodulator and it is shunted away from the grid of the phase splitter by the series-resonant trap, L301, C270.

In the I channel the detected I signal is passed through a 0- to 1.5-Mc filter and then through an I amplifier and an I phase inverter before

being applied to the same matrixing network. Positive I signals for the network are obtained at the plate of the I amplifier; negative I signals appear at the plate of the following phase inverter.

The response characteristics of the I and Q channels are shown in Fig. 15.

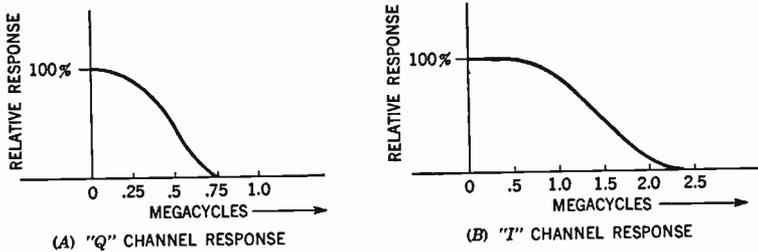


FIG. 15. The response characteristics of the I and Q channels of Fig. 12A.

A 0.5- μ sec delay is designed into the I system, and its purpose is to slow down all I signals so that they remain in step with the corresponding Q signals. The time it takes a signal to pass through a system is found to be inversely proportional to the bandpass of that system. That is, the narrower the bandpass, the longer it takes for signal passage. In a color receiver the Q channel has the narrowest bandpass (0 to 0.5 Mc), and its signals suffer the greatest amount of delay. The bandpass of the I channel extends from 0 to 1.5 Mc, and so its signals are not slowed down as much as the Q signal. Finally, the Y or monochrome channel has the widest bandpass (0 to 3.2 Mc), and its signals are delayed the least in passage.

An interesting way of looking at this signal-delay-bandpass relationship is to consider bandpass in terms of shunt capacitance. To achieve a wide bandpass, shunt capacitance must be kept as low as possible. As the bandpass becomes narrower, the shunt capacitance increases.

Now, when a signal passes through a network, it must pause and charge each shunt capacitor. Obviously, the larger the capacitor, the longer its charging time and the slower the passage of the signal. In terms of actual time the delay is barely perceptible; but in television circuits it is significant.

To ensure that the I , Q , and Y signals arrive at the matrix at the same instant, it is necessary to increase the delay time of the Y and I signals to that of the Q signal artificially. In the Y channel this is done by inserting a 1.0- μ sec delay line. In the I channel the additional delay required is on the order of 0.5 μ sec. While no special delay line is employed in the I circuit of Fig. 12, the over-all characteristics of the

system shown have been so fashioned that this added delay is actually present in distributed form. That is, each section of the circuitry contributes some share toward the delay, and by the time the signal has arrived at the matrixing network, it has been moved back in step with the Q signal.

Note that the I channel has one amplifier stage more than the Q channel. This is due to the narrower bandpass of the Q channel. A narrower bandpass permits us to use higher load resistances, with a corresponding increase in gain. The ratio of the gains of the two demodulators is on the order of almost 7 to 1. For a 2-volt peak-to-peak signal input, the peak-to-peak value of the signal at the plate of the Q demodulator is 20 volts, while at the plate of the I demodulator it is only 3 volts.

THE MATRIX SECTION

The matrix or mixing section is the place where the I , Q , and Y signals combine to reproduce the original red, green, and blue signal voltages. There are a variety of mixing networks possible, but the most economical and straightforward is the resistive network (see Figs. 12B and 16). From the NTSC specifications, the I and Q signals have the following composition:

$$\begin{aligned} I &= -0.27(B - Y) + 0.74(R - Y) \\ Q &= 0.41(B - Y) + 0.48(R - Y) \end{aligned}$$

If we solve these two equations simultaneously for $B - Y$ and $R - Y$ (as we did in Chap. 3) we obtain

$$\begin{aligned} B - Y &= 1.72Q - 1.11I \\ \text{or} \quad B &= Y + 1.72Q - 1.11I \\ R - Y &= 0.62Q + 0.96I \\ \text{or} \quad R &= Y + 0.62Q + 0.96I \end{aligned}$$

Now, what do these equations tell us? They reveal that if we take 1 volt of signal from the Y channel, 1.72 volts of positive Q voltage from the Q channel, and 1.11 volts of negative I voltage from the I channel, we obtain 1 volt of blue signal. Of course, we are not restricted to voltages this small; we may use much larger voltages, so long as we maintain the same relative relationship between the I , Q , and Y voltages taken from the three channels feeding into the matrix network.

The red signal is obtained by using different proportions (and polarities) of the Y , I , and Q voltages. This is indicated by the second equation and the red signal so obtained is then dealt with separately.

Still missing is a green voltage, and this can be obtained from still another equation which is also derivable from the NTSC specifications. That is,

$$G - Y = -0.51(R - Y) - 0.19(B - Y)$$

and from this, by a little mathematical manipulation,

$$\begin{aligned} G - Y &= -0.64Q - 0.28I \\ G &= Y - 0.64Q - 0.28I \end{aligned}$$

Hence, within the same matrix, we can obtain the desired green signal by combining 1 volt of Y signal with 0.64 volt of negative Q signal and 0.28 volt of negative I signal.

The foregoing equations make it evident why a resistive matrix network can work and also why positive and negative I and Q voltages are required, whereas from the Y channel only a single positive signal is needed.

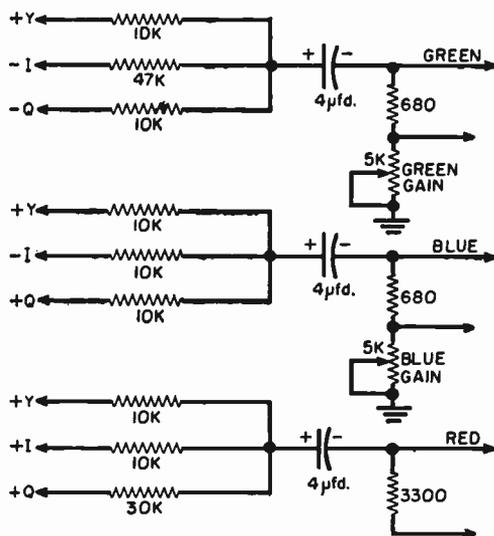


FIG. 16. The matrix network for combining the Y , I , and Q signals in the proper proportions to give red, green, and blue signals in the circuit of Fig. 12B.

Let us return now to Fig. 12B and briefly check the red, green, and blue amplifiers to make certain that the voltages they receive conform in polarity at least to the voltages indicated in the above equations.

The green amplifier (or Adder, as it is labeled in the diagram) receives a Y voltage, a negative I voltage, and a negative Q voltage. The

circuit, of course, is so designed that these signals are present in the ratio of 1 to 0.28 to 0.64.

The blue amplifier receives a Y voltage, a negative I voltage, and a positive Q voltage. Finally, the red amplifier receives a Y voltage, a positive I voltage, and a positive Q voltage.

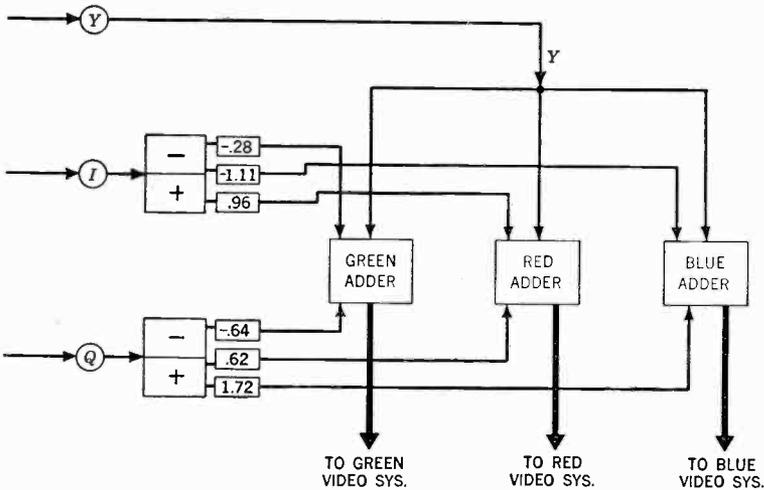


FIG. 17. Another way of illustrating the distribution of voltages in the matrix.

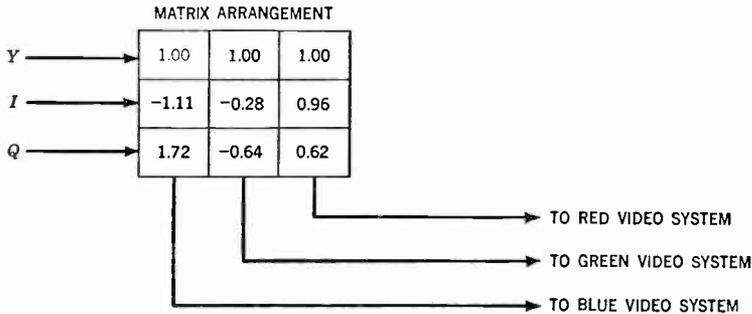


FIG. 18. The voltage distribution in the matrix network in still another configuration.

The coefficients of the I and Q voltages that must be supplied to the matrix can also be indicated by the block method of Figs. 17 and 18. Identical information is contained in both illustrations; only the form is different.

Beyond the matrix, each primary-color voltage is passed through two

video voltage amplifiers and then applied to its respective control grid in the three-gun picture tube. The bandpass of each system is on the order of 3.2 Mc. Over-all gain controls for the green and blue channels are provided to permit the gains of these sections to be adjusted with respect to the red channel. In the initial three-gun picture tubes that were made, the efficiency of the red phosphor was lower than the efficiencies of the green and blue phosphors. To compensate for this, more drive was required at the red control grid (or less drive for the green and blue grids). Adjustment of the two gain controls served to satisfy this condition.

A DC restorer is included in each path to bring each color signal to the proper level before it is applied to the picture tube. DC restorers, which have been eliminated in the past few years from monochrome receivers, are a distinct necessity in color receivers. Why this is so will be considered in more detail after the remaining chrominance circuits of this chapter have been investigated.

The chrominance channel of another color-television receiver is shown in Fig. 19. The complete signal is brought to the grid of the bandpass amplifier from the master contrast control. The tube admits all of the signal except the color burst, which during this interval is keyed off by a negative pulse applied to the screen grid.

In the output circuit of the bandpass amplifier there is a 2.1- to 4.2-Mc bandpass filter terminating in a 500-ohm chroma control. As before, the chroma control governs the amount of color signal reaching the rest of the chrominance section, and hence it regulates the intensity or saturation of the colors viewed on the picture-tube screen.

The color signal receives an additional stage of amplification beyond the chroma control, and then it is fed in equal measure to both the *I* and *Q* demodulators.

The demodulators in this system are also the recipients of two additional voltages. One voltage, in the form of a negative biasing voltage, is obtained from a color-killer tube. When a color signal is being received, this bias voltage drops to zero and both demodulators conduct. On the other hand, when no color signal (and hence, no color burst) is present, the negative voltage from the color-killer tube is high enough to cut both demodulators off. The over-all effect, then, is the same in this system as in the previous one, although the approach is slightly different.

The second voltage applied to the *I* and *Q* demodulators is provided by a 3.58-Mc generating section. This missing color subcarrier is applied in equal measure but with a 90° phase difference to each de-

modulator. The tubes then mix this signal with the incoming color sidebands to provide the detected I and Q color signals at the output.

In the I channel there is a 0- to 1.5-Mc low-pass filter, an amplifier, and a phase splitter. Also, sufficient delay is incorporated in this circuit to force the I -signal components to keep in step with the Q -signal components. Positive and negative I -signal voltages are available at the plate and cathode terminals, respectively, of the phase splitter for use in the matrix network.

The Q channel is somewhat less extensive, containing only a phase splitter and a 0- to 0.5-Mc low-pass filter. The output from this section, too, is fed to appropriate points in the matrix network.

The remainder of the chrominance channel (Fig. 19) consists of three individual 6CL6 amplifiers, one for each of the three color signals, and three DC restorers. Action here is similar to that existing at the same point in the previous system, and additional explanation is not required.

There are many ways of handling the color signals, and the chrominance circuits of each manufacturer differ in some respect from those of his competitors. Figures 12A and B and 19 illustrate two possible approaches. Still another, containing several interesting features, is shown in Fig. 20. The color signal is received from the first video amplifier by a bandpass amplifier. The chroma control is contained in the cathode of this stage, and the desired amount of signal is tapped off here and transferred to a second bandpass amplifier via a 1N34 crystal. The function of the germanium crystal is to deal with the negative triggering pulses which are fed into this circuit via R_1 and L_1 . The negative pulses appear during the horizontal retrace interval when the color burst is passing through the circuit. The arrival of the pulse prevents the 1N34 from conducting, and since the pulse amplitude is greater than that of the color burst coming from V_1 , the 1N34 is prevented from conducting and the color burst is effectively prevented from continuing farther into the chrominance section. At all other times, the signal polarity is such that 1N34 conducts, and whatever voltage is present across the chroma control reaches the grid of V_2 . This, then, is the way this circuit prevents the color burst from penetrating into the chrominance channel.

The bandpass of V_1 and V_2 extends from 2.1 to 4.8 Mc, and the signals within this range are amplified and then transferred to a 6J6 cathode follower V_3 .

The next recipients of the color signal are the I and Q demodulators. The signal is fed in equal measure to grid 1 of both 6AS6's. At the same

time, grid 3 of each tube receives a 3.58-Mc subcarrier voltage. The peak-to-peak value of this signal is on the order of 30 volts, and the only difference between the 3.58-Mc voltages which the tubes receive is a 90° phase displacement.

In the *I* section, the demodulator is followed by an amplifier and a phase splitter. The latter tube develops positive and negative *I* voltages for the matrix. The bandpass of the *I* section is 1.3 Mc.

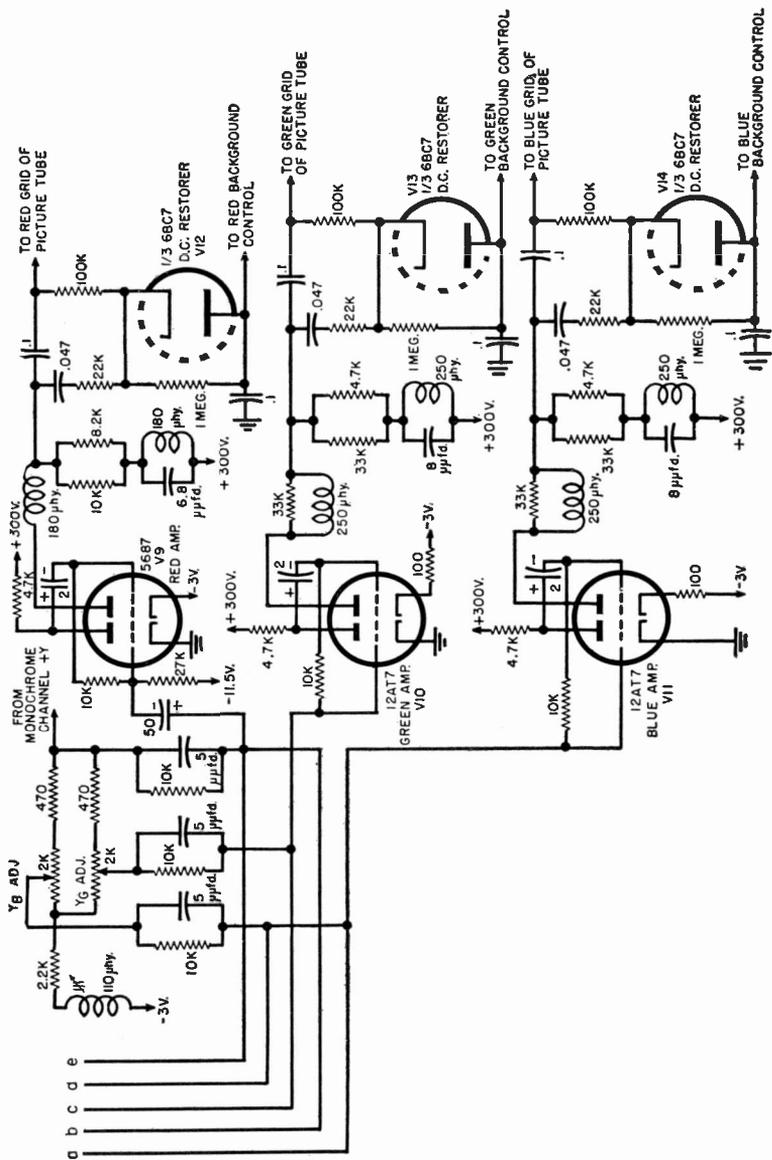
In the companion *Q* section the demodulator is followed by a single phase splitter which provides positive and negative *Q* signal voltages for the matrix. The bandpass of this section extends to 0.5 Mc in accordance with the nature of the received signal. It is interesting to note that should the bandpass of this channel be broadened above 0.5 Mc, color infidelity would occur because of the presence of some higher-frequency *I* signals in the *Q* channel. When the bandpass is limited to 0.5 Mc, these spurious *I* signals are attenuated below the point of visibility and do no damage. But if the cutoff were extended, they would reach the picture tube and cause color distortion.

There are several points worthy of special mention in the *I* and *Q* stages of Fig. 20. The $B+$ voltage for the screen grids of V_4 and V_5 may be cut off by a manual switch called the color-killer switch. When a black-and-white broadcast is being received, this switch is turned to the off position, disabling both demodulators and preventing any spurious signals from passing through the color section. For a color broadcast the switch is turned back on again.

This is a simple (and economical) form of color-killer circuit. However, it does possess the disadvantage of requiring the set user to know when a color transmission is being received. (Otherwise all he will get will be black-and-white pictures.) In the two previous systems the color-killer network functioned automatically; when a color signal was received, the killer voltage was automatically removed and a color picture appeared on the screen.

Another item of interest in Fig. 20 is the use of an actual delay line in the *I* section. In the previous system the delay was distributed throughout the *I* system.

The voltages which the *I* and *Q* phase splitters apply to the matrix are nearly all individually adjustable. In this respect it is of interest to note the names applied to these controls. In the *I* phase splitter there is a "green" *I* and a "blue" *I* adjustment. The "green" *I* control is so named because the voltage from this point goes to the green amplifier stage, and variation of this voltage would affect the intensity of the green seen on the screen. The same kind of reasoning applies to the



(B)

Fig. 20A, B. Chrominance circuit containing a manual color-killer switch and a 1N34 crystal circuit for eliminating the color signal from the chrominance channel.

"blue" I adjustment, since the voltage from this control goes to the blue amplifier stage. Three similar controls are employed in the Q phase splitter.

Finally, there are two adjustments near the point where the brightness signal enters the matrix. These are labeled as Y_B and Y_G adjustments, and they control the amount of Y signal fed into the blue (B) and green (G) amplifier stages via the matrix. Definite relationships must be carefully maintained if the proper hue, brightness, and saturation are to be obtained on the screen. By making a number of controls available, the serviceman can make whatever compensating adjustments may be required to achieve the proper color rendition.

THE ROLE OF DC RESTORERS IN COLOR RECEIVERS

When monochrome television receivers first appeared commercially, they invariably contained a stage known as a DC restorer. This stage was situated just before the picture tube, and it was the last stage that the signal encountered before entering the picture tube. Its purpose was to reinsert into the video signal the DC components which had been removed by prior video amplifiers.

To appreciate the significance of this action, let us examine the make-up of a video signal. Several lines of a typical video signal are shown in Fig. 21. Between every two successive synchronizing and

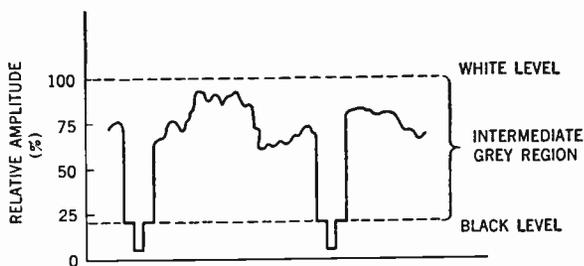


FIG. 21. Several lines of a video signal.

blanking pulses, we have the camera signal variations, ranging from white at the most positive value to black at the level of the blanking pulses. The sync pulses extend beyond the blanking level for a distance equal to 25 per cent of the over-all amplitude of the entire video signal.

Suppose, now, we take a video signal and, while maintaining the same signal variations, first move the signal closer to the blanking level

(Fig. 22A) and then shift them away from this level (Fig. 22B). The visual difference between the two signals is one of over-all brightness. That in Fig. 22B will contain exactly the same detail (objects, scenery, etc.), but the background will be bright. The other scene, in Fig. 22A, will be fairly dark because the average level of its signal variations is closer to the black reference level.

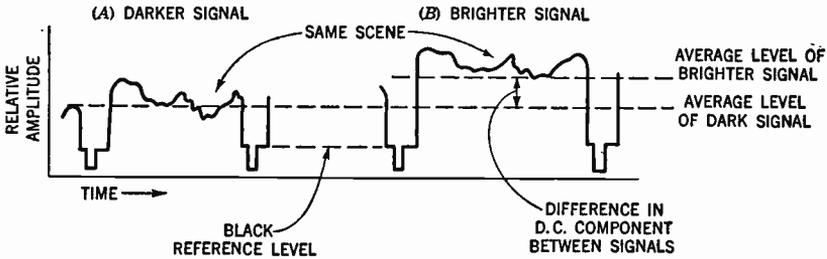


FIG. 22. Two identical video signals differing only in the amplitude of their DC component.

To distinguish between the camera signal variations and the average level of these variations (or the average distance of these variations from the blanking level), it has become standard to call the latter the DC component and the former the AC component of the video signal. We can alter the average level of a signal by inserting a DC voltage, raising or lowering the average level of the signal and, in consequence, changing the over-all brightness of the picture.

To properly reproduce each of the foregoing scenes on a picture tube, the blanking levels must be aligned with the cutoff level of the tube (see Fig. 23). Under these conditions, each signal will appear on the screen with the correct value of brightness.

Consider, now, a typical video amplifier system which employs *RC* coupling between stages. As the signals in Fig. 22 pass through the system, the capacitors will remove the DC component, leaving the AC component. Figure 24 demonstrates how the signals appear after they have passed through an *RC* network. Note that each distributes itself equally about a zero axis. By equal distribution we mean that there is as much signal *area* above the zero line as below. (This does not necessarily mean as much amplitude above and below the zero axis since the area contained in a long narrow pulse is quite small and easily counter-balanced by a voltage having a much smaller peak but a wider base.) As a result of the axis rearrangement, the sync-pulse tips, which were formerly on the same level for both signals (Fig. 22), are now on differ-

ent levels. The visual consequence of this is readily seen if we apply these voltages to the characteristic curve of a picture tube.

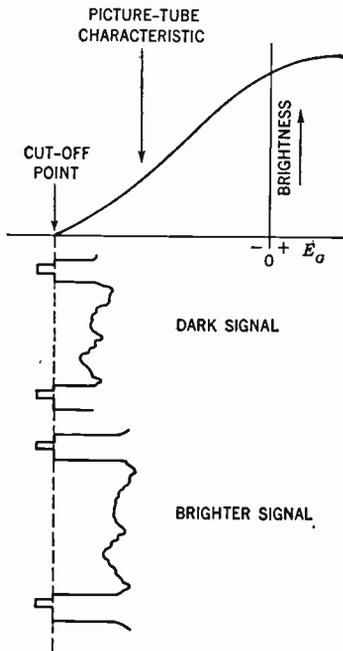


FIG. 23. To reproduce each of these scenes properly on the screen, the blanking levels of both signals must be aligned to the cut-off point of the picture tube.

The situation can be visualized by mentally moving both signals to the left until the blanking level of the darker signal coincides with the cutoff

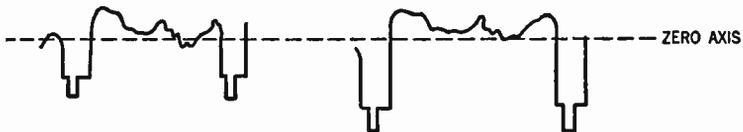


FIG. 24. The two signals of Fig. 22 after their DC components have been removed.

point of the picture tube.) Now the darker portion of the brighter signal will drive the picture tube into cutoff, and any signal variations within this region will be lost. By the same token, the bright portion

Let us assume first that the picture-tube bias is set up (via the brightness control) for the signal of Fig. 22B. That is, the control is so positioned that the blanking level just drives the tube to cutoff. When, now, the darker signal of Fig. 22A comes along, it will occupy the position shown at the bottom of Fig. 25 and it is immediately obvious that its blanking level, or even the sync-pulse tips, cannot drive the tube into cutoff. Retrace lines, particularly those occurring during the vertical retrace interval, will thus appear on the screen. Another thing we note from Fig. 25 is that although the background for video signal B should be dark, it will now appear lighter because the signal extends farther into the gray region.

If we were to adjust the picture-tube bias (via the brightness control) so that the blanking level of the darker signal drives the tube to cutoff, then the presentation of the lighter signal will be materially affected. (The situation

of the signal will now be closer to the cutoff level of the tube and hence appear darker than it should.

To correct the foregoing behavior so that the tube will function properly for bright and dark signals, the original DC component must be kept in the signal. This can be done by employing DC-coupled video amplifiers between the video second detector and the picture tube. A typical circuit is shown in Fig. 26. Note that there are no coupling capacitors from the video detector to the picture tube, and consequently there is no reason why the video signal should lose its DC component. That these amplifiers have not enjoyed more success than they have stems from the facts that DC amplifiers have a tendency to drift in operation and that they impose more restrictive conditions on the power supply. Since there is a direct connection between the plate of one stage and the grid of the next stage, it is apparent that, with the grid positive, the plate of its tube must be given an even greater positive voltage. After several stages, the range of B+ voltages required can be considerable. Also, when the grid of a tube is positive, a compensating positive voltage must be applied to its associated cathode. The latter action, in turn, will raise additional problems if the voltage difference between cathode and heater becomes sufficiently large. Thus the designer runs into a host of complications which affect the stability of the receiver.

A second, more suitable approach is by using RC-coupled amplifiers between video second detector and the picture tube and then having a DC restorer reinsert the missing DC component before the signal actually reaches the picture tube.

The most common method of DC restoration is by the use of the circuit shown in Fig. 27. Briefly this circuit operates as follows: The

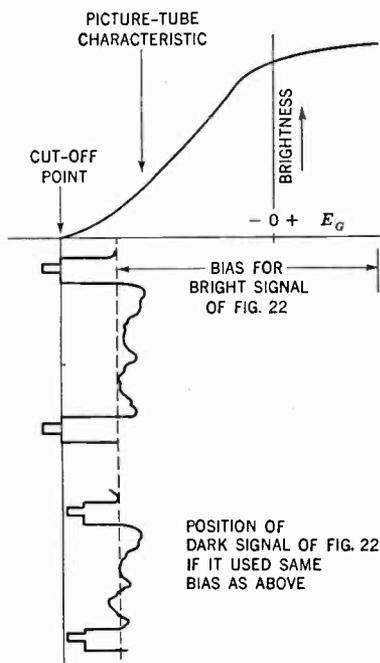


FIG. 25. Loss of the DC component results in improper background for video signals. See text for further details.

video signal at the plate of the video output amplifier is sync-pulse negative. A portion of this signal is applied to the diode restorer, V_1 , via the coupling network of R_1 and C_1 . When the sync pulses are active,

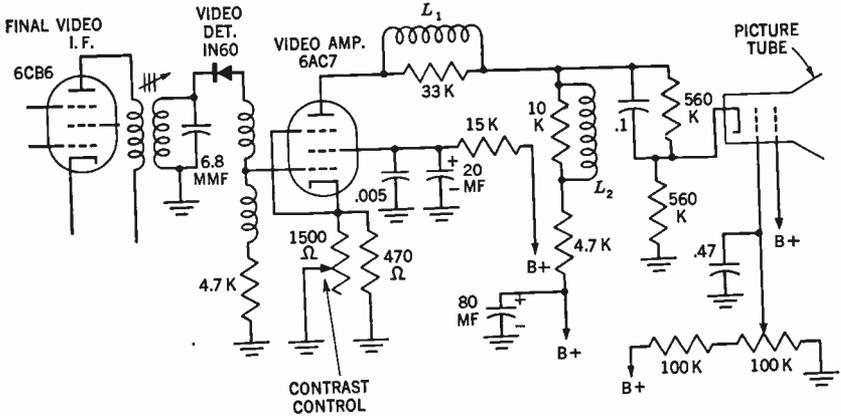


FIG. 26. A direct-coupled video amplifier system.

point A is negative with respect to ground, or, in terms of V_1 , its cathode is negative with respect to the plate. This causes the tube to conduct; the electrons travel from cathode to plate to ground and from there back through V_2 and its plate circuit and through R_1 into C_1 . A

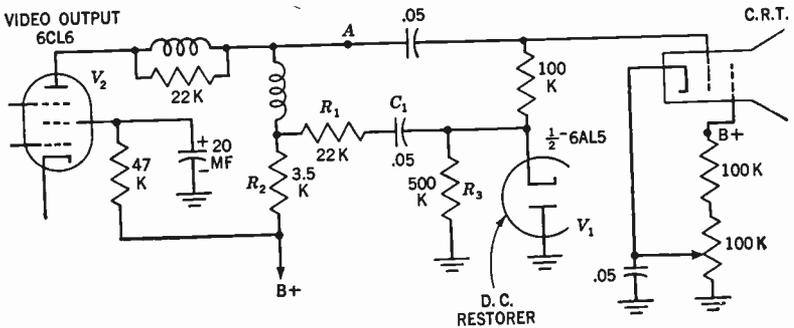


FIG. 27. A representative DC restorer circuit. Its operation is discussed in the text.

corresponding number of electrons flow out of the other side of C_1 and return to the cathode of V_1 , completing the circuit. The result, after several lines of a picture have passed through the circuit, is to charge C_1 to essentially the peak value of the sync pulses.

During the interval between sync pulses, V_1 is nonconductive and capacitor C_1 discharges slowly through R_1 , R_2 , the power supply, and R_3 back to the other side of C_1 . Since R_3 has a value that is considerably higher than either R_1 or R_2 , essentially the full voltage of C_1 will appear across R_3 . This voltage is between the control grid of the picture tube and ground, and therefore it acts as a variable bias on the grid of the picture tube, changing its value as the level of the sync pulses varies. However, this bias changes slowly, because of the long time constant of the circuit ($R_3 \times C_1$). Hence, it is effective over a number of lines.

The DC restorer serves as a clamp, bringing each sync-pulse tip to the same level. When the sync-pulse tip is just barely below the zero-axis line, only a small voltage appears across C_1 (and subsequently across R_3). This bias voltage is added to the signal, raising all portions of it by the same amount. When the sync pulses dip farther below the zero line, voltage across R_3 rises correspondingly. In each instance enough voltage (bias) is developed to bring all sync pulse tips back to a common level, just as they were when received. When this is done, each line of video signal variations will be operating with respect to the same blanking level and one setting of the brightness control will suffice for all lines and all pictures.

Since the operation of the DC restorer is so beneficial to the quality of pictures produced on a screen, it may come as a distinct surprise to learn that within recent years most monochrome set designers have dispensed with this circuit completely. Instead, the signal is AC coupled to the picture tube, and then the annoying vertical (and frequently the horizontal) retrace lines are blanked out by applying special blanking pulses to the picture tube during the retrace intervals. The true (or absolute) brightness of the picture is thus lost, but since the viewer appears to be more sensitive to relative contrast than to absolute contrast or brightness, he does not miss the loss. The contrast range is reduced, but the viewer is apparently unaware of this.

Another reason for dispensing with DC restoration circuits in monochrome receivers stems from the neglect of transmitter personnel to maintain a fixed black level in the signals they broadcast. That is, while the level of the sync pulses remains relatively stable, the black level varies from time to time. In the receiver the DC restorer clamps onto the sync-pulse tips and is completely "unaware" of the black-level variation. Under these conditions the receiver will be establishing a black level which is not truly representative of the black level at the transmitter, and hence we will obtain results which are, in many in-

stances, no better than what we obtain in the complete absence of DC restoration.

In passing it may be noted that the black level at the studio is not established at the blanking level (i.e., the base of the sync pulses) but at some small distance below this. The distance between the two levels is known as the *setup interval* and it is used to ensure that none of the video signal extends up into the blanking region and thereby gets clipped off. In the original monochrome standards promulgated by the FCC, the black level was to be made as nearly equal to the blanking level as the state of the art permitted. Setup, thus, was zero. However, stations found that it was desirable from an operating standpoint to use a definite setup interval, and this is now part of the standards for color television.

In color receivers the form and function of DC restorers remain the same, but the significance of what they accomplish takes on a more important meaning. This is because brightness, along with hue and saturation, determines the appearance of a color. If we maintain the hue and saturation constant but provide less than the normal amount of brightness, then as far as the viewer is concerned a change in color (hue and saturation) has occurred. The same is true if too much brightness is added to the signal. Thus, any deviation from the correct brightness level will convey an altered color indication to the viewer. Distortions of this type are readily detected by the eye and must be minimized.

The importance of the brightness component to the color signal is recognized by the FCC in their standards for color television. They state that the reference black level shall be separated from the blanking level by a setup interval which shall be 7.5 (± 2.5) per cent of the video range from the blanking level to the reference white level. By specifying definite tolerances and making the stations adhere to them, the FCC is ensuring that brightness will be established against a fixed level. This, in turn, will serve to prevent unwarranted variations in brightness levels during any given transmission. Only in this way is it possible to prevent apparent color variations because of a lack of a fixed brightness reference level.

Incidentally, once we appreciate the role of the DC restorer in a color receiver, we can also see why receiver designers take pains to prevent the color burst from reaching the DC restorers at the end of the color video amplifier section. It is possible, because of the proximity of the color burst to the horizontal sync pulses, to have the restorer potential influenced by the burst. This is especially critical in the case

of the blue grid because the brightness signal for blue is often near the black level. Any small variation in restorer voltage will have a greater effect on the blue signal than on some of the brighter colors.

QUESTIONS

1. Why must the RF response curve for a color receiver be flatter than the response curve for a monochrome receiver? What limit is suggested for color sets?
2. Draw the desired video IF response curve for a color receiver. In what respects does this differ from the response curve for a monochrome circuit?
3. What particular precautions must be observed with respect to the sound carrier in the video IF systems of color TV receivers? What approach is taken to achieve these ends?
4. Compare the sound channels of black-and-white and color sets.
5. What type of video second detectors are found in color receivers? Illustrate by means of a schematic diagram.
6. Describe briefly what happens to the color signal beyond the video second detector.
7. Why is it necessary to separate the chrominance and luminance signals from each other?
8. Draw the circuit diagram of a *Y* video amplifier. Explain the need for a delay line.
9. What happens to the color signal which reaches the picture tube via the *Y* channel?
10. What circuits receive their signals from the video second detector or the amplifier that follows it? What pitfalls must be avoided in securing these various voltages?
11. Which reaches the matrix first, the color signal or the *Y* signal? Explain your answer.
12. Draw the block diagram of the chrominance section of a television receiver. Indicate the function of the various stages.
13. How is the color burst in the signal prevented from reaching the DC restorers? Why is this necessary?
14. Why would the color video amplifiers beyond the matrix never be fed the color-killer voltage?
15. What signals do the *I* and *Q* demodulators receive? Include phase relationship and frequency.
16. In what ways does the *I* system differ from the *Q* system?
17. Outline briefly what happens in the matrix network. What are the equations for *R*, *B*, and *G* in terms of *Y*, *I*, and *Q*?
18. In what ways can we achieve the action of a color killer?
19. Explain briefly the action of a DC restorer in a television receiver (of any type).
20. Why are DC restorers particularly important in color television receivers?

CHAPTER 5

THREE-GUN RECEIVER CIRCUITS: PART 2

Thus far we have discussed at length the general formation of a color signal and what happens to this signal at various stages in the receiver. We have not, however, gone into any examination of what the color video signal looks like when it is viewed at the video second detector. Since this is something which the service technician should be familiar with, discussion of the remaining sections of a color receiver will be held in abeyance while we analyze color video signals.

Perhaps the best place to start is at the transmitter where a color-bar test pattern is being picked up by a color camera. The test pattern chosen (Fig. 1) consists of four vertical bars in the order blue, red, green, and white. These are the three color primaries and white. The light from this color pattern is received by the color camera, and the rays from each different primary color are directed to a specific camera tube. That is, the red rays of light go to the red camera tube, the blue light goes to the blue tube, and the green light is sent to the green camera tube. Within each tube the photosensitive mosaic is activated only by the light received. Thus, on the mosaic of the blue camera tube, for example, the incoming light is focused on the left edge in the same position as the blue bar on the test pattern. Also, a bar appears at the right edge of the mosaic because white contains blue and the blue component affects the blue camera tube. In between these two bars the mosaic surface would be unaffected because there is no blue color in the two center bars of the pattern.

By a similar type of analysis we can see that each camera tube would have parts of its mosaic activated and other parts unaffected.

Now, as the scanning beams (in the camera tubes) scan across one horizontal line of this color pattern, here is what we obtain. At the start, each beam is passing over the portion of the pattern occupied by the blue bar. During this time, an output voltage will be obtained from the blue camera tube only (see Fig. 1B). The red and green tubes are

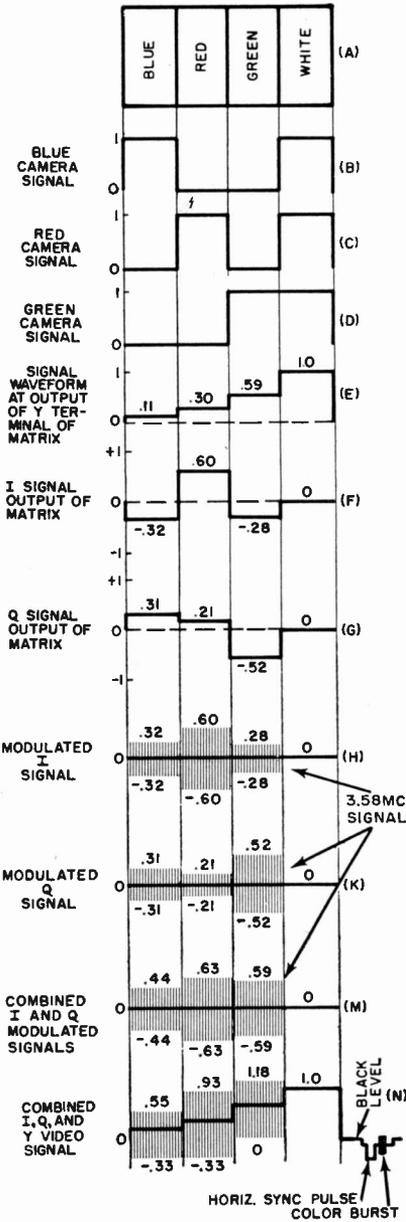


FIG. 1. The various stages in the formation of a color TV video signal using a color-bar pattern as a subject.

developing zero output because none of this blue light is reaching them.

The next bar to be scanned is the red bar, and for this the red camera tube becomes active, producing an output voltage while the blue and green tubes render zero output voltage. The third bar is green, and the output voltage is now derived from the green camera tube. The final bar is white, and when this is being scanned, the same voltage output is obtained from the blue, red, and green camera tubes. This is because white contains all three primary colors in more or less equal amount and all three color tubes are similarly affected.

In Fig. 1, B, C, and D show graphically the manner in which the voltage output from each color camera tube varies as the beam moves across the screen from left to right. This is the color-voltage information obtained from the scene to be transmitted. The next step, as we have seen in Chap. 2, is to convert this information into appropriate I, Q, and Y signals which will then be transmitted to the receiver. To achieve this transformation, the three voltages are fed into a matrix network. (This is similar to the matrix network in the receiver, where the reverse action occurs; i.e., I, Q, and Y are reconverted to equivalent R, B, and G voltages.)

Within the matrix at the trans-

mitter, the Y , I , and Q voltages are formed according to the following defining equations:

$$Y = 0.59G + 0.30R + 0.11B \quad (1)$$

$$I = -0.28G + 0.60R - 0.32B \quad (2)$$

$$Q = -0.52G + 0.21R + 0.31B \quad (3)$$

(The reader undoubtedly appreciates by now the fact that both I and Q signals can be expressed in terms of color-minus-difference voltages or directly in terms of R , B , and G . All are equivalent.)

Thus, coming out of the matrix at the Y terminal would be the wave form shown in Fig 1E. The blue voltage is only 11 per cent of what it was when it entered the matrix, the red is only 30 per cent, and the green is only 59 per cent. For the I signal, we take 28 per cent of the voltage produced by the green tube, 60 per cent of the voltage from the red tube, and 32 per cent of the blue tube output. Negative values, required for the green and blue components of the I signal, are achieved by passing these components through phase inverters. The Q -signal formation follows in similar order. Note that the white bar produces a full output in the Y channel, but zero output in the I and Q channels. In the Y channel the white amplitude is made up of 59 per cent green, 30 per cent red, and 11 per cent blue. When you add 0.59 plus 0.30 plus 0.11, you obtain 1. On the other hand, consider what happens to the white voltage in the I and Q channels. The scanning of the white bar produces equal voltage output from the red, green, and blue camera tubes with the result that the matrix receives voltages from each of these tubes at the same time. If we assume that each camera tube is providing 1 volt of signal and this is what the matrix receives, then Eq. (2) above tells us that what finally appears at the I terminal at the output of the matrix when the white bar is being scanned is

$$\begin{aligned} & -0.28 \text{ volt from the green channel} \\ & -0.32 \text{ volt from the blue channel} \\ & +0.60 \text{ volt from the red channel} \end{aligned}$$

The addition of -0.28 and -0.32 with $+0.60$ produces a net result of zero, which means that all three voltages cancel each other out completely.

This particular situation was purposely selected in order to reduce all color signal output to zero when black, white, or gray are being scanned.

In the Q channel we have a similar situation, for its voltages also cancel when white is being scanned.

Once the I , Q , and Y signals have been formed, they are sent through appropriate amplifiers until they have been strengthened sufficiently to perform the next step in the formation of a total color video signal. Let us concentrate first on the I and Q color signals. These amplitude-modulate separate 3.58-Mc color subcarriers which differ in phase by 90° . After this operation has been performed, the modulated I and Q signals appear as shown in Fig. 1H and K.* These are actually the color sidebands produced by the modulation, the 3.58-Mc carrier having been suppressed in the balanced modulators. The various colors (red, green, and blue) produce different amplitudes in the modulated waves in accordance with their amplitudes in the I and Q signals.

The next step is to combine these signals into one. Since the 3.58-Mc color subcarriers that were employed in the modulators differed in phase by 90° , their sidebands differ in the same way. Hence their resultant is not obtained by adding their amplitude arithmetically (as $3 + 4 = 7$) but rather by taking the square root of the sum of their squares (as $\sqrt{3^2 + 4^2} = \sqrt{9 + 16} = \sqrt{25} = 5$). If we follow this procedure for the I and Q modulated signals of Fig. 1H and K, we obtain the result shown in Fig. 1M.

(As a sample calculation, consider the blue voltage portion of the I and Q voltages of Fig. 1H and K. The peak amplitude of the I blue is -0.32 , and this figure squared $(-0.32)^2$ is 0.1024 . By the same token, the Q blue is 0.31 , and this squared is 0.0961 . The addition of 0.0961 and 0.1024 gives us 0.1985 , and the square root of this number is 0.44 . The remaining calculations are worked in a similar manner, with the results indicated.)

The color signals have now been combined and the next step is to add the monochrome or brightness signal to this resultant. The addition is straightforward, with the color sidebands extending for equal distances above and below the brightness level. The Y component represents the brightness of a color, and brightness in a video signal is determined by how far the average level of a video signal is from the black level. (The black level is the reference against which brightness is measured.)

In Fig. 1N, the 0.11 is added to the 0.44 positive peak of the com-

* Negative modulating voltages, such as the -0.32 for I blue, appear only as a reversal of subcarrier phase. A positive modulating voltage will cause the resulting modulated signal to have one phase; a negative modulating voltage will cause it to have the opposite phase. In outward appearance, however, both modulated waves will possess the same shape, or envelope.

bined blue I and Q signal to give a resultant of 0.55. By the same token, the 0.11 added to the -0.44 negative blue signal peaks results in a final value of -0.33 . Red has a brightness value of 0.30, and hence 0.30 would be added to this signal, moving it farther away from the black level than the blue voltage. Finally, the brightness level of green is 0.59, and it is positioned 59 per cent of the distance *away from* the black level. White has a brightness value of 1, and it is positioned at the farthest point from the black level of the video signal.

The total signal, with I , Q , and Y combined and with sync pulses and a color burst, appears as shown in Fig. 1N. In this illustration several items are of interest. First is the color burst; in the examination of any color video signal this burst must be present in order to ensure the proper reproduction of colors in the picture. It is this burst which establishes the frequency of the color subcarrier generator in the receiver, and any deviation from its correct phase will result in color distortion (i.e., a shift in color away from its original hue).

Second, the negative tips of the 3.58-Mc modulated blue signal and of the red signal extend beyond the black level into the blacker-than-black or sync-pulse region. At the other end, the positive tips of the 3.58-Mc modulated green signal extend beyond the point where the brightest level is indicated. These extensions beyond the normal excursions of the video signal are permitted by the FCC standards, but in practice they seldom occur. Actually, they appear only for highly saturated colors, and such saturations, though theoretically permissible, are almost never encountered.

At the video second detector a good oscilloscope would produce the signal pattern shown in Fig. 1N. Beyond the detector the color components of the total video signal are shunted off to the chrominance section of the receiver, while the monochrome portion is passed through one or two separate amplifier stages. The demodulated I and Q signals then meet the Y signal again in the receiver matrix network, and through the interaction of these three signals the original blue, red, green, and white bar pattern is re-created on the picture-tube screen.

It might be instructive to follow this reconstruction in detail to see how the original colors are reobtained. It was shown in previous discussions of the receiver matrix that

$$\begin{aligned} R &= Y + 0.62Q + 0.96I \\ B &= Y + 1.7Q - 1.1I \\ G &= Y - 0.64Q - 0.28I \end{aligned}$$

Let us consider the blue color first since it appears first on the bar

test pattern. From the *Y* signal we obtain a voltage of 0.11 volt, since this is the average brightness level of the blue bar. From the *Q* channel we get 1.7*Q* voltage or 1.7 times whatever blue voltage the *Q* channel possesses. If we refer back to Fig. 1*G*, we see that the *Q* voltage when blue was being scanned was 0.31. (This is 31 per cent of whatever voltage was being delivered by the blue camera tube to the transmitter matrix. If we assume that 1 volt of signal was being provided by this tube, then 0.31 volt of blue voltage was obtained at the *Q* terminal of the matrix.) Thus, this 0.31 is now multiplied 1.7 times to provide 0.527 volt from the *Q* channel toward the formation of the final blue bar to be presented on the screen. Thus far, then, we have 0.11 volt of blue voltage from the *Y* channel and 0.527 volt from the *Q* channel. Still to come is the voltage from the *I* channel. This is -1.1 times whatever blue voltage the *I* channel possesses. Again, if we refer back to Fig. 1*F*, we see that the *I* voltage when blue was being scanned was -0.32 . This value multiplied by -1.1 gives us a total of 0.352 positive, since multiplying two negatives gives a positive. Electronically, the multiplication of two negative numbers means that the reversal in polarity that occurred in the transmitter matrix is now being counteracted. Adding all three contributions from the *I*, *Q*, and *Y* channels, we obtain

$$\begin{array}{r} 0.11 \\ 0.527 \\ 0.352 \\ \hline 0.989 \end{array}$$

or essentially 1 volt of blue signal. Is this the same as the original voltage obtained from the blue camera tube? The answer, of course, is yes.

The red and green signal values can be obtained in the same manner, and the computations and solutions are shown in Fig. 2. For white there would be no contributions from the *I* and *Q* channels, since it was demonstrated previously that the scanning of white produced no *I* or *Q* voltage. White, then, would be obtained solely from the *Y* signal, which is as it should be.

In the foregoing discussion a relatively simple color-bar pattern was employed. With that knowledge behind us, we are now in a position to examine the video signal produced when the color-bar test pattern of Fig. 3*A* is scanned. Here we not only have the three primary colors, but mixtures of these colors, such as yellow, cyan, and magenta.

The wave forms shown in Fig. 3*B*, *C*, and *D* indicate how the output

voltage from each color camera tube varies as the scanning beam travels across the pattern from left to right. Consider the output from the blue camera tube first. When red, yellow, or green is scanned, the voltage developed by the blue tube is zero because these colors possess

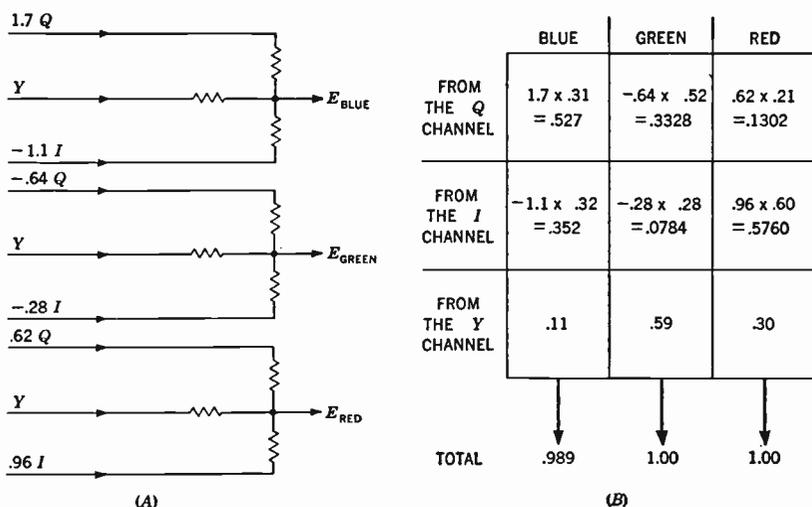


FIG. 2. The matrix (A) and the computations (B) demonstrating how the primary colors are re-formed in the receiver.

no blue. When cyan is reached, the voltage output of the blue tube jumps up to our assumed value of 1. Cyan is formed by combining green and blue, and it is the blue component which activates the blue camera tube. The output of the blue tube remains steady at 1 volt as the beam moves over the blue bar and the succeeding magenta. The latter color represents a combination of blue and red.

When the scanning beam passes over the red bar, the output of the blue camera tube drops back to zero. It shoots back up again to 1 volt when white is reached.

For the red camera tube an output signal is obtained for red, yellow, magenta, and white. And, finally, for the green camera tube output is present as the beam moves over yellow, green, cyan, and white.

Explanation of the wave form that appears in the Y channel rests, as it did before, on the equation

$$Y = 0.59G + 0.30R + 0.11B$$

Where a single color appears by itself, the value employed is that

which is placed in front of that color in the foregoing equation. The figure of 0.89 which is indicated for the yellow is derived from the addition of 0.59 for the green component of the yellow plus 0.30 for

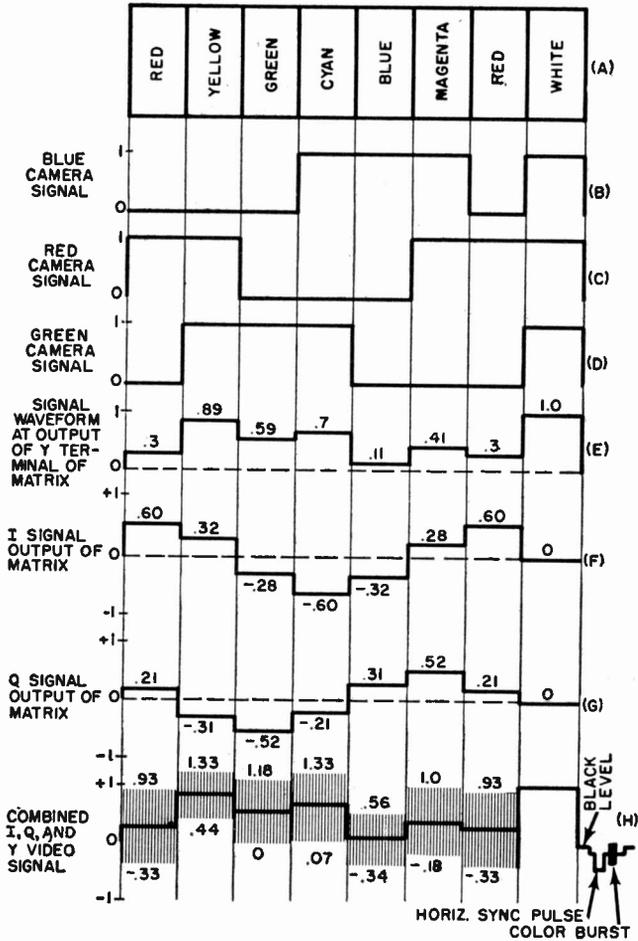


FIG. 3. Formation of a color video signal from a more complicated color-bar pattern than that used in Fig. 1.

the red component. Cyan, a mixture of green and blue, has a brightness value of $0.59 + 0.11$. The brightness value for magenta is similarly formed by addition of 0.30 from the red and 0.11 from the blue.

A similar procedure is followed in the formation of the *I* and *Q* wave forms. In the *I* signal, for example, red is 0.6, as indicated by Eq. (2).

Yellow is a combination color, and it is formed by adding 0.6 for its red component with -0.28 for its green component. The result of this addition ($0.6 - 0.28$) is 0.32. The remaining color values are obtained by the same process.

The final video signal, formed by the combination of Y , I , and Q , is shown in Fig. 3H. It is this signal which would be seen at the output of the video second detector in the television receiver.

The presence of combination colors means that when these colors are being presented on the receiver picture-tube screen, more than one electron gun is in operation. For example, to present a yellow bar, both the green and red guns must be activated by the signal. For cyan, the green and blue guns are required, and for magenta, red and blue dots must be struck. There are, of course, many other combinations of colors, and for a large number all three electron guns are operating to a greater or lesser extent. Appreciation of these facts concerning video signals and how they are formed will materially aid the technician in his work on color television receivers.

The scope presentation of one line of another color-bar test pattern is shown in Fig. 4. Each of the colors and the horizontal sync pulses

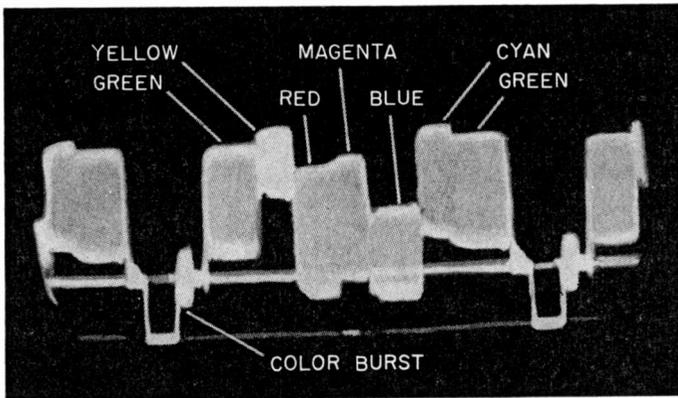


FIG. 4. An actual photograph of a color-bar test-pattern signal.

and color bursts are labeled. Finally, the display of a typical color scene (not a pattern) is shown in Fig. 5. The chief identifying characteristic is, of course, the color burst.

The entire preceding discussion has been concerned solely with the signals which fully saturated colors produce when scanned by an appropriate color camera. However, as we have pointed out, fully saturated colors are the exception rather than the rule. Far more com-

mon are the less saturated or paler colors. Let us see what happens when a color-bar pattern made up of pastel shades is televised. The pattern chosen (indicated in Fig. 6) consists of blue, red, green, and yellow bars saturated 50 per cent and a gray which may be considered

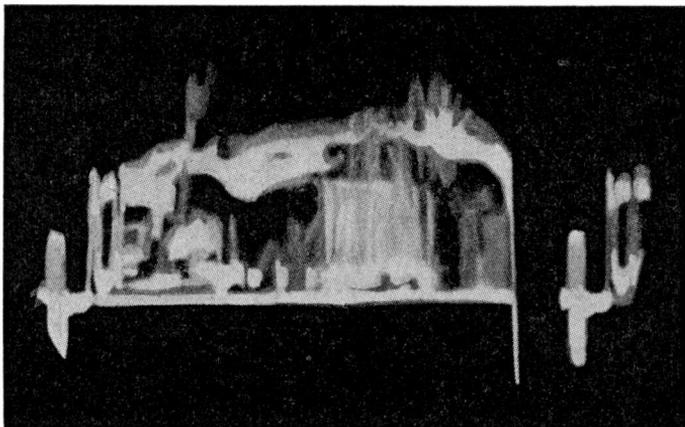


FIG. 5. The signal for a typical color scene (not a bar pattern).

as 50 per cent white (or black). The voltages which one line of this bar pattern will develop in each of the three camera tubes are shown in Fig. 6A, B, and C. When blue is being scanned, the blue camera provides a full output. However, since the blue is only 50 per cent saturated, this is equivalent to a mixture of 50 per cent white with the blue. Furthermore, since 50 per cent white is present, a 50 per cent voltage output should be available from both the green and red camera tubes at the same time. This is indicated in the first column of Fig. 6 A, B, and C.

When the red bar is being scanned, full output is obtained from the red camera tube. Again, since the red is 50 per cent saturated, it will contain 50 per cent white, which means that during this interval a 50 per cent voltage output will be obtained from the green and blue camera tubes. This is indicated in the second column of Fig. 6A, B, and C.

During the green bar interval the voltages indicated in the third column of Fig. 6 A, B, and C are obtained. The green voltage is maximum; the red and blue voltages are 50 per cent of their maximum value.

The next color, yellow, is a combination color, being composed of red and green. These two camera tubes will thus provide full output.

scanned, we have full output at the blue camera ($0.11B$), but only 50 per cent output at the green and red cameras. For these we use 50 per cent of 0.59 (for green) and 50 per cent of 0.30 (for red).

$$\begin{array}{r} +0.11 \\ +0.295 \\ +0.15 \\ \hline +0.555 \end{array}$$

This, then, is the figure placed in the first column of Fig. 6D. By the same method we obtain 0.65 as the brightness value for red, 0.795 for green, 0.945 for yellow, and 0.5 for gray.

At this point several things are becoming apparent. First, as the colors grow less saturated, the outputs from the various color camera tubes become more nearly equal. Second, if we compare the brightness values for these paler colors with those for the more saturated ones in Fig. 3, we see that they are larger. This, too, is another sign of desaturation.*

The voltages in the I and Q signals are shown in Fig. 6E and F. The I and Q value for each column is obtained by means of the equations given above. As an example, the I signal while blue is being scanned is:

$$\begin{array}{r} 50 \text{ per cent of } -0.28G, \text{ or } -0.14 \\ 50 \text{ per cent of } 0.60R, \text{ or } +0.30 \\ 100 \text{ per cent of } -0.32B, \text{ or } -0.32 \\ \hline \text{Total} \qquad \qquad \qquad -0.16 \end{array}$$

The remaining values are obtained in similar fashion.

A comparison of these I and Q values* with those for the same colors in Fig. 3 reveals that with desaturation the I and Q values decrease. If the process is carried to the point where complete desaturation occurs and all we obtain is black, white, or shades of gray, then the voltages in the I and Q channels will diminish to zero, which is exactly what we would expect. This, then, is another consequence of desaturating a color.

There is no further need to add to Fig. 6. Additional steps would show the combined I , Q , and Y signals, as in Figs. 1 and 3. In the receiver the reverse process would take place, bringing the voltages shown in Fig. 6A, B, and C to the picture-tube grids to produce the colors indicated.

* Note that this is a result, and not the cause, of desaturation.

THE COLOR SYNC SECTION

The service technician is by now fully acquainted with the function of the sync circuits in a black-and-white receiver. Briefly stated, they serve to maintain the picture in synchronism with the scene being transmitted by the station. In a color receiver similar circuits are employed for the same purpose. In addition, color receivers must be "told" what colors to produce at each point in the picture, and for this purpose a special color sync signal is sent. This sync signal takes the form of a burst which is placed on the back porch of each horizontal sync pulse and consists of at least 8 cycles of the missing 3.58-Mc color subcarrier.

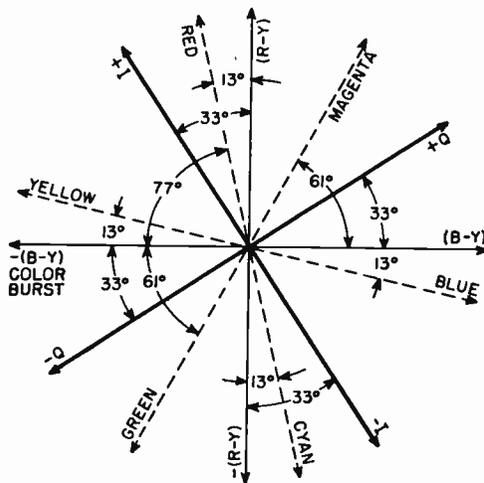


FIG. 7. Color phase diagram showing the positions of the various key colors and the I and Q vectors. The position of the color burst is also shown.

In the receiver this special color sync burst is separated from the rest of the signal and routed to a color sync section. (Here, again, the similarity to sync pulses is apparent.) The purpose of the color sync section in a color television receiver is to ensure that the color subcarrier which is recombined with the received color signal possesses the correct frequency and the proper phase. Both are important if we are to reobtain the desired color voltages at the output of the I and Q demodulators.

It may be well to recall at this point that each color is represented by a different angular position of the resultant I and Q vectors (see Fig. 7). For example, green is 61° behind the reference burst (in a

counterclockwise direction), red is 77° ahead of the burst, etc. To produce a given color requires that the I and Q vectors combine with each other to produce a resultant whose position occupies the angular position of that color.

There is nothing fundamentally rigid about these different color positions. Actually, all they represent is a system in which various colors are represented by certain angular positions *with respect* to a given reference. In the present instance, the phase of the color burst is the reference and the correct reproduction of the color scene at the receiver hinges on the facts that the phase of the color burst is fixed by the FCC and that the color subcarrier which is reinserted in the color signal has its phase established by the color burst.

If something should occur at the transmitter which causes the color burst phase to vary, without a corresponding change in the angular positions of the various colors, then the set viewer will be treated to the spectacle of seeing the different colors in the picture change.

By the same token, any instability in the color sync circuits of a receiver will also lead to the development of the wrong colors. In fact, it has been found that a change of only ± 5 degrees in the phase of the color subcarrier will produce a noticeable change in the color picture. From this it is evident that the tolerances in the color sync section are among the most stringent in the entire color receiver. It is safe to predict that many of the serviceman's headaches will originate right here.

The APC System. There are several approaches to the development of 3.58-Mc signals possessing the proper phase and frequency. One method, illustrated in Fig. 8A and B, employs an automatic phase control (APC) system in conjunction with a crystal oscillator. The input to the color sync section is at the burst amplifier. This stage is normally cut off (by a high positive voltage on the cathode) except when the color burst is passing through the receiver. At these instants, a negative pulse of about 37 volts peak to peak is obtained from a winding on the horizontal output transformer and applied to the cathode of the color burst amplifier. The pulse counteracts the positive cathode voltage and permits the tube to conduct, amplifying and then transferring the color burst to the following phase detector.

The transformer in the plate circuit of the burst amplifier has a high-impedance primary and a bifilar secondary tightly coupled to the primary. The burst signal voltage is on the order of 60 volts peak to peak on either side of the secondary center tap.

In the phase detector two triodes connected as diodes are employed

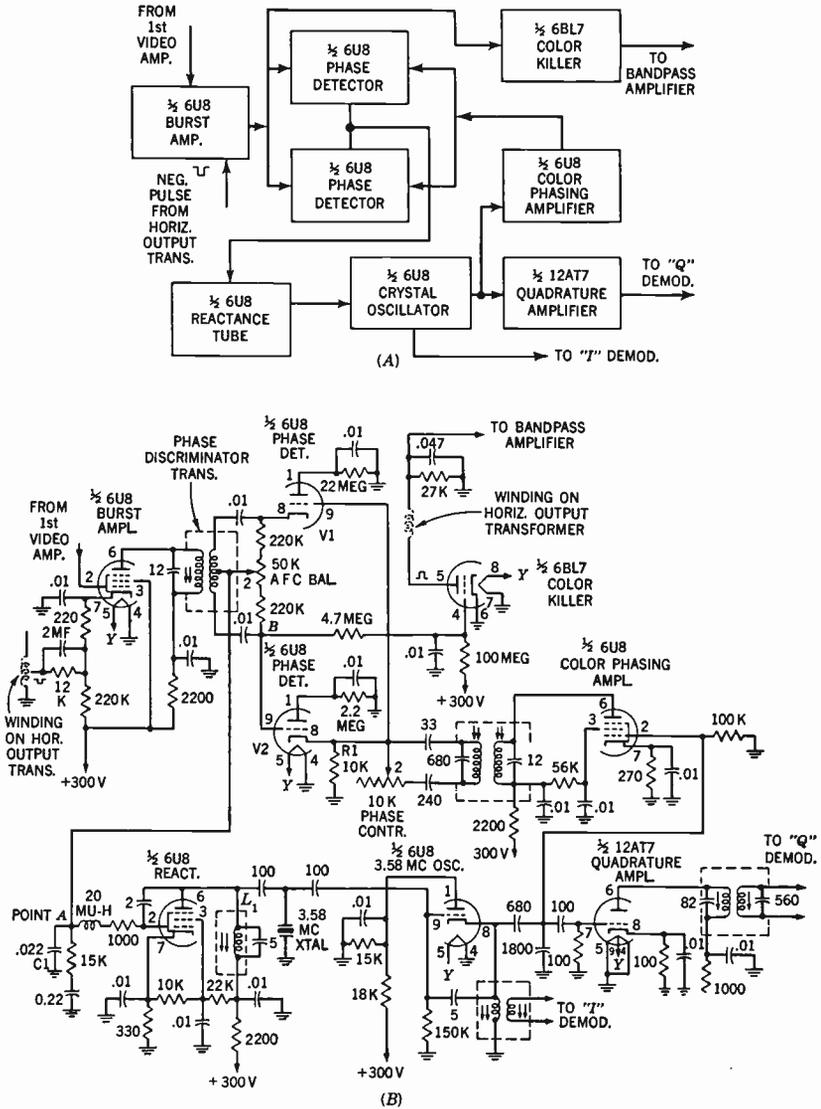


FIG. 8. (A) Block diagram of the color sync section of a color television receiver. (B) Schematic diagram of the color sync section outlined in (A).

to compare the frequency and phase of the received color burst with the frequency and phase of a locally generated CW signal. The latter voltage is brought into the phase circuit via a color-phasing amplifier

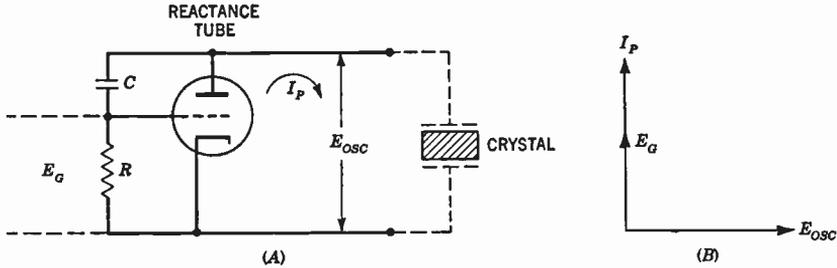


FIG. 9. (A) Equivalent circuit of reactance tube. (B) Phase relationship of E_{osc} , E_G , and I_P in the circuit.

and possesses an amplitude of 25 to 35 volts peak to peak. If any phase difference exists between the two signals, a correction voltage is developed at point A and fed to the grid of a reactance tube. Here it alters

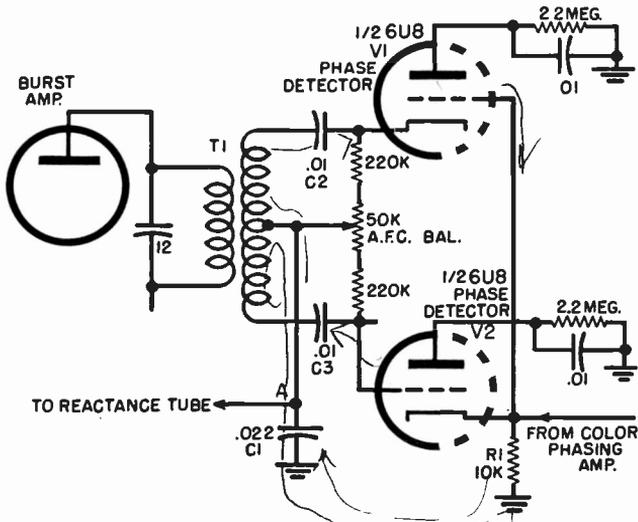


FIG. 10. Phase-detector portion of the circuit shown in Fig. 8B.

the effect of the reactance circuit on the 3.58-Mc crystal oscillator and thereby changes the frequency of the oscillator.

The phase-detector circuit is shown by itself in somewhat greater detail in Fig. 10. The incoming burst appears across the full secondary

of the phase discriminator transformer, and since the center tap of this winding is effectively at ground potential (via C_1 which has negligible impedance at 3.58 Mc), the signal polarity at one end is 180° out of phase with the signal polarity at the other end. We can represent this relationship as shown in Fig. 11A. E_{k_1} , the burst voltage applied to the cathode of one phase-detector section, is 180° out of phase with E_{g_2} , the voltage which the grid (and plate) of the other phase-detector section receives.

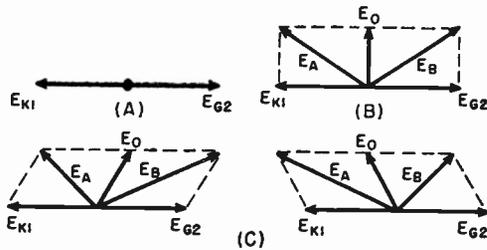


FIG. 11. Various voltage-vector relationships in the phase-detector circuit. (A) The incoming burst voltage applied to V_1 and V_2 . (B) The combination of the burst voltage and color-phasing voltage. (C) When the phasing voltage E_o lags (left) its normal phase, or when it leads it (right), the voltages across the phase-detector tubes in Fig. 10 are unequal.

At the same time the cathode of V_2 and the grid (and plate) of V_1 receive a portion of the generated 3.58-Mc voltage from the color phase amplifier. This voltage, labeled E_o , can be represented as shown in Fig. 11B. The resultants of E_o with E_{k_1} and of E_o with E_{g_2} are also indicated in Fig. 11B and it can be seen that they are equal ($E_A = E_B$). This represents the condition when the generated 3.58-Mc oscillations possess the proper frequency and phase with respect to the incoming color burst. There is no output voltage across C_1 and none to the reactance tube.

On the other hand, when the frequency of the generated 3.58-Mc voltage speeds up or slows down, one section of the phase detector conducts more heavily than the other and the reactance tube does receive a correcting negative or positive voltage from the phase detector. Figure 11C shows the positions of E_o for these two later conditions. Notice in each instance that E_A and E_B are no longer equal in length; in one case E_A is greater than E_B and in the other case it is shorter.

For those readers who like to follow electron flow, the path for V_1 is from cathode to grid (and plate), down through R_1 to ground, up

through C_1 to the center tap on the secondary of T_1 , and back through the upper half of this winding and C_2 to the cathode of V_1 .

For V_2 , electrons from the cathode travel to the grid (and plate) through C_3 to the center tap on the transformer secondary, down through C_1 to ground, and from here through R_1 to the cathode of V_2 . Each tube sends its currents through C_1 in opposite directions, and any resultant voltage is transmitted to the reactance tube.

The reactance tube functions as a variable capacitor across the crystal of the crystal oscillator. Variation of this electronic capacitance will, over a limited range, vary the frequency of the crystal. The limit here appears to be on the order of 35 μf , and this value of capacitance is sufficient to pull the crystal frequency approximately 1,000 cycles, which is quite adequate for a color television receiver.

To understand how the reactance circuit can simulate a capacitance consider the equivalent circuit of Fig. 9. The RF voltage appearing across the crystal is also impressed between plate and cathode of the reactance tube. Let us label this voltage as E_{osc} . This same voltage appears across the series network of R and C . The capacitance C is very small in comparison to R , so that at 3.58 Mc its reactance ($X_C = 1/2\pi fC$) is very large compared to R . The current through this network, therefore, leads the voltage applied to it by nearly 90° . The grid voltage is the voltage across R and leads the plate voltage by 90° . The plate current is in phase with the grid voltage, and thus the plate current also leads the plate voltage by 90° .

We have, then, a circuit which draws a leading current when a voltage is applied across it. This is identical to the action of a capacitor (current through a capacitor leads the applied voltage by 90°). Therefore, to the crystal, the reactance tube appears as a capacitor.

A large capacitor will draw a greater current than a small capacitor when the same voltage is applied across them.

The reactance tube can be made to appear as a large capacitance by causing it to draw more signal plate current. Or it can be made to appear as a smaller capacitor by drawing less signal plate current. The plate current, in turn, is proportional to its mutual conductance g_m . The g_m of a tube varies inversely with the amount of DC grid bias applied; it increases as the bias is decreased.

Thus, the value of capacitance that the reactance tube offers to the crystal can be varied by suitably adjusting the DC grid bias of the reactance tube. In practice the error voltage from a phase detector is applied as the bias for the reactance tube to automatically control the crystal frequency.

In the reactance tube circuit of Fig. 8B, the grid-circuit phase-shifting network (R and C of Fig. 9) consists of a $2\text{-}\mu\text{f}$ capacitor from plate to grid of the 6U8 and a 1,000-ohm resistor in the grid lead. The bottom end of the resistor is at AC ground potential because of the presence of C_1 .

The small $20\text{-}\mu\text{h}$ inductance in the grid lead is designed to cancel out the input capacitance of the 6U8 and make the grid circuit a true 90° phase-shift network.

The value of the static bias on the reactance tube is chosen so that the no-signal operating point lies in the center of the range of linear operation and so that this range lies in the region where the tube has good gain characteristics. When the value of this bias is determined it is found that the reactance tube offers too much capacitance, enough to swamp the crystal. Increasing the static bias would reduce the capacitance offered by the reactance tube but place the tube at a poorer operating point. To get around this problem, the reactance tube is operated at the optimum bias, and a coil L_1 is shunted across the reactance-tube plate to cancel out a large portion of the static capacitance offered by the reactance tube to the crystal. The coil is made tunable and adjusted so that the oscillator is at exactly 3.58 Mc when zero DC volts is on the grid of the reactance tube.

A color phase control in the output circuit of the color phase amplifier permits manual adjustment of the phase of the local oscillator voltage applied to the phase detector. The range here is 150° . This control is generally made available at the front panel (exposed or hidden behind a plate) to enable the set viewer to compensate for any color changes (shifts) in the color sync circuits. It is also possible that the phase of the color-burst signal has been altered *after* it was separated from the chrominance signal; a manual adjustment is needed to correct for this shift. In viewing a picture, the color phase control is adjusted to achieve the most pleasing flesh tones or color of some familiar object.

One other control in the phase-detector circuit is the AFC balance potentiometer. This enables the technician to bring both sections of the phase detector into balance if this adjustment is required.

The crystal oscillator produces the 3.58-Mc color subcarrier signal voltage needed by the I and Q demodulators. The I demodulator receives its voltage directly from the cathode of the oscillator tube. The 3.58-Mc signal for the Q demodulator is fed first to a quadrature amplifier where the 90° phase shift is introduced. Then it is transferred to grid 3 of the Q demodulator. Both 3.58-Mc signals are on the order of 25 to 30 volts peak-to-peak amplitude at the demodulators.

The final item in the color sync section is the color-killer stage. The grid of this tube ties into the phase detector at a point (*B* in Fig. 8*B*) where a negative voltage is developed when a color burst (and, hence, a color signal) is being received. The negative voltage is strong enough to bias the color-killer tube to cutoff, even when its plate receives a positive pulse from the horizontal output transformer. With no current through the tube, no voltage is developed across the plate load resistor and no bias voltage is produced for the grid of the bandpass amplifier. This enables the bandpass amplifier to conduct, which is the desired condition when color signals are being received.

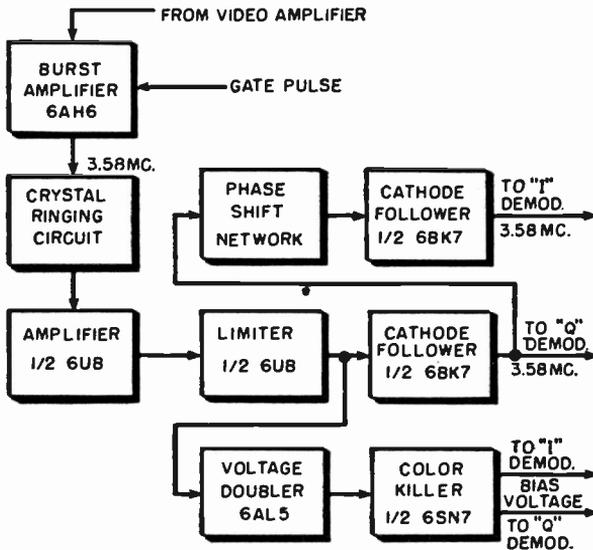


FIG. 12. Block diagram of a color sync system using a crystal ringing circuit.

Consider, now, what happens when no color signal and hence no color burst is present. The voltage at point *B* becomes slightly positive, and the killer tube conducts each time its plate is pulsed positively. The current through the killer tube establishes enough negative voltage across its plate load resistor to bias the bandpass amplifier to cutoff. This prevents extraneous information from reaching the color circuits and producing a random colored background.

Crystal Ringing Circuit. A second color sync section is shown in Figs. 12 and 13. This is seen, both from its block diagram and actual circuitry, to differ in several important respects from the APC system. The most important difference lies in the use of a crystal ringing circuit as the

generator of the 3.58-Mc color subcarrier signal. This circuit takes the place of the previous crystal oscillator and the phase-detector network and is seen to represent a saving in parts and tubes. Its method of operation is as follows.

A quartz crystal is used which, when excited by the color burst at the start of each horizontal line, will continue to "ring," or oscillate, at its natural frequency (here 3.58 Mc) for the duration of the line. A color

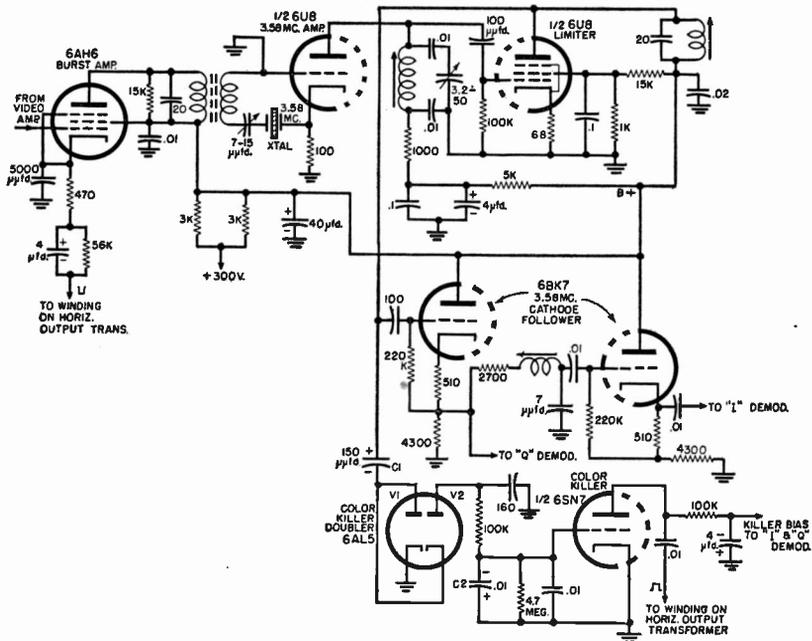


FIG. 13. Circuit diagram of crystal ringing color sync system.

burst from the burst amplifier activates the quartz crystal, and because of its extremely high Q (hence, low loss) it continues to oscillate with very little decrease in amplitude until the next burst arrives. The trimmer capacitor in series with the crystal can change its resonant frequency by several hundred cycles and thus take care of normal crystal tolerances.

The stage following the crystal is an amplifier, and the stage beyond that is generally a limiter to smooth out variations in the output of the ringing circuit. Output from the limiter may be used as one of the 3.58-Mc driving voltages for the I or Q demodulators, while the same out-

put, passed through a 90° phase-shifting network, will provide the driving voltage for the other demodulator.

The crystal ringing method is fairly simple and when properly designed will operate satisfactorily. It does not contain any particularly critical components and so will remain stable once it has been adjusted.

A color-killer network may be readily tied in with the ringing system. One approach to this is shown in Fig. 13. A portion of the oscillations developed by the crystal ringing circuit is fed to a double-diode rectifier. The circuit is a voltage doubler and operates as follows. During the positive half of the applied wave, tube V_1 conducts and effectively charges capacitor C_1 to the peak value of the wave with a polarity as indicated in Fig. 13. On the negative half-cycle, the applied voltage combines with the voltage present across C_1 to approximately twice the peak value of the 3.58-Mc wave itself. Since the voltage is now negative, V_2 conducts and charges C_2 to approximately the same value. The voltage across C_2 is negative with respect to ground and is high enough to bias the color-killer tube to cutoff. This prevents current through this tube when the plate is triggered by positive pulses obtained from the horizontal output transformer. As a result, no voltage is developed in the output circuit of the killer tube and so none can be forwarded to the grids of the I and Q demodulators. This permits the demodulators to accept color signals, the desired action under these conditions.

Consider now what happens when no color signal is present. At these times there are no color bursts to excite the ringing crystal and so no 3.58-Mc oscillations are generated. That means that the color-killer tube receives no negative voltage from the preceding bias rectifier and therefore is able to conduct freely whenever its plate is triggered positively. This conduction leads to the development of a fairly large negative voltage in the plate circuit of the killer tube, and this voltage is forwarded to the grids of the I and Q demodulators, keeping these latter stages in a cutoff condition.

THE SYNC SEPARATORS AND AGC

The sync separator and AGC sections of a color television receiver do not differ either in form or purpose from the same stages of a black-and-white receiver. In proof of this, the sync separator stages of a color television receiver are shown in Fig. 14. The input signal is obtained from the video detector or some point immediately thereafter and fed to the sync separator stages where as much of the video signal as possible is removed. The separated pulses then go to a phase splitter or

3. In what important respects does the color signal of Fig. 1N differ from a comparable monochrome signal?
4. How do we obtain the various values for the Y signal in Fig. 3E?
5. What happens to a color video signal as the colors become less saturated? Describe the action in terms of the primary colors and their relative amplitudes.
6. How is the color burst separated from the rest of the video signal? Draw a typical burst amplifier circuit.
7. Draw the block diagram of an automatic-phase-control system.
8. Describe briefly how it operates.
9. How does a crystal ringing system differ from the APC system?
10. Describe briefly the operation of a crystal ringing system.
11. How does the color-killer circuit of Fig. 13 operate?
12. What would happen if the color-killer tube in Fig. 8 went dead? Explain what you might see on the screen of the picture tube under these conditions.

CHAPTER 6

NARROW-BAND COLOR RECEIVERS

The color television receivers which have been produced to date can be divided into two categories: those which utilize the full color signal to develop a picture on the screen and those which use only part of the color information. We have, in previous chapters, discussed receivers in the first category. In the present chapter we will turn our attention to receivers in the second category.

By way of review, we have seen that a complete color signal consists of the following:

1. A monochrome signal with components that extend from 0 to 4 Mc. This is the Y signal.
2. A color subcarrier frequency that is set at 3.58 Mc (actually 3.579545 Mc).
3. Two color signals called the I and Q signals which modulate this color subcarrier.

The Q signal has color frequencies that extend from 0 to 500 kc, or 0.5 Mc. This means that the upper Q sideband extends from 3.58 Mc to $3.58 + 0.5$, or 4.08 Mc. The lower Q sideband goes from 3.58 Mc down to $3.58 - 0.5$, or 3.08 Mc.

The I signal has color frequencies that extend from 0 to 1.5 Mc. When this modulates the color subcarrier, upper and lower sidebands are formed. The lower sideband goes from 3.58 Mc down to $3.58 - 1.5$, or 2.08 Mc. If the full upper sideband were permitted to exist, it would prevent the use of a 6-Mc over-all band for the television signal (video and sound). To avoid this spilling over beyond the limits of the already established channels, the upper sideband of the I signal is limited to about 0.6 Mc. This brings the upper sideband of the I signal to 4.2 Mc. The video pass band then ends rather sharply at 4.5 Mc (see Fig. 1).

The need for two color signals of unequal bandwidth stems from the color characteristics of the human eye. Three primaries are required

only for relatively large colored areas or objects. On a television screen these are the objects produced by video frequencies of 0 to 0.5 Mc. For medium-sized detail (produced by video signals of 0.5 to 1.5 Mc) the eye is sensitive only to bluish green or reddish orange. The NTSC signal, by means of its *I* component, is fashioned to take advantage of this characteristic.

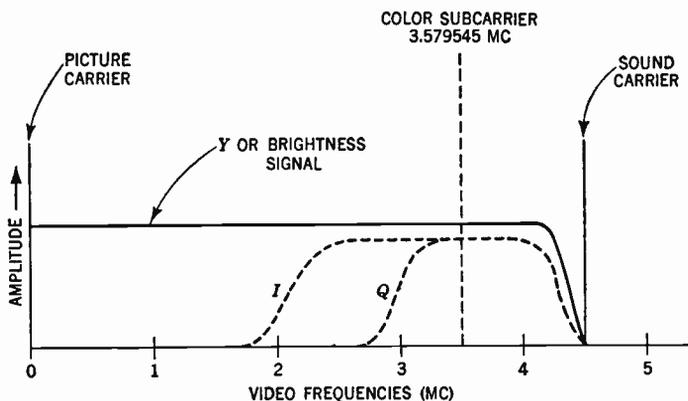


FIG. 1. Distribution of the color video signal in its pass band.

We know that when we present all the color of which the NTSC signal is capable, a very pleasing picture is obtained. Just how much less color the eye can take in a picture and still be satisfied is as yet unknown. However, a number of color-receiver manufacturers have designed (and produced) color sets in which the bandpass of the color signal is limited to values of less than 1.5 Mc.

Here is the basis for this action. A color-picture signal can be represented by the following equation:

$$E_T = E_Y + E_Q \sin (\omega t + 33^\circ) + E_I \cos (\omega t + 33^\circ) \quad (1)$$

The E_Y term, of course, represents the monochrome portion of the signal. The E_Q and E_I represent the color voltages. Since E_Q is multiplied by $\sin (\omega t + 33^\circ)$ and E_I is multiplied by $\cos (\omega t + 33^\circ)$, the E_Q and E_I signals are 90° out of phase with each other. (Sin and cos of the same function are 90° out of phase with each other.)

If, now, we limit the color video frequencies to a maximum of 0.5 or 0.6 Mc it can be shown that Eq. (1) becomes

$$E_T = E_Y + 0.492 (E_R - E_Y) \sin \omega t + 0.877 (E_R - E_Y) \cos \omega t \quad (2)$$

E_Y remains unaltered, since nothing has been done to affect it. How-

ever, in place of E_Q we now have $E_B - E_Y$ and in place of E_I we have $E_R - E_Y$. Also, we note that $E_B - E_Y$ is multiplied by $\sin \omega t$ instead of $\sin (\omega t + 33^\circ)$. Therefore, $E_B - E_Y$ is shifted 33° from the E_Q position on the color phase chart (see Fig. 2). The same situation is true of E_I and its replacement $E_R - E_Y$. Thus, if you take an incoming color signal containing E_I and E_Q voltages and shift the phase of the reinserted carrier by 33° , you obtain (at the output of the demodulators) $E_R - E_Y$ and $E_B - E_Y$ signals.

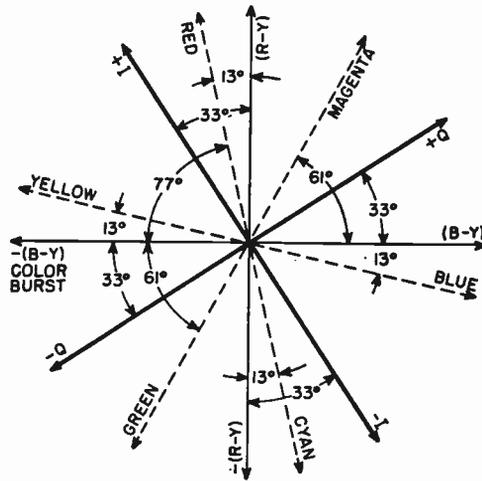


FIG. 2. Color phase diagram showing the position of the $B - Y$ and $R - Y$ vectors relative to the I and Q vectors.

This, then, is the basis of color receivers which have their color bandpass restricted to less than 1.5 Mc. If the theoretical considerations are closely followed, the bandpass should not extend beyond 0.5 Mc. However, it has been found practically that the bandpass can be extended to 1 Mc and somewhat beyond without visibly affecting the color presentation. It is true that the color fidelity will not be as great as in the I and Q systems but the deterioration is not detectable by the viewer, and in the final analysis this is the governing criterion.*

At this point, the reader might very well ask, "Why use the modified system if it does not provide a completely true color picture?" The

* If the color pictures produced by an I, Q receiver are placed side by side with corresponding color pictures developed by an $R - Y, B - Y$ set, the color deterioration of the latter is detectable. However, such comparison tests are never made in the home and the color pictures of an $R - Y, B - Y$ system prove satisfactory.

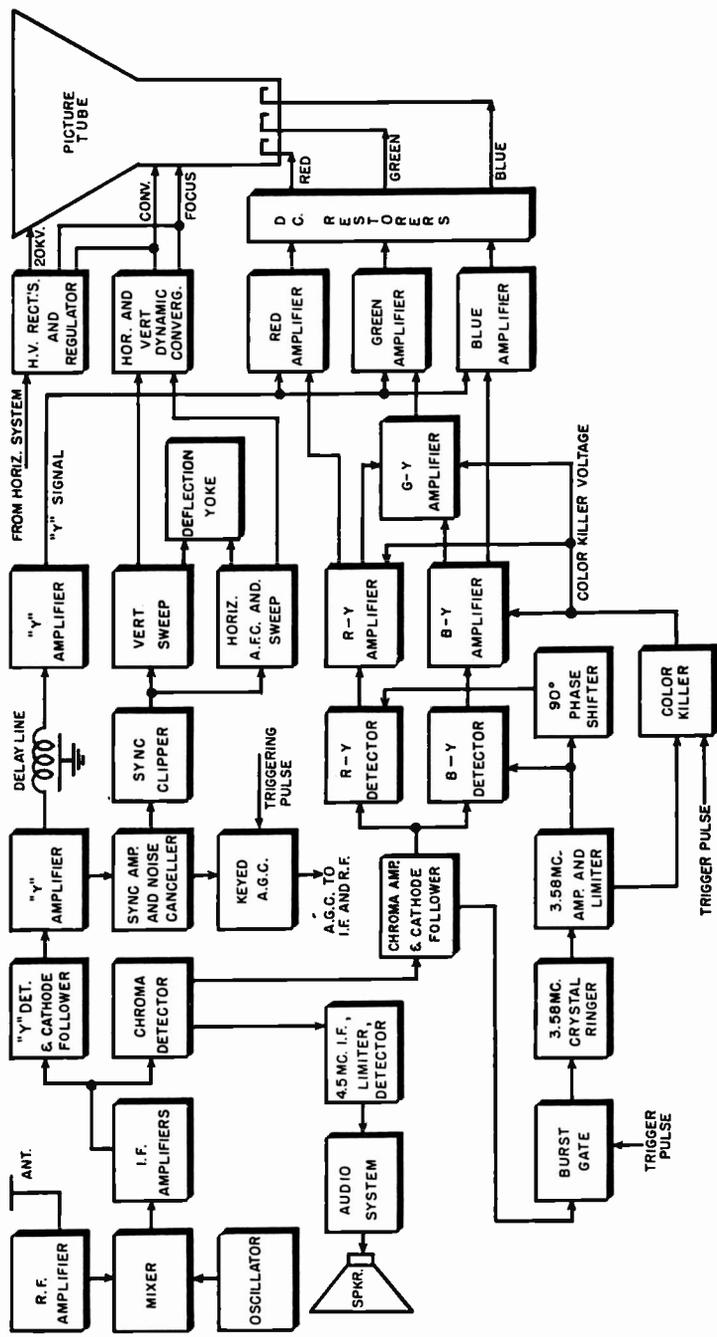


FIG. 3. Block diagram of one of the first R - Y, B - Y color receivers to appear commercially.

answer lies in certain economies which can be effected through the use of the narrow-band or $R - Y$, $B - Y$ method. Just what these are will become evident as we examine a number of receivers using this approach.

A COMMERCIAL RECEIVER

The block diagram of one of the first $R - Y$, $B - Y$ color receivers to appear commercially is shown in Fig. 3. The RF and video IF sections are similar to those of the I and Q color receivers discussed in previous chapters. The gain of the RF tuner and video IF stages is controlled by an AGC voltage derived from a conventional AGC keyer tube.

The video IF system feeds its signals to two separate detector circuits. One detector is designated as the Y detector and its output consists of the usual monochrome video and sync information. The Y detector output is applied to a cathode follower, which transfers the video signal to two Y amplifiers and beyond this to the color circuits for combination with the demodulated $R - Y$ and $B - Y$ color voltages. A 1- μ sec time-delay network between the first and second Y amplifiers retards the monochrome signal so that it remains in step with its associated color components when the two are subsequently combined in a matrix. (The latter network, we shall see, is less complex in these receivers than it is in I, Q sets.)

The Y detector also provides a portion of the monochrome signal for the sync system of the receiver. This is in accordance with standard monochrome practice.

The other detector in this receiver is the chrominance detector, and it delivers two output signals. One signal is the conventional 4.5-Mc intercarrier sound IF signal which is transferred, in turn, to a 4.5-Mc amplifier, a limiter, a ratio detector, and two audio amplifiers in the usual manner. The other signal is the color signal, and it is applied first to a chroma amplifier (see Fig. 4). At the output of this amplifier, the signal is applied to two separate sections of the color system. Part of the signal goes to a burst gate amplifier and part is transferred to a chroma cathode follower and from there to the signal grids of 6BE6, $R - Y$, $B - Y$ detectors. A chroma control in the cathode leg of the cathode follower stage is mechanically ganged to the contrast potentiometer in the Y cathode follower circuit so that both the Y and color signals will be similarly affected when the controls are rotated.

The burst gate tube is normally biased to cutoff. However, during the horizontal retrace interval it is driven into conduction by a pulse ob-

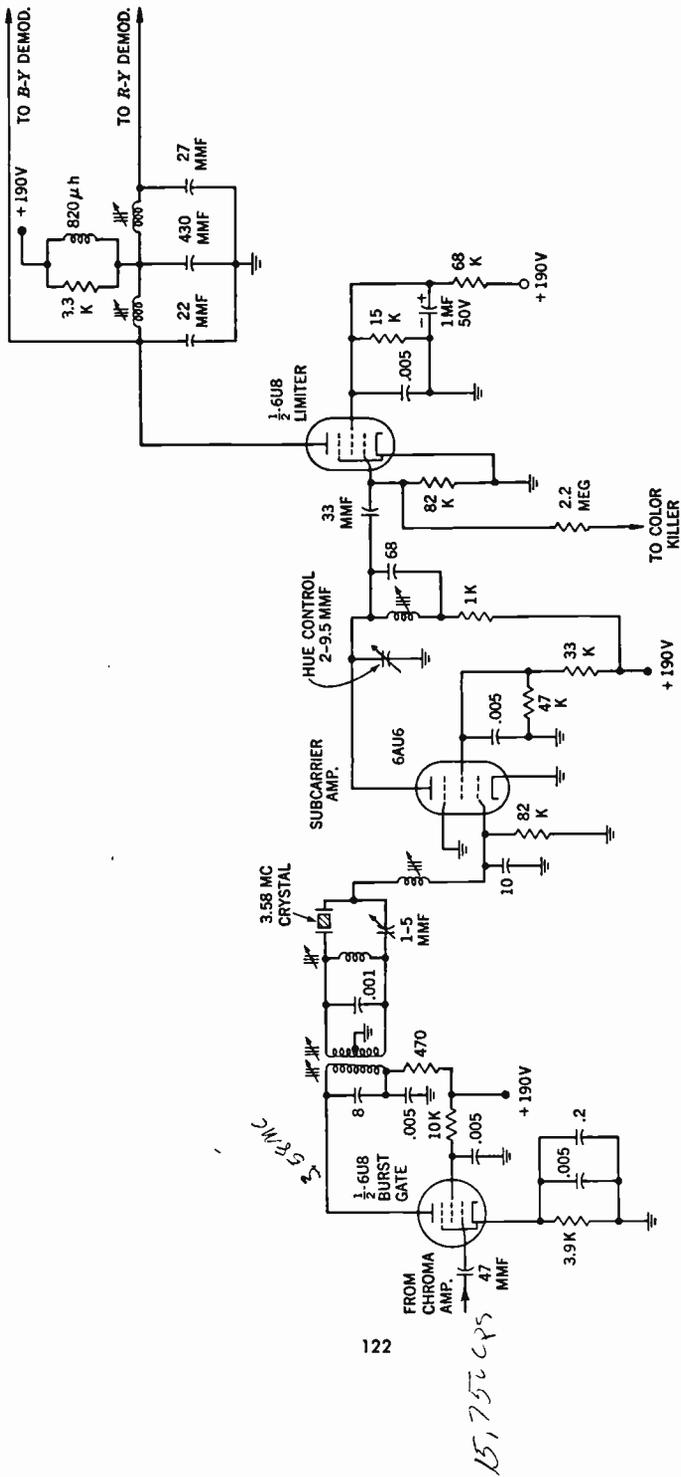


FIG. 5. The color sync section of the receiver in Fig. 3. Included are the burst-gate and subcarrier amplifiers, the crystal ringing circuit, and the output limiter and quadrature network.

A hue control in the plate circuit of the 3.58-Mc amplifier enables the viewer to make limited correcting adjustments in the phase of the generated 3.58-Mc oscillations. The control is set by the most pleasing flesh tones or by the color of some familiar object.

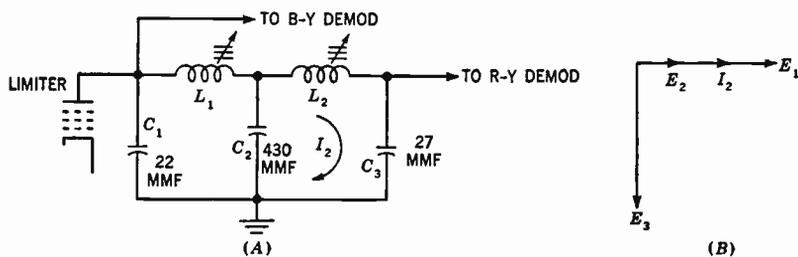


FIG. 6. (A) Simplified diagram of the quadrature network in the plate circuit of the limiter. (B) Phase relationships in the network.

The two color detectors of Fig. 7 now have all the ingredients needed to recreate the demodulated color video signals. The output circuits of both tubes are almost identical, because both branches possess the same bandpass, 0 to 0.5 Mc. This arrangement obviates the need for any special delay lines in the color circuits; the only delay line in the receiver is that found in the Y section.

The $R - Y$ and $B - Y$ detectors are each followed, in turn, by an amplifier, and then the signals are divided into two separate signal paths. First, portions of the output voltages from both amplifiers are fed to a simple resistive adder (R_1 , R_2 , and R_3) to form a negative $G - Y$ signal. This is possible because, as shown in Chap. 2,

$$-(G - Y) = 0.51(R - Y) + 0.19(B - Y)$$

The specific proportions are developed by the adder network and fed to a $G - Y$ amplifier. Here the signal is inverted, giving us the needed $G - Y$. Now we have all three color-minus-brightness signals ($R - Y$, $B - Y$, and $G - Y$) and by simply adding $+Y$ to each, we obtain the original red, blue, and green video signals. The addition of $+Y$ takes place via R_4 , R_5 , and R_6 (Fig. 7).

The output section of the chrominance portion of the receiver consists of separate channels for the red, green, and blue color signals. Each branch has two amplifiers and a DC restorer. The amplifiers use degenerate feedback to reduce their input impedance and to enable the proper mixing action to occur between the color-minus-brightness signals and the Y signal.

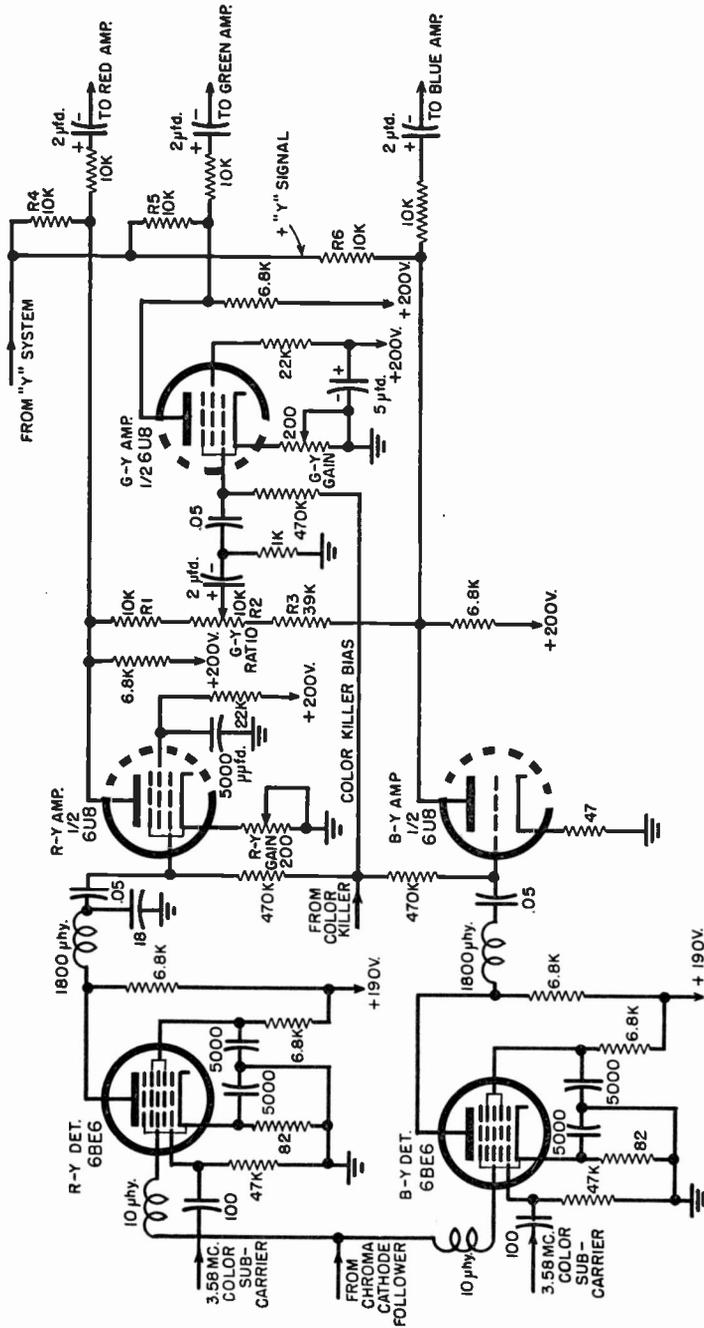


FIG. 7. Circuitry of the R - Y, B - Y demodulators. Note the resistive network for combining R - Y and B - Y signals to form C - Y.

A color-killer circuit is also employed in this system to prevent the appearance of any spurious color signals when a black-and-white program is being viewed. The grid of the killer triode (Fig. 8) is connected to the grid of the 3.58-Mc limiter tube. When no color signal is being received, the 3.58-Mc crystal is quiescent and the grid-leak bias on the limiter tube is zero. Under these conditions the color-killer tube con-

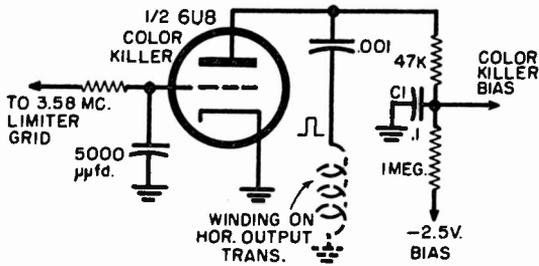


FIG. 8. Color-killer circuit of the receiver in Fig. 3.

ducts whenever its plate receives a positive pulse from the horizontal output transformer. The resulting current develops a negative charge across C_1 , and this, added to the -2.5 volts normally present across the capacitor, is sufficient to bias all $R - Y$, $B - Y$, and $G - Y$ amplifiers to cutoff.

When a color signal is received, the 3.58-Mc generated oscillations develop enough negative grid-leak bias on the limiter grid to cut off the color-killer tube. This prevents the tube from conducting, even when pulsed, and the only negative voltage appearing across C_1 is the -2.5 volts from the receiver power supply. This value is not sufficient to prevent the color-minus-brightness amplifiers from operating.

The remainder of the color receiver consists of those circuits required to generate and synchronize the various sweep wave forms, as well as to generate special dynamic convergence and focus wave forms required by the three-color picture tube. These do not differ in form from corresponding circuits in I, Q receivers.

If we pause at this point and compare the block diagram of the $R - Y$, $B - Y$ receiver just discussed with preceding I, Q circuits, we see that while a certain amount of circuit simplification has taken place, it has not been extensive enough to offer the $R - Y$, $B - Y$ system any decided economic advantage over the I, Q approach. The simplification that did take place was centered chiefly in the removal of one delay

line and in the matrix network where the $R - Y$, $B - Y$, and $G - Y$ color signals combined with the Y signal.

A 19-IN. $R - Y$, $B - Y$ RECEIVER

The second $R - Y$, $B - Y$ color receiver to be discussed was designed for a 19-in. color tube. The designers of this set approached the problem a little differently and were able to effect a considerable reduction in tubes. A partial diagram of the receiver is shown in Fig. 9. Of the RF and video IF stages, little need be added to what has already been said.

Of particular interest are the circuits which are found beyond the video detector. Following the detector are two video amplifiers which resemble monochrome video amplifiers except for the lack of special peaking coils in the first video stage. However, it will be noted that the principal load resistor for V6A is only 820 ohms (R92), a value low enough to maintain the amplifier response up to 4.0 Mc. There is compensation in the output of the second video amplifier, and hence higher-value load resistors are permissible.

Both the color and monochrome components of the composite signal remain together through both video amplifiers. Separation then takes place at the plate of the second video amplifier. The brightness component is led off to a separate brightness output amplifier (V29, a 12BY7) via R98 (2,200 ohms) and L40, a 0.6- μ sec delay line. (The reduction in delay time from the usual 1 μ sec to 0.6 μ sec will be discussed presently.) At the same time, the chrominance portion of the signal appears across R97A and R96 and is applied to a 12BY7 bandpass amplifier. Just how much chrominance signal reaches V8 is governed by the setting of R97A. This potentiometer, labeled Contrast Control, acts in conjunction with R97B in the cathode leg of the brightness output amplifier. Both are mechanically ganged together, permitting the simultaneous adjustment of the chrominance and monochrome signal levels. A separate control is available at a subsequent point in the color system to permit independent adjustment of the color intensity of the picture.

Brightness Signal. The brightness or monochrome signal is amplified by V29 and then passed through a 3.58-Mc filter before being applied to all three cathodes of the picture tube. The 3.58-Mc trap serves to attenuate color sidebands that may be present at this point. The trap also tends to limit the bandpass of this circuit to a value somewhere between 3 and 3.2 Mc. Hence, in spite of the fact that monochrome

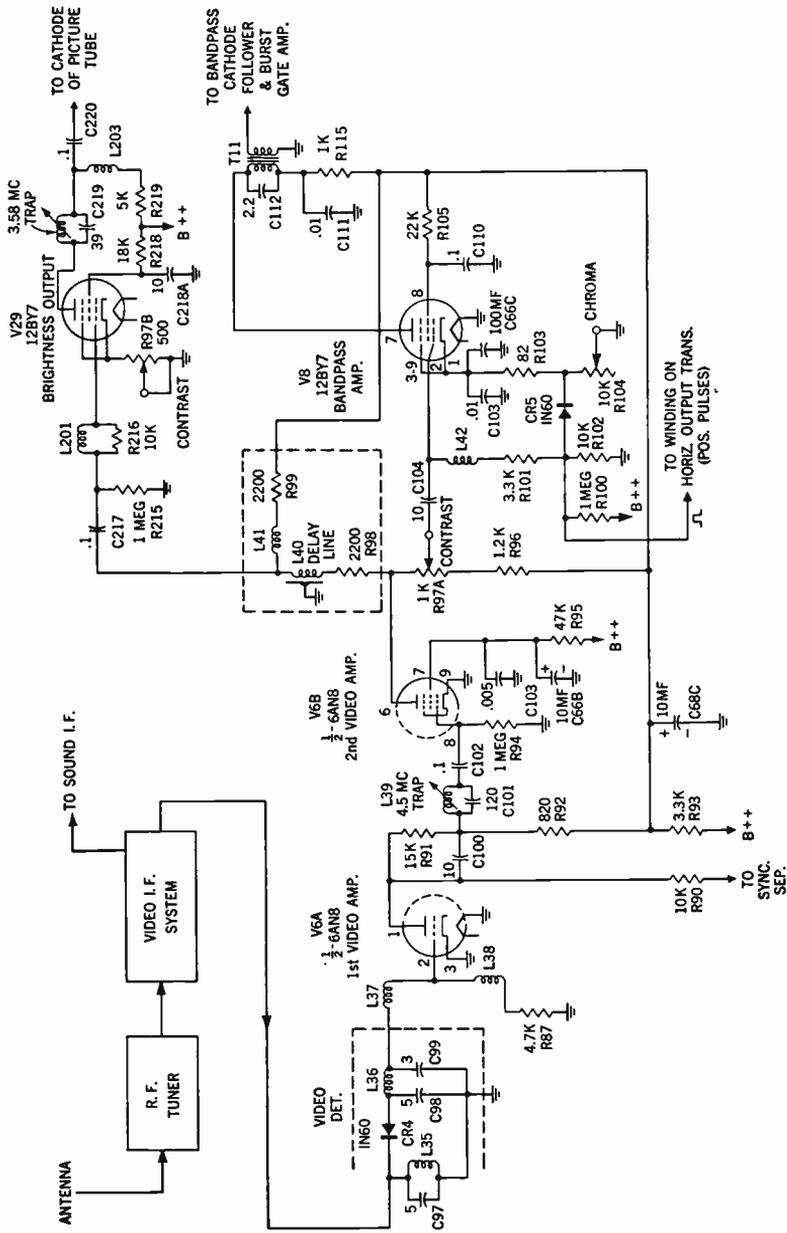


Fig. 9. A partial schematic of a second color receiver. Additional sections are shown in Figs. 10 and 12.

signals up to 4.2 Mc are initially sent from the station, only those frequencies up to 3.2 Mc are effective in developing the picture.

The monochrome signal, at the picture-tube cathode, is in the $-Y$ polarity, a condition that is required for the proper combination of the brightness and chrominance components of the color signal. Actually, as the reader will see in the ensuing analysis of this circuit, the matrixing of the two portions of the color signal occurs within the picture tube itself rather than in a separate resistive network. This method possesses several advantages, not the least of these being economy. Some of the others are:

1. The circuit is simplified, rendering servicing easier and more straightforward.

2. Each signal applied to the picture tube is processed through its own separate system. This is true for the monochrome as well as the color signals. Hence the engineer can design each system for the best performance within its range.

3. Since the matrixing occurs within the tube, there is no problem with resistors changing value, or tube aging or tube drift. Thus, the operational stability of the circuit is enhanced.

Bandpass Amplifier. The color signal, once it leaves the second video amplifier, travels to V8, a 12BY7 bandpass amplifier. A potentiometer in the cathode leg of this tube varies the gain of this stage, and since only the color portion of the signal is thus affected, the control is labeled on the diagram as the Chroma Control. For the consumer, this knob is labeled Color Intensity, this being considered more descriptive of its action than the more technical chroma. Maximum gain occurs when the 10,000-ohm resistor is completely out of the circuit. At this point the chroma knob is turned fully clockwise.

The color-burst signal also passes through the bandpass amplifier. To ensure that sufficient burst voltage is available at all settings of the chroma control, a special positive pulse is fed into the grid circuit of V8. The pulse is obtained from the horizontal output transformer and is so timed that it arrives at the same instant as the color burst. The pulse decreases the bias on the tube, causing it to furnish more plate current during this interval. In this way, a color-burst signal is obtained which is strong enough at every setting of the chroma control to drive the color AFC network adequately.

An IN60 germanium diode is inserted between the chroma control and the grid circuit. It is designed to maintain the amplitude of the burst signal at its most efficient level in the following way. The cathode end of the IN60 is connected to the top end of the chroma control and

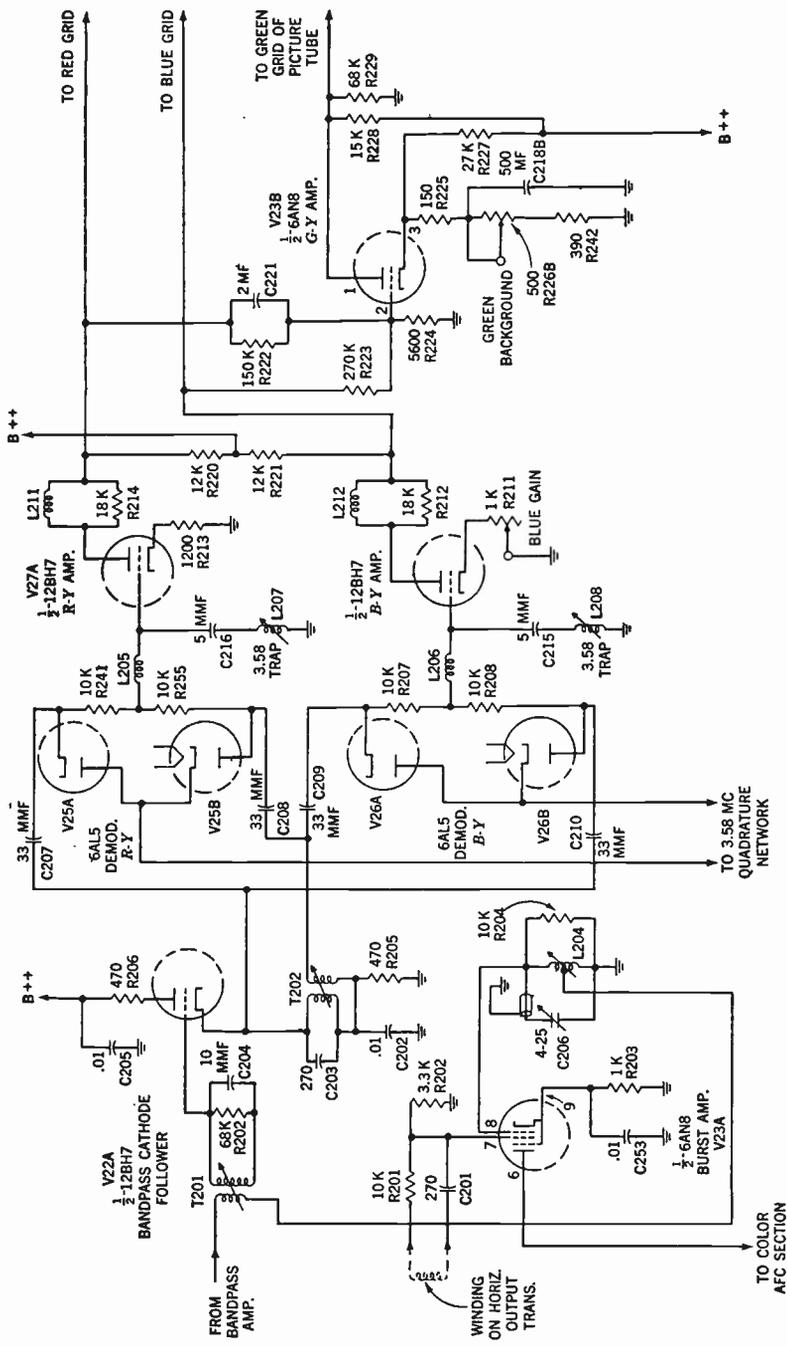
hence is subject to whatever positive potential exists at this point. Let us say this is +5 volts. The other (or plate) end of the IN60 connects to R102, a 10,000-ohm resistor in the grid circuit. This same resistor develops the positive boosting pulse. If the pulse raises the voltage across R102 above +5 volts, the IN60 conducts and serves to maintain the voltage across R102 at the same level as the voltage across the chroma control. When the chroma control is fully in the circuit, V8 grid bias is high and more positive boost voltage is required for the arriving color burst. On the other hand when the chroma control is completely out of the circuit, V8 is operating at full gain. At this point no intensifying pulse is needed, and none actually reaches the tube, because the IN60 tends to maintain the voltage across R102 at zero.

Burst Amplifier. The output of the bandpass amplifier is applied to two points, a bandpass cathode follower and a burst amplifier (see Fig. 10). Considering the latter first, the signal is brought to the amplifier by way of L204. L204 and C206 form a 3.58-Mc tuned step-up network in which the applied burst voltage is actually fed to the grid of V23A in greater amplitude than it is received. Adjustment of C206 will vary the phase of the burst which the burst amplifier receives. When the circuit is tuned to precisely 3.58 Mc, the signal developed by the circuit will have the same phase as the incoming burst signal. If C206 is detuned, the signal developed by the resonant circuit will either lag or lead the incoming burst signal. Since the color AFC stage receives the burst from this amplifier, it will shift the phase of the generated 3.58-Mc subcarrier to follow suit. This, in turn, will alter the colors produced on the screen.

Because of this action, the shaft of C206 is extended to the front panel and labeled the color-shading control. Its proper setting is determined by the set user according to the color of some familiar object.

The burst amplifier stage is seen to be without any B+ screen voltage. Instead, the grid is connected to a special winding on the horizontal output transformer, and from this point it receives periodic positive pulses. These pulses are timed to arrive with the color bursts and possess sufficient amplitude to drive the tube into conduction. R201, R202, and C201 serve as a phase-shifting and -shaping network to ensure that only the color burst passes through the stage. The action of the network is illustrated in Fig. 11.

Color Sync Section. The entire color sync section in Fig. 12, consisting of V24A, V24B, V28A, V28B, and V22B, is sufficiently similar to the color sync sections discussed in previous chapters not to warrant addi-



tional explanation here. The phase-shifting network T204, however, is of interest. It provides two 3.58-Mc signals to the color demodulators which are 90° out of phase with each other.

The network is shown by itself in Fig. 13A. The plate of the buffer connects to the top of L210, and it is from this point that the R - Y demodulator obtains its 3.58-Mc signal. On a vector diagram of this

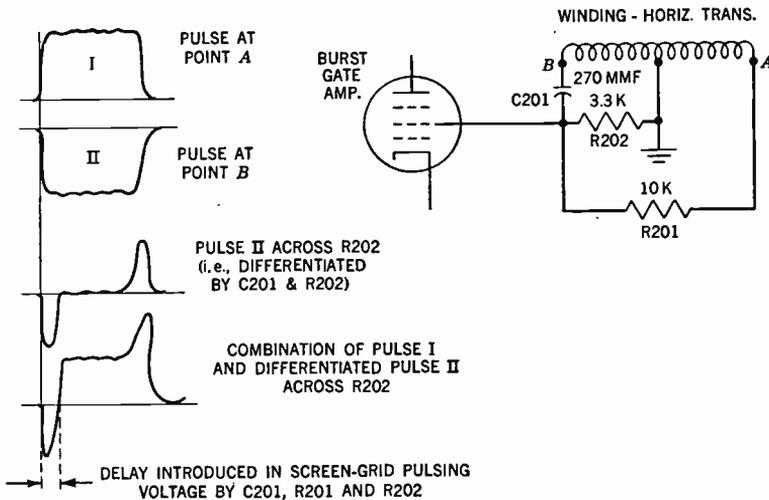


FIG. 11. An illustration of the action of the phase-shifting and -shaping network of C201, R201, and R202 in Fig. 10.

network we can use the R - Y vector as our starting point (see Fig. 13B). Let us call the voltage across L210, E_1 . This same voltage also appears across the series combination of C212 and C213 and divides across them in inverse ratio to their capacitance. The voltage across C213 is of interest, and this is shown as E_2 .

E_2 is also the voltage which is applied across the series combination of C211 and L209. Since this combination is resonant to 3.58 Mc, any current through C211 and L209 will be in phase with E_2 . This current is labeled I_2 in Fig. 13B. The voltage drop produced across L209 by I_2 leads the current by 90°. This is E_3 and is the 3.58-Mc voltage which the B - Y demodulator receives.

Color Demodulators. This receiver uses balanced diode demodulators which respond to phase differences in the incoming color signal in much the same manner as the diodes in the color sync section. As a matter of fact, the circuits are similar, as the following analysis will re-

veal. (The discussion will cover only the $R - Y$ demodulator, since the $B - Y$ demodulator corresponds to it exactly.)

A simplified diagram of the $R - Y$ demodulator is shown in Fig. 14. The incoming color sidebands appear across transformer T202 and both

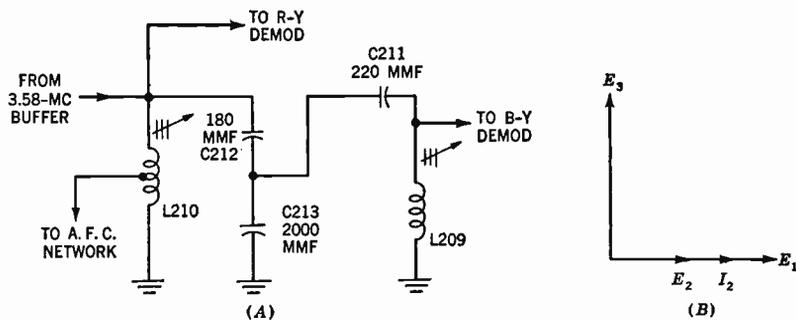


FIG. 13. (A) Simplified diagram of T204 of Fig. 10. (B) Phase relationships in this network.

$R - Y$ diodes receive equal and oppositely phased portions of this voltage. The midpoint of the two transformer windings is placed at AC ground potential by the presence of a 0.01- μ f capacitor C202.

At the other end of this circuit a 3.58-Mc subcarrier voltage is applied from a buffer stage linked to the 3.58-Mc crystal oscillator. If we

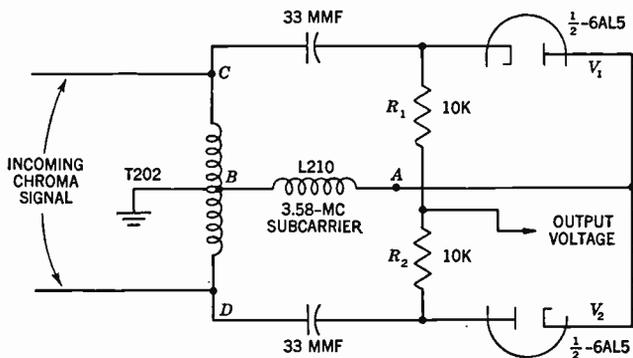


FIG. 14. Simplified diagram of the $R - Y$ demodulator circuit of Fig. 10.

were to draw a vector diagram depicting the phase relationships in this circuit, it would appear as shown in Fig. 15A. BC represents the color signal applied to V_1 , and BD is the color signal for V_2 . At the same

time the 3.58-Mc subcarrier is present across L210, and it assumes the position shown by vector BA .

Tube V_1 , then, is subjected to voltages BC and BA , producing a combined voltage which is labeled Resultant No. 1. V_2 and its circuit produces Resultant No. 2. In the case shown in Fig. 15A these resultant voltages are equal, and since they develop equal and opposite voltages across their respective load resistors, R_1 and R_2 , the net output voltage from the circuit will be zero.

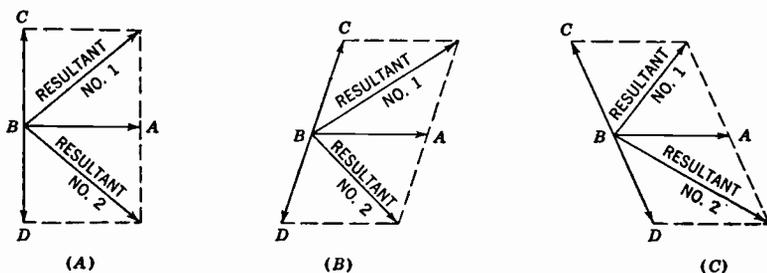


FIG. 15. Various phase conditions between the 3.58-Mc subcarrier and the incoming chroma signal in the circuit of Fig. 10. See text for details.

(If the current path through R_1 and R_2 appears somewhat obscure, remember that each 33- μ f capacitor charges up whenever V_1 and V_2 conduct and then discharge through R_1 and R_2 during each half-cycle when V_1 and V_2 do not conduct.)

Zero output is obtained when the incoming color sideband voltages are 90° out of phase (in quadrature) with the injected 3.58-Mc subcarrier voltage. In the $R - Y$ demodulator this, of course, will happen when the $B - Y$ color sidebands are applied to it.* However, for $R - Y$ signals the phase relationship is not 90° (or 270°), and output voltages are obtained (see Fig. 15B and C). These represent the demodulated $R - Y$ color voltages and are transferred to the following $R - Y$ amplifier through a 3.58-Mc trap.

The polarity of the signal voltages which are obtained from these demodulators depends upon two things: the phase of the applied subcarrier signal and the manner in which the incoming signal voltage is fed to the demodulator diodes. Concerning the subcarrier signal, this can be applied to its respective demodulator either possessing the

* Zero output will also be obtained when there is no incoming color signal or no 3.58-Mc oscillator voltage. Neither one of these alternate situations is important to this discussion. They are important, though, in servicing a defective receiver.

proper phase or 180° from this position. When the latter condition holds, we obtain $-(R - Y)$ from the demodulator instead of $R - Y$. The same action is true of the $B - Y$ demodulator.

A reversal in signal output polarity will also be obtained if the connections to the diodes are reversed. Thus, if you examine the two demodulators in Fig. 10 you will note that the incoming signal connections to the $B - Y$ demodulator are the reverse of the connections to the $R - Y$ diodes.

In the present receiver both sets of detectors produce negative output voltages, $-(R - Y)$ and $-(B - Y)$. Reversal to the positive phase is achieved by separate $R - Y$ and $B - Y$ amplifiers, after which these two signals are transferred to the control grids of the color-picture tube.

A $G - Y$ amplifier is also present in the circuit, and it obtains the required $R - Y$, $B - Y$ signals from the plate circuits of the respective amplifiers. A simple matrix network consisting of three resistors and one capacitor is all that is needed to provide the $G - Y$ amplifier with the correct proportions of the $R - Y$, $B - Y$ signals. Thereafter, the $G - Y$ amplifier combines these voltages to provide the necessary $G - Y$ signal to the color-picture tube.

Note that there are no DC restorers in this circuit because of the DC path from the color demodulators to the control grids of the picture tube. Stabilization of the circuit is achieved by operating the three color-minus-brightness stages as degenerate amplifiers. Elimination of the three DC restorers plus the use of the picture tube for matrixing has served to simplify the color circuitry of this receiver to a remarkable extent. Not only is this beneficial to the customer in price reduction, but it greatly assists the service technician in locating possible defects. And this, too, benefits the customer in reduced repair bills.

It was previously mentioned that the delay line in the brightness channel introduced a delay of only $0.6 \mu\text{sec}$. The reason for the reduction from the normal value of $1 \mu\text{sec}$ stems from the fact that the band-pass of the $R - Y$, $B - Y$ circuits is about 1.0 Mc wide. This attempts to take advantage of the full color signal, yet relies on the fact that the small amount of color distortion produced through cross talk will escape the viewer. Visual tests conducted on the receiver serve to substantiate these conclusions.

HIGH-LEVEL COLOR DEMODULATORS

The second color receiver was able to achieve a substantial reduction in the number of tubes required. The principal place where it achieved

this reduction was beyond the color demodulators. In the circuit of Fig. 3 there were three color-minus-brightness amplifiers, followed in turn by six individual color amplifiers (two each for red, green, and blue) and finally three DC restorers. In the second circuit the three DC restorers were eliminated, together with three of the color amplifiers, or a total of six stages (although not six tubes). Still remaining are the three color-minus-brightness amplifiers, and it would be possible to eliminate these too if the color demodulators could develop sufficient output voltage to drive the grids of the picture tube directly. This has been accomplished in one design which has recently been evolved.

The basic circuit of this high-level demodulator is shown in Fig. 16. The subcarrier reference signal is applied between grid and cathode,

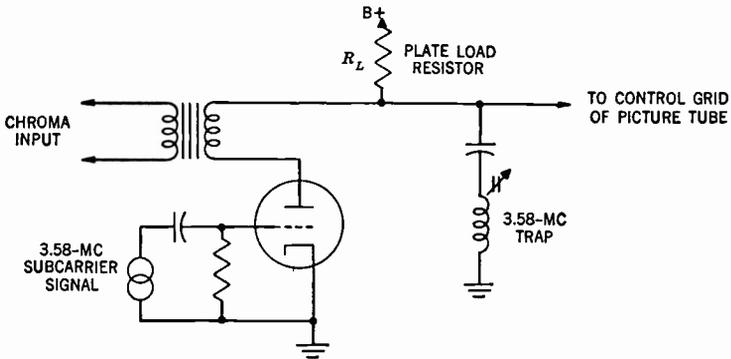


FIG. 16. Basic high-level demodulator.

while the chroma signal is brought into the plate circuit via a transformer. The grid circuit is grid-leak biased by the signal, and the applied subcarrier voltage is powerful enough so that there is current through the tube during only part of the positive half-cycle of the sine wave.

If we first consider the circuit without any chroma signal at the plate, then the high peak plate currents through the tube bring the plate voltage down to some low value. As a matter of fact, the applied B+ voltage can vary over a considerable range and the plate voltage (at the tube) will still be brought down to the same value. Also, the grid signal can vary by as much as ± 50 per cent without any appreciable change in plate voltage. Circuit operation is relatively independent of these two factors, and this is an important feature, since it ensures that what-

ever variation in output voltage is obtained will stem directly from the applied chroma signal.

For the discussion to follow, we shall use the voltage and circuit values shown in Fig. 17A. The triode load resistor will have a value of 17,500 ohms and the applied B+ voltage will be 200 volts. Of this, 175 volts will appear across R_L and 25 volts across the tube. If we were

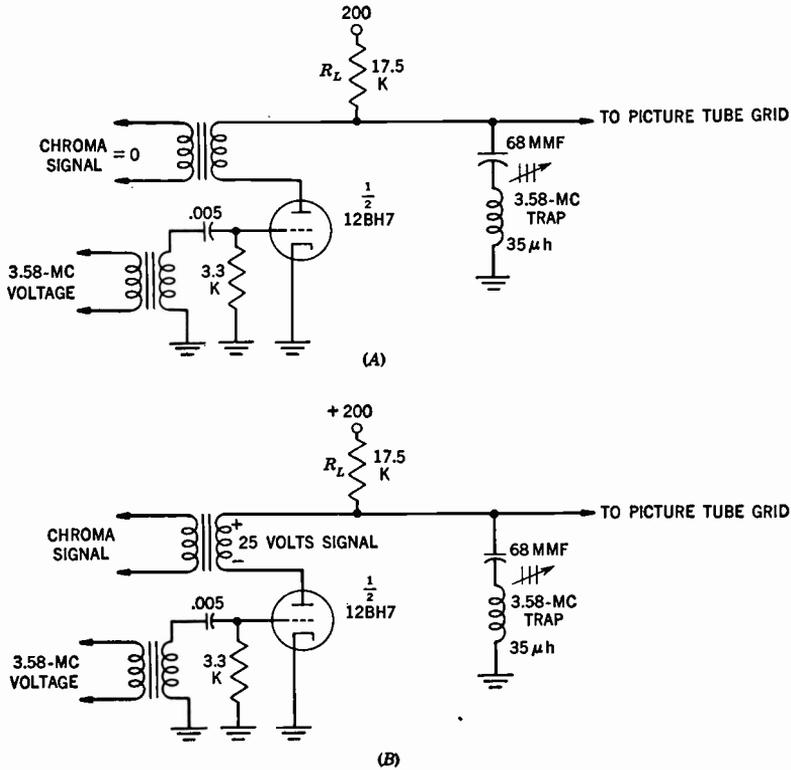


FIG. 17. (A) Triode demodulator circuit with no chroma signal. (B) Demodulator with chroma signal.

to increase the B+ value to 300 volts, the tube current would rise. However, the internal tube resistance would drop, tending to maintain the plate voltage at the original 25 volts. The difference between this and the 300 B+ volts would appear across R_L .

Now let us apply to the plate circuit a chroma signal possessing the instantaneous polarity as shown and with a peak value of 25 volts (see Fig. 17B). The signal will add to the applied B+ voltage to provide a

total plate voltage of 225 volts. This additional voltage will not affect the drop across the triode, but it will cause more current through the circuit, producing a greater voltage drop across R_L .

By the same token, when the instantaneous chroma voltage becomes -25 volts, the current through the tube decreases and this reduces the voltage drop across R_L . Thus, the instant-to-instant voltage appearing across R_L will depend on the relative phase of the incoming chroma signal and the subcarrier grid signal. In other words, the voltage variations across R_L represent the demodulated color signal, and these can be applied directly to the appropriate control grid of the picture tube.

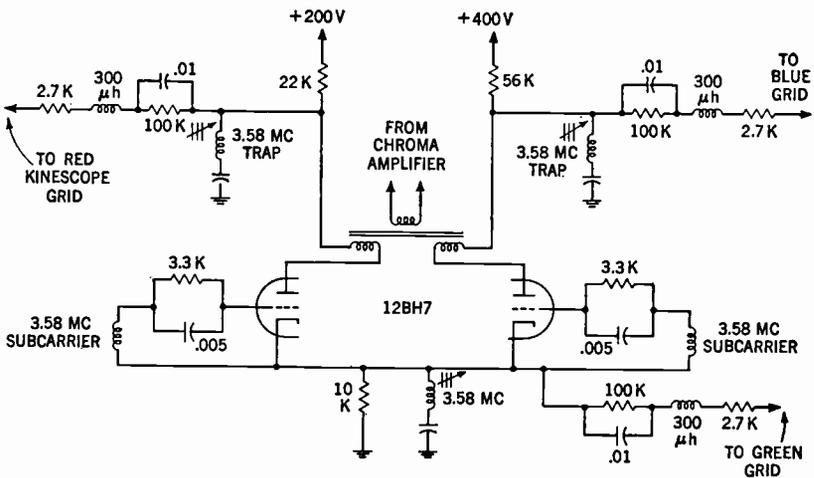


FIG. 18. Demodulator circuit of Fig. 16 as it actually appears in receiver.

If the phase between the incoming chroma signal and the subcarrier grid signal is 90° (or 270°), the demodulator triode will always conduct when the chroma sine waves are going through zero, thereby producing no change in voltage across R_L . Hence, we can achieve separation of the $R - Y$ and $B - Y$ signals from each other by using appropriate 3.58-Mc subcarrier voltages in the grid circuit of these demodulators.

Now that we appreciate the manner in which these triode demodulators operate, let us examine the circuit as it is actually used in the receiver. This is shown in Fig. 18, and it consists of two triodes (sections of a 12BH7). Subcarrier reference signals are applied to each triode, while the chroma voltages are obtained from a preceding chroma amplifier through an interstage transformer. One triode pro-

duces a $B - Y$ signal, the other an $R - Y$ signal. These are then fed, respectively, to the blue and red control grids of the picture tube. The voltages are powerful enough to drive the grids directly, eliminating the need for intervening amplifiers. Furthermore, because of the direct connection, DC restorers are not required.

The signal for the green control grid of the picture is obtained from a cathode resistor which is common to both triode demodulators. This arrangement is possible because $G - Y$ is made up of negative components of $R - Y$ and $B - Y$. If we obtain a positive $R - Y$ voltage from the plate resistor of the $R - Y$ demodulator, then the cathode of this stage will provide a negative $R - Y$. The same situation exists for the $B - Y$ demodulator. Thus, by adjusting the two plate load resistors and the cathode resistor in the ratio of

$$R_2: R_1: R_K = 5.23:1.96:1$$

we will obtain the proper $R - Y$, $B - Y$, and $G - Y$ voltages for the control grids of the color picture tube.

The use of a common cathode resistor produces cross talk between the $R - Y$ and $B - Y$ demodulators. That is, the $R - Y$ demodulator circuit will be subject to demodulated $B - Y$ video voltages, and the $B - Y$ demodulator will be subject to detected $R - Y$ signals. To eliminate the cross talk, the phase of the two subcarrier signals is altered from the normal 90° to 63.6° . What this does is to introduce in each demodulator just enough of the other signal component to exactly cancel out the cross talk arising from the common cathode resistor.

There are several other features of this circuit worth noting. Each load resistor is shunted with series 3.58-Mc trap circuits. These serve to prevent any of the subcarrier signal present in the plate and cathode circuits from reaching the picture tube. Furthermore, since higher subcarrier harmonics are also developed, these are dealt with by inserting 300- μ h chokes and 2,700-ohm resistors in each signal lead. Special peaking resistors are not employed in the demodulator output circuits because of the relatively low impedance which the demodulators themselves present to the circuit.

Note the absence of all amplitude adjustments in this circuit. By properly proportioning the various resistors in this circuit, the correct values of color-minus-brightness signals are produced and these go directly to their respective control grids in the picture tube.

Note that while all the color demodulators which have been discussed in this chapter have been employed for $R - Y$, $B - Y$ type of receivers, suitable operation can also be obtained using I and Q signals.

The only change required is a shift in the subcarrier reference voltages used with these tubes. This, plus the subsequent circuitry, determines whether the stage is an $R - Y$, $B - Y$ demodulator or an I, Q demodulator.

QUESTIONS

1. Explain the reasoning behind the use of narrow-band color receivers.
2. What differences exist between the receiver of Fig. 3 in this chapter and the I, Q sets previously discussed?
3. What simplifications did the designers of the second $R - Y$, $B - Y$ receiver make which enabled them to reduce the number of tubes used in this set substantially?
4. Describe the operation of the color demodulators shown in Fig. 10.
5. List all the matrix components indicated in Fig. 10. What resistors and capacitors affect the combination of the Y and color-minus-brightness signals? Explain your answer.
6. What is the purpose of the 1N60 crystal in the grid circuit of V8 (Fig. 9)? Explain how it functions.
7. What determines whether we get $R - Y$ or $-(R - Y)$ from a color demodulator?
8. How does the triode demodulator of Fig. 17 operate?
9. Why are the subcarrier voltages fed to the two demodulators of Fig. 18 not 90° out of phase with each other?
10. What savings does an arrangement such as shown in Fig. 18 permit over the circuit of Fig. 10?

CHAPTER 7

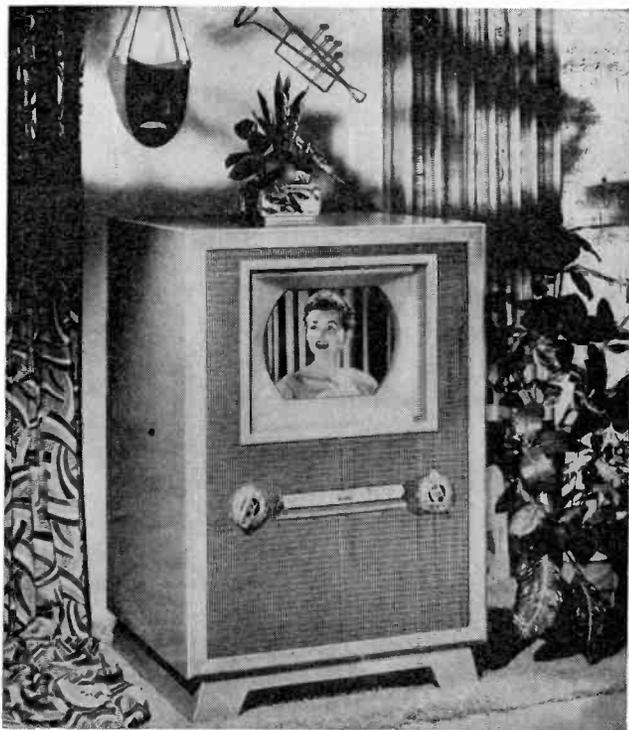
THREE-GUN COLOR PICTURE TUBES

The display device which is used to develop the color image is the most important single component in the entire color television system. Not only is it given the difficult task of converting the incoming video signal into a color image, but as an adjunct to this operation, it must reproduce the image in colors which are as close to the original as the present state of the art permits. Either one of these operations, by itself, represents a major undertaking. When the two are combined, the obstacles to be overcome are often monumental.

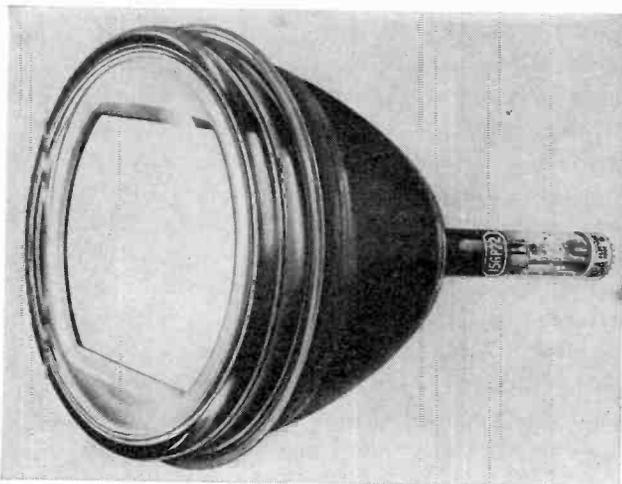
In view of the requirements which a color picture tube must satisfy, it is not surprising to find that this component is the weakest link in the color television system. Much work has been done on color-tube development and much work is being done. Modern tubes, when properly set up and adjusted, will provide satisfactory images possessing good color rendition. There is, however, considerable room for improvement, and undoubtedly many changes will be made in the years ahead.

A number of different approaches to color television picture tubes have been theoretically and experimentally attempted, and those who wish to read the full fascinating story should read the October 1951 issue of the Proceedings of the Institute of Radio Engineers. In the present text we are concerned solely with the color picture tubes which the service technician will encounter in the field. To date only the three-gun color tube has been employed in commercial receivers made available to the public. Initially this tube appeared with a 15-in. screen (see Fig. 1). While the basic operation of all these tubes is the same, there are significant differences between the construction of the 19- and 21-in. tubes on the one hand and the 15-in. tube on the other. Some of these variations will be brought out in the ensuing discussion, although the major emphasis will be on the more recent, larger tubes.

Perhaps the best way to understand the operation of the three-gun color tube is by comparing it with the present monochrome or black-



(A)



(B)

FIG. 1. (A) A color television receiver using a picture tube with a 15-in. screen. (Arvin Industries, Inc.) (B) A 15-in. three-gun color picture tube. This is the RCA 15GP22.

and-white picture tube. The latter appears in Fig. 2 and is seen to consist of an electron gun at one end of the tube and a fluorescent screen at the other. The gun structure develops a narrow high-velocity electron beam which produces light when it impinges on the fluorescent screen. If the beam remains stationary at one point, only a small pin-

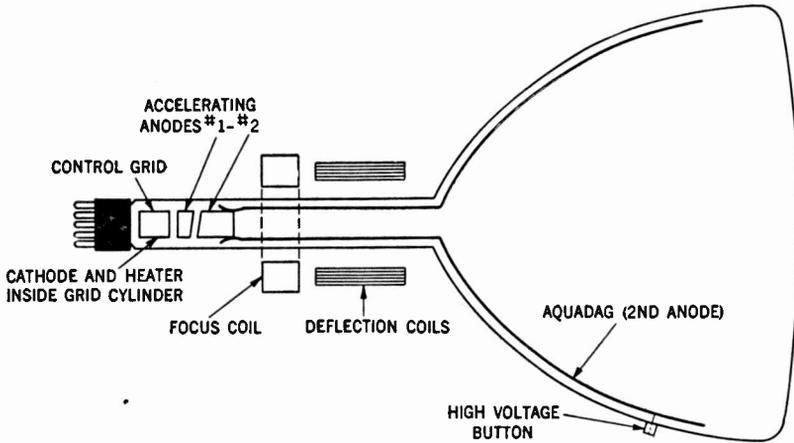


FIG. 2. Internal structure of a black-and-white picture tube employing magnetic deflection and focusing.

point circle of light is obtained. If, as is more characteristic of its normal behavior, the beam sweeps back and forth across the screen, then a series of lines will be seen. Finally, if we vary the intensity of the electron beam from instant to instant, a corresponding variation in light intensity will occur and a picture will be produced.

In the three-gun color tube, we employ the same basic process, but the end result must be a color image when a color broadcast is being received and a black-and-white image when a monochrome signal is received. The question is, "What changes were made in the basic structure of a black-and-white picture tube to accomplish this job?"

PHOSPHOR-DOT SCREEN

A partial answer appears when we examine the phosphor screen of the three-gun color tube. This is shown in Fig. 3 and is seen to consist of a number of phosphor dots which have been deposited on the viewing screen. The actual number of such dots, for a 19-in. screen, is somewhere in the neighborhood of 1,026,000. This represents a three-

fold advance over the 351,000 dots contained on the screen of the first three-gun tubes shown in 1950.

Placement of the dots on the screen is not done haphazardly; rather it follows a very definite pattern in which triangular groups of three (a trio) are deposited in interlaced positions. Each trio consists of a

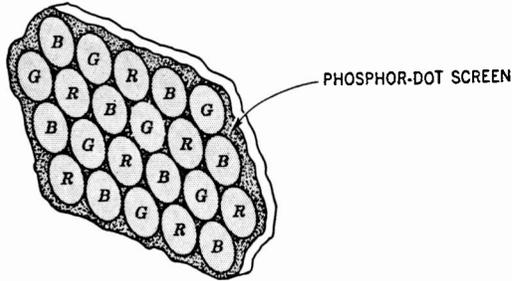


FIG. 3. Pattern of phosphor dots on color screen.

blue-emitting dot, a green-emitting dot, and a red-emitting dot. This is the color of the light which each dot emits when activated by an electron beam. Dots do not overlap, a fact which the reader can determine for himself by examining the face of a color tube with a low-power microscope or a magnifying lens.

With 1,026,000 dots on the screen, there are 342,000 trios. Each dot has a diameter of approximately 0.01 in. If all three dots in a group are bombarded at the same time, the combined red, green, and blue light output will form one resultant color in the observer's eyes.

For example, if the blue gun output is made low, while most of the light reaching the observer comes from the red and green dots, what he will see is some shade of yellow. Increasing the intensity of the red gun (by lowering its control-grid bias) will shift the color toward the red, possibly from yellow to orange. On the other hand, increasing the number of electrons emitted by the green gun will draw the color in its direction. By varying the intensity of the beams striking the various dots, we can cover the entire color range which these three primary colors are capable of producing. White is included, too, since it is obtained when the proper amounts of red, green, and blue light are emitted.

The dots on the screens of the earliest tubes were deposited by a silk-screen printing process. This is a form of stenciling operation where a silk screen, its mesh forming a pattern of holes, is placed over a flat glass plate and the appropriate phosphors are forced through onto the

glass. After the dots had all been applied to the screen, a thin layer of aluminum was placed over them to increase light output and prevent ion-spot blemish.

Subsequent improvement was obtained through the use of photographic techniques similar to photoengraving. One of the three color phosphors is laid down first and is allowed to cover the entire screen. After drying, a photosensitive material is coated over the phosphor. This is then exposed to light through an aperture mask which serves as a "negative."

When exposing the screen, a pin point of light is accurately positioned in the same location that the beam from the electron gun will occupy when the faceplate is assembled into the finished tube. Light passes through the holes in the aperture or shadow mask and exposes the photosensitive material in a pattern of dots all over the screen. The exposed areas, upon development, bind the phosphor beneath them to the faceplate. All the remaining phosphor lying beneath the unexposed photosensitive layer is washed away. This leaves one complete dot array containing the phosphor material necessary to produce one of the primary colors.

By depositing over the entire screen again a second and then a third colored phosphor and by using the same aperture mask but with the light source moved to coincide with the future position of the electron beam from the second and third guns, the second and third arrays of dots appropriately spaced between the dots of the first array are progressively obtained.

ELECTRON-GUN STRUCTURE

At the other end of the color picture tube there are three parallel, closely spaced electron guns which produce three independent electron beams (see Fig. 4). Each gun consists of a heater, a control grid (grid 1), an accelerating (or screen) grid (grid 2), a focusing electrode (grid 3), and a converging electrode (grid 4). The heaters of all three guns are in parallel and require only two external connections to the tube base. Each control grid has its own base pin, and the same is true of each screen electrode. The focusing electrodes (grid 3) of all the guns are electronically connected in order that one over-all voltage variation may bring all three beams to a focus at the phosphor-dot screen.*

* Grid 3 of the blue gun has two special built-in pole pieces. These function in conjunction with an external magnet to assist in converging the beams at the center of the screen. This will be discussed later in more detail.

The final electrode in the gun structure is grid 4, the converging grid. This is a small-diameter cylinder which is internally connected to (and operated at the same high potential as) the Aquadag coating (25,000 volts). A pair of pole pieces is mounted above each number 4 grid. External coils on the neck of the tube induce magnetic fields in

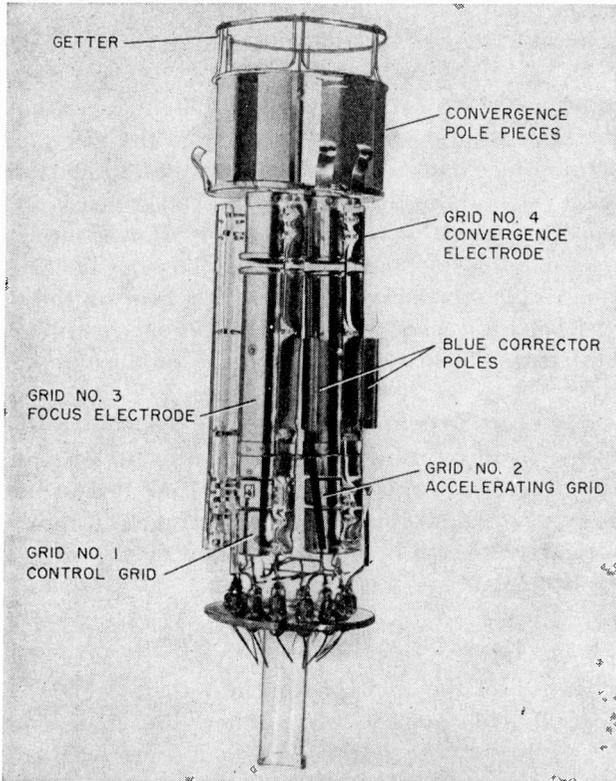


FIG. 4. Electron-gun structure of 19-in. color picture tubes.

each set of pole pieces, as shown in Fig. 5. These fields force the three beams to converge, or come together, so that each beam will strike the proper phosphor dot in the same group at any one instant of time. That is, one beam will strike the red dot, a second beam will strike the green dot, and the third beam will hit the blue dot, all three in the same group. The dots of each trio are bunched together closely enough so that the light they produce will be seen as a single resultant color. In the absence of this converging action, it would be possible for the beams

to hit phosphor dots at sufficiently separated points so that an observer would see three individual points of light. Under these conditions, mixing of colors to obtain different hues would not be possible.

It is interesting to note that in the 15-in. color tubes the number 4

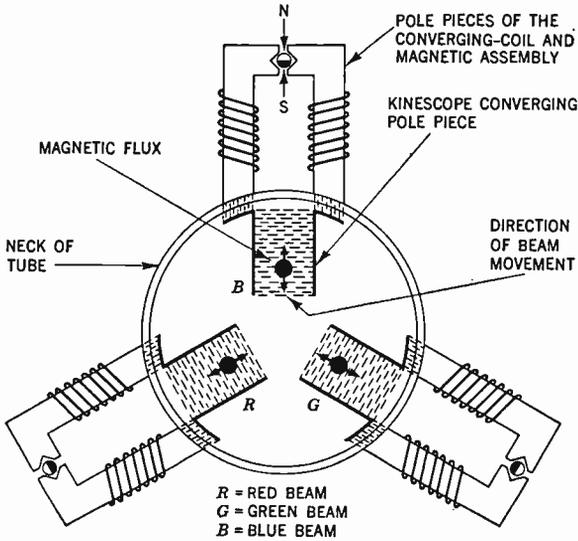


FIG. 5. Convergence coil and magnet assembly position with respect to the picture-tube converging pole pieces.

grids opened into a common cup, which, together with the Aquadag neck coating, formed a common electrostatic convergence lens. In the 19- and 21-in. tubes, the converging action is accomplished magnetically.

THE SHADOW MASK

Proper beam convergence is an important aspect of three-gun picture-tube operation. To further ensure that each beam strikes only one type of phosphor dot a mask (known as a *shadow mask*) is inserted between the electron guns and the phosphor-dot screen (see Figs. 6, 7, and 8). The mask is positioned in front of and parallel to the screen. It contains circular holes, equal in number to the dot trios. Each hole is so aligned with respect to its group that any one of the approaching beams can "see" and therefore strike only one phosphor dot (see Fig. 9). The remaining two dots of the trio are hidden by the mask. That is,

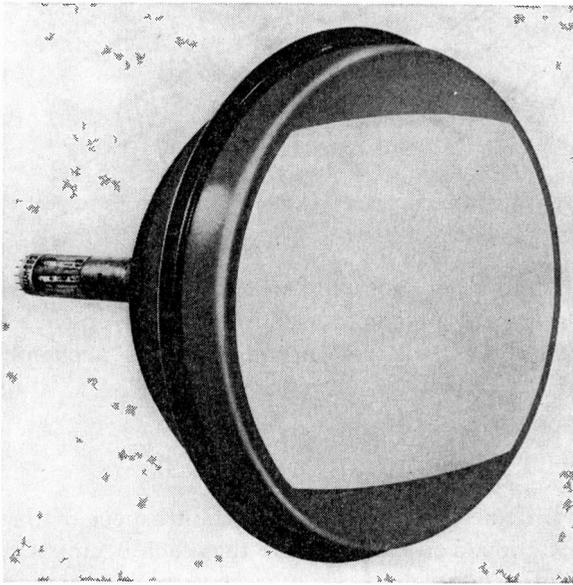
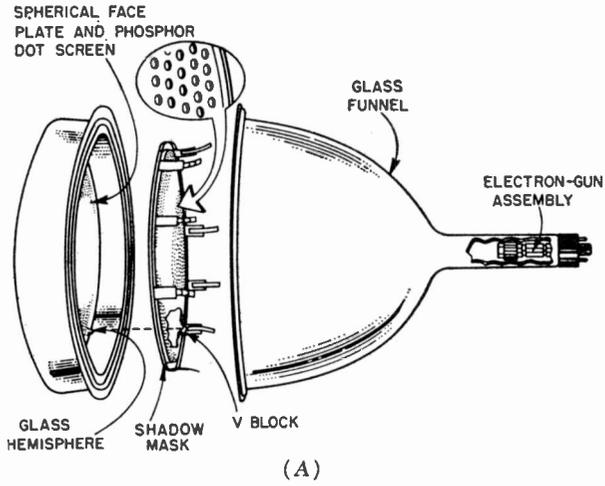


FIG. 6. (A) "Exploded" view of the CBS 19-in. color picture tube showing its internal construction. (B) Actual view of 19-in. color picture tube. The tube designation is 19VP22. (CBS-Hytron.)

the two other dots are in the "shadow" of the mask opening; hence the name "shadow mask."

What is true for one beam is true for the other two beams. Each of these can also "see" one phosphor dot. In this way, we are able to

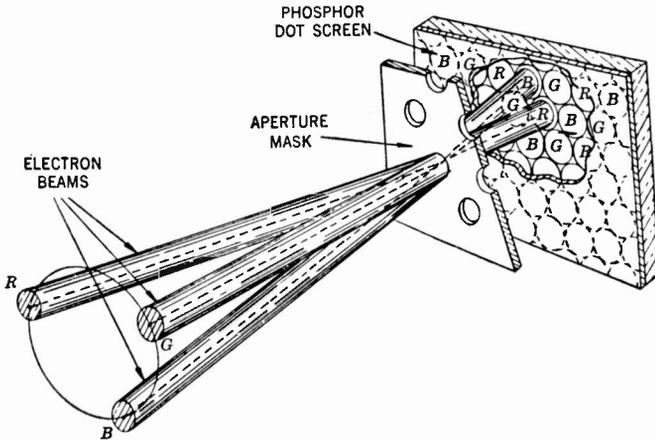


FIG. 7. Diagrammatic illustration of the mask and screen showing the convergence of the three beams at a single hole in the aperture mask. Note that the converged beams pass through the hole and strike their respective color dots.

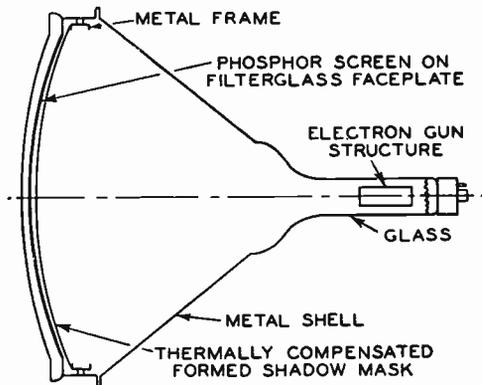


FIG. 8. A drawing of the RCA 12-in. color kinescope. Outwardly it looks very much like the 19-in. tube shown in Fig. 6B.

minimize color contamination, which would occur when a beam either hit the wrong dot or overlapped several dots at the same time.

It will be appreciated from the foregoing description that the shadow-mask aperture must be precisely aligned with the phosphor dots on the

screen. As a matter of fact, achievement of this precise alignment and adapting it to mass production was one of the major obstacles that had to be overcome before the tube could be successfully manufactured.

RCA, the originator of the shadow-mask tube, resolved this problem in the earlier 15-in. tubes by using special pins which fit into collets

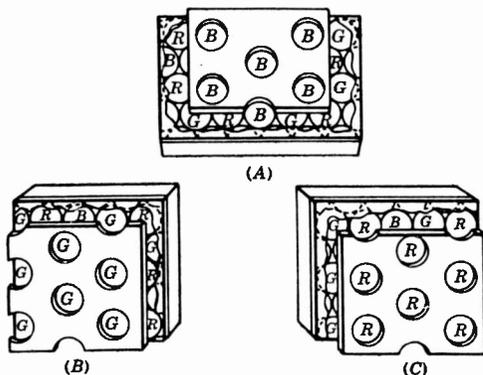


FIG. 9. Views of mask-and-screen assembly as seen from the deflection points of the three beams. (A) View from the deflection point of blue beam source. (B) View from deflection point of green beam source. (C) View from deflection point of red beam source.

equipped with locking nuts located 120° apart around the edge of the shadow-mask frame. The heads of the pins carry a hemisphere which is located off the axis of the pin. The heads mate with three V grooves in the glass phosphor-dot plate. Therefore, there is one and only one position in which the glass plate can fit upon these pins. When the mask and the screen have been fitted together, they are placed in the cathode-ray tube and held in proper relationship to each other.

In the initial color tubes which RCA produced the phosphor-dot screen was not the front-end faceplate of the tube. Instead, a separate clear-glass plate was used for this purpose and the picture developed on the phosphor-dot screen was viewed through the front faceplate (see Fig. 10). The phosphor-dot plate employed a neutral filter glass to improve the contrast ratio of the image. The thin layer of aluminum deposited over the dots was also helpful in this respect.

In its recent large-screen tubes, RCA has dispensed with the flat phosphor plate and followed the CBS method of depositing the phosphor dots directly on the faceplate just as we do in black-and-white tubes. CBS used this method from the first. Then, for the mask, CBS

used a metal plate which was suitably etched with holes and curved to form a portion of a spherical surface. The mask assembly was mounted on raised points of glass molded around the edge of the faceplate, beyond the picture area. Its position was secured by six spring clips that were mounted over the inside lip of the metal flange which was

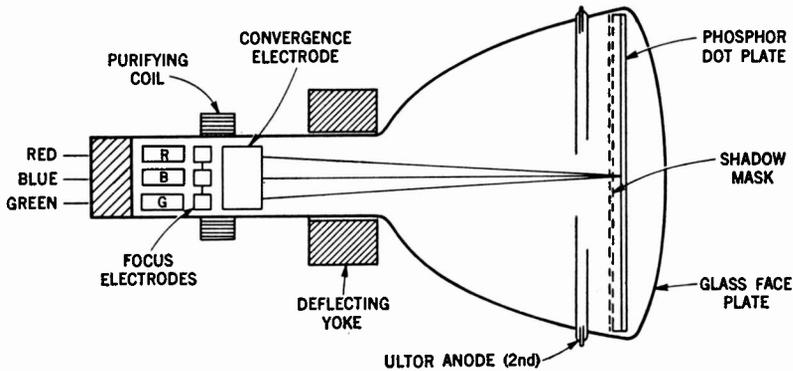


FIG. 10. In the RCA 15-in. color picture tube (15GP22) the phosphor dots were deposited on a separate glass plate. The picture was then viewed through the front faceplate of the tube.

used to attach the faceplate panel to the funnel. These clips provided a small amount of forward thrust to keep the mask pressing down on the mounting hemispheres.

During tube operation the shadow mask receives about 85 per cent of the beam current. This heats the mask, and the temperature range may vary by as much as 50°C when the tube is operated in a typical receiver. The changes in mask diameter caused by the temperature variations may lead to loss of registration between the mask and the phosphor-dot screen unless special precautions are taken. There are several solutions to this problem, and it may be of interest to observe the one used by RCA in their 21-in. tube.*

The path of the three electron beams from the point where they are deflected to the phosphor screen is shown in Fig. 11A. When the mask is cold and the beams are converged, no trouble is encountered in reaching the various color dots on the screen. However, as the mask heats up, it expands to form a sphere of larger diameter. This is represented by the outer concentric circle. Note that now the beams are not always able to reach the phosphor dots, resulting in the loss of color or color purity or both at points off to the side of the screen.

* From information furnished by the Radio Corporation of America.

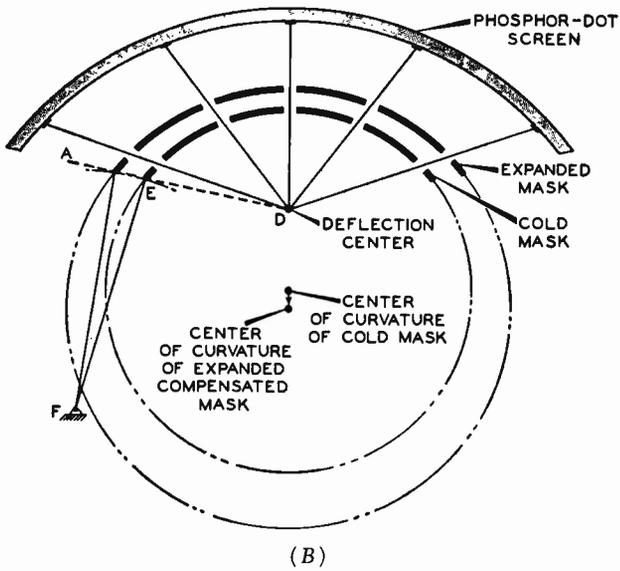
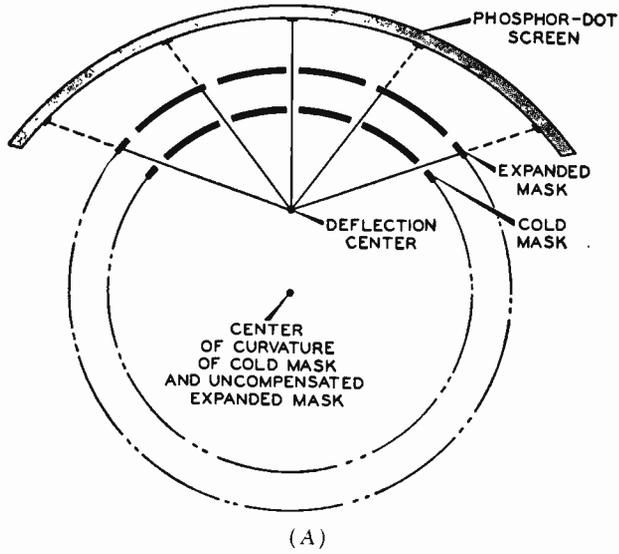


FIG. 11. (A) Beam and phosphor-dot misalignment resulting from expansion of uncompensated mask. (B) Proper beam and phosphor-dot alignment obtainable with expansion of compensated mask.

It was found, however, that if the heated mask is moved down somewhat from its position shown in Fig. 11A, then the beams could again reach the proper phosphor dots. This is indicated in Fig. 11B. The object is to make the edge of the mask move along line *AED* as it heats up, and this is accomplished by fastening the edge of the mask to a fixed support (here labeled *F*) by a series of hinges. Since the mask movement is only on the order of a few thousandths of an inch, hinges need be only about $\frac{1}{4}$ in.

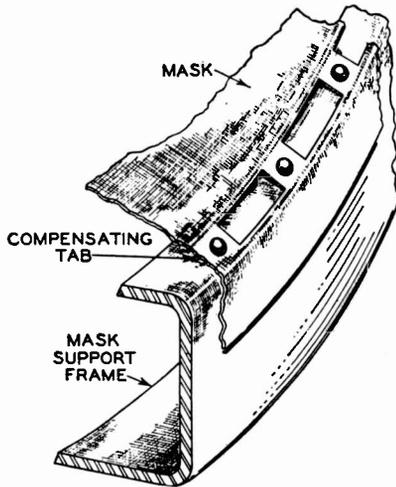


FIG. 12. Detail of 21-in. tube mask showing thermal compensation tabs. (RCA.)

A partial view of the manner in which the mask is held down to its support frame is shown in Fig. 12. The compensating hinges are welded to a light steel frame which serves as a fixed support.

Let us review tube operation briefly. Each electron gun develops its own beam which is focused by grid 3 for sharp focus at the phosphor-dot screen. A convergence electrode follows the focus electrode and serves to converge the three beams at the shadow mask. The three beams must go through the same hole at the same time in order to ensure that they will strike only the phosphor dots of a single trio or group.

The converging force is obtained by magnetic fields formed between each of three pairs of pole pieces mounted above the number 4 grids. These magnetic fields are provided by electromagnetic coils mounted on the neck of the tube. In the 15-in. color picture tubes electrostatic

convergence is employed, and here the voltage applied to grid 4 is varied.

It is important that the difference between beam convergence and beam focus should be carefully noted. The term *beam focus* pertains to the phosphor-dot screen; beam convergence is related to the shadow mask and the task of getting all three of the beams through the same hole at the same time.

The critical nature of beam alignment has led to protective measures designed to counteract the effect of stray magnetic fields which might

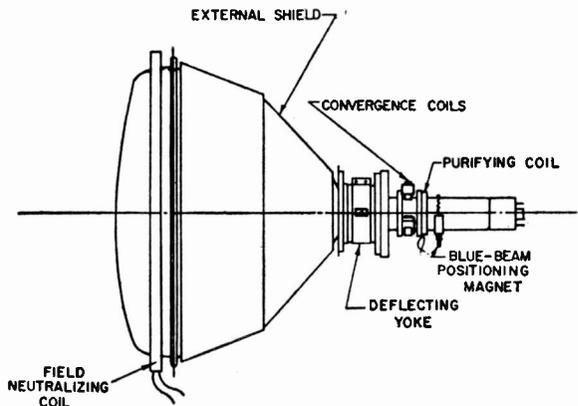


FIG. 13. A field neutralizing coil and mu-metal external shield serve to protect the 19-in. color picture tube from the distorting effects of stray magnetic fields.

cut across the tube. The 15- and 19-in. tubes are completely glass-constructed, and for these units mu-metal shields are placed over the bulb portion. In addition, a field neutralizing coil is positioned around the periphery of the faceplate as shown in Fig. 13. The coils ordinarily used possess about 150 turns of wire and carry a current of about 100 ma.

In the 21-in. RCA tube the mu-metal shield and the rim-coil are dispensed with and a device called a *color equalizer* is used instead. This unit consists of two bands of soft iron which serve as pole pieces, operating together with eight permanent magnets. Each magnet may be individually adjusted by rotation in its fixed position on the bands, affording control of the magnetic field in its immediate vicinity. This provides eight different adjustment points around the face of the picture tube, in case this many are needed.

STATIC AND DYNAMIC CONVERGENCE

In the foregoing introductory discussion, beam convergence has been covered in a general manner. Actually, as we shall see now, there are two types of convergence, static convergence and dynamic convergence. In static convergence we adjust the positions of the beams using either fixed DC voltages or fixed magnetic fields, depending on the type of gun. As a further aid in this action, the electron guns in the 19- and 21-in. tubes are tilted inward slightly. And if the adjustments

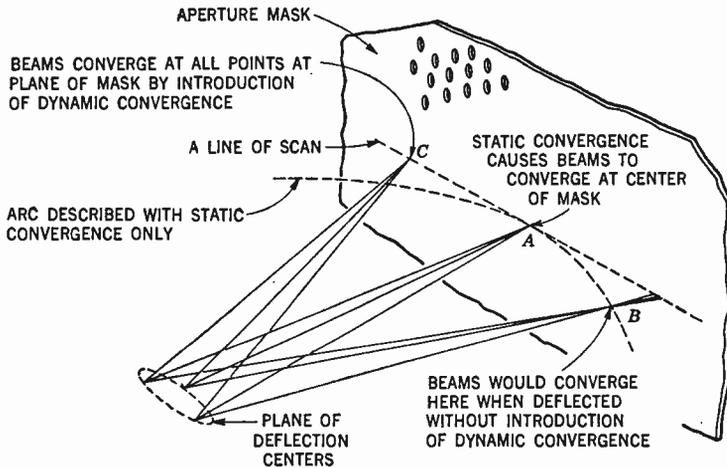


FIG. 14. Dynamic convergence voltages are required because the screen and shadow mask are not perfectly spherical. (The departure from the correct curvature is exaggerated in the illustration to make it more evident.)

are made carefully, the beams will converge properly over the central area of the screen.

However, to maintain this converged condition of the beams as they swing away from the center, it is also necessary to vary their relative angles slightly. This process of changing the beam angle in step with the scanning is referred to as dynamic convergence. It is required because the distance traveled by the beams increases as they swing away from the center of the screen. This occurs because the curvature of the screen is not perfectly spherical and beams which are converged at the screen center will tend to converge in front of the shadow mask at points away from the center (see Fig. 14).

A moment's reflection will reveal that the extent of convergence

changes the farther the beams are from the center of the screen. Furthermore, there is a direct relationship between the convergence needed at any one point and the instantaneous horizontal and vertical deflection voltage values. Thus it is possible to obtain whatever correction voltages are needed from the vertical and horizontal deflection systems. These additional voltages are known as dynamic-convergence voltages in distinction to the DC or static-convergence adjustment which is made over the central area. Where magnetic convergence means are employed, the static adjustment is made with a permanent magnet. The dynamic convergence is then achieved by introducing varying magnetic fields via converging coils mounted on the neck of the picture tube.



FIG. 15. Parabolic wave shapes are required for dynamic-convergence correction.

The basic form of the correcting current is parabolic, as shown in Fig. 15. When the three beams are in the center of the screen, the correction current is zero. On either side of center, however, the current varies, and the combined effect of the correction and static fields is to keep the beams properly converged at every point of the screen.

In the 15-in. color picture tubes electrostatic convergence is employed, and here convergence is achieved by means of DC and AC voltages.

PICTURE-TUBE VOLTAGES

The tricolor picture tube requires a regulated high-voltage supply of 25,000 volts in order to develop sufficient screen brightness. This is because the shadow mask intercepts 85 per cent of the electrons in the scanning beams. With only 15 per cent of the emitted electrons striking the phosphor screen, light output would be low if we employed the 12,000 volts commonly found on black-and-white tubes. By developing 25,000 volts, the screen brightness is increased to an acceptable level.

The convergence electrode (grid 4) of the 19- and 21-in. tubes is connected internally to the Aquadag coating and thereby receives the

full 25,000 volts. In the 15-in. tube a variable potential of 8,500 to 10,500 volts is needed by this element. This is usually obtained from a bleeder network shunted across the high-voltage supply.

The potential applied to the focus electrode depends upon the gun structure. In the 15-in. tube 3,000 volts was needed. In the 19-in. tube the value rose to about 7,500 volts. However, in the 21-in. tube a reduction in gun length enabled the focus voltage requirement to be reduced to 4,600 volts.

The screen of each gun is operated from 140 to 300 volts above the cathode, and the setting of the screen control in conjunction with the bias control enables the technician to match the light output from each of the three guns over a complete range of signal voltages so that a monochrome picture may be properly reproduced for all shades of gray.

EXTERNAL PICTURE-TUBE COMPONENTS

We come now to the components which are mounted on the neck of the three-gun tricolor picture tube (see Fig. 16). The first item that we recognize is the deflection yoke. This is, to a considerable extent, similar to the deflection yokes used with black-and-white tubes. However, its design is more complex; three beams must be deflected instead of one, and it is of the utmost importance that a symmetrical and uniform magnetic field be maintained throughout the deflection area. Also, the deflection power required is about twice that of present black-and-white TV sets (for the same size screen) and special insulation must be employed in the yoke structure to prevent arcing.

A second component found on the neck of the color picture tube is the purity coil or magnet. This device adjusts the axis of each electron beam so that it approaches each hole in the shadow mask at the right angle to strike the appropriate color phosphor dot. In other words, the purity magnet provides for the proper alignment of the three beams with respect to the phosphor-dot plate and the shadow mask. When this component is properly set, a uniform color field will be obtained for each gun. For example, with only the red gun in operation a uniform red raster should be observed. Any departure from pure red at any point on the screen indicates that the beam is striking phosphor dots other than red. Similarly, when only the green gun is in operation, a uniform green raster should be obtained, and when only the blue gun is active, a blue field should be visible.

The larger screen color tubes which we are most concerned with uti-

lize magnetic convergence and toward that end employ three sets of convergence coils, each positioned directly over the pole pieces which are internally associated with each number 4 grid. The magnetic fields set up by the coils are coupled through the glass neck of the tube to the internal pole pieces, which serve to shape and confine the fields so as

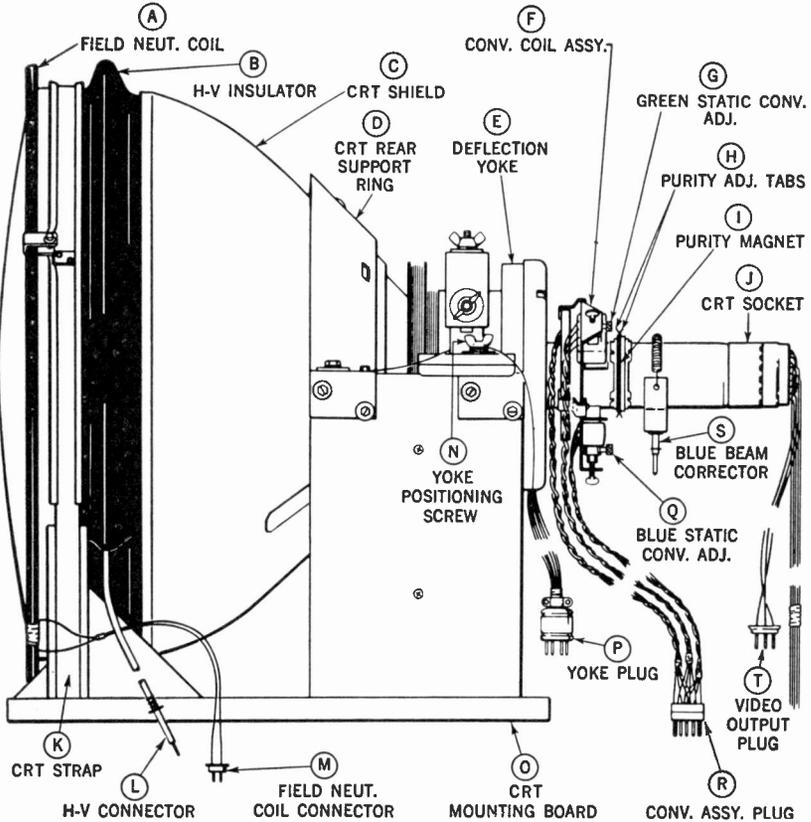


FIG. 16. A 19-in. picture-tube assembly and external components. (CBS.)

to affect only the particular electron beam to which the individual pole pieces correspond. For example, the change in convergence angle of the red beam is a function only of the current through the external coil which couples to the internal set of pole pieces adjacent to the red beams. Similarly, the current through the green and blue external magnets affects only the green and blue beams, respectively.

Each external coil possesses two separate windings to provide for

horizontal and vertical dynamic-convergence correction. For the static-convergence adjustment, each coil has associated with it a small permanent magnet whose position can be varied.

A diagram of the individual dynamic-convergence controls is shown in Fig. 5. The heavy dots represent the individual electron beams as they pass through the gun on their way to the screen. The arrows at the beams indicate their direction of movement. Note that the red and green beams are confined to paths that make an angle of 30° on either side of a perpendicular axis. The blue beam, on the other hand, can only move vertically, up or down.

Now it could readily happen that while the color dots of the green or red beams fall within the same trio, that of the blue beam does not. This means that while we can always cause the red and green (or color dots) to converge, it may not be possible to have the blue beam meet the other two. Still another adjustment is required, that of being able to move the blue beam from side to side, and this is also found on the neck of the tube (see item S, Fig. 16). Convergence of the three beams at the center of the screen is thus always possible.

Note that no ion traps are used in this tube, principally because the color screen is aluminized. The layer of aluminum presents a barrier to any oncoming ions and prevents them from reaching and damaging the screen. Electrons, having only $1/1,800$ of the mass of an ion, encounter little difficulty in passing through this aluminum layer.

COLOR-TUBE ADJUSTMENTS

From the foregoing discussion of the color picture tube and its operation, it is quite evident that the setup procedure for this tube will differ considerably from its monochrome prototype. First, there is the all-important requirement that each beam strike only one type of color dot at every point on the screen. The name given to this is purity, and a purity test or check is the first adjustment to be made. After this has been successfully carried out, the tube is adjusted for proper convergence, that is, that all three beams pass through the same hole in the shadow mask at the same time. Finally, the screen-grid and cathode-bias voltages are adjusted until a satisfactory black-and-white image is produced when a black-and-white program is being received. This latter goal is actually more difficult to achieve than a good color image, because the development of white, black, and intermediate shades of gray requires, first, excellent color purity over the entire screen and, second, perfect convergence, not only in the center where

it is fairly simple to achieve, but at the sides as well, where unbalance is much more prevalent.

Color-purity Adjustment. The manner in which the purity adjustment is made on a large-screen color tube is as follows:*

1. The first step is to inject the signal from a dot-pattern generator. The unit must be capable of developing white dots on the screen. This, the reader will recognize, is in direct contrast to a black-and-white set, where black dots are required.

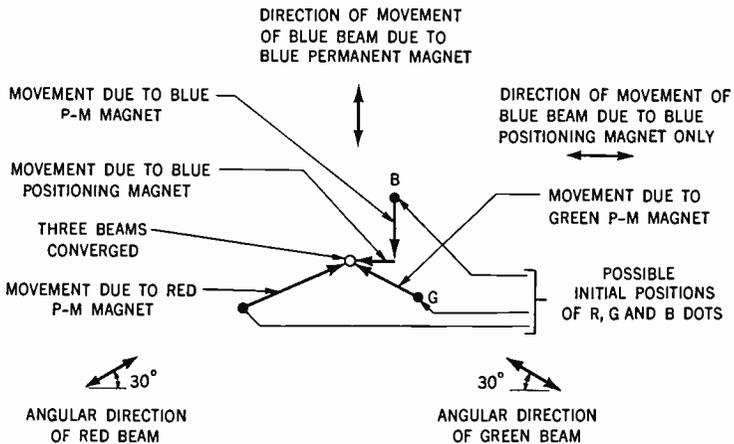


FIG. 17. The movement of the three color dots due to adjustment of the static controls and the blue-positioning magnet.

2. With the dot pattern on the receiver screen, adjust the three beam-positioning magnets † and the blue beam-corrector magnet for the best possible convergence of the three beams over the central portion of the screen (see Fig. 17). This means that each trio of color dots should be brought together to form as white a dot as possible with no color fringing around its edges.

3. Remove all signal to the receiver.

4. Cut off the blue and green guns by grounding their grids into the ground holes of a special receptacle provided for that purpose. This permits the red gun to function by itself.

5. Adjust the Brightness control for normal raster brightness.

6. Loosen the four screws on the yoke bracket. Position the yoke

* This particular section is taken from the service manual of a Motorola color receiver.

† Labeled Static Convergence Adjustments in Fig. 16.

as far back as the mounting will allow. Keep the yoke concentric with the neck of the picture tube.

7. Locate the purity device, consisting of two magnetic rings mounted on the tube neck. Position the tabs of one ring opposite the tabs of the other ring so that a minimum-strength magnetic field is produced. If the correct tabs are opposite each other, rotating both rings of the device together should have no effect on the raster. If the position of the tabs is incorrect, rotate the rings to place the opposite tabs adjacent to each other.

8. Check the purity at the center of the screen by visual inspection. A uniform red field indicates good purity. If it is not satisfactory,

- a. Separate the tabs by a small amount to produce a weak magnetic field.
- b. Rotate the purity device to obtain better red purity in the central area of the screen.
- c. Continue the process of adjusting the field strength and direction of the magnetic field until the purity in the central screen area has been extended as far out as possible.

NOTE: Use as weak a magnetic field as possible. Avoid shadow due to beam cutoff by the tube neck.

9. Move the yoke forward and backward along the neck of the tube to obtain best edge purity.

10. Readjust the purity device for maximum purity. If satisfactory edge purity cannot be obtained, it may indicate a defective yoke or picture tube.

After a pure red field has been produced on the screen, the grid of the red gun is grounded and the grid of the green gun is returned to its normal position. A pure green field should now appear on the screen. Next, reground the grid of the green gun and remove the ground on the blue gun. The visible field should now be uniformly blue. Any color impurities in any of these fields may be reduced by a compromise adjustment of the purity magnet, but the red field should be favored in all adjustments because it is the most critical so far as color reproduction is concerned.

Dynamic-convergence adjustments. The next step after the color-purity and static-convergence adjustments have been made are the dynamic-convergence adjustments. These are concerned with the proper convergence of the three electron beams at points away from the center. For these adjustments two sets of vertical and horizontal controls are available: vertical amplitude and tilt (phase) and horizontal amplitude and phase. While there are several ways of carrying

out this convergence procedure, the one given below is general in nature and indicative of what is being attempted and how it can be carried out. (The amplitude and phase controls regulate currents through each set of convergence coils mounted on the neck of the picture tube. The actual dynamic-convergence circuitry will be studied in Chap. 8.)

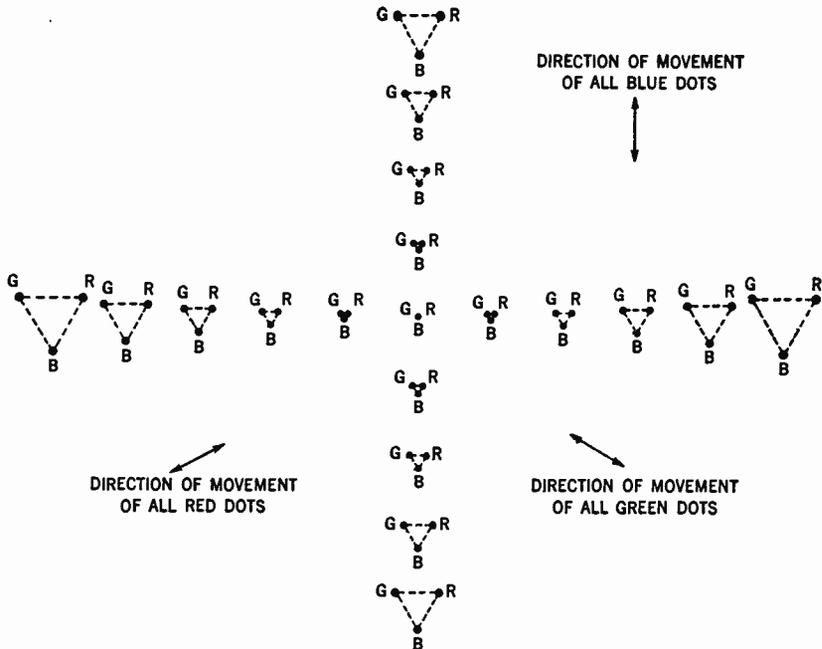


FIG. 18. A dot pattern which is converged only at the center of the screen. The misconvergence elsewhere has been exaggerated for illustrative purposes.

At the outset, turn all dynamic amplitude controls to minimum (fully counterclockwise). Turn the vertical tilt controls also to minimum. With a color-dot generator feeding its signal to the receiver, what you will see on the screen is the pattern shown in Fig. 18. (The entire screen will be covered with dots, but in the ensuing alignment, attention is centered on the central row and central column shown; all the other dots have been eliminated for the sake of simplicity.) Note from Fig. 18 that while the trio in the center of the screen is perfectly converged, the extent of misconvergence increases the farther we get from the center.

Before we continue, it should be borne in mind that all the dots of the same color can be moved an equal amount in the same direction by the permanent magnet associated with that particular gun. Hence, if all the red dots, for example, had been shifted a small distance from their fellow green and blue dots, we could adjust the permanent magnet to obtain perfect convergence.

The problem, however, is much more complicated than that. If we stop and examine the column of tricolor dots running vertically through the center of the screen, then we will see that lines drawn through the red and green dots will be curved (see Fig. 19). The red line will curve to the right and the green line will be curved to the left, both lines touching briefly in the center. As the green and red vertical amplitude controls are slowly rotated clockwise, the associated color dots will move in the directions indicated for them in Fig. 19. The middle portion which was converged at the center actually deconverges, while the dots above and below the center will tend to move so as to form a straight vertical line. And if the controls are turned far enough, the curvature of the lines may even be reversed. The object, however, is to find that setting where the red and green dots form straight vertical rows (Fig. 20A). Furthermore, the red and green dots should exist side by side at the same level.

Next, observe the position of the blue dot in each trio along this vertical column of dots. Adjust the red and green vertical tilt controls so that the red and green dots are spaced symmetrically from the blue dot in each trio. In other words, if you were to draw an imaginary line through the blue dots in the central vertical column, each pair of red and green dots would be equidistant from this line.

The next step is to adjust the blue vertical amplitude control. When this control is turned clockwise, the blue dots at the top and bottom of the screen move upward while those in the central area of the screen move downward (see Fig. 20B). The object is to form equilateral triangles with the green and red dots that are equal in size from top to bottom of the screen (see Fig. 20C).

The static convergence is now readjusted. The green, red, and blue dots in the central vertical row should converge simultaneously. A slight readjustment of the vertical controls will permit more accurate convergence because slight errors will be more readily seen.

The action of the horizontal controls is similar to that of the vertical, only now we are working with a row of dots that pass through the

center of the screen. The horizontal phasing controls are similar to the vertical tilt controls. The movement produced by the horizontal amplitude controls for red, green, and blue is shown in Fig. 21. Once equi-

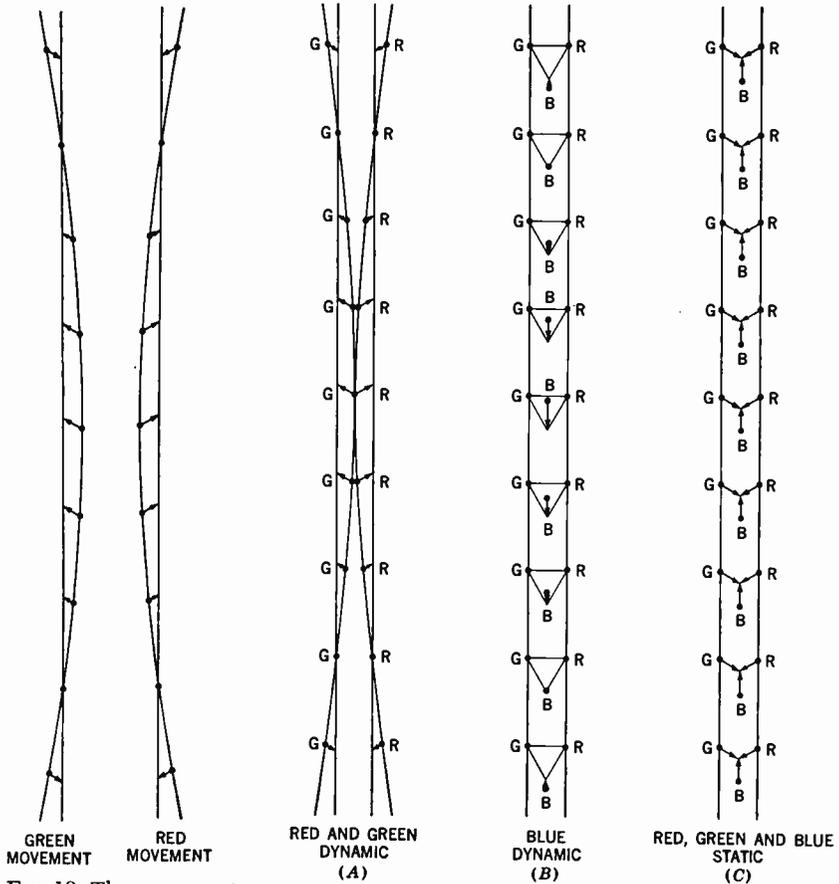


FIG. 19. The movements of the green and red dots when the green and red dynamic-convergence amplitude controls are rotated.

FIG. 20. The motion of the various dots due to dynamic and static convergence adjustments. See text for details.

lateral triangles are obtained, then the static convergence controls can be employed to bring all the dots in a trio together for perfect convergence. The following step-by-step procedure is indicative of the method to follow:

1. Peak each of the horizontal dynamic phase controls for maximum as follows:

- a. Turn all horizontal dynamic amplitude controls to maximum (fully clockwise).

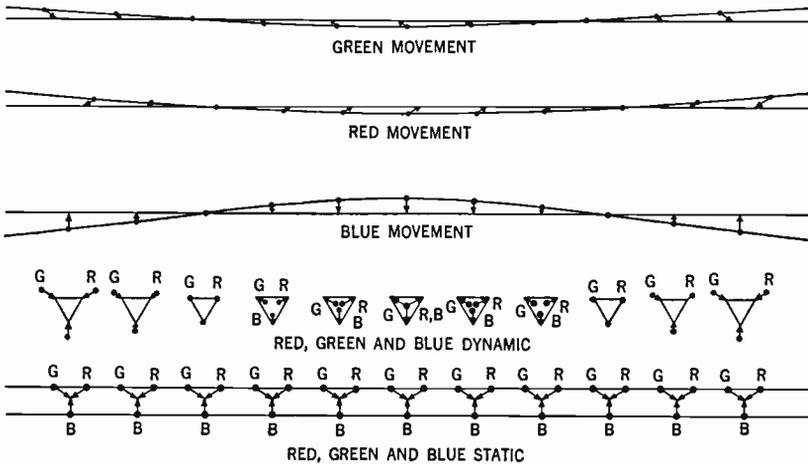


FIG. 21. Dot movements due to adjustment of horizontal convergence controls.

- b. Tune each coil so that its associated color dot receives maximum displacement near the center of the screen from the other two dots. This displacement must be in a direction to cause convergence at the screen edges.
 - c. Return all horizontal dynamic amplitude controls to minimum (fully counterclockwise).
2. Select a horizontal row of dots along the center of the screen.
 3. Adjust the blue dynamic amplitude and phase controls to obtain equal spacing of the blue dots from a horizontal reference line.
 4. Adjust the green horizontal dynamic amplitude and phase controls so as to obtain uniform and symmetrical displacement of the green dots away from the blue dots in all horizontal dot trios.
 5. Follow the procedure of step 4 for the red dots.
 6. Now use the static convergence magnets to converge all the dots simultaneously.

Finally, make any additional touch-up adjustments necessary to give best possible over-all convergence of all the dots. The beam-positioning magnets and the dynamic controls are used as indicated by a study of the dot pattern. It will generally not be necessary to reset purity when

the touch-up adjustments are made, since the adjustments should be small enough not to upset the purity.

BLACK-AND-WHITE ADJUSTMENTS

We come now to the final set of adjustments, namely, that of setting up the receiver for producing good black-and-white pictures. In essence what we do is to adjust the three gun potentials in the color tube until the three colors blend to form a black-and-white picture. The procedure is as follows:

1. Turn the channel selector to a channel transmitting a black-and-white picture.

2. Set Brightness and Contrast controls for a normal picture. Disregard color effects; this will be corrected by steps 3-7.

3. Turn all three screen-grid controls of the picture tube fully clockwise. (Maximum voltage is now being applied to these electrodes.)

4. Adjust the green, blue, and, if necessary, red screen-grid controls for highlight white on the brightest picture portions.

5. Turn Brightness control counterclockwise so that screen becomes less bright (gray). If a color begins to tint the screen as brightness is reduced, adjust the screen-grid control corresponding to this color until the bright portions of the screen are again white or gray.

6. Adjust the Brightness control for normal brightness on the screen. Reset the screen-grid controls so that a highlight white appears on the brightest portion of the picture.

7. Repeat steps 4, 5, and 6 until no color tinting occurs over the usable range of the Brightness control. Maximum brightness setting is not considered part of the usable range.

QUESTIONS

1. What basic requirements must a color picture tube satisfy? Contrast this with a monochrome picture tube.

2. Describe the type of screen employed in the three-gun color tube.

3. How are different colors developed on the picture tube screen? How are black-and-white pictures developed?

4. Contrast the gun structure of color and monochrome picture tubes.

5. What is meant by beam convergence? How does it differ from beam focus?

6. What is a shadow mask and what is its function?

7. Differentiate between static and dynamic convergence.

8. Indicate why dynamic convergence is required in addition to static convergence.

9. How are static and dynamic convergence achieved in a 15-in. tube? in 19- and 21-in. tubes?

10. What voltages are required by the various electrodes in a 21-in. color picture tube?
11. Indicate the external components which are mounted on the neck of a 19- or 21-in. picture tube. Briefly describe purpose of each.
12. What do we mean by color purity and how is it achieved in a color picture tube?
13. Outline a general procedure for obtaining color purity in a tube.
14. Do the same as in question 13 for dynamic convergence.
15. How do we go about adjusting the tube for a good black-and-white presentation? Assume color purity and convergence are OK.

CHAPTER 8

DEFLECTION AND CONVERGENCE CIRCUITS OF THREE-GUN COLOR RECEIVERS

DEFLECTION SYSTEMS

The deflection systems of a three-gun color television receiver possess a marked similarity to the deflection systems of monochrome receivers. The same type of deflection wave forms are required at the deflection yoke, and they are produced in more or less the same manner. Circuit variations that do exist stem primarily from the altered requirements

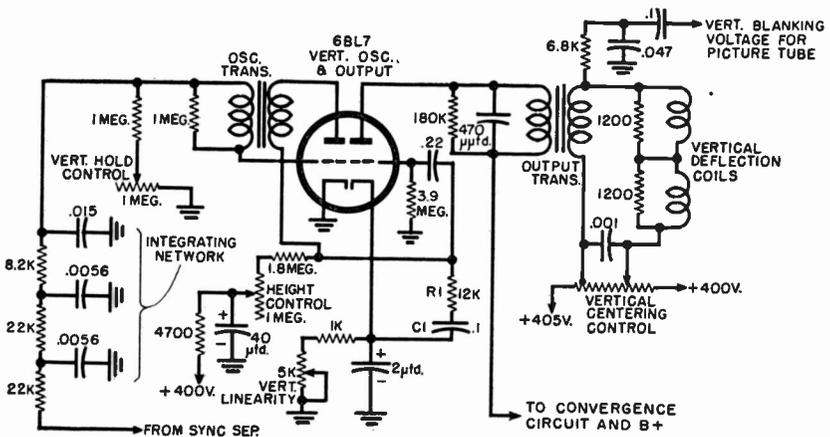


FIG. 1. The vertical sweep system employed in a color television receiver. Aside from the voltage made available for a vertical convergence network, the circuit is identical to the vertical stages found in many black-and-white television receivers.

of the high-voltage supply or because of the added precautions needed to maintain the three beams in close convergence over the entire area of the screen. Just what these differences are will become evident as we analyze, step by step, the deflection system of a color television receiver.

In the vertical section (Fig. 1) there is an integrating network, a

blocking oscillator, and an output amplifier. The incoming sync pulses, both horizontal and vertical, are applied to the integrator network, but because of the time constant involved only the vertical sync pulses develop a sizable voltage at the grid of the blocking oscillator.* The latter, in turn, uses these periodic pulses to synchronize its frequency to that of the received broadcast. A vertical hold control helps bring the oscillator frequency to a point where effective lock-in can be achieved.

The amplitude of the deflection wave (Fig. 2) developed by the

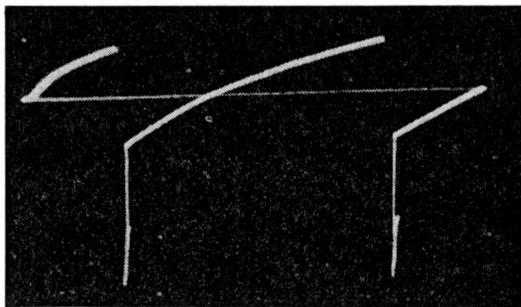


FIG. 2. Typical deflection voltage wave form at the grid of the vertical output amplifier.

oscillator is governed by the vertical size (height) control. The sawtooth shape of this wave is established by C_1 and R_1 . This signal is then applied to the grid of the vertical output amplifier and, beyond this, to the vertical deflection coils of the yoke.

The only significant departure from monochrome practice is the fact that the bottom end of the vertical output transformer connects to a vertical convergence circuit. This will be discussed in greater detail presently.

In the horizontal sweep system there is an AFC network, a stabilized horizontal multivibrator, and a power output amplifier (see Fig. 3A). These are then followed by the horizontal output transformer, the high-voltage system, and the boost B+ circuit, where additional B+ voltage is developed by utilizing the excess deflection energy. (The latter portion of the circuit is shown in Fig. 3B.)

For a more detailed analysis of the horizontal deflection system, let

* Those readers who wish to refresh their memory concerning the synchronizing and deflection circuits of television receivers are referred to Milton S. Kiver, *Television Simplified*, 5th ed., D. Van Nostrand Co., Inc., New York.

us start with the phase detector. Its purpose is to compare the frequency of the horizontal oscillator with that of the incoming horizontal sync pulses. If a variation exists, a proportionate DC voltage is developed which is fed back to the oscillator, altering its frequency accordingly. In brief, here is how the phase-detector AFC network functions. (This explanation is best followed by reference to Fig. 4.)

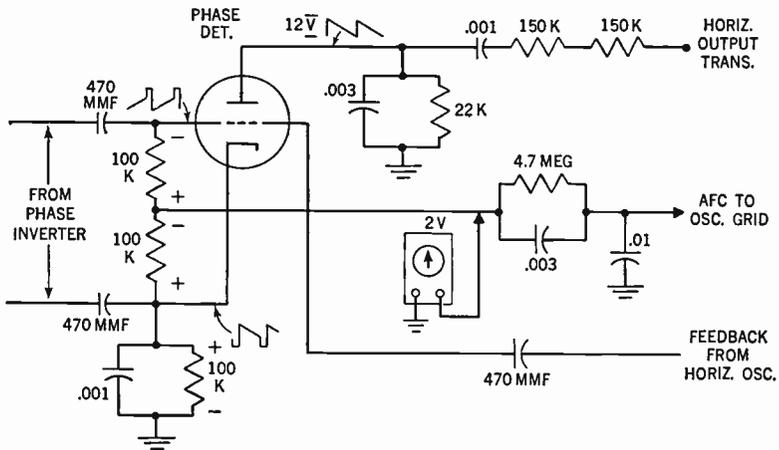


FIG. 4. Simplified diagram of the phase detector of Fig. 3A.

The second clipper tube feeds positive sync pulses into the phase-detector grid and negative sync pulses into the cathode. During sync-pulse time the phase-detector grid and cathode act as a diode section with the grid acting as the plate and drawing current. Grid-leak bias is produced across the grid resistors, with the top end of the resistors negative with respect to the chassis. A tap at the midpoint of the grid resistors connects any developed voltages to the grid of the horizontal oscillator.

A saw-tooth voltage is applied to the plate of the phase detector from the horizontal output transformer and capacitance-resistance network, causing current through the cathode resistor, the tube, and the coupling capacitor. A positive voltage is thus developed at the cathode, or top end, of the 100,000-ohm cathode resistor. Since the cathode resistor also ties to the grid-leak resistors, a cancellation of the voltages can result. In other words, the negative grid-leak bias cancels the positive cathode voltage resulting in a zero output to the horizontal oscillator when it is operating at the correct frequency.

Should the oscillator begin running faster or slower than the frequency of the sync pulse, the saw-tooth at the phase-detector plate will move ahead of or behind the sync signal at the grid. In one case the plate saw-tooth can be made ineffective by falling into the area cut off by the grid-leak bias, resulting in a negative output voltage due to the grid bias alone. The opposite action would be for the plate saw-tooth to occur during a time of tube conduction—in which case a positive voltage would develop across the cathode resistor greater than the grid voltage, and it will be fed to the horizontal oscillator grid. A DC voltage of either positive or negative polarity is thus supplied to the grid of the horizontal oscillator depending on its frequency, and this AFC voltage is always of such polarity as to correct for oscillator drift.

A positive or negative voltage fed to the horizontal oscillator grid will vary its frequency, because this is determined by the length of time required to discharge the oscillator grid capacitor from a negative value up to the firing point of the tube. The AFC voltage can retard or advance this firing point, resulting in frequency correction.

The horizontal oscillator is a frequency-stabilized cathode-coupled multivibrator. The presence of the resonant coil L43 and capacitor C130 tend to make the oscillator more immune to off-beat triggering by noise pulses and other circuit disturbances. This can be seen by comparing the wave forms present at the grid of the second oscillator triode grid with and without the stabilizing circuit. In the first case (Fig. 5B) there is no resonant circuit present. Note that the grid voltage approaches cutoff gradually, and near the end of its discharge cycle any slight disturbance will be capable of bringing the grid voltage above cutoff and triggering the circuit.

In the second instance (Fig. 5E), the resonant circuit is present. Note that the grid voltage now comes out of cutoff quite sharply, and it will require a considerably stronger noise pulse to trigger this tube prematurely than without the stabilizing circuit.

The final stage in the horizontal deflection system is a 6CD6 power output amplifier. The power requirements of the final stage in a color receiver are greater than for a comparable monochrome receiver because, first, three beams must be deflected instead of one and, second, a 25-kv accelerating voltage is required by the three-gun picture tube.

The horizontal output transformer contains two principal windings and a number of auxiliary windings. The two principal windings provide connections for the plate of the 6CD6, the high-voltage rectifiers, the deflection yoke, and the 6AU4 damper tube. The auxiliary windings provide positive and negative triggering pulses for the various AGC

and chrominance circuits and filament power for the high-voltage rectifiers. In the circuit of Fig. 3B three high-voltage rectifiers are employed to develop the 25-kv accelerating potential required by the three-gun picture tube. The circuit is apparently unlike any we have ever seen in monochrome receivers, although its operation is readily followed.

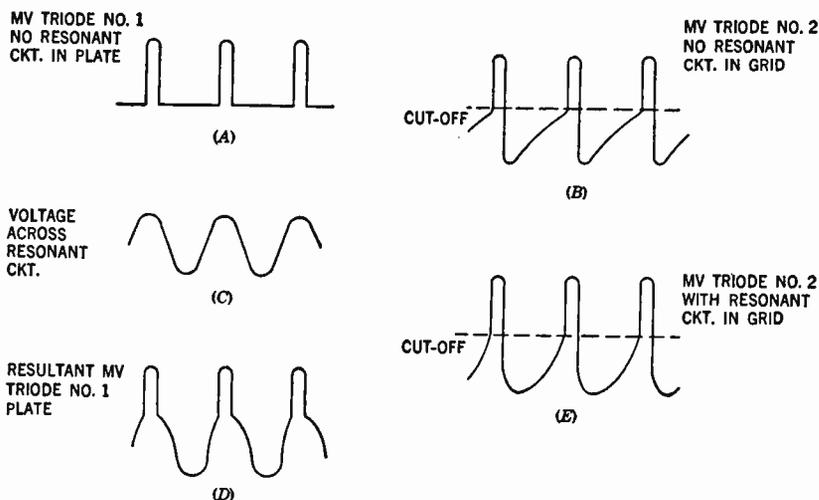


FIG. 5. The effect of a resonant stabilizing circuit on the operation of the multi-vibrator shown in Fig. 3A.

To understand how this section operates, let us examine a high-voltage doubler that was used for a time in monochrome sets. The circuit is shown in Fig. 6. In brief, it operates as follows: During the retrace interval, the voltage developed across the full primary of the output transformer rises sharply to, say, 14,000 volts. This causes V_1 to conduct, and C_1 charges to 14,000 volts (after the first few cycles) with the polarity as indicated. In the longer interval between retraces, C_1 and C_2 are seen to be essentially in parallel with each other through the primary winding of T_1 and R_3 , R_4 , and R_5 . Hence, C_2 also charges up to the full 14,000 volts.

At the next retrace interval, 14,000 volts once again appears across the transformer. If we pause at this moment and add up the voltages existing between point A and ground, we see that the transformer voltage and the voltage across C_2 are equal to 28,000 volts. This potential is applied to V_2 , causing this tube to conduct, and C_3 charges

to 28,000 volts with the polarity indicated. Losses in the circuit plus the current drain on the power supply by the picture tube usually reduce the output voltage to some value less than twice the peak applied pulse, say 25,000 volts.

It can be seen from the preceding discussion that the purpose of the resistive network of R_3 , R_4 , and R_5 is to help transfer the charge from C_1

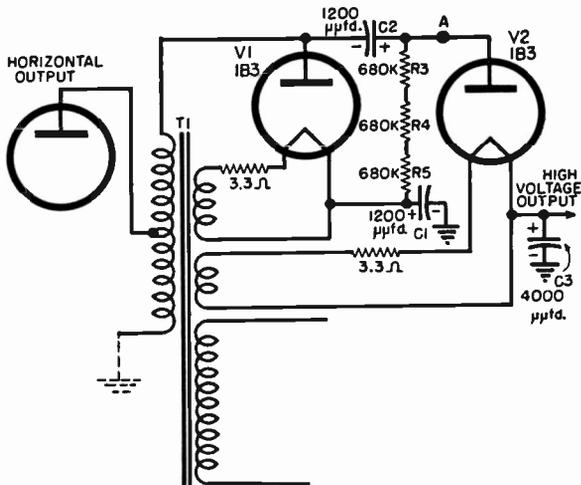


FIG. 6. A voltage-doubler circuit of the type once used in monochrome sets to obtain high voltage. The bottom end of the primary of T_1 appears grounded to the 15,750-cycle horizontal retrace pulses.

to C_2 and thereby assist in the voltage-doubling action. The same job can be accomplished more efficiently (with less high-voltage power loss) by substituting a diode for the resistive network. When this is done, the circuit of Fig. 6 becomes equivalent to that of Fig. 3B.

The accelerating potential required by the focus electrode is much less than the 25,000 volts of the Aquadag coating. Hence, it is possible to obtain the focus voltage from a prior point in the high-voltage rectifier system, A variable resistor is inserted between the first 3A2 and the diode coupler that follows it, and from this resistor the needed focus voltage is obtained.

Within the same high-voltage supply of Fig. 3B is a special gaseous regulator (see Fig. 7). The unit, labeled CR6, is a long, narrow cylinder filled with hydrogen gas. This regulator is very similar in operation to VR tubes where the current drain is dependent on the applied voltage.

As the voltage attempts to rise, the current drain increases and this restrains the voltage from rising. The CR6 may be considered a passive regulator in that the applied voltage must exceed a certain level before the unit will begin to function.

The purpose of this device is to maintain a constant load on the high-voltage power supply so that changes in picture content will not cause the high voltage to change, with corresponding variations in brightness,

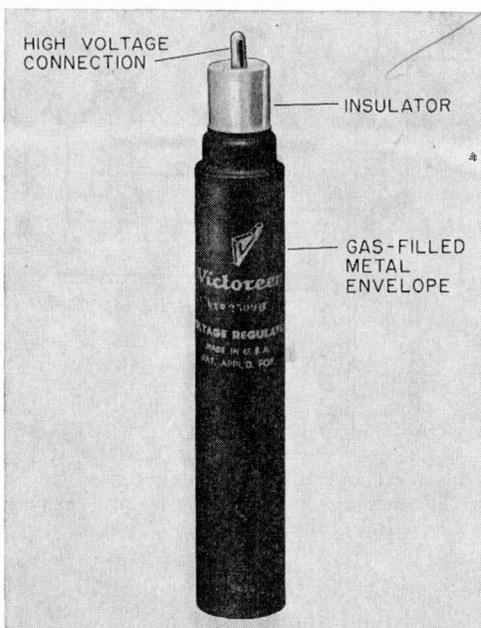


FIG. 7. A special gaseous high-voltage regulator. This is CR6 in Fig. 3B.

focus, and deflection (picture size). What the regulator tube does, in essence, is vary its internal resistance in a manner opposite to the current drawn by the picture tube. For example, when a bright element is being traced out on the screen, picture-tube current is high and the drain on the high-voltage power supply is increased. During this interval the drain of the regulator tube is reduced by a proportionate amount.

Conversely, when a darker portion of the picture is being traced out, the current requirements of the picture tube are reduced. This reduction would tend to cause the high voltage to rise were it not for the fact that now the regulator tube increases its current drain, thereby

maintaining a constant over-all load on the power supply. And this, in turn, keeps the high voltage constant.

An alternate method of regulating the high voltage is shown in Fig. 8. In place of the previous gaseous regulator we now find a special vacuum-tube triode. The plate of the tube connects to the 25,000-volt output of the high-voltage system, while the cathode is returned to a positive low-voltage point, in this instance 200 volts. The grid is then

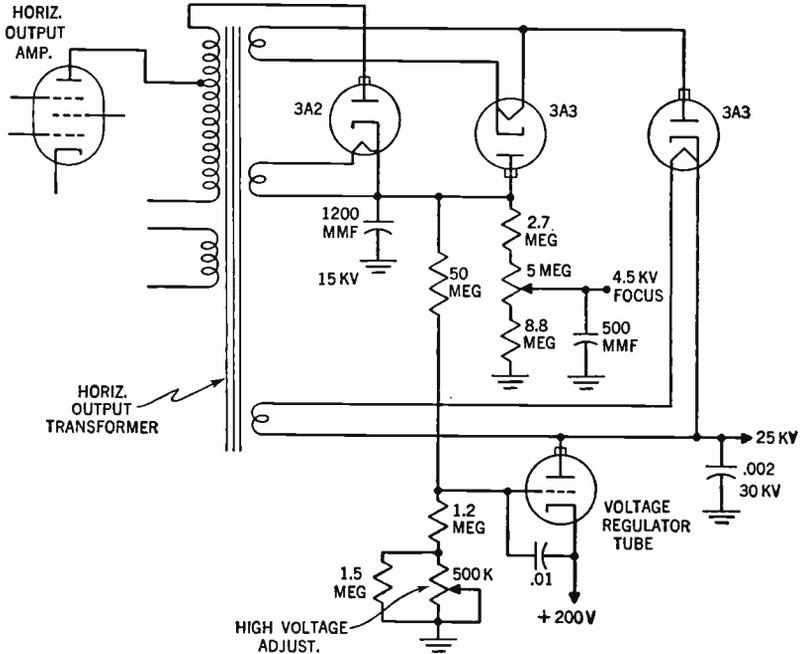


FIG. 8. A high-voltage circuit using a triode vacuum-tube regulator.

tapped into a bleeder network hung between the plate of the diode coupler and ground. The voltage obtained by the grid is of a correct value to bias it with respect to the cathode. While the grid voltage could have been obtained from many other points in the set, it was necessary to use the high-voltage system so that the grid of the regulator tube is "informed" of every change in voltage conditions in this network. It is on this very fact that the regulating action is obtained.

Operation of the circuit is as follows: If the high voltage rises, due perhaps to less current drain by the picture tube, then this increase will be transmitted in part to the grid of the regulator triode because of

the grid tap on the high-voltage bleeder string. A more positive grid means increased tube current, and if the circuit has been properly designed, this increased current will just take up the slack shed by the picture tube and bring the high voltage down to its correct level.

On the other hand, when the picture tube draws more current, the high voltage has a tendency to drop. This lowers the voltage across the bleeder, providing less positive voltage for the shunt regulator and thereby driving its grid more negative. This reduces the current drawn by the regulator and tends to counteract the increased picture-tube current. Again the high-voltage system "sees" a fairly constant load, and its voltage value remains stable.

The damper tube in the output circuit absorbs whatever excess energy is developed during the horizontal retrace interval and converts this into an equivalent amount of voltage which is then combined with the receiver B+ to provide a boost B+ voltage. In the circuit of Fig. 3B this boost B+ is employed only by the plate of the 6CD6 horizontal output amplifier and by the screen grids of the picture tube.

Electrical centering is usually employed with the three-gun color picture tube. For this purpose there are vertical and horizontal centering potentiometers, each with enough DC potential difference in them to achieve the picture-centering variation.

CONVERGENCE CIRCUITS

The one remaining section of a color television receiver still to be examined is the convergence circuit. Convergence, it will be recalled, is the action which causes the three electron beams to pass through the same hole in the aperture (shadow) mask at the same time. When the beams do this, they emerge from the mask at the correct angle to strike the dots of the proper color (see Fig. 9).

At the center of the screen, beam convergence is accomplished by physically tilting the electron guns inward as well as by external individually adjustable beam-bending magnets. The latter action can also be achieved by passing a direct current through each of the convergence coils mounted on the neck of the tube.

Static convergence is the adjustment of beam convergence at the center of the screen. Dynamic convergence is concerned with maintaining the beams in proper convergence at points away from the center. This added difficulty arises, as we have seen, from the fact that the shadow-mask surface is not completely spherical and therefore does not follow the curve necessary to keep the beams converged at all

points. To correct this condition, we must introduce an additional voltage which will change the convergence point of the beams as they sweep over the face of the screen, both from side to side and up and down. At the center of the screen no additional convergence voltage is

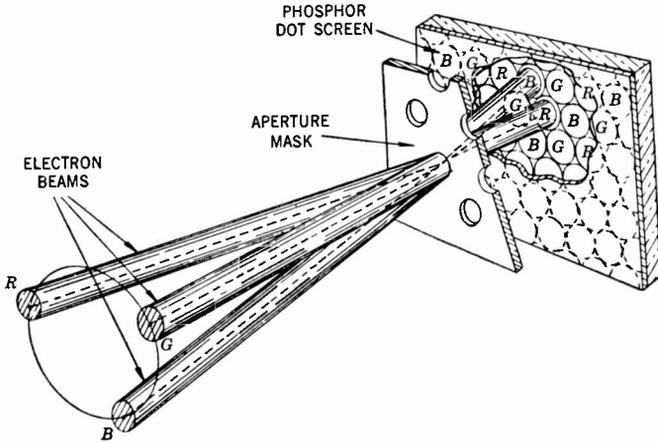


FIG. 9. Diagrammatic illustration of the mask and screen, showing the convergence of the three beams at a single hole in the aperture mask. Note that the converged beams pass through the hole and strike their respective color dots.

needed. The shape or form of the voltage best suited to achieve this variation is a parabolic wave (see Fig. 10).

The convergence of the three beams at the center of the screen is



FIG. 10. A parabolic wave is best suited to provide the proper beam convergence.

shown in Fig. 11. As the beams are moved toward the edges of the screen and the point of convergence is moved in toward the guns (because of the greater length of travel), it will be found that two of the beams move above the horizontal scanning line while the third dot (blue) drops below the horizontal scan line. It can be seen from Fig. 11 that at the right- and left-hand edges, the separation between the three color dots is considerable.

What occurs horizontally also takes place vertically. The effect now, however, is somewhat different. The red dots veer off to the right with

increasing distance from the center line while the green dots move off to the left. The blue dots remain in the center of the screen, but their spacing from each other changes.

The dynamic-convergence system consists of three separate coils

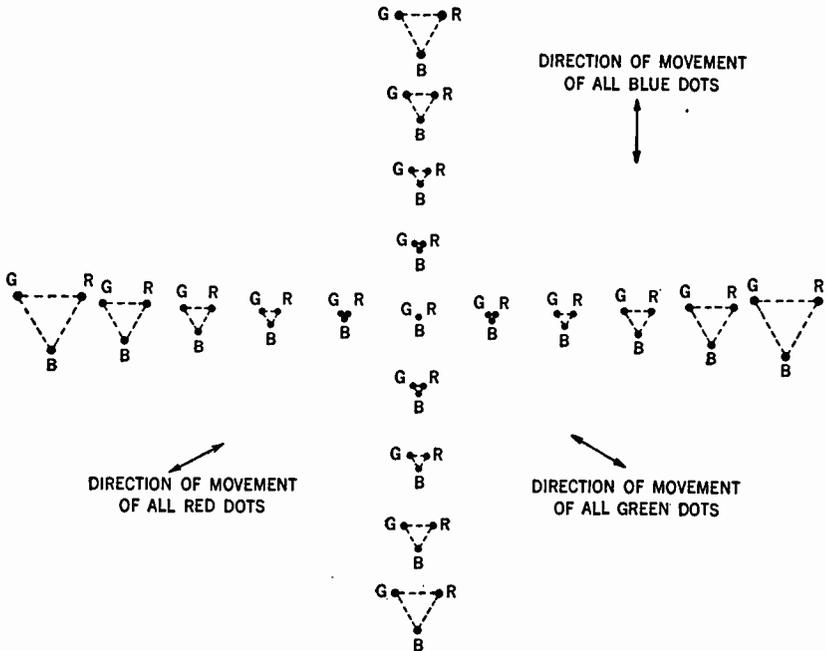


FIG. 11. A dot pattern which is converged only at the center of the screen. The mis-convergence elsewhere has been exaggerated for illustrative purposes.

mounted on the neck of the picture tube. Each coil is positioned over a pair of pole pieces which is part of the structure of each electron gun. The internal pole pieces shape and confine the fields so as to affect only the particular electron beam to which the individual pole piece corresponds. Each beam will be moved at right angles to the magnetic field produced by the coils. Furthermore, since the guns are spaced at intervals of 120° from each other, the red and green beams will be shifted at an angle while the blue beam will move straight up and down.

Each of the foregoing coils is supplied with vertical and horizontal parabolic currents, and it is the amplitude and phase of these currents which govern the convergence of the three beams at every point on the

screen. In the following paragraphs several suitable dynamic-convergence circuits will be examined.

The dynamic-convergence network for a 19-in. three-gun color tube is shown in Fig. 12. Signal voltages for this circuit are obtained from two points: the plate circuit of the vertical output amplifier and a separate winding on the horizontal output transformer.

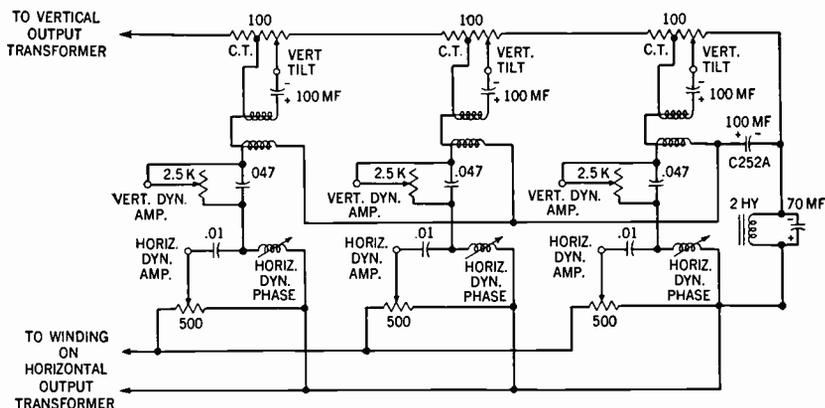


FIG. 12. The dynamic-convergence network for a 19-in. three-gun color tube.

Let us start with the horizontal section of this circuit first. A simplified diagram of the convergence network is shown in Fig. 13A, and if we consider the operation solely in terms of the horizontal line frequency, then the diagram can be further simplified to the form shown in Fig. 13B. A pulse having an over-all amplitude of 65 volts is made available at the horizontal-output transformer winding. The portion of the pulse which the rest of the network receives is governed by the arm setting of the horizontal dynamic amplitude control. Whatever value of pulse the control picks off is then used to shock-excite a series-resonant circuit formed by the 0.01- μf capacitor and the "Horizontal Dynamic Phase" coil. The circuit is tuned to 15,750 cycles, and the strong circulating currents develop fairly large sine-wave voltages across each of the resonant components (see Fig. 13C). This voltage, in turn, is forwarded to the dynamic-convergence coils on the picture tube neck and, through the resulting magnetic field, influences the electron beams which the guns develop. So far as the 15,750-cycle voltages are concerned, the 0.05- μf capacitor, the 70- μf capacitor, and the 100- μf capacitor all present low impedances between the horizontal phase coil and the convergence coil.

The horizontal dynamic amplitude control determines how much voltage reaches the convergence coil and, in consequence, how powerful a magnetic field is developed. The phase of the 15,750-cycle sine wave depends upon the adjustment of the phase coil. Changing the

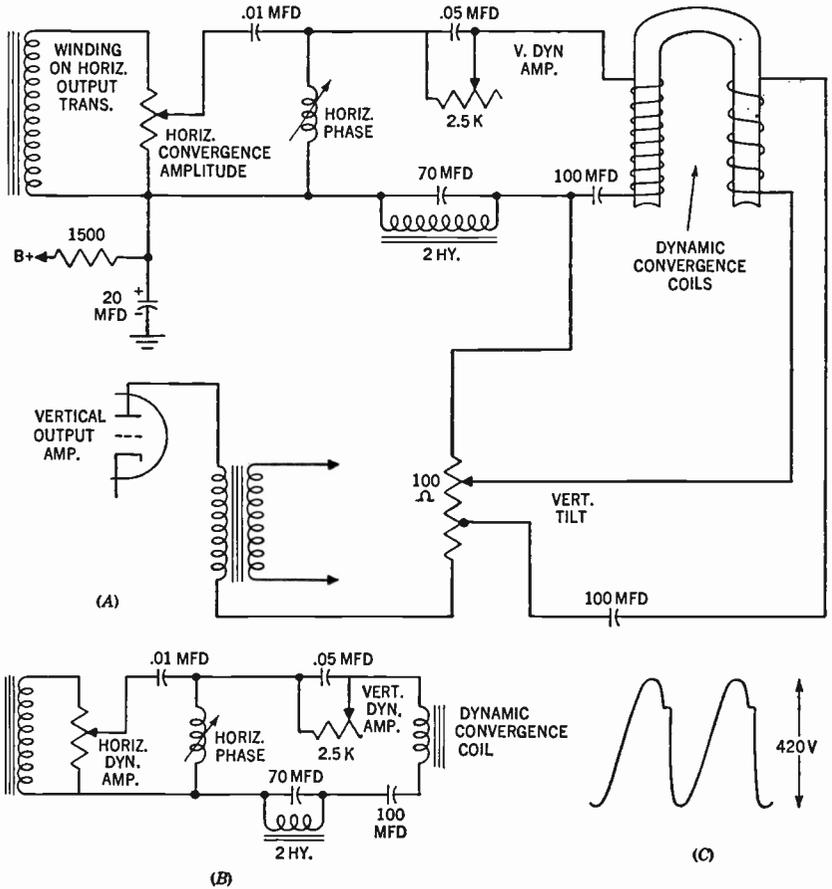


FIG. 13. (A) A simplified diagram of the convergence circuit of Fig. 12. (B) Further simplification of the circuit of Fig. 12 when only the horizontal frequencies are considered. (C) The sine wave which is developed across the horizontal dynamic phase coil when the amplitude control is at maximum.

frequency of the circuit by rotating the phase-coil slug will vary the phase of the voltage applied to the convergence coil. This, in turn, will change the deflection angle of the electron beam and thereby alter its point of convergence with the other two beams as they move from left

to right across the screen. Thus it is possible to change the beam convergence at the sides of the screen, permitting us to counteract the normal misconvergence of the beams.

Each beam has a similar convergence circuit and responds in a similar way.

One further point concerning this circuit should be made. The series-resonant network develops a sine wave instead of a parabolic wave. However, only the bottom portion of the wave is used in the converging action, and this is close enough to a parabola in shape to do an effective job.

Let us consider now the vertical portion of the dynamic-convergence network (see Fig. 13A). We note that the bottom end of the vertical output transformer reaches B+ through the vertical tilt potentiometer (100 ohms), through a 2-henry choke and a 70- μ f capacitor (in parallel), and finally through a 1,500-ohm resistor. The plate current (from the vertical output amplifier) develops a voltage across the 2-henry choke, and the subsequent current between the choke and its parallel capacitor produces a parabolic voltage across the combination. What happens here is that the saw-tooth plate current is converted by the capacitor (principally) into a parabolic wave, and this voltage is applied across the convergence coil. The path from the choke and the 70- μ f capacitor to the convergence coil consists of a 100- μ f capacitor, the horizontal dynamic phase coil, and the parallel combination of a 0.05- μ f capacitor and a 2,500-ohm potentiometer. At the vertical sweep frequency of 60 cycles, the horizontal dynamic phase coil and the 100- μ f capacitor offer negligible opposition. The vertical current, however, finds that the opposition of the 0.05- μ f capacitor is high, and so the current is driven through the 2,500-ohm potentiometer. The latter, then, rightfully becomes the vertical dynamic amplitude control.

Some method of varying the phase of the vertical dynamic-convergence voltage is still required, and this is achieved through the presence of another winding on each convergence coil. This is the so-called tilt coil, the word "tilt" referring to the effect which the tilt voltage has on the vertical parabolic wave (see Fig. 14).

The method of developing the required tilt (or phase) voltage is quite simple. The saw-tooth plate current of the vertical output amplifier passes through a 100-ohm potentiometer. The control contains a center tap, and the movable arm may be moved above or below this tap. When the arm position is above the tap, the saw-tooth voltage fed to the tilt coil possesses one polarity; when the arm is below the tap, the polarity is reversed. No saw-tooth voltage is fed to the tilt coil when

the tap and center arm coincide. In other words, a saw-tooth of variable amplitude and with positive or negative polarity may be added to the electron beam. The net effect of this is to add the saw-tooth to the vertical dynamic parabola to shape them as required for best convergence in the vertical plane.

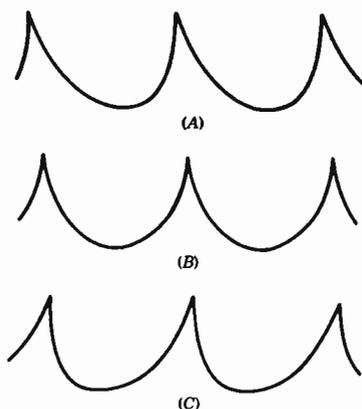


FIG. 14. The effect of a saw-tooth voltage on the vertical parabolic wave. In (A) the parabola is tilted to the left. In (C) it is tilted to the right. In (B) there is no tilt, because the amplitude of the saw-tooth voltage has been reduced to zero.

Another dynamic-convergence circuit, this time for a 21-in. color picture tube, is shown in Fig. 15. The object here, as before, is to develop parabolic currents at line and field frequencies. These are passed through suitable convergence coils mounted over the appropriate internal pole pieces of the picture-tube gun structure.

The converging-coil and magnet assembly is indicated in Fig. 16. There is a dual coil winding with a horseshoe-shaped ferrite core for each gun. Each ferrite core has two sections and a permanent magnet. The windings conduct the dynamic-convergence currents; the permanent magnet, in the form of a small-diameter cylinder, fits into a slot in the arch of the ferrite core assembly. This cylinder is permanently magnetized, with one half-section north and the other half-section south. When the north-south poles of the cylinder are rotated so that the lines of force are parallel to the core sections, no resultant field is set up between them. When the magnet is rotated from this position, a resultant magnetic field is set up across the core sections and, in consequence, across the internal pole pieces of the gun.

The three fixed magnets, together with the special blue positioning

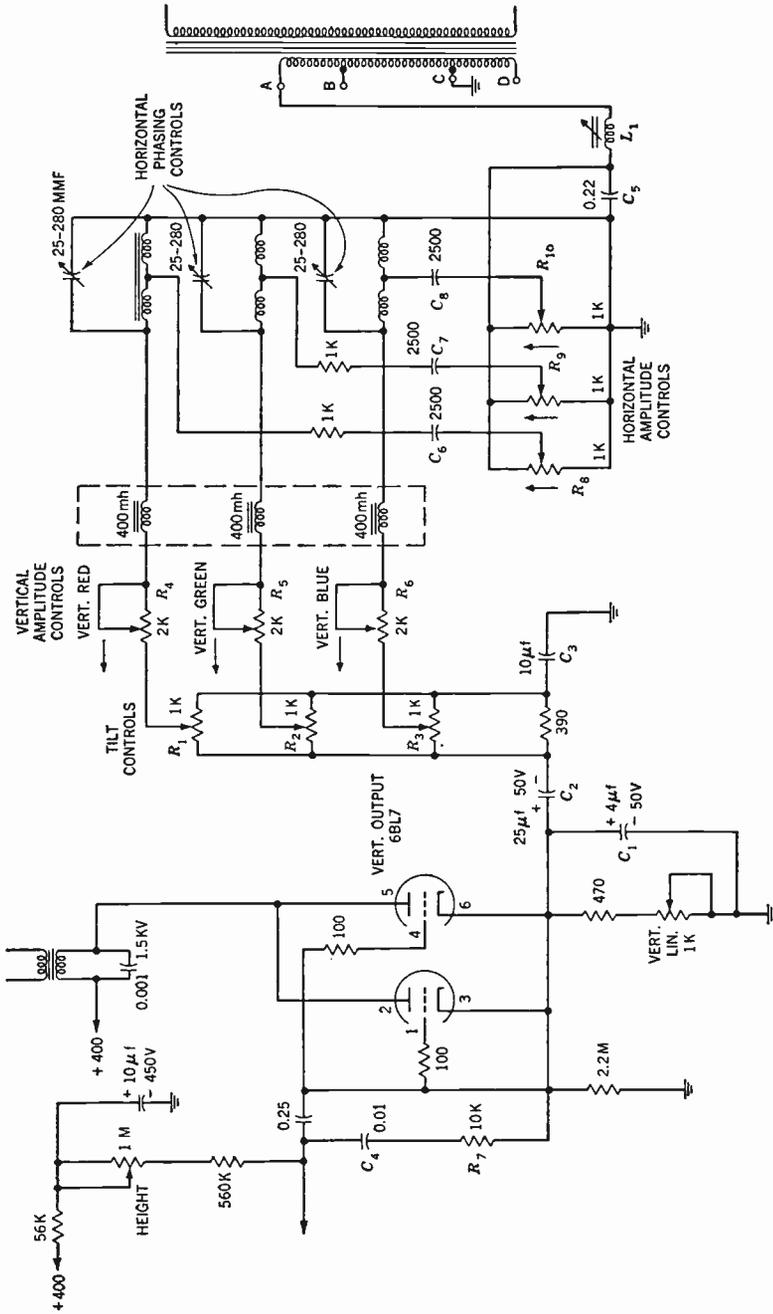


FIG. 15. A dynamic-convergence circuit for the 21-in. color picture tube.

magnet, help align the three beams at the center of the screen. These, then, constitute the static-convergence adjustments.

Operation of the dynamic-convergence network is as follows: A vertical frequency parabola voltage obtained from the cathode of the vertical output tube is fed via the blocking capacitor C_2 and the three vertical tilt controls R_1 , R_2 , and R_3 to capacitor C_3 . The voltage across

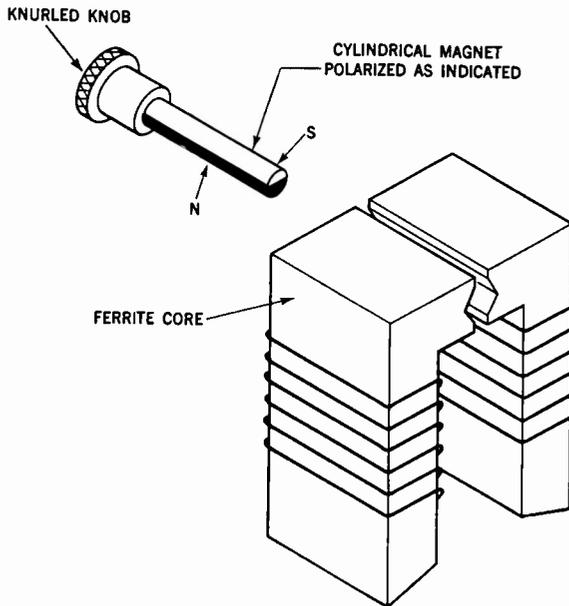


FIG. 16. The converging-coil and magnet assembly employed in the circuit of Fig. 15.

C_3 is a parabola delayed and tilted differently from the voltage across C_1 . The tilt controls permit the voltage applied to each coil to have an adjustable tilt. The current in each coil is limited by the vertical amplitude controls (R_4 , R_5 , and R_6). Resistors R_4 , R_5 , and R_6 constitute the chief impedance offered to the voltage; hence the current will remain parabolic in shape. The vertical tilt adjustment shifts the minimum point of the parabola toward the start or finish of each cycle.

In order to permit the vertical output tube to operate normally, the saw-tooth charging capacitor C_4 and peaking resistor R_7 are not returned to ground, as is usually done, but are returned to the cathode of the output triodes.

The horizontal-frequency component of voltage originates as a nega-

tive pulse of about 200 volts at point A in the horizontal output transformer. The current through L_1 is saw-tooth in shape, and it produces a horizontal-frequency parabola across C_5 , which is supplied to three horizontal amplitude controls, R_8 , R_9 , and R_{10} . An adjustable amount of this voltage is then applied to the 800-turn winding of the convergence coil through a 2,500- μf capacitor. This capacitor, the 800-turn coil, its companion 1,200-turn coil, the 400-mh choke, and the associated horizontal phasing capacitors form a series-parallel resonant circuit (see Fig. 17). By adjusting the trimmer capacitors, the phase of the current may be shifted as desired.

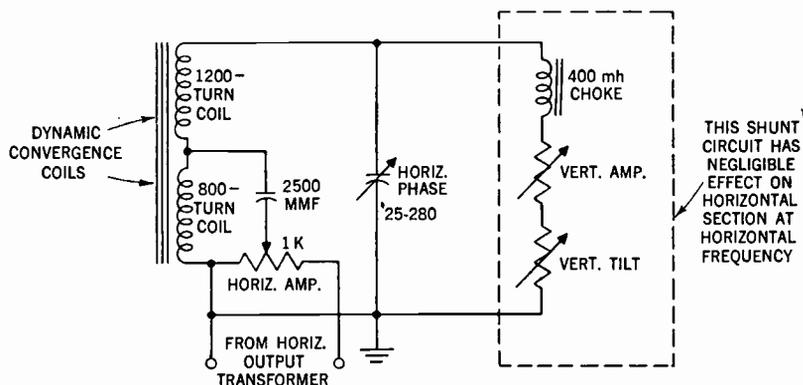


FIG. 17. A simplified version of the convergence circuit of Fig. 15 if the horizontal frequency currents alone are considered.

The purpose of the 400-mh coils in this convergence circuit is to effectively isolate the vertical and horizontal circuits from each other and yet serve as the connecting link between them. At 60 cycles a 400-mh choke has comparatively little impedance (about 150 ohms). Hence 60-cycle currents pass easily to the dynamic convergence coils. However, at 15,750 cycles the impedance of this choke coil is in the neighborhood of 39,000 ohms, and hence it prevents the vertical tilt and amplitude controls from affecting the horizontal currents through the dynamic-convergence coils.

LOW-VOLTAGE SUPPLIES FOR COLOR RECEIVERS

Low-voltage power supplies for color television receivers range from fairly elaborate three-tube rectifier systems to rather simple voltage doublers using selenium rectifiers. An example of the former is shown

in Fig. 18. Two individual transformers are employed, supplying power to three separate full-wave rectifiers. T_1 provides the filament voltage for all three tubes and the plate voltages for two of them. The second transformer T_2 furnishes the plate voltage for the third rectifier and the filament power for all of the remaining tubes in the set.

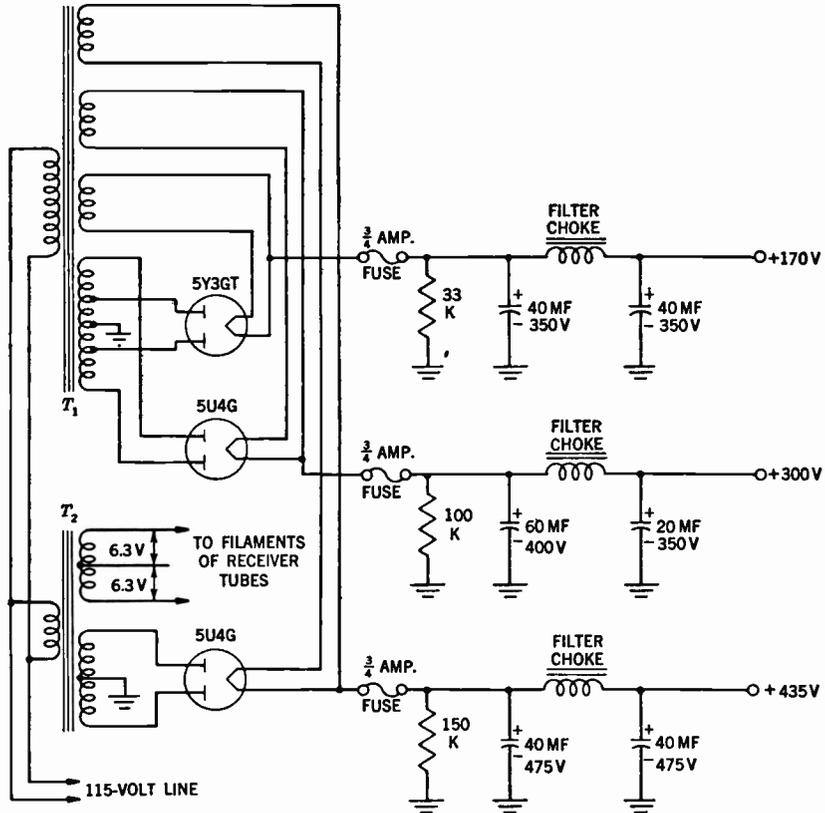


FIG. 18. A fairly elaborate low-voltage power supply used in a color television receiver.

DC output voltages of +170, +300, and +435 volts are made available from this supply. Adequate filtering is provided through the use of three separate pi (π) filters, each possessing a choke as the series element.

A second supply, not quite as elaborate, is shown in Fig. 19. Two selenium rectifiers are so connected that each is subjected to the full

secondary voltage of the transformer. However, because of their reverse placement in the circuit, each selenium unit functions over a different portion of the AC cycle. For those readers who have never encountered this type of arrangement before, the following explanation

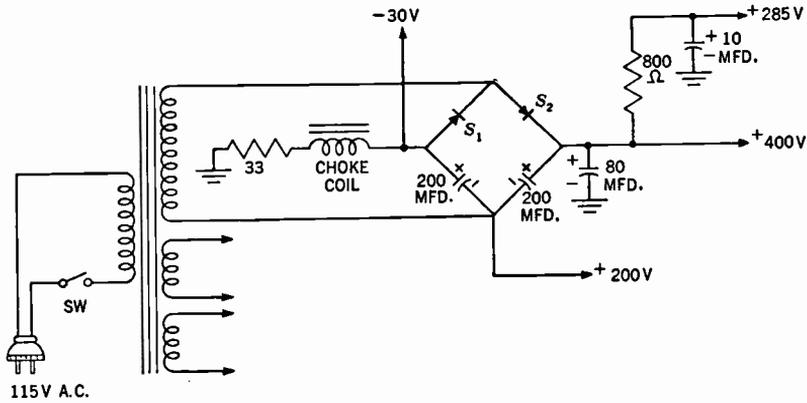


FIG. 19. Another low-voltage power supply for a color receiver.

is offered. For convenience, the simplified diagram of Fig. 20 will be used.

The AC sine wave that appears across the transformer secondary makes each end of the winding alternately positive and negative.

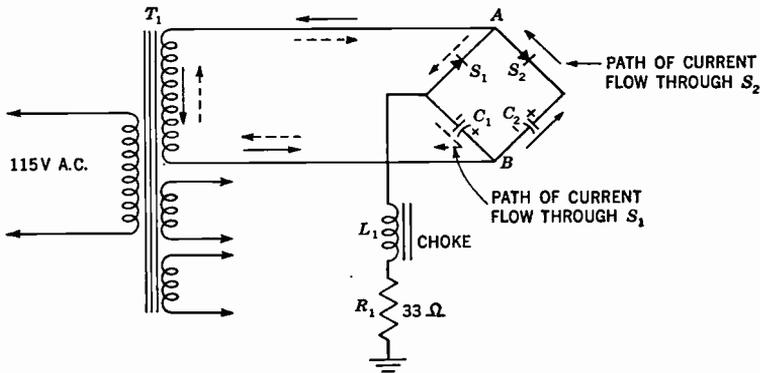


FIG. 20. A simplified diagram of Fig. 19 showing current through the circuit.

If point A is positive with respect to point B, electrons will flow from B through C₂ and S₂ to point A and through the transformer winding, completing the circuit. The charge across C₂ will have the

polarity indicated in Fig. 20, and if we assume that the peak value of the applied AC wave is 235 volts, then essentially this value of voltage will appear across C_2 . Actually, due to the current drain of the rest of the circuit, what we finally have across C_2 will be less, say 215 volts.

There is no current through C_1 and S_1 during this interval because of the way S_1 is connected into the circuit. Note that S_1 and S_2 are connected in reverse manner across T_1 , and when S_2 conducts, S_1 does not and vice versa.

During the following half-cycle, point A will be negative with respect to point B. Electrons will flow from point A through S_1 and C_1

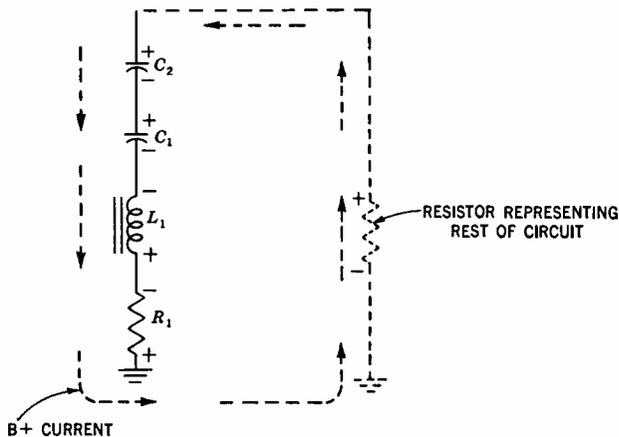


FIG. 21. The current between the power supply and the rest of the receiver.

to point B and then through the secondary winding back to point A. The voltage polarity developed across C_1 by this current is indicated in Fig. 20. If, now, we ground the negative end of C_1 (here through choke L_1 and R_1), then from the positive plate of C_2 to ground we will have around 400 volts, obtained through the series addition of the two capacitor voltages. If we tap in between C_1 and C_2 , we will obtain the benefit only of the voltage across C_1 and this will give us approximately 200 volts.

The reason for the negative voltage across R_1 and L_1 can be understood if we consider C_1 , C_2 , L_1 , and R_1 and the external receiver circuits (see Fig. 21). When current is drawn from this power supply, it follows the path indicated in Fig. 21. This current, passing through R_1 and L_1 , develops a voltage across these two components with the top

end of L_1 being negative with respect to ground. The value here is -30 volts, and it reduces the maximum voltage between the positive end of C_2 and ground from 430 volts to the 400 volts specified in Fig. 20. (The voltage values indicated there are with respect to ground.) In addition, other voltage-dropping resistors in this supply also make available a voltage of 285 volts to a number of stages in the receiver.

While the number of power-supply arrangements is endless, there is one further supply which may be of interest because of its relative simplicity. The circuit is shown in Fig. 22. Part of the power supply,

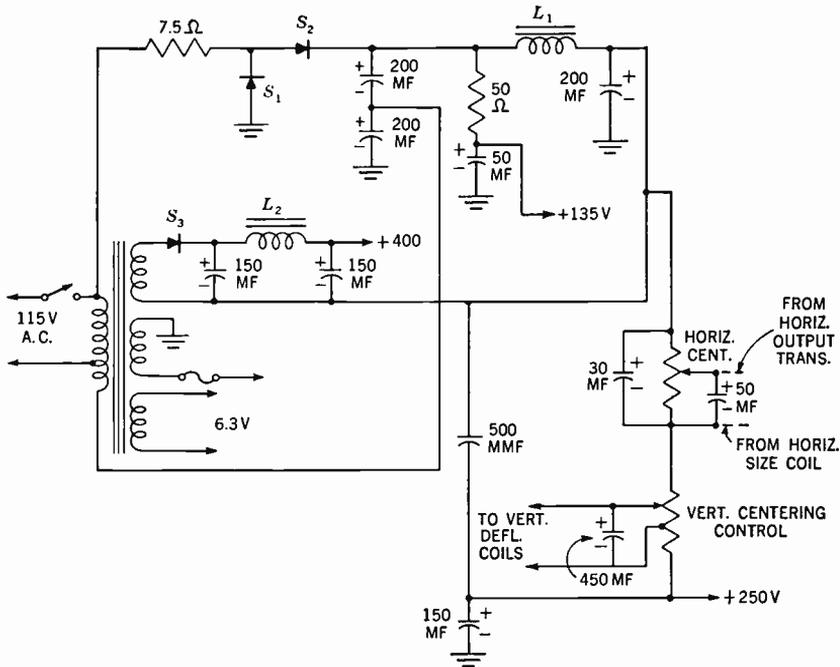


FIG. 22. A power supply using a voltage doubler.

consisting of rectifiers S_1 and S_2 , functions as a transformerless voltage doubler. From this section voltages of 135 and 250 volts are obtained. The other portion of the supply is formed by a half-wave rectifier S_3 , which develops an output voltage of $+150$ volts. However, this 150 volts is not used by itself. Rather, it is combined in series with the 250 volts of the voltage doubler to present an over-all voltage of 400 volts. Note that to achieve this combining, it was necessary to isolate the circuit of S_3 from chassis ground. This was accomplished by using a power transformer.

The same transformer also supplies the filament power for all the tubes in the receiver.

QUESTIONS

1. In what general respects does the vertical deflection system of color receivers differ from the vertical systems of black-and-white receivers? In what ways are they similar?
2. Perform the same general analysis for the horizontal deflection systems of monochrome and color sets.
3. Explain how the high-voltage system in Fig. 3B operates.
4. Why is high-voltage regulation employed in color sets? What would happen in the absence of such regulation?
5. Explain briefly two methods of high-voltage regulation.
6. Distinguish between static and dynamic convergence. What sort of voltage wave form is required for dynamic convergence?
7. Describe the physical appearance of the dynamic-convergence assembly. Indicate where this assembly is placed.
8. What controls are found in the dynamic-convergence systems employed by 19- and 21-in. color picture tubes?
9. Explain briefly how the dynamic-convergence circuit of Fig. 12 operates.
10. Describe the operation of the low-voltage power supply of Fig. 19.

CHAPTER 9

TYPICAL COLOR TELEVISION RECEIVERS: ANALYSIS AND ALIGNMENT

In prior chapters, each of the various sections of a color receiver was considered first from the standpoint of purpose or function and then from the analytical viewpoint of operation. Emphasis was primarily on circuit analysis. We are now in a position to consider complete receivers and the proper adjustment of their circuits. This will serve to acquaint the reader with the important task of installing and aligning color television receivers, regardless of picture-tube size or number of stages.

Two commercial receivers will be analyzed in this chapter. One set, the first, is the CBS Model 205. This operates on the I, Q system and develops a 19-in. color picture.* The second receiver is the Motorola Model TS-902A-03, and it employs the $R - Y, B - Y$ approach to color. Both are representative of current design trends and will afford the reader a good insight on what to expect when he encounters a color television receiver.

THE CBS MODEL 205

Block and circuit diagrams of the CBS Model 205 color television receiver are shown in Figs. 1 and 2. The set contains 44 tubes, 2 selenium rectifiers, and 2 crystal diodes. (The tuner section is not shown, but its tubes are included in the total.) It operates from the 60-cycle AC line and has a power consumption of 500 watts. Antenna input impedance is 300 ohms, and stations operating on channels 2 through 82 can be received. Intermediate frequencies are: video IF, 45.75 Mc; sound IF, 41.25 Mc; and sound intercarrier, 4.5 Mc.

Many of the circuits in this receiver were described in detail in pre-

* The picture-tube size is actually unimportant, since the same set is capable of driving a 21-in., or even larger, tube if the tubes are similarly designed.

ANTENNA TO INPUT VIDEO DET 10-1 FA E
 VICE DET UP TO HALLZ -UTPUT
 AC 100-1 PROGE PLATE OF HORIZ OUTPUT TUBE
 DC 100-1 PROGE SECOND ANODE OF PICTURE TUBE

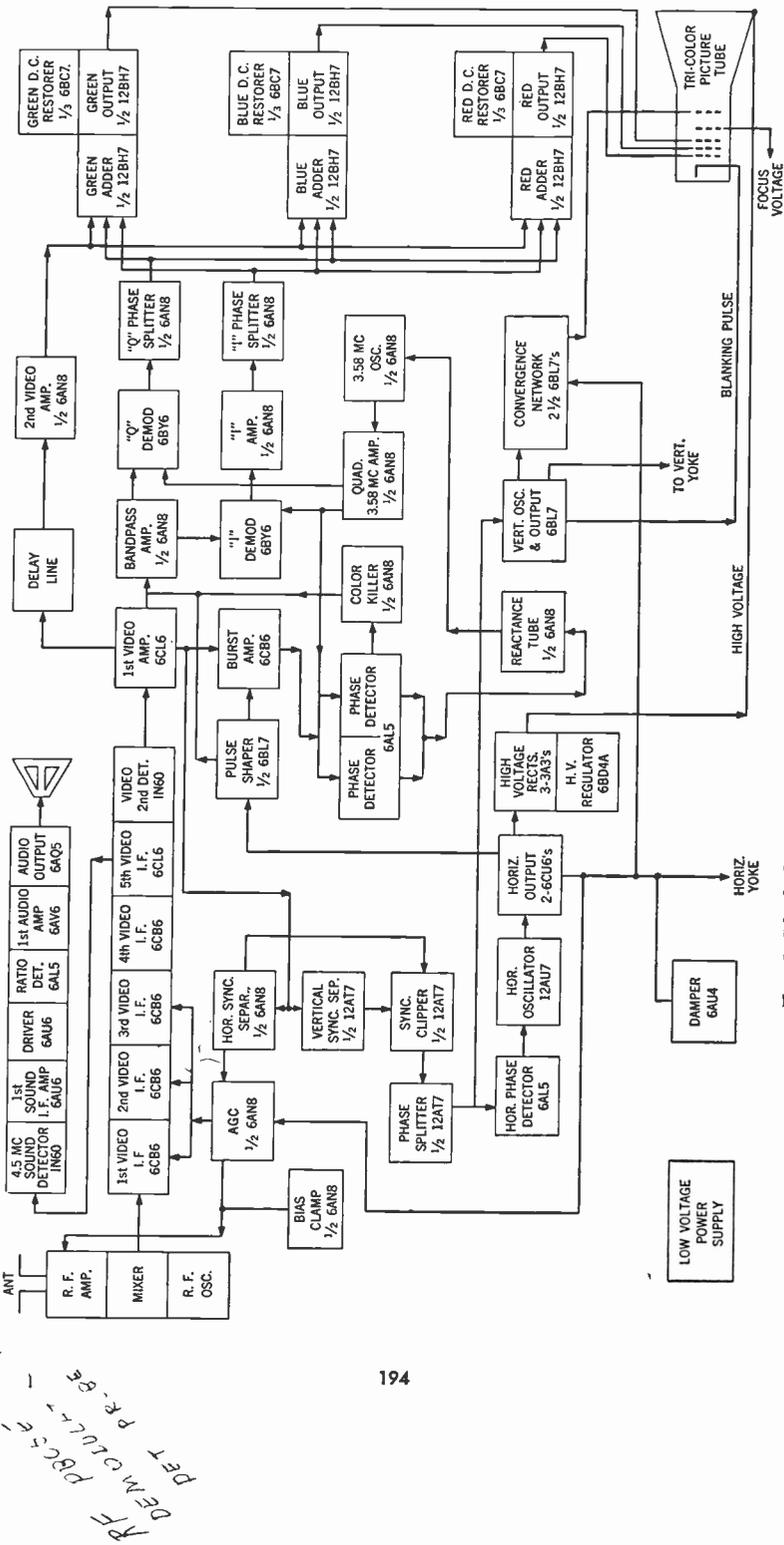


Fig. 1. Block diagram of the CBS Model 205 color television receiver.

vious chapters, and a restatement here is unnecessary. In the general analysis to follow, those sections which have received prior treatment will be touched on briefly; all others will be discussed in appropriate detail.

Video IF System. The output of the tuner is applied to a five-stage video IF amplifier system.* Trap frequencies in this section include 39.75 Mc (video carrier of adjacent higher channel), 47.25 Mc (sound carrier of adjacent lower channel), and 41.25 Mc (sound carrier of the same channel). AGC bias is applied to the first three stages from a keyed AGC system.

Sound take-off in Fig. 2 occurs at the plate of the final video IF amplifier. Additional attenuation for this frequency is then imposed by a bridged-T network inserted just prior to the video second detector. By this arrangement we permit sufficient sound signal to reach the sound system, yet provide enough additional attenuation between the sound take-off point and the video detector to prevent any appreciable amount of 920-kc beat signal from being developed in the detector.

Sound System. The sound system follows the pattern established for color television receivers. The intercarrier sound signal of 4.5 Mc is formed by beating the sound signal with a portion of the video carrier in a IN60 germanium crystal. This is followed by two 4.5-Mc IF amplifiers, and then the signal is applied to a ratio detector. Here the audio intelligence is abstracted from the FM signal. Further amplification by an audio voltage and then a power amplifier raise the signal to the proper level for driving a loud-speaker. In this particular receiver two 6×9 speakers are employed.

Video Amplifiers. The video amplifier † following the video second detector serves both the color and monochrome portions of the video signal. Thereafter the monochrome signal proceeds alone through the delay line and V15A to the matrix network beyond. The chrominance signal, on the other hand, leaves this portion of the circuit at the cathode of V14 and proceeds to V16A, a bandpass amplifier. The contrast control for the color signal is mechanically ganged to the luminance contrast control, ensuring that both signals will be varied equally. This is needed to maintain the proper voltage relationship between the two signals.

V14 also supplies portions of the signal for the burst amplifier and sync separator circuits. This is in addition to the luminance and chrominance amplifiers already mentioned. Here, then, is a very im-

* See explanation for circuit of Fig. 5C, Chap. 4.

† See Fig. 10A, Chap. 4, and accompanying explanation.

portant separation point and one to be kept in mind when servicing this (or any similar) receiver.

Chrominance Section. The bandpass amplifier V16A stands at the head of the chrominance section* and serves to sort the color components from the luminance portion of the total video signal. The color signal is then directed to *I* and *Q* demodulators, where, in combination with suitably phased 3.58-Mc subcarrier voltages, the original *I* and *Q* video signals are reobtained. Each signal is subsequently amplified and then made available in positive and negative polarity to a matrix network. R25-1, -2, and -3, R26-1, -2, and -3, and R27-1, -2, and -3 form the nine-resistor matrix circuit.

Beyond the matrix, each primary color voltage is passed through two video voltage amplifiers before being applied to its respective control grid in the three-gun picture tube. The bandpass of each section is on the order of 3.2 Mc. Over-all gain controls for the green and blue channels are provided to permit the gains of these sections to be adjusted relative to the red channel. Finally, there is a DC restorer in each path to bring each color signal to the correct brightness level before it is applied to the picture tube.

Color Sync Section. The formation of 3.58-Mc subcarrier signals possessing the proper phase is the responsibility of the color sync section. For this purpose, the CBS receiver employs an APC system in conjunction with a crystal oscillator.† The burst amplifier V17 receives the color burst (together with portions of the color signal) from the plate circuit of the first video amplifier V14. The tuned take-off coil L14-6 has a small variable capacitor shunted across it. This is the front-panel Hue control, with which we can alter the colors on the screen. In essence, what the capacitor does is vary the frequency of its resonant circuit and, in this way, vary the phase of the color burst which is fed to the burst amplifier. When the circuit is tuned to precisely 3.58 Mc, the signal developed will possess the same phase as that of the incoming burst signal. Since the color AFC system receives the burst from L14-6 and C14-9, it will shift the phase of the generated 3.58-Mc subcarrier to follow suit. This will force the colors on the screen to change.

The burst amplifier V17 is ordinarily cut off by a high positive voltage applied to its cathode. During each retrace interval, however, it is pulsed into conduction, permitting the color burst to actuate the phase-

* See explanation for Fig. 12, Chap. 4. This differs slightly from the above circuit, the difference residing in the point of application of the negative triggering pulse.

† See Fig. 8, Chap. 5, and associated discussion.

detector circuit. Thereafter this signal and that generated by the 3.58-Mc crystal oscillator are compared as to frequency and phase, and if a difference exists, a correction voltage is produced and fed to the reactance tube V19A. The latter, in turn, alters the frequency of the 3.58-Mc oscillator to bring it in step with that of the color burst.

The 3.58-Mc subcarrier voltages which the *I* and *Q* demodulators receive are obtained from the quadrature transformer T21A-1. L_1 , L_2 , and L_3 are all inductively coupled to each other, and through the transfer of energy between them and their resonance we obtain the neces-

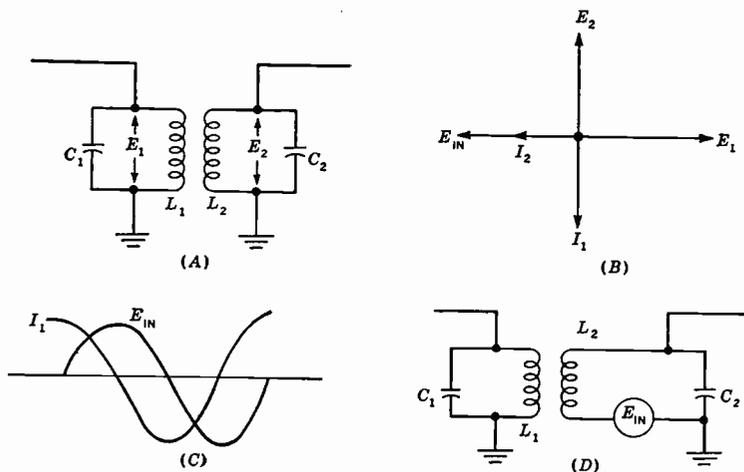


FIG. 3. Mutually coupled resonant circuits can be employed to provide a 90° shift. See text for details.

sary 90° phase relationship. A simple illustration using two tuned circuits coupled together will illustrate this.

In Fig. 3A we have two 3.58-Mc resonant circuits. E_1 is the voltage across L_1 , C_1 , and it is represented vectorially as shown in Fig. 3B. This voltage will cause a current I_1 through L_1 , and since the current through a coil lags the voltage by 90°, I_1 will lag E_1 by this amount.

The current I_1 in L_1 will induce a voltage in L_2 because of their mutual coupling. The phase relationship between primary current I_1 and induced secondary voltage E_{in} is shown in Fig. 3C. The current and the induced voltage differ by 90°, with the current leading. This places E_{in} 90° behind I_1 in Fig. 3B and 180° behind E_1 .

The induced secondary voltage is not the voltage across L_2 or C_2 . Rather, it is as though we had opened the secondary circuit and had

inserted a small RF generator (see Fig. 3D). So far as the induced voltage is concerned, L_2 and C_2 form a series circuit. If, as we presume, L_2 and C_2 are tuned to 3.58 Mc, then the secondary current I_2 produced by the presence of E_{in} , will be in phase with E_{in} . This, too, is shown in Fig. 3B. The phase angle of E_2 now follows logically since the current through L_2 produces a voltage (here, E_2) across the coil which leads the current by 90° . Once E_2 is placed on the vector graph, its relationship to E_1 becomes evident.

A color killer is also part of the color sync system and its operation is based on the presence or absence of the color burst. The grid of the color-killer tube V16B is tied to one side of the phase detector. With a color signal being received, the voltage at the tie-in point (junction of C18-2 and R18-3) is sufficiently negative to bias the color-killer tube to cutoff. This removes the effect of this tube from the circuit and permits the 6AN8 bandpass amplifier V16A to function normally. The cathode of the 6AN8 has +150 volts applied to it. This is offset by the +150 volts applied to the grid of the tube through resistor R16B-2 (10,000 ohms).

When the color burst is active, a negative pulse is fed into the grid circuit of V16A via capacitor C16B-3. The pulse drives the bandpass amplifier to cutoff and prevents the color burst from passing through.

In the absence of a color signal and, consequently, color bursts, the highly negative potential at the junction of C18-2 and R18-3 disappears and the color killer conducts heavily because its grid is made slightly positive by the presence of the positive voltage applied to one end of grid resistor R16B-1. The plate current in V16B causes the plate voltage to drop considerably below 150 volts. Since the grid of V16A is tied to the plate of the color killer, it assumes the same potential. The cathode of V16A is 150 volts positive, and the difference between this value and the less positive grid is sufficient to prevent V16A from conducting.

This color-killer circuit differs from those previously described in Chap. 5 in that it does not depend upon triggering pulses from the horizontal output transformer for its operation. The negative pulses which are fed into the plate circuit of this tube serve only to prevent the bandpass amplifier from passing the color bursts when a color signal is being received. The pulses do not enter into the operation of the color-killer tube itself.

Deflection Circuits. The vertical and horizontal deflection circuits do not offer any particular difficulty, since they are straightforward and

follow monochrome practice plus the discussion in Chap. 8. The sync signal is obtained from the plate circuit of the first video amplifier V14 and is DC-coupled to the grid of the horizontal sync separator V29A and AC-coupled to the grid of the vertical sync separator V31A. The vertical sync separator is grid-leak-biased employing a double time constant for better noise immunity. The horizontal sync separator is cathode-biased. The outputs of both sync separators are fed to a sync amplifier and clipper V31B. Variable clipping with signal strength is obtained by returning the grid resistor of the sync amplifier to the third picture IF screen grid.

The output of the sync clipper is applied to a phase splitter whose purpose is to provide positive and negative horizontal sync pulses for the horizontal phase detector. For the vertical sync pulses this stage functions as a cathode follower, receiving the vertical sync pulses at the grid and forwarding them to the vertical integrating network from the cathode.

The AGC amplifier V29B derives its control voltage from the cathode of the horizontal sync separator. The control voltage acts as a bias on the AGC amplifier and is varied in amplitude with the AGC control P29-1. Plate voltage for the amplifier is obtained from a horizontal kickback pulse taken from the horizontal output transformer.

Negative AGC bias voltage is obtained by charging the plate capacitor C29B-3 (0.22 μf) and is applied to the first, second, and third video IF and the RF amplifier grids. V21B is connected as a diode and serves as a clamp on the RF bias, delaying the rise of RF bias for improved signal-to-noise ratio.

The horizontal deflection system consists of a phase detector, a stabilized multivibrator, two 6CU6 horizontal output amplifiers, and a damper. The high-voltage system is regulated and provides 8,000 volts for focusing and 25,000 volts for beam acceleration.

The horizontal output transformer contains special windings for positive and negative pulses required by certain circuits in the receiver, such as the burst amplifier, bandpass amplifier, AGC, and convergence circuits. Electrical centering is provided by the horizontal centering control P36-1, which applies an adjustable DC voltage across the horizontal deflection coils.

The vertical deflection system employs a single duo-triode V32 to perform the functions of oscillator and amplifier. The saw-tooth deflection voltage is amplified by the output amplifier and then used to drive the vertical deflection coils via the output transformer T32-2. Electrical centering is provided through the vertical centering control P45-1,

which applies an adjustable direct current through the vertical deflection coils.

There is one transformer, T32-3, between the vertical centering control and the vertical deflection coils. This is for isolation purposes to prevent a change in picture centering from affecting the linearity of the vertical scan.

Dynamic-convergence Network. The dynamic-convergence system of this receiver employs five stages: V41A, V41B, V42A, V42B, and V43A.

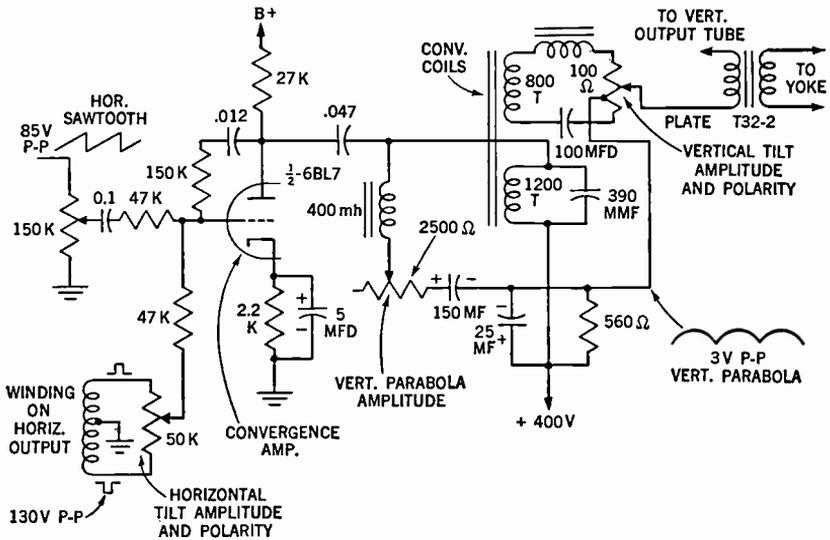


FIG. 4. A simplified diagram of one portion of the convergence network in Fig. 2.

Its purpose is to develop vertical and horizontal parabolic voltages of adjustable amplitudes. In addition, vertical and horizontal saw-tooth voltages are generated, which, when combined with their respective parabolic wave forms, tilt or vary the phase of these parabolic waves. As noted in Chap. 8, all this is needed to obtain beam convergence in areas removed from the center.

Examination of the convergence system is best accomplished in progressive steps.* A simplified diagram of one portion of this circuit is shown in Fig. 4. The vertical output tube current, which is saw-tooth in shape, flows through the primary of the vertical output transformer T32-2 and is returned to B+ through a 100-ohm center-tapped potentiometer and the parallel combination of a 560-ohm resistor and a 25- μ f

* From notes provided by the Radio Corporation of America.

capacitor. (The center-tapped potentiometer is referred to in Fig. 2 as the Vert. Tilt control.) The 560-ohm resistor serves as a DC path, while the 25- μ f capacitor offers less impedance (about 125 ohms) to the 60-cycle vertical frequency, and therefore it passes the major portion of this component of the current. The voltage developed across the capacitor is a parabola of about 3 volts peak-to-peak amplitude. (The capacitor "integrates" the saw-tooth current, producing a parabolic voltage wave.)

The parabolic voltage is applied through a 150- μ f DC blocking capacitor, a 2,500-ohm vertical amplitude control potentiometer, and a 400-mh horizontal frequency isolation choke to a 1,200-turn convergence coil. Since the amplitude control and convergence coil offer a substantially resistive impedance to 60 cycles, the current through these components remains parabolic, which is what we desire.

The 1,200- and 800-turn coils are wound on the same core and represent one convergence coil unit which is mounted on the neck of the color picture tube. Each gun has a similar unit, giving us a total of three.

Thus far, we have utilized the saw-tooth vertical output current to give us a vertical parabola which can be applied to one winding of the convergence coil. A series 2,500-ohm potentiometer enables us to vary the amplitude of the parabola.

What we also require is some means of adjusting the phase of the parabolic voltage. This is achieved by using the saw-tooth voltage across the 100-ohm potentiometer to produce a saw-tooth current in the 800-turn convergence coil. The direction of current may be altered by shifting the movable arm either above or below the center tap on the tilt potentiometer. (The saw-tooth voltage, of course, is obtained from the saw-tooth vertical output plate current through the tilt potentiometer.)

Now let us see how the horizontal parabolic current and its tilt or phase control are added to this circuit. The horizontal frequency components are applied to the 1,200-turn coil and induced in the 800-turn convergence coil because of their common U-shaped core. The 400-mh choke isolates the horizontal frequency signal from the low impedance offered by the vertical-convergence circuit.

Horizontal frequency pulses of about 130 volts peak to peak are fed to one triode section of a 6BL7 from a low-impedance center-tapped winding on the horizontal output transformer. Adjustable horizontal pulses of either polarity are obtained from a potentiometer across this winding. An adjustable horizontal saw-tooth wave is also brought to

the grid of this 6BL7 through a 47,000-ohm resistor and 0.01- μ f capacitor. This will be discussed more fully in a moment.

The pulse and saw-tooth signals are amplified in the 6BL7 horizontal frequency convergence amplifier. Feedback from plate to grid through a 0.012- μ f capacitor and a 150,000-ohm resistor serves to stabilize amplifier operation and achieve better convergence. The output of the 6BL7 is applied to the 1,200-turn convergence coil through a 0.047- μ f capacitor.

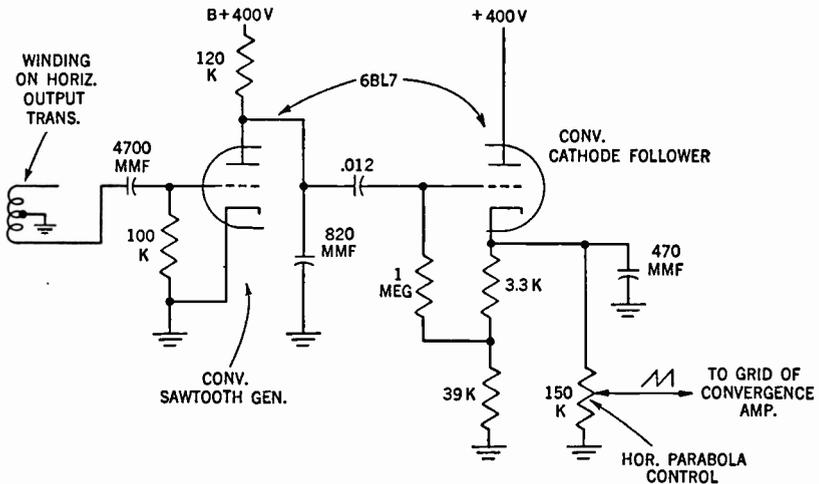


FIG. 5. The portion of the convergence circuit of Fig. 2 which develops the horizontal saw-tooth voltage fed to the three convergence amplifiers. The reason for labeling the 150,000-ohm potentiometer Hor. Parabola is indicated in the text discussion.

Now when a saw-tooth voltage at the horizontal frequency is applied to the 1,200-turn coil, a parabolic current is produced. This gives us one component of the horizontal convergence wave. Furthermore, a pulse voltage applied to the 1,200-turn coil will produce a saw-tooth current. Here, then, is the second component.

The origin of the saw-tooth voltage which is applied to the 6BL7 convergence amplifier is shown in Fig. 5.

A positive pulse voltage of about 130 volts peak to peak is applied to a triode section of another 6BL7 during the horizontal retrace interval. This causes grid current, which develops enough grid-leak bias to cut the tube off during the long scanning interval between pulses. While the tube is inactive, the 820- μ f plate capacitor slowly charges

up because one end is connected to B+ through a 120,000-ohm resistor and the other end is grounded. The capacitor charging continues until the positive pulse comes along and drives the tube sharply into conduction. The capacitor then discharges quickly. After the pulse has passed, the tube once again drops into cutoff and the capacitor charging starts again.

The reader will recognize that this process is similar to the development of a saw-tooth wave in the deflection systems.

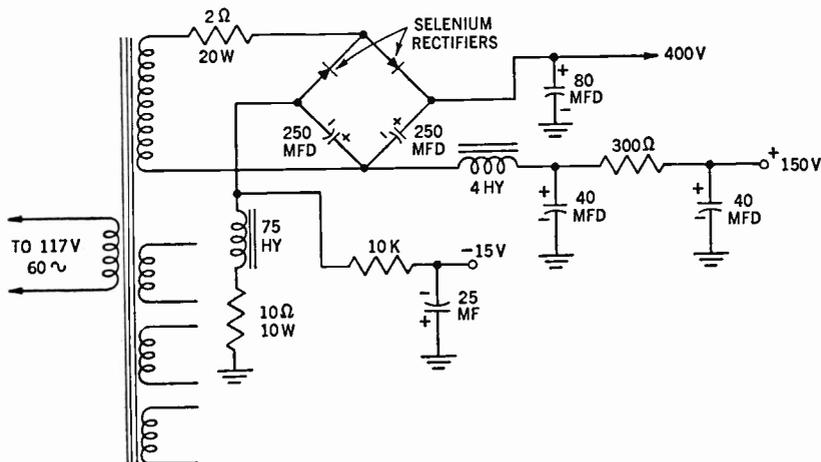


FIG. 6. Low-voltage power supply of CBS color receiver. The 285-volt output tap is not shown.

The second triode section of the 6BL7 is simply a cathode follower, passing the saw-tooth voltage it receives to the following 6BL7 horizontal convergence amplifier via a 150,000-ohm potentiometer.

While the foregoing explanation has dealt with a single section of the convergence network, actually three convergence circuits are employed, one for each gun. The only portion of this circuit of which there is only one is the horizontal saw-tooth generator and its cathode follower. The wave produced by these stages is utilized by all three sections of the convergence system.

Of remaining interest in the CBS color receiver is the low-voltage power supply. If this is redrawn to the form shown in Fig. 6, it will immediately be recognized as being similar to the power supply discussed in Chap. 8, Fig. 19. Output voltages of +400 volts, +285 volts, +150 volts, and -15 volts are made available for the various circuits in the receiver. Suitable currents for the purity and field neutralizing

coils are also obtained by inserting these components in the branch which provides an output voltage of 285 volts.

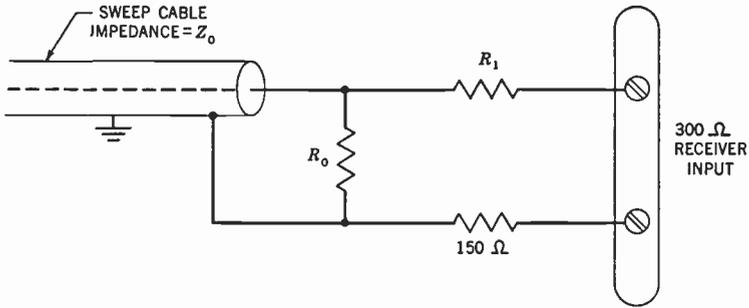
COLOR-RECEIVER ADJUSTMENTS AND ALIGNMENTS

So much for a description of the various circuits in this color receiver and how they function. Of interest now are the various adjustments and alignments that the service technician will be expected to perform when a receiver is either installed or brought into the shop for repair. Under installation there are the usual checks for picture centering, focus, width and horizontal drive, height and vertical linearity. These follow the same approach employed with black-and-white receivers. In addition, there are the adjustments occasioned by the use of a three-gun picture tube, and into this category fall color purity, static and dynamic convergence, and the setting of the screen-grid voltages on the picture tube to obtain a black-and-white picture when a monochrome signal is received. A procedure to follow for the latter adjustments was outlined in Chaps. 7 and 8, and if these instructions are followed, no trouble will be experienced in achieving good color-tube operation.

Alignment and adjustment of the receiver circuits themselves consist in part of procedures which are familiar from black-and-white practice and in part of new methods which arise because of the added color circuits. In the discussion to follow, both the old and the new will be covered.

Radio-frequency-tuner Alignment. In the RF tuner the situation is unchanged from monochrome practice. That is, the sweep generator is connected to the antenna terminals through an appropriate matching network. Many instrument manufacturers provide such matching devices. Where this is not available, then the arrangement shown in Fig. 7 may be employed. One series resistor has a fixed value of 150 ohms. The other series resistor has a value which depends upon the impedance of the sweep generator output; this is also true of the shunt resistor R_0 . The resistors should be of the noninductive variety, preferably carbon or of composition construction.

The response curve of the RF circuits is viewed by connecting the vertical input terminal of an oscilloscope (through a 10,000-ohm isolation resistor) to the mixer grid. Most tuners are designed so that an appropriate test point in the mixer-grid circuit is made available from the top of the tuner assembly (see Fig. 8). The oscilloscope beam should be driven by a 60-cycle sine-wave voltage obtained either from the sweep generator or from the oscilloscope if the latter contains a



Z_0	R_0	R_1
50 Ω	56 Ω	120 Ω
72 Ω	82 Ω	110 Ω
92 Ω	110 Ω	100 Ω

FIG. 7. Resistive network to match sweep cable impedance to receiver input.

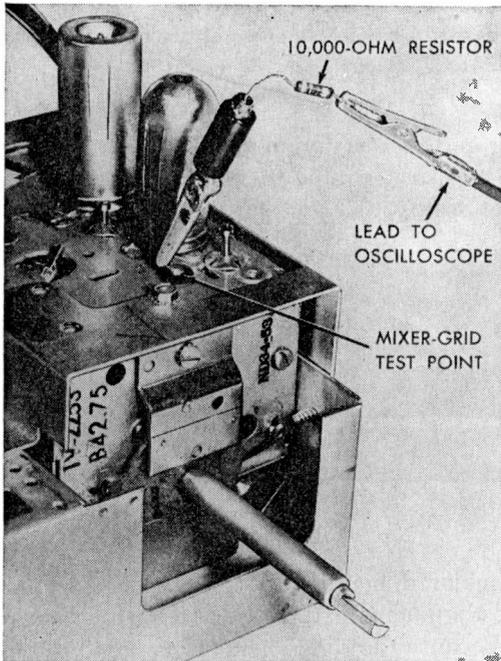


FIG. 8. Method of connecting oscilloscope to mixer grid of RF tuner in order to observe RF response pattern. (H. W. Sams & Co.)

phase control. A marker signal, when it is needed after the response curve has been obtained, would be loosely coupled to the sweep generator, either by connection through a small (5- or 10- μf) capacitor, or by laying the marker generator output cable across the resistive matching network.

From this point, the value of AGC bias to apply to the tuner and the adjustments to make will depend upon the instructions issued by the manufacturer. In any event, the RF response curve should appear as shown in Fig. 9 or be reasonably close to this form. In monochrome

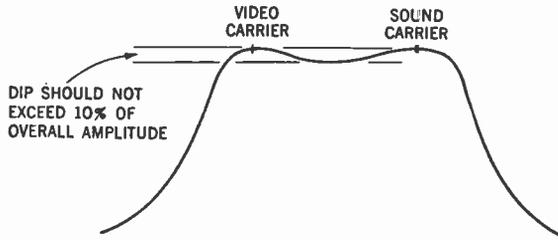


FIG. 9. Recommended RF response curve of tuner for color television receiver.

practice it is permissible for the dip in the center of the curve to extend down as much as 30 per cent. In color receivers the tolerances are much narrower and the maximum extent of the dip should not exceed 10 per cent. It is also desirable that the region around the color sub-carrier be as flat as possible.

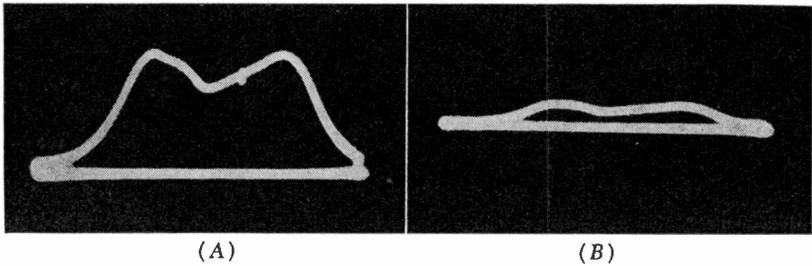


FIG. 10. Tuner response curves.

One of the major difficulties that the service technician often encounters in RF alignments is the lack of a usable pattern on the scope screen. This is because the signal generator provides too small a signal, or the scope is insensitive, or both. In place of the curve shown in Fig. 10A, the equipment may produce a pattern such as that shown in Fig. 10B. The latter curve is almost impossible to work with.

To circumvent this difficulty, a preamplifier inserted between the oscilloscope and the take-off point (in the mixer) is useful. The amplifier will increase the amplitude of the signal, helping it to provide a reasonable deflection on the screen. For this specific purpose, response of the preamplifier need not be very extensive, possibly 100,000 to 150,000 cycles.

A commercial preamplifier possessing a gain of 100 over a band from 60 cycles to 100 kc is shown in Fig. 11.



FIG. 11. A commercial preamplifier possessing a gain of 100 over a band from 60 cycles to 100 kc. (Kirby Products Corp.)

Sound Intermediate-frequency Alignment. The sound IF system alignment follows established monochrome practice. The presence of the IN60 germanium crystal at the head of this section does not alter the procedure. Initially it is perhaps best to start the alignment using an AM signal generator and a VTVM. The generator is connected to the input terminal of T8-3. This is the network which is situated in the grid circuit of V9, the first sound IF amplifier. Generator ground attaches to the receiver chassis. With a short jumper, ground the grid of the fifth video IF amplifier, pin 2 of V8.

Next, connect the VTVM (DC range) to the negative end of C11 in the ratio detector circuit. VTVM ground goes to the receiver chassis.

Set the generator to 4.5 Mc with maximum output and adjust T8-3

and T10-2 (both slugs) for maximum indication on the VTVM. Tune the primary of the ratio detector transformer T10-1 for maximum DC output on the VTVM.

Next connect the VTVM between the junction of R11-1 and C11-2, ratio detector output, and ground. Tune the secondary of the ratio detector transformer for zero DC on the VTVM. Repeat the adjustments of the primary of T10-1 for maximum DC and of the secondary of T10-1 for zero DC.

Connect a 1,500-ohm resistor across terminals 3 and 4 of T10-2, and, using the same signal output from the generator, readjust the secondary

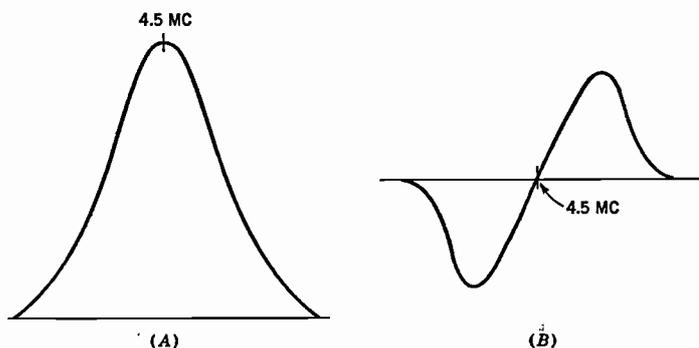


FIG. 12. (A) Response curve of sound IF system. (B) Response curve of ratio detector.

slug of T10-2 for maximum indication on the VTVM. Change the 1,500-ohm loading resistor to terminals 1 and 2 of T10-2, and adjust the primary of this transformer for maximum indication on the meter.

This completes the alignment of the sound section. Remove the 1,500-ohm resistor, signal generator, and VTVM from the circuit. Remove the jumper at pin 2 of V8.

Sweep alignment of the circuit can also be performed, if desired. Fig. 12A reveals the sound IF response curve; Fig. 12B gives the response curve of the ratio detector.

Video Intermediate-frequency Alignment. Alignment of the video IF system in this receiver (Fig. 2) requires much more time than most conventional monochrome IF systems because it is more extensive. Aside from the various trap circuits present, there are also complex-coupling networks that should be individually adjusted for optimum performance. This may not always be characteristic of color sets, but at the present time it is the practice being followed by many receiver

manufacturers. Furthermore, greater attention must be given to the low end * of the curve where the color frequencies are contained.

The foregoing procedure is the one recommended by the manufacturer. In other sets it will undoubtedly differ in some respects. In nearly all cases, however, the end result will be the same.

Connect the oscilloscope, preceded by a preamplifier if required, to the junction of L14-4 and R14-1 in the grid circuit of the first video amplifier V14. Use a 10,000-ohm series resistor for isolation.

Connect the signal generator to the grid of the fifth video IF amplifier, pin 2 of V8, and to ground. Modulate the signal generator to pro-

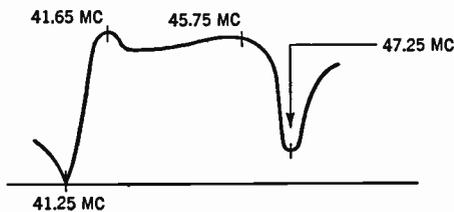


FIG. 13. Response curve for tuned circuits between fifth video IF amplifier and video detector.

vide an indication on the oscilloscope screen. With a short jumper, ground the grid of the fourth video IF amplifier, pin 1 of V7. Set the signal generator to 47.25 Mc, and adjust the slug of coil L8-1 for minimum indication on the scope screen. Then tune the signal generator to 41.25 Mc, and adjust L8-3 slug for minimum deflection on the scope screen.

Now disconnect the signal generator and the oscilloscope preamplifier, if used, and reconnect the oscilloscope as before. Connect a sweep generator to the grid of V8 and to ground. Set the sweep generator for maximum output or 6 volts peak on the oscilloscope, whichever is the lower. Couple the signal generator loosely to the grid of V8 in order to obtain markers. (If the sweep generator develops its own markers or if the generator contains provision for accepting marker signals, this latter injection method would be employed instead.)

Adjust the slug of L8-2 and L8-4 for maximum gain and curve shape as shown in Fig. 13. While observing the curve on the oscilloscope screen, adjust P14-1, the sound-rejection control, for maximum rejection at 41.25 Mc.

* Low in terms of IF value. This end, however, contains the high video frequencies.

Remove the sweep and signal generators, oscilloscope, and jumper shorting pin 1 of V7.

The balance of the video IF alignment is performed with the sweep or signal generators connected to the grid of the mixer. Also, a low-impedance bias supply is required to take the place of the normal AGC bias voltage. For the initial adjustment, connect -6 volts between the AGC line and ground. Connect a VTVM between the junction of L14-4 and R14-1 and point *E* of T14-1.

Next the signal from an AM signal generator is injected into the mixer-grid circuit. A simple and extremely effective way of doing this is by way of the mixer-tube shield. Lift the shield off the mixer tube

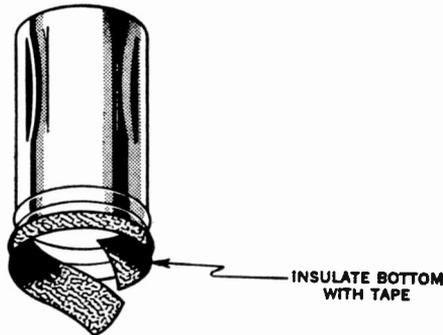


FIG. 14. Insulation of bottom of mixer-tube shield.

and insulate the bottom end with plastic-backed electrical tape (see Fig. 14). Then return the shield to the mixer tube, but let it rest lightly on the tube, thereby avoiding electrical contact between the shield and the chassis. Attach to the floating shield the signal lead from the generator. Connect the ground lead of the generator to the receiver chassis. The shield will couple whatever signal it receives from the generator to the tube elements and into the circuit.

Set the signal generator to each of the following frequencies and peak the specified adjustment for maximum indication on the VTVM.

44.9 Mc	T5-4
42.1 Mc	T6-1
41.3 Mc	T7-1

Remove the signal generator and VTVM. The bias supply remains in position, still set at -6 volts. Now, connect a sweep generator to the mixer-tube shield. Note whether the generator cable is terminated in its

characteristic impedance. (This information will be found in the operating manual of the instrument.) If it is not, place a carbon resistor of the proper value across the ends of the cable. Then attach the cable to the mixer shield as indicated above.

For marker pips, couple the AM signal generator loosely to the same shield, perhaps using a 10- μmf capacitor to the grid of the first video IF stage (whichever least affects the sweep generator output).

With a special detector (Fig. 15) connect the oscilloscope vertical

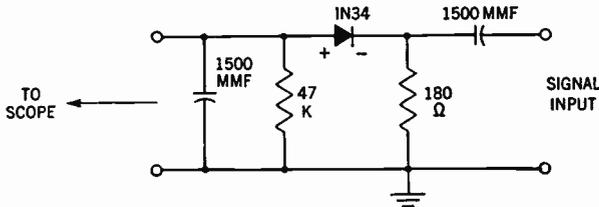


FIG. 15. Special detector for response checking at points in video IF system prior to video detector.

input terminal to the plate of V4. Oscilloscope ground connects to receiver chassis. Connect the loading network shown in Fig. 16 between plate and chassis of V5. Now adjust the slug of L4-3 (at grid

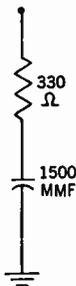


FIG. 16. Loading network required in alignment of certain sections of the video IF system.

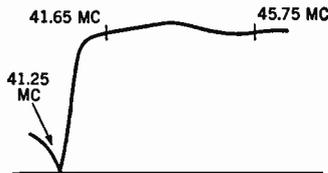


FIG. 17. Response curve for network in plate circuit of mixer and grid circuit of V₄, first video IF amplifier.

of V4) and the mixer output circuit (in tuner) for maximum gain and curve shape, as shown in Fig. 17. While observing the response on the oscilloscope screen, set P4-1 for maximum rejection at 41.25 Mc. Also adjust slug in L4-2 for the same result.

Next shift the detector network (Fig. 15) from the plate of V4 to the plate of V5, and move the loading network to the plate of V6. Leave sweep and signal generators in their former positions, but temporarily turn off the power to the sweep generator. Reduce bias on AGC line to zero. Set signal generator to 39.75 Mc and modulate signal. Then adjust slug in L4-5 for minimum indication on the scope screen. Change signal generator to 47.25 Mc, and adjust slug of L5-2 for minimum oscilloscope-screen indication.

Increase bias voltage to -6 volts again. Turn on power to sweep generator. Adjust L4-4 and L5-1 for maximum gain and curve shape as shown in Fig. 18.

We are now ready to check the over-all IF alignment. The special detector network for the oscilloscope is removed, as well as the loading network. The oscilloscope is then shifted to the junction of L14-4 and R14-1 in the grid circuit of the first video amplifier. A 10,000-ohm series isolating resistor should be used between the vertical input lead of the scope and the L14-4, R-14-1 junction point.

The over-all IF response from mixer grid to the video detector output is shown in Fig. 19. It may be desirable to retouch some of the slugs

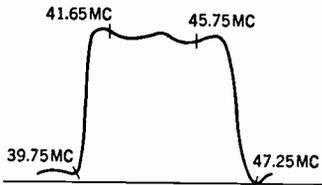


FIG. 18. Response curve from mixer plate to V_5 , second video IF amplifier.

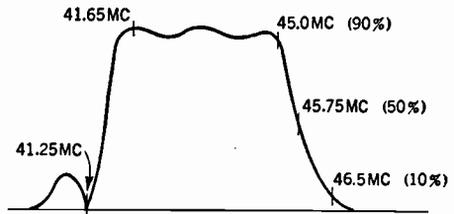


FIG. 19. Over-all IF response curve.

for better gain and over-all curve shape. It is important that the over-all response conform to the shape shown, with the markers placed *exactly* as indicated.

This completes the alignment of the video IF system.

Video-trap Adjustment. The video amplifier system contains a 4.5-Mc trap and two 3.58-Mc traps which must be adjusted to their respective frequencies. Signal injection, using an AM signal generator, is best achieved at the control grid of V14. (Generator ground terminal attaches to set chassis.)

As a precautionary measure, short the grid, pin 2, of V8 to ground. This will prevent noise from appearing on the oscilloscope screen. Connect the oscilloscope, using a demodulator probe or the detector

circuit of Fig. 15, to the top of the chroma control P16A-1. Turn the contrast control completely clockwise. Then set the AM generator to 4.5 Mc, and modulate it with an audio signal (in the generator). Adjust the slug in L14-2 (4.5-Mc trap) for minimum indication on the oscilloscope screen.*

Next shift the oscilloscope and its demodulator probe to the grid of V15A. Set signal generator to 3.58 Mc and amplitude-modulate it. Adjust the slug in L14-5 for minimum oscilloscope indication.

Move the scope and its demodulator probe (or the detector circuit) to the junction of resistors R16B-2 and R16B-3 in the grid circuit of V16A, the band-pass amplifier. Adjust L14-6 for *maximum* indication on the oscilloscope screen.

Perhaps a better place for the demodulator probe and oscilloscope is at the plate of V16A. However, V16A is cut off by the color-killer tube (due to the absence of a color burst). To bring the tube out of cutoff, the cathode lead of V16B may be unsoldered. Tube removal will not suffice, since the same tube is used for V16A and V16B. Another approach is through the use of a dummy 6AN8 tube in which pin 3 is clipped off.

Adjustment of Bandpass Amplifier. Between the bandpass amplifier and the *I* and *Q* demodulators there is an adjustable bandpass filter which should possess the response shown in Fig. 20. To check this, we would proceed as follows.

First make the color-killer tube inoperative by using one of the methods just described. Then connect a video sweep generator to the grid of V14, the first video amplifier. Use a 0.1- μ f series capacitor for DC isolation between generator and grid. Connect the oscilloscope, with a demodulator probe, to the grid (pin 1) of the *Q* demodulator. Turn contrast and chroma controls to maximum.

Adjust the cores in the coils of T16A-1 and L16A-1 for maximum gain and curve shape as shown in Fig. 20.

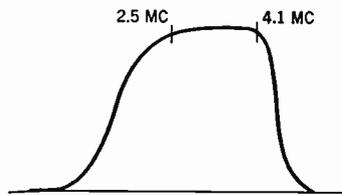


FIG. 20. Over-all bandpass response.

* There are moderately priced oscilloscopes available whose vertical section bandwidth extends up to 4.0 Mc or beyond. These instruments will permit 3.58- or 4.5-Mc waves to be viewed directly. For these units a demodulator probe (as indicated above) is not required and the AM signal need not be modulated.

Frequently useful with these moderately priced oscilloscopes is a wide-band preamplifier, such as the Simpson Model 406 chromatic amplifier.

The video sweep generator required for this alignment is one which provides a range of frequencies from approximately 0 to 5 Mc. (Actually, the low end is not zero but something like 30 to 50 kc, which is just as satisfactory.) One such instrument is the RCA Model WR-59C TV sweep generator (Fig. 21). In addition, some method of frequency identification is required in order to establish the ends of the curve.

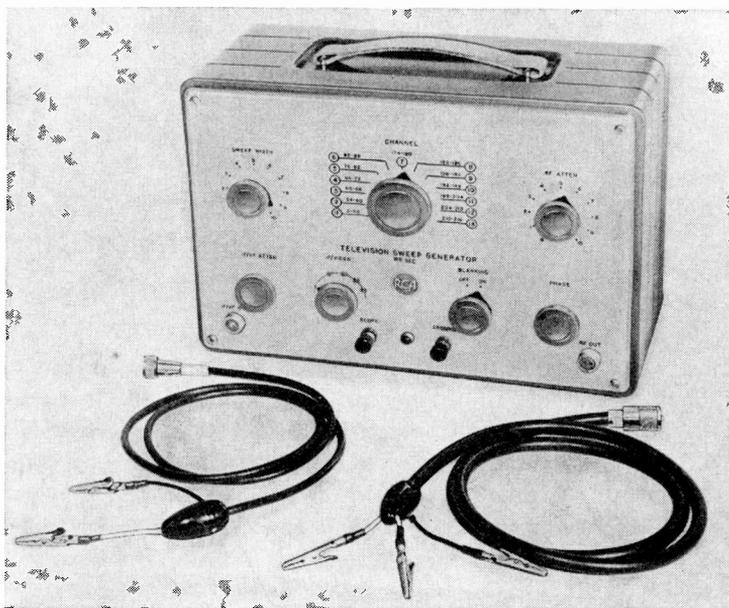


FIG. 21. A sweep generator capable of supplying a video sweep signal (0 to 5 Mc) as well as IF and RF sweep signals. (RCA.)

For this, RCA has a Model WG-295A Video Multimarker to be used in conjunction with the WR-59C (see Fig. 22). The WG-295A is an absorption marker with five preset markers: 0.5 Mc for *Q* filter, 1.5 Mc for *I* filter, 2.5 Mc for bandpass filter, 3.58 Mc for color-subcarrier frequency, 4.5 Mc for sound-trap frequency.

The multimarker is connected between the WR-59C and its output cable, and as the sweep signal passes through the device, the energy at each of the five frequencies listed is rather sharply attenuated. This produces notches at these frequencies in the circuit response curve and serves to identify the various points on the curve. Each of the marker frequencies may be definitely and individually identified on the response curve simply by touching appropriate contacts on the side of

the device itself. This has the effect of reducing the amplitude and shifting the position of the particular marker notch.

Another method of obtaining a suitable sweep signal is shown in

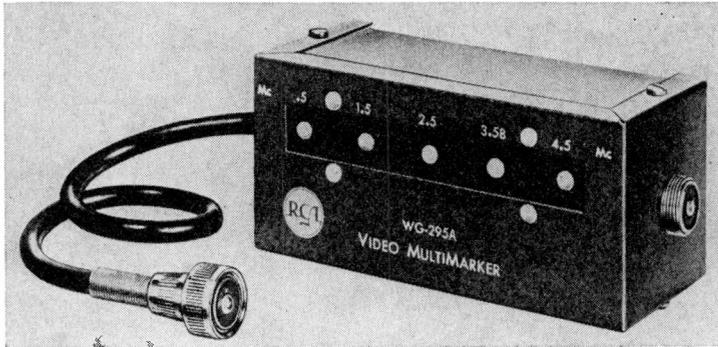


FIG. 22. An absorption-type multimarker which is useful in identifying certain frequencies on video and chrominance response curves. (RCA.)

Fig. 23.* An IF sweep signal and an IF marker signal are applied to the input of the video detector. (In the video detector of Fig. 2 it might be desirable to shunt a 220-ohm resistor across L8-4 and then attach both

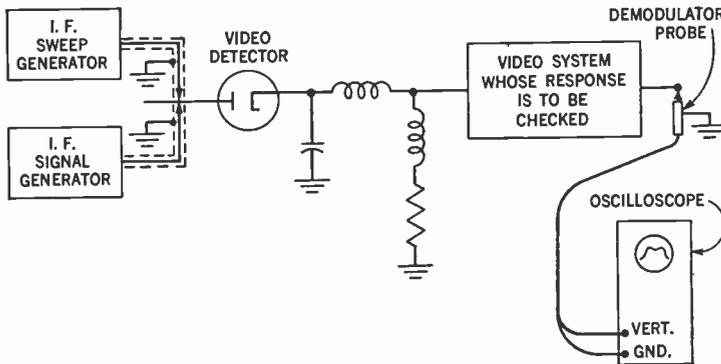


FIG. 23. Suitable sweep signals to check response of video system, bandpass amplifier, or I_Q (or $R - Y, B - Y$) stages can be obtained by the method shown above.

sweep and marker signals to the top end of this coil. This would ensure that all frequencies produced by the sweep generator affect the video detector uniformly.)

* From Milton S. Kiver, *How to Understand and Use TV Test Instruments*, Howard W. Sams & Co., Inc., Indianapolis, Ind.

The sweep generator would be set to swing over the IF range of the receiver, here 41.25 to 45.75 Mc.

The marker signal generator is connected to the same point as the sweep generator, possibly through a 50- μ f capacitor, and set at exactly the video IF carrier value, in this instance 45.75 Mc. With both these signals feeding into the detector, here is what happens. When the sweep generator is at 45.75 Mc, the zero beat between it and the marker generator signal produces no output (actually a DC voltage). As the sweep generator frequency swings away from 45.75 Mc, the beating with the marker signal continues and the difference (and sum) frequencies will be developed in the video detector. At 44.75 Mc the difference frequency is 1 Mc; at 43.75 Mc, it is 2 Mc, etc. With an over-all 5-Mc sweep (say from 40.75 to 45.75 Mc), a continuously sweeping difference-frequency signal from 0 to 5 Mc would appear at the output of the video detector and proceed through the first video amplifier and the bandpass amplifier.* At the grid of the *Q* demodulator some of these frequencies would be stronger than others because they received more amplification. If we now take a crystal detector and rectify this amplitude-varying (or modulated) signal and feed the amplitude variations to an oscilloscope, we will develop the response characteristic of the bandpass amplifier between 0 and 5 Mc.

Actually, the curve would represent the response of the video system from the video detector to the grid of the *Q* demodulator. However, we can rightfully call the observed pattern that of the bandpass filter because the preceding networks have a wider bandpass than the filter and hence will pass everything the filter will. The latter, then, is the circuit which imposes the attenuation below 2.0 Mc and above 4.0 Mc, and it fashions both cutoff ends of the response.

Those readers who find this reasoning confusing might recall that if a sweep generator is applied to the antenna terminals of a receiver and an oscilloscope is placed beyond the ratio detector, what is observed on the screen will be the response pattern of the ratio detector. Here, too, the detector possesses the narrowest bandpass and so its response is the governing factor.

With the equipment set up and operating as in Fig. 23 and the phase control properly set for a single trace, you might obtain a pattern such as shown in Fig. 24. The zero beat point (representing zero frequency) is shown here in the center of the pattern. Actually, it may be in the

* The same sweeping 0- to 5-Mc signal will also pass through the second video amplifier and appear at the matrix. Demodulation and inspection of the wave form at this point would reveal the response characteristic of the luminance channel.

center of the pattern or off to one side. When it is in the center, it signifies that the frequency in the sweep generator is swinging above and below the marker frequency, which, for our present illustration, is 45.75 Mc. To move the zero beat indication over to the left, lower the sweep generator frequency. If this is done carefully and the sweep width is set to cover a range of 5 Mc, the zero-frequency marker pip will be stationed at the extreme left-hand side of the screen and the shape of the pattern from this point to the right will represent the response characteristic of the bandpass amplifier from 0 to 5 Mc.

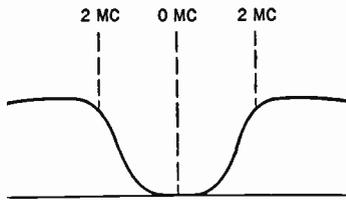


FIG. 24. Double response trace that may be obtained with the equipment setup of Fig. 23. Extent of the curves depends on sweeping range of generator.

Once the curve is obtained, the next step is to check it at various points in order to determine at what frequencies the curve rises and where it starts to fall off. For this a variable marker pip is required. Such a pip can be obtained from any AM signal generator operating between 500 kc and 5 Mc. Couple the output of this generator very lightly into the video amplifier circuit (by one of the methods outlined previously) so that the response curve is not disturbed. Then by changing the frequency of the marker pip, we can inspect the entire response curve, noting at what point it rises and where it dips.

Either of the two foregoing methods can also be used to check the response of the complete video amplifier system, from the video second detector to the matrix (beyond V15A) or even to the grids of the picture tube itself. Even though there are no adjustable circuits in these stages, still it may be desirable for the technician to know how well these circuits are retaining their characteristics.

The *I* and *Q* sections should also be checked. In the *Q* section video sweep signal injection would occur at the grid (pin 1) of V22. The demodulator probe and its oscilloscope are connected to the cathode (pin 3) of the *Q* phase splitter, V15B. The desired response is shown in Fig. 25. Remove V19 tube for these *I, Q* checks.

In the *I* section signal injection is at pin 1 of V23 and the response is viewed at pin 3 of V24B. The desired response is shown in Fig. 26.

(If the two-generator method of obtaining a video sweep signal is employed for the *I* and *Q* system checks, the setup shown in Fig. 27 should be used. The additional crystal diode serves to beat the generator signals together to produce the difference frequencies. It takes the place of the video second detector used in Fig. 23.)

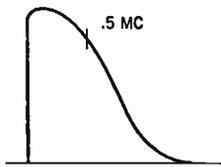


FIG. 25. *Q* channel response.

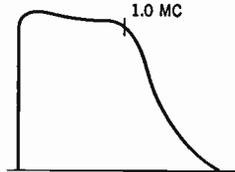


FIG. 26. *I* channel response.

Color-sync-section Alignment. The color sync section contains a number of tuned circuits upon whose correct adjustment depends the attainment of the proper colors on the screen. The step-by-step procedure is not difficult to carry out and principally involves the balancing of the phase detector circuit and the peaking of several tuned coils and transformers.

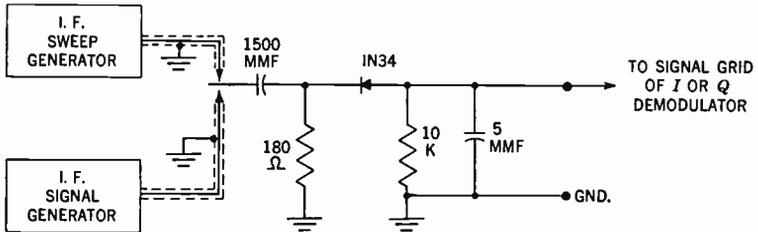


FIG. 27

The dominant frequency throughout the entire color sync section is, of course, 3.58 Mc. If a wide-band oscilloscope is available, the 3.58-Mc signal may be observed directly. Otherwise a VTVM with a demodulator probe will be required.

To start the alignment of the color sync section, place the receiver in operation, but turn the channel selector to an unused channel. Turn Color Intensity and Contrast controls to minimum.

The first step is adjustment of coil T19B-1 (in the plate circuit of V19B) to obtain the proper amplitude of signal from the 3.58-Mc oscillator. Connect a VTVM in series with a calibrated RF probe (or use a

wide-band oscilloscope) to terminal 2 of T19B-1. Then adjust the slug in this coil to read 5 volts peak to peak on the instrument.

Next ground the grid of V17 to prevent any extraneous noise signals from entering this section. Move the VTVM (or the scope) to pin 7 of V18, and adjust the slug in L2 of the quadrature transformer T21A-1 for maximum indication on the instrument. This indicates that L2 is at resonance. Then L3 is adjusted for a dip in the meter reading. L3 is coupled to L2, and when L3 is resonant, it absorbs maximum energy from the circuit, resulting in the dip just mentioned.

For the next step, we require the presence of an incoming color burst. This may be obtained either from a color broadcast or from a color-bar generator. Remove the ground jumper on V17 and set the Hue control C14-9 to mid-position. Then adjust L14-6 and T17-1 for maximum indication on the instrument. (The latter is still at pin 7 of V18.) Now move the VTVM to the grid of the reactance tube V19A. A VTVM is required here because a DC voltage is being checked. Adjust the reactance-tube plate coil until the VTVM reads 0 volts. Reduce the chrominance signal, by turning the fine-tuning control, so that it is just barely visible on the screen. This is done so that an extremely weak burst signal is supplied to the AFC diodes. The color oscillator may now possibly be out of sync. If it is, adjust the AFC balance potentiometer until the 3.58-Mc oscillator returns to sync again.

The foregoing represent substantially all the adjustments which a color receiver would normally require. Admittedly there might be alternate approaches to the procedures just given. For example, the cores in the quadrature transformer T21A-1 could be adjusted by using a color-bar generator to apply only an *I* signal to the receiver. Under these conditions, no signal should be observed in the *Q* channel. If such a signal is noted, the phase of the 3.58-Mc subcarrier to the *Q* demodulator (from L3 in Fig. 2) would be adjusted until the wave diminished to zero. Alternately, the color-bar generator could be set to supply only a *Q* signal to the receiver. Then L2 in the quadrature transformer would be adjusted until any signal in the *I* channel was reduced to zero.

Another adjustment for which the color-bar generator would be useful is the setting of the *I* gain control in the cathode leg of V24A. A color-bar signal is applied to the antenna terminals of the receiver and set to apply a red color signal. The contrast, chroma, and hue controls are adjusted to provide the proper shade of red on the screen. Then an oscilloscope is connected to the blue grid of the picture tube. The signal voltage here should be zero. If not, then the *I* gain control

is adjusted for minimum signal voltage here. The same setting of the *I* gain control should provide zero (or minimum) signal voltage at the green grid. If it does not, a compromise setting will be required.

Many of the actual procedures to follow will depend upon the particular receiver design. Hence it is of the utmost importance that the instructions issued by the manufacturer in his service manual be followed as closely as possible.

THE MOTOROLA MODEL TS-902A-03 COLOR RECEIVER

The Motorola Model TS-902A-03 color television receiver is a narrow-band receiver utilizing the *R - Y, B - Y* method of color demodu-

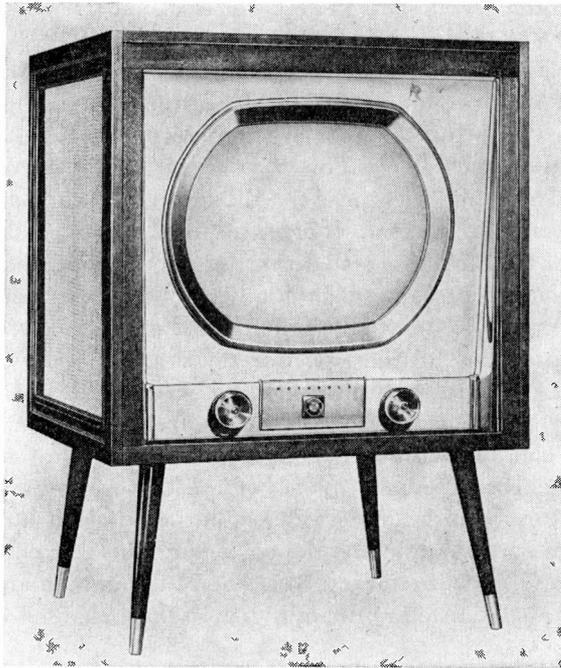


FIG. 28. Appearance of Motorola color television receiver in the cabinet. (*Motorola, Inc.*)

lation. The receiver possesses 29 circuit tubes, a 19VP22 19-in. tricolor picture tube, and three germanium diodes and three selenium rectifiers.

The appearance of the receiver is indicated in Fig. 28, together with a close-up of the front and rear panel controls. Views of the receiver

chassis itself are given in Fig. 29. The entire unit is surprisingly compact, and most components are readily accessible for servicing purposes.

For block diagram of Motorola receiver see Fig. 30; for schematic diagram see Fig. 2A (facing p. 195). In many RF and IF circuits Motorola is using the same circuits that they ordinarily use in their black-and-white receivers with modifications to encompass the wider composite color signal. Also, sound take-off is accomplished at the plate of the third video IF rather than beyond the second detector. This enabled the circuit designers to impose additional attenuation on the sound carrier prior to the video detector in order to minimize the appearance of the 920-kc signal obtained when the sound and color subcarrier signals beat with each other.

Beyond the video detector, there are two amplifiers through which the entire video signal (color and monochrome) passes. Separation then takes place, with the brightness component shunted off to V29 while the chrominance portion of the signal is transferred to V8, a bandpass amplifier.*

The brightness signal is amplified by V29 and then transferred to all three cathodes of the picture tube. It arrives here at the same time that the color signals arrive at their respective grids in the picture tube.

AGC Stages. An amplified AGC system is employed in this receiver, and even though it is still basically a keyed AGC circuit, the presence of a special cathode follower prior to the keyed tube modifies its operation somewhat. In the conventional keyed AGC circuit the video signal and its sync pulses are applied to the keyed tube, while positive triggering pulses from the horizontal output amplifier are applied to the plate of the tube. With the circuit properly adjusted, there will be current through the keyed tube when the sync pulses are active at the grid. This is because the triggering pulses are, at these instants of time, active at the plate.

The conduction period is seldom longer than 7 μ sec, and it often happens that when the horizontal hold control is varied (thereby affecting the horizontal sweep frequency), the grid and plate pulses do not fully coincide at the keyed tube. This causes less than the normal amount of AGC voltage to be developed. It also leads to contrast changes with horizontal hold setting and reduced horizontal pull-in range.

To reduce these side effects, Motorola has added a cathode follower ahead of the keyed AGC tube. The circuit is so designed that the

* A more detailed circuit analysis will be found in Chap. 6.

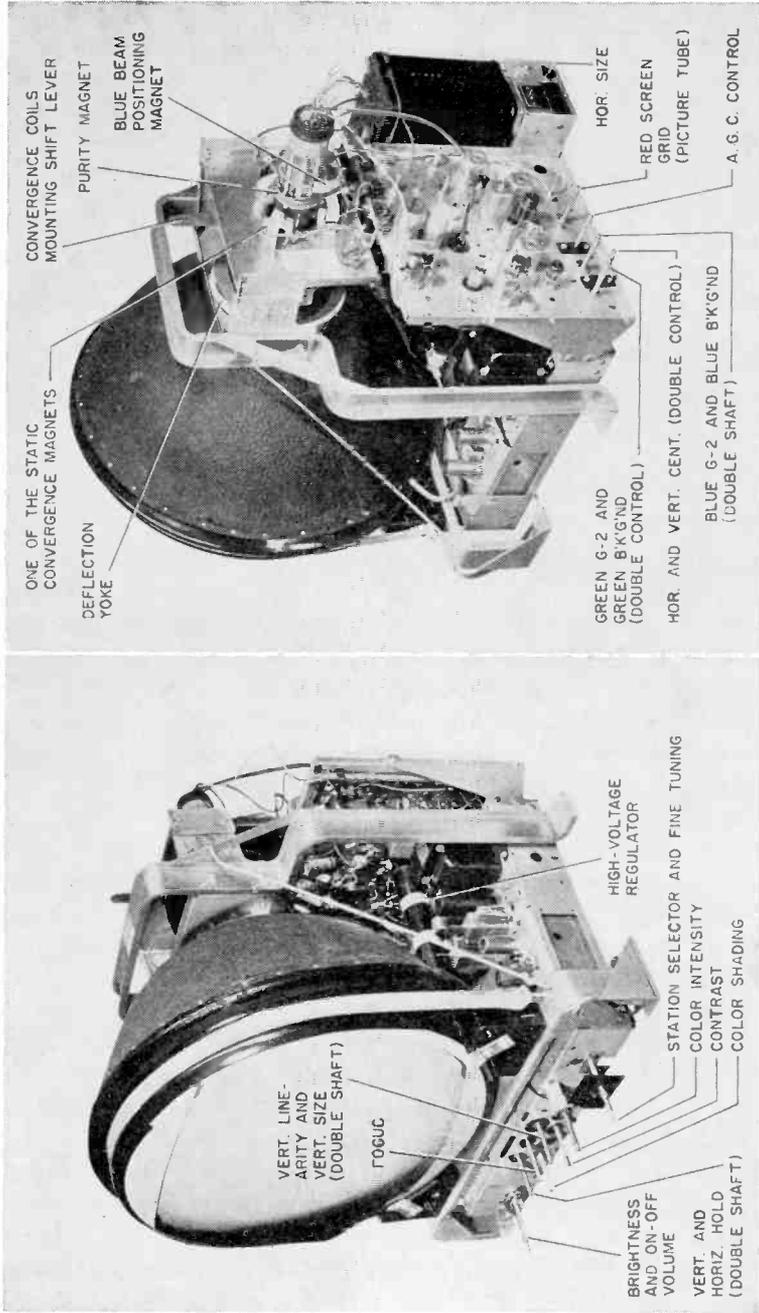


FIG. 29. (A) Front chassis view of Motorola color receiver. (Motorola, Inc.) (B) Rear chassis view of Motorola color television receiver. (Motorola, Inc.)

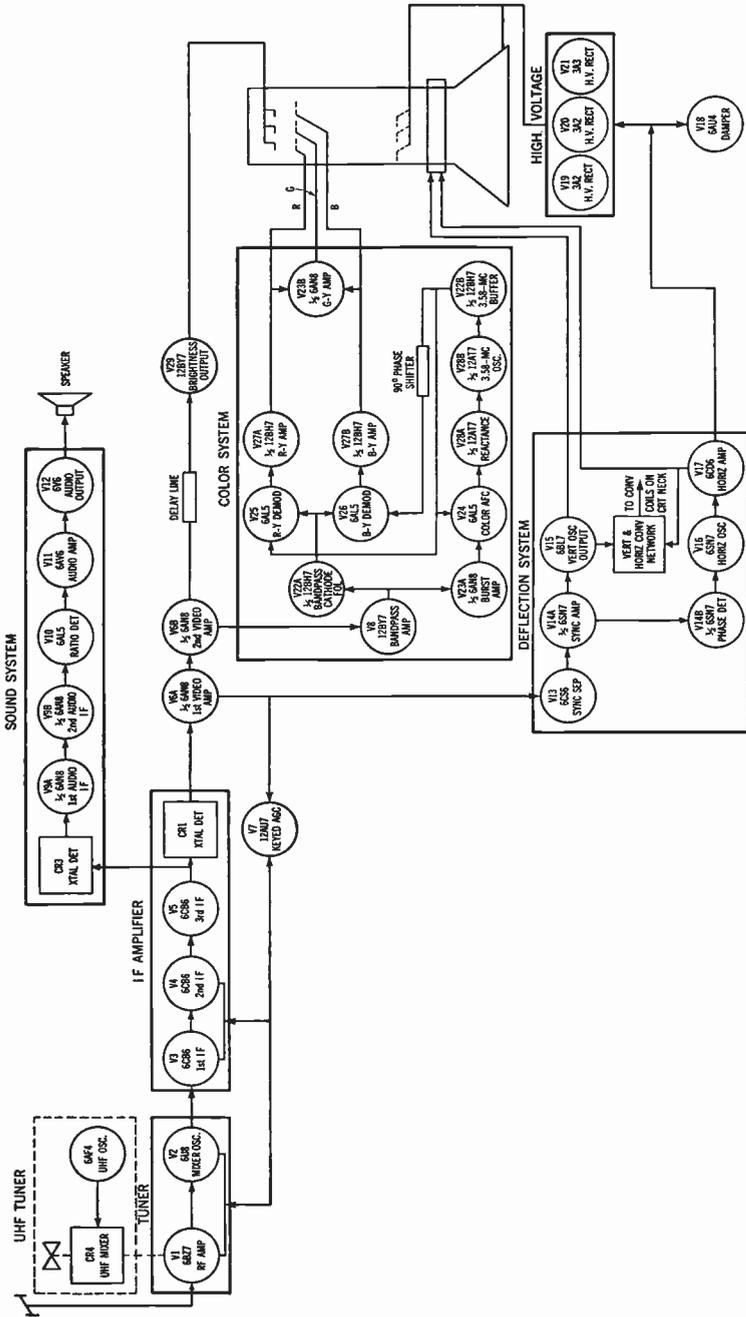


Fig. 30. Block diagram of the Motorola Model TS-902A-03 color television receiver. The dotted block in the upper left-hand corner indicates a UHF tuner. This circuit is not shown in the schematic.

cathode is able to follow increases in grid voltage, but the time constant of R106 and C106 in the cathode does not permit it to follow the decreases. Thus, when a sync pulse (which is positive at the grid) causes tube plate current, the cathode potential rises rapidly with the leading edge of the sync pulse and follows the change up to the peak. But when the grid voltage falls abruptly on the back end of the sync pulse and the grid voltage drops, the voltage on the cathode can only fall at the discharge rate of C106 and R106. The result is a saw-tooth voltage (see Fig. 31). This saw-tooth on the grid of V7B keeps the tube

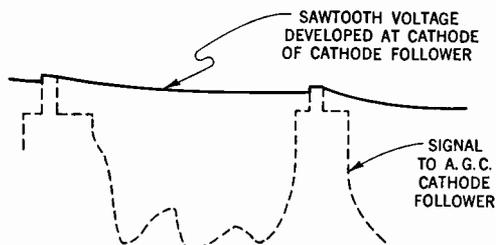


FIG. 31. The cathode follower V7A of FIG. 2A feeds a saw-tooth voltage to the keyed AGC tube instead of the horizontal sync pulses.

in the conduction range so that exact coincidence (as in the conventional keyed AGC circuit) is not necessary in order to derive the full benefit of the AGC action.

In the prior receiver (Fig. 2), essentially the same results were obtained by feeding to the grid of the keyed tube an average voltage developed in the cathode circuit of the horizontal sync separator.

Chrominance Section. The color signal is first met by the bandpass amplifier. Beyond this it is divided, part of the signal going to a cathode follower and part to a burst amplifier. The latter stage stands at the head of the color sync section, and inspection of this portion of the receiver schematic reveals it to be quite similar to the color sync section of the previous CBS receiver.

$R - Y$ and $B - Y$ demodulators receive the color signal from the cathode follower V22A and the appropriate 3.58-Mc subcarrier signals from quadrature network T204. Each demodulator is followed by an amplifier, after which the two signals are transferred to the control grids of the picture tube.

Here, in somewhat greater detail, is an analysis of this portion of the receiver.

$R - Y$ Amplifier. The $-(R - Y)$ signals are coupled from the $R - Y$

demodulator to the grid of V27A, the $R - Y$ amplifier, through peaking coil L205. L205, in conjunction with the $R - Y$ demodulator output capacity and the input capacitance of V27A, forms a low-pass pi-section filter with a pass band from 0 to 1.3 Mc. L207 and C216 at the grid of V27A form a series-resonant trap to further attenuate any 3.58-Mc signals which may have been stray capacitance coupled through the demodulator. The plate of V27A is DC-coupled through L211 to the control grid G_1 of the red gun. R220 (12,000 ohms) forms the DC plate load. Series peaking is provided by L211 damped by R214 (18,000 ohms). L211, R214, R220, the output capacitance of V27A, and the input capacitance of the red gun form a pi-section filter with a pass band of 0 to 1.3 Mc. Degeneration, by current feedback, is provided by the unbypassed 1,200-ohm cathode resistor R213. This type of degeneration, in addition to reducing amplifier distortion, is essential in DC amplifiers. It improves the DC stability of the tube. This is important, for otherwise tube aging and the subsequent plate-voltage drift would change the bias on the red gun and require either a service adjustment or tube replacement.

The DC plate voltage of the $R - Y$ amplifier is also the DC voltage appearing on the control grid of the red gun. This voltage minus the cathode voltage is the bias on the red gun. The grid voltage of this gun is fixed by the circuitry and is not adjustable. The red gun's cathode voltage (all three cathodes are tied together) is adjusted with the brightness control by the set viewer.

Under normal conditions, the gain of the $R - Y$ amplifier is on the order of five times.

$B - Y$ Amplifier. The $B - Y$ amplifier V27B operates very similarly to the $R - Y$ amplifier. It has the same bandwidth characteristics and is compensated in the same manner. The DC plate voltage of V27B is the DC voltage applied to the control grid of the blue gun, and it is controllable with the blue background potentiometer. The blue background control R209A (1,000 ohms) and R210 (33k-ohms) form a voltage divider from $B+$. A small adjustable positive voltage appears at the arm of the blue background control. This is passed through the demodulator circuit without change in value and is applied to the grid of the $B - Y$ amplifier V27B. The setting of the blue background control determines the DC plate current of V27B. This, in turn, determines the DC plate voltage which is applied to the grid G_1 of the blue gun. Thus the blue background control adjusts the bias on the blue gun. The control does not affect the gain of the $B - Y$ amplifier because the tube μ remains fairly constant in the range of plate-current values used.

The gain of the $B - Y$ amplifier is adjustable with the blue gain control R211 (1,000 ohms). The $B - Y$ channel requires more gain than the $R - Y$ channel because the $B - Y$ signal is reduced in level more than the $R - Y$ signal prior to modulation at the transmitter. Approximately 49 per cent of the $B - Y$ signal is transmitted, whereas 87 per cent of the $R - Y$ signal is transmitted. At the receiver, this difference is compensated by making the gain of the $B - Y$ channel $9/5$ that of the $R - Y$ channel. Degeneration is provided in the $B - Y$ channel by the unbypassed cathode resistor R211, which is a potentiometer and labeled the blue gain control. The value of the cathode resistor determines the amount of degeneration and hence the gain of the $B - Y$ amplifier. The blue gain control should be adjusted so that the gain of the $B - Y$ amplifier is $9/5$ that of the $R - Y$ amplifier.

Adjustment of the blue gain control also affects the bias of the $B - Y$ amplifier and, hence, the bias applied to the blue gun. When the blue gain control is adjusted, it will be necessary to make a slight readjustment of the blue background control to return the bias of the blue gun to its former value.

Under normal conditions, the gain of the $B - Y$ amplifier is on the order of nine times.

The $G - Y$ amplifier V23B receives its input signal from a matrix rather than from a demodulator as do the $R - Y$ and $B - Y$ amplifiers. The matrix furnishes a low-level $-(G - Y)$ signal to the grid of the $G - Y$ amplifier. The gain of the $G - Y$ amplifier required to raise this signal to correct level is relatively high and on the order of 35 times. The gain of the $G - Y$ channel should be approximately $3/5$ that of the $R - Y$ channel.

The gain of the $G - Y$ amplifier is not adjustable. It is fixed by the amount of degeneration provided by the unbypassed cathode resistor R225.

The plate of V23B is directly connected to the control grid G_1 of the green gun. The plate voltage of V23B and hence the bias on the green gun is adjusted by means of the green background control R264. R264 is part of a voltage divider from $B+$ consisting of R227, R225, and R242. Varying R264 adjusts the bias on V23B and, hence, controls the DC static plate voltage. R264 and R242 are heavily by-passed with C218B (500 μf), so that only the fixed amount of degeneration provided by R225 is obtained.

No inductive peaking is used to compensate the $B - Y$ plate circuit. Sharp response peaks are carefully avoided to prevent ringing or enhancing the ringing of $G - Y$ signals occurring in certain transmis-

sions. Excessive ringing (due to overpeaking) would be objectionable in the green channel because the eye is most sensitive to the green region of the spectrum. The desired response of the green channel corresponds to that of a resistance-capacitance loaded stage. The response of the $G - Y$ amplifier thus rolls off very gently toward 1.5 Mc.

In the deflection system * there are initially two sync separators. The vertical pulses are then routed to a vertical blocking oscillator, while the horizontal sync pulses go to a phase detector. Neither the vertical nor the horizontal deflection system differs to any appreciable extent from similar sections in monochrome receivers. What difference there is rests principally in the high-voltage circuit, which was fully covered in Chap. 8. Also discussed in the same chapter are the dynamic-convergence network and the low-voltage power supply.

ADJUSTMENTS IN THE MOTOROLA COLOR RECEIVER

The simplicity of the Motorola circuit plus the use of diodes in the color sync section and as demodulators makes the set rather easy to adjust. Of principal interest here is the adjustment of the stages in the color section of the receiver, and detailed procedures are given below.

Color-sync-section Adjustment. The principal stage in this section is the 3.58-Mc oscillator. As a first step, oscillator injection and alignment will be checked. To begin with the oscillator injection, connect a VTVM to the cathode of V24A using a 100,000-ohm isolation resistor. (If the VTVM probe has its own isolation resistor in its probe, the 10,000-ohm resistor is not required.) Short the control grid of the burst amplifier V23A to ground to eliminate readings from spurious incoming signals.

If the 3.58-Mc oscillator is operating normally, the VTVM will read approximately 12 volts of injection. Next remove the short circuit from the burst amplifier grid and tune in a color signal or a transmission supplying the standard burst of color sync. The chroma control is set for a normal color picture or near maximum rotation. Then the color shading control (at the grid of the burst amplifier) is set to half mesh so that capacitance increase or decrease will be available later. The VTVM remains connected to the cathode of V24A.

The first step in circuit alignment is to ensure that the maximum amplitude of color burst is reaching the two diodes of the AFC network. Toward that end, first L204 is adjusted and then T203. The procedure is as follows:

* See Chap. 8 for more detailed discussion of circuit operation.

Fully retract the slugs of the burst amplifier grid coil L204 and the coupling transformer to the AFC circuit T203. Adjust both slugs for maximum reading on the VTVM. Next remove the burst signal by connecting a short from the burst amplifier grid coil to ground. Move the VTVM to the center arm of the AFC balance potentiometer. The meter ground lead connects to the chassis. Now adjust the AFC balance potentiometer for 0 volts on the VTVM.

The short is then removed from the grid of the burst amplifier, permitting the incoming burst signal to reach the AFC circuit. Adjust L215 in the plate circuit of the reactance tube to bring the 3.58-Mc oscillator in phase with the incoming burst. This condition is reached when the VTVM reads 0 volts. At this reading no correction voltage is being developed by the AFC system.

The final step in the alignment of the color sync section is the peaking of L210 and L209 in T204. This is the quadrature network which provides suitably phased 3.58-Mc subcarrier signals to the $R - Y$ and $B - Y$ demodulators. Alignment of T204 is carried out as follows:

A VTVM is connected to the cathode of V25A, the $R - Y$ demodulator, through a 10,000-ohm isolating resistor. Ground terminal of the meter goes to the receiver chassis.

With the receiver in operation, a DC voltage will appear at the cathode of V25A because the diode is detecting the applied 3.58-Mc oscillations. The value will be somewhere in the neighborhood of 25 volts. The slug in L210 is now adjusted until the VTVM reading is maximum.

L209 is taken next, and a moment's reflection will reveal that since C211 and L209 form a series-resonant circuit, they will impose maximum load across the rest of the quadrature network when they are tuned to 3.58 Mc. Hence the slug in L209 is rotated until the meter at the cathode of V25A dips. To ensure that the alignment is precise, the over-all procedure is repeated several times until no further adjustments are required.

Each of the foregoing procedures is straightforward and should present little difficulty. Note how advantage is taken of the various diodes to provide suitable demodulators for the 3.58-Mc signal. Actually, if an oscilloscope capable of presenting a 3.58-Mc wave on its screen is available, the various demodulation points can be dispensed with and the amplitude of the oscillations observed directly. The results, in either case, will be similar.

Alignment of Bandpass System. The stages which are encompassed in the alignment of the chrominance bandpass system are: the first

video amplifier, the second video amplifier, the bandpass amplifier, the bandpass cathode follower, and the $R - Y$ demodulator. The sweep signal (obtained by one of the prior methods) is injected into the first video amplifier by unsoldering the grid series peaking coil leading to the video detector and connecting the sweep generator to the loose end. The manufacturer indicates that the sweep generator be terminated in the network shown in Fig. 32 in order for the proper results to be obtained.

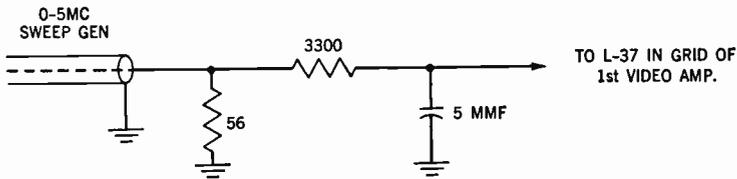


FIG. 32

The oscilloscope connects to the input side of the $R - Y$ demodulator (junction of 33- μf capacitor and 10,000-ohm resistor). Use a 10,000-ohm isolation resistor in the vertical input lead.

The sections tuned during this procedure are: the first video amplifier 4.5-Mc plate trap coil L39, the coupling transformer at the grid of the bandpass cathode follower T201 for 2.5 Mc on the bandpass curve, and coils in the cathode follower T202 for a symmetrical curve.

As a first step, remove the 3.58-Mc color oscillator tube V28B. Then connect a bypass capacitor of 0.05 μf , 400 volts, from the junction of the 2,200-ohm resistor R218 and the delay line to ground. This is done to prevent the delay line from affecting the bandpass response curve.

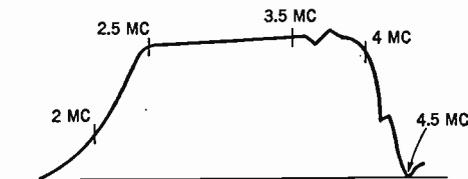


FIG. 33. Response curve of bandpass amplifier in Fig. 2A.

Set the channel selector switch to an unused channel. Set the contrast control for maximum (fully clockwise). Also set the color intensity (chroma) control to maximum. Couple a marker generator into the circuit and set it to 4.5 Mc. Then adjust the 4.5-Mc trap coil L39 for a trap dip in swept curve (see Fig. 33).

Adjust coil in grid circuit of bandpass cathode follower T201 to place 2.5-Mc marker at the knee of the curve. Finally, adjust T202 for least tilt and symmetrical response curve.

It is interesting to note that in this circuit we can dispense with a demodulator probe for the oscilloscope because of the use of diodes in the color demodulator circuit.

Color-demodulator Adjustment. For the proper rendition of colors on the screen, it is important that the two diodes comprising each demodulator be balanced as closely as possible. While the circuit is not critical and small circuit unbalances due to parts tolerances will not noticeably affect the color reproduction, still any appreciable unbalance will have a very marked effect.

A testing procedure has been set up to check demodulator balance, and it is rather easily carried out. One end of a VTVM is connected to the cold side of the oscillator injection coils (L209 or L210) while the DC probe of the meter goes to the junction of the two 10,000-ohm load resistors of one set of diodes (say V25A and B). The purpose of this test is to check the oscillator injection only, and hence chrominance signals must be prevented from reaching the detectors. Toward this end V8, the bandpass amplifier tube, is removed from its socket.

The VTVM should read less than ± 2 volts. This test should be made in both demodulator circuits and if satisfactory, the diodes are balanced so far as the 3.58-Mc subcarrier injection voltage is concerned.

The next check is balance of the circuit with respect to the incoming signal. This is carried out as follows:

1. Return V8 to its socket, and remove V6, the preceding video amplifier tube.
2. Turn the chroma control to maximum position (fully clockwise).
3. Disable the 3.58-Mc local oscillator by removing the oscillator tube V28.
4. Apply a substitution signal of 3.58 Mc to the control grid of V8, the bandpass amplifier. An external signal generator is employed for this purpose.

If the balance of the bifilar coil T202 feeding the demodulators is correct and the diode detectors are OK, then the VTVM connected to the junction of the two 10,000-ohm load resistors should read less than ± 2 volts.

When an appreciable unbalance is revealed by *either* of the foregoing checks, then it is suggested that a wide-band oscilloscope using a low-capacity probe be employed to determine where the unbalance is arising. For example, the voltage applied to each diode should be

checked to determine its amplitude. At the bifilar coil T202, each hot lead should be tested for equal output. At the oscillator, the symmetry of the generated wave form should be examined, since this too can be the cause of unequal output voltages from the demodulators. The approach is a logical one and enables the service technician to work step by step from the two $R - Y$, $B - Y$ detectors to the source of the applied signal.

The final test to be made on the diode demodulators is one for equal efficiency. In other words, are both diodes in a demodulator circuit functioning with equal effectiveness in producing the demodulated output voltage? Here is how this test is carried out.

1. Remove V6, the first and second video amplifiers.
2. Turn chroma control to maximum.

3. Connect an external generator set at approximately 3.58 Mc, CW, to the grid of V8. Tune the generator so that it is at least several hundred cycles removed in frequency from the local 3.58-Mc color oscillator (which is now in operation). Four or five slanting color bars will appear on the screen. Low-frequency sine waves will appear at the output of both $R - Y$ and $B - Y$ demodulators. Both should possess the same height (peak-to-peak amplitude) if both circuits are operating with equal efficiency.

Adjustment of $B - Y$, $R - Y$, and $G - Y$ Stages. Two methods are suggested for adjusting $B - Y$ channel gain. Each is equally valid; the choice is made for convenience, considering the equipment setup available.

1. *With external 3.58-Mc generator.* Connect a CW signal at approximately 3.58 Mc to the grid of the bandpass amplifier V8. (If the generator has enough output, connect it to the grid of the bandpass cathode follower V22A.) Carefully tune the generator near but not exactly at 3.58 Mc. A sine-wave voltage (the heterodyne product between the local 3.58-Mc oscillator and the external CW signal) will appear at both demodulator outputs. Connect an oscilloscope to the output of the $R - Y$ amplifier. It is preferable to use an oscilloscope with low-capacitance probe. Tune the external generator so that the beat note is low in frequency. Avoid overloading the receiver amplifiers. Adjust the oscilloscope gain so that the peak-to-peak signal occupies 5 units on the screen's graticule. Do not make any further adjustments of either oscilloscope or external signal generator.

Connect the oscilloscope to the output of the $B - Y$ amplifier. Adjust the blue gain control until the peak-to-peak signal on the oscilloscope screen occupies 9 units on the graticule.

The $G - Y$ channel gain may be conveniently checked when the preceding setup has been effected. Connect scope to output of $G - Y$ amplifier. The beat note should have a peak-to-peak value of 3 (2.5 to 3.5 is allowable) units on the graticule.

2. *With fixed color-bar signal from a transmitter or a color-bar generator.* Tune receiver to channel transmitted and adjust operating controls for normal operation. Turn color intensity control to desaturate bars on screen slightly below what would be normal, so as to avoid possible overloading of color-difference amplifiers.

Cause the receiver local oscillator to go far enough out of sync to produce at least four or five diagonal color bars on the screen. One of a number of methods of accomplishing this is to short out to ground one side of the AFC diode on the burst input side, to produce an extreme unbalance condition.

Connect a wide-band low-input-capacitance oscilloscope, synced at horizontal frequency rate, to the output of the $R - Y$ amplifier. The wave form observed on the oscilloscope will appear to be very much like that appearing at the output of the bandpass amplifier. If the local 3.58-Mc oscillator is far enough out of sync, a stable pattern will be obtained.

Observe the pattern and choose the bar signal (seen as voltage pulse) with the greatest peak-to-peak value (do not choose the burst). Set the oscilloscope gain so that the chosen bar occupies 5 units of the screen's graticule.

Do not change any receiver controls or equipment controls except as directed in the following:

Connect the oscilloscope to the $B - Y$ amplifier output.

Adjust the blue gain control so that the chosen bar occupies 9 units of the graticule on the face of the oscilloscope.

COLOR-BAR GENERATORS

Mention has been made at several points in this chapter of color-bar generators. These are instruments which develop color signals for use in the servicing and alignment of color receivers. In service, for example, a color-bar generator can be put to a variety of uses, from the overall inspection of the color behavior and color fidelity of a receiver down to a stage-by-stage analysis of either the luminance or chrominance sections of the receiver. In adjustment and alignment, use of a known color signal quickly enables the technician to determine whether a

circuit or a section is in adjustment and, if not, when this condition is attained in subsequent alignment.

Color-bar generators come in a variety of designs, with the three in Figs. 34 and 35 fairly representative of those most widely used. The unit in Fig. 34 is the RCA Model WR61A color-bar generator. This instrument generates the signals for producing 10 bars of different colors simultaneously (without switching), including the bars corresponding to the $R - Y$, $B - Y$, $G - Y$, I , and Q signals (see Fig. 36). The bars are accurately spaced at 30° phase intervals.

The output signal from the WR61A, fixed at channel 3, consists of an unmodulated sound carrier, a picture carrier modulated by a color subcarrier, and horizontal synchronizing pulses at 15,750 cps. The picture carrier, color subcarrier, sound carrier, bar frequency, and horizontal sync pulses are crystal-controlled for accuracy and stability.

A separate video output of either positive or negative polarity is available at a front-panel terminal for trouble-shooting color receivers. The video output is useful, for example, in determining whether the defective stage is ahead of or after the second detector. RF output is

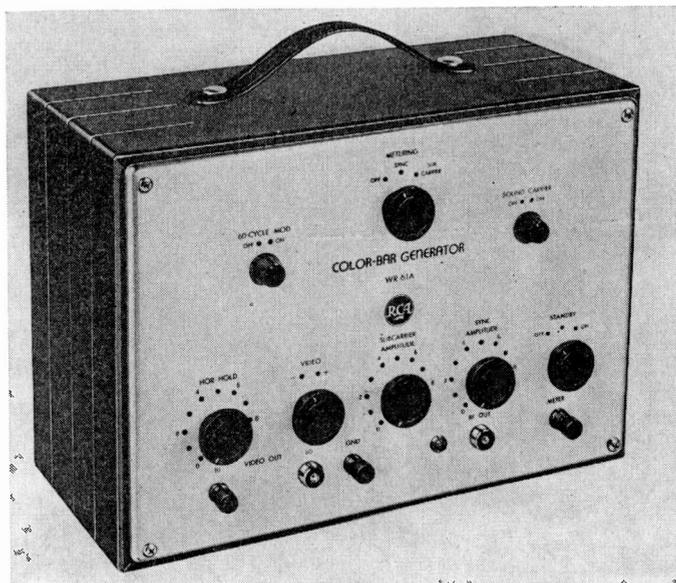
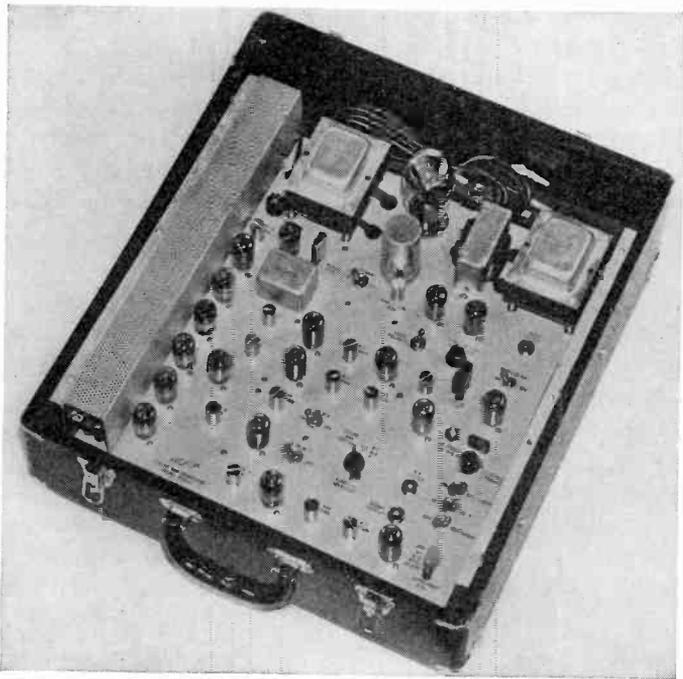
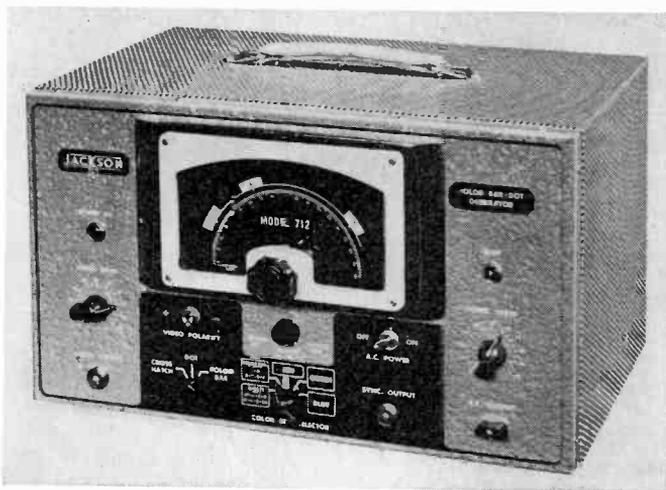


FIG. 34. RCA Model WR61A color-bar generator.



(A)



(B)

FIG. 35. (A) Hickok Model 655XC and (B) Jackson Model 712 color-bar generators.

approximately 0.01 volt peak to peak across a balanced 300-ohm load; video output at maximum is approximately 8 volts peak to peak across 4,700 ohms.

A front-panel switch permits removal of the sound carrier from the output signal. This permits identification of sound interference in the bar pattern. The sound carrier is provided to ensure precise tuning of the receiver and to check sound rejection and beat interference between the color subcarrier and the sound carrier.

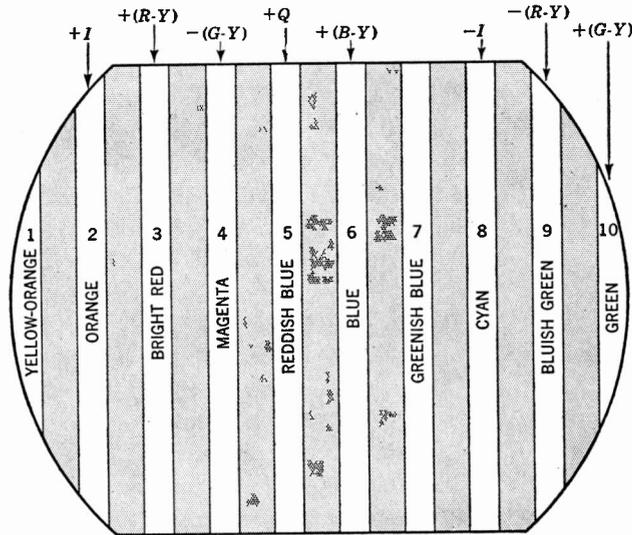


FIG. 36. Bar pattern developed by RCA Model WR61A color-bar generator. The relationship of the color bars and specific points on a color phase diagram is indicated at the top of the illustration.

Luminance signals are provided between the color bars to check the registration of the luminance and chrominance signals. (This is, in essence, a check on the time-delay networks in the receiver.) A 60-cps brightness signal, applied to the output by means of a front-panel switch, produces a horizontal area of increased brightness to check for possible change of hue in the bright areas or highlights of the color picture. The amplitude of the color subcarrier and color-burst signal is adjustable by means of another front-panel control to facilitate checking of the color-sync lock in the receiver.

The second color-bar generator (Fig. 35A) is the Hickok Model 655XC. It provides several types of signals, either at radio frequency (channels, 4, 5, or 6) or in direct video form. These signals are:

1. A standard NTSC 100 per cent saturated bar pattern with the.

colors in the following order from left to right across the screen: green, yellow, red, magenta, white, cyan, and blue.

2. I, Q bars with selector switch in the second position.

3. $B - Y, R - Y$ bars with the selector switch in the third position.

Switches are available for removing either the I or Q when these are being shown together or for removing $R - Y$ or $B - Y$ when these two are being presented on the screen. The latter feature is useful in adjusting the relative phase of the 3.58-Mc subcarrier signals fed to the color demodulators. The same facility can also be employed for checking the adjustment of the separate I, Q or $R - Y, B - Y$ channels, since I (or $R - Y$) signals should not be present in Q (or $B - Y$) channels (and vice versa).

A crystal for a 4.5-Mc sound carrier or a suitable crystal for the sound radio frequency for channels, 4, 5, or 6 can be obtained.

The third color-bar generator is the Jackson Model 712. In addition to the color signals which it provides, there is also available a dot pattern for convergence adjustments and a cross-hatch pattern for linearity adjustments.

In the color section of the unit the following signals are available either in modulated form (radio frequency on channels 3, 4, or 5) or in video form.

1. A color-bar pattern with the colors appearing in the following sequence: white, yellow, cyan, green, magenta, red, blue, and black.

2. I, Q or $R - Y, B - Y$ signals.

3. A separate red color.

4. A separate green color.

5. A separate blue color.

The last three items are designed to permit the technician to check how well the system beyond the color demodulators has been adjusted. For example, with red only appearing on the screen, no video signals should be present at the green or blue control grids of the color tube. Similarly, with each of the other colors active, no signal should be observed on the remaining two grids. In essence, this is a dynamic check on the color purity of the various receiver circuits. Static color purity tests were previously covered in Chap. 7. These, it will be recalled, were concerned with the adjustment of the color purity magnet on the neck of the picture tube.

In conclusion, then, color-bar generators enable the service technician to check over-all receiver performance as well as the alignment condition of individual circuits. For the practicing serviceman, this is a valuable adjunct to his normal complement of service instruments.

QUESTIONS

Answer the following questions concerning the CBS color receiver Model 205:

1. How many trap circuits are there in the video IF system? List them by frequencies and stage location.
2. Which stages beyond the video second detector deal with the luminance signal (either exclusively or in conjunction with the color signal)?
3. List the resistors in the matrix network.
4. List the tubes in the dynamic-convergence system. Indicate the function of each.
5. What type of color sync system is employed? Briefly outline its mode of operation.
6. How is high voltage developed? What is the function of V40? How does it achieve this?
7. How much time delay is introduced in the *I* channel? Indicate the components in the time-delay network.
8. Which demodulator has higher gain, V22 or V23? Substantiate your answer.
9. How does the color-killer stage function in this receiver?

Answer the following questions concerning the Motorola color receiver Model TS-902A-03:

10. How does the quadrature network of T204 function?
11. Why is the response of the *G* - *Y* amplifier narrower than that of the *R* - *Y* and *B* - *Y* amplifiers?
12. How is the *G* - *Y* signal formed?
13. What is the advantage of the AGC system employed in this receiver compared to the conventional keyed AGC system?
14. Explain briefly the operation of the convergence network in Fig. 2A.
15. Trace the paths of the luminance and chrominance signals through this receiver. Start at the video second detector.
16. Explain the operation of the low-voltage power supply of the Motorola receiver.

The following questions are either general in nature (i.e., apply to no specific receiver) or else pertain only to the circuit indicated:

17. What are the general steps in the alignment of an RF tuner?
18. How would you align the sound IF system of the Motorola receiver? Use a VTVM and signal generator only.
19. How do you view the response of individual circuits in a video IF system? Use the CBS receiver as your example.
20. Draw the over-all response curve of the video IF system of a color receiver. In what respects is this more critical than the video IF response of a monochrome receiver?
21. What equipment is needed to obtain the response curve of a video amplifier system?
22. Outline the alignment procedure of the bandpass amplifier of the CBS receiver.
23. Do the same for the bandpass section of the Motorola receiver.

24. What is the general procedure for aligning the color sync section of the CBS receiver?
25. How is the circuit balance of the color demodulators in the Motorola receiver checked?
26. What test is made to ascertain the equality of their efficiency?
27. What are color-bar generators?
28. Indicate the type of signals color-bar generators furnish.

CHAPTER 10

COLOR TELEVISION SERVICING

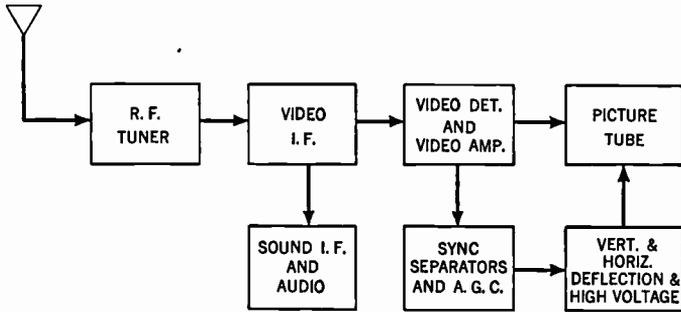
We have, in prior chapters, been investigating the basic operating principles of color television receivers, using typical circuits taken from receivers which have been exhibited to the public. All this has been, in a sense, a forerunner for the job that the service technician will have when color sets are placed in the hands of the public in quantity—the job of servicing these receivers and of nursing them back to good operating condition.

The color television receiver, we have seen, contains many more circuits than a black-and-white or monochrome receiver. This does not necessarily imply that color sets will be proportionately more difficult to service. Undoubtedly they will present more problems, but experience has shown that much of this difficulty can be reduced if the technician appreciates the differences between monochrome and color sets and develops a logical basis of approach founded on these differences.

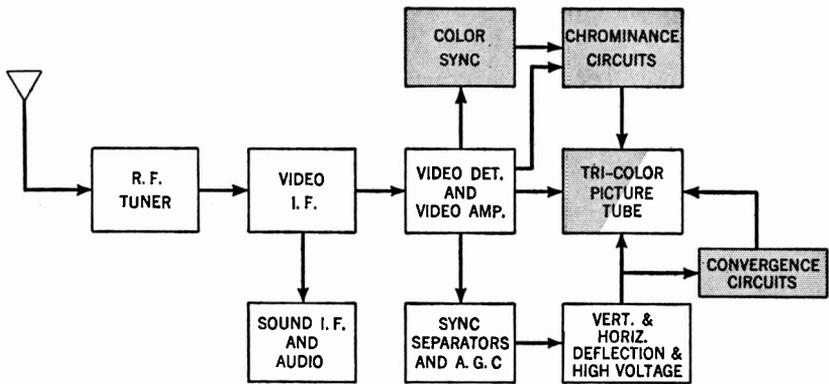
A comparison between black-and-white and color receivers was made at the outset of the book, but it may not be amiss to review the situation briefly at the start of this servicing discussion.

Block diagrams of color television and monochrome receivers are shown in Fig. 1. To emphasize the differences between the two systems, every box in the color television diagram which has no counterpart in the black-and-white receiver has been shaded. This immediately reveals that the color sync section, the chrominance circuits, and the convergence circuits are nonexistent in a monochrome receiver. The picture tube has been shown as partially shaded to draw attention to the fact that while it differs considerably from its black-and-white counterpart, still the two have many points in common. Both use electron guns to develop scanning beams and phosphor screens to convert this electrical energy into light. On the other hand, the color screen must present three colors in place of one, and its structure differs accordingly.

In the remaining receiver circuits, such as the RF section, the video IF amplifiers, the sound system, the sync separators, the AGC, and the sweep sections, both receivers use substantially the same circuits. Differences here are more a matter of degree than of basic form. In the



(A) BLACK-AND-WHITE RECEIVER



(B) COLOR TELEVISION RECEIVER

FIG. 1. Comparison block diagrams of black-and-white and color television receivers. The shaded boxes in (B) have no counterpart in the black-and-white receiver.

video IF system, for example, the response is wider, but it still possesses the same general shape with the same trap frequencies. In the deflection system, principally the horizontal section, more drive is required and more high voltage must be developed, but again anyone familiar with these circuits in monochrome sets would have little trouble in analyzing the corresponding circuits in color sets. Every bit of knowl-

edge acquired by the technician from his work on black-and-white sets will be of value in servicing color receivers. This is an important fact to remember.

THE FIRST STEP

The initial step in the servicing of a color receiver starts with observing the picture and listening to the sound. If one is affected but not the other, we would confine ourselves to that portion of the receiver which dealt with that particular signal alone. For example, suppose we found the picture normal, but the sound either distorted or missing. Then we would start at the sound-video separation point and proceed along the path followed by the sound signal alone until it reached the loud-speaker. In every color receiver which has been shown to date, sound and video signal separation occurred either in the last video IF stage or in the video second detector. All sets operated on the inter-carrier principle, and consequently the sound intermediate frequency was 4.5 Mc.

The other alternative is if the sound is normal but the picture affected. Speaking generally, the video signal travels by itself through the video amplifiers, through portions of the chrominance circuits, through several DC restorers, and finally to the picture tube. The path taken by color signals is more extensive, since we must include a complete color sync section and a chrominance section.

Another consideration when the picture is affected, is whether it is the picture which is at fault or the raster. If it is the raster which is causing the difficulty, then other circuits would come under consideration, for example, the vertical sweep system, the horizontal sweep system, and the high-voltage section.

Thus, as the initial step in analyzing a defective color television receiver, we see that three major items should be checked: the sound, the video portion of the picture, and the raster. Trouble in any one of these, without a corresponding distortion in either of the others, would more or less indicate that the trouble was confined to a specific well-defined section of the receiver, and all subsequent tests would be directed toward this section.

Mention has already been made of the procedure to follow if the sound only is affected. This is exactly the same approach that would be taken in a monochrome receiver.

Concerning trouble in the picture, the first thing to do is determine whether it is the raster or the video signal which is at fault. To perform

this test, switch the set to a channel which is not being used. With the contrast control turned completely counterclockwise and the brightness control set at mid-position, a raster should be obtained which is more or less gray in appearance and which completely covers the screen. If this condition is observed, then we know the following facts concerning the receiver:

1. The picture tube has been properly adjusted insofar as purity and convergence are concerned. (We are referring here to the three-gun color tube using a shadow mask.)
2. The deflection systems, vertical and horizontal, are functioning normally, producing the required beam sweep and the correct amount of high voltage.
3. The convergence circuit, with its amplifier and wave-shaping networks, can also be presumed to be operating satisfactorily.

Now suppose that you have inspected the raster and found it to be OK. However, when you switch to a channel transmitting black-and-white pictures, you obtain an image which is color-tinted, say yellow. Since the signal is a monochrome one, you know that the color sync section and the chrominance circuits are inoperative. Therefore, the trouble could not exist in these stages.

To find the source of the trouble, let us examine the video section of one type of color receiver. This is shown in Fig. 2. The Y or monochrome signal travels from its detector through a cathode follower and then a video amplifier. Beyond this is the matrix, and if we continue to follow the Y signal, we see that it enters the matrix and is distributed equally to each of the color adder stages. This means that the red, green, and blue amplifiers will each receive equal amounts of the Y signal, and if nothing happens in any of these sections, then each of the grids in the color picture tube should receive the proper amount of voltage to produce a black-and-white picture. (Note that we do not say each should receive the same amount of Y signal voltage. Actually, in most tubes, the red grid will receive more voltage because of the lower efficiency of the red phosphor. Whether this condition will always be true depends upon the progress made in developing more efficient phosphors.)

Up to the matrix or distribution point of the Y signal, all segments of the signal are kept together. Furthermore, nothing in the video detector or Y video amplifiers can affect one color on the screen and not the others. It is only after the Y signal is divided among the red, green, and blue amplifiers that trouble in picture coloring could arise. This would occur if something prevented one of these sections from

functioning normally. In the present instance we indicated that the picture had a yellowish overcast. The job, now, is to determine which section contains the defect.

There are several possible approaches to this problem. One would be to remove each of the 6CL6 color video amplifiers. This would remove the picture completely from the screen. Then reinsert one of the tubes, say the red video tube. The picture on the screen should be completely red. If it is, then this tube can be removed and the blue video amplifier tube inserted in its socket. The same picture should appear on the screen, only this time colored completely in blue. For the final test, remove the blue amplifier tube and insert the green video amplifier tube. The image now should be green. Failure of any one of these colors to appear at all or in sufficient strength would indicate that the trouble existed in its section. In the present instance, it was the blue section which was at fault. The green and the red voltages, reaching the picture tube, combined to produce a yellowish image.

The same solution can be achieved much more quickly if the serviceman applies the principles of additive color mixing. For example, red and green will produce mixtures ranging from orange to yellow. Green and blue will produce cyan; and red and blue will give us magenta. The same facts are indicated on the chromaticity diagram (Fig. 3) and, to a lesser extent, on the color phase diagram (Fig. 4).

Here is how we would employ the chromaticity chart to help us locate the defective section in the case history assumed above. Since the predominant color on the screen was yellow, we would locate the general area occupied by yellow on the chromaticity diagram (see Fig. 3). Now, with a finger at this point, trace out a straight line to white and beyond this, to blue. Blue is the complementary color of yellow, since blue added to yellow will produce white. Thus, blue is obviously missing from our picture and investigation of the blue channel is indicated.

The complementary color of cyan or bluish green can be found in a similar manner. Place your finger on the area marked bluish green and move it on a line through white. The color you meet on the opposite side of white is among the reds, and hence red is the complementary companion of cyan. For magenta, or reddish purple, the complementary color is green.

The same information is contained in the color phase diagram of Fig. 4. Note that yellow is located between red and green. Also, blue is at the opposite end of the yellow line, this being the position of the com-

plementary color. The same procedure can be carried out for all other colors.

Thus, being familiar with color mixing is especially helpful to the color-receiver technician. In fact, it is a good idea to have a chromaticity chart and a color phase diagram pinned up over your workbench for quick reference.

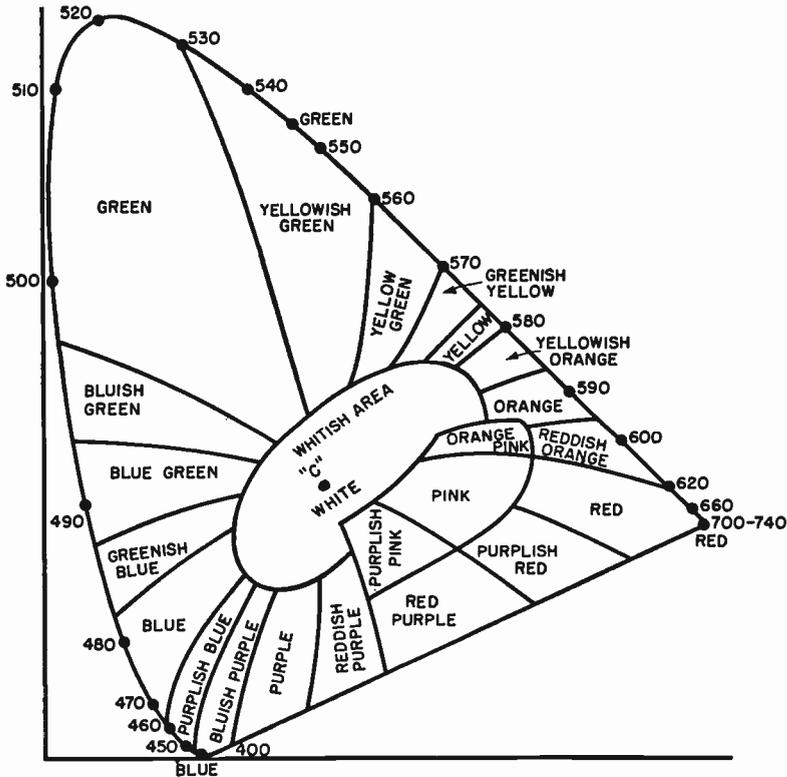


FIG. 3. A chromaticity diagram, which is useful for color mixing.

The statement was made that the receiver should be checked on a black-and-white picture before any check is made on color. For those who may wonder how this can be done when only color broadcasts are being received, the answer is quite simple. Disable the color section by removing the bandpass amplifier tube. This will prevent the color signal or the color burst from reaching the color sync or chrominance

section and actuating them. The result will be a black-and-white picture.

When a receiver gives normal indications on the raster test and with a black-and-white signal, we know that, in addition to the sections previously listed as being normal, we can now add the entire Y chan-

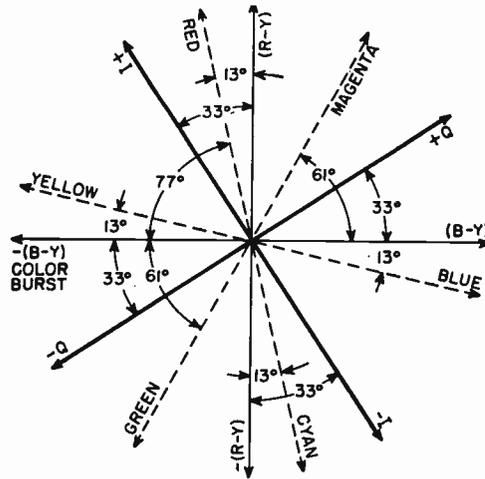


FIG. 4. Color phase diagram, showing the positions of the various key colors and the I and Q vectors. The position of the color burst is also shown.

nel * plus the matrix plus the color video amplifiers that follow the matrix. As the reader can well appreciate, this represents a fair-sized section of the set.

A precise method of determining whether each of the color video amplifiers is operating as it should is to measure the gain of each section. The check can be made by using a low-frequency signal generator and an oscilloscope. A frequency around 50 kc is satisfactory. Connect the generator to the control grid of the red video amplifier (Fig. 2) and connect the vertical input terminals of the oscilloscope between red grid and ground of the picture tube. Turn the equipment on and adjust the signal generator until the 50-kc sine wave appears on the face of the oscilloscope screen. Measure the peak-to-peak value of this wave after it has been adjusted to a suitable height on the screen. The measurement may be made with the oscilloscope, if such a facility is available, or an external voltage calibrator may be employed.

* It is possible for the delay line to be defective and escape disclosure with the tests prescribed. This will be discussed later.

Transfer the oscilloscope to the control grid of the 6CL6 video amplifier, and measure the peak-to-peak value of the applied signal. This figure divided into the previous figure will give the over-all gain of the entire video system. If the manufacturer furnishes this information, then a precise check can be made of the operating conditions of these amplifiers.

(The foregoing discussion will not apply to those $R - Y$, $B - Y$ receivers in which the matrixing takes place in the picture tube. In these circuits, if the monochrome presentation is color-tinted, the raster will be similarly affected in the absence of a signal.)

RASTER COLORED

Thus far we have assumed that the raster is a normal gray when observed by itself, without the presence of a picture. It is possible that this will not occur and that the raster, when viewed, will be colored or tinted. Let us see under what conditions this can occur and what can be done to correct it.

The components which affect or govern the shading or coloring of a raster (and subsequently, the coloring of a picture) are the following:

1. The purity coil.
2. The electron guns.
3. The voltages on each electron gun.
4. The DC and dynamic-convergence controls.

Let us consider each in turn.

The purity coil is mounted near the base end of the picture tube, and its purpose is to guide the electron beam from each gun to the correct color dots. That is, the green beam (the beam from the green gun) should strike only green-light-emitting phosphor dots, the red beam should strike only those phosphor dots emitting red light, etc. Any deviation from this desired action will lead to color contamination (the appearance of colors other than the desired ones).

When the color-purity coil is not positioned properly or the color-purity control is not correctly set, then it will be impossible to obtain a pure white (or gray) over the entire screen. If white is achieved in one sector, the raster will be colored elsewhere. Color changes will occur gradually, rather than sharply or abruptly.

To determine whether the color purity is acceptable, the following procedure is recommended:

1. Turn the Contrast control to minimum and the Brightness control nearly to maximum.

2. Turn the blue and green screen controls completely counter-clockwise. Turn the red screen control to the extreme right. This will cut off the currents in the blue and green guns and operate the red gun at maximum.

Now examine the screen, which should contain a red raster. If the red color is uniform over the screen, purity of this color is indicated. It may be found that some departure from pure red is present near the edges of the screen, but if the color variation is not too great, the condition may be normal for that tube. If in doubt, it might be advisable to go through the color purity-adjustments as prescribed by the manufacturer.

Once a uniform red field is obtained, chances are that uniform green and uniform blue fields will also be obtained. The latter checks are carried out by advancing the associated screen-grid control while the other screen-grid controls are turned to the left.

Failure to obtain uniform red, green, and blue fields, even after the manufacturer's instructions are carried out, usually signifies that the tube or the purity coil is defective. Defects in picture tubes stem from electron guns that are out of alignment or shadow masks that are warped.

The voltages which are applied to the various electrodes of an electron gun will seldom be the cause of poor color purity. However, they can lead to a raster (or a picture) which is deficient in one of the primary colors. The visual result is as though we had placed a sheet of transparent filter paper over the screen, giving everything appearing on the screen a tinted appearance. The gun responsible for the color deficiency can be isolated by applying the principles of color mixing indicated earlier.

Another reason for a colored raster is improper DC or dynamic convergence or both of the electron beams. Color purity, which we have just discussed, serves to force each beam to strike only one type of phosphor dot whenever these beams strike the screen. Still required, however, is some means of bringing together all three beams so that each passes through the same hole in the shadow mask at the same time in order that adjacent dots will be activated. This action is needed to ensure that the observer will see a single, resultant color from the action of the three beams and not two or three separate colors. In the absence of this converging action, it would be possible for the beams to strike phosphor dots at sufficiently separated points so that an observer would see three individual points of colored light, and mixing of the colors would not be possible.

When the DC convergence control is properly set, the red, green, and blue pin points of light in each trio of dots will blend together and produce white light on a raster. On the other hand, when the DC convergence control is misset, the individual red, green, and blue pin points of light will be visible everywhere. This effect is perhaps best observed with a picture on the screen. The misregistration of the colors leads to a blurred rainbow effect, such as we occasionally find in roto-gravure pictures when the various colors are improperly aligned with each other.

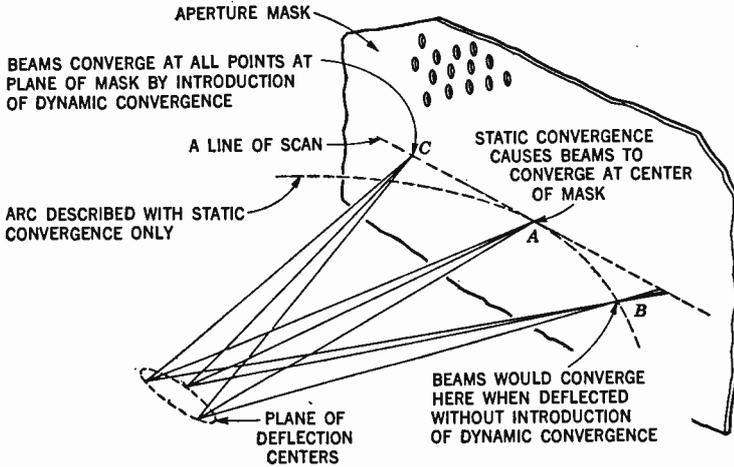


Fig. 5. Dynamic-convergence voltages are required because the screen and shadow mask are not perfectly spherical. (The departure from the correct curvature is exaggerated in the illustration to make it more evident.)

Poor color purity and improper DC convergence can thus be distinguished as follows: When the color purity is poor, it is not possible to develop uniform red, green, or blue fields on the screen. On the other hand, with poor convergence, individual primary color fields which are pure can be developed, but combination colors cannot.

In addition to DC convergence, there is also dynamic convergence. The need for this additional correction stems from the fact that neither the shadow mask nor the phosphor-dot screen are properly curved surfaces. That is, as the beam sweeps back and forth across the face of the tube, it follows an arc, as shown in Fig. 5. The curvature of the screen and the shadow mask deviate sufficiently from this arc so that a beam which is properly converged over the central area of the screen will not be correctly converged at the edges of the screen.

To correct this condition, special parabolic-shaped currents are applied to neck-mounted convergence coils, and when the system is operating properly, the raster (or picture) is as correctly converged at the edges as it is in the center. It may be that with some tubes a slight amount of misconvergence is normal at the sides of the screen, and here you will see some of the red, green, and blue colors. When the dynamic convergence controls are not properly adjusted or the associated circuits are not functioning properly, then the misconvergence will be marked.

The distinguishing characteristic of dynamic misconvergence is the appearance of colors at the edges of an otherwise white (or gray) raster. This effect is best seen on a raster, although it is detectable in a picture.

COLORED SNOW

There is one further difficulty that may lead to the appearance of color in what should be a black-and-white picture. This time the effect is that of a picture having a mottled look. The picture contains a background of small colored pinpricks of light such as you might obtain with colored snow in a picture in place of black-and-white snow in monochrome receivers. The colored flashes have no discernible pattern, leading to the conclusion that they are random in nature.

The source of this trouble lies in the chrominance section of the receiver. Ordinarily, with the reception of black-and-white signals, one or more chrominance amplifiers are held beyond cutoff by a negative bias generated in a color-killer stage. However, if something should prevent this stage from functioning properly and a killer bias not be developed, then signals will be able to pass through the chrominance section and reach the matrix and beyond this the three color grids of the picture tube. The random appearance of the color is due to the fact that the 3.58-Mc color subcarrier oscillator is not being synchronized (since no color-burst voltages are present in monochrome signals), and consequently there is no definite pattern to the phase of the signal it generates. Color is a product of the combined interaction of signal voltages reaching the color demodulators and the phase of the 3.58-Mc subcarrier.

Colored snow can also be obtained in the absence of any received video signals by the noise picked up by the antenna or generated in the receiver. This behavior is normal and need cause no concern.

DEFECTS IN THE COLOR SECTIONS OF COLOR TV RECEIVERS

Thus far we have considered two major aspects of color television receiver servicing: raster checking and the viewing of a black-and-white picture to see whether any extraneous color appears. These two checks are always made in the sequence given in order to isolate a trouble to a specific section of the receiver. We refer here to defects whose origin is not immediately recognizable from an inspection of the screen in the first place. However, if we find that no picture at all can be obtained on the screen, then obviously raster inspection as indicated above would hardly be necessary. In this instance, the best approach would be to trace the signal with an oscilloscope, starting perhaps at the video second detector. On the other hand, if we do obtain a picture on the screen and it is distorted either in shape or in color, then the testing procedure previously outlined would be entirely in order.

We come now to those color troubles which have their origin in the color sections of the receiver. Analysis reveals that these color defects will generally fall into one of three categories.

1. No color at all when we know that there should be color.
2. Incorrect color rendition.
3. Color instability.

The foregoing categories are fairly well defined and the service technician will generally have little difficulty in finding the proper group for a specific trouble. Once the allocation is made, the technician is then able to proceed in a logical manner to further narrow down the location of the defect. The rewards of a systematic procedure include not only shorter servicing time and the assurance of doing the job correctly the first time, but also the satisfaction and pride that every successful technician feels from the knowledge of a job well done.

COMPLETE LACK OF COLOR

There are a number of possible reasons for a color set's not developing a color picture when it is definitely known that a color signal is being received.

Misadjustment of the Fine-tuning Control. One possibility which immediately suggests itself and which is likely to be a common cause of no color is misadjustment of the fine-tuning control. To appreciate the reason for this, let us consider the action of this control in its relation to the manner in which the set treats the signal.

In the incoming signal the picture carrier is always below the sound carrier. In channel 3 (60 to 66 Mc), for example, the picture RF carrier is positioned at 61.25 Mc and the sound RF carrier is at 65.75 Mc. These signals mix with the output of an RF oscillator to produce the desired intermediate frequencies. In nearly all designs the oscillator frequency is above any of the frequencies of the incoming signal. For the example chosen, channel 3, the oscillator radio frequency would be 107.00 Mc.

The result of this mixing (in the mixer stage) is to produce a video IF carrier signal at 45.75 Mc ($107 - 61.25$ Mc) and a sound IF carrier at 41.25 Mc ($107 - 65.75$ Mc). On the response curve of the video IF system these carriers would appear in the positions shown in Fig. 6.

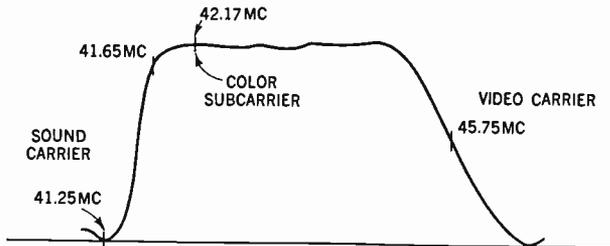


FIG. 6. Positions of the video and sound carriers and the color subcarrier on the video IF response curve. The 41.65 Mc represents the point where the color sidebands end.

The color subcarrier of the signal is positioned 3.58 Mc above the video intermediate frequency. Its value, then, would be 42.17 Mc, and it would occupy the position shown in Fig. 6. The left-hand edge of the response curve should extend to at least 41.65 Mc, this being the end frequency of the video signal with its color sideband components (41.65 Mc is 4.1 Mc from the video IF carrier of 45.75 Mc).

All the foregoing signals will fall at the points designated in Fig. 6 if (and here is the crux of this discussion) the oscillator frequency is set at exactly 107.00 Mc. This, in turn, depends upon the setting of the fine-tuning control.

Now let us see what happens if the control is rotated too far to one side or the other of this correct position. If the viewer has the common misconception that tuning a set for best picture means striving for high contrast, then he will adjust the fine-tuning control until the video carrier is on the flat portion of the response curve and not at the 50 per cent point. With this situation, the high end of the signal spectrum, where the color information exists, will be pushed down the opposite side of

the response curve. This will usually attenuate the color burst to such an extent that not enough will get through to activate the various color circuits, resulting in no color on the screen.

Rotation of the fine-tuning control in the opposite direction will lead to the loss (or attenuation) of the video carrier and its companion low video frequencies and produce either a negative picture (as in black-and-white sets) or no picture at all. Present, too, will be sound bars because of the increased amplification accorded the sound signal.

Thus, adjustment of the fine-tuning control in present color television receivers is a more critical operation than in monochrome receivers, and this fact must be carefully impressed upon the lay set user. One manufacturer provides the following instructions on the adjustment of the controls of his receiver for black-and-white and then for color reception.

For black-and-white reception:

1. Turn the receiver on and advance the Sound Volume control to approximately mid-position.
2. Set the Channel Selector to the desired channel.
3. Adjust the Fine-tuning control for best picture quality and the Sound Volume for suitable volume.
4. Turn the Brightness control fully counterclockwise, then clockwise until a light pattern just appears on the screen.
5. Adjust the Contrast control for suitable picture contrast.

For color reception:

1. Adjust the receiver for a black-and-white picture as outlined above.
2. Advance the Color control approximately two-thirds from its maximum counterclockwise position.
3. Carefully advance the Fine-tuning control clockwise until the picture just begins to disappear; then turn counterclockwise slowly to the position where the sound bars just disappear and color is in the picture.
4. Adjust the Color control for the desired saturation or strength of color.
5. Adjust the Hue control for hue quality of the picture to achieve the most pleasing flesh tones or color of some familiar object.

Another method of correctly adjusting the fine-tuning control which the serviceman can use is to rotate this control to the point where the visible 920-kc beat pattern (between the 4.5-Mc sound carrier and the 3.58-Mc color subcarrier) on the CRT screen is minimized. This is a

more precise method, particularly when the low end of the IF response curve has a steep roll-off.

Circuit Misalignment. The importance of having the color end of the video signal receive sufficient amplification—as indicated by the foregoing discussion—will also point up to the serviceman other causes of poor or no color rendition in the picture. For example, a video IF response curve which falls off too rapidly at its low end or an RF bandpass which is too narrow will produce the same results as misadjustment of the fine-tuning control.

In black-and-white receivers the extent of the circuit's bandpass, while important, is nowhere near as critical as it is in a color receiver. In a monochrome set we might possibly lose some detail, a fact which very few observers could detect. In a color set the picture will still be seen, but all semblance of color will be absent.

The critical dependence of color on bandwidth can conceivably force circuit realignment of the RF and video IF systems every time a tube is changed. Different interelectrode capacitances in tubes even of the same type will have marked effects on the bandpass of the fairly high-frequency circuits now common in RF and IF systems. Any technician who has aligned these sections knows this well. If a change in tubes affects the ends of the response curves, then realignment will be necessary. It may be that methods will be found to overcome this very evident weak point, but until that happens there is likely to be some difficulty even if it is encountered only part of the time.

Limited Antenna-system Bandwidth. It has also been found that poor color in a picture or total lack of color may stem from inadequate bandwidth of the antenna system, encompassing the antenna and any RF boosters or distribution amplifiers that may be employed. Particularly important is the response to those frequencies clustered around the color subcarrier. Ideally, gain or loss should not vary more than 1 db from 1.5 Mc below to 0.6 Mc above the color subcarrier. Now let us apply these suggested limits to a popular antenna operating over the 12 VHF channels. The gain curves are shown in Fig. 7. Over the low band the responses to channels 3, 4, 5, and 6 fall within the limits specified above. On channel 2 the gain variation from the low to the high end is greater than 2 db. However, in its favor is the fact that the high end receives more gain than the low end, thereby tending to accentuate the color signals. Furthermore, the gain variation around the color subcarrier frequency (near the upper end of the channel) is less than 1 db.

On the high band the response is excellent for channels 7, 8, 9, and

10. On channel 11, gain variation near the upper end is quite marked and could lead to trouble. This is particularly true since the gain is decreasing here. Channels 12 and 13 are subject to an even greater drop-off in gain, and the performance of a color receiver on these channels might be poorer.

High-gain, narrow-band antennas such as the multielement yagi may be especially troublesome in this respect.

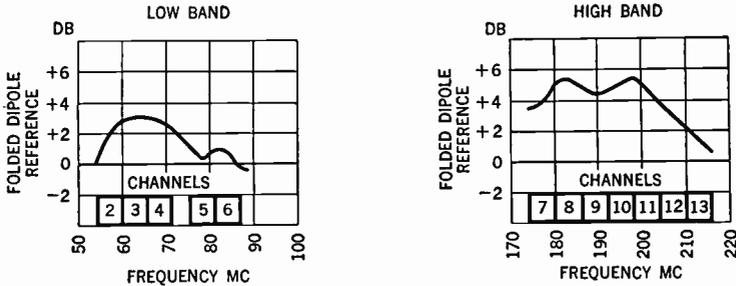


FIG. 7. The gain curves for a popular antenna over the 12 VHF channels.

Another item that is frequently found in the antenna system is an RF booster. If this is of the untuned wide-band variety, it probably would not attenuate the color subcarrier any more than it might affect the video carrier. However, in an adjustable booster, where each channel is tuned in separately, narrow bandwidth is a distinct possibility. Also, it is well to remember that while one item by itself may not cause too much damage, the combined attenuation of several components can prove decisive. (This is the reason some color receivers will operate satisfactorily with marginal antennas while other sets will not.)

What has been said with regard to boosters applies with equal force to antenna distribution systems where the incoming signal is first amplified before it is dispatched to the various sets. The necessity for knowing whether each component is doing its share fully will be more pressing than ever and undoubtedly impose the need for additional testing equipment on the serviceman. The technician will require more comprehensive methods for checking receivers in the home. If a set does not produce suitable color pictures, is the receiver at fault or is the trouble an inadequately applied signal? Some instrument, such as a color-bar generator, which will definitely establish the condition of the receiver will be almost a necessity. The only alternative would be to take the set back to the shop, a time-consuming and certainly un-

economical procedure. The reliance of the service technician on accurate test equipment will be greater than ever.

Defective Subcarrier Oscillator. There are, of course, additional possible causes when a color television receiver is unable to produce color pictures. Consider, for example, the color subcarrier oscillator in the color sync section. The color signals which the I and Q (or $R - Y$, $B - Y$) demodulators receive from the bandpass amplifier are amplitude- and phase-modulated. To reobtain the original information imparted to this signal we need the presence of the missing subcarrier. This is supplied, with the proper phase, by the color sync section. The heart of this section is the 3.58-Mc subcarrier oscillator, and if something should prevent this oscillator from generating the necessary voltage, no color demodulation will occur and thus no color signals.

In the absence of color, then, a good place to check is at the 3.58-Mc oscillator. The tube might be tested first. If it is found to be good, an oscilloscope might be employed to check for the presence of 3.58-Mc signal in the oscillator circuit. Measuring the control-grid voltage of the oscillator is another good way to determine whether or not this stage is operating.

There are two methods of generating 3.58-Mc oscillations in use, and a different service approach is required in each instance. For example, in the color sync system shown in Fig. 8 the 3.58-Mc oscillator is always in operation, color signal or no color signal. This means that if a color signal is reaching the color demodulators, the 3.58-Mc oscillator voltage should be present unless the oscillator itself is inoperative. It makes little difference here whether the color burst is reaching the color sync section. The oscillator, whether it is on frequency or not, will be developing a 3.58-Mc signal, and some color should appear on the screen, even if this color has the wrong hue or is unstable.

On the other hand, consider the situation in a ringing type of color sync system (Fig. 9). Here the 3.58-Mc generator is not in operation unless it is being pulsed by the incoming color bursts. Failure of the bursts to reach the ringing oscillator, perhaps because of a defective color-burst amplifier, would result in a colorless picture. Hence, it is logical to check the color-burst amplifier to see if the tube is good and if it is, to check the rest of the color-burst stage, including the voltages.

Note that in the color sync system of Fig. 8, trouble in the color-burst stage or in the reactance tube or in the phase detector would not keep the 3.58-Mc oscillator from operating. Color would appear on the screen even though, in all probability, the shading of the objects would be wrong.

In the ringing system, for the generated 3.58-Mc voltage to reach the color demodulators it is necessary that the stages between the oscillator and the demodulators be operating normally. This includes

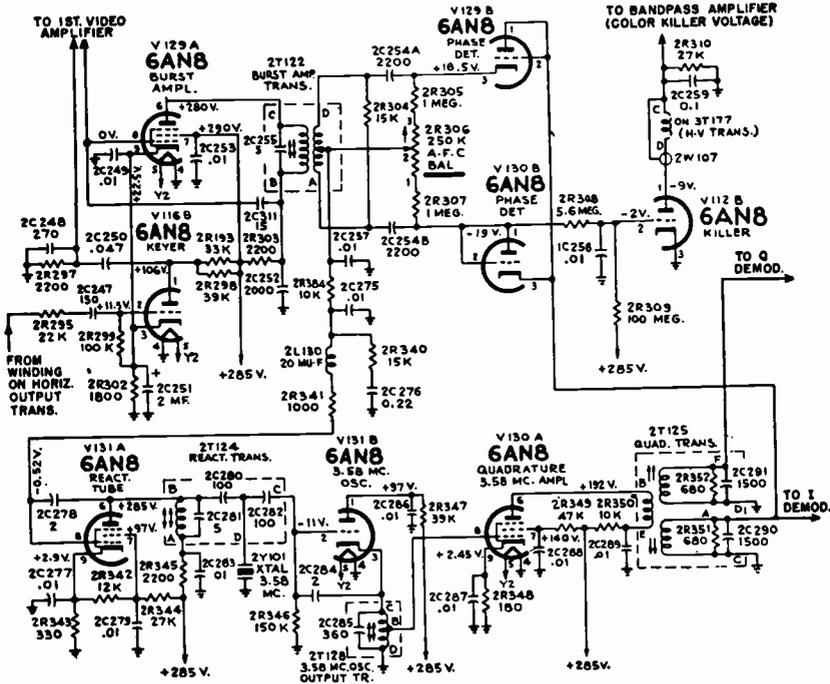


FIG. 8. In this color sync system the 3.58-Mc oscillator is always in operation, color burst or no color burst.

an amplifier, a limiter, and perhaps a cathode follower (see Fig. 9). Tests should be made with a wide-band oscilloscope at each of these points.

Defective Bandpass Amplifier. Another item which may be responsible for the absence of color is a defective bandpass amplifier. This stage stands at the head of the entire chrominance section of the receiver, and any break in the signal path here would prevent the color sidebands from reaching the color demodulators.

Whether a defective bandpass amplifier will cause the complete absence of color on a screen or lead to a condition where we have a black-and-white picture with a mottled (confetti-like) background depends upon the circuit in question. In the partial circuit of Fig. 10 the burst gate amplifier receives its bursts from the plate circuit of the

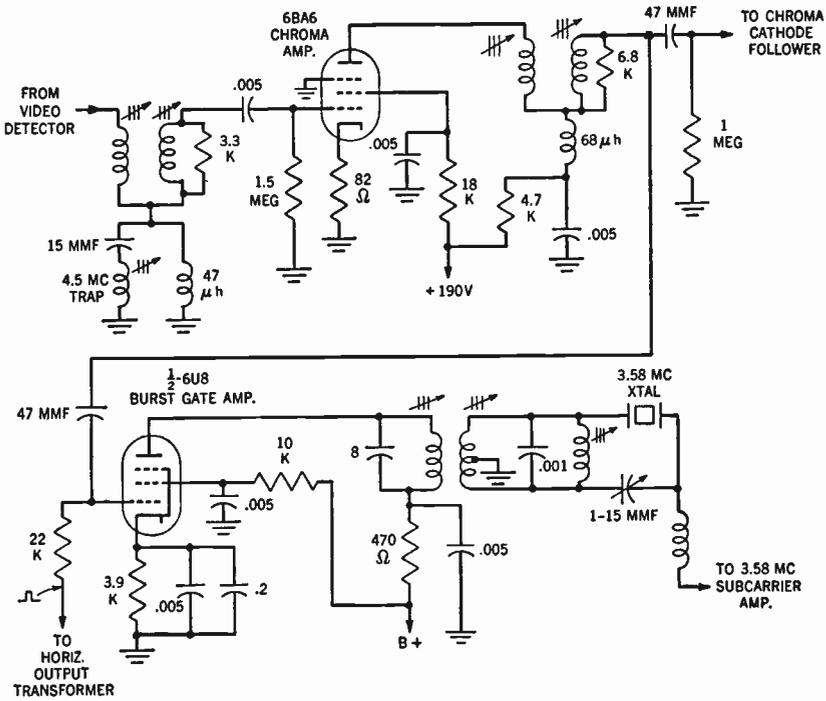


FIG. 10. In this circuit the burst-gate amplifier receives its bursts from the chroma (bandpass) amplifier.

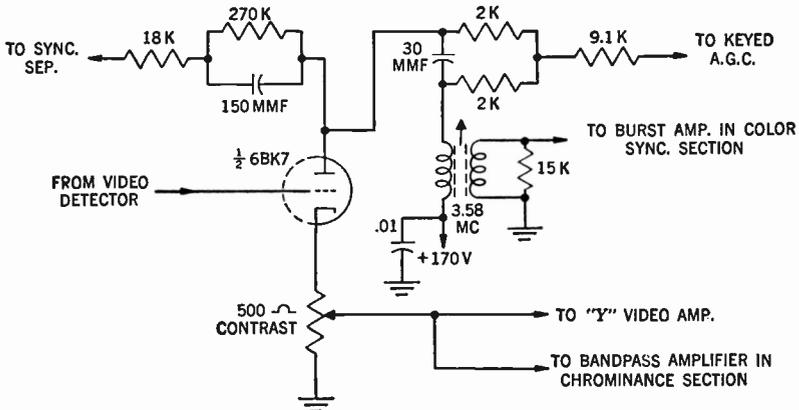


FIG. 11. Cathode-follower video amplifier circuit for color TV.

voltages either in the second chroma amplifier circuit or in the grid circuits of the demodulators. It is quite possible that under these conditions this will happen.

Thus, whether a defective bandpass amplifier leads to a colorless picture or one which has random color depends upon the relationship between the color sync section and the chrominance section.

Defective Color Killer. A defective color killer can also be the cause of no color in a picture. If the killer cutoff bias is on at all times, irrespective of whether color-burst signals are being received, no signals will pass through the chrominance section and none will reach the picture tube. It is also true that if the receiver employs a separate detector for the color portion of the signal, as the circuit of Fig. 12

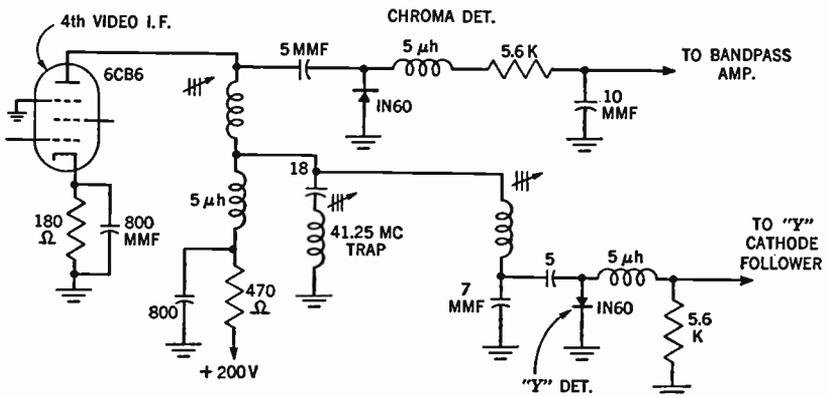


FIG. 12. Separate detectors for chroma and brightness are employed in this circuit.

does, any failure here would likewise result in no color. This same set has a separate germanium detector for the Y signal, and consequently this signal would appear on the screen.

INCORRECT COLOR RENDITION

In the preceding section the discussion centered principally about the possible causes of pictures lacking color in a color receiver. Now let us consider another common ailment of color television reception, incorrect color rendition. This term describes the condition of the presence of color in the picture, but of the wrong hue.

One of the first things to check with this condition is the Hue * control. Either this is mounted on the front panel of the set or the

* Color Fidelity is another name for this control.

technician can reach it from the front by lifting a small metal plate. Rotation of this control will have a marked effect on the colors observed on the screen. Red may change to yellow, green to blue, and blue to magenta or red. Circuitwise, the control may be located directly in the oscillator circuit, where it deals with the phase of the oscillator voltage, or it may affect the 3.58-Mc color burst which is used by the phase detector to establish the frequency and phase of the generated 3.58-Mc subcarrier voltage. Both methods have been employed to date.

If the various color circuits in the receiver are functioning normally, then some point should be found over the range of the Hue control where the observed colors possess the proper hue. Probably the best reference to use is the color of a person's skin. In the absence of this reference, any familiar object, such as a yellow banana or a red apple, may be employed. Of course, errors can be made here in assuming the shade of a color which may not be its true shade.

The best solution, and one which will undoubtedly be used the most, is the substitution of the signal from a color-bar generator for the transmitter signal. The colors then produced on the screen will be known definitely, and any necessary adjustment can be made accordingly.

The color sync section, the chrominance section, and the color-burst reference of the incoming signal are responsible for the color in the picture developed on the screen of a color television receiver. All the other sections beyond the video second detector can be checked by observing the monochrome portion of the color signal on the screen. This was indicated earlier, and it is the reason why the picture is observed first in black-and-white. With this in mind, let us see what the effect would be of various difficulties in the color sync and chrominance sections.

In the color sync section we have the burst amplifier plus whatever method is used to generate the 3.58-Mc subcarrier and to synchronize its phase with that of the incoming color burst. In the system shown in Fig. 8 the oscillator is continuously in operation, and a phase detector and a reactance tube are employed to keep the oscillator frequency in step with that of the color burst. A Hue, or color phasing, control permits variation of the oscillator phasing; the check on this control has already been mentioned. A defective reactance tube would lead to the loss of color synchronization with the visual result that the colors would keep shifting. Under these conditions, too, rotating the color phase control would have no effect on the colors in the picture. This is be-

cause in this circuit any change effected by the control could not reach the oscillator because of the intervening defective reactance-tube circuit (see Fig. 2, Chap. 9 for position of Hue control).

Another cause for the appearance of the wrong colors on the screen could be trouble (a defect or misalignment) in the quadrature transformer shown in Fig. 8. This transformer is normally set up to provide the I and Q demodulators with 3.58-Mc subcarrier voltages 90° out of phase with each other. Any departure from this 90° (or quadrature) relationship will lead to incorrect color rendition.

There is another difficulty that can develop in the quadrature transformer, but to appreciate its significance we require the presence of a color phase diagram (see Fig. 4). Here we see the phase relationships among the various colors, together with the relative positions of the $I, Q, R - Y$, and $B - Y$ vectors and the color burst.

As we examine this diagram we note that the I and Q vectors are 90° out of phase with each other. Furthermore, there is a positive I and a positive Q as well as a negative I and a negative Q . The positive I and Q vectors are 90° out of phase with each other; the same is true of the negative I and Q vectors. Since there are positive and negative values for each of these vectors, it will be evident that what we obtain from the quadrature transformer is not only important as to the 90° relationship between I and Q but also as to whether the set of signals is positive or negative.

A reversal in polarity of the 3.58-Mc subcarrier voltages fed to either the I or Q demodulator will cause a reversal in the polarity of the demodulated video signal obtained from that stage. What should rightfully be $+I$ becomes $-I$ or what should be $+Q$ becomes $-Q$. This flip-over is transmitted all the way down the affected I or Q channel, resulting in the production of the wrong colors when the voltages combine in the matrix. For example, red is obtained by combining $+0.60I$ with $+0.21Q$ in the matrix (see Fig. 13A). Suppose, however, that what the Q system produces is $-0.21Q$ (through the inadvertent use of a 3.58-Mc subcarrier shifted 180° in phase). Then the color produced in the matrix will no longer be red, but quite close to yellow (see Fig. 13B).

Figure 13C shows what we would obtain if instead of $+0.60I$ we obtained $-0.60I$ from the I section. This, added to $+0.21Q$, would give us a blue. And, finally, changing the polarity of both I and Q (through the use of two 3.58-Mc subcarriers shifted in phase) would give us the complement of red, or cyan.

Thus, it is very important that the polarity of the subcarrier applied

to the demodulators be exactly that for which the receiver was designed.

The *I* and *Q* Stages. Trouble in the *I* and *Q* systems may also lead to the appearance of the wrong colors in the picture. Typical *I* and *Q*

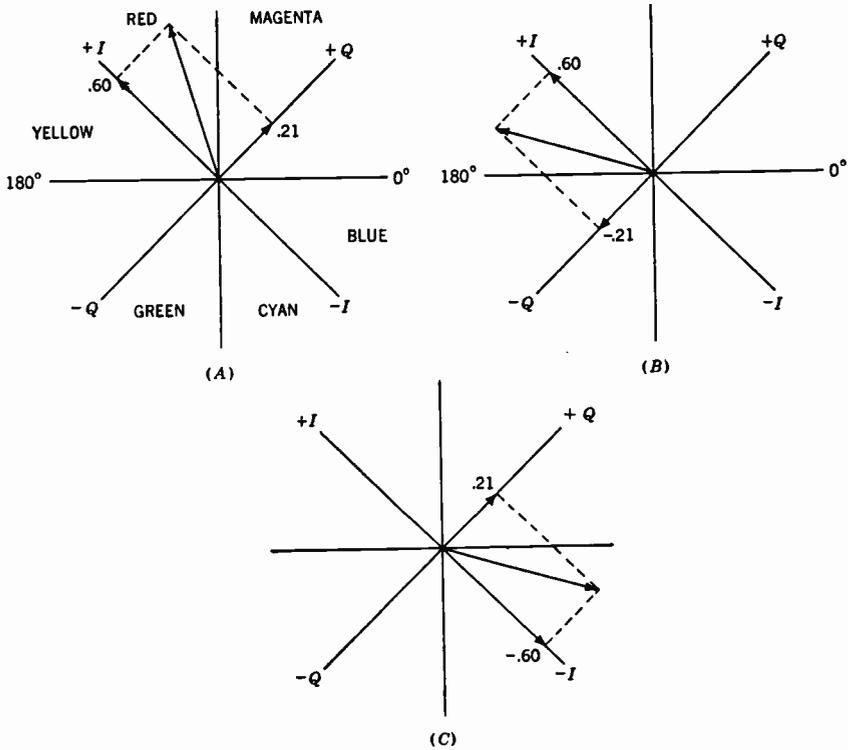


FIG. 13. (A) Addition of $+0.60I$ and $+0.21Q$ results in red color. (B) $+0.60I$ and $-0.21Q$ gives us a color in the yellow range. (C) Addition of $-0.60I$ and $+0.21Q$ brings the resultant color near blue.

sections of a color receiver are shown in Fig. 14. Note that each section, *I* and *Q*, provides positive and negative voltages to the matrix. The question is: "What would be the effect on the picture of a missing *I* or *Q* voltage or of a missing partial component, such as a missing $-I$ or $-Q$?"

The answer to these and other similar questions may be found in the color phase diagram: $+I$ extends into the orange sector of the diagram; $-I$ is in the cyan region; $+Q$ is near magenta; while $-Q$ is in the dark-green region. If some defect should completely inactivate the entire *Q*

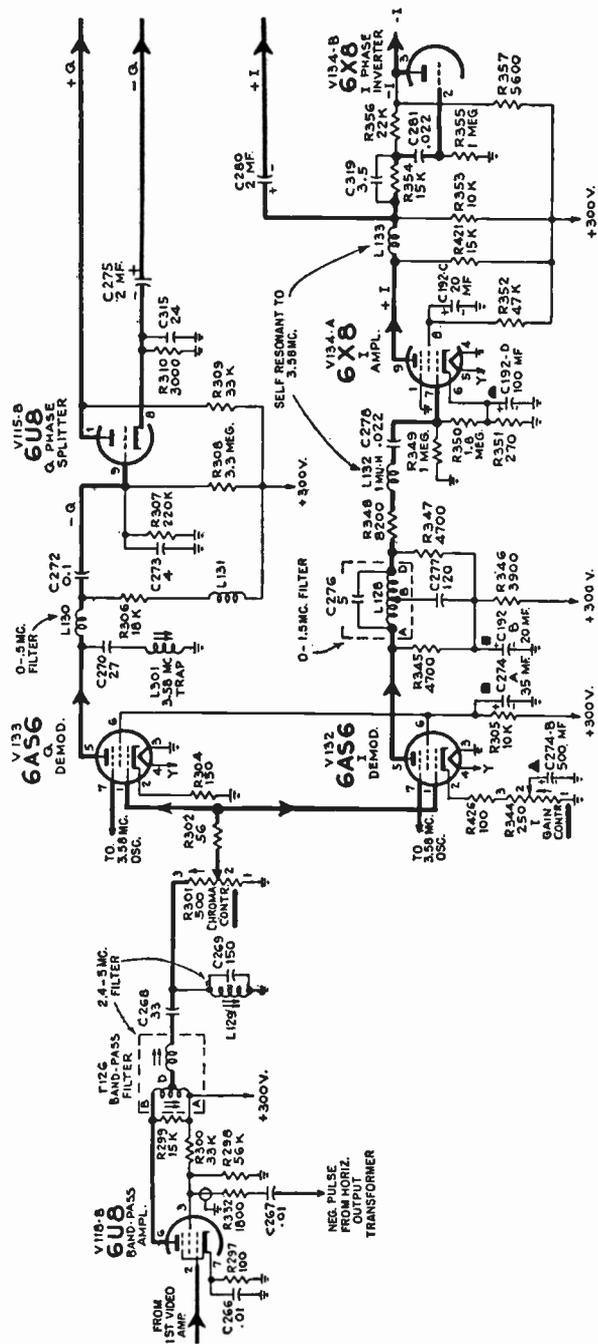


FIG. 14. A typical I,Q section of a color receiver.

section, we would be removing all of the Q components from the picture. These include, from the foregoing analysis, magenta ($+Q$) and green ($-Q$). All that would be left in the picture would be the I components, consisting chiefly of orange and cyan. In a good many scenes both outdoor and indoor tests have shown that removal of the Q components is not readily discernible by the viewer (layman or serviceman) unless he has the original for comparison. The reason for this is the preponderance of the lighter, pastel shades in our surroundings and the subordination of colors like magenta ($+Q$) and the darker green ($-Q$). As a test the reader may look about him and see how much magenta and dark green are present in contrast to orange and cyan. He will find that in most instances lack of response to magenta and dark green would hardly alter the scene to any noticeable extent.

Thus it is often difficult to look at a color broadcast and determine from the picture just what colors are missing. On the other hand, a color-bar generator with its test pattern would immediately bring this fact to light. Passage of the color-bar signal through the defective circuit mentioned above would yield black bars in place of the correct magenta and green. Furthermore, any other bar that depended upon $+Q$ or $-Q$ signals would also have its hue altered. A serviceman who was familiar with the color phase diagram and receiver layout would immediately spot this deficiency and pin-point the trouble as existing in the Q channel of the receiver. The time saving in defect location is indeed remarkable.

Loss of the I signal components would have a more noticeable effect on any color picture because of the greater use made of the I components. For positive identification, however, a color-bar generator would still be required.

At the output of the I and Q sections, individual positive and negative I and Q voltages are made available for the matrix. It is possible that the negative I signal may be affected without disturbing the companion $+I$ signal. Or the same thing may happen in the Q section. What effect such individual loss will have on a picture can again be determined from the color phase diagram. Loss of $-I$ would remove cyan from the picture; loss of $+I$ would delete the oranges, light reds, and orange-yellows; magenta would disappear with the loss of $+Q$; while the elimination of $-Q$ would affect the green.

We have been using an I, Q receiver in the foregoing discussion, but the same method may be employed with an $R - Y, B - Y$ system. The color phase diagram in Fig. 4 illustrates the relative positions of these two vectors, and by studying the chart the reader can easily figure out

what the absence of either of these signals would mean to the color in the picture. (Detail, of course, is not affected to any extent, since the monochrome portion of the signal will adequately provide this information.)

In an $R - Y$, $B - Y$ receiver loss of one of these components would also affect the formation of the green color, since green is formed by combining $R - Y$ and $B - Y$ according to the equation

$$-(G - Y) = 0.51(R - Y) + 0.19(B - Y)$$

A missing $R - Y$ or $B - Y$ component would alter the final value of G and cause its appearance on the screen to be distorted.

Misaligned Radio-frequency and Intermediate-frequency Systems. While the color sync and chrominance stages are the major sources of trouble when the color shading is incorrect, still other sections of the receiver may also be responsible. In the RF and IF stages, for example, poor alignment, particularly in the region occupied by the color signal, can lead to incorrect color on the screen. Of course, if the color burst itself is affected, then the color may disappear completely, as we have already noted.

Probably the best way of isolating such trouble is with a color-bar generator. Apply the unmodulated signal to the video second detector, and observe the colors of the bars in the resulting pattern. Then modulate the signal and inject it at the antenna terminals. Again observe the pattern produced. If the colors are true on the first test but altered in hue on the second test, trouble is indicated ahead of the detector. The best check to make then would be to observe the response pattern, both RF and IF, paying particular attention to the portion of the response which deals with the color-signal sidebands.

The Delay Line. Another cause for poor color rendition is a delay line in the Y channel which does not introduce the proper amount of delay in the Y signal. To appreciate the visible consequence of this action, let us briefly review the part played by the Y signal in the over-all formation of the color picture.

The Y signal contains all the video frequencies displayed in the picture. In the absence of color, perhaps due to a defective color section in a receiver or in a monochrome set, a full black-and-white picture is obtained.

When a color picture is desired, three pieces of information are required: first, the color or hue itself, green, blue, red, yellow, etc.; second, the saturation or the intensity of a particular color; and third,

its brightness. The first two components are carried by the color sidebands; the third, brightness, is carried by the Y signal.

With this in mind, let us examine some common colors to see how much of their total make-up is formed by the brightness component. In Fig. 15 we have a series of six colors: red, yellow, green, cyan, blue, and magenta.

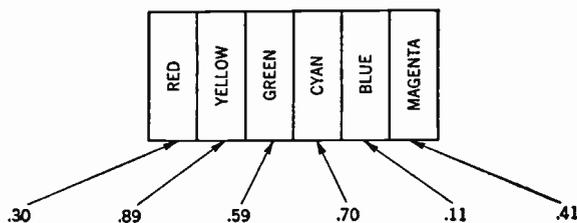


FIG. 15. Six colors and their brightness value, for full saturation.

and magenta. To ascertain their brightness value, we require the formula for the brightness signal,

$$Y = 0.59G + 0.30R + 0.11B$$

From this equation we see that green has a brightness value of 59 per cent, red a value of 30 per cent, and blue, 11 per cent. Yellow and cyan are not given directly because they are combination colors. To arrive at their brightness values, we must add the brightness values of their components. Since yellow is formed from red and green, its brightness value is 0.59 plus 0.30, or 0.89. By the same reasoning, cyan has a brightness value of 0.70 and magenta of 0.41.

Of the six colors yellow has the highest brightness value and blue the lowest. On a screen, then, yellow will appear brightest and blue will be darkest. However, if something should cause the Y component to disappear, perhaps a defect in the Y channel, then the yellow would become quite dark. Cyan, which contained 70 per cent brightness, would also become darker, although not as much as yellow. Green would lose even less brightness, red still less, and blue practically none at all since it possessed only 11 per cent to start with. Thus with the complete loss of brightness the apparent intensity of the colors appearing on a screen would reverse, with the normally brightest colors appearing darkest and the darkest colors appearing brightest. If you come across a situation like this, you can check for the brightness component by observing the picture in black-and-white. (This can be accomplished most easily by turning the chroma control to its extreme

counterclockwise position.) You should then see on the screen either a very dim picture, a barely visible picture, or no picture at all.

Instead of the complete loss of the Y signal, we might encounter a situation in which the delay line in the Y channel did not introduce sufficient delay. This would occur if part or all of the line shorted out. Under these conditions the Y signal would appear at the matrix before its corresponding color component. As a result the Y component will combine with some other, prior color. If we had the color-bar pattern of Fig. 15 on the screen, then what might appear is this. Part of the red bar would possess its proper brightness and part would be lighter in appearance because the higher-brightness component of the yellow would now be mixing with the red. In the yellow bar the first part would be normal, but the second half would be darker (although still yellow, of course) because it would be combining with the lower-brightness component of the green bar. The same thing would occur all along the line.

On a completely black-and-white picture this defect in the line would not have any noticeable effect because all components of the Y signal would be affected similarly. Hence this trouble could not be detected by simply viewing a color picture in black-and-white. The best testing device would again be a color-bar generator.

It is possible, although not as likely, for the delay line to introduce too much delay. In that event the brightness signal would arrive later than usual at the matrix. In the color-bar pattern, the effect would be that the first part of each bar would be altered while the second half would possess the proper brightness value.

In receivers of the I, Q variety a delay line is also employed in the I channel. Any variation in its characteristics would not affect the brightness of color but rather the color itself. This is because the I signal combines with the Q signal in the matrix to form the color signals which are fed to the picture tube. Any variation in either I or Q would then directly concern the amount of signal which the red, green, and blue control grids of the picture tube received, and this, in turn, is directly related to the colors produced on the screen.

COLOR INSTABILITY

The last general category of troubles that may affect the color of a picture is the inability of the receiver to maintain a constant color rendition. Symptoms of this condition may be either an erratic fluctuating variation in color or the appearance of color bands moving across the image. This behavior usually stems from a defect in the color sync

section of the receiver. For example, in the sync system shown in Fig. 8 the reactance tube may be defective, the phase detector may not be functioning properly, or the oscillator may be off frequency. Another possibility, in this particular arrangement, is a burst amplifier which is not amplifying or passing the color bursts properly.

In the ringing type of color sync system there is less possibility of loss of color lock-in. This is because the crystal must be triggered (or shock-excited) by the incoming color bursts, and this tends to establish the phase of the generated 3.58-Mc oscillations. On the other hand, if the crystal is not triggered, no 3.58-Mc oscillations, and, of course, no color, appears. Once the 3.58-Mc signal is developed, there are no components beyond the ringing circuit which can cause the color to fluctuate. The color, of course, may be shifted from its true value, but this shift will be fixed and rotation of the Hue control will ordinarily bring it back to normal. This is not a defect, since the circuits are operating within their designed limits.

SUMMARY

Always analyze each problem first in terms of its effect on sound or picture, then in terms of black-and-white or color. If the color of the picture is at fault, first try to obtain a normal black-and-white image; then turn to the color circuits. Remember that present-day color sets consist basically of monochrome receivers with an additional number of circuits to provide the color. If they cannot produce a normal black-and-white picture, they will not produce a normal color picture. Considered from this angle, servicing of the color receiver loses much of its complexity.

QUESTIONS

1. Describe some of the initial observations that should be made when servicing a defective color receiver.
2. Which stages in a color receiver deal exclusively with the color signal?
3. Of what use is a raster check? How is this check made?
4. If the raster check is OK, what do we know concerning the condition of the receiver?
5. If a raster checked OK but monochrome pictures appeared tinted, how would you go about tracking down the trouble?
6. How can the chromaticity chart be useful in color receiver servicing?
7. Name four possible causes of a colored raster.
8. Discuss in detail two of the causes listed in the previous question.

9. Describe a simple purity check.
10. How would you distinguish between poor color purity and improper convergence?
11. When would colored snow be normally expected on the screen? When would this not be normal?
12. Color defects arising in the color sections of a receiver generally fall into one of three categories. List these categories.
13. Name five causes for a complete lack of color in a picture.
14. Indicate the correct tuning procedure for a color receiver. Contrast this with the tuning procedure for a monochrome receiver. Assume that both are Inter-carrier sets.
15. How is it possible for an antenna to affect the reception of color signals? What antenna characteristics are desirable for good color reception?
16. Which type of color sync section is more susceptible to frequency instability? Explain.
17. How would a defective bandpass amplifier affect a color presentation?
18. Where would a color-bar generator be useful in color receiver servicing?
19. What are some of the causes for the appearance of the wrong colors on a screen?
20. Why is the polarity of the 3.58-Mc subcarrier applied to a color demodulator important?
21. What could cause color instability in a color picture?

APPENDIX

ADDITIONAL FACTS ABOUT COLOR TELEVISION

The general mechanics of color-signal formation was covered in the initial chapters of this book. It was shown there that every color signal contains a monochrome or Y component with video frequencies ranging from 0 to 4.0 Mc and two color components having video frequencies respectively from 0 to 0.5 Mc and 0 to 1.5 Mc.

A considerable amount of mathematical detail was omitted in the preceding discussion because the primary objective was to acquaint the reader with the basic principles of color television without complicating the presentation to such an extent that the forest could not be seen for the trees. However, as the reader can well appreciate by now, knowledge of the mathematical relationships that exist among the various segments of a color television system is not only important to a full understanding of its operation but also extremely useful in defect analysis and repair.

The two components of a color signal possess information concerning the hue and saturation of the color to be transmitted. The hue is represented by the angle which the resultant signal voltage makes with a reference axis or voltage. The saturation of the color is established by the amplitude or length of this resultant signal.

In more specific terms, suppose that a saturated red color is being scanned. Then only the red camera would be providing an output signal to which we can assign the arbitrary value of 1. The output voltages from the green and blue cameras would be zero. That is, $E_R = 1$, $E_B = 0$, and $E_G = 0$.

If we use $R - Y$ and $B - Y$ carrier signals in place of I and Q (which we will consider presently) then the situation is as indicated in Fig. 1. $B - Y$, which is equal to $B - 0.59G - 0.30R - 0.11B$, or $0.89B - 0.59G - 0.30R$, reduces to $-0.30R$, since B and G are both zero. By the same token, $R - Y$, which is equal to $R - 0.59G - 0.30R - 0.11B$, or $0.70R - 0.59G - 0.30R$, reduces to $0.70R$. Because of the negative value for the $B - Y$ vector, it is drawn 180° from its normal position. The resultant vector of these two voltages is seen in Fig. 1 to be on the left side of $R - Y$.

Before we compute the value of the resultant, $B - Y$ must be divided by 2.03 and $R - Y$ by 1.14. This is done because the above method of forming the signal results in a high modulation level at the transmitter for certain colors and a low modulation level for others. By using these factors, the modulation levels are more nearly equal for all saturated

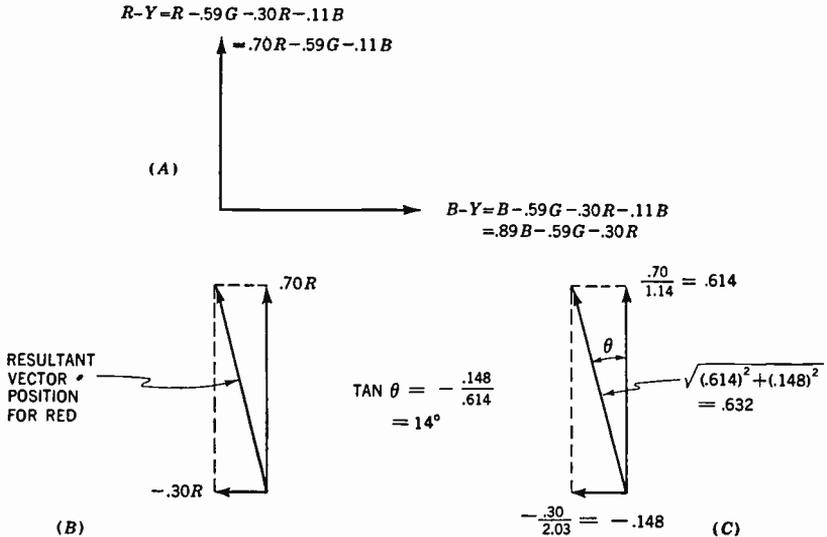


FIG. 1. (A) The $R - Y$, $B - Y$ vectors with equivalent equations. (B) The positions of the vectors when a saturated red color is being scanned. (C) The angular position of the resultant vector and its amplitude.

colors. It is a simple matter to provide the necessary amplification in the receiver to return the signals to their original relative amplitudes.*

We can now proceed with the computations. The value of the resultant vector is found by taking the square root of the sum of $(.614)^2$ and $(.148)^2$ to be 0.632.

To determine precisely what angle the resultant makes with respect to $R - Y$, we apply the familiar trigonometric function for the tangent. That is,

$$\tan \theta = \frac{-0.148}{0.614} = -0.241$$

$$\theta = 14^\circ \text{ counterclockwise from } R - Y$$

This means that when a saturated red color is being sent, the resultant

* This point is considered in greater detail at the end of this section.

vector occupies the position shown in Fig. 1. When a saturated blue area is being sent, the resultant vector shifts to the position shown in Fig. 2. That is, with $R = G = 0$, $R - Y = -0.11B/1.14$ and $B - Y = 0.89B/2.03$. The value of the resultant vector is equal to

$$\sqrt{\left(\frac{0.89}{2.03}\right)^2 + \left(\frac{0.11}{1.14}\right)^2} = 0.447$$

To find the angle which this vector makes with $B - Y$

$$\tan \theta = \frac{-0.11/1.14}{0.89/2.03} = -0.220$$

$$\theta = -12^\circ$$

In a similar manner we can determine the position of the resultant vector when green or cyan or yellow or magenta or any other color is

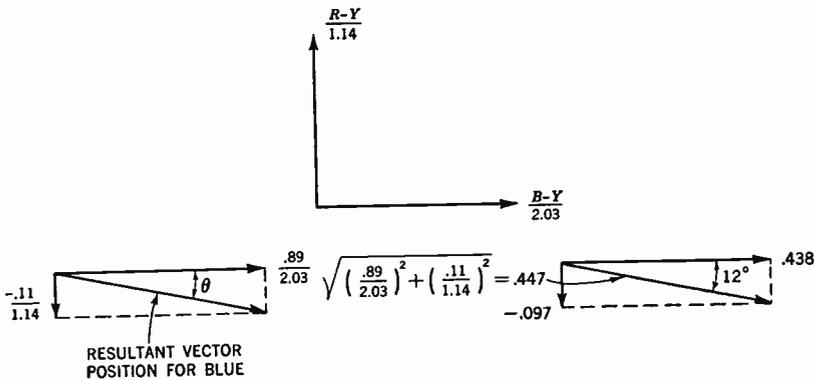


FIG. 2. The angular position and amplitude of the vector representing saturated blue.

being transmitted (see Fig. 3). Quite clearly the phase angle of the resultant vector determines the hue of the color being sent, and it is because of these circular gyrations of the resultant that it is often stated that the color subcarrier is phase-modulated. The same carrier is also amplitude-modulated, the different vector amplitudes representing color saturation.

The color phase diagram of Fig. 3 shows each of the colors in terms of its $R - Y$ and $B - Y$ components. Table 1 does essentially the same thing except that its coverage is somewhat more extensive. In using Table 1, note that the $E_R - E_Y$ and $E_B - E_Y$ values must be multiplied

by the appropriate factors, namely, 0.877 for $E_R - E_Y$ and 0.493 for $E_B - E_Y$. This has already been taken into account in Fig. 3.

To rephrase what we have said before, the total color signal is composed of a brightness component and a color component (Y plus a

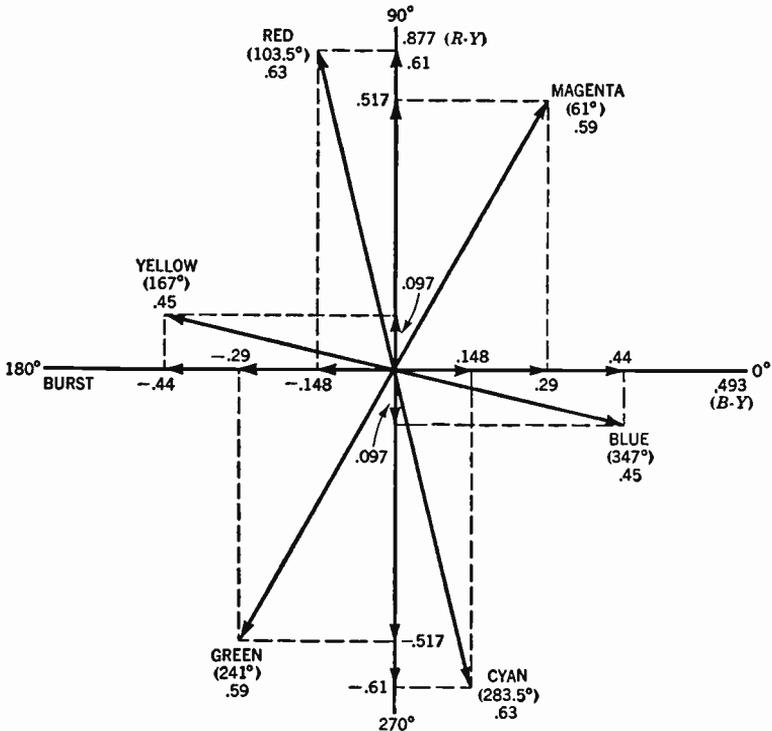


FIG. 3. A color phase diagram showing the various colors in terms of $B - Y$ and $R - Y$.

color signal, where Y is equal to $0.11B + 0.3R + 0.59G$). If we consider the $R - Y$ and $B - Y$ voltages as representing the two components of the color signal, then we can express the color portion of the total signal as

$$\frac{1}{2.03} (B - Y) \sin \omega t + \frac{1}{1.14} (R - Y) \sin (\omega t + 90^\circ)$$

or

$$\frac{1}{2.03} (B - Y) \sin \omega t + \frac{1}{1.14} (R - Y) \cos \omega t$$

because $\sin(\omega t + 90^\circ)$ is equal to $\cos \omega t$. In these equations ω is equal to $2\pi f$, where f is the frequency of the color subcarrier, 3.58 Mc.

TABLE 1

Color	E_G	E_R	E_B	E_Y	$E_G - E_Y$	$E_R - E_Y$	$E_B - E_Y$
Green ..	1	0	0	0.59	0.41	-0.59	-0.59
Yellow ..	1	1	0	0.89	0.11	0.11	-0.89
Red	0	1	0	0.3	-0.3	0.7	-0.3
Magenta.	0	1	1	0.41	-0.41	0.59	0.59
Blue	0	0	1	0.11	-0.11	-0.11	0.89
Cyan ...	1	0	1	0.70	0.3	-0.7	0.3

Mathematically,

$$\text{Total signal} = Y + \text{color signal}$$

$$= Y + \frac{1}{2.03} (B - Y) \sin \omega t + \frac{1}{1.14} (R - Y) \cos \omega t$$

That the foregoing is not the standard NTSC signal is because the designers of this system wished, among other things, to take advantage of some of the characteristics of the human eye. Thus, while the color system is primarily based on the use of three primaries, red, green, and blue, to produce the total color range, it was found that the average human eye requires these three primaries only for relatively large colored areas or objects. When the size of the area or object decreases, the color perceptivity of the eye is reduced. For example, blue and green are often confused with each other, as are brown and crimson. Blue tends to look like gray, and yellow too becomes indistinguishable from gray. Reds remain fairly distinct, but all colors tend to lose some of their vividness. Thus, where the eye formerly required three primary colors, now it finds that it can get by very well with only two. That is, these two will, in different combinations with each other, provide all the range of colors that the eye needs or can see.

Finally, when the detail becomes very small, all the eye can see are changes in brightness; colors cannot be distinguished from gray and to all intents and purposes, the eye is color-blind.

To adapt these characteristics of the eye to the color signal it was decided first to restrict the bandwidth of the two color signals. One color signal was given a bandwidth only to 500 kc (approximately), while the second color signal had a somewhat wider bandwidth, extending from 0 to 1.5 Mc.

Second, instead of using $B - Y$ and $R - Y$ for the two color signals, another pair of signals was chosen. For reasons which are no longer valid, one signal was called a Q signal and the other an I signal. The position of these two new signals is shown on the color phase vector diagram, Fig. 4. It is seen that the Q vector leads the $B - Y$ vector by

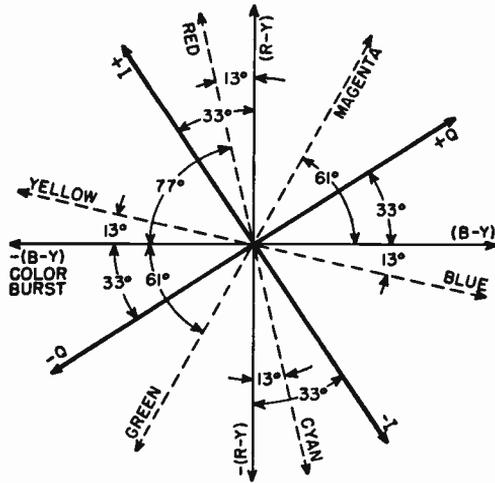


FIG. 4. Color phase diagram showing the positions of the various key colors and the I and Q vectors. The position of the color burst is also shown.

33° and the I vector leads the $R - Y$ vector also by 33° . The I and Q vectors are still 90° out of phase with each other, just as the $B - Y$ and $R - Y$ vectors were.

Thus, if we were to write the equation of the total signal using I and Q , we would obtain the following:

$$\text{Total signal} = Y + Q \sin(\omega t + 33^\circ) + I \cos(\omega t + 33^\circ)$$

There are additional ways of representing this signal, but first let us turn our attention to the color vector phase diagram and determine from the positions of the I and Q vectors what their values are.

To start, take the $R - Y$ vector and divide it into two components, one in phase with the I vector and one in phase with the Q vector. This is done in Fig. 5. The segment in phase with the Q vector is

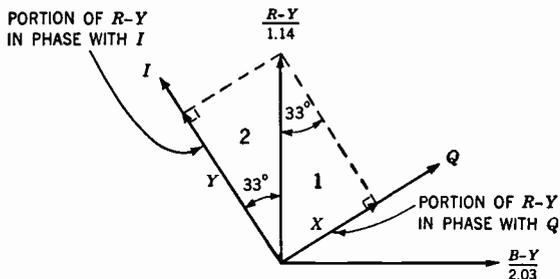
$$\frac{R - Y}{1.14} \sin 33^\circ$$

and is arrived at by using simple trigonometry. The segment of the

$R - Y$ vector which falls along the I line is obtained in the same manner, and it turns out to be

$$\frac{R - Y}{1.14} \cos 33^\circ$$

This done, we apply the same technique to the $B - Y$ vector, breaking it down into two components, one of which falls along the Q vector



COMPUTATIONS

FOR RIGHT TRIANGLE NO. 2

$$\cos 33^\circ = \frac{Y}{\frac{R-Y}{1.14}}$$

OR,

$$Y = \frac{R-Y}{1.14} \cdot \cos 33^\circ$$

FOR RIGHT TRIANGLE NO. 1

$$\sin 33^\circ = \frac{X}{\frac{R-Y}{1.14}}$$

OR,

$$X = \frac{R-Y}{1.14} \cdot \sin 33^\circ$$

FIG. 5. Method for determining values of I and Q vectors in terms of $R - Y$.

line, the other along the I vector line. This is shown in Fig. 6. The results are:

For the Q vector

$$\frac{B - Y}{2.03} \cos 33^\circ$$

and for the I vector

$$- \frac{B - Y}{2.03} \sin 33^\circ$$

The Q vector is then equal to the sum of the $R - Y$ and $B - Y$ components that are in phase with it.

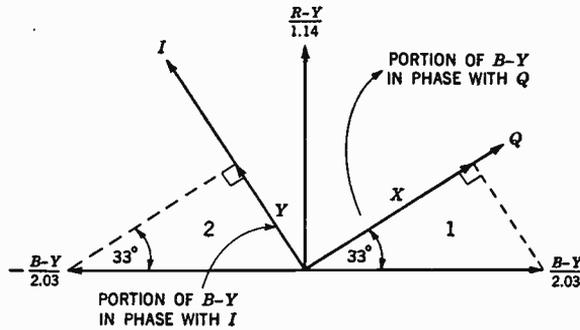
$$Q = \frac{B - Y}{2.03} \cos 33^\circ + \frac{R - Y}{1.14} \sin 33^\circ$$

$\cos 33^\circ = 0.8387$ and $\sin 33^\circ = 0.5446$. Using these figures in the above equation, we obtain

$$\begin{aligned} Q &= \frac{0.8387}{2.03} (B - Y) + \frac{0.5446}{1.14} (R - Y) \\ &= 0.41 (B - Y) + 0.48 (R - Y) \end{aligned}$$

By the same token,

$$\begin{aligned} I &= -\frac{B - Y}{2.03} \sin 33^\circ + \frac{R - Y}{1.14} \cos 33^\circ \\ &= \frac{-0.5446}{2.03} (B - Y) + \frac{0.8387}{1.14} (R - Y) \\ &= -0.27 (B - Y) + 0.74 (R - Y) \end{aligned}$$



COMPUTATIONS

FOR RIGHT TRIANGLE NO. 2

$$\sin 33^\circ = \frac{Y}{\frac{B-Y}{2.03}}$$

OR,

$$Y = -\frac{B-Y}{2.03} \cdot \sin 33^\circ$$

FOR RIGHT TRIANGLE NO. 1

$$\cos 33^\circ = \frac{X}{\frac{B-Y}{2.03}}$$

OR,

$$X = \frac{B-Y}{2.03} \cdot \cos 33^\circ$$

FIG. 6. Method for determining values of I and Q vectors in terms of $B - Y$.

We can transform the foregoing equations into their equivalent form using R , G , and B values by substituting the equivalent R , G , and B formulas for the $R - Y$ and the $B - Y$ vectors. Doing this, we obtain

$$\begin{aligned} Q &= \frac{0.89B - 0.3R - 0.59G}{2.03} \cos 33^\circ + \frac{-0.11B + 0.7R - 0.59G}{1.14} \sin 33^\circ \\ &= 0.31B + 0.21R - 0.52G \end{aligned}$$

$$I = \frac{-0.11B + 0.7R - 0.59G}{1.14} \cos 33^\circ - \frac{-0.89B - 0.3R - 0.59G}{2.03} \sin 33^\circ$$

$$= -0.32B + 0.6R - 0.28G$$

The total video voltage can now be written as

$$E_T = E_Y + E_Q \sin (\omega t + 33^\circ) + E_I \cos (\omega t + 33^\circ)$$

where

$$E_Y = 0.3E_R + 0.59E_G + 0.11E_B$$

$$E_Q = 0.41(E_B - E_Y) + 0.48(E_R - E_Y)$$

$$= 0.21E_R - 0.52E_G + 0.31E_B$$

$$E_I = -0.27(E_B - E_Y) + 0.74(E_R - E_Y)$$

$$= 0.60E_R - 0.28E_G - 0.32E_B$$

It is interesting to note that when the three color cameras are providing the same R , G , and B voltages, as when a black-and-white image is being transmitted, both E_Q and E_I become zero. Thus, if $E_R = E_G = E_B$,

$$E_Q = 0.21E_R - 0.52E_R + 0.31E_R$$

$$= 0.52E_R - 0.52E_R$$

$$= 0$$

$$E_I = 0.60E_R - 0.28E_R - 0.32E_R$$

$$= 0.60E_R - 0.60E_R$$

$$= 0$$

To employ this condition to fullest advantage, the color signal is sent without a carrier. After the I and Q voltages modulate their respective 3.58-Mc carriers, the carriers are dropped and only the sidebands are combined and sent along with the Y signal. This means that when a monochrome picture is being transmitted, no color carrier or sidebands are present.

With color broadcasts a color carrier must be reinserted into the received color signal before demodulation can occur. It is not sufficient simply to reinsert any 3.58-Mc carrier; we must use one which possesses precisely the same phase as the carrier employed in the modulation process at the transmitter. To provide information concerning the frequency and phase of the missing color subcarrier, a color burst is sent along with the signal. This burst follows each horizontal pulse and is located on the back porch of each blanking pedestal (see Fig. 7). It consists of a minimum of 8 cycles of the subcarrier, and it is phased in step with the color subcarrier used at the station. In the receiver this burst is used to lock in the frequency and phase of a 3.58-Mc oscillator,

and thus we are assured at all times that the reinserted carrier will do its job correctly when it recombines with the color sidebands.

The position of the color burst on the back porch of each horizontal sync pulse ensures that it will not be seen on the screen of either color or monochrome television receivers since the screen is ordinarily blacked out during this retrace interval. If the burst were to be placed

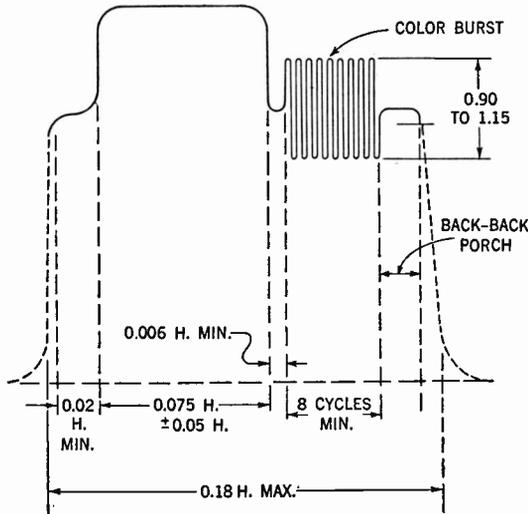


FIG. 7. The color burst is located on the back porch of every horizontal sync pulse.

at a lower level, it would produce undesirable spurious picture-tube light, especially on those sets which did not contain special horizontal blanking signals.

The burst does not appear during the vertical serrated pulses or after the equalizing pulses. It was found that the 3.58-Mc oscillator in the receiver remains in synchronism during this brief interval when no burst signal is being received. Upon the reappearance of the horizontal sync pulses and the accompanying color burst at the end of the vertical pulse interval, control of the 3.58-Mc receiver oscillator is smoothly resumed.

As a final comment on the form of the color signal, it should be appreciated that we obtain the same color signal whether we use $R - Y$ and $B - Y$ signals or I and Q signals. This is evident from the color vector phase diagram, Fig. 4. The only difference between the $R - Y$ and $B - Y$ vectors and the I and Q vectors is the angular dis-

placement of 33° . If we shift the $R - Y$ and $B - Y$ signals 33° (in the right direction), we obtain the I and Q signals. Conversely, if we cause the I and Q signals to lag by 33° , we obtain the $R - Y$ and $B - Y$ signals. This behavior is significant because it permits variations in receiver operation.

For those readers who may wonder about the relative positions of the $I, Q, R - Y$, and $B - Y$ vectors on the chromaticity diagram, this information is given in Fig. 8.

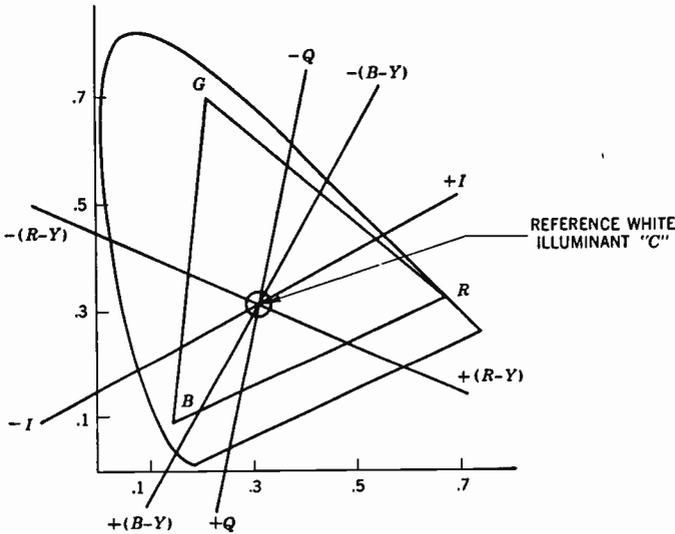


FIG. 8. Relative positions of $I, Q, R - Y$, and $B - Y$ vectors on a chromaticity chart.

FORMATION OF I AND Q SIGNALS

Now that we have seen the relationship between the $I, Q, R - Y$, and $B - Y$ signals, let us examine briefly how the I and Q signals are formed from the red, green, and blue signal voltages obtained from their respective cameras. Each of the camera signals is first passed through a gamma corrector which is designed to compensate for the fact that the over-all color television system is essentially nonlinear. That is, the curve drawn for the light output (at the picture tube) versus the light input (at the color camera) is not linear but shaped like curve A in Fig. 9.

The chief source of this non-linearity is the picture tube in the

receiver. If we examine the light output of this tube versus the applied signal input (at its control grid), we see that it requires a greater voltage variation when the control-grid bias is highly negative than when it is less negative (or relatively positive) to produce the same change in screen brightness (see Fig. 10).

To overcome or nullify this non-linearity, it is the accepted practice to pass the signals received from the color camera tubes through a nonlinear amplifier. These amplifiers have been so designed that they

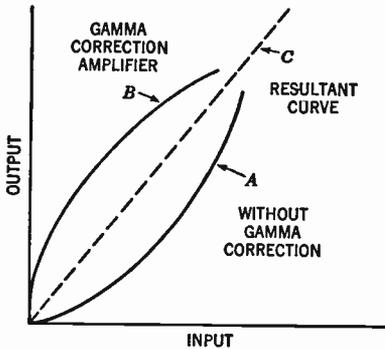


FIG. 9. Curves illustrating the need for gamma correction of color video signals.

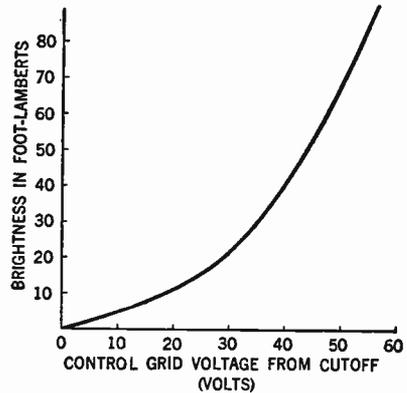


FIG. 10. A picture-tube characteristic curve.

provide nonlinear transfer characteristics which are the inverse of those of the rest of the system—principally of that of the picture tube. If, now, we add the transfer characteristic of the gamma-correction amplifier to that of the rest of the system, as in Fig. 9, we obtain an over-all resultant which is essentially linear.

It is customary to label gamma-corrected signals with a small prime. Thus E_g is the uncorrected video signal from the green camera tube, and E_g' is the same signal after it has been gamma-corrected. This is the strict usage of the prime. However, in all our discussions it will be assumed that gamma-corrected signals are being dealt with, and the prime sign will be omitted.

The signal, after it has been gamma-corrected, is fed to some sort of matrixing device where the individual red, green, and blue signals are combined to form the FCC-specified I and Q signals. A device for achieving this matrixing is the Colorplexer, shown in block-diagram form in Figs. 11 and 12. The three signals from the color cameras are

applied to a resistive mixing network where they are combined in the following proportions:

$$Y = 0.30R + 0.59G + 0.11B$$

$$I = 0.60R - 0.28G - 0.32B$$

$$Q = 0.21R - 0.52G + 0.31B$$

The resistive networks which produce the I and Q signals both require phase inverters in order to provide the negative voltages each signal needs. Thus, the I signal requires $-0.28G$ and $-0.32B$ voltages; the Q signal requires a $-0.52G$ voltage.

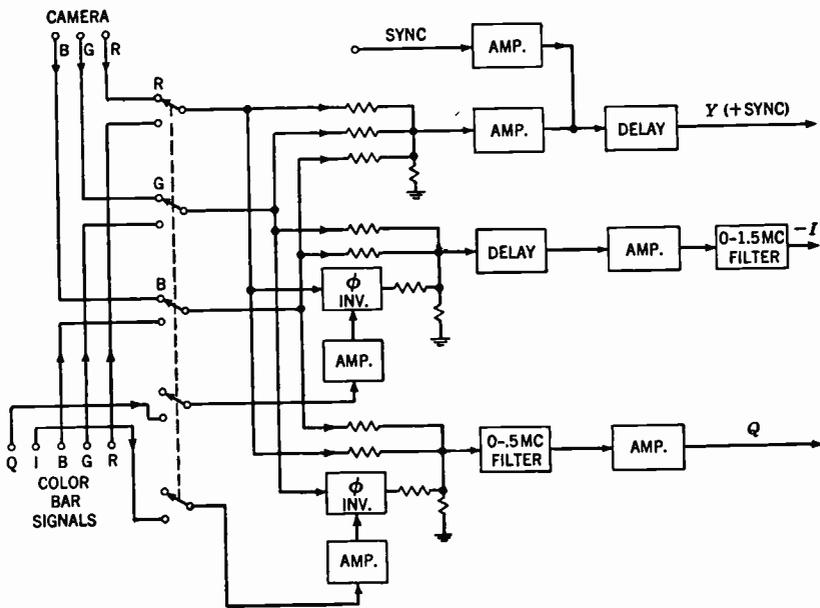


FIG. 11. Block diagram showing the matrix and filter section of the Colorplexer. (RCA.)

A 0- to 0.5-Mc filter is inserted in the Q channel to limit the frequencies here to the bandpass established in the standards. The I channel has a 0- to 1.5-Mc filter for the same reason. Note, too, that there is a delay network in the I channel to keep the I and Q signals in time-step with each other. The time delay of the Q signal in passing through its 0- to 0.5-Mc filter is greater (by about $\frac{1}{2}$ μ sec) than the time delay suffered by the I signal in passing through its 0- to 1.5-Mc filter.

In the monochrome channel the bandpass is 0 to 4.0 Mc, and the

delay here is even less than it is in the *I* channel. Hence, it becomes necessary to introduce enough delay in this channel artificially to keep all signals abreast of each other.

Another section of the Colorplexer (Fig. 12) is the multiplexer, where the final color signal is formed. The first step is the formation of the *I* and *Q* sidebands, and this is achieved by doubly-balanced modu-

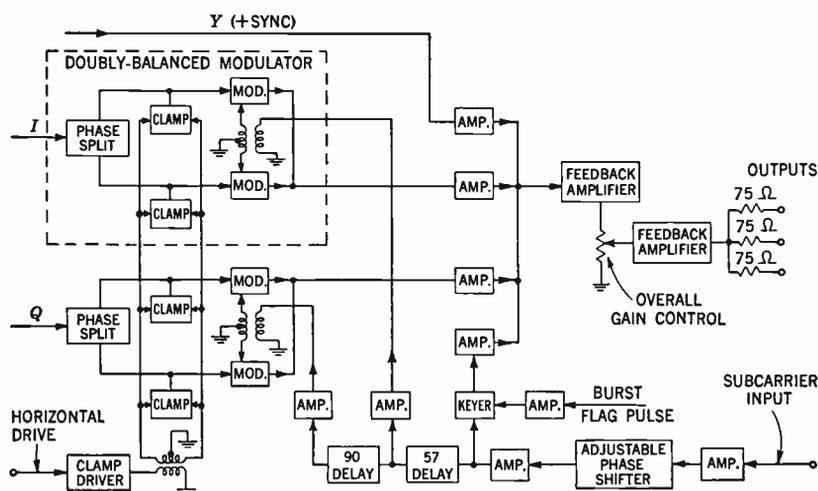


FIG. 12. Block diagram of the multiplexer section of the Colorplexer. (RCA.)

lators for each signal. The original input signals cancel in the common output, but the sidebands, which represent the product signals, reinforce each other in the output and thus remain. The blocks marked Clamp restore the DC component at the video input of each modulator.

The 3.58-Mc subcarrier is obtained from an outside source and brought into the Colorplexer via the circuits shown at the bottom of Fig. 12. The adjustable phase shifter permits a phase variation in the subcarrier of more than 360° . Its purpose is to enable the signals from all the Colorplexers in a studio or station to be lined up with respect to subcarrier phase at some common point in the equipment.

A portion of the subcarrier signal is then shifted back (delayed) in phase by 57° and applied through a suitable isolating network to the *I* demodulators. The subcarrier signal applied to the *Q* modulators requires an additional 90° delay. These delays, of course, can be seen from any of the color phase diagrams previously given.

The remainder of the multiplexing system serves to combine the *Y*,

I, and *Q* signals together with the subcarrier burst. Sync was previously added to the monochrome portion of the signal back in the matrix section of the Colorplexer.

MODULATION AND DEMODULATION

At the other end of the television system, the receiver, we have in essence the reverse sequence of events. After the signal has been detected (i.e., after it has divested itself of the RF or IF carrier that made it possible for the signal to reach the receiver), it is initially separated into two components. One component is the brightness signal, which proceeds through one or two video amplifiers and a delay line before reaching the matrix. The other segment is passed through a bandpass filter where all video frequencies below approximately 2.0 Mc are attenuated. After some additional amplification, this portion of the signal is applied in equal measure to an *I* and a *Q* demodulator. At the same time a locally generated 3.58-Mc signal is fed to the same demodulators. The only difference between the 3.58-Mc voltages which the two demodulators receive is a 90° phase difference.

To appreciate fully the manner in which the demodulators are able to separate the *I* and *Q* voltages from each other, we must examine in greater detail the modulation process which takes place at the transmitter.

It has been customary in radio practice to illustrate the process of modulation by the diagrams shown in Fig. 13. In the first illustration we have the audio modulating voltage obtained usually from a microphone and suitably strengthened by repeated amplification. This voltage modulates the carrier, shown in Fig. 13B, to produce the resultant or modulated wave shown in Fig. 13C. The effect of this modulation is to vary the carrier at each point in accordance with the amplitude variations of the applied audio signal.

When the modulated carrier is analyzed, it is found to contain three different frequencies. One frequency is that of the original RF carrier, unchanged by the modulating action. Also present are two additional frequencies and these are traceable directly to the modulating process, since in the absence of modulation these other signals would not be present. The frequency of one signal is equal to the RF carrier value plus the audio modulating frequency. Thus, if the RF carrier is 1,000 kc and the audio signal is 5 kc, the frequency of one of these newly developed signals would be 1,005 kc. The frequency of the other signal is 1,000 kc minus 5 kc, or 995 kc.

As most readers know, these additional signals are called sidebands and they carry the intelligence of the broadcast.

Now, while the foregoing method of illustrating amplitude modulation is instructive as far as it goes, a better insight into the mechanics of modulation, at least so far as it applies to color television, can be obtained by resorting to a vector type of notation.

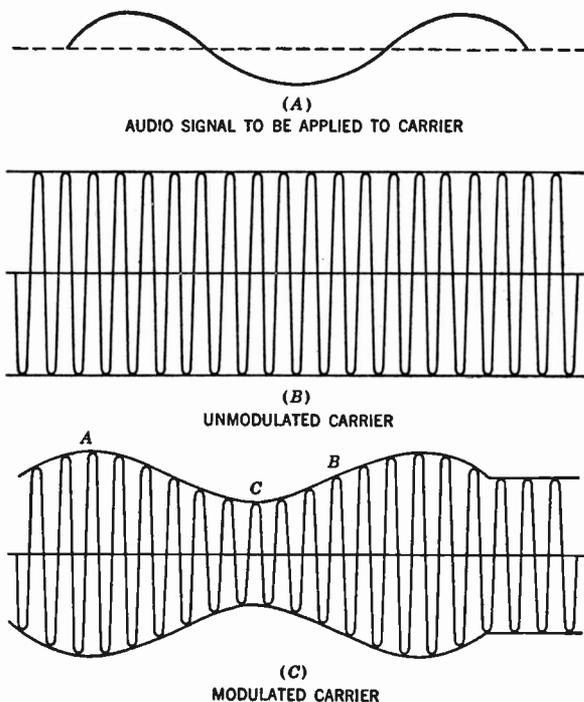


FIG. 13. An audio signal (A) and an unmodulated RF carrier (B) combine to form a modulated wave (C).

The RF carrier can be represented by a single vector pointing upward (see Fig. 14A). (The direction is chosen for convenience only.) The two sidebands can then be added to this vector in the manner shown in Fig. 14B. The two sideband vectors each rotate with the same angular velocity but in opposite directions. This is indicated by the two small arrows drawn alongside each sideband vector.

To appreciate the significance of this sideband vector placement and the stipulation concerning their rotation, let us draw the resultant of the two side vectors with the main carrier vector. In Fig. 14C we see

that the addition of the two side vectors produces a resultant which is in the same direction as the carrier vector. Hence, this resultant and the carrier vector add, producing a combined vector which is greater

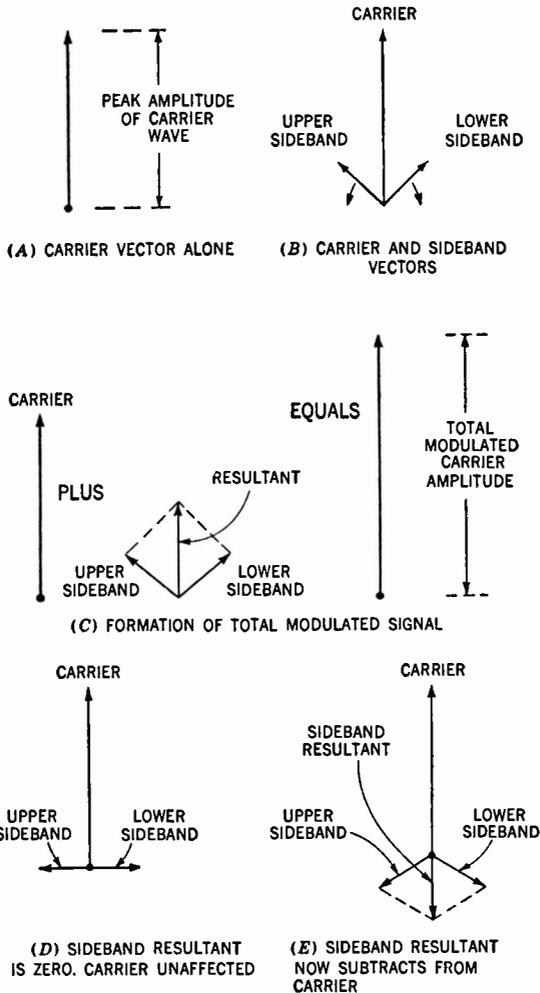


FIG. 14. An illustration of carrier amplitude modulation using vectors.

than the carrier vector alone. Referring back to Fig. 13C we know that at some point on the modulated wave the amplitude is increased beyond the normal carrier peak value because the audio modulating voltage is adding to the carrier signal (see point A in Fig. 13C).

When the two sideband vectors occupy the position shown in Fig. 14D, they will not affect the amplitude of the carrier vector. This is because the sideband vectors are equal (as they always are) and 180° out of phase with each other. This situation, too, has its counterpart in Fig. 13C at point B. Within this region the audio modulating voltage is passing through zero and the amplitude of the RF carrier is unaffected.

The third situation is shown in Fig. 14E. Now both sideband vectors are pointing down. Their resultant will still fall on the axis of the RF carrier vector, but since it is pointing in the opposite direction, it will subtract from the carrier and reduce its amplitude. Again we can find

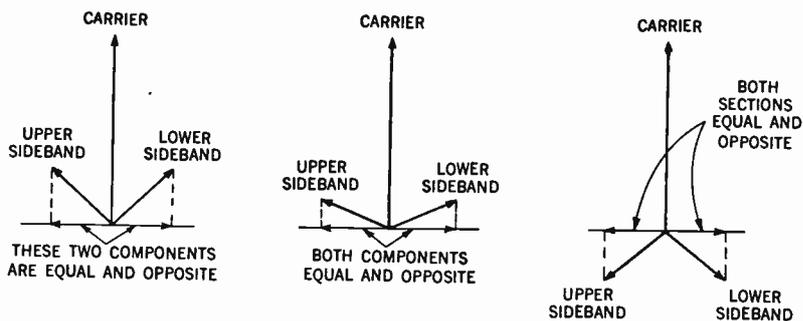


FIG. 15. In amplitude modulation the two sidebands have zero resultant voltage at 90° to carrier signal.

a similar occurrence in Fig. 13C in the region designated C. Throughout this section the audio modulating frequency is negative, and it depresses the amplitude of the carrier in the modulated signal.

Note that the resultants of the two sideband vectors can affect only the amplitude of the RF carrier vector. They cannot cause it to change its angular position (which would mean phase, and with this, frequency modulation). In other words, the sideband vectors cannot produce a resultant at right angles to the RF carrier. No matter what position the two sideband vectors occupy, their components at right angles to the carrier vector will always be exactly equal and hence will always cancel each other. Several examples are shown in Fig. 15, and the reader may try others if he wishes. The result will always be the same.

With this briefing, let us return to the *I* and *Q* modulators in the color transmitter. In each modulator the incoming *I* or *Q* video signal amplitude modulates a 3.58-Mc carrier. This means that in each case we

obtain a pair of sidebands. The two unmodulated carriers are shown 90° apart, which is specified (see Fig. 16A). After modulation they should appear as shown in Fig. 16B. However, since the balanced modulators suppress the RF carriers after the sidebands have been created, what we really have are the sidebands alone (see Fig. 16C).

Once the sidebands have been developed, the two signals are combined. This is shown in Fig. 16D. Each set of sidebands develops its own resultant, and then these resultants combine to form the over-all

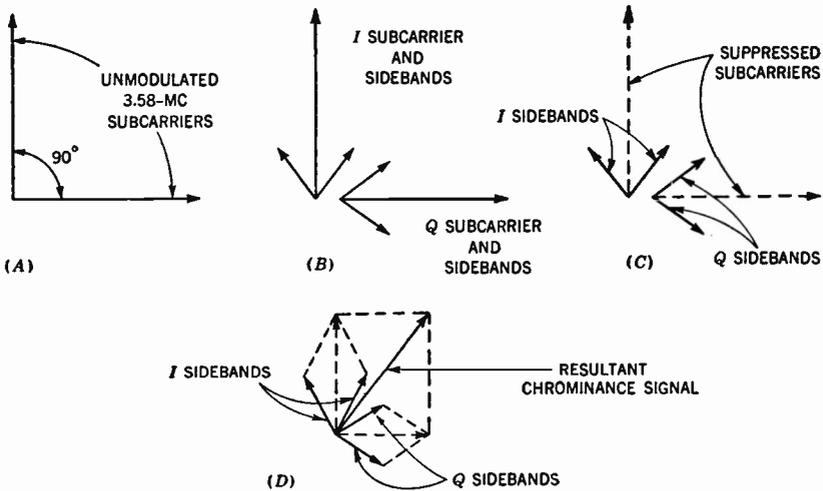


FIG. 16. (A) The two unmodulated 3.58-Mc subcarriers fed to the *I* and *Q* modulators. (B) Modulated subcarriers with sidebands. (C) *I* and *Q* sidebands alone; subcarriers suppressed. (D) Resultant chrominance signal derived from combination of *I* and *Q* sidebands.

chrominance signal. It is at this point that we first achieve the phase variation which represents the different colors being sent. When the amplitude of one set of sideband resultants is large and the other is small, the chrominance vector shifts in one direction. When the amplitudes change, it shifts in the other direction. Thus, by the combination of two amplitude modulated signals 90° out of phase we can achieve phase modulation in addition to the original amplitude modulation. In the color signal the various phase positions represent the different colors in a scene, whereas the varying amplitudes represent the saturations of these colors.

The outstanding advantage of the vectorial method of presentation is the clarity with which it brings these facts to light. In prior discus-

sions we could only state what happened without being able to show it graphically; with the present method we can effectively do both.

In the receiver the I and Q signals must be recovered, and this is achieved in the demodulators. Both demodulators receive the same video signal, but the 3.58-Mc subcarrier voltages which are applied to the tubes differ from each other by 90° . The result of this phase difference is shown in Fig. 17. In the first illustration (Fig. 17A) the 3.58-Mc signal is in phase with the missing carrier of the Q signal and takes the place of this carrier. The interaction, then, of the Q sidebands and the 3.58-Mc subcarrier produces the necessary Q video signal in the output of the detector. The 3.58-Mc signal is then subsequently removed by an appropriate filter network.

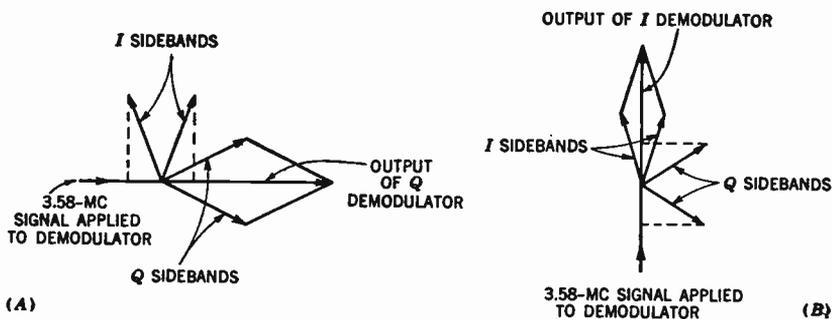


FIG. 17. Vector diagrams illustrating demodulator action.

Contained in the same video signal are the I signal sidebands, and these too interact with the same 3.58-Mc subcarrier voltage. Note, however, that because of the 90° phase difference between the inserted 3.58-Mc signal and the position of the missing carrier for the I sidebands, the interaction between the I sidebands and the subcarrier produces equal and opposite voltages at the output of the detector. This effectively eliminates the effect of the I signal so far as the Q demodulator is concerned.

At the I demodulator we have the conditions shown in Fig. 17B. The 3.58-Mc subcarrier signal now is in phase with the missing I carrier and 90° out of phase with the absent Q carrier. Under these conditions we obtain the I video signal at the output of the I detector, while the Q signal components cancel.

The importance of using a subcarrier, possessing the proper phase is thus quite apparent.

While we are on this subject of carrier and sideband signals, it may be instructive to observe what happens when a signal is sent with only one sideband. This happens partially with the I signal where we have double sidebands only up to ± 0.6 Mc on either side of the 3.58-Mc sub-carrier frequency. On the low side, the I signal sideband then extends farther to 1.5 Mc. However, on the high side this is not possible because the video system bandpass is limited to 4.2 Mc. Hence, the upper I sideband extends only for 0.6 Mc and then ends.

The situation can be visualized if we mentally remove one of the I signal sidebands in Fig. 17A. Under these conditions the I signal cannot cancel itself out (as it could when both sidebands were present), and I signal components between 0.6 and 1.5 Mc appear in the output of the Q demodulator. This is called cross talk, and it does not contaminate the color rendition because of the presence of the 0- to 0.5-Mc filter in the Q section. The single-sideband I signal frequencies are greater than 0.5 Mc and the filter removes them. But in the absence of this filter color contamination would occur.

THE NEED FOR $R - Y$, $B - Y$ MODIFYING FACTORS

It was previously mentioned that the $B - Y$ vector was multiplied by a factor of 0.493 and the $R - Y$ by a factor of 0.877 in order to reduce the overshoot that would occur when certain fully saturated colors were sent. To see this somewhat more concretely, let us see how a color signal would appear, using the full $R - Y$, $B - Y$ amplitudes, and then compare this with the signal obtained when the foregoing multiplying factors are applied. For the video signal we will use the color-bar pattern shown in Fig. 18. For the computations that follow, we will also need the values given in Table 1, page 277.

The color sequence is black, blue, red, magenta, green, cyan, yellow, and white. In the scanning of such a pattern the output from the three color camera tubes would appear as indicated in Fig. 18A, B, and C. The corresponding Y signal formed in the proper proportions from the three camera signals is shown in Fig. 18D. The color sequence was purposely chosen in this order of ascending brightness values so that the various aspects of signal formation could perhaps be more clearly seen.

The corresponding $R - Y$ and $B - Y$ values for each of the colors can be obtained directly from Table 1. Positive values are shown above the zero line; negative values below this line. Full values of $R - Y$ and $B - Y$ are being used.

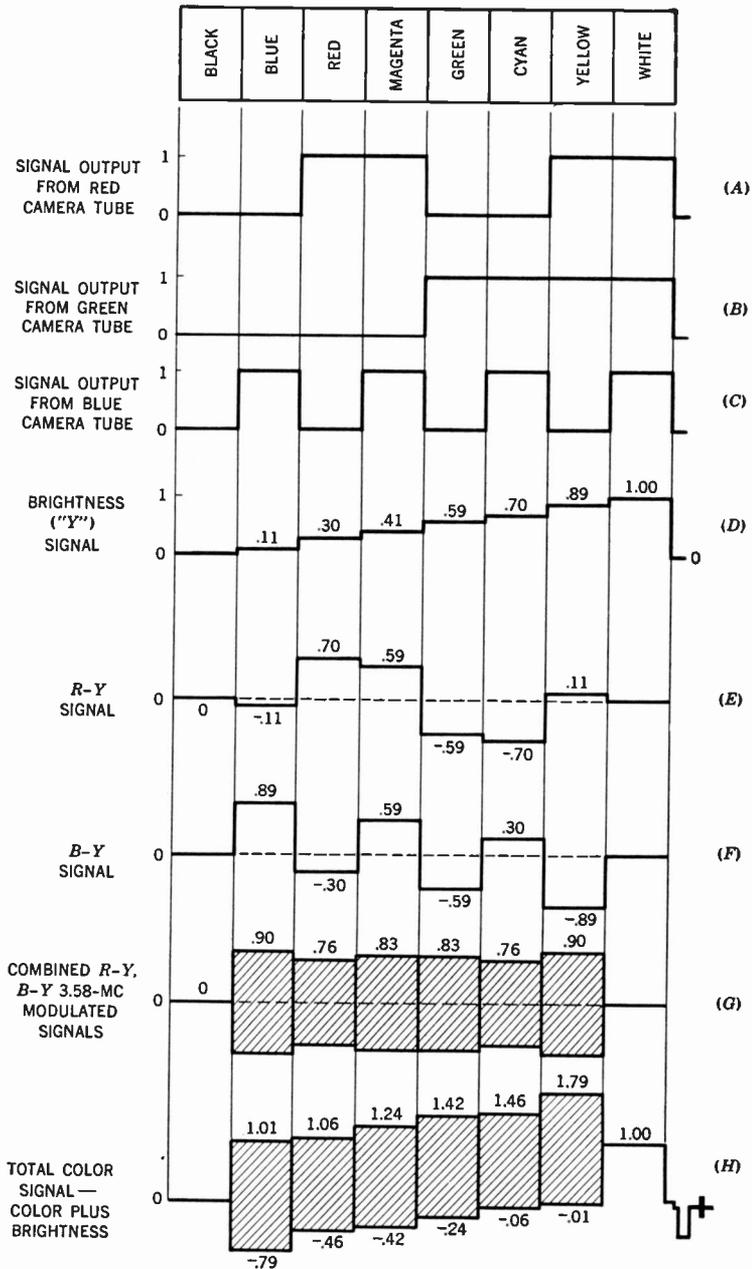


FIG. 18. When a color signal is formed using full $R - Y$, $B - Y$ values, it tends to overshoot considerably on the colors of saturated yellow and cyan.

After the $R - Y$ and $B - Y$ video signals have modulated their respective 3.58-Mc subcarriers and have been combined, the result appears as shown in Fig. 18G. The manner in which the figures shown were obtained follows the discussion given previously in Chap. 5.

To form the final signal the corresponding Y component must be added to Fig. 18G, and when this is done, Fig. 18H results. This is the full video signal, with horizontal sync pulse and color burst. Note how various portions of the signal overshoot the maximum brightness level (i.e., the white level in monochrome) at one end and the black level

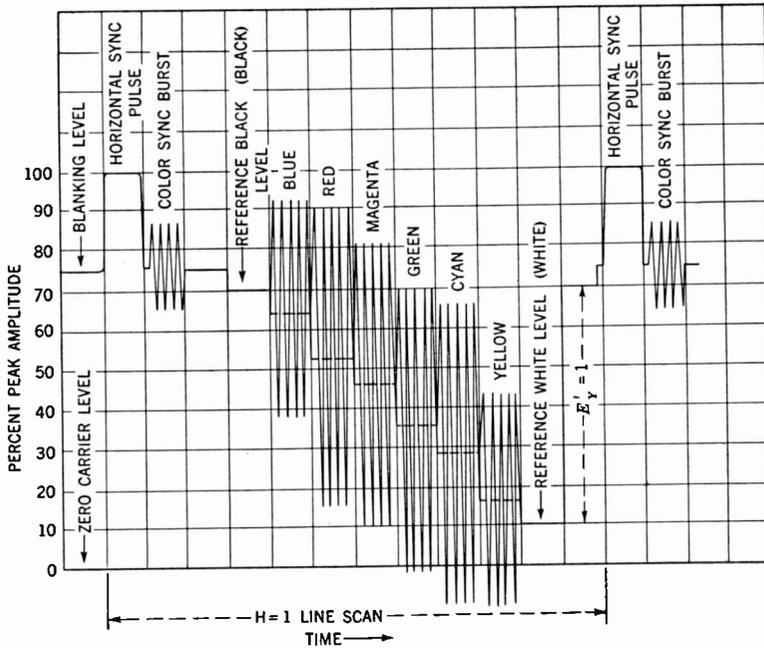


FIG. 19. Video signal obtained from scanning one line of color-bar pattern. The dashed lines represent brightness levels of various saturated colors.

at the other end. Yellow, for example, extends almost twice the distance of a pure white, while blue, at the other end, extends far beyond the tips of the sync pulses themselves. In a receiver, a good portion of the yellow and cyan overshoots would be clipped off, thereby desaturating these signals. The same clipping action would remove portions of the blue and red signals, altering their appearance, too. Besides, the overshoots of the blue and red signals would undoubtedly interfere with the synchronizing action of the receiver.

By modifying the $R - Y$ and $B - Y$ vectors by the factors of 0.877 and 0.493, respectively, we restrict the maximum overshoots to a value of 33 per cent. Both transmitter and receiver are able to handle this much excessive signal amplitude without causing color compression or overmodulation. Furthermore, the full amplitudes of the color signals which do attain the additional 33 per cent amplitude require highly saturated colors which are seldom, if ever, encountered in normal broadcasts. Actually, their only appearance is with color test patterns or with color-bar signals.

The development of the same color-bar pattern using the modified $R - Y$, $B - Y$ values can be followed through step by step (Fig. 19). The signal here has been turned right-side up, and the per cent peak amplitude has been inserted on the side as a reference. The illustration is in accordance with FCC specifications, which state:

"The blanking level shall be at 75 (± 2.5) per cent of the peak amplitude of the carrier envelope. The reference white (luminance) level shall be 12.5 (± 2.5) per cent of the peak carrier amplitude. The reference black level shall be separated from the blanking level by an interval which shall be 7.5 (± 2.5) per cent of the video range from the blanking level to the reference white level."

TECHNICAL SPECIFICATIONS OF THE NTSC COLOR TELEVISION SIGNAL

There are presented here the technical signal specifications formulated by the National Television System Committee and approved by the Federal Communications Commission on Dec. 17, 1953, as the technical transmission standards for commercial color television broadcasting in the United States.

I. GENERAL SPECIFICATIONS

- A. Channel
The color television signal and its accompanying sound signal shall be transmitted within a 6-Mc channel.
- B. Picture signal frequency
The picture signal carrier, nominally 1.25 Mc above the lower boundary of the channel, shall conform to the frequency assigned by the FCC for the particular station.
- C. Polarization
The radiated signals shall be horizontally polarized.
- D. Vestigial sideband transmission
Vestigial sideband transmission in accordance with Fig. 2 shall be employed.
- E. Aspect ratio
The aspect ratio of the scanned image shall be four units horizontally to three units vertically.
- F. Scanning and synchronization
 1. The color picture signal shall correspond to the scanning of the image at uniform velocities from left to right and from top to bottom with 525 lines per frame interlaced 2:1.
 2. The horizontal scanning frequency shall be $2/455$ times the color

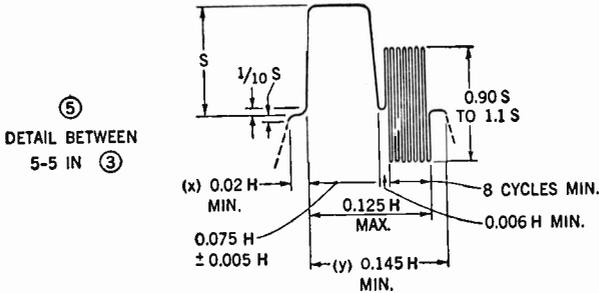
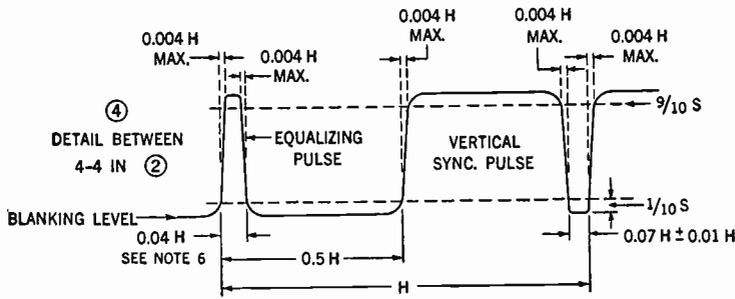


FIG. 1 (cont.)

NOTES

1. H = Time from start of one line to start of next line.
2. V = Time from start of one field to start of next field.
3. Leading and trailing edges of vertical blanking should be complete in less than $0.1 H$.
4. Leading and trailing slopes of horizontal blanking must be steep enough to preserve minimum and maximum values of $(x + y)$ and (z) under all conditions of picture content.
5. Dimensions marked with asterisk indicate that tolerances given are permitted only for long time variations and not for successive cycles.
6. Equalizing pulse area shall be between 0.45 and 0.5 of area of a horizontal sync pulse.
7. Color burst follows each horizontal pulse, but is omitted following the equalizing pulses and during the broad vertical pulses.
8. Color bursts to be omitted during monochrome transmissions.
9. The burst frequency shall be 3.579545 Mc. The tolerance on the frequency shall be $\pm 0.0003\%$ with a maximum rate of change of frequency not to exceed $1/10$ cycle per second per second.
10. The horizontal scanning frequency shall be $2/455$ times the burst frequency.
11. The dimensions specified for the burst determine the times of starting and stopping the burst, but not its phase. The color burst consists of amplitude modulation of a continuous sine wave.
12. Dimension P represents the peak excursion of the luminance signal from blanking level, but does not include the chrominance signal. Dimension S is the sync amplitude above blanking level. Dimension C is the peak carrier amplitude.
13. Refer to text for further explanations and tolerances.

subcarrier frequency; this corresponds nominally to 15,750 cycles per second (with an actual value of $15,734.264 \pm 0.047$ cycles per second). The vertical scanning frequency is $2/525$ times the horizontal scanning frequency: this corresponds nominally to 60 cycles per second (the actual value is 59.94 cycles per second).

3. The color television signal shall consist of color picture signals and synchronizing signals, transmitted successively and in different amplitude ranges except where the chrominance penetrates the synchronizing region, and the burst penetrates the picture region.
4. The horizontal, vertical, and color synchronizing signals shall be those specified in Fig. 1, as modified by vestigial sideband transmission specified in Fig. 2 and by the delay characteristic specified in III B.

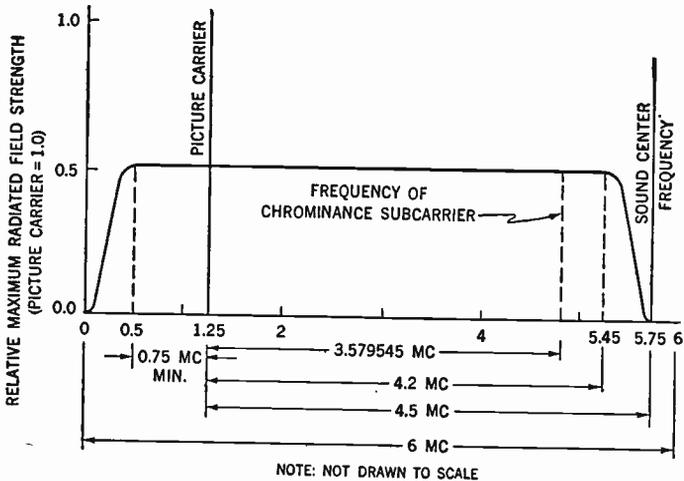


FIG. 2

G. Out-of-channel radiation

The field strength measured at any frequency beyond the limits of the assigned channel shall be at least 60 db below the peak picture level.

II. SOUND

A. Sound signal frequency

The frequency of the unmodulated sound carrier shall be $4.5 \text{ Mc} \pm$

1,000 cycles above the frequency actually in use for the picture carrier.

B. Sound signal characteristics

The sound transmission shall be by frequency modulation with maximum deviation of ± 25 kc, with pre-emphasis in accordance with a 75- μ sec time constant.

C. Power ratio

The effective radiated power of the aural-signal transmitter shall be not less than 50 per cent nor more than 70 per cent of the peak power of the visual signal transmitter.

III. THE COMPLETE COLOR PICTURE SIGNAL

A. General specifications

The color picture signal shall correspond to a luminance (brightness) component transmitted as amplitude modulation of the picture carrier and a simultaneous pair of chrominance (coloring) components transmitted as the amplitude modulation sidebands of a pair of suppressed subcarriers in quadrature having the common frequency relative to the picture carrier of $+3.579545$ Mc ± 0.0003 per cent with a maximum rate of change not to exceed 1/10 cycle per sec per sec.

B. Delay specification

A sine wave, introduced at those terminals of the transmitter which are normally fed the color picture signal, shall produce a radiated signal having an envelope delay, relative to the average envelope delay between 0.05 and 0.20 Mc, of zero μ sec up to a frequency of 3.0 Mc; and then linearly decreasing to 4.18 Mc so as to be equal to -0.17 μ sec at 3.58 Mc. The tolerance on the envelope delay shall be ± 0.05 μ sec at 3.58 Mc. The tolerance shall increase linearly to ± 0.1 μ sec, down to 2.1 Mc, and remain at ± 0.1 μ sec down to 0.2 Mc * The tolerance shall also increase linearly to ± 0.1 μ sec at 4.18 Mc.

C. The luminance component

1. An increase in initial light intensity shall correspond to a decrease in the amplitude of the carrier envelope (negative modulation).

* Tolerances for the interval of 0.0 to 0.2 Mc should not be specified in the present state of the art.

2. The blanking level shall be at (75 ± 2.5) per cent of the peak amplitude of the carrier envelope. The reference white (luminance) level shall be (12.5 ± 2.5) per cent of the peak carrier amplitude. The reference black level shall be separated from the blanking level by the setup interval, which shall be (7.5 ± 2.5) per cent of the video range from the blanking level to the reference white level.
3. The over-all attenuation versus frequency of the luminance signal shall not exceed the value specified by the FCC for black-and-white transmission.

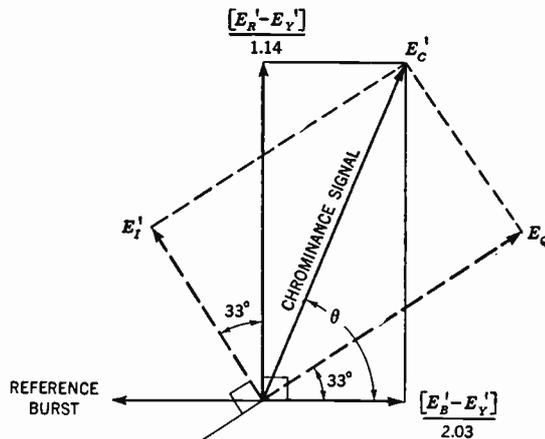


FIG. 3

D. Equation of complete color signal

1. The color picture signal has the following composition:

$$E_M = E_Y' + [E_Q' \sin (\omega t + 33^\circ) + E_I' \cos (\omega t + 33^\circ)]$$

where

$$\begin{aligned} E_Q' &= 0.41 (E_B' - E_Y') + 0.48 (E_R' - E_Y') \\ E_I' &= -0.27 (E_B' - E_Y') + 0.74 (E_R' - E_Y') \\ E_Y' &= 0.30 E_R' + 0.59 E_G' + 0.11 E_B' \end{aligned}$$

The phase reference in the above equation is the phase of the (color burst + 180°), as shown in Fig. 3. The burst corresponds to amplitude modulation of a continuous sine wave.

NOTES: For color-difference frequencies below 500 kc, the signal can be represented by

$$E_M = E_{Y'} + \left\{ \frac{1}{1.14} \left[\frac{1}{1.78} (E_{B'} - E_{Y'}) \sin \omega t + (E_{R'} - E_{Y'}) \cos \omega t \right] \right\}$$

In these expressions the symbols have the following significance:

E_M is the total video voltage, corresponding to the scanning of a particular picture element, applied to the modulator of the picture transmitter.

$E_{Y'}$ is the gamma-corrected voltage of the monochrome (black-and-white) portion of the color picture signal, corresponding to the given picture element.*

$E_{R'}$, $E_{G'}$, and $E_{B'}$ are the gamma-corrected voltages corresponding to red, green, and blue signals during the scanning of the given picture element.

The gamma-corrected voltages $E_{R'}$, $E_{G'}$, and $E_{B'}$ are suitable for a color picture tube having primary colors with the following chromaticities in the CIE system of specification:

	x	y
Red (R)	0.67	0.33
Green (G)	0.21	0.71
Blue (B)	0.14	0.08

and having a transfer gradient (gamma exponent) of 2.2 † associated with each primary color. The voltages $E_{R'}$, $E_{G'}$, and $E_{B'}$ may be respectively of the form $E_{R'}^{1/\gamma}$, $E_{G'}^{1/\gamma}$, and $E_{B'}^{1/\gamma}$ although other forms may be used with advances in the state of the art.

$E_{Q'}$ and $E_{I'}$ are the amplitudes of two orthogonal components of the chrominance signal corresponding respectively to narrow-band and wide-band axes, as specified in paragraph *D*.

The angular frequency ω is 2π times the frequency of the chrominance subcarrier.

The portion of each expression between brackets represents the chrominance subcarrier signal which carries the chrominance information.

1. The chrominance signal is so proportioned that it vanishes for the chromaticity of CIE illuminant C ($x = 0.310$, $y = 0.316$).

2. $E_{Y'}$, $E_{Q'}$, $E_{I'}$ and the components of these signals shall match each other in time to 0.05 μ sec.

* Forming of the high-frequency portion of the monochrome signal in a different manner is permissible and may in fact be desirable in order to improve the sharpness on saturated colors.

† At the present state of the art it is considered inadvisable to set a tolerance on the value of gamma and correspondingly this portion of the specification will not be enforced.

3. A sine wave of 3.58 Mc introduced at those terminals of the transmitter which are normally fed the color picture signal shall produce a radiated signal having an amplitude (as measured with a diode on the RF transmission line supplying power to the antenna) which is down (6 ± 2) db with respect to a radiated signal produced by a sine wave of 200 kc. In addition, the amplitude of the radiated signal shall not vary by more than ± 2 db between the modulating frequencies of 2.1 and 4.18 Mc.

4. The equivalent bandwidths assigned prior to modulation to the color-difference signals $E_{Q'}$ and $E_{I'}$ are given by the following table:

<i>Q-channel bandwidth</i>	<i>I-channel bandwidth</i>
At 400 kc less than 2 db down	At 1.3 Mc less than 2 db down
At 500 kc less than 6 db down	At 3.6 Mc at least 20 db down
At 600 kc at least 6 db down	

5. The angles of the subcarrier measured with respect to the burst phase, when reproducing saturated primaries and their complements at 75 per cent of full amplitude, shall be within $\pm 10^\circ$ and their amplitudes shall be within ± 20 per cent of the values specified above. The ratios of the measured amplitudes of the subcarrier to the luminance signal for the same saturated primaries and their complements shall fall between the limits of 0.8 and 1.2 of the values specified for their ratios. Closer tolerances may prove to be practicable and desirable with advance in the art.

GLOSSARY

Aperture mask: A thin, perforated plate positioned between the phosphor-dot plate and the electron guns in the three-gun color picture tube. The mask is designed to prevent any beam from striking the wrong color phosphor dot.

Balance: *See* Color balance.

Chroma: That quality of color which embraces both hue and saturation. White, black, and grays have no chroma.

Chromatron tube: *See* Lawrence tube.

Chrominance: That property of light which produces a sensation of color in the human eye apart from any variation in brightness that may be present.

Chrominance channel: Those stages of a color television receiver which deal exclusively with the color portion of the total video signal.

Color burst: The eight or more sine-wave cycles of color-subcarrier frequency which are located on the back porch of every horizontal sync pulse of a color television signal.

Color-difference signal: A signal which, when added to the monochrome signal, produces either a red, green, or blue signal.

Color dilution: A reduction in the saturation of a color by the addition of white light, for example, changing red to pink.

Color edging: Spurious color at the boundaries of differently colored areas in a picture. Color edging includes color fringing and misregistration.

Color fringing: The appearance of spurious color at the boundaries of differently colored areas in a picture as a result of motion in the scene.

Colorimetry: The science of determining and specifying colors in terms of their primary-color composition and intensity.

Color picture signal: The electrical signal which represents color picture information, consisting of a monochrome component plus a subcarrier modulated with color information.

Color primaries: The basic colors from which all other colors can be obtained. In television, red, green, and blue are the color primaries.

Color purity: The degree to which a color is free of white or any other color.

Color saturation: The degree to which a color is free of white light.

Color subcarrier: The carrier whose modulation sidebands are added to the monochrome signal to convey color information. In the NTSC system the color subcarrier frequency is 3.579545 Mc.

Color sync signal: See Color burst.

Color transmission: In television, the transmission of a signal wave for controlling both the luminance and chromaticity values in a picture.

Colortron: The name given to the CBS three-gun color picture tube.

Compatibility: The property of a color television system which enables existing black-and-white sets to receive the color signal and produce from it an equivalent black-and-white picture.

Composite color signal: The color picture signal, including blanking and all synchronizing signals.

Convergence: The orientation of the three electron beams so that they pass through the same hole in the shadow mask at the same time.

Decoding: The process whereby the color sidebands are recombined with the color carrier to provide the original color video signals.

Dynamic convergence: The maintenance of proper convergence as the scanning beams sweep over the picture tube screen.

Hue: Color.

Lawrence tube: A color picture tube employing a single gun. The screen phosphor is laid down in a series of horizontal strips in a sequence of green, red, green, blue, green, red, etc. The electron beam is directed to a specific color phosphor by the potential variation on a grid-like structure positioned directly behind the phosphor screen. Also called Chromatron tube.

Luminance: The amount of light which is emitted, reflected, or transmitted from the surface of an object.

Luminance channel: Those stages which are concerned solely with the luminance signal.

Luminance signal: Another name for the brightness or monochrome signal.

Matrix: The network (resistive, electronic, or combinations of both) in which the I, Q or $R - Y, B - Y$ signals combine with each other and with the brightness signal to re-create the red, green, and blue voltages of which the color image is formed.

Misregistration: The effect produced when the red, green, and blue primary colors are seen separately rather than in combination.

Moire: In television, the spurious pattern in the reproduced picture resulting from interference beats between two sets of periodic structures in the image. Moires may be produced, for example, by interference between regular patterns in the original subject and the target grid in an image orthicon, between patterns in the subject and the line pattern and the pattern of phosphor dots of a three-color kinescope, and between any of those patterns and the pattern produced by the carrier color signal.

Monochrome bandwidth (of the signal): The video bandwidth of the monochrome signal.

Monochrome bandwidth (of the monochrome channel): The video bandwidth of the monochrome channel.

Monochrome channel: In a color television transmission, any path which is intended to carry the monochrome signal. (The monochrome channel may also carry other signals, for example, the carrier color signal, which may or may not be used.)

Monochrome signal: In monochrome television transmission, a signal wave for controlling the luminance values in the picture but not the chromaticity values. In color television transmission, that part of the signal wave which has the major control of the luminance of the color picture and which controls the luminance of the picture produced by a conventional monochrome receiver.

Monochrome transmission: In television, the transmission of a signal wave for controlling the luminance values in the picture but not the chromaticity values.

NTSC: Abbreviation for National Television System Committee. This is the committee which sponsored the development of the NTSC color television system.

Planar mask: Aperture, or shadow, mask.

Shadow mask: Aperture mask.



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