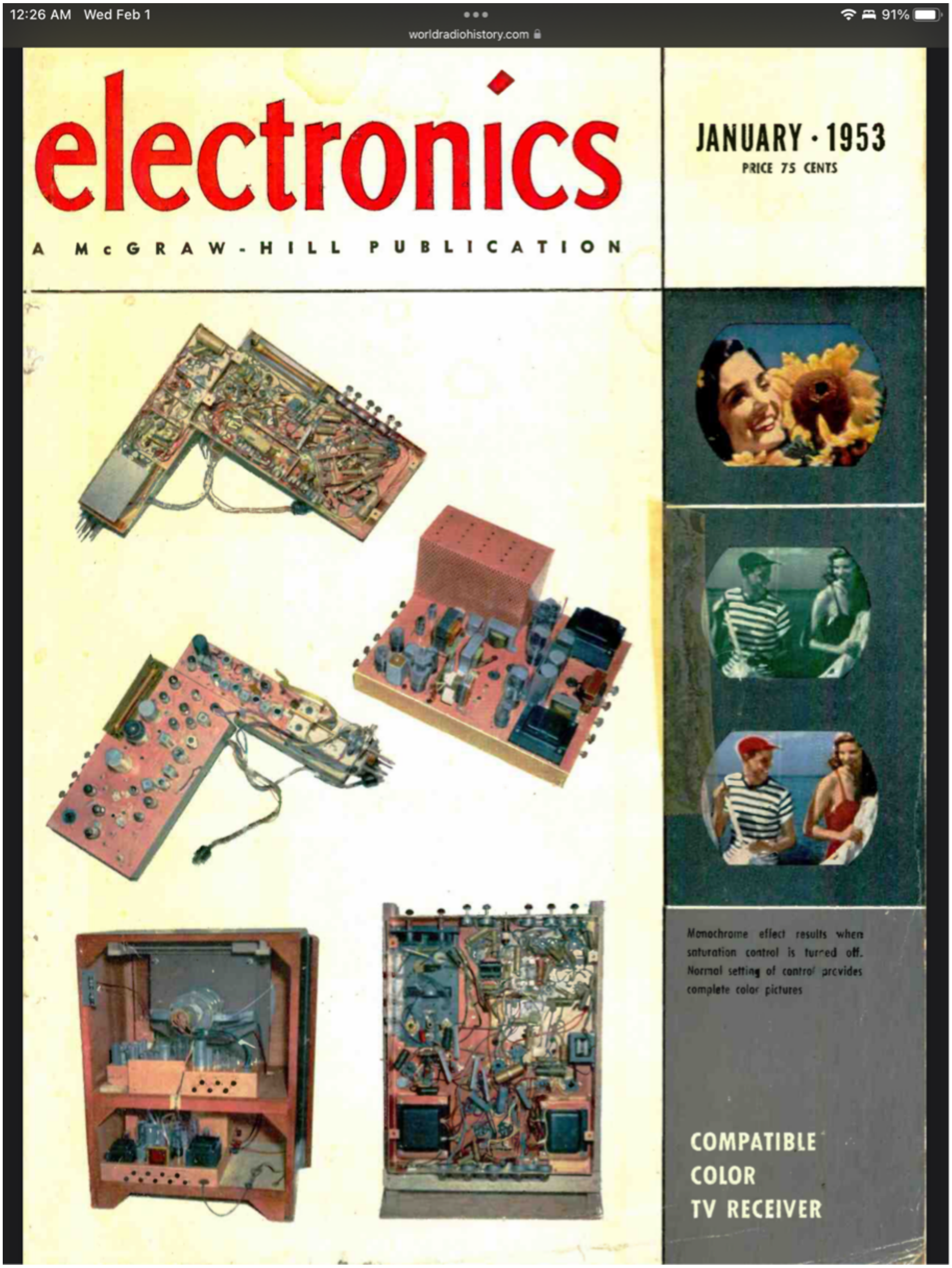

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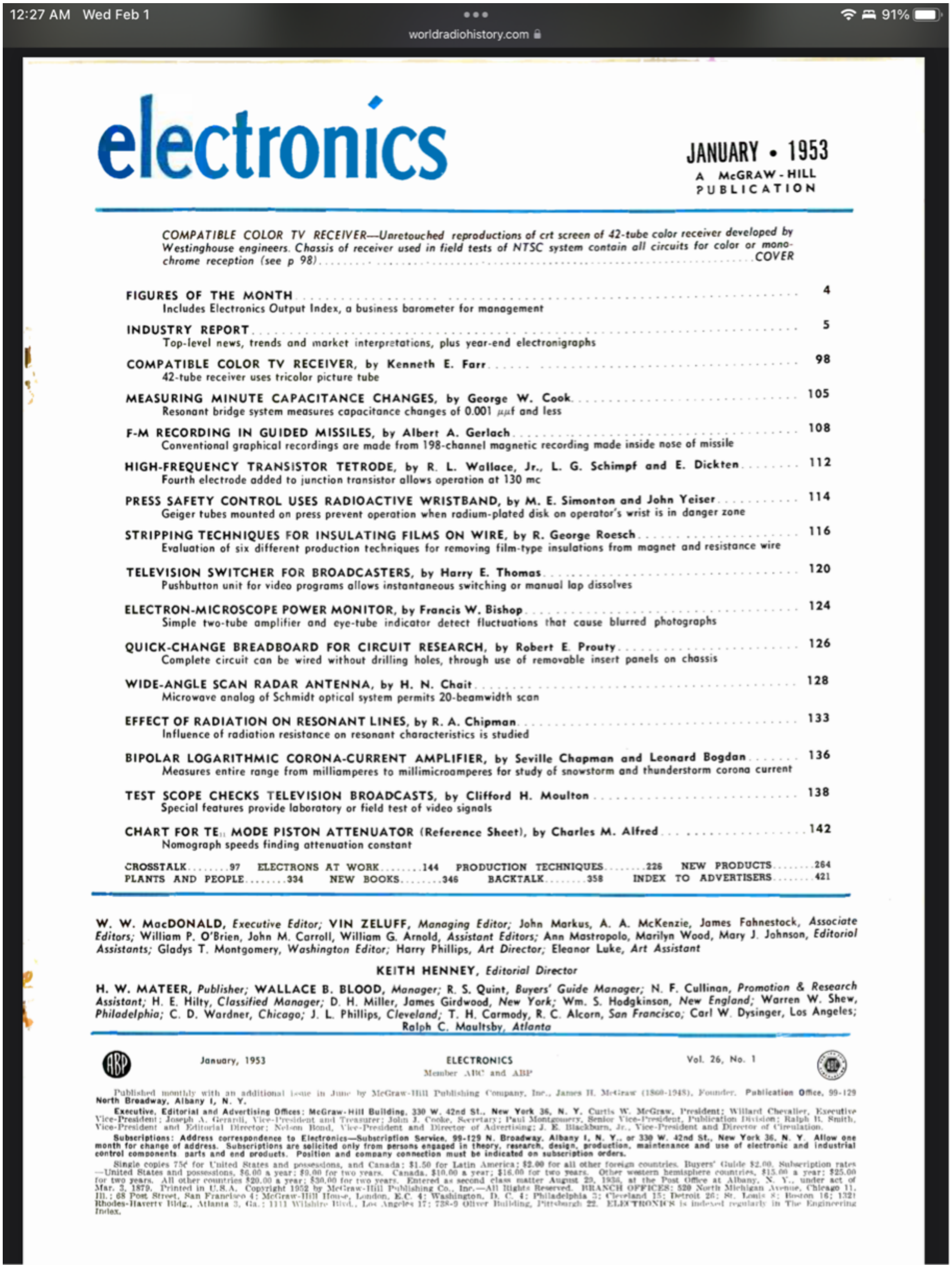
COMPATIBLE COLOR TV RECEIVER



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COMPATIBLE COLOR TV RECEIVER—Unretouched reproductions of crt screen of 42-tube color receiver developed by Westinghouse engineers. Chassis of receiver used in field tests of NTSC system contain all circuits for color or monochrome reception (see p 98) .... *COVER*

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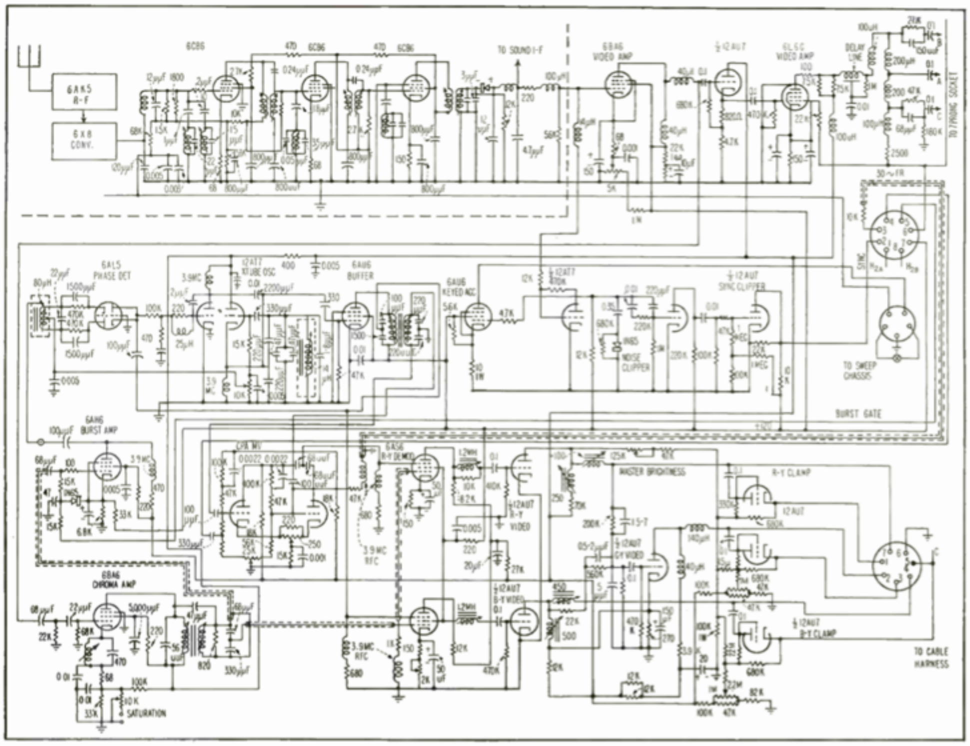


Circuits of chassis shown on front cover of this issue of ELECTRONICS

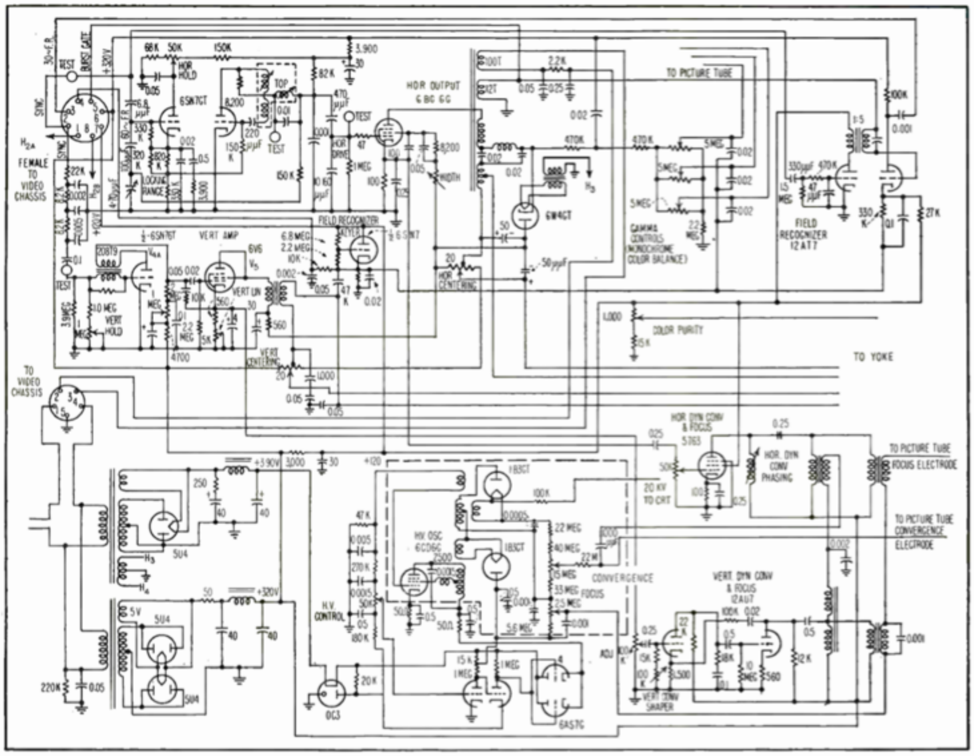
Compatible Color TV Receiver

By KENNETH E. FARR
Westinghouse Electric Corp.
Metuchen, N. J.

COLOR PICTURES produced by the receiver to be described are equivalent in size to a 12½-inch black and white picture. The receiver accommodates all vhf channels as well as UHF channels, and is capable of black and white as well as color reception. An overall block diagram showing the basic functions of the receiver is given in Fig. 1.

The upper portion of the block diagram is essentially a conventional black and white television receiver. It includes the tuner and i-f the video channel, deflection and sync circuits and a sound channel. The portion which shows the features particular to the color section includes the color decoders, color difference amplifiers, the color subcarrier generator, and the dynamic convergence and focus circuits which are peculiar to the RCA tricolor picture tube.

The essential monochrome elements of this receiver include the main signal and video channel, the sync and deflection circuits, and the intercarrier sound system. The sync separator, the tuner, i-f and sound portion are patterned closely after present black and white circuits. The i-f passband requirements for color reception are somewhat more critical but the essential difference from standard black and white in this portion of the receiver is in the video section. This has somewhat more gain and driving



Front-end and sound channel circuits are omitted for clarity

A straightforward approach to the problem of receiver design for the NTSC color system results in this 42-tube receiver. Used in numerous NTSC field tests of color tv, its performance on monochrome transmissions is comparable to current black and white receivers

---

capability than the average receiver, due to the requirements of the tricolor tube.

The receiver is designed for a compatible color television system, namely the NTSC system.[1] In this system, information is added to a standard black and white transmission to produce color in an appropriately designed receiver. A normal black and white receiver is capable of receiving a black and white picture from the transmission without any modifications.

There are several ways of specifying color. One way, which is probably the most familiar, is to break the colors down to three primaries—green, red and blue. Any visible color may then be specified in terms of the percentage of red, green and blue which could be used to duplicate the impression of this color as far as the viewer is concerned. Another method of specifying color is to describe the color sensation to the eye in terms of brightness, hue and saturation. Brightness is self-explanatory.

Hue is the attribute normally called color by the layman. That is, whether it is red, green, orange, and so on.

Saturation is a term which describes the amount of white mixed with the color, or as the artist would call it, the tint. This describes the difference between red and pink, for instance. Pink is a lower saturation red and 100-percent saturation would be the pure, strong color. Zero-percent saturation would be white.

The latter system of specifying color is utilized in the NTSC sys-

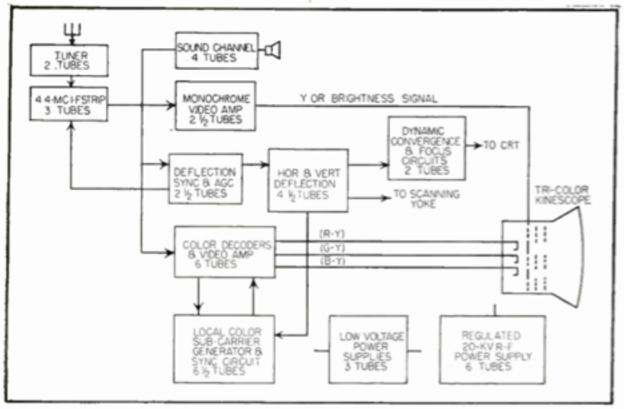


FIG. 1—Arrangement of stages in the overall receiver

tem. The brightness information is what is presently transmitted in the standard black and white system. This is modified somewhat in the NTSC system so that the black and white pictures represent the true brightness of all colors in accordance with the luminosity curve of the eye. To this brightness signal, two further degrees of information are added relating to the hue and saturation of the color.

Bandwidth

The brightness signal conveys the detail information or the resolution of the picture, and it should be transmitted at the full bandwidth of which the system is capable. It has been demonstrated,[2] however, that the eye is much less sensitive to detail in color than in brightness.

Translated into engineering terms, this means that less bandwidth is required for the hue and saturation signals than for the brightness signals. Taking advantage of this limitation of the eye, the hue and saturation signals can be transmitted over a much narrower bandwith without notable degradation of the picture. In actual practice, approximately four megacycles of bandwidth is used to transmit the brightness signal, and from 1 to 2 mc for the combined hue and saturation information.

This might seem to require at least a 5-mc channel. However, use is made of an additional phenomenon—the frequency makeup of a scanned television signal.[3] Since the scanning occurs at a constant repetition rate, frequency components of the signal lie in groups at line frequency and harmonics thereof. Definite gaps exist between these frequencies.

Figure 2 shows the frequency spectrum of the television video signal. The solid lines represent the harmonics of line frequency with 30 and 60-cycle sidebands corresponding to the field and frame information. The spaces between groups can be noted. This diagram shows the 200th and 201st harmonic of line frequency. The same pattern, however, exists from zero frequency up to the maximum transmitted in the signal.

The question might be raised that if there are no signal components present between these groups, what might happen if signals were placed there. From the theory of scanning,[3] it can be shown that a signal existing between the harmonics of line frequency, or more specifically at an odd multiple of half the line frequency, such as the 401st as shown here, will not be visible in the television picture. This is because it will be of opposite polarity on alternate lines and will thus integrate out to the eye.

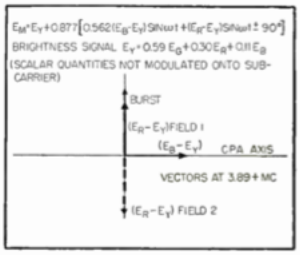


FIG. 2—Frequency spectrum of color signal

The hue and saturation information is amplitude modulated onto a color subcarrier whose frequency is such that all this color information falls in these odd multiples of half line frequency between the brightness components and thus have low visibility to the eye. This information, however, can be extracted by an inverse process in the color receiver and used to recreate the colors of the original subject.

The color subcarrier used is at the upper end of the brightness band, namely 3.898125 kilocycles, which is the 495th harmonic of half-line frequency. This high frequency was selected to further reduce the visibility of these color components in the brightness channel.

Hue and saturation information can be modulated onto a single subcarrier by using two subcarriers of the same frequency 90 degrees apart in phase. One piece of information is modulated onto one carrier and one onto the other. Synchronous demodulation at the receiver will recover each piece of information separately.

Suppressed-carrier transmission is used to further reduce the visibility of the color information on black and white receivers. Thus, only the sidebands are transmitted and the carrier, or subcarrier in this case, is reinserted at the receiver. This technique is not common in the television field.

To obtain maximum use of the bandwidth, vestigial sideband transmission is used with the upper sideband extending approximately 0.4 mc above the color subcarrier and the lower side band extending 1 to 2 mc below it. Thus, the entire color information is interleaved in the video frequency region of 3 to 4.5 mc.

A vector diagram of the color subcarrier with modulation is shown in Fig. 3. The equation at the top is the expression for the entire color signal. It is written as a brightness term E_Y plus another term which is the color information. The brightness signal is made up of 59-percent green, 30-percent red and 11-percent blue, in accordance with the color sensitivity of the human eye.

The color term consists of two parts. The plus or minus sign on the phase of the second part indicates color phase alternation. That is, this second term alternately leads and lags the first term by 90 degrees.

The vector diagram of Fig. 3 shows the various components of the color subcarrier. The vertical vector marked BURST is the color sync. It consists of about 9 cycles of color subcarrier transmitted on the back porch of each horizontal blanking interval. This burst is designated as the reference phase of the system. Lagging this burst phase by 90 degrees is the blue color signal ($E_B - E_Y$). This signal is derived by substracting the brightness video signal from the blue video signal and modulating the color subcarrier with this difference. How this is accomplished in the actual equipment will be shown a little more clearly in what follows. It should be noted, however, that if the brightness signal is added back to the color difference signal, the blue signal E_B results.

Shown in phase with the burst is the red color difference signal. This phase is that obtained in the so-called odd field. On alternate fields, the phase is reversed 180 degrees, as shown dashed. This periodic reversal of the phase of this component of the color subcarrier, known as color phase alternation, is necessary when vestigal sideband color transmission is used. It cancels out the quadrature components that result from the single-sideband portion of the transmission, and cause cross modulation between the two components of the signal. The amplitude of these $E_B - E_Y$ and $E_R - E_Y$ vectors is a function of the color content of the picture is zero for black and white areas of the picture. Thus, the entire vector diagram with the exception of the burst disappears on black and white pictures.

No green signal is used as such to make up a component of the subcarrier. The reason for this can be seen in the actual makeup of the ($E_G - E_Y$) color difference signal.

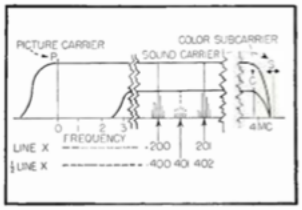


FIG. 3—Specification of NTSC signal. Color information is modulated onto subcarrier for vestigial sideband suppressed-carrier transmission

$$E_Y = 0.59\,E_G + 0.30\,E_R + 0.11\,E_B \qquad (1)$$

$$\begin{aligned} E_G - E_Y &= E_G - 0.59E_G \\ &\quad - 0.30E_R - 0.11E_B \qquad (2) \\ &= 0.41E_G - 0.30E_R - 0.11E_B \end{aligned}$$

Similarly,

$$E_R - E_Y = -0.59E_G + 0.70E_R - 0.11E_B \qquad (3)$$

$$E_B - E_Y = -0.59E_G - 0.30E_R + 0.89E_B \qquad (4)$$

Each of these color difference signals contain all three of the color video signals. By taking 0.51 unit of the $E_R - E_Y$ signal, combining it with 0.19 unit of the $E_B - E_Y$ signal, and reversing the polarity of the combination, the $E_G - E_Y$ signal will result. This operation can be expressed by

$$\begin{aligned} -0.51\,(E_R - E_Y) - 0.19\,(E_B - E_Y) \\ = E_G - E_Y \qquad (5) \end{aligned}$$

Thus it is not necessary to transmit the ($G - Y$) signal as a separate vector, since it can be derived from the proper combination of the red and blue color difference signals in the receiver.

Typical Transmitter

A simplified block diagram of a color transmitter may make this somewhat clearer. In Fig. 4 is shown a color camera that splits the light from the image into red, blue and green components, and delivers signals corresponding to each of these three colors to a mixer. This mixer is essentially a linear adder which combines green, red and blue in the proper proportions to form the Y or brightness signal which is shown at the top of the diagram.

The mixer also produces the red and blue color difference signals which are shown written in both forms, for instance ($R - Y$), and underneath ($0.6G - 0.7R - 0.1B$), which is the actual make-up of this signal. The blue and red color difference signals then are passed through 2.5-mc filters to a pair of balanced modulators. These modulators are supplied with color subcarriers at 3.89 mc, which modulate the ($B - Y$) signal in the reference phase and modulate the ($R - Y$) signal at 90 degrees and 270 degrees, alternately at field rate. This is the color phase alternation described above.

The sync and color burst is generated and added to the output of the two balanced modulators, and this mixture is then added to the brightness signal to produce a com-

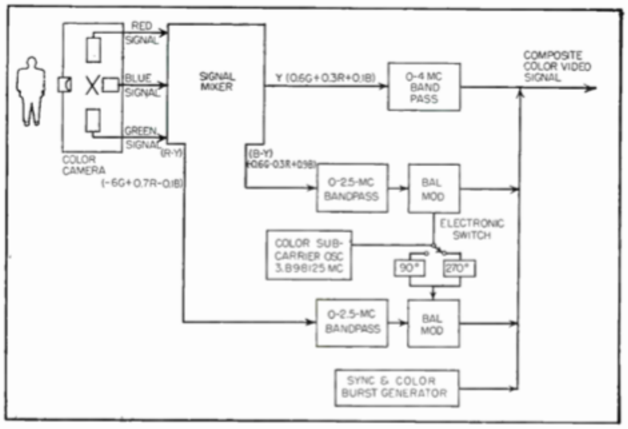


FIG. 4—Color transmitter video circuits

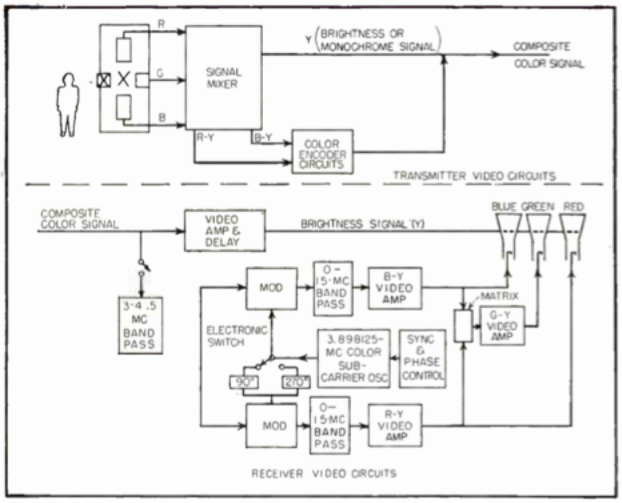


FIG. 5—Video circuit functions of receiver are inverse of those in transmitter

posite color video signal. The upper portion of Fig. 4, with the addition of the sync, produces a standard black and white picture. The lower portion of the diagram generates the color information which is added to this brightness information.

Figure 5 shows this transmitter schematic simplified further, and below it, for comparison, is shown the video section of a typical receiver. In the transmitter schematic, the brightness or monochrome signal circuits are at the top, and below them are the color encoder circuits, producing the color information that is added to the brightness signal. The receiver video circuits perform the inverse of this transmitter function.

The composite color video signal is supplied through the video amplifier to the grids of the tricolor kinescope. If the circuit shown in the lower portion of the block diagram is made inoperative, an ordinary black and white picture will be obtained. The color subcarrier information existing in the region of 3 to 4.5 mc in the composite video signal is applied through a bandpass circuit, to eliminate unwanted monochrome components, to a pair of modulators in a very similar fashion to that done in the transmitter. These modulators are supplied with a local subcarrier generated and controlled in phase by receiver circuits to be described later.

The color subcarrier modulates the information in the 3 to 4.5-mc region, beating it down to low-frequency even harmonics of half line frequency from zero to 1 mc. This demodulated information will then be the $(B - Y)$ signal, and the $(R - Y)$ signal as originally derived at the transmitter.

By combination of the $(B - Y)$ and the $(R - Y)$ signals in the matrix, which is simply a resistive mixing pad, the $(G - Y)$ signal is produced as was shown earlier. These three color difference signals are then applied to the cathodes of the blue, green and red guns of a tricolor kinescope or other suitable display device. Addition of the color difference signals to the brightness signal takes place within the kinescope. Thus the blue gun gets the Y signal on its grid, and the $(B - Y)$ signal on its cathode, and the effective signal applied between the grid and cathode of this tube then is B.

The same is true for the green and red tubes, so that finally the red, green and blue signals are used to control the beam current of the tube. The three images are superimposed to produce the complete color picture.

Turning to more specific details of the receiver design, it might be interesting to look at the receiver i-f passband requirements. Figure 6 shows the transmitted frequency spectrum of the composite video signal. The picture carrier is shown at zero frequency, with the lower vestigial sideband, the full upper sideband, and the sound carrier shown in their relative positions. The location of the color subcarrier and its components is also shown in the region of 2 to 4.5 mc.

Receiver I-F System

For proper reception of the vestigial sideband monochrome signal, the receiver passband should locate the picture carrier at the 50-percent response point, and the passband response should be down to essentially zero within the region of the vestigial lower sideband. This locates one edge of the i-f response rather critically. Since the color information is also a vestigial sideband transmission, it becomes necessary to locate the color subcarrier at the 50-percent response point on the *upper* slope of the i-f passband. This upper slope must be down to essentially zero at about 4.3 mc, which is the minimum width of the vestigial sideband called for in the NTSC standard proposal.

The sound carrier must, of course, be suppressed at least 26 db for intercarrier sound reception. Actually, it must be down somewhat further than this, approximately 30 to 40 db, to prevent an undesirable beat between the color subcarrier and sound carrier in the monochrome channel. The lower curve marked receiver i-f characteristic shows the idealized receiver passband for proper reception of the color signal. The receiver described has essentially this passband, centered at 44 mc.

Color Decoders and Video

In Fig. 7 is shown a block diagram of the color decoder section of the receiver. The composite video from the second detector is amplified in the chroma amplifier. The gain of this stage is adjustable from the front panel by the saturation control. Its function is to vary the saturation of the color in the picture. When turned completely off, a black and white picture results. As the control is advanced, the colors become more brilliant. If the control is set above normal, an appearance of fluorescent colors can be produced.

The output of the chroma amplifier, after going through a bandpass circuit, consists primarily of the interleaved color information. This is applied to the grids of the decoders or demodulators. The 3.89-mc local color subcarrier oscillator signal is applied directly to the suppressor of the $(B - Y)$ demodulator tube, and through a 90-degree phase shift network (which is simply a tuned circuit), to the suppressor of the $(R - Y)$ decoder.

The output of these decoders are the low-frequency color difference signals. These are applied to the cathodes of the red and blue guns of the tricolor kinescope. The $(G - Y)$ signal, derived from the matrix, is applied to the cathode of the green gun of the kinescope.

The d-c restorers are shown as they are actually connected from the common Y signal to the respective color difference signals. The signals seen by each restorer and by each respective gun of the kinescope are then actually the reconstructed red, green and blue signals. These color difference signals are restricted in bandwidth to about 1 mc in the receiver while the brightness signal has a 4-mc passband. This causes the color difference signal to suffer a delay relative to the brightness signal. To correct this condition and make the components coincident in time, a delay line is inserted in the monochrome channel. This line has a bandwidth of approximately 4 mc and introduces a delay of one micro-second.

Color Sync and Subcarrier Generator

The local color subcarrier generator and sync circuit is shown in block diagram form in Fig. 8. The 3.89-mc signal is generated at the transmitter by a crystal oscillator. In the receiver, this frequency must be generated and held to an exact phase relationship relative to that at the transmitter. This is accomplished by using the color synchronizing information or burst, consisting of about 9 cycles of the 3.89-mc subcarrier on the back porch following each horizontal sync pulse.

The signal from the output of the chroma amplifier is applied to the burst amplifier, which is a high-gain amplifier gated on by the horizontal retrace for the duration of the burst interval. The output of this amplifier then contains only the separated burst signal. This signal is applied to a 6AL5 phase detector where it is compared with the signal from the local 3.89-mc oscillator.

A d-c voltage is developed which is proportional to the phase difference between these two signals. This d-c voltage is applied to a reactance tube to control the phase and frequency of the local 3.89-mc oscillator. The output of this local oscillator, through a buffer stage, is used to modulate the $(B - Y)$ decoder directly, and through a tuned circuit introducing a 90-degree phase shift, it is applied to the color phase alternation multivibrator. This is a flip-flop multivibrator which reverses the polarity of this local oscillator wave at field rate. Thus the signal applied to the $(R - Y)$ modulator will lead that

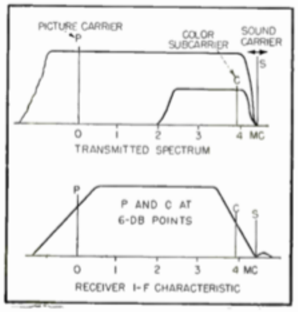


FIG. 6—Idealized receiver passband and location of color subcarrier

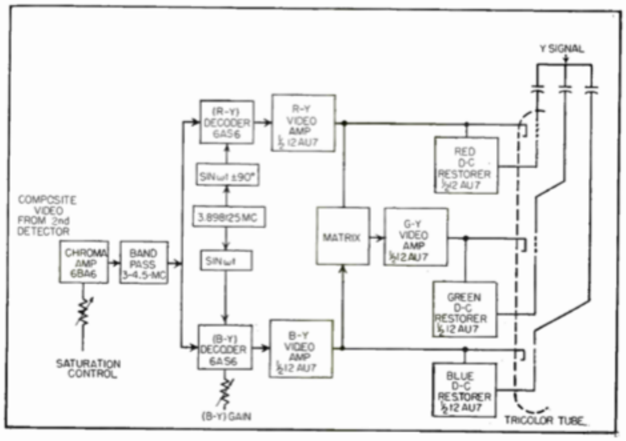


FIG. 7—Color decoder section and the signals handled

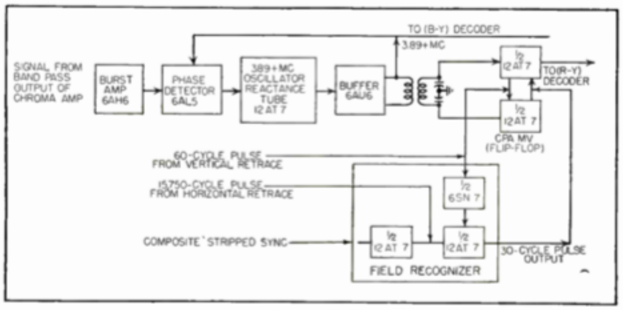


FIG. 8—Local color subcarrier generator and sync circuits

applied to the $(B - Y)$ modulator by 90 degrees in one field and lag it by 90 degrees in the next field.

Attention must be paid to the phase of this alteration. It must flip when the transmitter flips and flop when the transmitter flops. To accomplish this, a unit called a field recognizer is used.[4] The necessary sensing information is implicit in the ordinary black and white synchronizing signal, in the alternate field interlacing. The field recognizer gates in a horizontal sync pulse on alternate fields, thus producing a 30-cycle output.

The field recognizer circuit is shown in Fig. 9. The composite stripped sync is partly integrated and applied to the grid of a 12AT7 tube. In the plate circuit of this tube is a transformer having a secondary resonant at one-half the horizontal line frequency. The integrated stripped sync, consisting primarily of vertical sync pulses, excites this resonant circuit.

On one field the peaks of this damped wave will occur in phase with the horizontal sync pulses while on the alternate field the horizontal sync pulses fall on the axis of the damped wave. A voltage pulse from the horizontal retrace, picked up from a winding on the horizontal output transformer, is added to this damped wave, and the combined signal is applied to the grid of the other half of the 12AT7 tube.

The horizontal pulse at the beginning of one field will ride on the peaks of the damped wave and have higher amplitude than the horizontal pulses at the beginning of the next field, which are riding on the axis of the damped wave. By clipping the peaks of this composite wave in the output half of the 12AT7, one or two horizontal pulses are gated out on alternate fields. This then is the 30-cycle wave having a definite sense relative to the transmitted signal.

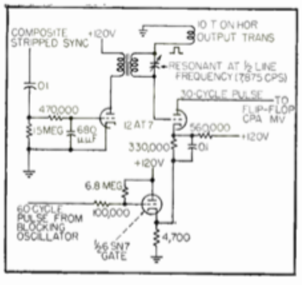


FIG. 9—Field recognizer circuit controls flip-flop multivibrator for color phase alternation

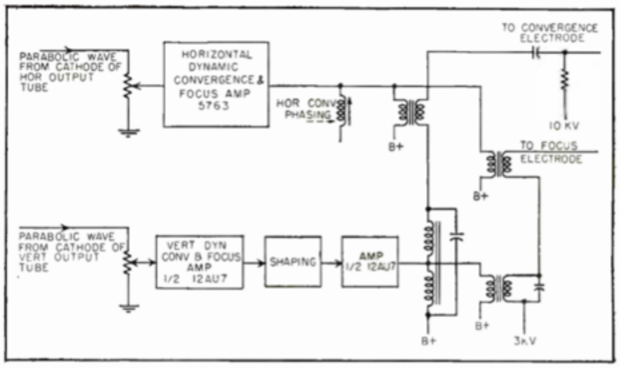


FIG. 10—Dynamic convergence and focus circuits control color registration on picture tube screen

The 6SN7 gate tube, shown at the bottom of the diagram, gates on this field recognizer circuit only during the vertical retrace interval to improve its signal-to-noise ratio, since it is then only responsive for a fraction of the total time. The 30-cycle pulse from this field recognizer unit is applied to one grid of the cpa flip-flop multi-vibrator. The 60-cycle vertical retrace pulse is applied to the other grid, with the result that the flip-flop multivibrator is driven in the correct phase at all times.

Scanning Circuits

The horizontal and vertical scanning circuits are quite conventional. The main difference between those used in this receiver and those in standard black and white receivers is that somewhat more scanning power is required, since the tricolor kinescope has a 2-inch neck with a large yoke and requires more scanning current. The high voltage for the kinescope is a regulated r-f supply delivering 20,000 volts at about 300 microamperes for an average picture. Regulation is required in this supply to maintain color registration under variations in beam current.

Some special circuitry in conjunction with the scanning is required for the RCA tricolor tube to maintain correct color registration.[5] These circuits, known as dynamic convergence circuits, are outlined in Fig. 10. After the d-c potentials and magnets at the tube neck are adjusted to bring the beams from all three guns into registry at the center of the tube, a-c signals must be applied to the convergence and focus electrodes to maintain convergence and focus of the three beams over the entire face of the tube.

Parabolic waves derived from the cathodes of the horizontal and vertical output tubes are applied to amplifiers. Some phasing and shaping of these waves is done in these amplifier stages. The outputs of the two amplifiers are combined in series, through transformers, to form the combined dynamic convergence and focus waves, which are applied to the picture tube. By careful adjustment of the amplitude and phase of these convergence waves, good registration of the colors can be obtained over the entire face of the tube.

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