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# PRACTICAL CIRCUITS FOR COLOR TELEVISION

## Part III. Chrominance Channel and Matrix

A clear understanding of the chrominance channel operation is dependent upon a knowledge of the chrominance signal itself. It is therefore desirable at this point to review briefly the composition of the chrominance signal.

### CHROMINANCE SIGNAL

It will be recalled from previous color articles that the individual outputs of the red, green and blue cameras are applied to the transmitter matrix where they are proportioned to form three separate outputs. One is the brightness signal ($E_Y$) and the other two are color difference signals ($E_I$ and $E_Q$). The signals that are important to this discussion are the color difference signals, which are proportioned as follows:

$$E_I = .60\ E_R - .28\ E_G - .32\ E_B$$
$$E_Q = .21\ E_R - .52\ E_G + .31\ E_B$$

As indicated, the signals can be either negative or positive. When scanning red, for example, there is output from the red camera only, resulting in $E_I = +.60$ and $E_Q = +.21$. When green is being scanned, $E_I = -.28$ and $E_Q = -.52$. For blue, $E_I = -.32$ while $E_Q = +.31$. The polarities and amplitudes of the signals when scanning other colors depends on the amount of red, green and blue content of the particular color.

The color difference signals are applied to individual modulators in the transmitter. The $E_I$ signal modulates a 3.58 mc carrier supplied to the I modulator, and the $E_Q$ signal modulates a 3.58 mc carrier supplied to the Q modulator. It is important to note that the carrier modulated by the $E_I$ signal is 90° out of phase with the carrier modulated by the $E_Q$ signal.

Special "balanced" modulators are employed. The design of the modulators is such that there is no output when the applied color difference signal is zero. When the color difference signal is positive or negative, the modulator output is a 3.58 mc sine wave signal, and the amplitude of the output is determined by the amplitude of the color difference signal. As the color difference signal increases in amplitude (from a positive level to a more positive level or from a negative level to a more negative level) the modulator output increases with it. However, the output signal for negative values of color difference signal is 180° out of phase with the output obtained when the color difference signal is positive. In other words, the phase of the output signal changes abruptly 180° as the color difference signal goes from negative to positive or vice versa.

The outputs of the I modulator and Q modulator are added together to produce the chrominance signal. Figure 1 shows how the two signals are combined to form one resultant. The figure is not intended to show conditions for a particular hue and saturation, but rather to show the additive process. As shown by B of the figure, the potential of the resultant (C) at any instant is equal to the algebraic sum of I and Q at the same instant. Observe also that the phase of the resultant is exactly half way between the I and Q phase *when I and Q are equal in amplitude.* A change in the amplitude of either I or Q results in a change in phase *and* amplitude of the resultant.

The signals illustrated in figure 1 would result with positive values of $E_I$ and $E_Q$. To illustrate the effects of negative values of $E_I$ and $E_Q$, the plotted waveform would be inverted, shifting the phase by 180°. This

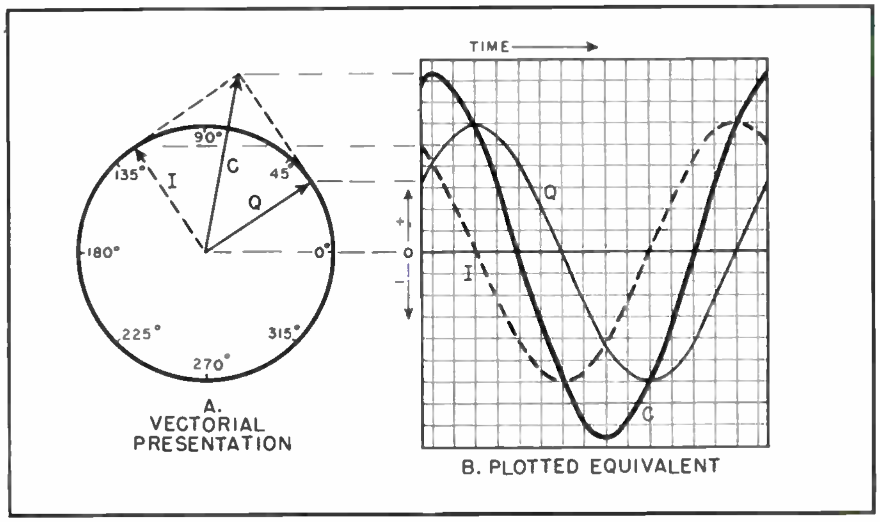


Figure 1. Addition of two a-c voltages, I and Q. The resultant is C (chrominance).

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would be shown vectorially by rotating all vectors 180°.

It has been shown that the chrominance signal, as transmitted, is actually *one* signal which represents the vector sum of the I and Q subcarrier signals in phase quadrature. It can be viewed as a 3.58 mc signal that is phase and amplitude modulated in accordance with the $E_I$ and $E_Q$ signals applied to the modulators. The function of the chrominance channel in the receiver is to recover, from this signal, I and Q voltages that are representative of the $E_I$ and $E_Q$ voltages applied to the transmitter modulators.

## CHROMINANCE CHANNEL

**Bandpass amplifier**—The signal taken from the 1st video amplifier for application to the bandpass amplifier contains some composite signal components that are undesirable in the chrominance channel. As indicated by the waveform on figure 2, the signal from the 1st video amplifier contains sync, blanking, brightness and burst information in addition to the desired chrominance signal. If the superfluous information were allowed to pass through the chrominance channel, improper operation could result.

It is desirable to remove as much brightness information from the signal as possible because it represents misinformation so far as the chrominance channel is concerned. Accordingly a bandpass filter is included in the plate circuit of the bandpass amplifier. Figure 3 shows the frequency response of the bandpass circuit. Since the bandpass circuit discriminates against frequencies below 2 mc, most of the undesired signal is attenuated. At the same time, the response of the circuit is sufficiently wide to pass the chrominance information, which is at frequencies between 2 mc and 4.1 mc.

If burst information were passed through the chrominance channel, incorrect picture brightness would result. This is so because d-c restorers are used in the picture tube grid circuits to restore the signal components to their original d-c levels. The restorers "clamp" the tips of the sync pulses to a common level in the same manner as in some black and white receivers. The sync pulses referred to are those which accompany the signal through the *brightness* (Y) channel. It will be recalled that the operation of a d-c restorer involves charging a capacitor to a potential which is determined by the sync pulse amplitude and duration. Any spurious signal at an amplitude near that of the sync pulse has the effect of increasing the charging time of the capacitor, resulting in the capacitor being charged to an erroneously high potential.

Any burst information reaching the matrix through the chrominance channel and combining with the Y signal would represent a spurious signal, increasing the capacitor charging time. Clamping would then occur at a level determined by the sync pulse plus the burst signal. With the brightness control set for correct picture brightness under this condition, incorrect brightness would result when receiving a black and white transmission which does not include burst information. Thus, with burst information passing through the chrominance channel, it

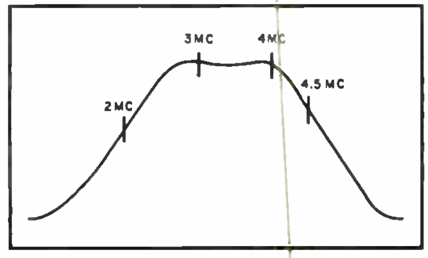


**Figure 3. Bandpass amplifier response curve.**

would be necessary to re-adjust the brightness control when changing from a black and white program to a color program and vice versa.

The sync and blanking information is easily removed from the signal in the chrominance channel because the bandpass amplifier response is negligible at their frequency (15,734 cps). But since the 3.58 mc burst information is at a frequency within the passband of the circuit, it is not so easily removed.

To remove the burst information, a negative pulse from the horizontal output transformer is applied to the screen grid of the bandpass amplifier as shown in figure 2. The pulse is phased so that it coincides in time with the burst signal, and the pulse amplitude is sufficient to cut off conduction in the tube. As a result, the burst information is effectively keyed out. The effect is illustrated by the time relationship waveforms of figure 2.

Observe that the chrominance signal in the output is centered on one

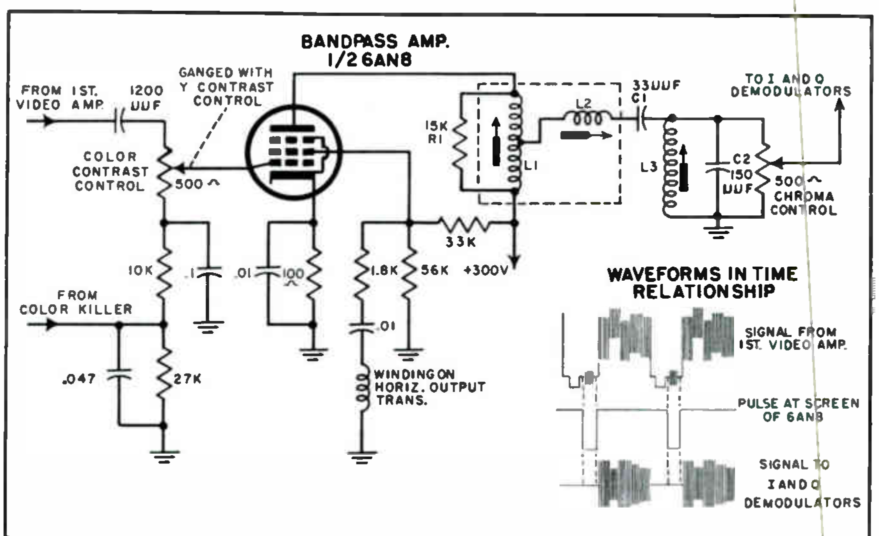


**Figure 2. Bandpass amplifier with waveforms shown in time relationship.**

axis (zero) rather than the varying axis on which it was centered at the video amplifier output. This is so because the varying axis represents brightness information, which is not present in the output. In other words, the d-c component has been eliminated, and the bandpass amplifier output is now representative of the added outputs of the I and Q modulators at the transmitter.

Two controls are included in the circuit, both of which affect the chrominance signal level. The chroma control, located in the output circuit of the bandpass amplifier, allows the chrominance signal amplitude to be adjusted for the desired *ratio* of chrominance signal to brightness signal. Color saturation is thereby established. The color contrast control in the bandpass amplifier input circuit is ganged with the Y contrast control. When this control is rotated, the amplitudes of the brightness and chrominance signals vary together, maintaining the ratio established by the chroma control setting. Thus the saturation need not be readjusted each time the contrast setting is changed.

As indicated on figure 2, a signal from the color killer is applied to the bandpass amplifier grid circuit. This signal is a control voltage which is sufficiently negative to cut off conduction in the bandpass amplifier when the receiver is tuned to a black and white transmission. During reception of a color program, the voltage from the color killer falls to zero, allowing the bandpass amplifier to function normally. A description of the color killer circuit appears in the preceding issue of the Service News.

The bandpass amplifier output circuit is designed to have a definite response characteristic as mentioned previously and illustrated in figure 3. To obtain the desired response, three tuned circuits are employed (see figure 2). The plate inductance, L1, resonates with its distributed capacitance at a frequency within the passband. L2 and C1 form a series circuit that is also resonant within the passband. Another resonant circuit is formed by L3 and C2.

Maximum voltage is developed across L1 at its resonant frequency, and the same is true of the parallel circuit formed by L3 and C2. Maximum transfer is obtained through L2 and C1 at the series resonant frequency. With the three circuits tuned to different frequencies, each tending to produce maximum response at its frequency, the overall response is broadened as in a stagger-tuned i-f system. The series inductance, L2, is connected to a tap on L1 in order to match the high impedance of the plate circuit to the low resistance of the chroma control.

**I and Q demodulators** — As shown in figure 4, chrominance information is applied through the chroma control to the control grids of the I and Q demodulators. To each of the suppressor grids is applied a 3.58 mc reference signal taken from the 1st quadrature amplifier circuit as described in the preceding issue. It will be recalled that the reference signal fed to the Q demodulator lags the signal fed to the I demodulator by 90°, and both have exactly the same phase relationship to the chrominance signal as the original 3.58 mc carriers that were applied to the modulators at the transmitter.

Also applied to the suppressor grids is a negative bias of approximately —2.5 volts. This voltage is provided by the voltage divider, R1 and R2, in the ground return circuit of the 1st quadrature amplifier output coils.

Cathode bias is applied to both demodulators. The cathode currents of both tubes flow through a common cathode resistor, R3, developing a bias voltage across the resistor. In addition, the individual cathode currents flow through separate resistors, R4 and R5, developing more bias for each tube. C1, C2 and L1 in the cathode circuit act as a very effective by-pass across R3 for the 3.58 mc signals, preventing interaction between the two demodulators. Approximately 2.5 volts of bias are applied to the cathode of each demodulator.

Characteristic curves for the type 6AS6 tube are shown in figure 5. Suppressor grid voltage is plotted against plate current for different values of control grid voltage. The applied signals (chrominance and reference) are shown in relationship to the curves to illustrate the effects of the signals.

Since the cathode bias is approximately 2.5 volts, and approximately — 2.5 volts of bias are applied to the suppressor grid, the effective cathode to suppressor grid bias is about 5 volts. With the 30 V. peak-to-peak

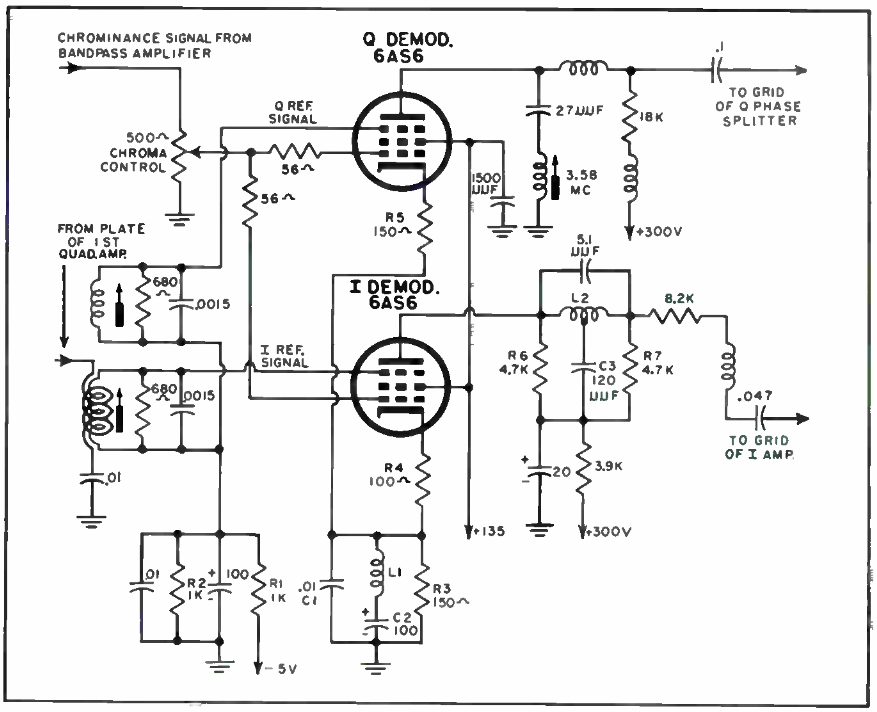


Figure 4. I and Q demodulator circuits.

reference signal applied to the suppressor grid, the suppressor voltage swings from +10 volts to —20 volts with respect to the cathode. As a result, there is no plate current flow during most of the negative excursion time. Moreover, as shown on figure 5, the control grid has very little effect on the plate current as the suppressor grid voltage approaches the cut off value.

It is therefore apparent that the magnitude of the plate current is determined by the control grid voltage *during the time the suppressor grid is driven positive.* Stated differently, as the suppressor grid voltage increases in a positive direction, the effect of the control grid potential increases also. Accordingly, it can be considered that the control grid voltage (chrominance signal) is "sampled" at the time of each peak positive excursion of the reference signal, and the amount of plate current flow depends on the instantaneous potential at the control grid during the sampling time.

With the chrominance signal being sampled at a definite time, it can be seen that the signal *phase* is an important consideration. Figure 6 illustrates the effect that the chrominance signal has on the plate current under various conditions of phasing. The heavy arrows on the drawing indicate relative magnitudes of plate current. Observe that maximum plate current flows when the chrominance signal is in phase with the reference signal. The reason is that the control grid voltage is at its peak positive amplitude during the sampling time. As the phase of the chrominance signal deviates from that of the reference signal, the plate current decreases until it reaches minimum when the two signals are 180° out of phase.

The amount of plate current flow depends also on the peak-to-peak amplitude of the chrominance signal. When the chrominance signal is sampled during the positive half of its cycle, an increase in signal amplitude results in an *increase* in plate current. When the signal is sampled during the negative half of its cycle, an increase in amplitude causes a *decrease* in plate current. When the chrominance signal is 90° out of phase with the reference signal, a change of amplitude has no effect on the plate current, because the signal is at zero potential during sampling time. The last statement is significant because it points out that each demodulator is affected only by the chrominance signal component which it is intended to detect.

For example, if a color corresponding to the exact phase of +I (an orange hue) were being transmitted, the chrominance signal would be in phase with the reference signal applied to the I demodulator. Plate current in the I demodulator would then be maximum so far as phase relationship is concerned, and the greater the peak-to-peak amplitude of the chrominance signal (varies with color saturation), the greater the plate current flow.

The Q demodulator reacts quite differently to this same chrominance signal. Since the reference signal applied to the Q demodulator lags the I reference signal by 90°, the chrominance signal is going through zero during sampling time in the Q demodulator. Under this condition the plate current is not affected by a change in the amplitude of the chrominance signal. Therefore, the plate current flow is determined entirely by the reference signal at the suppressor grid.

In the absence of chrominance signal, or in the case described in the preceding paragraph, the reference signal alone causes pulses of plate current that represent a *zero-signal reference level*. This is the same as saying that the output of the Q demodulator is zero under these conditions. Since plate current flow in the I demodulator under the above conditions is much greater than the zero-signal reference level, an I output voltage is derived. The requirements for demodulation are therefore satisfied, because a chrominance signal which corresponds to the phase of I consists of I component only; the Q component is zero.

It should be noted, however, that the zero-signal level mentioned above does not mean zero voltage at the plate of the demodulator. Instead, it means a voltage which *represents* zero so far as the demodulated component is concerned. Figure 7 illustrates this point. As a result of the plate current pulses, the demodulator output voltage is a series of 3.58 mc pulses extending in a negative direction from the plate supply voltage level. The amplitude of the pulses is determined by the magnitude of plate current flow during each pulse. In the absence of chrominance information, as during the white and the black bars, the pulse amplitude is determined by the reference signal alone. This amplitude is the zero reference level.

When chrominance information is present, the magnitude of the plate current pulses changes in accordance with the phase and amplitude of the chrominance signal. As a result, the

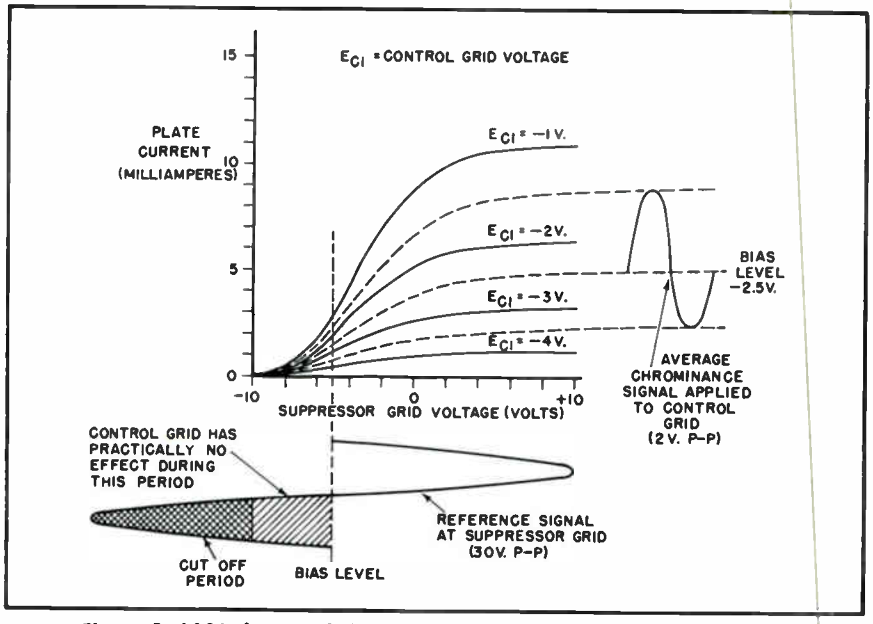


**Figure 5. 6AS6 characteristic curves showing effects of applied signals.**

output voltage pulses extend above or below the zero reference level. Figure 7 shows the step waveform that results when color bars are being transmitted. A and C of the figure show the negative-going 3.58 mc pulses of varying amplitude that appear at the plate of each demodulator. B and D show the resultant waveform after the 3.58 mc component has been removed by the filter action of the demodulator output circuits.

Since the demodulator output pulses extend in a negative direction and their amplitudes increase with an increase in plate current, it follows that the signals obtained after filtering (B and D of the figure) are inverted with respect to the original $E_I$ and $E_Q$ polarities at the transmitter. The signals, under this condition, are termed −I and −Q signals. Except for the inverted polarity, however, these signals are essentially proportional to the original $E_I$ and $E_Q$ signals.

The output circuit of the Q demodulator is designed to attenuate frequencies above .5 mc. This is necessary because modulating frequencies above .5 mc are removed from the Q channel at the transmitter, and any signals above this frequency represent misinformation so far as the Q channel in the receiver is concerned. A 3.58 mc series-resonant trap is included between the plate of the Q demodulator and ground to assure removal of the 3.58 mc component of the output signal.

A characteristic of low pass filters is that they introduce a time delay. The time by which a signal is delayed as it passes through the circuit is determined by the passband of the circuit; the narrower the passband, the greater the delay. Since the Q signal is limited to a bandwidth of .5 mc, the delay in the Q channel is an important consideration. It is, in fact, the reason why a delay line is included in the brightness channel of the receiver (see December, 1954, Service News). Since the brightness channel has a bandwidth of approximately 3.2 mc, it does not introduce as much delay as the Q channel introduces. If the delay line were not included, the brightness signal would arrive out of step with the Q signal at the matrix.

The I signal must also arrive in step at the matrix. If the bandwidth of the I channel were the same as that of the Q channel, this would not involve special consideration. However, modulating frequencies up to 1.5 mc are passed through the I channel of the transmitter. Since an I channel bandwidth of 1.5 mc is therefore desirable in the receiver, the output circuit of the I demodulator is designed to attenuate frequencies above 1.5 mc. To make the delay in this 1.5 mc channel equal that of the .5 mc Q channel, an "artificial transmission line" is included in the I demodulator output circuit.

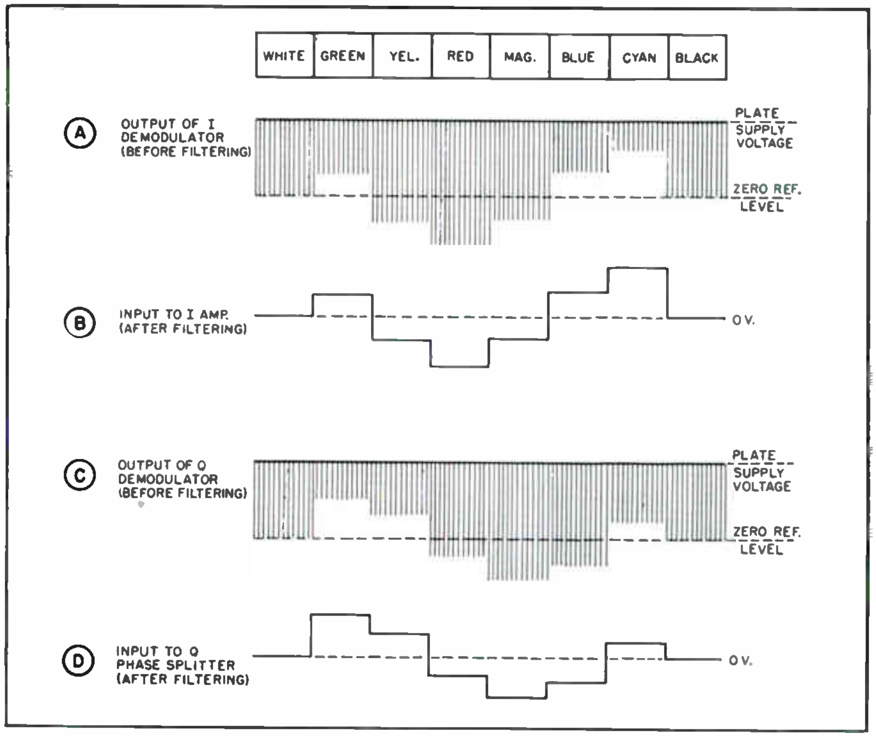


**Figure 7. Waveforms obtained when receiving a color bar signal.**

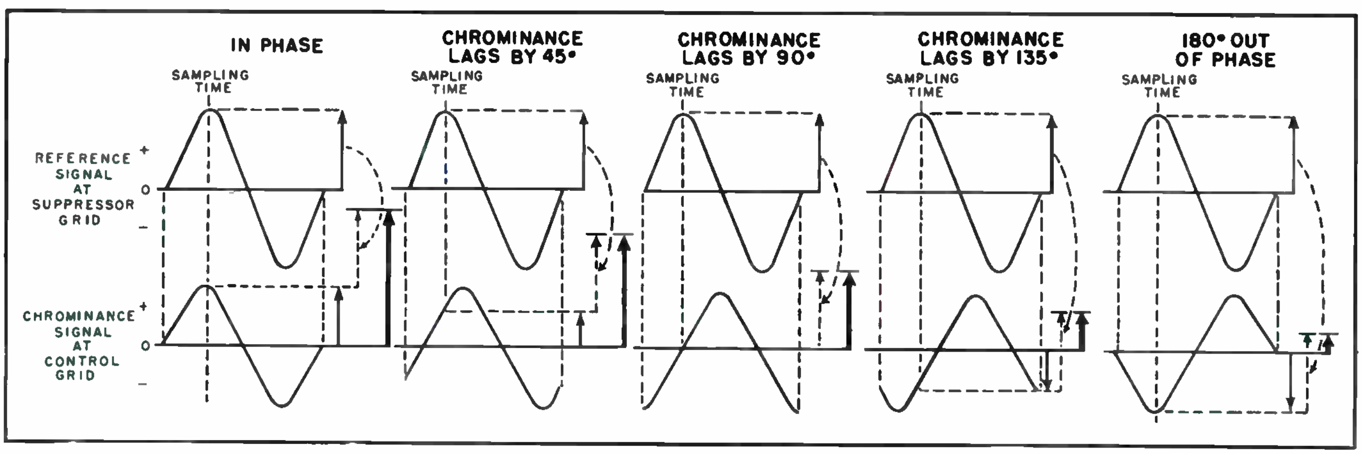


**Figure 6. Demodulator plate current as a function of phase relationship. Heavy arrows indicate relative current flow.**

An "artificial transmission line" is a network which has characteristics similar to those of a transmission line but is composed of lumped constants. Such a network is shown in figure 8. It will be recalled that a transmission line has a definite delay characteristic. The artificial line also has this characteristic and is frequently used when it is desired to delay the passage of a signal. As used in the I demodulator output circuit, the line consists of fewer sections than shown in figure 8. The inductive elements are formed by L2 (see figure 4), and the capacitive element by C3. The impedance of the line is matched by R6 across the input terminals and R7 across the output terminals.

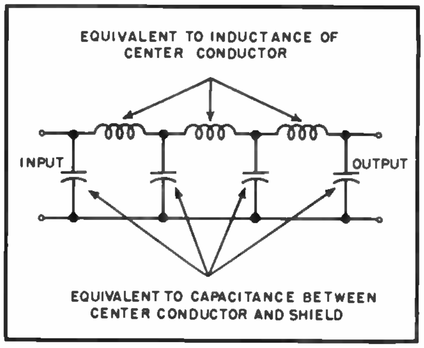


**Figure 8. Artificial transmission line.**

**I amplifier** — The I signal (figure 7B) is applied to the grid of the I amplifier. This stage of amplification is required because the I channel has a wider passband than the Q channel. Since gain decreases with an increase in passband, the I channel gain would not be proportional to the Q channel gain without this additional amplification.

As shown in figure 9, the I amplifier is a conventional circuit. A gain control in the cathode circuit allows the amplitude of the I signal to be adjusted for the correct ratio of I signal to Q signal. The passband of the I amplifier is designed to complement that of the I demodulator in providing an I channel passband of 1.5 mc. L1 and C1 in the I amplifier plate circuit serve as a low pass filter, providing the required attenuation of frequencies above 1.5 mc.

**I and Q phase splitters** — Figure 10 illustrates the I and Q phase splitters. Except for a few component variations, the two circuits are identical. They will be recognized as adaptations of the so-called "paraphase" amplifier occasionally encountered in audio frequency work. The purpose of each is to supply two output signals that are representative of the signal applied to the grid, but which are 180° out of phase with one another.

To obtain these conditions, use is made of the fact that the signal at the cathode of a tube is 180° out of phase with the signal at the plate. The amplitude of the cathode signal with respect to the plate signal can be varied by changing the value of the cathode resistor or the plate load resistor. Accordingly, these resistors are carefully chosen to provide the correct relative amplitudes. The reason why the relative amplitudes are important is discussed under the matrix section.

The 3.3 megohm resistors, R1 and R2, which are connected between grid and plate of each tube, serve two purposes. First, they apply a slight positive voltage to the grid, which cancels part of the relatively high cathode bias developed across R2 and R3. Second, they provide some degenerative feedback from plate to grid, which minimizes distortion in the stages.

As noted on the figure, the input to the Q phase splitter is a —Q signal. Due to the 180° phase reversal through the tube, a +Q signal appears at the plate. The cathode signal is, of course, a —Q signal. In contrast, a + I signal is applied to the I phase splitter. This is true because the I amplifier causes a 180° reversal which is not present in the Q channel. As a result, a —I signal appears at the plate of the I phase splitter, and a +I signal is obtained from its cathode. These signals are applied to the matrix.

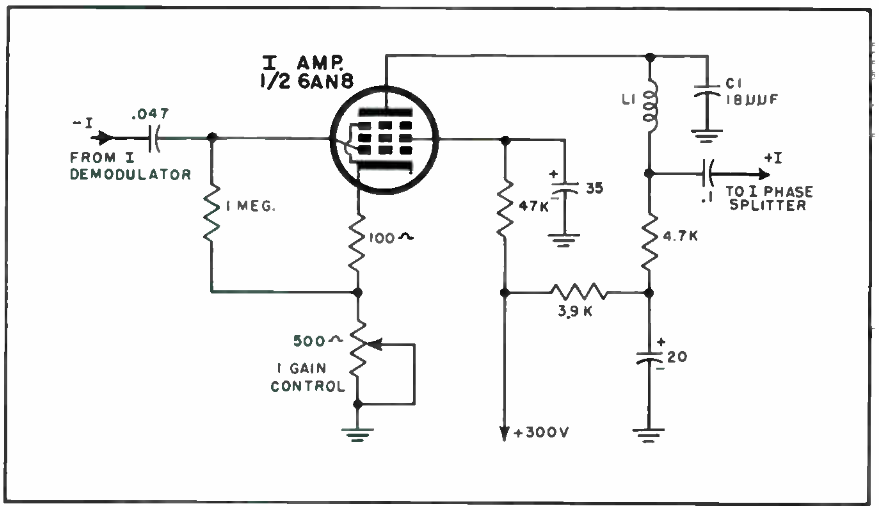


**Figure 9. I amplifier circuit.**

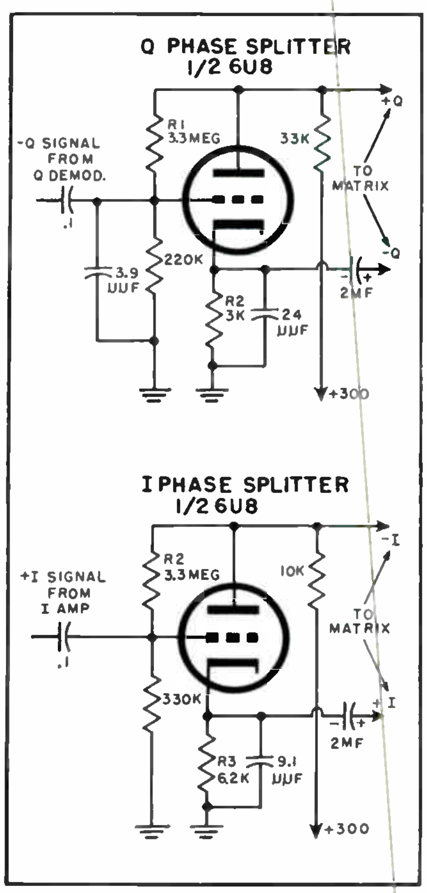


**Figure 10. I and Q phase splitters.**

**Matrix circuits** — In the matrix, the brightness signal (Y) is combined with chrominance information (+ I, — I, + Q and — Q) to derive signals that correspond to the red, blue and green camera outputs at the transmitter. To accomplish this, the signals must be combined in the following proportions:

$$E_R = 1.00\,E_Y + .96\,E_I + .63\,E_Q$$
$$E_G = 1.00\,E_Y - .28\,E_I - .64\,E_Q$$
$$E_B = 1.00\,E_Y - 1.11\,E_I + 1.72\,E_Q$$

In the above formulas, $E_R$, $E_G$ and $E_B$ are respectively the red, green and blue signal voltages desired. The negative values of $E_I$ required for the formulas are taken from the plate of the I phase splitter, and positive values of $E_I$ are taken from the cathode. Negative values of $E_Q$ are taken from the Q phase splitter cathode, and positive $E_Q$ comes from the plate. Only positive values of $E_Y$ are required, and this signal is provided by the 2nd video amplifier.

The signals are added in their correct proportions by using three separate voltage divider networks as shown in figure 11. Each divider network satisfies one of the above formulas and provides the resultant signal. The network can be simplified for study as shown in figure 12. This is permissable because of the low impedance offered by the 4 mfd capacitors, C1, C2 and C3.

Examination of the circuits discloses that 10,000 ohm resistors are used in all arms (R1 through R9) except R2 which is 47,000 ohms and R7 which is 30,00 ohms. From this, we can determine the required output voltages from the phase splitter in relation to the Y signal amplitude.

Since Y is applied to a 10,000 ohm resistor in each section and is given as the 100% reference in each of the formulas, it follows that all voltages applied to a 10,000 ohm arm will have to be related to the Y signal by the percentage indicated in the appropriate formula. For example, a — Q signal is applied to R1 in the green matrix. From the formula for the green signal, a — Q voltage of .64 is required. The signal at the cathode of the Q phase splitter must therefore have an amplitude equal to 64% of the Y signal amplitude.

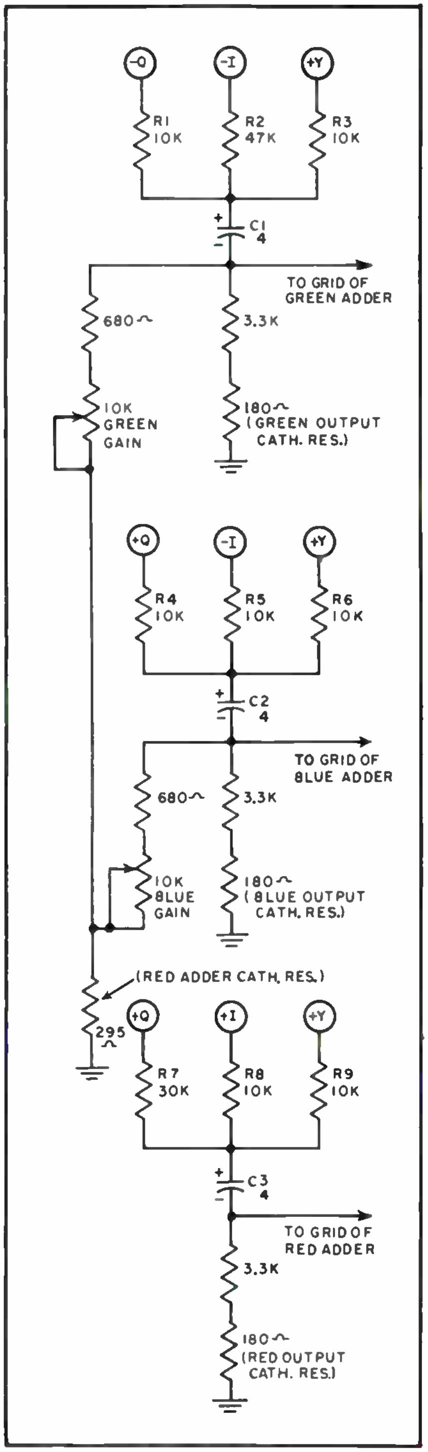


**Figure 11. Matrix circuit. Points marked I and Q connect to phase splitters and Y connects to video amplifier.**

In a like manner, the + Q signal applied to R4 in the blue matrix must have an amplitude of 1.72 times the Y amplitude as specified in the blue formula. The output voltages of the I phase splitter can be determined by continuing the process. It will be found that the required outputs of the I phase splitter, relative to the Y signal, are .96 for + I and 1.11 for — I.

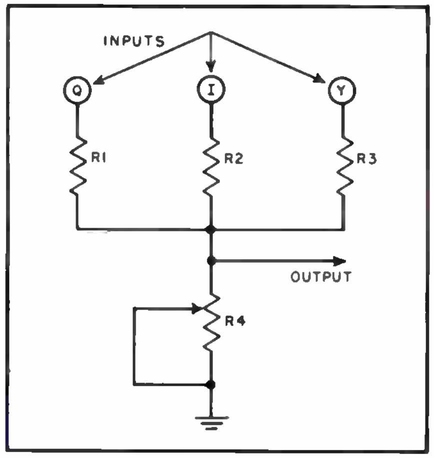


**Figure 12. Simplified matrix section.**

Since the — I output of the I phase splitter is 111% relative to the Y amplitude, and only 28% is required for the green signal, it must be divided down in the green matrix. Accordingly, R2 in the green matrix is 47,000 ohms to provide the correct voltage division. Similarly, the + Q signal in the red matrix must be divided down to 63% from its output level of 172%. The 30,000 ohm resistor, R7, provides the necessary division.

The green gain control serves to adjust the resistance in the bottom leg of the green matrix. This is equivalent to adjusting R4 in figure 12. It can be seen that the amplitude of the signal applied to the green adder is thereby adjusted. The blue gain control likewise affects the amplitude of the signal applied to the blue adder. These controls are adjusted so that the signals they control are of the correct amplitude with respect to the red signal output which is a fixed value.

The ground return for each of the matrix sections is through a cathode resistor as indicated on figure 11. The green and blue gain controls are also returned to ground through a cathode resistor. However, these ground return methods are not significant as far as the matrix operation is concerned. Instead, they affect the operation of the adder and output circuits which will be discussed in the next issue.

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