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LB-950

THE DESIGN OF IF AMPLIFIERS FOR COLOR TELEVISION RECEIVERS

RADIO CORPORATION OF AMERICA
RCA LABORATORIES DIVISION
INDUSTRY SERVICE LABORATORY

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The Design of IF Amplifiers for Color Television Receivers

Approved

Stuart Wm Seeley.

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Introduction

The designer of i-f amplifiers for color television receivers is confronted with new problems introduced by the addition of the chrominance subcarrier and its sidebands. This bulletin evaluates these problems as they affect the design of the i-f amplifier. An i-f amplifier using novel non-minimum phase shift coupling circuits is described. These circuits provide the required attenuation of the sound carrier without introducing excessive delay distortion.

Requirements

The components of the compatible color television signal as described in Fig. 1 dictate the performance requirements of the i-f amplifier. Over the range occupied by the chrominance signals, i.e., the I and Q color-difference signals, the amplitude response as well as the time delay of the chrominance channel must be substantially constant.

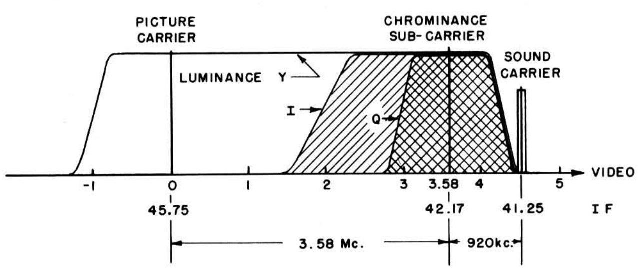


Fig. 1 - Spectrum of compatible color television signal showing the video and intermediate frequencies corresponding to the luminance, chrominance and sound portions of the complete signal.

For a region of ±500 kc on either side of the chrominance subcarrier, uniform amplitude response and constant time delay are required to prevent crosstalk between the I and Q components of the color signal. Over the complete region occupied by the color signal, constant time delay is desirable to prevent distortion of the chrominance information.

An ideal color i-f amplifier response differs from that of a conventional monochrome amplifier in that the bandwidth is increased to approximately 4.1 Mc to accommodate the chrominance signal and in that greater attenuation is required for the accompanying sound carrier. The ideal delay characteristic shown in Fig. 2b is flat up to approximately 3 Mc and then rises, as the sound carrier is approached, in a manner complementary to the predistortion introduced at the transmitter. This transmitter predistortion was selected to ease the requirement of maintaining constant time delay in the i-f amplifier circuits.

The i-f amplifier response may depart from these ideal characteristics provided the chrominance amplifier circuits between the second detector and the chrominance demodulator restore the overall amplitude and delay response shown in Fig. 2. This is discussed in connection with alternative i-f responses.

Greater attenuation is required at the accompanying sound carrier in color receivers to prevent beats between the chrominance components and the sound carrier. Approximately 45 db attenuation is required, as against the 30 db normally adequate to prevent beats between the sound carrier and high-frequency video components in a monochrome receiver. In addition, some margin must be allowed to take care of vagaries in transmission and reception. The peak rejection is not the only criterion. The sound notch must be sufficiently wide so that slight variation in tuning or oscillator drift will not result in the appearance of objectionable beats between the sound carrier and the chrominance information.

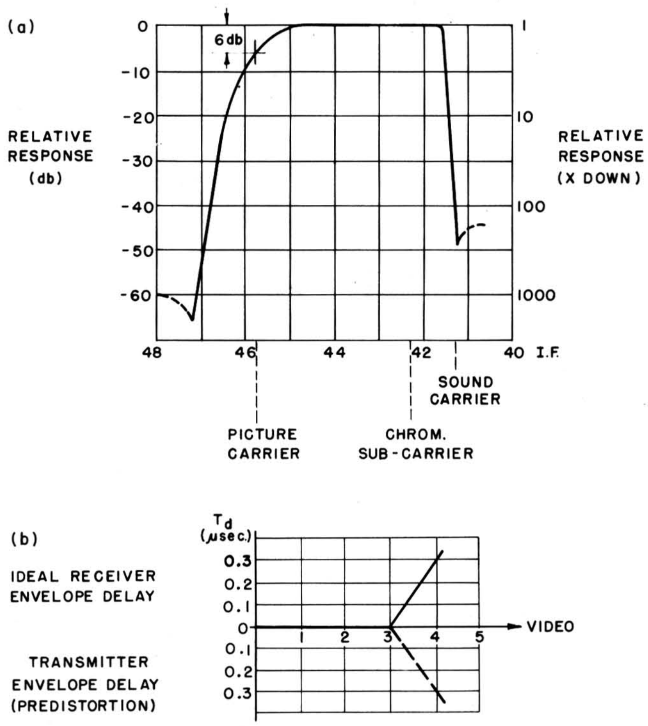


Fig. 2 – Ideal amplitude response of a color i-f amplifier. The flat response is required to accommodate the chrominance information. The required delay characteristic is shown in (b).

Adjacent channel traps are required as usual. The concentration of energy near 42.17 Mc makes the 39.75-Mc trap assume greater importance because of the 2.42-Mc beat between these two carriers. The adjacent channel color subcarrier frequency falls at 48.17 Mc and a trap may be required at this frequency if the selectivity is not adequate. As normal in monochrome practice, these traps should be placed near the mixer output circuit for greatest effectiveness in preventing cross modulation.

Alternative IF Response Curves

Monochrome receivers have used a wide variety of i-f designs ranging in bandwidth from less than 3.0 Mc to 4.0 Mc. Although color introduces the severe requirements previously outlined in the range between 3.0 and 4.1 Mc a wide range of response characteristics i also possible in color receivers. Two extremes are illustrated qualitatively in Fig. 3. In each case the corresponding video (chrominance) response curves required to produce the necessary overall flat response are also shown.

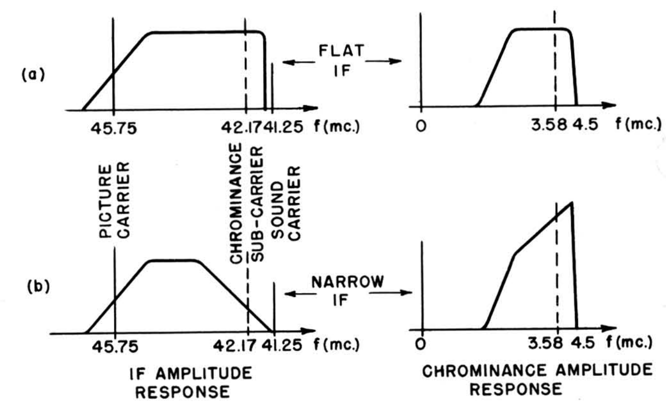


Fig. 3 – Alternative i-f amplitude responses and the corresponding chrominance amplifier bandshapes required to produce an overall flat response.

The flat type of i-f response which has already been described is the straightforwar approach. Here the i-f amplifier is essentially free of amplitude distortion so that no compensation is required in the chrominance amplifier. On the other hand, in the type of response characteristic shown in Fig. 3b, there is considerable attenuation for the color subcarrier and its sidebands. In order to obtain an overall flat response prior to color demodulation, it is apparent that the chrominance video amplifier circuits must boost this region of the video spectrum to prevent color crosstalk between the I and Q components of the signal, and in addition must equalize the delay of the components of the chrominance signal. In between these two extremes illustrated qualitatively in Fig. 3, there are many possible designs ranging from those having considerable attenuation at the color subcarrier as in (b) to those having the flat characteristic shown at (a).

The flat type of i-f characteristic requiring no compensation in the chrominance video amplifier was investigated intensively. This was done on the general principle that, other things being equal, it is desirable to make each part of a circuit as distortion free as possible, rather than require critical compensation of one part for another. This in turn requires an investigation of simplified circuits for obtaining high rejection at the sound carrier frequency without "biting" appreciably into the region of the chrominance sidebands. It was felt that knowing more about what is involved in obtaining a flat response would be a logical first step in the determination of the optimum i-f characteristics.

No attempt was made to compensate in the i-f amplifier for the vestigial sideband transmission of the I signal at frequencies above approximately 500 kc. If compensation for this proves desirable, it is best accomplished in the chrominance channel following the video detector, rather than in the i-f amplifier.

Sound Channel Considerations

The requirement of high attenuation at the sound carrier frequency in color receivers conflicts with conventional intercarrier-sound receiver design where the sound carrier is attenuated only enough--some 30 db--to prevent beats from appearing in the picture. A direct solution to this problem is the use of a separate detector to mix the sound and picture carriers so as to produce the 4.5-Mc intercarrier beat. A desirable point at which to take off the sound and picture carriers is in the plate circuit of the last i-f tube just prior to the final 41.25-Mc trap which is interposed between the plate of the last i-f tube and the video second detector.

Under these conditions, it is possible to introduce approximately 30 db of attenuation of the sound carrier up to the sound carrier take-off point. The additional rejection required in the picture channel is then supplied between the plate of the last i-f tube and the video detector.

If an attempt is made to use a common detector for video and sound as in conventional intercarrier-sound receivers, the peak 41.25-Mc attenuation must be accurately controlled in order not to impair the sensitivity of the sound channel. A compromise must thus be made between providing adequate rejection of the 920-kc beat in the picture channel and obtaining high sensitivity in the sound channel.

Cross Modulation—920-kc Beat

The presence of the chrominance subcarrier and the sound carrier gives rise to the production of a 920-kc beat between these two components at the video detector. The magnitude of this beat depends upon the product of the amplitudes of the sound and chrominance subcarrier signals at the video detector. If the combined attenuation at 42.17 Mc and 41.25 Mc is greater than 45 db, the beat is not visible.

In an i-f amplifier where there is no attenuation at the color subcarrier, i.e., the flat response of Fig. 3a, it follows that the minimum permissible attenuation is approximately 45 db from the top of the pass band. As the i-f design departs from the flat type toward the narrow type shown in Fig. 3b, the attenuation required at the sound carrier decreases so that the combined attenuation of the color subcarrier and the sound carrier is maintained at more than 45 db.

Although the 920-kc beat is normally produced at the video detector because of insufficient sound attenuation, the beat can also be produced in the mixer and i-f stages. Thus cross modulation between sound and chrominance components can give rise to a 44.83 Mc (=45.75 - 0.92) component which is passed on through the i-f amplifier and then shows up as a 920-kc beat when the signal is detected at the second detector. This effect makes it desirable to include some 41.25-Mc attenuation in the mixer output circuit.

The possibility of cross modulation can be reduced by dividing the a-g-c voltage in the proper ratio between the tuner and the i-f tubes under control. Placing the first and second i-f tubes in series for d.c. and applying the a-g-c voltage to the grid of the first tube is effective in dividing equally the "attenuation" provided by each of these stages. This is helpful since operation close to cutoff results in a rapid increase in the cross modulation introduced by an i-f or r-f amplifier tube.

Evaluation of 41.25-Mc Trap Circuits

Without qualification, the most difficult part of color i-f amplifier design is the design of the 41.25-Mc traps which provide the required sound carrier attenuation. The difficulty of the problem can be seen from the fact that the separation between the edge of the pass band (41.65 Mc) at which the response is flat and the trap frequency (41.25 Mc) is only 1 per cent of the carrier frequency. Furthermore, despite the high attenuation slope--the response must drop from 100 per cent to less than 0.5 per cent in 400 kc--it is necessary that the phase be linear so that there will be uniform time delay for the chrominance components.

In evaluating trap circuits, the factors of importance include the following:

(a) How much attenuation can be obtained for a 400-kc rise from the notch to 100 per cent response?

(b) How uniform is the time delay (phase linearity)?

(c) How high is the gain of the interstage network associated with the trap?

(d) How complex is the alignment?

(e) How critical are the parameters of the circuit?

(f) How high are the grid and plate impedances? This determines the maximum stable gain which can be obtained since plate-to-grid feedback is a factor at 40 Mc.

The traps which have been used for sound carrier attenuation in monochrome receivers leave much to be desired in color receiver applications. In general they are of the minimum phase shift type so that the phase response is poor if the required attenuation slope is obtained. As a result, the need for the development of new trap circuits became apparent. As an outgrowth of this investigation, two circuits were developed which meet the criteria of trap performance tabulated above. Both of these circuits are used in the i-f amplifier design described in Fig. 8. Both circuits are of the non-minimum phase type and have excellent delay characteristics, considering the relatively high rejection secured.

The Stagger-Tuned Bridge Trap

The interstage trap circuit shown in Fig. 4 was developed to meet the requirements of color i-f amplifiers. The form shown in Fig. 4a illustrates the balanced nature of the circuit. At a frequency just above the parallel resonant frequency of $L_T C_T$, the upper branch of the link circuit appears capacitive so that the transmission through the upper branch just balances the transmission through the lower branch which is also capacitive. Exact cancellation or

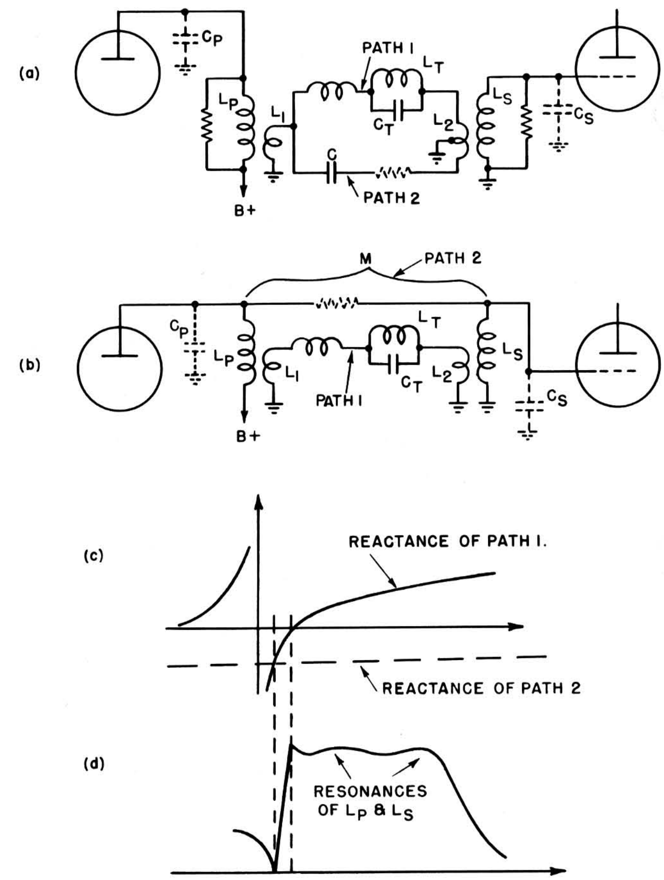


Fig. 4 - Two forms of the stagger-tuned bridge trap. The reactance of each path and the overall amplitude response is shown.

"infinite" rejection is secured if a small resistance is added in series with C (or across C) in order to decrease the Q of the lower branch and thereby make the phase of the current in the lower branch equal the phase of the current in the upper branch. Flat response over the pass band is secured by stagger tuning the primary and secondary windings and suitably damping them. In a typical design the primary and secondary are tuned near 45 Mc and 42 Mc. The primary and secondary tuning adjustments are independent of each other and the circuit behaves as a staggered pair, rather than as a double-tuned circuit. The benefits of stagger tuning are secured without compromising the gain. This is possible because the load resistors across the grid and plate circuits are higher than in a conventional double-tuned coupled circuit.

The circuit of Fig. 4a can be simplified as shown in Fig. 4b. Here the transmission which is provided by the lower capacitive branch in Fig. 4a is now provided by using mutual inductive coupling. This procedure makes it possible to place the primary and secondary windings on a single form and at the same time eliminates the need for a center-tapped link winding. To obtain high peak rejection, the plate and grid windings can be bridged, as shown by the dotted resistor, to equalize the "Q's" of the two transmission paths as in the circuit of Fig. 4a.

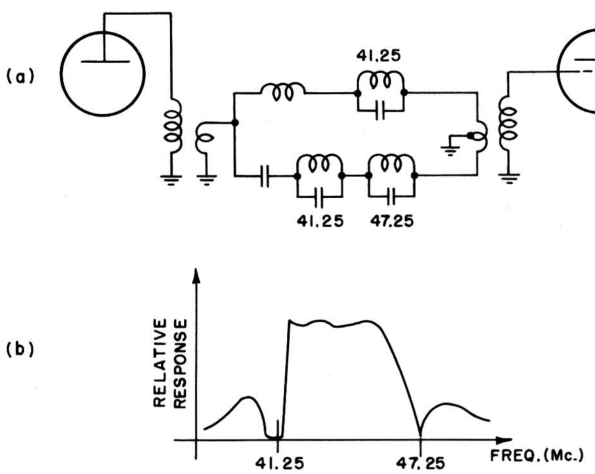


Fig. 5 – A more complex form of the stagger-tuned bridge trap to provide a wide rejection notch at 41.25 Mc.

More complex forms of this stagger-tuned bridge trap can be used to provide a wide rejection "notch" near 41.25 Mc and to provide attenuation at 47.25 Mc. One such circuit is shown in Fig. 5, along with a typical response curve.

Bifilar-T Trap

Another basically different type of trap suitable for 41.25-Mc attenuation is shown in Fig. 6. Here the interstage coupling is provided by a bifilar (or two-layer) inductance connected between the plate and grid circuits. At the "center" point of the bifilar, a low-impedance parallel-resonant trap is connected to ground. This trap is tuned slightly above the sound carrier frequency. At frequencies appreciably removed from the rejection frequency, the impedance level of the trap is sufficiently low so that the midpoint of the bifilar winding is effectively grounded.

A typical response curve for this trap circuit is shown in Fig. 6b. The response is basically similar to that of a single-tuned circuit, except near the rejection frequency where the inductive reactance looking into the bifilar-tuned circuit between points x and y is balanced by the inductive reactance looking into the trap between points y and z. At this frequency the voltage between y and w cancels the voltage between y and z so that the open-circuit voltage appearing in the output mesh falls to zero.

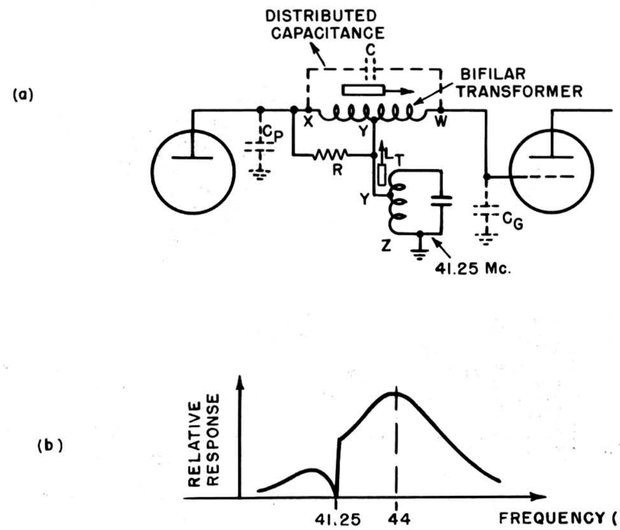
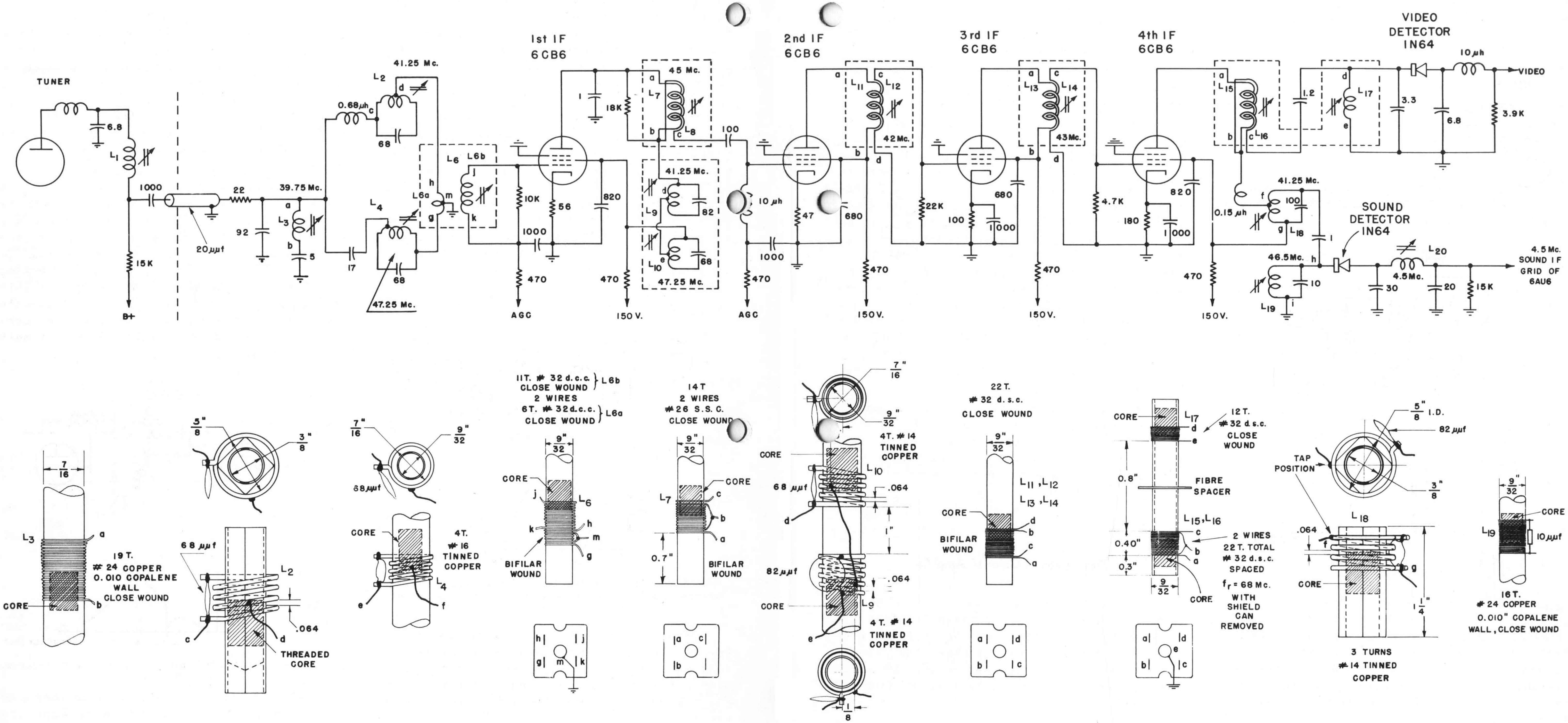


Fig. 6 – Bifilar-T trap and typical amplitude response.

This circuit has a relatively uniform time delay characteristic as would be expected because the shape of the output voltage is little modified from that of a single-tuned circuit except for frequencies very close to the trap frequency.

The circuit operates best when the resonant peak of the circuit is relatively far removed from the trap frequency. This makes it possible to combine the response of an interstage using this trap with that of another staggered element



NOTE: L_3 IS MOUNTED ON THE TUBE SIDE OF CHASSIS.

L_2, L_4 AND ASSOCIATED COMPONENTS ARE ENCLOSED IN A SHIELD BOX.

L_{18}, L_{19}, IN64 SOUND ASSOCIATED COMPONENTS ARE MOUNTED IN A SHIELD BOX.

Fig. 8 – A color i-f amplifier using a stagger-tuned bridge and bifilar-T traps to provide rejection at 41.25 Mc.

tuned near the trap frequency, to produce an overall response differing from that of a flat staggered pair only in that high attenuation is introduced by the trap at the edge of the flat top.

A number of factors determine the circuit performance. These include the turns ratio of the bifilar or two-layer coil (if other than unity), the coefficient of coupling of the bifilar, the distributed capacitance or self-resonant frequency of the bifilar, and the ratio of the input and output capacitances, i.e., the plate and grid capacitances and the associated wiring capacitances.

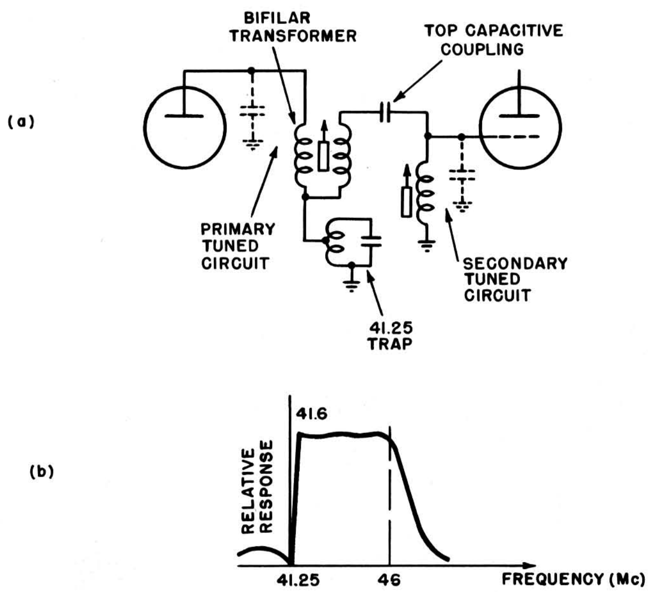


Fig. 7 - Double-tuned form of bifilar-T trap and typical amplitude response.

In the single-tuned bifilar trap, rejections of the order of 25 times can be readily obtained with a "rise" of 400 kc and negligible "after response". The rejection obtainable is determined in considerable part by the resistance R connected between the plate and the center tap of the bifilar winding. The value of this resistance provides a convenient control over the amount of rejection produced. As in most trap circuits the rejection obtainable increases with the separation between the edge of the pass band and the trap frequency. This separation is controlled by varying the impedance level of the trap, i.e., by varying the position of the tap on the trap inductance.

This trap circuit may also be used in modified forms for obtaining rejection at 47.25 Mc and for obtaining rejection at more than one trap frequency. In one form, two traps in series are placed between the center tap of the bifilar winding and ground.

A double-tuned form of the bifilar-T trap is shown in Fig. 7. Here the output of the bifilar winding is coupled by means of high-side capacitance coupling to the secondary or grid-tuned circuit. This circuit tends to behave as a double-tuned circuit; however the selectivity characteristic associated with a double-tuned circuit is modified by the introduction of high rejection at the trap frequency. Rejections of the order of 200 times can be secured by adjusting the circuit elements. Particularly significant in determining the magnitude of the rejection secured is the coupling between the two halves of the center-tapped winding. If a bifilar winding is used, the equivalent effective coupling which yields maximum rejection can be obtained by inserting an inductance of the order of a few tenths of a microhenry in series with the center tap of the bifilar winding.

The double-tuned bifilar-T trap is capable of excellent trap performance. Its gain is high, although less than that of a double-tuned circuit because of the additional capacitance introduced by the distributed capacitance of the bifilar winding.

Description of Color IF Amplifier

The schematic diagram of a color i-f amplifier using stagger-tuned bridge and bifilar-T traps to attenuate the sound carrier is shown in Fig. 8. Fig. 9 shows the overall selectivity measured on v-h-f channel 10, while Fig. 10 shows the selectivity measured from the mixer grid.

The contributions made by each of the interstage networks to the overall selectivity is shown in Figs. 11 to 13. Fig. 12 is the combined response of the first, second and third i-f stages which form a flat staggered triple.

The coupling between the mixer stage and the grid of the first i-f tube is a stagger-tuned bridge filter with traps at 41.25 and

47.25 Mc. These traps provide the adjacent channel rejection at the i-f input so that cross-modulation effects are minimized. Low-side capacitance coupling to the mixer plate circuit, rather than a link winding as in Fig. 4b, is used in order to reduce radiation of oscillator energy. A series-tuned trap at 39.75 Mc is added in order to provide additional adjacent channel attenuation. The response of this network is shown in Fig. 11.

The coupling between the first i-f amplifier plate and the second i-f amplifier grid is by means of a staggered element tuned to 45.2 Mc. This staggered element is part of a bifilar-T trap circuit which provides attenuation at 41.25 Mc and 47.25 Mc. This circuit is followed by another high-Q staggered element tuned to 41.8 Mc forming the coupling between the second and third i-f amplifier tubes. The staggered triple is completed by a low-Q staggered element tuned to 43.2 Mc in the plate circuit of the third i-f tube. The response of the triple is shown in Fig. 12.

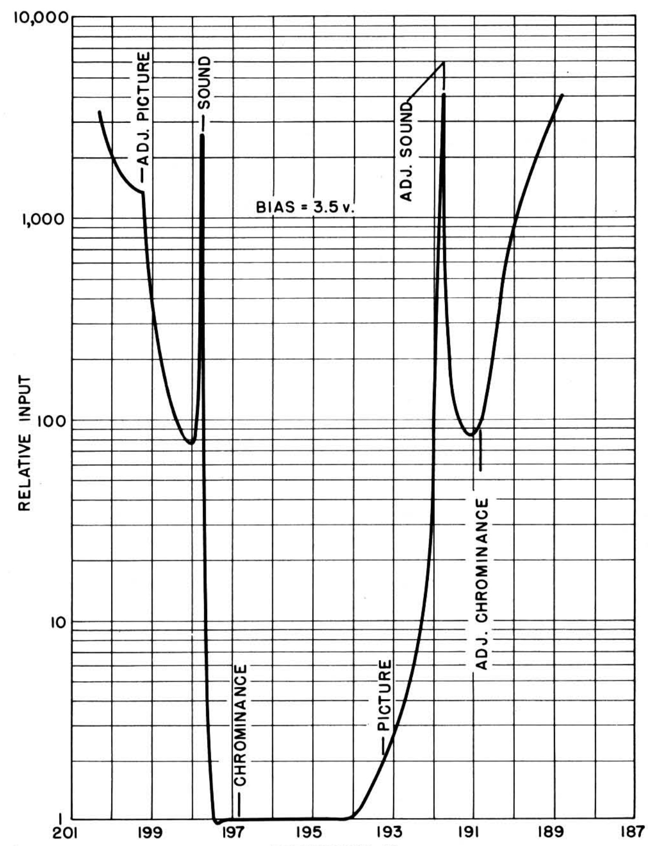


Fig. 9 - Overall rf-if response (channel 10) of the amplifier shown in Fig. 8.

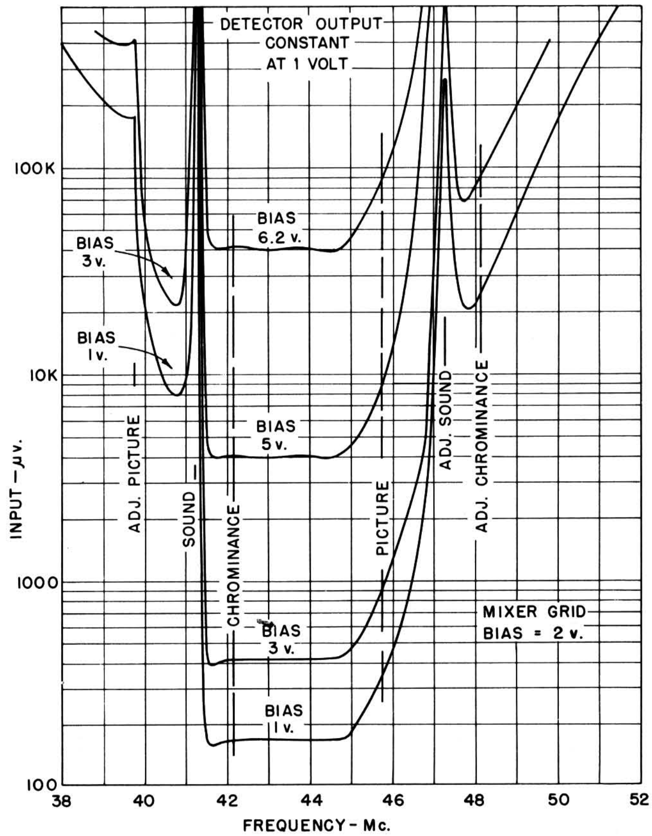


Fig. 10 - Overall response measured from mixer grid of the amplifier shown in Fig. 8.

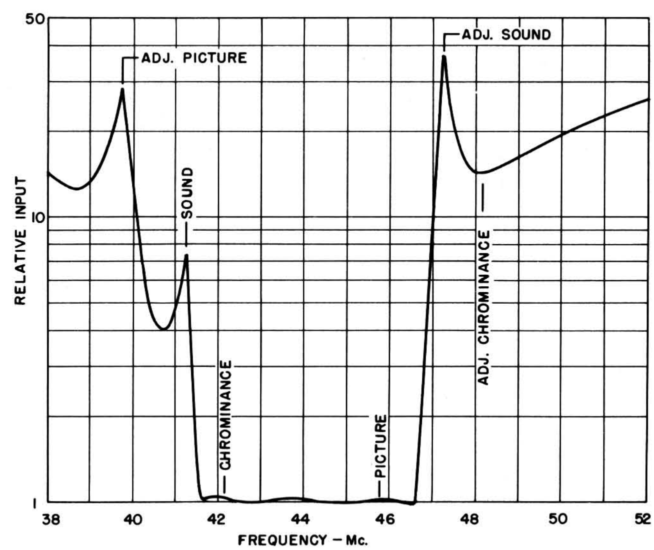


Fig. 11 - Response of the circuit between the mixer grid and the first i-f grid (Fig. 8).

The overall sound carrier attenuation up to the grid of the fourth i-f tube is approximately 35 db if there is no staggering of the two sound traps.

The output coupling network between the plate of the last i-f tube and the video detector is a double-tuned bifilar-T trap which provides additional 41.25-Mc attenuation. The response across the pass band (Fig. 13) is flat to obtain the highest output from the last i-f stage without overload and cross modulation.

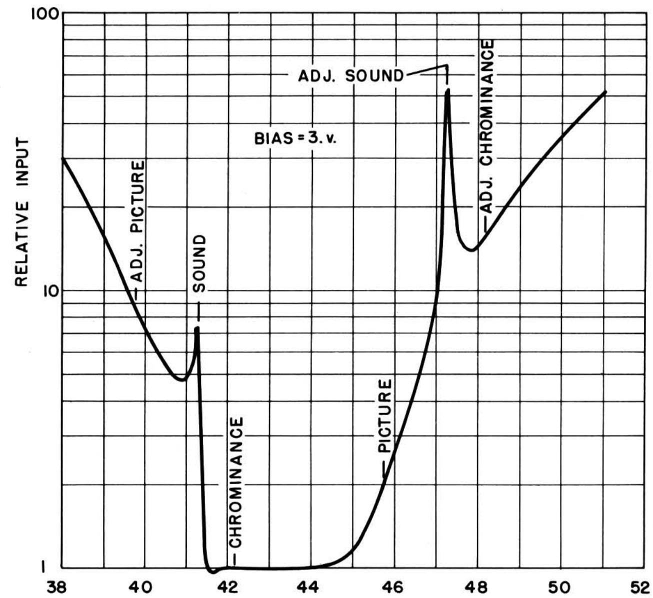


Fig. 12 - Response of the staggered triple measured between the first i-f grid and the fourth i-f grid (Fig. 8).

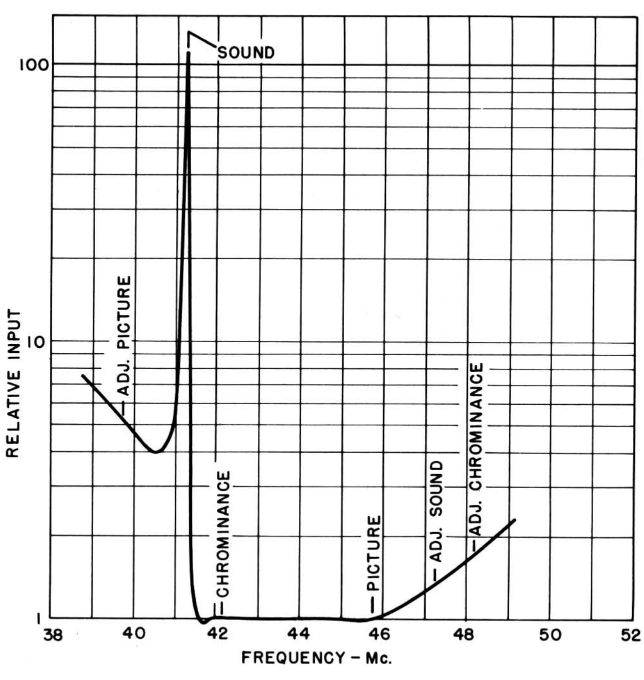


Fig. 13 - Response of the circuit between the fourth i-f grid and the video detector (Fig. 8).

The feed to the separate intercarrier sound detector for producing the 4.5-Mc intercarrier beat is taken by coupling a 46.5-Mc tuned circuit to the final 41.25-Mc trap. This yields the response curve shown in Fig. 14, measured from the grid of the last i-f tube. As shown, the sound carrier is up approximately 6 db with respect to the picture carrier, so that the overall 41.25-Mc attenuation, measured from the mixer grid to the separate sound detector, is approximately 30 db.

The sound carrier input to the separate sound detector is approximately equal to that which would be obtained if a conventional combined video and sound second detector were used and the overall attenuation of the sound carrier were 30 db. It follows that the gain required in the 4.5 Mc channel is comparable to the gain required in a conventional intercarrier-sound receiver.

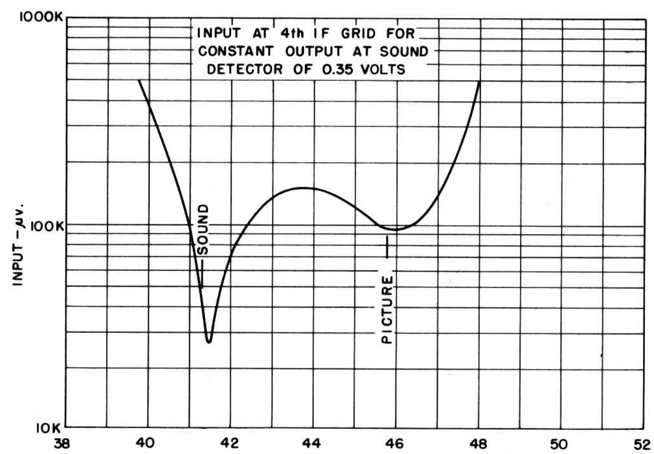


Fig. 14 - Response measured from the fourth i-f grid to the sound detector.

Excessive coupling of the sound detector to the picture channel should be avoided since it results in the production of a 920-kc beat because of the variation in loading on the last i-f tuned circuit.

The detector coupling circuit behaves as a double-tuned circuit which has all the loading on the secondary. There is a slight reaction between the primary bifilar tuning and the trap tuning, so that the final tuning adjustment should be the setting of the trap for maximum rejection at 41.25 Mc. Differences in layout will affect the value of the high-side coupling condenser which should be adjusted to provide a response similar to that shown in Fig. 13.

Addition of unnecessary capacitance to ground at the plate of the last i-f tube should be avoided, since it affects the response of the circuit.

Depending upon the exact layout in a particular design, a change in the position of the tap on the 41.25-Mc trap may be required in order to obtain maximum attenuation at 41.25 Mc.

A wide variation in the rectification efficiency of the type 1N64 (as well as other types of crystals) used in the video detector was observed. A crystal having average characteristics should be used when fixing the design center for the coupling condenser, since the coupling required varies with the loading and hence with the rectification efficiency.

With 100,000 µvolts input to the last i-f grid, the d-c detector output across the 3900-ohm load was 0.55 volt d.c. This value was obtained with a crystal having a rectification efficiency of 65 per cent. New 1N64 crystals having half this rectification efficiency were encountered in the course of this development.

The staggered triple can be adjusted and aligned as a unit, in the same manner as a conventional staggered triple. The three tuned circuits are aligned to the spot frequencies indicated in Fig. 8, and the two traps associated with the bifilar-T circuit are adjusted to 41.25 Mc and 47.25 Mc. The tuning of the bifilar winding controls the position of the picture carrier, and its final adjustment should be such as to place the picture carrier 6 db down from the top of the pass band. The high-Q circuit in the second-third i-f interstage controls the response at the low-frequency end of the band, while the low-Q circuit in the third-fourth i-f interstage functions as a tilt control, as is normal for a staggered triple.

Capacitance at the plate of the first i-f tube feeding the bifilar-T trap circuit affects the response of this circuit. An increase in the value of this capacitance affects the slope of the response at the high-frequency end between 46 and 47 Mc.

With the last i-f stage and the staggered triple aligned, the mixer-first i-f circuit can be tuned by feeding a swept signal into the mixer grid or into the mixer test point. The stagger-tuned primary and secondary are adjusted to the indicated frequencies, as for a staggered pair, and the traps tuned for maximum rejection at the indicated frequencies.

Once the last i-f stage and the staggered triple have been aligned, the mixer circuits can be aligned without the use of an auxiliary detector. This is accomplished by adjusting the mixer plate tuning and the first i-f grid tuning for flat overall response. In particular the first i-f grid circuit should be adjusted so as not to alter the carrier position.

Some difficulty will be experienced in adjusting the 41.25-Mc mixer trap circuit because of the high overall rejection. This can be overcome by detuning the 41.25-Mc detector trap; then adjusting the mixer 41.25-Mc trap; and finally readjusting the detector 41.25-Mc trap.

It is essential to thoroughly shield the detector circuit, including the 41.25-Mc trap. This is best accomplished by placing the video and sound detectors and associated tuned circuits in a shielded enclosure as is conventional in monochrome receiver design. This is necessary to prevent regeneration and to prevent i-f harmonics reaching the input of the receiver. The mixer output circuit should be similarly shielded. Shielding of the remaining interstage circuits is limited to placing the coils and traps in shield cans as indicated in Fig. 8.

The input signal required at the grid of the first i-f tube to produce 1 volt d.c. at the video detector output was 200 µvolts. Using a conventional turret v-h-f tuner, the input required on the low channels for 1 volt above noise at the detector output was approximately 10 µv on the low v-h-f channels and 20 µv on the high channels. All inputs were measured at the center of the pass band.

The third i-f tube is shown in Fig. 8 as not being under a-g-c control. Depending upon the overall a-g-c control characteristics, including the tuner, a-g-c control of this tube may prove desirable. Provided the distribution of a-g-c voltage is accurately controlled, some reduction of vulnerability to cross modulation may be expected by controlling the third i-f tube since the amount of "attenuation" needed per stage decreases as the number of stages under control is increased.

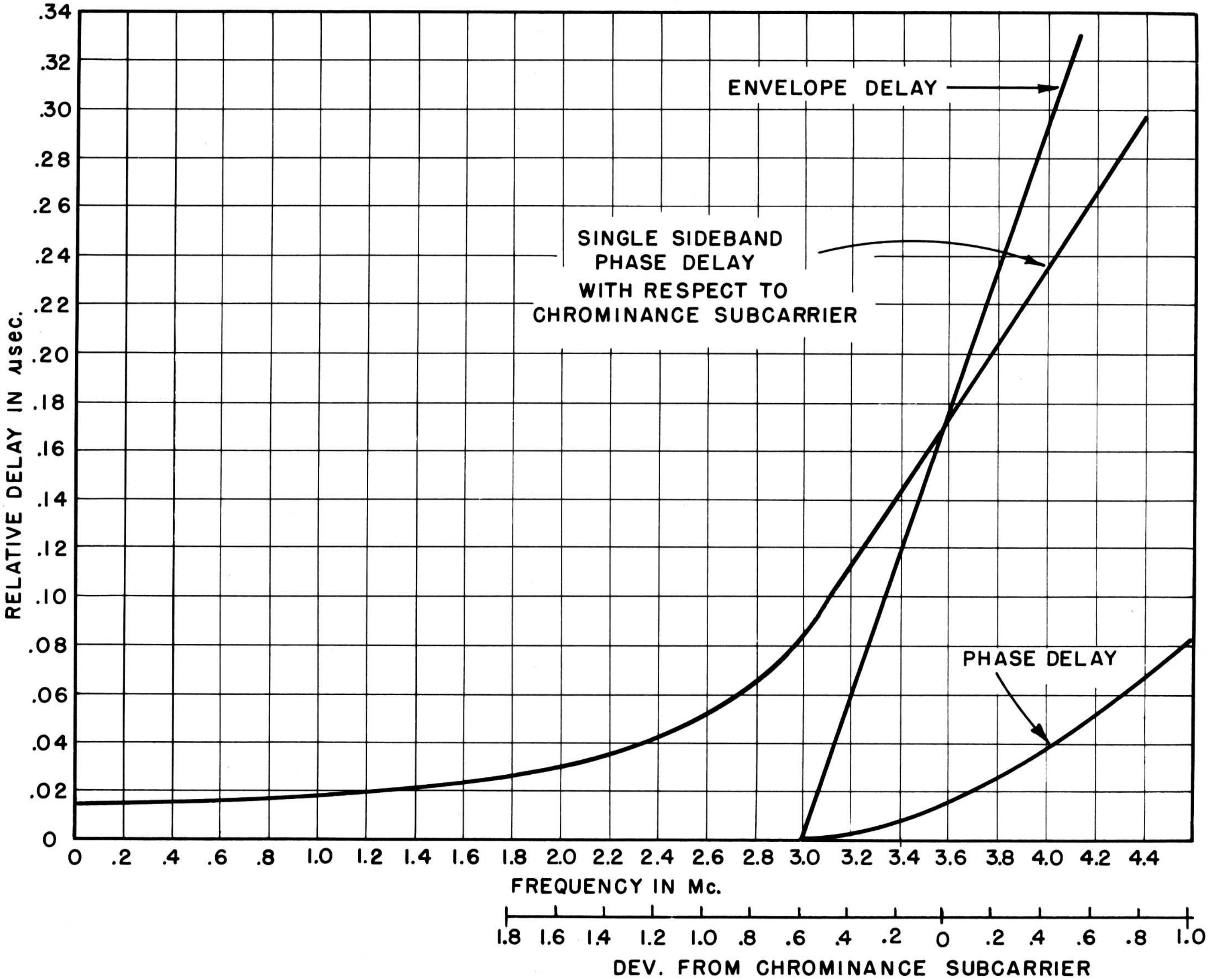


Fig. 15 - Three equivalent methods for representing the standard transmitter which is intended to compensate for the delay distortion introduced by the i-f amplifier.

The narrow separation between the edge of the pass band and the 41.25-Mc traps makes stability of the 41.25-Mc traps important. The mechanical construction of the coils and the temperature coefficient of the trap tuning condensers should be such as to yield the required stability.

Delay Characteristics

Consideration of the standard transmitter predistortion is an appropriate starting point in discussing time delay characteristics. Fig. 15 shows this predistortion curve plotted in three different ways:

(a) In terms of envelope delay. This is the form in which the delay is specified.

(b) In terms of phase delay. This is an equivalent form representing the spectrum delay, i.e., the delay of a single sinusoidal component between 0 and 4.5 Mc.

(c) In terms of the delay of the envelope formed by a single chrominance sideband beating with the chrominance subcarrier. This is termed the single-sideband phase delay with respect to

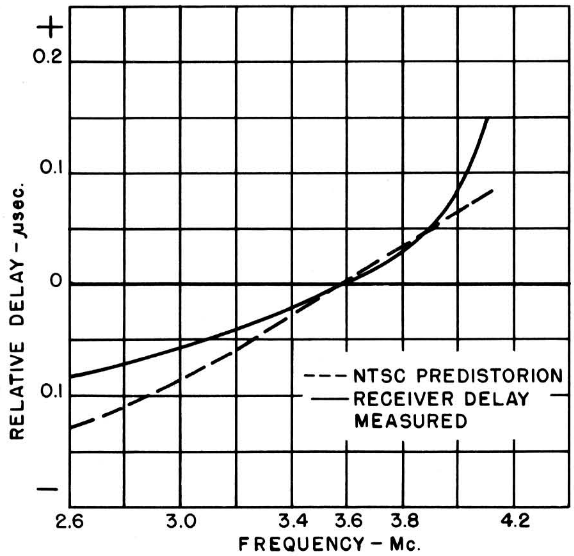


Fig. 16 - The single-sideband phase delay, measured with respect to the color subcarrier, corresponding to the overall amplitude response shown in Fig. 8. The "ideal" receiver delay which just matches the transmitter predistortion is shown for comparison.

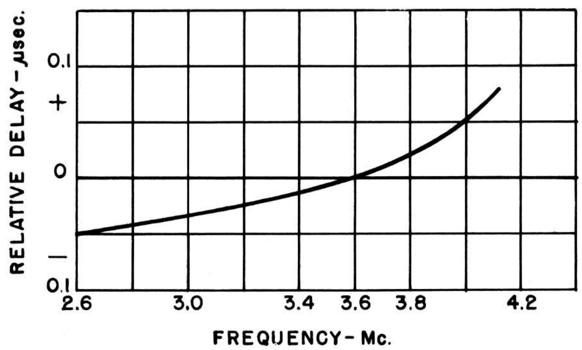


Fig. 17 - Single-sideband phase delay, measured with respect to the color subcarrier, for the mixer-to-first i-f grid circuit (see Fig. 11).

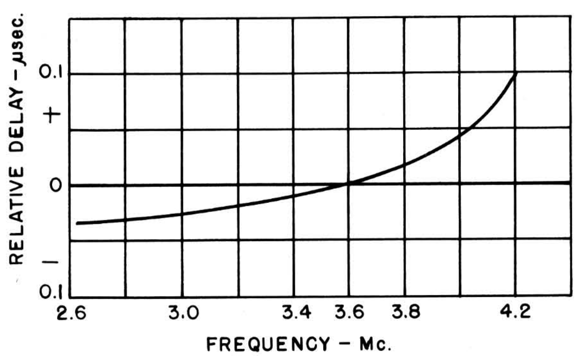


Fig. 18 - Single sideband phase delay, measured with respect to the color subcarrier, for the circuits between the first i-f grid and the fourth i-f grid (see Fig. 12).

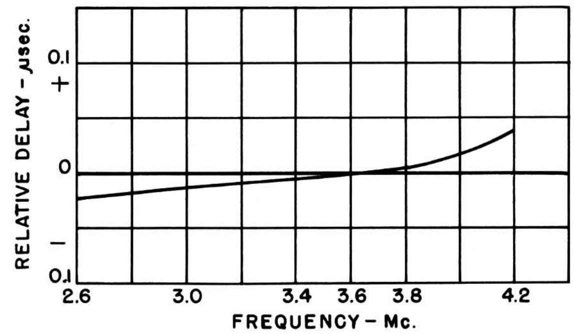


Fig. 19 - Single sideband phase delay, measured with respect to the color subcarrier, for the circuit between the fourth i-f grid and the video detector.

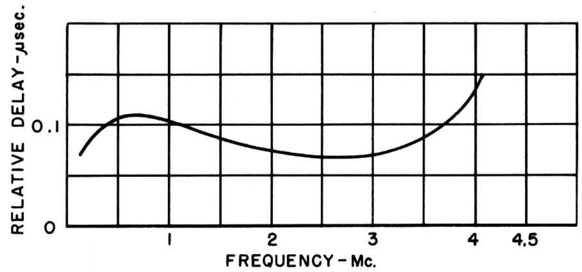


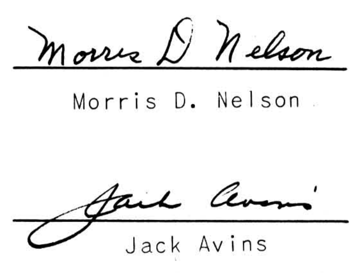
Fig. 20 - Overall phase delay measured between the mixer grid and the video detector.

the chrominance subcarrier and is useful in evaluating the performance of the amplifier over the chrominance region.

The overall single sideband phase delay measured with respect to the chrominance subcarrier is shown in Fig. 16. It will be observed that over the greater part of the chrominance region the delay is less than the transmitter predistortion.

Single sideband phase delay curves, measured with respect to the chrominance subcarrier, for the mixer output circuit, the staggered triple, and the detector circuit, are shown in Figs. 17-19.

The overall double sideband video phase delay measured by modulating the picture carrier is shown in Fig. 20.



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