LB-961

AN ANALYSIS OF THE BIFILAR-T TRAP CIRCUIT

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Approved

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Introduction

This bulletin describes the performance of a selective circuit designed to meet the requirements of color television i-f amplifiers. The use of this circuit simplifies the problem of obtaining high attenuation at the sound carrier frequency without introducing phase and amplitude distortion in the chrominance signal adjacent to the sound carrier.

The bifilar-T trap circuit provides high attenuation at critical frequencies with a rapid rate of cutoff and no "after response". To simplify the design of band-pass amplifiers, universal response curves are shown for the range of values encountered in practice.

General Discussion

The bifilar-T trap circuit has the basic structure shown in Fig. 1. C_1 and C_2 represent the output and input capacitances of the associated amplifier tubes. L/2 represents the inductance of a closely-coupled center-tapped winding, such as a bifilar. L_t and C_t represent a parallel-tuned circuit. L is designed to be series resonant with C_1 and C_2 at a desired frequency, f_s, in the pass band. The magnitude of R determines the Q of this resonance. The equivalent circuit between terminals, x, y and z is shown in Fig. 2a for k = 1.

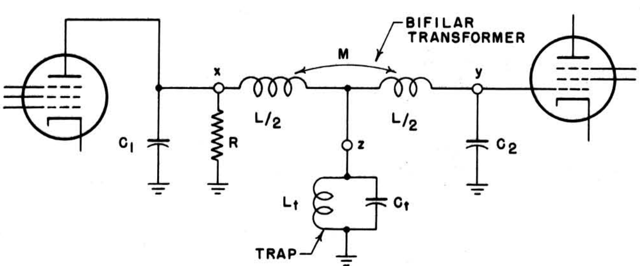

Fig. 1 - Basic structure of bifilar-T trap circuit.

A typical amplitude response which results from this configuration is shown in Fig. 2b. If capacitors C_1 and C_2 are equal, the voltage

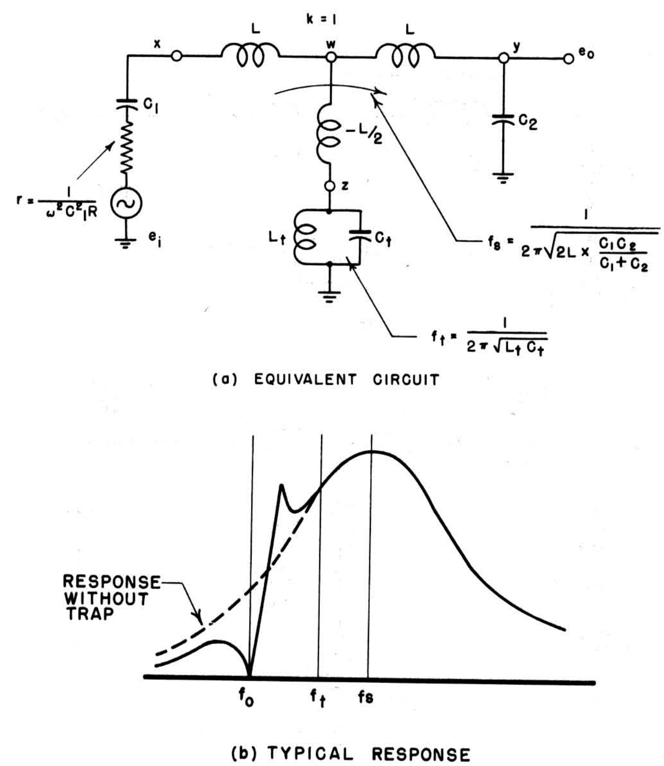

Fig. 2 - Equivalent circuit. The arrow for f_s indicates the resonant frequency with the trap removed.

developed at point w is zero except for the small quadrature voltage at this point due to the resistance r. Hence the presence of the trap little affects the overall series resonant response.

At a frequency such that the reactance of L_tC_t is equal, and opposite to the reactance between points w and z the net reactance between w and ground is zero. Therefore the voltage at point w and the voltage across C_2 must be zero at that frequency.

For a finite value of Q of the trap L_tC_t, the equivalent series resistance of the trap adds resistance into the branch w-to-ground, thereby reducing the attenuation. This effect can be avoided by shunting a resistor across one-half the bifilar winding, as shown in Fig. 3a, and the equivalent circuit Fig. 3b. The effect of bridging the bifilar winding is to introduce a negative resistance into the branch w-z. This resistance can be made equal to the resistance of the trap at the frequency of maximum attenuation thereby making the net impedance from w-to-ground equal to zero. By bridging a resistor across the bifilar transformer in this manner an absolute null can be obtained. The small equivalent series resistance introduced by the bridging augments the series resistance r and normally only slightly lowers the Q of the series resonance of 2L and $(C_1C_2)/(C_1+C_2)$.

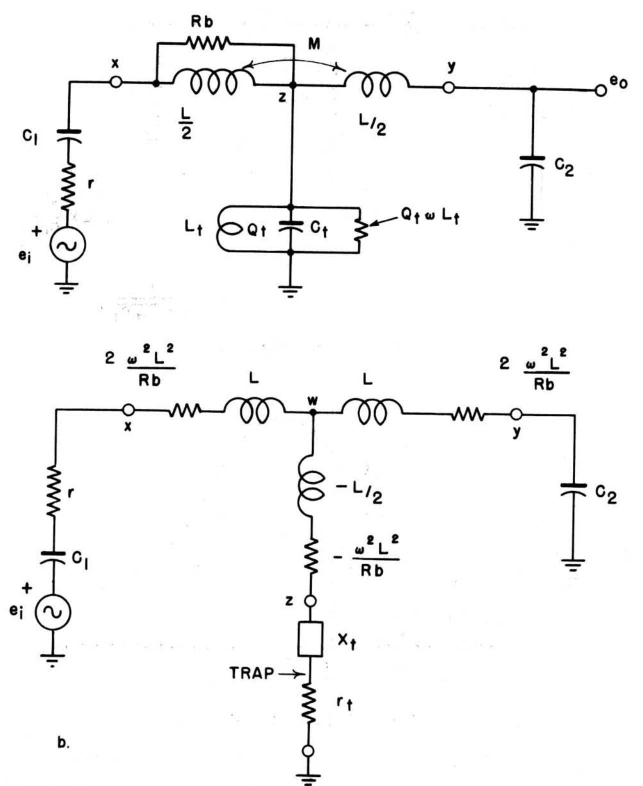

Fig. 3 - The effect of bridging a resistor across half the bifilar winding (a) is shown in the equivalent circuit (b).

Analysis of the Bifilar-T Trap Circuit

The circuit of Fig. 2a, which represents the equivalent circuit of the basic bifilar-T trap, is used as the basis for plotting universal amplitude and phase response curves for the case of primary interest, where $C_1 = C_2$. The following parameters are defined:

$$C_1 = C_2 = C$$

$$f_s = \frac{1}{2\pi\sqrt{LC}}$$

$$f_t = \frac{1}{2\pi\sqrt{L_tC_t}}$$

f_o = frequency of maximum attenuation

$$Q_s = \frac{1}{\pi f C r}$$

Q_t = Q of trap L_tC_t

$$n = \frac{L}{L_t} = \frac{\text{inductance of bifilar transformer}}{2 \times \text{inductance of trap}}$$

$$Q_s\delta = Q_s\frac{f-f_s}{f_s}$$

$$Q_s\delta_t = Q_s\frac{f_t-f_s}{f_s}$$

$$Q_s\delta_o = Q_s\frac{f_o-f_s}{f_s}$$

All frequency increments δ are taken with respect to the series resonance of 2L and C/2. These increments are normalized by taking the frequency variable as $Q_s\delta$.

Fig. 4 shows a typical circuit response

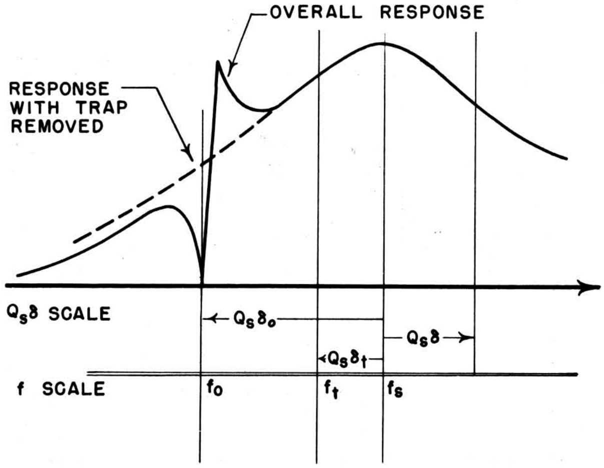

Fig. 4 - Typical response of a bifilar-T trap circuit.

and for comparison also shows the response of the same circuit if the trap were removed and point z of Fig. 3 were left floating. General expressions are derived for the amplitude and phase response. Universal curves are calculated from these formulas for the cases of particular interest in television i-f amplifiers. These are shown in Figs. 5-8, plotted as a function of the four independent parameters, $Q_s\delta_o$, n, Q_t, and Q_s.

In Fig. 5 the response is shown as a function of Q_s. Values of Q_s of 12.5, 25 and 50 are representative of those used at television i-f frequencies. This family of universal curves shows that the phase and amplitude response are not greatly affected by the value of Q_s. The rising response characteristic at the edge of the pass band is equivalent to an increase in the gain-bandwidth factor. At the frequency of maximum circuit gain the response is over 10 db greater than that obtained without the trap, while the phase departs from linearity by 60 degrees at this frequency.

Fig. 6 shows the effect of varying the impedance level of the trap. Curves are shown for:

$$n = \frac{\text{bifilar inductance}}{2 \times \text{trap inductance}} = \frac{L}{L_t} = 10,\ 15 \text{ and } 30.$$

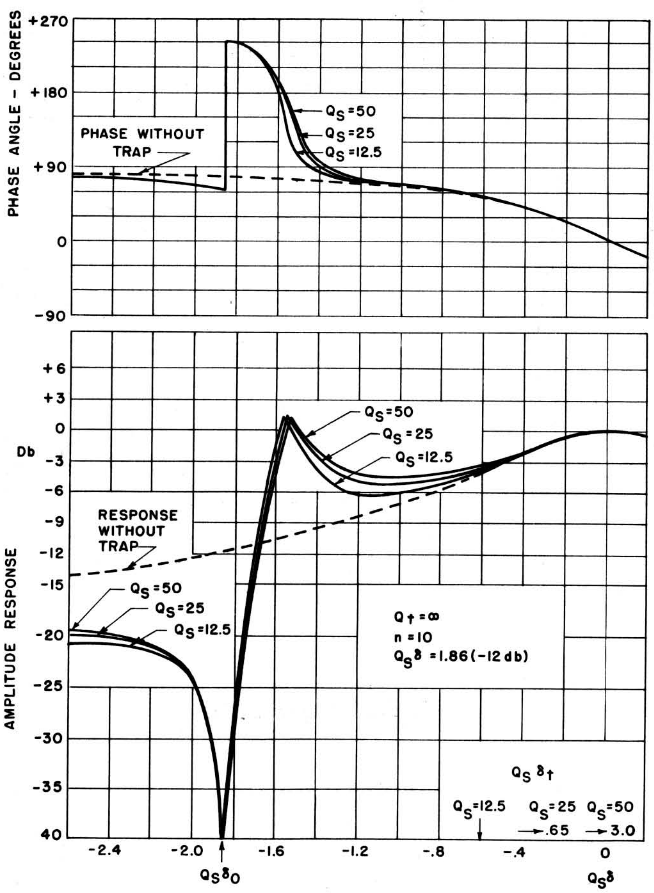

Fig. 5 - Universal response curves as a function of Q_s.

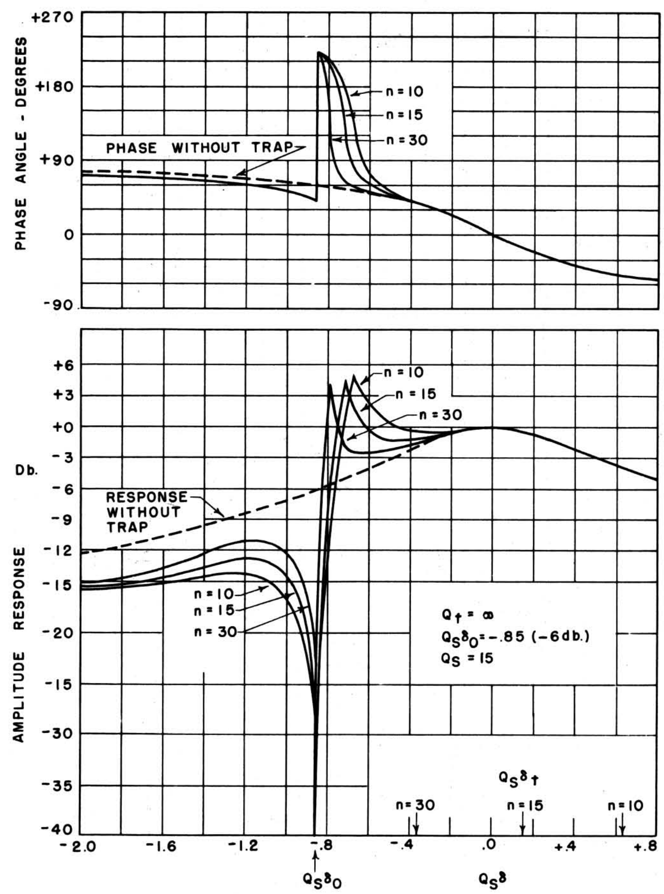

Fig. 6 - Universal response curves as a function of the trap impedance level.

This family of curves shows that the cut-off rate of the network is a direct function of the value of n used. For small values of n the cut-off rate is gradual while the after response is decreased.

Although it is not apparent from Fig. 6, the peak attenuation is also a function of n where the trap Q is finite. For a given value of Q_t the peak attenuation decreases as n is increased, i.e., as the rate of cutoff is increased. This is to be expected since the equivalent resistance introduced by the trap into the center leg increases as n is increased.

Fig. 7 shows the effect of trap position relative to the position of the series-tuned mesh and illustrates that the trap can be used to form a band-pass amplifier, with similar results on either side of resonance. An optimum phase condition is obtained when the attenuation occurs at the frequency of series resonance. In this case the phase with or without the trap is unaltered.

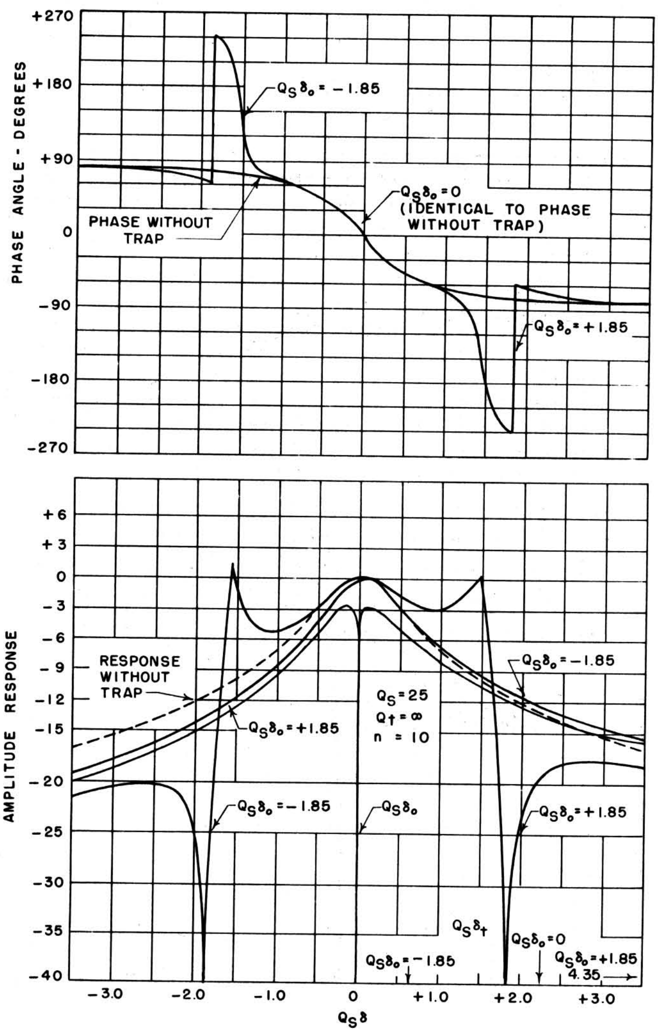

Fig. 7 - Universal response curves as a function of relative trap location.

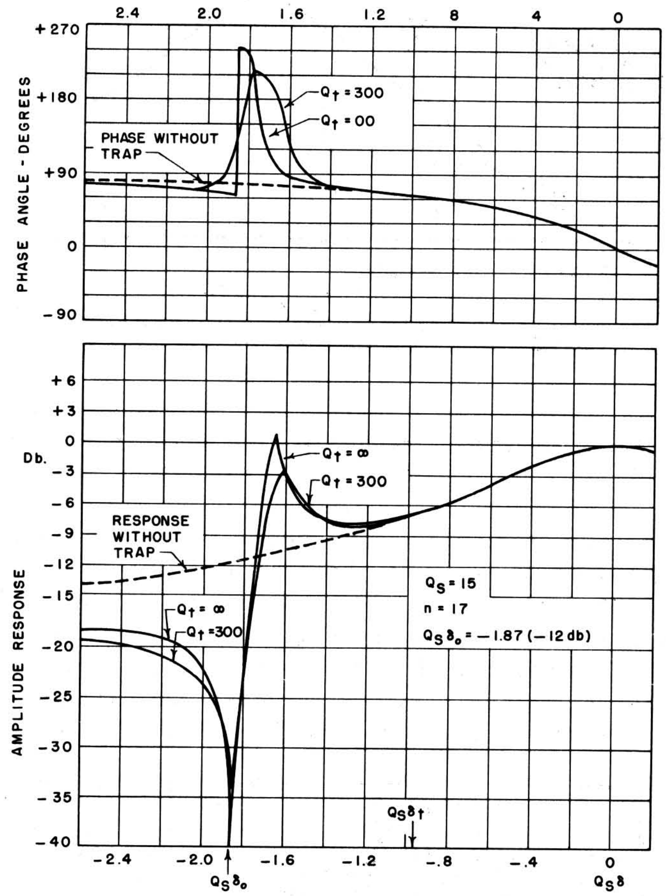

Fig. 8 - Effect of finite trap Q.

Fig. 8 shows the effect of finite trap Q. As predicted from the equivalent circuit the peak attenuation obtained is less than that for an infinite Q trap. At the same time the phase non-linearity at the edge of the pass band is increased. For this reason it is desirable to use the highest practical value of Q_t.

Typical Applications

The basic circuit of Fig. 1 applied to a practical i-f interstage coupling network and to a detector input is shown in Fig. 9. The universal curves are directly applicable provided the input and output capacitances are equal.

Examples of the use of the bifilar-T circuit as part of a staggered pair interstage transformer are shown in Figs. 10 and 12. The universal curves are not directly applicable here since they are calculated on the basis of a constant voltage vs frequency input to the trap circuit. However, an approximation to the overall response can be obtained by modifying the trap response (as given by the universal curves) by the selectivity of the tuned circuit which precedes it and to which it is coupled.

This is valid only when the coupling between the "primary" and "secondary" is not excessive, so that the reactance reflected from the primary is not sufficient to modify the characteristics of the trap circuit. In practice, the primary and secondary can be stagger tuned just as though the trap were not present and the overall response will be similar to that of a staggered pair, but modified by the rejection of the trap.

In the detector input network shown in Fig. 10, the plate and detector input circuits are stagger tuned to 42.5 and 45.5 Mc, respectively. Low side inductive coupling between the circuits is used. As shown by the selectivity measured from the grid of the amplifier tube to the detector in Fig. 11, the network provides attenuation of the accompanying sound

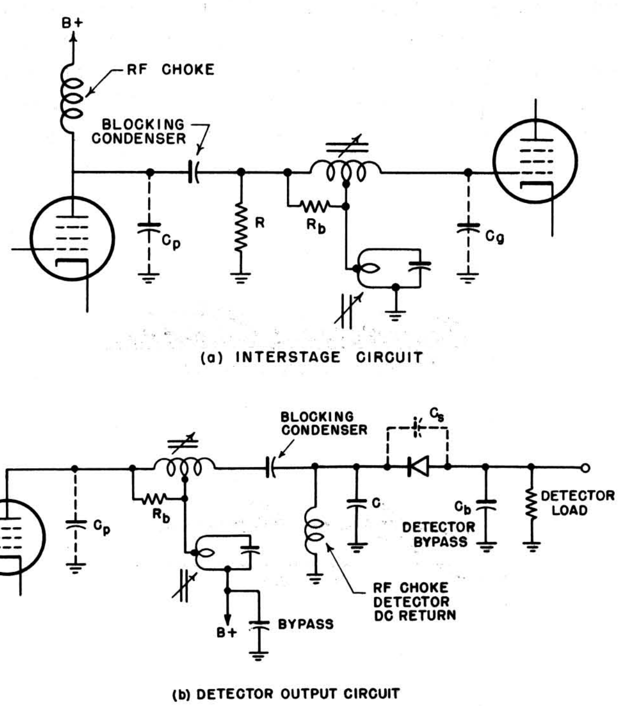

Fig. 9 - Typical bifilar-T trap circuits.

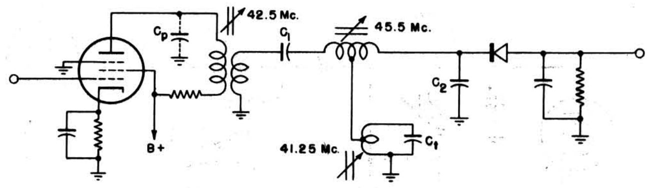

Fig. 10 - Bifilar-T trap circuit used as part of a staggered pair.

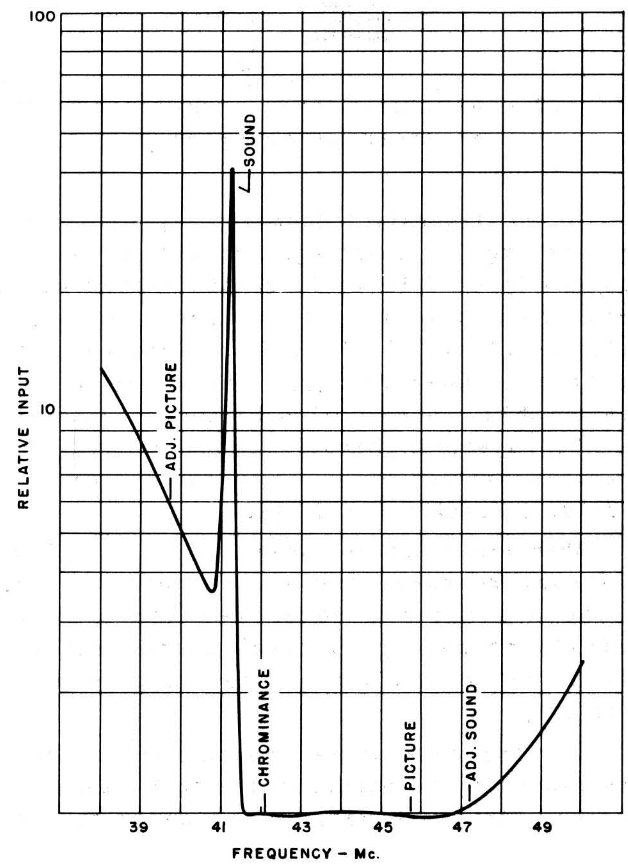

Fig. 11 - Response of the circuit shown in Fig. 10.

carrier at 41.25 Mc with a flat response over the full video band.

The conditions of operation of this circuit are similar to those plotted in Fig. 8 where the trap has a Q of 300. For this network a value of n of 17 was chosen by tapping down on the trap inductance, so that the network provided maximum attenuation at 41.25 Mc and full response to 41.65 Mc. With a detector video load impedance of 4700 ohms and a bridging resistance of 5600 ohms, the Q_s of the bifilar circuit was 15. The Q of the plate circuit with an 82-ohm series damping resistor was 13.

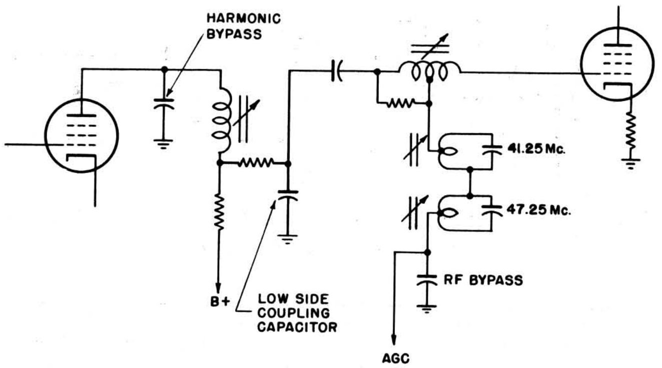

Fig. 12 - Bifilar-T trap circuit used for mixer-to-if coupling.

The configuration shown in Fig. 12 is used for mixer to i-f coupling. Low side capacitive coupling is used to minimize oscillator radiation. The plate circuit is tuned to 45.5 Mc while the bifilar-T circuit is tuned to 42 Mc. Two traps, tuned to 41.25 and 47.25 Mc, are used to obtain attenuation at the accompanying and the adjacent channel sound carrier frequency. The selectivity, as measured from grid-to-grid, is shown in Fig. 13.

When two traps are used as in Fig. 12, the universal response curves are generally applicable since the total reactance in the vicinity of each trap parallel resonance is only slightly modified by the presence of the other trap.

For the case where the cut-off rates at both sides of the bandpass are to be equal and the trap Q's are equal, the bridging resistor will equally increase the attenuation at the two desired frequencies. If the cut-off rates are to be unequal, as is frequently the case, the bridging resistor will have the effect of compensating at one frequency while over- or under-compensating at the other frequency.

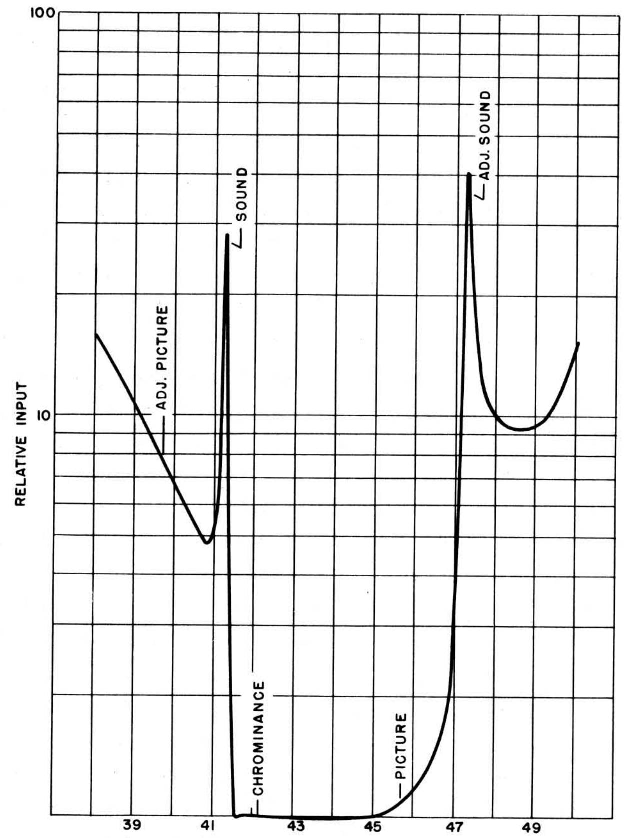

Fig. 13 - Response of circuit in Fig. 12.

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Appendix

Using the notation defined in the text and dividing each impedance (Fig. 2a) by the reactance of the bifilar transformer ωL results in the normalized impedances:

$$\frac{\omega L}{\omega L} = 1 \tag{1}$$

$$\frac{1}{\omega C} \cdot \frac{1}{\omega L} = \frac{1}{\omega^2 LC} = \frac{1}{1+2\delta} \tag{2}$$

$$\frac{\omega L}{2n(\delta-\delta_t)} \cdot \frac{1}{\omega L} = \frac{1}{2n(\delta-\delta_t)} \tag{3}$$

$$r \cdot \frac{1}{\omega L} = r\omega C \cdot \frac{1}{\omega^2 LC} = \frac{2}{Q_s} \cdot \frac{1}{1+2\delta} \tag{4}$$

$$-\frac{\omega L}{2} \cdot \frac{1}{\omega L} = -\tfrac{1}{2} \tag{5}$$

This results in an equivalent circuit shown in Fig. 14.

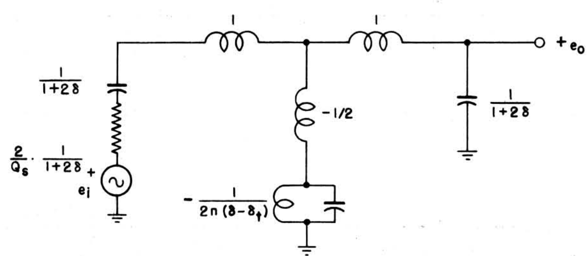

Fig. 14 - Equivalent circuit.

The ratio of the output voltage e_o to the input voltage e_i can be expressed in terms of the normalized self impedances of the two meshes Z_1 and Z_2, and the mutual impedance Z_m. Using this system of normalized impedances the circuit solution is:

$$\frac{e_o}{e_i} = -j \frac{Z_m}{Z_1 Z_2 - Z_m^2} \cdot \frac{1}{1+2\delta} \tag{6}$$

By reference to Fig. 14 it may be shown that the normalized impedances for an infinite Q trap are:

$$Z_1 = \frac{2}{Q_s}\left(\frac{1}{1+2\delta}\right) + j\left[\frac{1}{2} - \frac{1}{1+2\delta} - \frac{1}{2n(\delta-\delta_t)}\right] \quad (7)$$

$$Z_2 = j\left[\frac{1}{2} - \frac{1}{1+2\delta} - \frac{1}{2n(\delta-\delta_t)}\right] \quad (8)$$

$$Z_m = -j\left[\frac{1}{2} + \frac{1}{2n(\delta-\delta_t)}\right] \quad (9)$$

In terms of these impedances the ratio of output to input voltage is given by:

$$\frac{e_o}{e_i} = -\frac{Q_s/2[1+1/n(\delta-\delta_t)]}{2Q_s\delta[1/(1+2\delta)+1/n(\delta-\delta_t)]-j[(1-2\delta)/(1+2\delta)+1/n(\delta-\delta_t)]} \quad (10)$$

The response is equal to zero when:

$$\delta_o = -\frac{1}{n} + \delta_t \quad (11)$$

This follows from Eq. 5 by letting the numerator equal zero.

When the Q of the trap is finite it has a normalized impedance which is equal to:

$$Z_t = \frac{Q_t/n}{1+4Q_t^2(\delta-\delta_t)^2} - \frac{j2Q_t^2(\delta-\delta_t)/n}{1+4Q_t^2(\delta-\delta_t)^2} \quad (12)$$

For a finite Q trap the circuit normalized impedances are:

$$Z_1 = \frac{2}{Q_s}\left(\frac{1}{1+2\delta}\right) + \frac{Q_t/n}{1+4Q_t^2(\delta-\delta_t)^2} + j\left[\frac{1}{2} - \frac{1}{1+2\delta} - \frac{2Q_t^2(\delta-\delta_t)/n}{1+4Q_t^2(\delta-\delta_t)^2}\right] \quad (13)$$

$$Z_2 = \frac{Q_t/n}{1+4Q_t^2(\delta-\delta_t)^2} + j\left[\frac{1}{2} - \frac{1}{1+2\delta} - \frac{2Q_t^2(\delta-\delta_t)/n}{1+4Q_t^2(\delta-\delta_t)^2}\right] \quad (14)$$

$$Z_m = \frac{Q_t/n}{1+4Q_t^2(\delta-\delta_t)^2} - j\left[\frac{1}{2} + \frac{2Q_t^2(\delta-\delta_t)/n}{1+4Q_t^2(\delta-\delta_t)^2}\right] \quad (15)$$

The circuit response may be calculated for any particular value of trap Q by applying Eq. 6 using the impedances given in Eqs. 13, 14 and 15.