LB-1085

DESIGN CONSIDERATIONS OF TRANSISTORIZED PICTURE IF AMPLIFIERS

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Approved

Stuart Wm Seeley

A power gain of 16 db, and an average noise factor of 6 to 8 db, is secured in a neutralized picture i-f amplifier stage using RCA 2N384 drift transistors in grounded-emitter configuration. A four-stage neutralized amplifier provides a power gain of 60 db with a 6-db noise factor.

Various methods of neutralization have been evaluated. The use of neutralization increases the power gain and isolation between the input and the output circuits, and minimizes input and output capacitance variations due to the application of a.g.c.

Methods of applying a.g.c. to individual stages have been evaluated. With variation of the emitter current, either directly or by changing the base-to-emitter bias, an a-g-c range of 40 to 46 db may be secured without marked detuning of the collector tuned circuit.

The cross-modulation ratio of a single i-f stage is independent of the picture carrier level. It varies linearly with the input level of the sound carrier or the chrominance subcarrier, and with a square law relationship when both are varied simultaneously. The cross-modulation ratio is inversely proportional to the emitter current.

Introduction

The development of commercially available v-h-f transistors, notably drift types[1,2] (i.e., graded base triodes) and various grown junction tetrodes, has made possible the design of practical transistor amplifiers at the picture intermediate frequencies having performance substantially equivalent to that of vacuum tube strips. The RCA-2N384 drift transistor features a carefully controlled impurity distribution in the base region, which results in a "built-in" accelerating field with consequent decreased transit time and increased alpha-cutoff frequency.

Single stage amplifiers, using 2N384 transistors, have been evaluated at 44 Mc with respect to (1) power gain and noise factor; (2) input and output impedance variations with change in frequency and d-c bias conditions; (3) application of a.g.c.; and (4) cross modulation. On the basis of these single-stage measurements, a four-stage picture i-f amplifier strip was designed.

[1] RCA Semiconductor Products Special Announcement "RCA - 2N384 New High-Frequency Transistor for VHF Applications", 12 July, 1957.

[2] *LB-1018, The Drift Transistor.*

Single Stage Considerations

Power Gain and Noise Factor

When the 2N384 drift transistor was used in the grounded-emitter configuration, a power gain of 16 db per stage, at 44 Mc, was measured under conjugately-matched, neutralized, circuit conditions. The corresponding noise factor of a number of units averaged 6 to 8 db.[3] Both the power gain and noise factor are degraded at higher frequencies.

Unilateralization and Neutralization

Experience has shown that some form of neutralization or unilateralization is required for ease of alignment and minimum interaction between the input and output.[4] The reduction in interaction is necessary to

[3] G. E. Theriault and H. M. Wasson, "Determination of Transistor Performance Characteristic at VHF", *IRE Transactions,* vol. BTR-3, No. 1, pp. 40-48, June, 1957.

[4] *LB-1014, Stability Considerations in Transistor IF Amplifiers.*

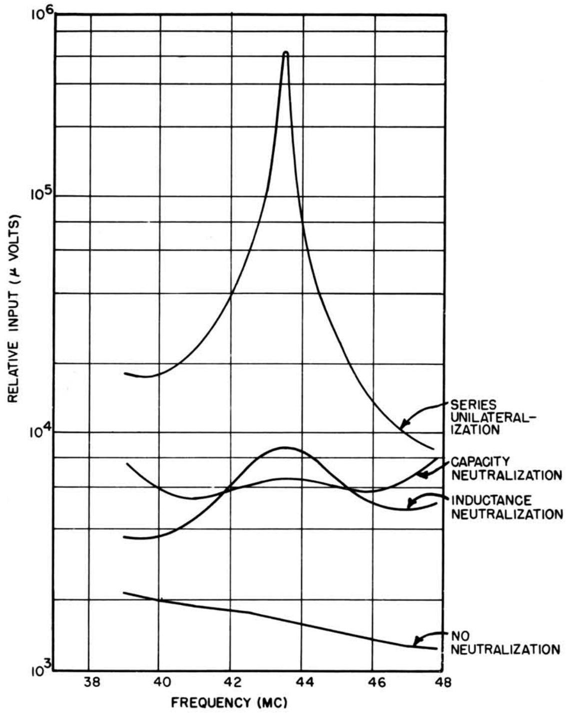


Fig. 1 - Isolation characteristics.

keep the terminal impedance variations to a minimum throughout the frequency band of interest. For practical picture i-f amplifiers a simple method, using fixed component values, of "balancing out" the feedback parameters of the transistor stage is desired. Investigation has shown that unilateralization provided a higher degree of isolation (back to forward voltage ratio) than neutralization. The isolation, in terms of micro volts input required at the collector to provide a constant reading on a measuring device at the base, is illustrated graphically in Fig. 1. This method of monitering the isolation characteristic is also the technique used to determine when the circuit is neutralized, i.e., the neutralization or unilateralization components are tuned for a minimum voltage at the base. Four curves are shown in Fig. 1, representing the isolation characteristic for: (a) series unilateralization; (b) capacitance neutralization; (c) inductance neutralization; and (d) no neutralization. The sharp peak associated with the series unilateralization curve is extremely sensitive to capacitance and resistance change of unilateralizing components, and is difficult to adjust; therefore, from a practical standpoint, neutralization is recommended since it achieves essentially the same desired result.

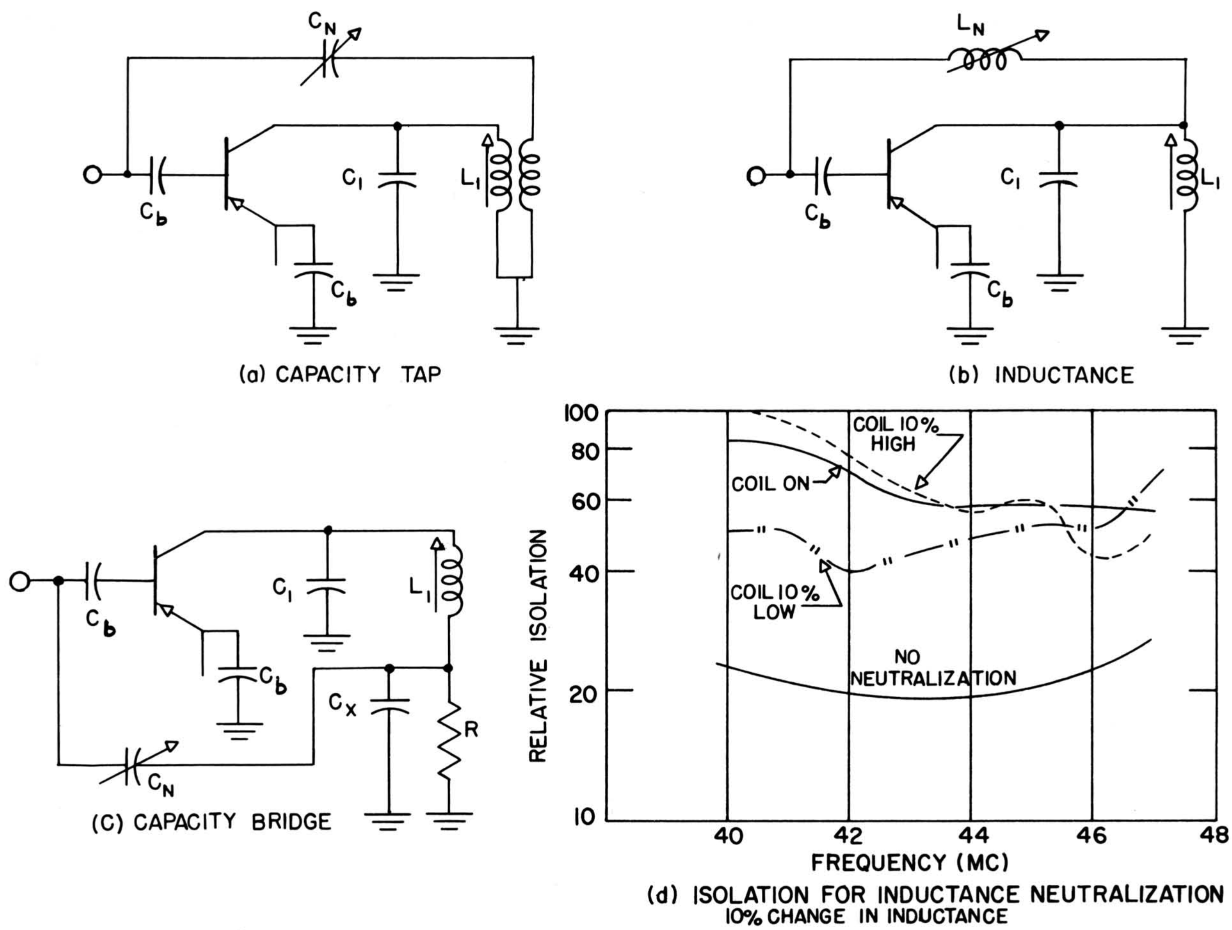


Fig. 2 - Neutralization means.

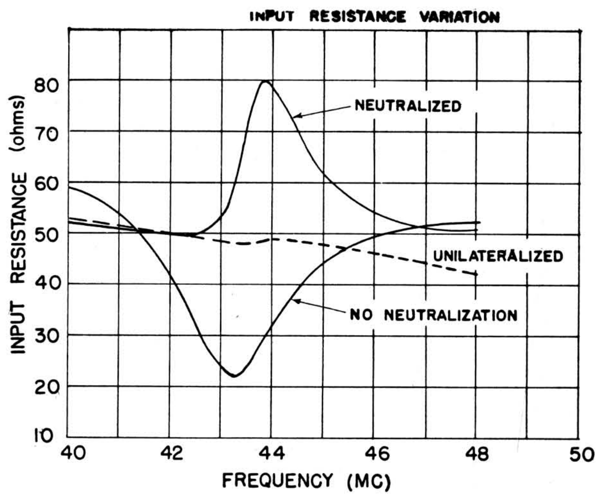
Neutralization may be secured in several ways as shown by Fig. 2. The capacity bridge circuit of Fig. 2c utilizes three components for neutralization designated C_x, C_n and R. Because this method is rather complicated it is not the most desirable for a practical television i-f amplifier.

The simple capacitance method of Fig. 2a requires a tap on the tuned circuit (either input or output). At 44 Mc the tight coupling required to produce the perfect phase reversal desired may not always be realized. Fig. 2b is the inductance neutralization circuit. Since a transformer tap is not needed, the coupling problem is not a factor. However, care has to be exercised in the placing of parts to minimize any mutual coupling between the tuned circuits and the neutralizing inductance. Fig. 2d shows the isolation characteristic for the inductance neutralization circuit, and the effect of varying the component value by ± 10 percent. The isolation characteristic for no neutralization is also shown.

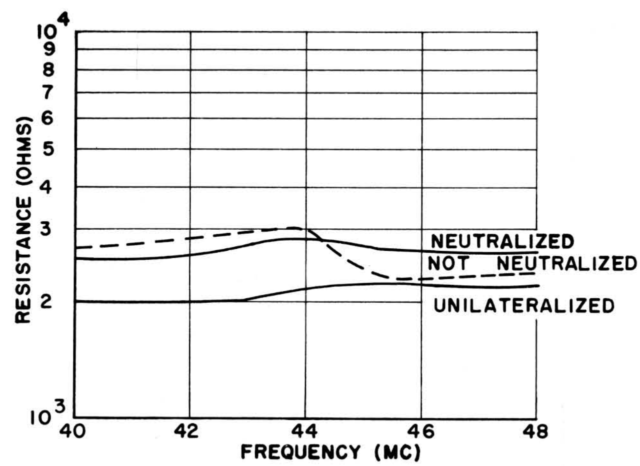
Input and Output Impedance Variations

The capacitance and resistance values at the input and output of transistors, over the useful frequency range, has been previously described in the literature.[5] The results of measurements, plotted in Fig. 3a, show the variations of input capacitance and resistance across the 40 to 48 Mc frequency region, under the neutralized, unilateralized, and not-neutralized circuit conditions. The bias values were: $E_c = -22.5$ volts and $I_e = 1$ ma. Unilateralization almost completely eliminates the effect of the output tuned circuit appearing at the input. However, the improvement due to neutralization is also fairly substantial when compared to the not-neutralized case. The output parameters for the same conditions are shown in Fig. 3b. Again, neutralization or unilateralization minimizes the resistance and capacitance variations.

[5] *LB-989, Performance of a Radio-Frequency Alloy Junction Transistor in Different Circuits.*

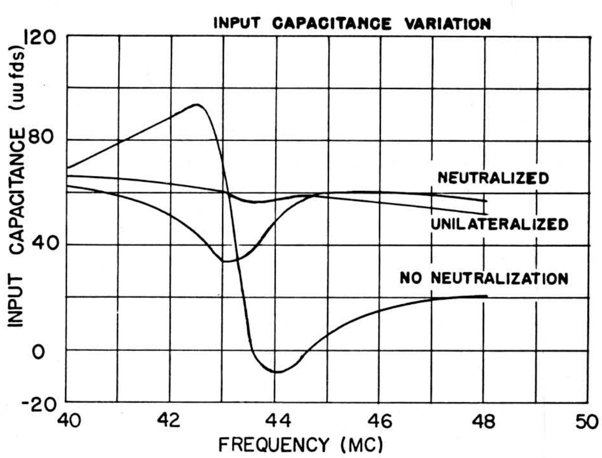


Input resistance variation

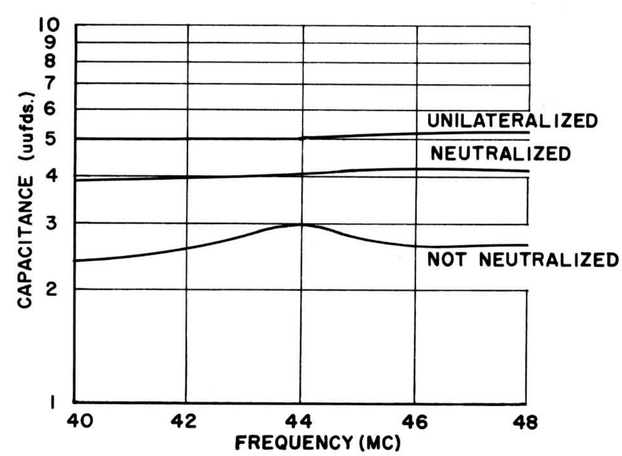


Output resistance variation

Fig. 3(a) - Variations of input resistance and capacitance.

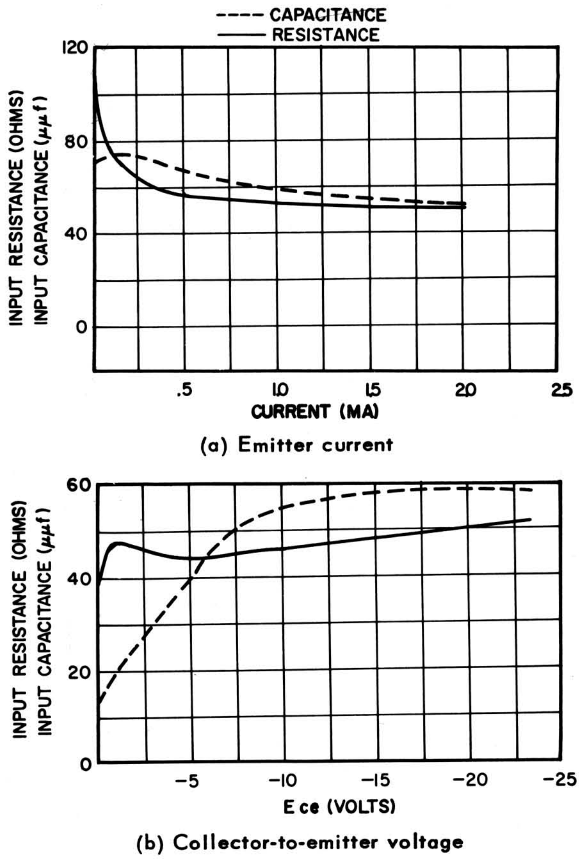


Input capacitance variation



Output capacitance variation

Fig. 3(b) - Variations of output resistance and capacitance.



(a) Emitter current

(b) Collector-to-emitter voltage

Fig. 4 - Input resistance and capacitance variations with d-c bias.

A prime consideration, when the application of a.g.c is contemplated, is the variation of the terminal capacitances and resistances with changes in d-c bias conditions. The input capacitance and resistance variations are shown in Fig. 4a as a function of emitter current and Fig. 4b as a function of collector voltage. Decreasing the emitter current increases the input resistance 2 to 1, while the capacitance increases approximately 25 percent. Decreasing the collector voltage, on the other hand, has relatively little effect on the resistance, but the capacitance decreases by more than 3 to 1. The corresponding output terminal capacitance and resistance variations are shown in Fig. 5a and Fig. 5b. The capacitance remains constant and the resistance rises with the decreasing emitter current. As the collector voltage is decreased both the output resistance and capacitance change rapidly for collector voltage below -5 volts.

AGC

Several methods of applying automatic gain control to transistor amplifier stages are available.[6,7,8] However, the practical control of gain in a triode transistor amplifier stage is secured by, (a) controlling the emitter current or, (b) controlling the collector voltage. Collector voltage control has the disadvantage of introducing excessive change of input and output capacitance, particularly for low values of collector voltage where the a-g-c action is effective, and may considerably distort the selectivity curve.

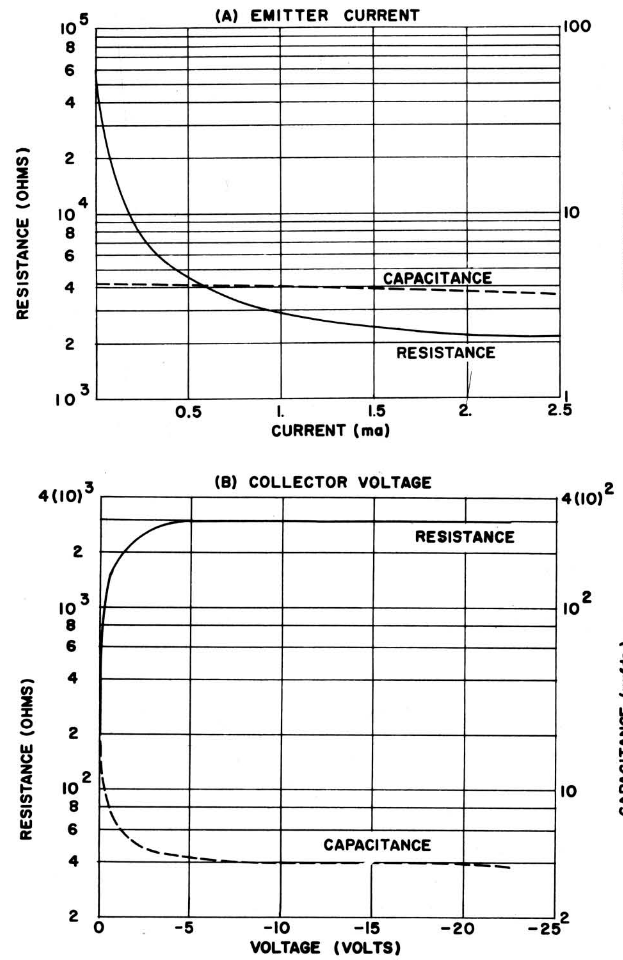


Fig. 5 - Output resistance and capacitance variations with d-c bias.

Fig. 6 shows the a-g-c range obtained by the emitter current and the collector voltage control means. The a-g-c ranges are plotted versus the percentage of nominal bias values, which are, emitter current of 1 ma and collector voltage of -22.5 volts. An approximation is utilized in that the 0.1 percent point is actually zero. The a-g-c action with emitter current control is fairly linear when plotted in this manner, and the total a-g-c

[6] W. F. Chow and A. P. Stern, "Automatic Gain Control of of Transistor Amplifiers," *Proc. IRE*, Vol. 43, No. 9, pp. 1119-1127, September 1955.

[7] F. H. Blecher, "Automatic Gain Control of Junction Transistor Amplifiers," *Proc. NEC*, Vol. 9, pp. 731-737, 1953.

[8] *LB-957, A Developmental Pocket-Size Broadcast Receiver Employing Transistors.*

range to cutoff is 46 db. While the total a-g-c range is the same for the collector voltage control, no change in gain is noticeable until approximately 40 percent of -22.5 volts or -9 volts bias is attained. The gyration in the 1 percent region of the curve is due to the forward biasing of the collector-to-base diode.

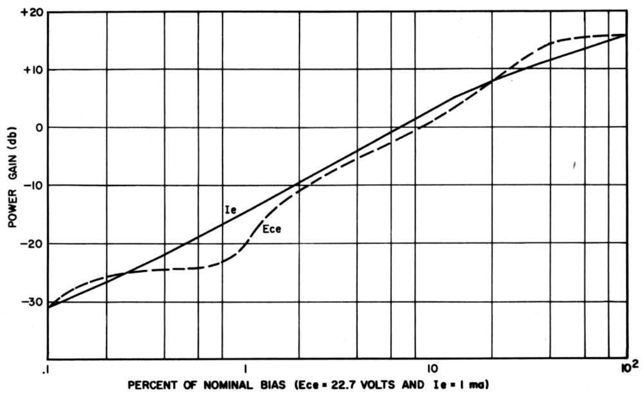


Fig. 6 - Available automatic gain control.

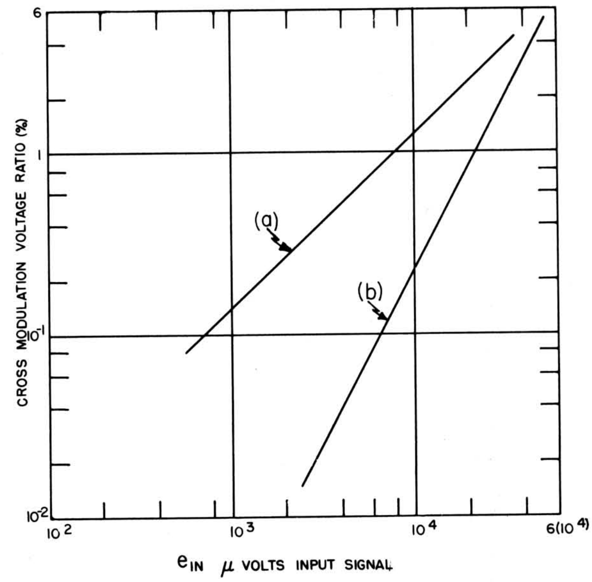


Fig. 7 - Cross-modulation voltage ratio vs. input signal level.

Cross Modulation

The consideration of cross modulation in picture i-f amplifiers is limited to the three-carrier case, that is, the production of a lower frequency sideband of a desired or picture carrier at 45.75 Mc because of the presence of a beat-note component related to the accompanying sound carrier at 41.25 Mc and the chrominance subcarrier at 42.17 Mc. In this case, the undesired sideband will be found at 44.83 Mc (picture carrier minus the difference between the color subcarrier and sound carrier frequencies). The input and output of the transistor were conjugately matched, the stage neutralized, and the d-c operating point set at -22.5 volts collector bias and 1 ma emitter current. The cross-modulation voltage ratio (CMVR) is defined as the ratio of the 44.83 Mc output to the desired 45.75 Mc picture carrier output. This ratio should be less than 1 percent (100 times in voltage or 40 db below unity) to appear negligible in a received picture.

Fig. 7 shows how the cross modulation percentage varies with the input signal level. In curve (a), a linear function, only the signal level of the sound carrier (or chrominance sub-carrier) is varied, with the other carriers held at 50 mv. The cross modulation becomes objectionable at about 8 mv of sound carrier signal (or chrominance subcarrier) at this level. Curve (b) shows all three carriers varied simultaneously. The curve follows a square-law relationship and the cross modulation reaches 1 percent when the level of the three carriers is approximately 20 millivolts.

The effect of the application of a.g.c. in the amplifiers on cross modulation was also secured. Two cases were evaluated with emitter-current control and are shown in Figs. 8a and 8b.

Case 1: P_{in} (pix) = P_{in} (chrom) = P_{in} (sound). This case is depicted in the curves of Fig. 8a. The input power of all carriers is 0.5, 5.0 and 50 μwatts for each of the curves. Even with only 0.5 μwatts input, the cross modulation is objectionable when the emitter current is decreased below 0.15 ma.

Case 2: P_{in} (pix) = P_{in} (chrom) = $100\times P_{in}$ (sound). This simulates more reasonably the typical operation of a television receiver. For intermediate values of input signal, approximately 20 db improvement may be noted. Here at 50 μwatts of desired input signal level, if the transistor is operated in a high emitter current bias condition, the cross modulation is below the objectionable 1 percent.

Four-Stage IF Amplifier Strip

The schematic diagram of a four-stage television picture i-f amplifier strip is shown in Fig. 9. The input and output stages are broadband and the remaining stages stagger-tuned to produce the desired passband characteristic curve. Automatic gain control is applied only to the first stage. As the schematic indicates, the grounded-emitter circuit was used throughout to obtain the higher power gain that is realizable. Inductance neutralization was used, chosen mainly on the basis of

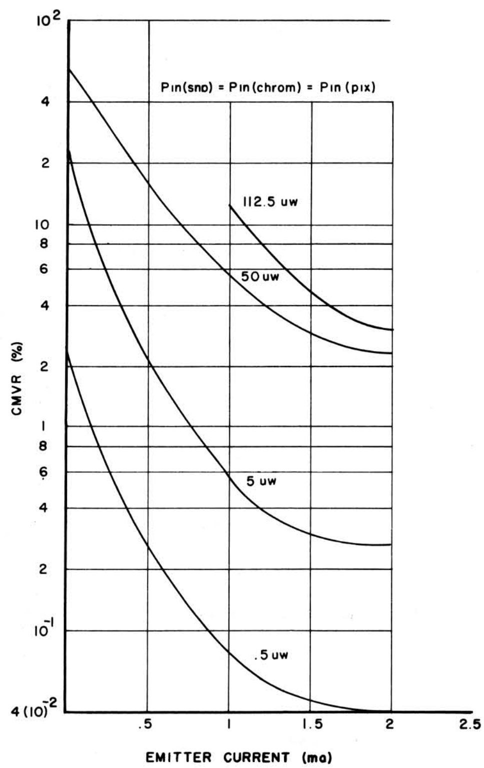


Fig. 8(a) - Cross-modulation voltage ratio.

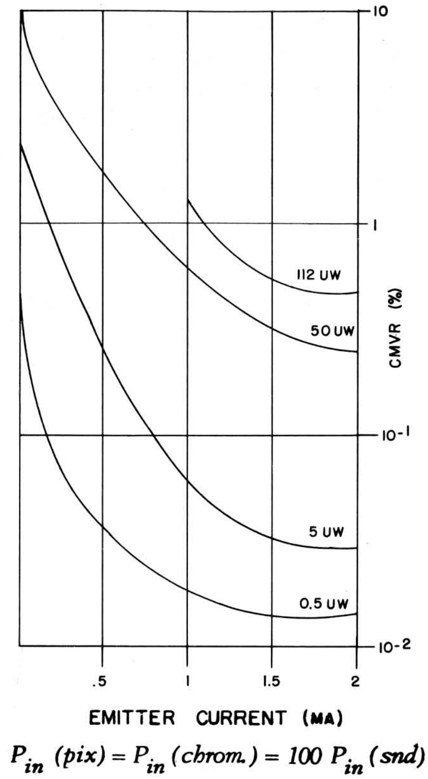


Fig. 8(b) - Cross-modulation voltage ratio.

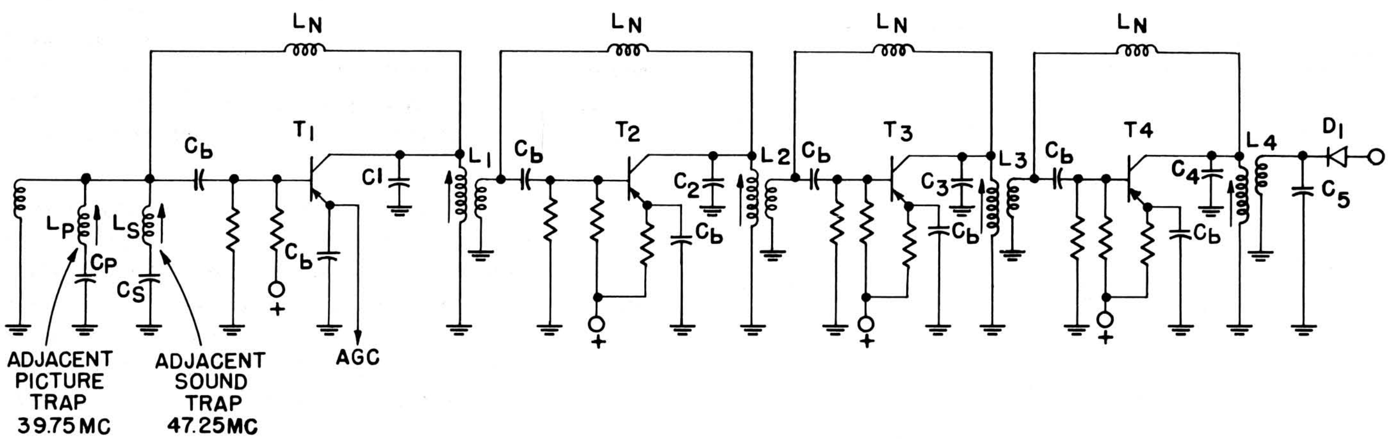


Fig. 9 - Transistorized picture i-f amplifier.

cost. The power gain at the center frequency of 44 Mc is 60 db and the noise factor 6 db.

The trap circuits for the adjacent sound carrier at 47.25 Mc and adjacent picture carrier at 39.75 Mc, were inserted at the input of the first stage. The desired rejections were thereby obtained to decrease the cross-modulation probability at high level input signals. The transistors were biased for 2 ma operation to further decrease cross-modulation difficulties. Automatic gain control is secured by changing the base-emitter bias at the emitter, thereby controlling the emitter current.

The overall selectivity characteristics are shown in Fig. 10 for various values of emitter current. With full gain, or 2-ma emitter current, the overall bandwidth is 3.4 Mc with the center frequency at 44.2 Mc. Under these conditions, the adjacent sound rejection is 31 db and the adjacent picture rejection is more than 40 db with respect to the picture carrier. The associated sound carrier is down 10 db.

The center frequency a-g-c range with the emitter current controlled from 2 ma to 0 ma is 46 db. As anticipated with emitter current control, marked detuning

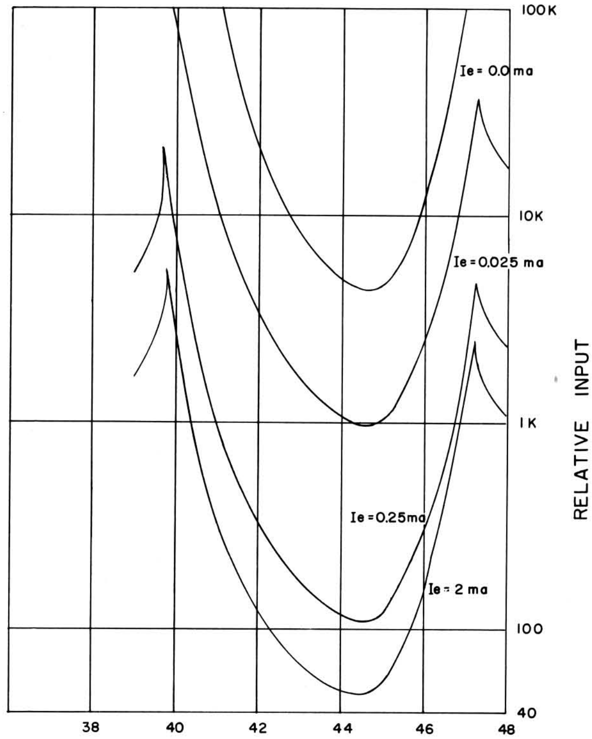


Fig. 10 - Selectivity and a-g-c characteristics, four-stage transistor amplifier.

and center frequency shift are not noticed, as the emitter current is decreased. The bandwidth is reduced slightly due to the unloading of the collector tuned circuit by the increase in output impedance with the a.g.c. applied.

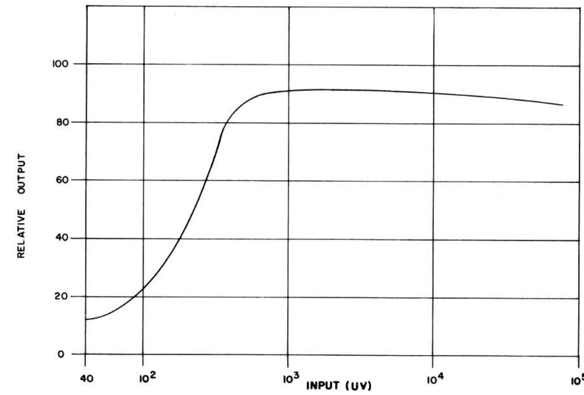


Fig. 11 - Overall a-g-c characteristics.

The curves of Fig. 10 also reveal the fact that the amplifiers gain was not materially decreased until the emitter current reached 250 μa. This led to the construction of another i-f strip with five stages (and a.g.c. applied to the first two stages). A closed loop from the second detector through an a-g-c amplifier was used to simulate a receiver and an overall a-g-c characteristic was obtained as shown in Fig. 11. The output power is constant for an input level of from 400 μv to greater than 0.5 volt.

Aside from lower power gain per stage and power handling capability because of cross-modulation difficulties, a television i-f amplifier using drift transistors provides substantially comparable performance to that of an amplifier strip using vacuum tubes.

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