LB-1079

AN INVESTIGATION OF CROSS MODULATION AND HETERODYNE INTERFERENCES IN TRANSISTOR IF AMPLIFIERS

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Approved

Stuart Wm Seeley

In the reception of color television signals, the percentage of cross modulation of a transistor high-frequency i-f amplifier in the form of a 920-kc beat-note, varies linearly with the input level of the sound carrier or the chrominance sub-carrier and is independent of the picture-carrier level. When both the sound and chrominance levels are varied simultaneously, the cross-modulation percentage varies with a square-law relationship which is effective over a wide range of signal amplitudes and frequency of operation.

Two-signal heterodyne interference in the form of a 1.5-mc beat note may be observed in both color and monochrome television receivers due to the presence of the sound carrier of the adjacent lower channel. The resulting interference varies linearly with the amplitude of the undesired sound carrier and with a higher power relationship when both the desired picture carrier and the undesired sound carrier are varied simultaneously.

An 87-mc (sum of the picture and sound carrier frequencies--45.75 mc + 41.25 mc) parallel-tuned rejector circuit in the emitter lead has been developed. It provides a considerable improvement in the cross modulation ratio of color television reveivers.

Introduction

As discussed in this bulletin, the interferences in a non-linear high-frequency amplifier device are limited to the production of a lower frequency sideband of a desired picture carrier due to the presence of either (a) a 920-kc beat-note component related to two additional signals (41.25-mc sound carrier and 42.17-mc chrominance sub-carrier) or (b) a 1.5-mc beat-note component related to the desired picture carrier (45.75-mc) and the adjacent sound carrier (47.25-mc). In either case the interference (designated IVR) is a complex function of the extrinsic transconductance (g_{21e}) of the transistor, the second derivative of g_{21e}, the operating bias values, the input signal levels, and the load impedances of the input and output circuits, which differ for the various frequencies involved and affect the interference ratio.

Mathematical derivations are not given in this bulletin.[1] The material to follow describes the measured interference voltage ratio (IVR) data with RCA drift transistors in television i-f amplifiers.

[1] *LB-1008, Cross Modulation in Transistor RF Amplifiers.*

Instrumentation

The measurement setup is shown in Fig. 1 in which a matching pad for three signal generators at 41.25, 42.17, and 45.75 mc was followed by a wide-range impedance-matching transformer.[2,3] A capacitively-coupled transformer with tapped primary and secondary was utilized in the collector circuit. The 45.75-mc and undesired signal components were measured by the use of a calibrated vhf communications receiver.

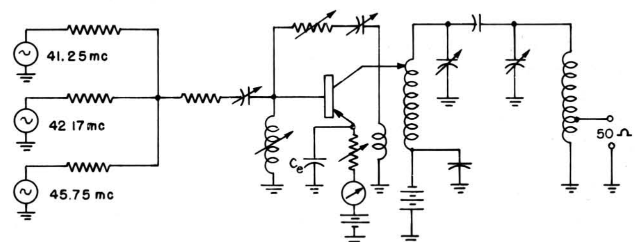


Fig. 1 - Measurement setup.

[2] *LB-976, An Immittance Chart.*

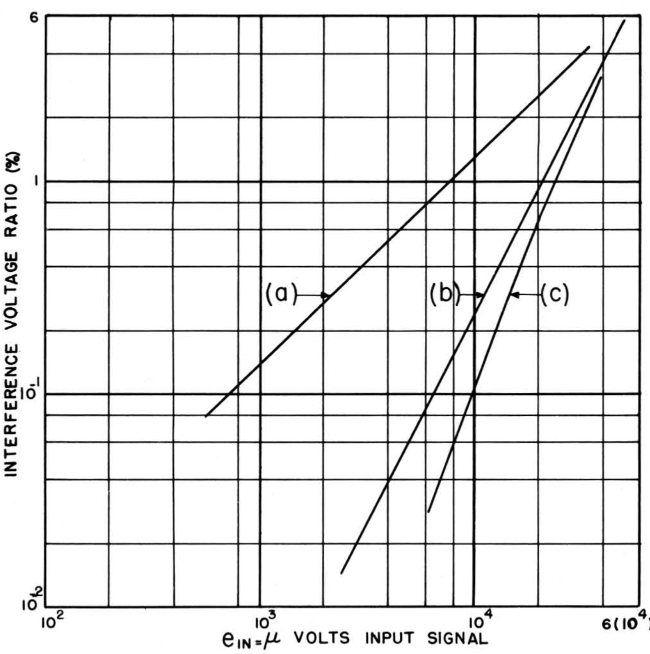
[3] *LB-1046, Wide-Range Impedance Transformer.*

For the two-signal tests (45.75-mc picture carrier and 47.25-mc adjacent channel sound carrier), a modified matching pad was used. The measurements were made with RCA drift transistors.[4,5] The normal bias conditions were $E_c = 22.5$ v and $I_e = 1.0$ ma. Either neutralization or unilateralization was performed at the center frequency of the response curve.

Factors Affecting IVR

Input Signal Levels

Curves (a) and (b) of Fig. 2 present interference voltage ratios vs input-signal levels for the three-signal tests. The undesired carrier component formed by these tests is 45.75 - (42.17 - 41.25) = 44.83 mc. *IVR is defined as the ratio of 44.83-mc output to the desired 45.75-mc output.* Curve (a) shows a linear relationship between the input signal level and IVR when either the sound carrier or the chrominance sub-carrier is varied. Curve (b) exhibits a square-law relationship when all three signals are varied simultaneously. The three-signal IVR does not vary with the picture-carrier level.



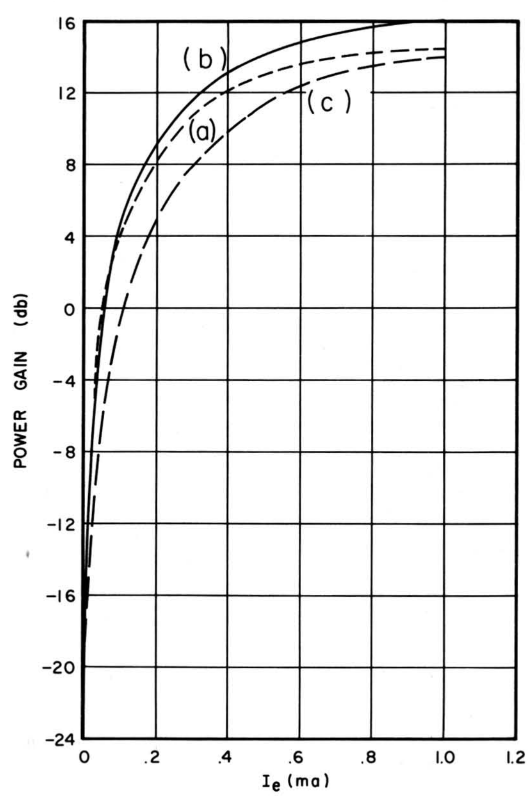
(a) In three-signal tests the sound carrier or chrominance subcarrier varied. The other two input signals held at 50 mv. In two-signal tests adjacent sound carrier varied, (picture carrier held at 50 mv).
(b) Three-signal tests. All three carriers varied simultaneously.
(c) Two-signal tests. Both carriers varied simultaneously.

Fig. 2 - Interference voltage ratio vs input signal level.

Similar heterodyne-interference curves were also secured for the two-signal tests. The undesired carrier component in this case is 2 × 45.75 - 47.25 = 44.25 mc. The ratio of the 44.25-mc output to the 45.75-mc desired output is the heterodyne-interference voltage ratio which is also designated IVR for simplicity. When the picture carrier is held constant at 50 mv, the IVR as a function of the adjacent sound-carrier level is also indicated by curve (a) of Fig. 2. When both carriers are varied simultaneously, the curve (c) reveals approximately 5/2 power law relating the IVR with input levels.

Emitter Current, I_e

An attractive means of securing automatic gain control (a-g-c) of transistor i-f stages is by varying the emitter current. This may be effected either by use of a bias supply in the emitter circuit or by use of a low-



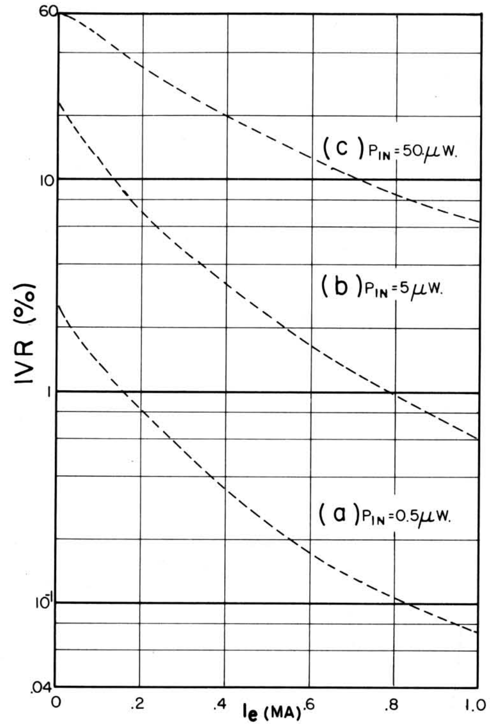
(a) $P_{in} = 0.5 \mu w$, (b) $P_{in} = 5.0 \mu w$, (c) $P_{in} = 50.0 \mu w$.
P_{in} (pix) = P_{in} (chrom.) = P_{in} (sound)
(RCA drift transistor, neutralized)

Fig. 3 - Three-signal tests.

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

[5] *LB-1048, The Design, Construction and High-Frequency Performance of Developmental Drift Transistors.*

voltage bias means in the base-emitter connection. Power gain characteristics as a function of I_e are shown by curves (a), (b), and (c) of Fig. 3 for input powers of 0.5 μw, 5.0 μw, and 50 μw. It is noted that an a-g-c range of approximately 40 db is obtainable by varying I_e from 1.0 ma to 0. The a-g-c range, however, is secured only at the expense of greatly increased IVR. Three operating cases for television i-f amplifiers are next considered.

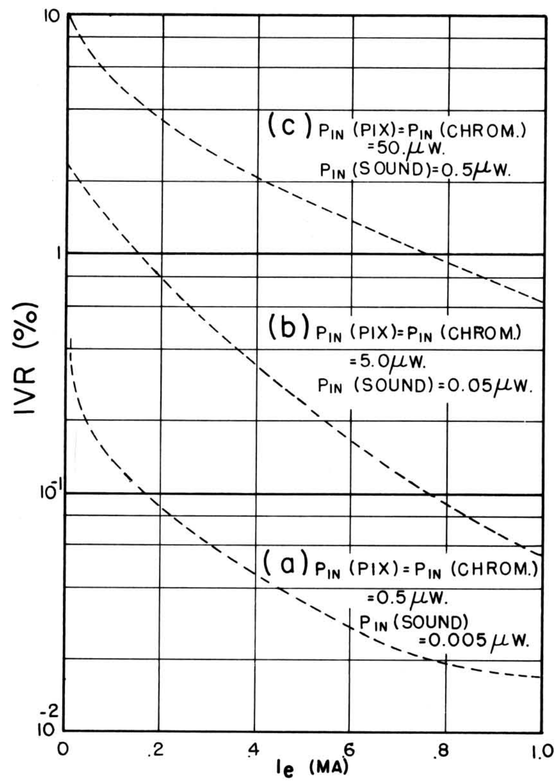


P_{in} (pix) = P_{in} (chrom.) = P_{in} (sound)
(RCA drift transistor, neutralized).

Fig. 4 - Three-signal tests.

Case 1: Three signals, P_{in} (pix) $\doteq$ P_{in} (chrom.) = P_{in} (sound). Curves (a), (b), and (c) of Fig. 4 show the change in IVR vs I_e variation for 0.5, 5.0, and 50-μw input of each carrier respectively. The spacing between curves (a) and (b) is seen to be approximately 20 db, as anticipated. However, for curve (c), with 50-μw input of each carrier, the overload tends to limit the further increase in IVR. The tolerable limit of cross modulation or of heterodyne interference may be considered to be 1 percent. In Fig. 4 the 1 percent value is exceeded for all bias adjustments with strong input signals and for I_e values less than 0.15 ma when the input levels are reduced to 0.5 μw.

Case 2: Three signals, P_{in} (pix) = P_{in} (chrom.) = 100 P_{in} (sound). The curves shown by Fig. 5 are similar to those in Fig. 4 but the sound carrier is maintained 20 db lower than the picture and chrominance levels to simulate the typical operating conditions of color television receivers. For intermediate values of input signal, an approximately 20-db improvement may be noted due to the lower sound-carrier level. The improvement is somewhat modified for high input signals by limiting and, at low input levels, by the noise level of the communications receiver used in the measurements. The 1 percent tolerable IVR is exceeded over most of the a-g-c curve for 50-μw input signal and for I_e values less than 0.1 ma with 5.0-μw input.



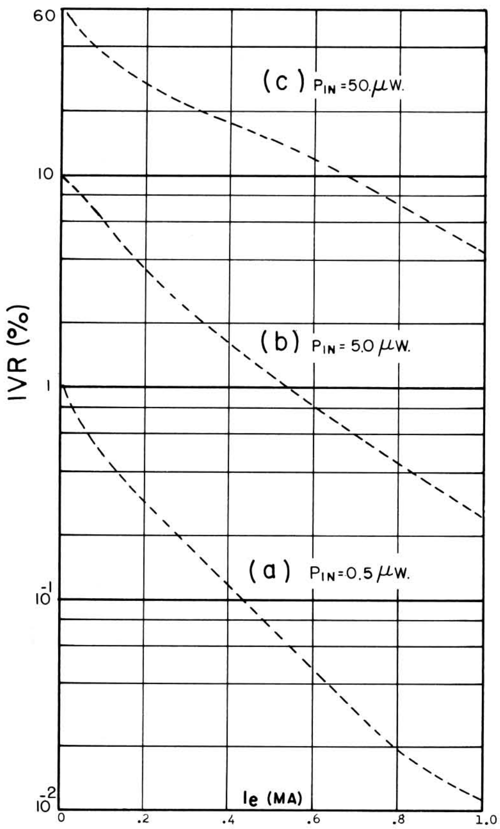
(RCA drift transistor, neutralized)

Fig. 5 - Three-signal tests.

Case 3: Two signals, P_{in} (pix) = P_{in} (adjacent sound). Fig. 6 presents the change in two-signal IVR due to emitter current variation as an a-g-c means. At locations where the adjacent-lower-channel strength is much stronger than the desired-channel signal strength, the input power of the two carriers to the i-f amplifier stages may be comparable. Curves (a), (b), and (c) of Fig. 6 are for 0.5, 5.0, and 50 μw of each of the two carriers respectively. The interference curves for 0.5 and 5.0-μw input powers are considerably lower than the equivalent three-signal curves. Because of limiting, the two-signal and the three-signal 50-μw input IVR curves are substantially equal.

Collector-Emitter Voltage, E_{ce}:

The a-g-c range may also be secured by varying the



P_{in} (pix) = P_{in} (adjacent sound)
(RCA drift transistor, neutralized).

Fig. 6 - Two-signal IVR vs I_e tests.

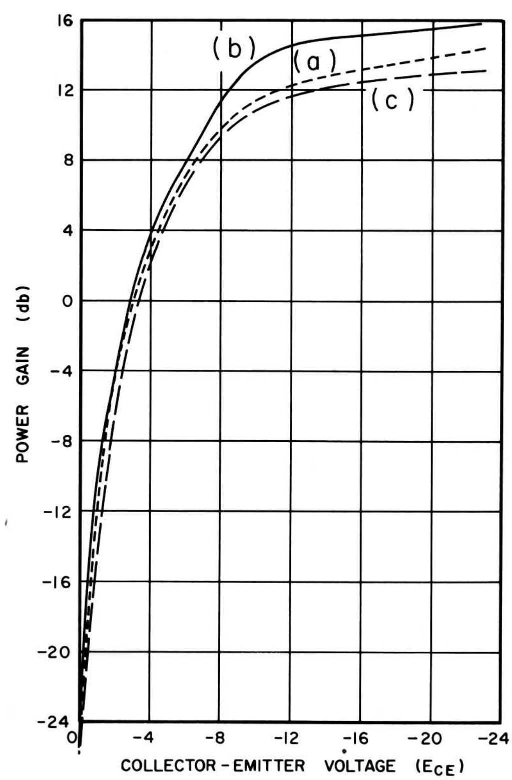
Direct comparison of Fig. 4 with Fig. 6 and of Fig. 8 with Fig. 9 reveals that on the average the IVR is degraded to a greater extent, for the same percentage change in the bias means, for a-g-c by emitter-current control than for a-g-c by E_{ce} variation. A test was made of the possible merits of varying both E_{ce} and I_e simultaneously by the same percentage of the nominal values. The a-g-c range secured was only 35 db. The IVR data were generally intermediate to that secured by the two single a-g-c means.

Transistor By-pass Capacitors

Three-signal cross modulation measurements were made in which the emitter by-pass capacitor C_e was varied from 120 μμf to 0.03 μf. For each C_e value the circuits were retuned and the stage reunilateralized. The minimum interference percentage was not secured for C_e values less than 0.01 μf.

Transistor Types

Table I presents comparative power gain and three-

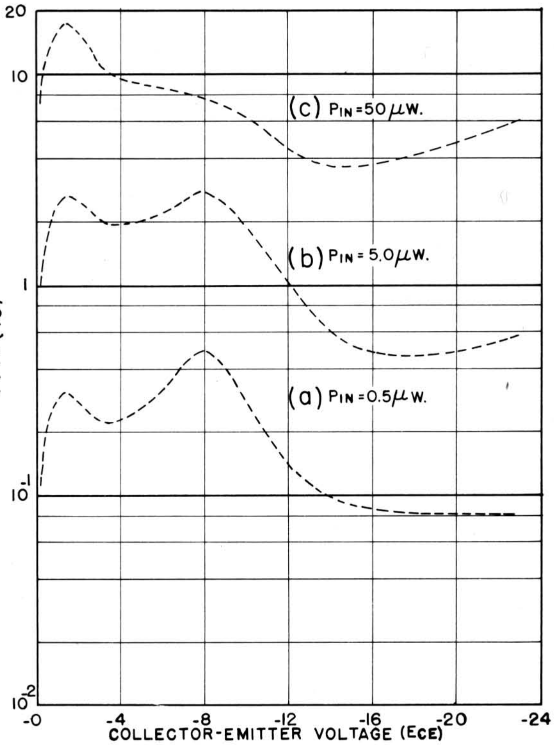


(a) P_{IN} = 0.5 μW., (b) P_{IN} = 5.0 μW., (c) P_{IN} = 50.0 μW.
P_{in} (pix) = P_{in} (chrom.) = P_{in} (sound)
(RCA drift transistor, neutralized).

Fig. 7 - Three-signal tests.

collector-emitter bias voltage. The power-gain characteristics as a function of E_{ce} are shown by curves (a), (b), and (c) of Fig. 7 for input powers of 0.5, 5.0 and 50 μw of each of the three carriers respectively. An a-g-c range of 40 db is secured by varying E_{ce} from -22.7 volts to 0.0 volts (i.e., E_c = 0.2 v, E_e = 0.2 v). Curves (a), (b), and (c) of Fig. 8 illustrate the change in three-signal IVR vs E_{ce} variation for 0.5, 5.0, and 50 μw input of each carrier respectively. An approximate difference of 20 db in IVR is obtained over the greater portion of curves (a) and (b). The separation between curves (b) and (c), however, is modified by limiting with the 50 μw input of each carrier. Additional curves were secured with the sound carrier set 20 db lower than the picture and chrominance input levels with the result that the improvement in IVR was roughly 20 db for each signal level. Therefore, no further reduced sound-carrier-level curves are presented.

Fig. 9 shows the variation in two-signal IVR due to E_{ce} change. Curves (a), (b), and (c) were secured for 0.5, 5.0, and 50 μw input of each carrier, respectively. The relationship is similar to the above three-signal data.



P_{in} (pix) = P_{in} (chrom.) = P_{in} (sound)
(RCA drift transistors, neutralized).

Fig. 8 - Three-signal tests.

signal IVR for three types of transistors--drift, surface barrier, and p-n-p germanium tetrodes--with base-input connection, unilateralized. As in the above by-pass capacitor tests, the output power for the three signals was held at P_o (pix) = P_o (chrom.) = 100 μw and P_o (sound) = 1 μw.

The drift transistors exhibit much smaller percent cross modulation than the surface barrier and tetrode transistors. The difference in performance of the three types may be caused either by (a) substantially different base-emitter diode behavior at very high frequencies, or (b) the effect of the complex input parameters upon the actual vhf extrinsic transconductance vs base bias curve.

Amplifier Configuration

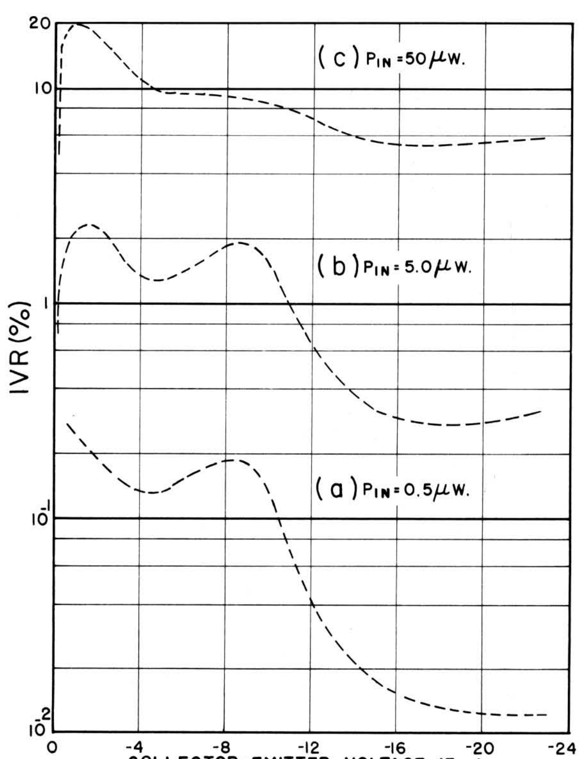
Emitter-input measurements, unilateralized, have been secured for the drift transistors and the p-n-p tetrodes. Table II presents the power gain and IVR values for the two types with an arbitrarily chosen output power.

By comparison with the base-input data of Table I for the same transistors, it is seen that the emitter-input connection results in only a small loss in power gain and IVR when using the drift transistors. However, a 7 to 8 db decrease in power gain was found for the emitter-input operation with the p-n-p tetrodes.

Frequency

To evaluate the cross-modulation characteristics of transistors at lower frequencies, 4.20, 4.29, and 4.50 mc were used as the simulated sound carrier, chrominance sub-carrier, and picture-carrier frequencies respectively. Data on certain drift transistors have been added to secure a direct comparison of performance at 4.2 to 4.5 mc and 41.25 to 45.75 mc. As previously, the P_o (pix) = P_o (chrom.) = 100 P_o (sound) = 100 μw, output-power condition was used. The measurement setup was basically similar to Fig. 1 but with (a) single-tuned input and output circuits, (b) an 8-step π-type input matching attenuator, (c) L-type resistive attenuator in the output circuit. The measurement technique was quite similar to that utilized in the 41.25 to 45.75 mc tests.

On a relative basis, the IVR curves vs signal level were similar to those of Fig. 2. The power gain of a typical RCA 2N140 junction-alloy unit varies directly with collector voltage, but the IVR value is substantially



P_{in} (pix) = P_{in} (adjacent sound).
(RCA drift transistor, neutralized).

Fig. 9 - Two-signal tests.

TABLE I

Comparison of Transistor Types

Type	E_c (-v)	I_e (ma)	I_{b2} (ma)	PG (db)	IVR (%)
Drift	22.5	1	-	15.9	0.11
Surface Barrier	6.0	1	-	4.4	1.07
Tetrode	9.0	1	0.3	18.4	1.58

TABLE II

Emitter Input Tests

Type	E_c (-v)	I_e (ma)	I_{b2} (ma)	PG (db)	IVR (%)
Drift	22.5	1	-	13.9	0.124
Tetrode	9.0	1	0.3	10.5	0.313

uniform above E_c = -3 volts. However, the interference decreases rapidly with increase in I_e value. It may be concluded that no material change in cross-modulation performance may be noted due to a 10 to 1 change in operating frequency.

IVR Rejector Circuits

The production of the lower sideband component (f_{sb}) at 44.83 mc may be considered to be due to

$$(f_{pix} + f_{sound}) - f_{chrom.} = 87 - 42.17 = 44.83 \text{ mc}.$$

Two different 87-mc rejector circuits incorporating change in the L/C ratio have been connected in the emitter circuit and the results are presented by Table III. An 87-mc (sum of the picture and sound carrier frequencies) parallel-tuned rejector in the emitter circuit substantially improves the cross modulation ratio but within the L/C ratio range tested the power gain is seriously lowered. Further experimentation would possibly result in a more satisfactory combination of L and C elements with respect to the stage power gain. In the above tests, the picture and chrominance output powers were arbitrarily held at 100 μw and the sound output powers at 1 μw.

TABLE III

Performance of 87 mc Rejectors

L (μh)	C ($\mu\mu$f)	PG (db)	IVR (%)
0.37	9.0	14.9	0.039
0.14	24.0	15.8	0.028
no rejector		18.5	0.122

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