PERFORMANCE ANALYSIS OF 3- AND 4-COIL FM TUNERS* USING RCA HIGH-FREQUENCY TRANSISTORS

by

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High-quality FM multiplex performance imposes stringent requirements on tuner gain, quieting, and limiting sensitivities. In addition, the spurious response of the tuner becomes relatively more important as the receiver sensitivity is increased. When high-performance receivers are used in metropolitan areas, good receiver operation is made very difficult (if not impossible, in some instances) by the presence of powerful stations which transmit frequencies close to the carrier, image, or half-if frequency of the desired carrier. When harmonics of other signals combine with harmonics of the receiver, sum or difference frequencies close to the intermediate frequency may produce an undesired response.

This paper describes a design analysis program undertaken to improve the spurious-response immunity of high-quality tuners. Commercially available 3-and 4-coil tuners were investigated thoroughly to determine the quiescent operating points, circuit configurations, and component layouts which would provide maximum tuner sensitivity while maintaining good tuner gain and low noise.

3-COIL TUNER PERFORMANCE

Fig.1 shows the circuit diagram used to evaluate the performance of a 3-coil tuner incorporating single-tuned antenna and rf interstage coils. The common-emitter configuration is used in the rf-amplifier and mixer stages, and the common-base configuration in the oscillator stage.

The selectivity of the antenna and rf interstage coils is shown in Fig.2, together with the in-circuit unloaded and loaded coil Q's used to obtain the desired selectivity and the over-all response of the

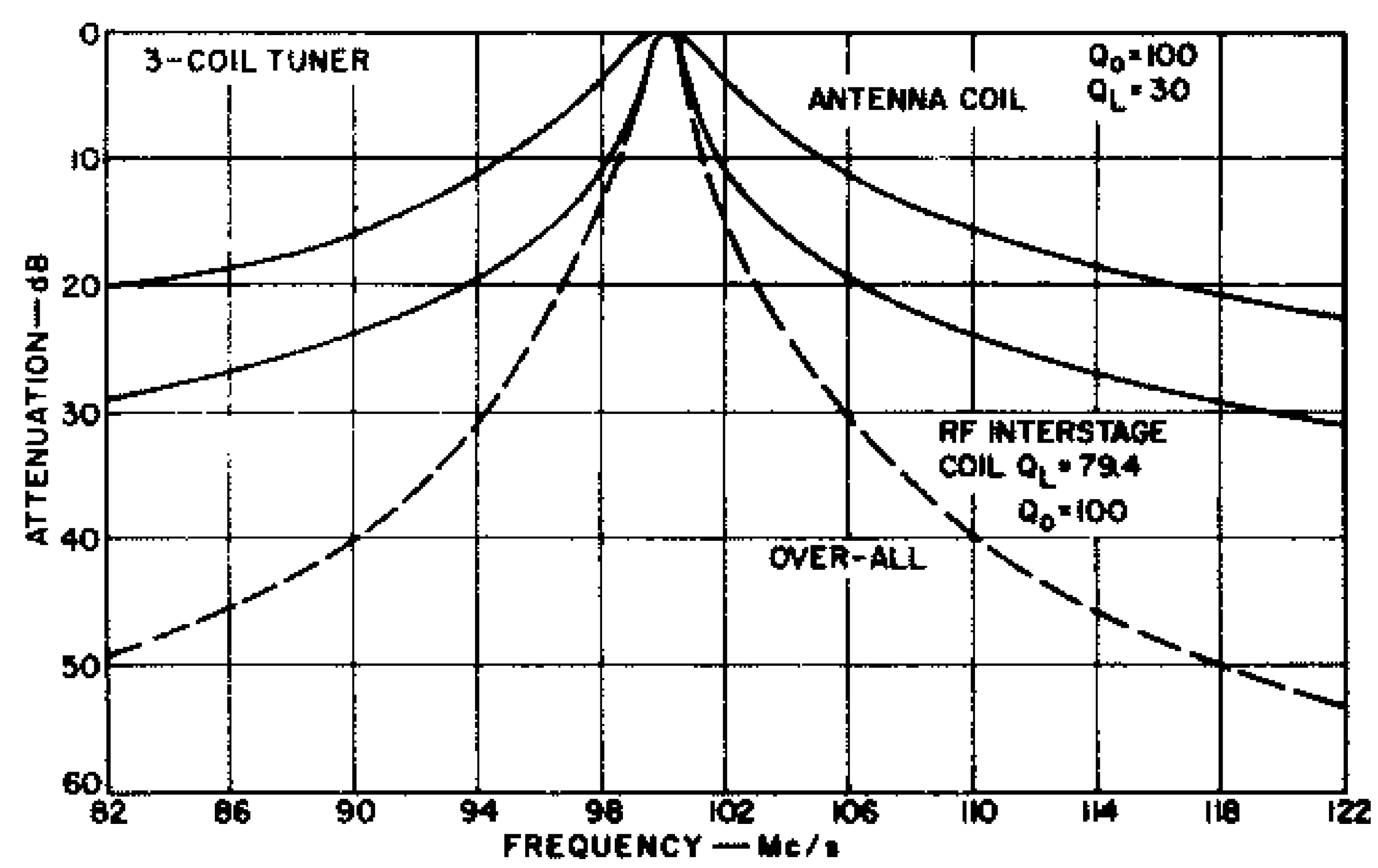

Fig.2 - Selectivity and response curves for 3-coil tuner.

tuner. The tuner was assembled carefully to assure that component layout and/or ground loops did not alter the degree of loading necessary to obtain the desired coil Q. It was necessary to check frequently for tuner gain, noise quieting, bandwidth, and spurious rejection to be certain that a change in lead dress or bypass capacitor did not significantly change the coil Q's from the values employed in the design calculations.

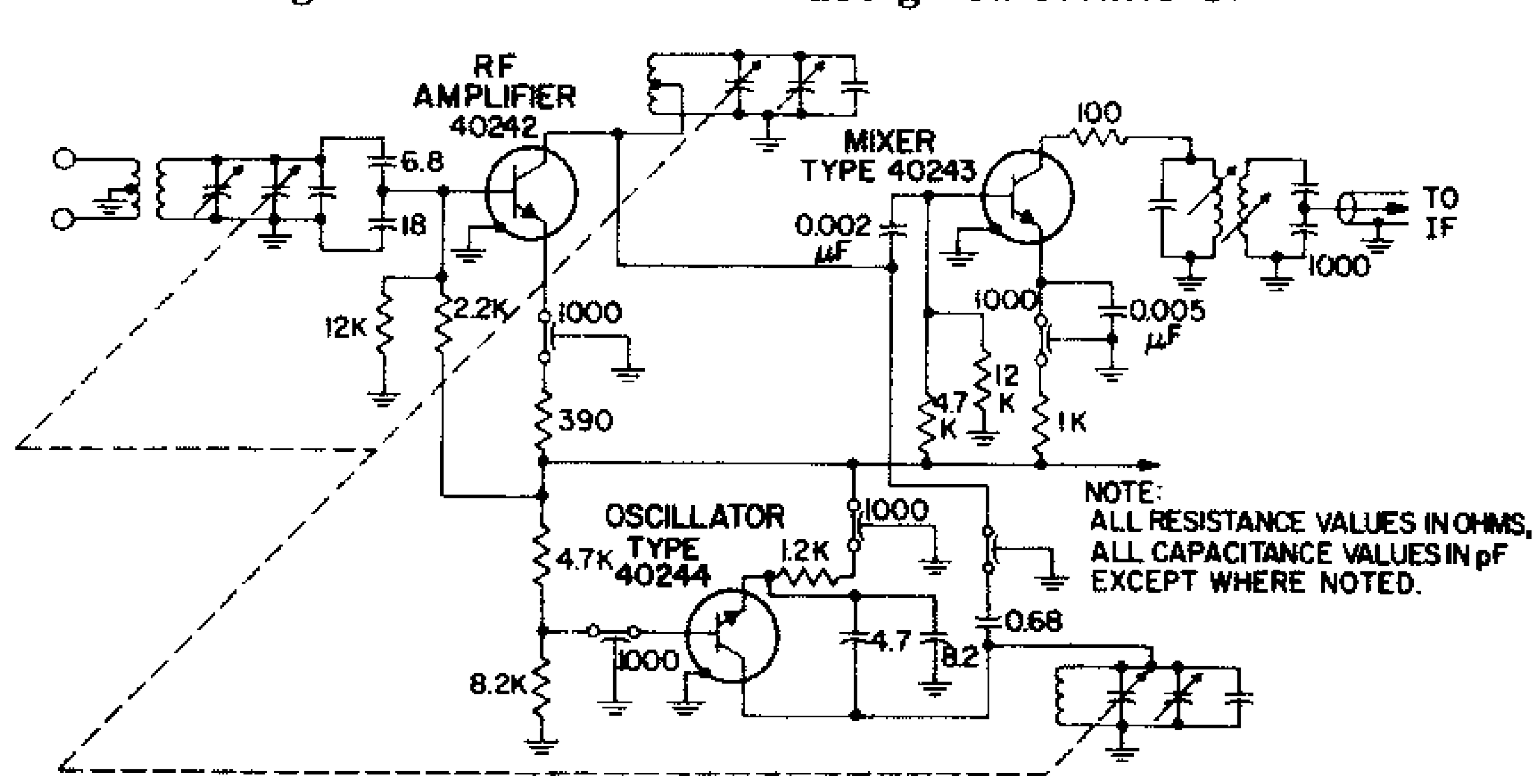

Fig.1 - Circuit diagram of 3-coil FM tuner.

*In the text, the word "tuner" refers to the rf-amplifier, mixer, and oscillator sections of the FM receiver only.

The signal-to-noise ratio and limiting performance of the tuner as a function of input signal level from a 75-ohm source generator are shown in Fig.3. For these measurements, the tuner was connected to a 3-stage neutralized if amplifier that

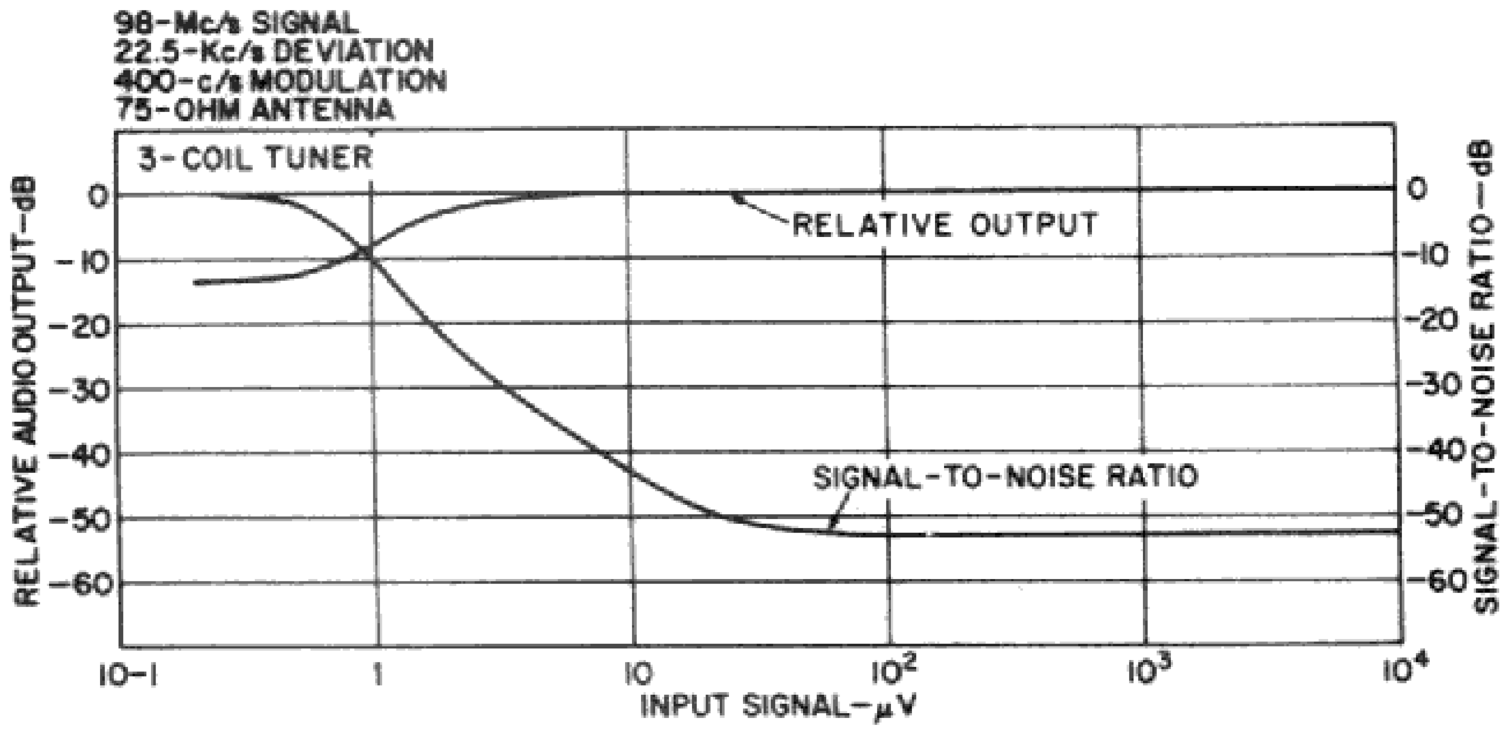

Fig.3 - Signal-to-noise ratio and limiting performance of 3-coil tuner.

had a power gain of 88 dB, and the ratio-detector transformer was terminated into a load impedance of 10,000 ohms.

Fig.4 shows small-signal response characteristics of the tuner at the 20-dB quieting-sensitivity input level of 1.6 microvolts. Although the use of a pi-section tunable trap (such as that used with permeability tuners, see Appendix A) might provide

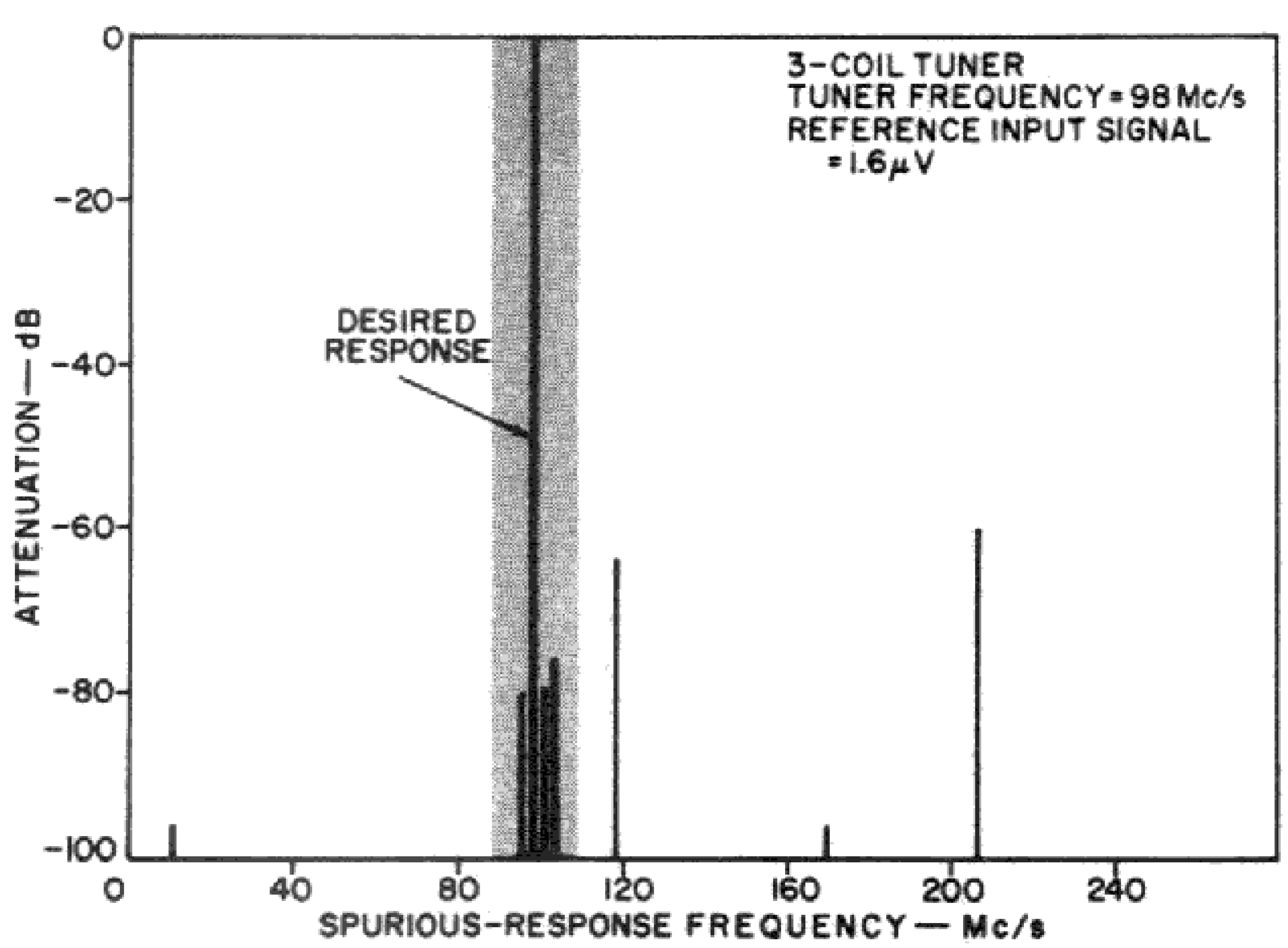

Fig.4 - Small-signal response characteristics of 3-coil tuner.

a better image-rejection ratio, only parallel-tuned antenna and rf coils were used for comparison of the 3- and 4-coil tuner performance. On strong signal inputs, several responses were observed across the FM band and outside the FM band, as shown in Fig.5. For these measurements, the signal input at the antenna was 0.2 volt, the receiver was tuned to 98 megacycles per second, and the signal-generator frequency was varied from 10.7 to 220 megacycles per second. The responses shown represent actual voltages measured across the dummy 10,000-ohm audio load resistor. The fact that the frequency deviation of some of the spurious responses was as much as 10 times the carrier deviation indicated the presence of harmonics of either the incoming rf or oscillator signals (see Appendix B) that were as high as the 10th order of magnitude.

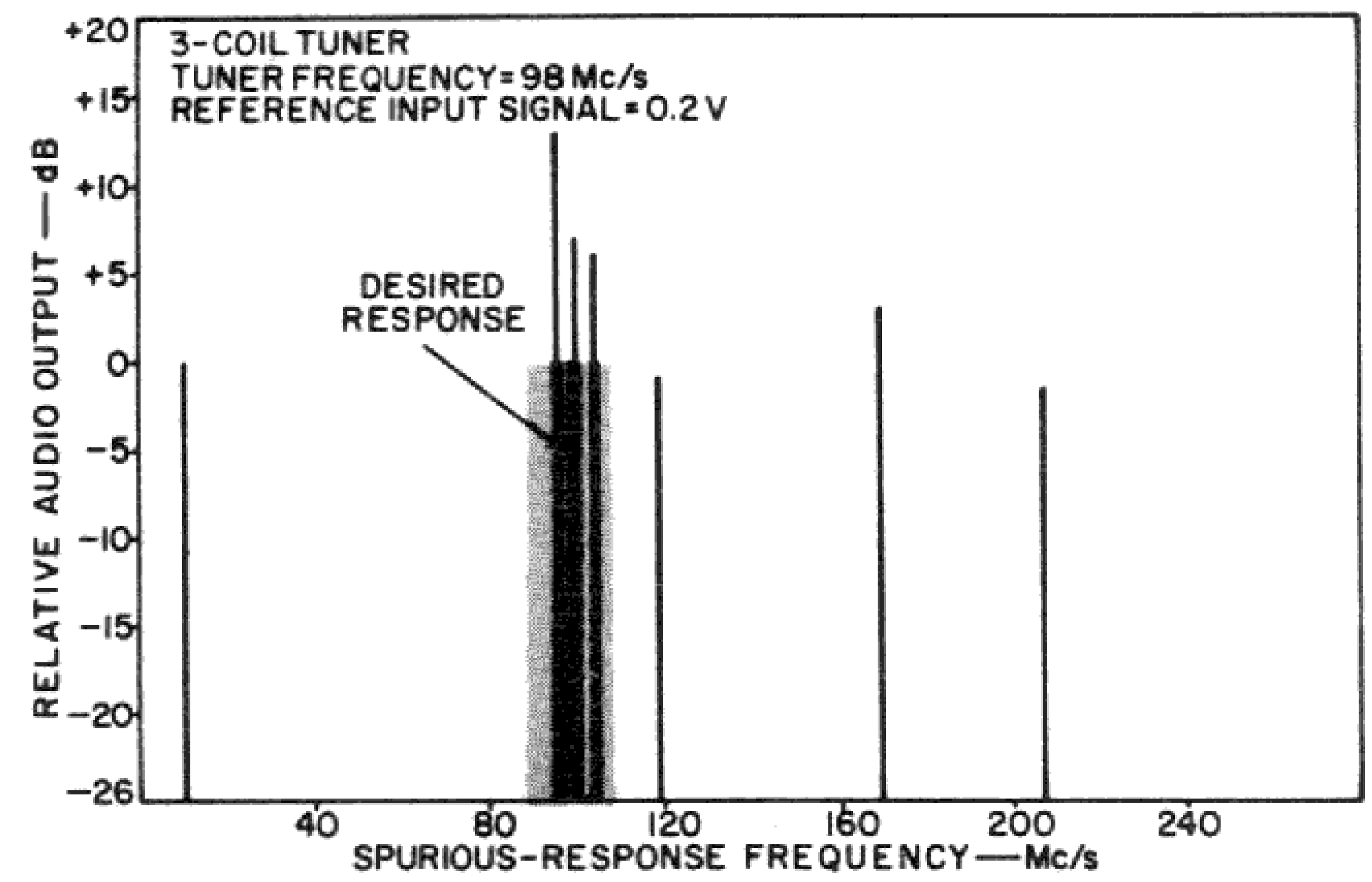

Fig.5 - Large-signal response characteristics of 3-coil tuner.

The most significant reduction in spurious counts across the band was obtained by modifications in three areas: (1) the oscillator circuit, (2) injection levels, (3) lead dress and component layout.

Oscillator Circuit - Investigations showed that the spurious-response characteristics of the tuner were improved when an external oscillator having a guaranteed harmonic suppression of at least 40 dB below its fundamental waveform was used. An oscillator circuit was developed which minimized the harmonic content of the waveform and eliminated any tendency toward parasitic oscillations in the circuit.

Injection Levels - Although use of various methods of oscillator injection into the mixer stage did not produce significant differences in receiver measurements, a noticeable decrease in the number and amplitude of the spurious responses was observed when the oscillator injection level was limited to a maximum of 40 millivolts across the band. Driving the mixer base from a low-impedance tap on the rf interstage coil also helped to reduce spurious response as well as to eliminate the need for a 10.7-megacycle trap.

Lead Dress and Component Layout - Further reduction in the number of spurious counts was achieved by careful placement of components on the tuner chassis, coil shielding, and circuit grounds. For example, some critical ground locations had little effect on image and half-if responses, but significantly reduced the amplitude of some higher-order responses.

4-COIL TUNER PERFORMANCE

The circuit diagram of the 4-coil tuner is shown in Fig.6. As in the case of the 3-coil tuner, the common-emitter configuration was employed in the rf-amplifier and mixer stages, and the common-base configuration in the oscillator stage. The antenna circuit was double-tuned instead of the rf interstage coils to obtain good selectivity ahead of the rf-amplifier stage and thus minimize its contribution to harmonic generation. The resulting coupling loss, plus mismatch loss in the antenna, degrades the signal-to-noise performance of the tuner by approximately 4 dB.

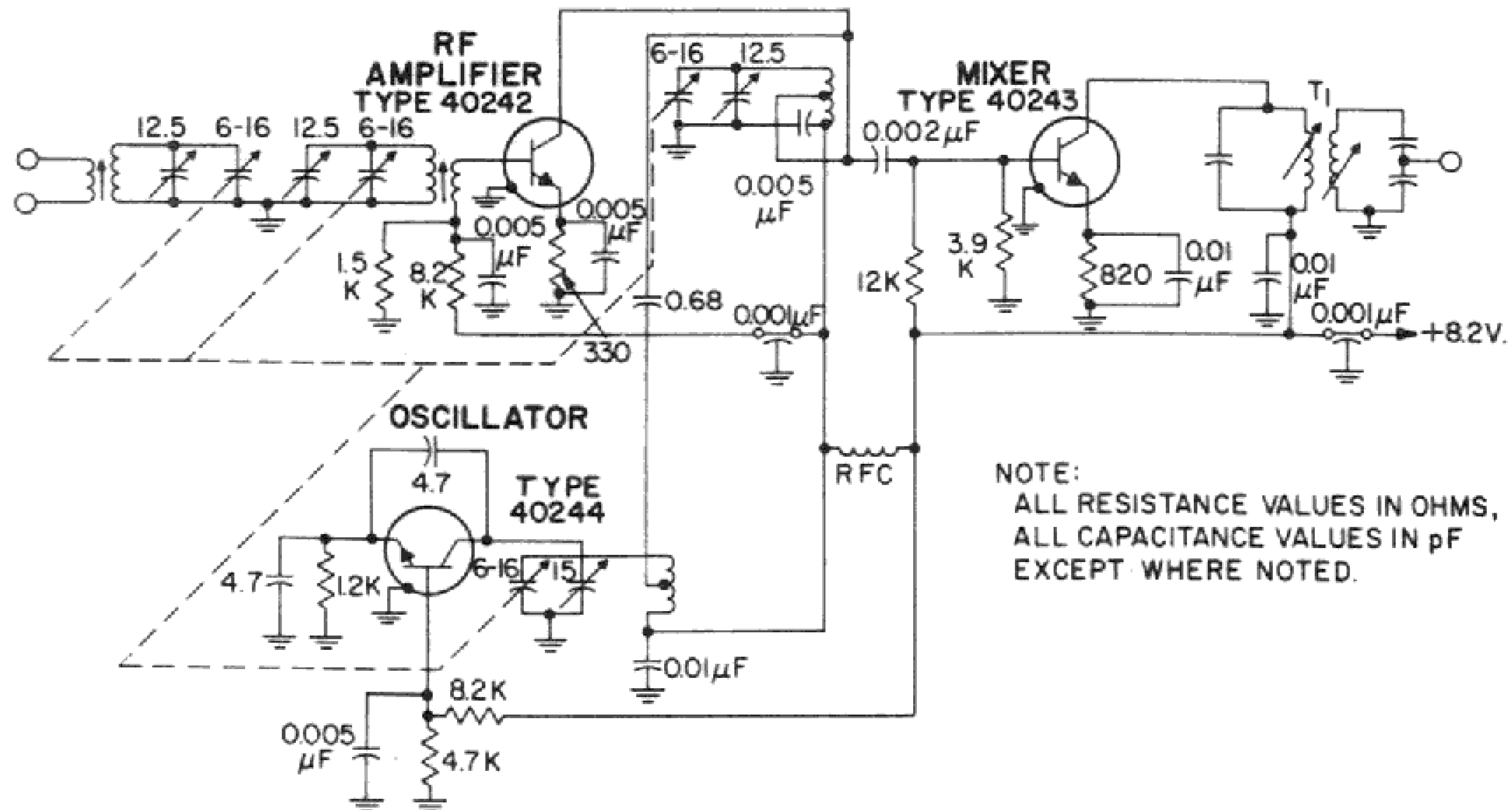

Fig.6 - Circuit diagram of 4-coil FM tuner.

The selectivity curves for the double-tuned antenna and the single-tuned rf interstage coils and the over-all response curve for the tuner are shown in Fig.7. The over-all selectivity curve shows considerable attenuation of half-if and image frequencies as compared with the curve for the single-tuned antenna circuit in Fig.2.

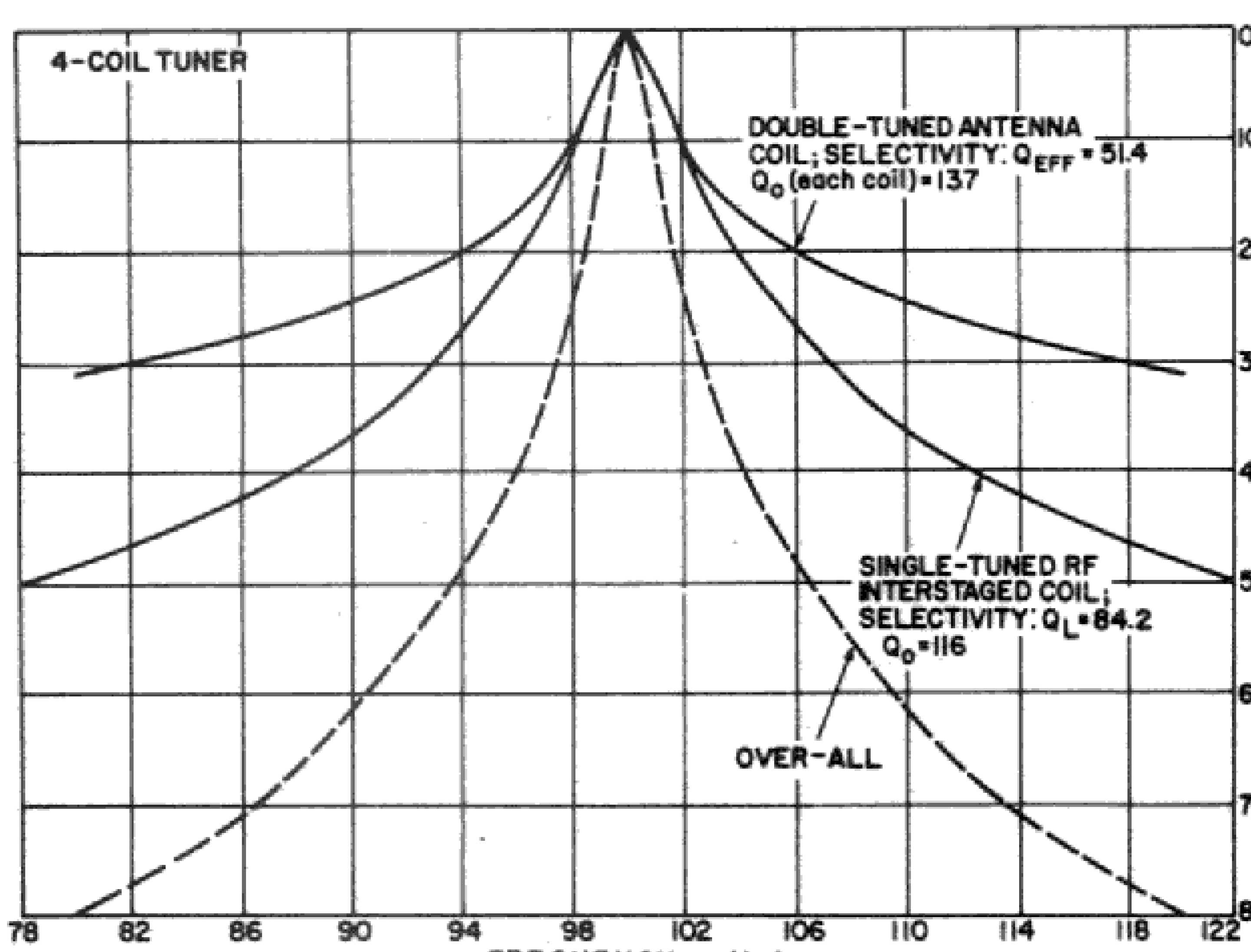

Fig.7 - Selectivity and response curves for 4-coil tuner.

Curves showing signal-to-noise ratio and relative receiver output as a function of input signal levels are shown in Fig.8. Because of the additional coupling loss in the double-tuned antenna, the noise quieting and limiting sensitivities are reduced by approximately 4 dB.

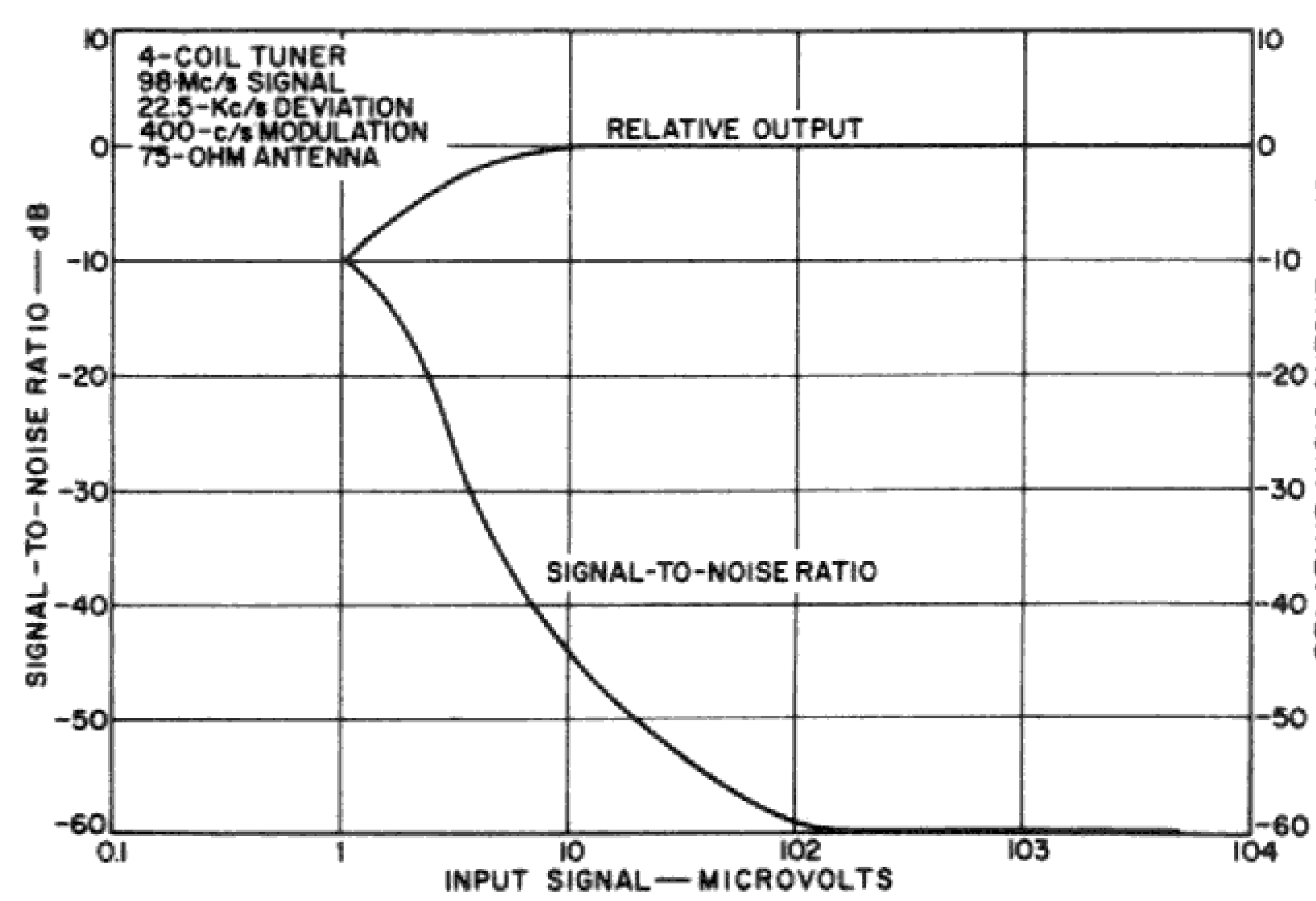

Fig.8 - Signal-to-noise ratio and limiting performance of 4-coil tuner.

Fig.9 shows the small-signal response characteristics of the tuner at a 2.5-microvolt input signal from a 75-ohm source generator. Comparison of

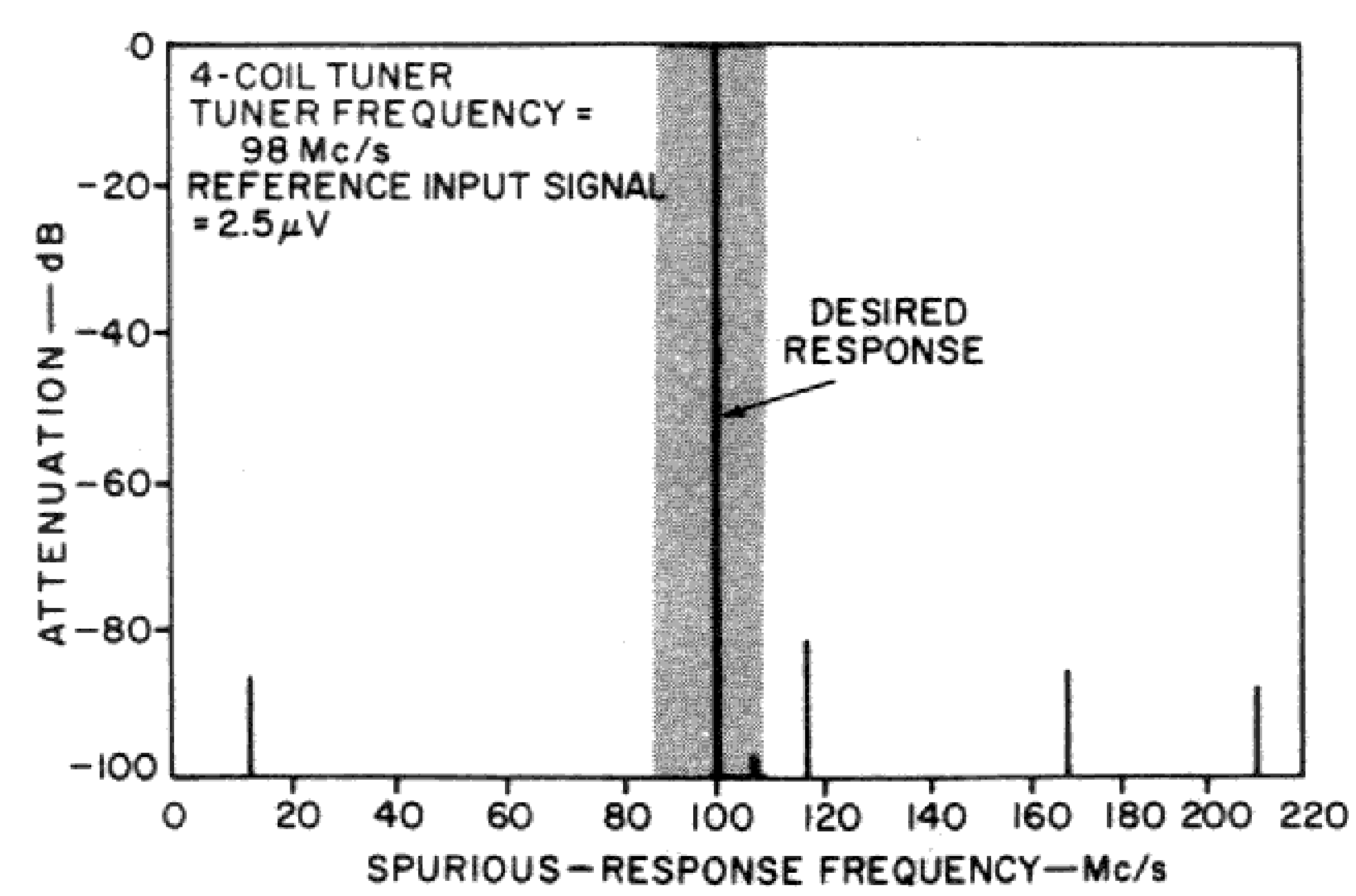

Fig.9 - Small-signal response characteristics of 4-coil tuner.

this figure with that for the 3-coil tuner (Fig.4) readily shows the effectiveness of the double-tuned antenna. The half-if response is noticeably absent in Fig.9. In fact, the only measurable response within the FM band occurred at 106.9 megacycles per second, which is 8.9 megacycles per second on the high side of the carrier, and was 98 dB below the reference signal.

The large-signal response of the 4-coil tuner receiver is shown in Fig.10. It can be seen that even on large signals there is no half-if response

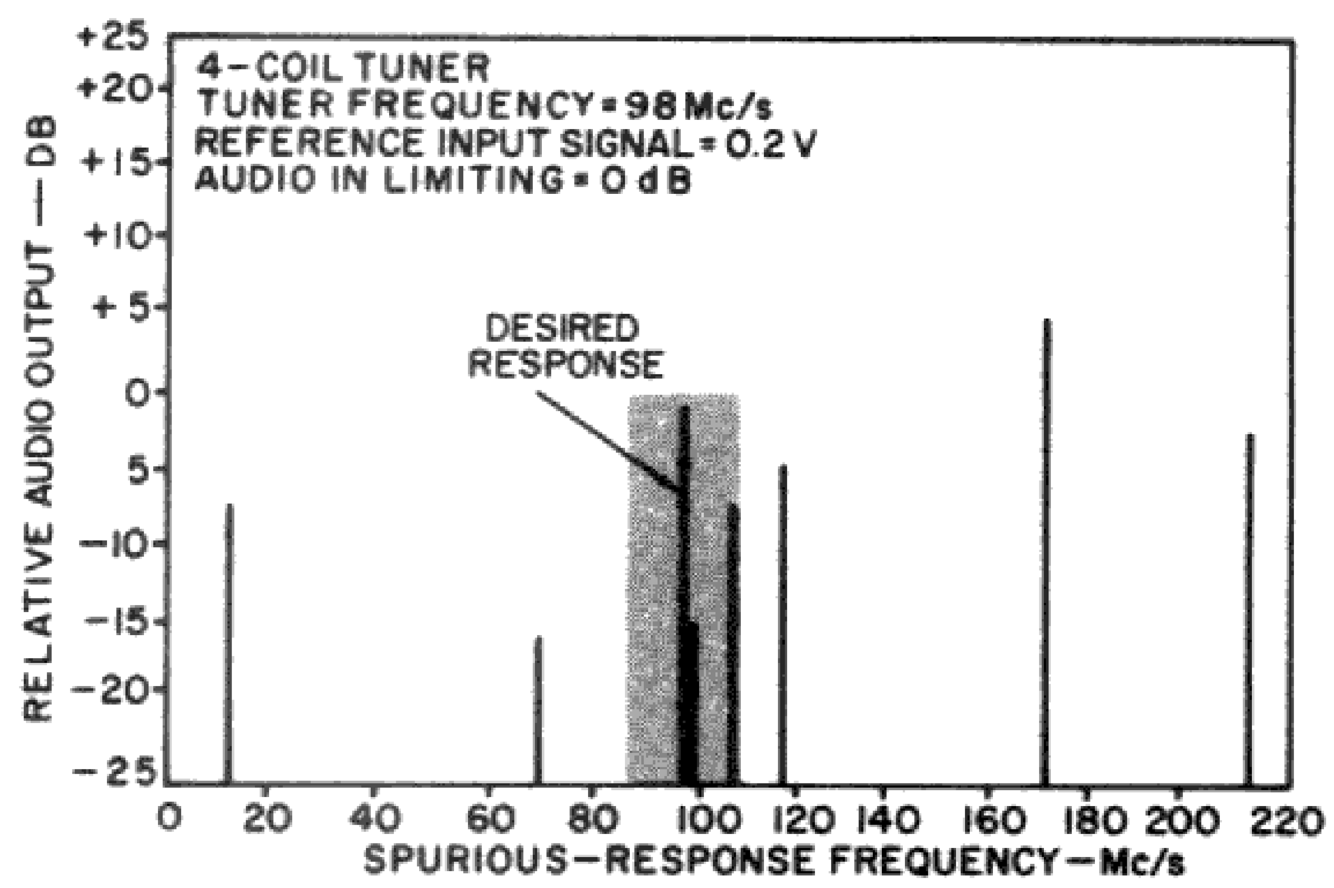

Fig.10 - Large-signal response characteristics of 4-coil tuner.

to the tuner. Only two responses occurred in the FM band, with audio output levels 14.5 dB below the reference at 98.7 megacycles per second and 6 dB below the reference at 106.9 megacycles per second.

SUMMARY

Table I compares the receiver measurements for the 3- and 4-coil tuners. Although the coupling loss introduced by the double-tuned antenna in the 4-coil tuner reduces the quieting and limiting sensitivities by approximately 4 dB, this compromise has considerable merit when the over-all receiver performance is evaluated. Because the 4-section capacitance gang used for the 4-coil tuner was no larger than the conventional 3-section capacitance gang, coupling between sections was more critical on the 4-section gang. It was also more difficult to obtain consistently high Q's in the smaller-size gang. As a result, the if rejection of the 3-coil tuner was slightly better than that of the 4-coil tuner. Undoubtedly, the slightly different layout of the two tuners also contributed to the difference in if rejection.

The most dramatic performance difference between commercially available 3-coil tuners and the two modified receivers was demonstrated by replay of tape recordings of FM interference made in large metropolitan areas. The tuners were installed in auto radios that had identical if and audio amplifiers and a 30-inch hood-mounted antenna. In some

TABLE I

COMPARISON OF TUNER PERFORMANCE CHARACTERISTICS MEASURED AT 98 Mc/s WITH AN UNBALANCED INPUT OF 75 OHMS

	3-coil tuner	4-coil tuner	
Sensitivity:			
For 20-dB quieting	1.6	2.5	μV
For 30-dB quieting	3.2	3.5	μV
For -3-dB limiting	1.6	3.2	μV
Rejection:			
IF (10.7 Mc/s)	97	93	dB
1/2-IF (103.35 Mc/s)	76	103	dB
Image (119.4 Mc/s)	64	82	dB
Double 1/2-IF (206.7 Mc/s)	60	88	dB
IF amplifier gain	88	88	dB
Over-all receiver bandwidth	290	270	kc/s
Field test results in metropolitan areas (installed in auto with 30" antenna)	Fair to Good	Very Good	

instances, it was possible to hear three different stations simultaneously when the standard, commercial 3-coil tuner was used. When the modified 3-coil tuner shown in Fig.1 was used, immunity from spurious responses was generally good, although a strong carrier transmitting on a frequency 6.4 megacycles per second on the high side of the tuned frequency caused appreciable interference. When the 4-coil tuner was used, only a "tick" was heard every now and then, even when the car was driven within 200 feet of an interfering-signal antenna radiating 80 kilowatts (ERP).

Both 3- and 4-coil tuners designed and constructed for this investigation utilized the RCA high-frequency FM line of n-p-n silicon planar transistors. These devices are characterized by small size, low feedback capacitance, low noise, and high useful power gain. The transistors are supplied in a four-lead hermetically sealed package; the fourth lead is connected to the case to reduce interlead capacitance and to permit grounding of the case for most effective shielding.

CONCLUSIONS

The use of a double-tuned antenna and the other circuits developed in this investigation make it possible to design tuners that have good gain and the quieting and limiting sensitivities necessary for high-quality FM-multiplex reception. Laboratory tests, supplemented by extensive field testing, have shown that the 4-coil tuner provides acceptable performance in areas where even the best 3-coil tuners provide only marginal performance.

APPENDIX A

The use of a pi-section tunable-trap rf interstage coil is well suited to permeability tuners in which the coils may be electrically isolated from ground. In the case of capacitive tuning, the use of a pi-section tunable trap requires that one section of the tuning gang be electrically isolated from the other sections. For practical reasons, only parallel capacitive tuning was evaluated in the investigation described. However, the calculations below illustrate the difference in attenuation between a parallel-tuned circuit and a pi-section circuit.

Fig.11 shows the equivalent circuit for a parallel-tuned circuit. As an illustrative example,

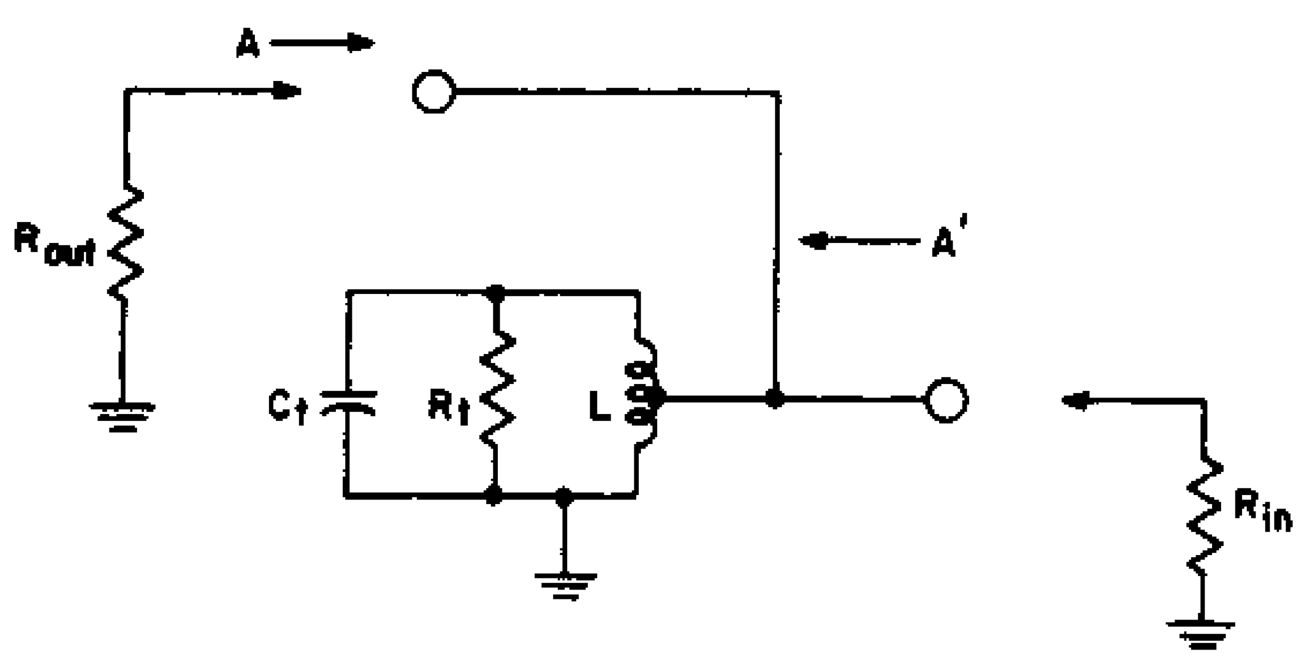

Fig.11 - Equivalent circuit for parallel-tuned circuit.

the following parameter values are assumed for this circuit:

operating frequency, $f_o = 98$ megacycles per second

tuning capacitance, $C_t = 11.8$ picofarads

tuned resistance, $R_t = 9000$ ohms

input resistance, $R_{in} = 450$ ohms

output resistance, $R_{out} = 30{,}000$ ohms

inductance, $L = 0.224$ microhenry

unloaded Q, $Q_o = 65.4$

The value of A, the terminal impedance of the rf collector, is given by

$$A = \frac{(9000/n^2) \times 450}{(9000/n^2) + 450} = 123.5 \text{ ohms}$$

This equation can also provide the following values:

terminal impedance of mixer base, $A' = 170$ ohms

loaded Q, $Q_L = 47.4$

turns ratio, $n = 7.25$

The attenuation ρ at different frequencies can then be calculated as follows:

$$\rho = (1 + \bar{X}^2)^{1/2}$$

where $\bar{X}$ is given by

$$\bar{X} = (Q_L{}^2 + f)/f_o$$

For the half-if frequency of 103.35 megacycles per second, ρ is equal to 5.26, or 14.44 dB; at the image frequency of 119.4 megacycles per second, ρ is equal to 10.35, or 20.3 dB.

The equivalent circuit for a pi-section network with a tunable trap is shown in Fig.12(a). For the same parameters used in the case of the parallel-tuned circuit ($L = 0.224$ μH, $A = 123.5$ ohms, $A' = 170$ ohms) at an operating frequency f_o of 98 megacycles per second and with the trap tuned to the image frequency of 119.4 megacycles per second, the pi-section circuit may be simplified as shown in Fig.12(b). The coil inductance and tuned resistance may then be transformed to the series combination by use of the following equations:

$$R_s = r_s/(1-\alpha^2)^2$$

$$L_s = l_s/(1-\alpha^2)$$

where R_s and L_s are the coil resistance and inductance, respectively, at the operating frequency f_o, r_s and l_s are the resistance and inductance values at the tuned frequency f_x, and α is the ratio of operating frequency to tuned frequency f_x/f_o. The transformed circuit is shown in Fig.12(c). The circuit attenuation at the half-if frequency of 103.35 megacycles per second is 8.2 dB, and the attenuation at the image frequency of 119.4 megacycles per second is 36.48 dB.

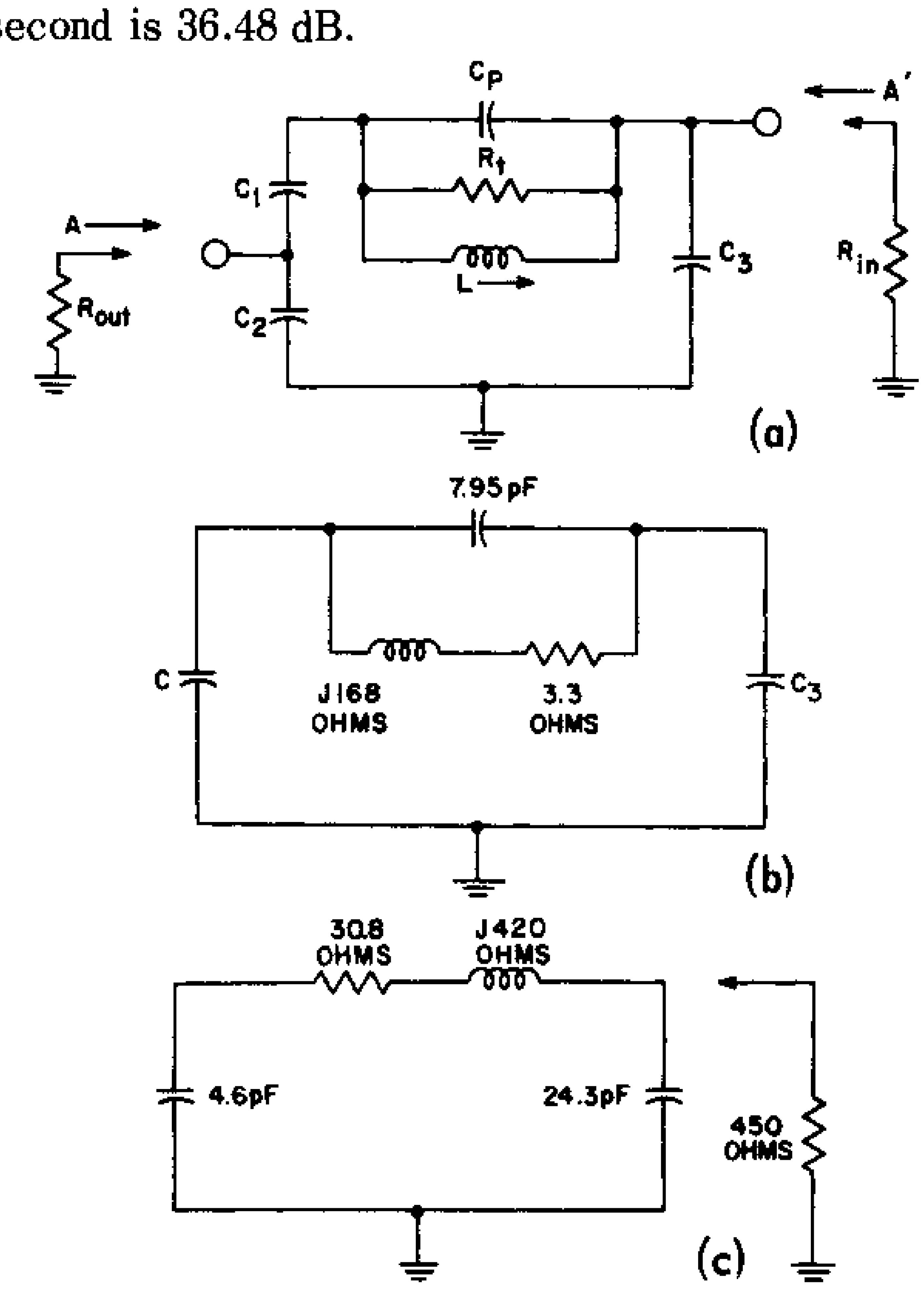

Fig.12 - Equivalent circuits for pi-section network with tunable trap.

APPENDIX B

The characteristic E_iI_c curves of a transistor may be represented by the following power series:

$$I_c = A_o + A_1E_i + A_2E_i{}^2 + A_3E_i{}^3 + A_4E_i{}^4 \ldots .$$

where I_c is the collector current for the input voltage E_i. In the case of a transistor mixer stage operated in the common-base or common-emitter configuration, the input voltage E_i may be represented by

$$E_i = E_s \cos \omega_s t + E_h \cos \omega_h t - E_b$$

where $E_s \cos \omega_s t$ is the rf input voltage, $E_h \cos \omega_h t$ is the local-oscillator input voltage, and E_b is the bias voltage.

These two equations can be combined to provide an expression for the conversion transconductance of the mixer in which the difference-frequency output-voltage terms E_{if} may be represented by

$$E_{if} = A\ E_s\ E_h{}^n \cos (n\ \omega_s - \omega_{hn})$$

$$E_{if} = A\ E_s{}^n\ E_h \cos (n\ \omega_h - \omega_{sn})$$

where $\omega_s = 2\pi f_s$ (f_s = angular frequency of the rf signal)

$\omega_h = 2\pi f_h$ (f_h = angular frequency of the oscillator signal)

$\omega_{sn} = 2\pi f_{sn}$ (f_{sn} = harmonics of the signal frequency)

$\omega_{hn} = 2\pi f_{hn}$ (f_{hn} = harmonics of the oscillator frequency)

n = number of the harmonic frequency (1, 2, 3 . . .)

These difference-frequency equations show that harmonics of either the rf or the oscillator frequency may produce an undesired signal equal to the intermediate frequency of the receiver. Furthermore, because the interfering signal involves signal-frequency harmonics, the frequency deviation is increased. As a result, it is possible that a spurious response may cause an audio output greater than that produced by the desired carrier.

REFERENCES

(1) M. J. O. Strutt, "On Conversion Detectors", **Proc. I.R.E.**, vol. 22, P. 981, August 1934.

(2) K. R. Starley, **Radio Receiver Design**, Part 1, Chapman and Hall Ltd, London.

(3) RCA Application Note, AN-185, "Modulator and Converter Circuits Using the RCA - 7360 Beam-Deflection Tube", 1960.

The attached RCA paper provides a simple “worked example” of the benefits of extra front-end selectivity for FM receivers.

That showed that in the case of bipolar transistors, it was better to place the bandpass at the input and sacrifice some noise performance in favour of better spurious response rejection. When dual-gate mosfets arrived, it was more common to place the bandpass at the interstage, with a single-stage at the input. Presumably the better inherent linearity of the mosfets allowed this. Although there were some mosfet examples with a bandpass input, such as the D&W four-gang front ends (https://vintage-radio.net/forum/showthread.php?p=1153245).

Cheers,