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RCA MANUFACTURING COMPANY, INC.
A RADIO CORPORATION OF AMERICA SUBSIDIARY
Harrison, New Jersey

RCA RADIOTRON
DIVISION

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APPLICATION NOTE ON AN INVERSE-FEEDBACK CIRCUIT FOR RESISTANCE-COUPLED AMPLIFIERS

An inverse-feedback circuit, sometimes called a degenerative circuit, is one in which a portion of the output voltage of a tube is applied to the input of the same or a preceding tube (A) in opposite phase to the signal applied to tube (A). Two important advantages of inverse feedback are: (1) reduced distortion from each stage included in the feedback circuit and (2) reduction in the variations in gain due to changes in line voltage, possible differences between tubes of the same type, or variations in the values of circuit constants included in the feedback circuit.

Inverse-feedback circuits are of the constant-voltage or constant-current type. Constant-current inverse feedback is usually obtained by removing the by-pass condenser across a cathode resistor. The effects of removing a cathode-resistor by-pass condenser are to increase the plate resistance of the tube, reduce the gain of the amplifier stage, and decrease distortion. When the plate resistance of an output tube is increased, the hang-over effects at the resonant frequency of the speaker are accentuated. Constant-voltage inverse-feedback circuits, however, reduce the rise in output voltage with frequency, decrease hang-over effects at the resonant frequency of the speaker, and reduce distortion. Thus, with sufficient inverse feedback of the constant-voltage type in a power-output stage, it is not necessary to employ a resistance-capacitance network to reduce response at high audio frequencies.

There are two general types of constant-voltage inverse-feedback circuits, i.e., series and parallel. In the series type, a portion of the output voltage is applied in series with the input signal; in the parallel type, a portion of the output voltage is applied in parallel with the input signal to the tube. The parallel type of inverse-feedback circuit is often more simple and more economical than the series type. However, there are several factors which limit the extent to which it can be employed. It is the purpose of this Note to discuss the parallel type of inverse-feedback circuit and to show the improvements obtained through its use in radio receivers of typical design.

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Discussion of Circuit

Fig.1A is the circuit of an amplifier employing parallel type of inverse feedback. The circuit is conventional, except that a resistor (R_3) is connected between the plates of T_1 and T_2. The output signal voltage of T_1 and a portion of the output signal voltage of T_2 appear across R_2. Because distortion generated in the plate circuit of T_2 is applied to its grid through the feedback circuit, the total distortion appearing across R_L is comparatively low. Designate the internal resistance of T_1 as r_{p1}, the transconductance of T_1 as g_{m1}, and the parallel combination of r_{p1}, R_1, and R_2 as R_{12}; then the fraction of the output signal voltage (e_o) that is applied to the grid through the feedback circuit is

$$n = \frac{R_{12}}{R_3 + R_{12}}$$

An analysis of the circuit shows that n cannot be increased to unity by reducing R_3 to zero. When $R_3 = 1/g_{m2}$, where g_{m2} is the transconductance of T_2, the current through R_L due to g_{m2} equals that due to direct conductance through R_3 from grid to plate; the net current through R_L is then zero and the gain of the amplifier is zero. Practically, therefore, R_3 must be made sufficiently high to prevent appreciable direct conductance from grid to plate.

If the effects of direct conductance through R_3 are neglected, the gain of T_2 is independent of the amount of feedback present in the amplifier; the gain of T_2, defined as the ratio of e_o/e_2, is the same with and without feedback. This condition does not obtain with series feedback circuits, in which the gain of the output stage depends on the magnitude of feedback. However, the overall gain (e_o/e_1) of the amplifier of Fig. 1A does depend on the value of feedback. Actually, then, the gain of T_1 reduces to a new value when feedback is introduced. Thus, with parallel feedback, it is necessary to consider the performance of both T_1 and T_2.

The manner in which the gain of T_1 depends on feedback can be predicted from an analysis of the equivalent circuit of Fig.1B. Such an analysis shows that the a-c load of T_1 is not merely the parallel combination of R_1 and R_2, but to a good first approximation is the parallel combination of R_1, R_2, and a fictitious resistor $R_3/(1 + G_2)$, where G_2 is the gain of T_2. Therefore, reduction in gain with parallel feedback is due to the low value of the a-c load of T_1.

With parallel feedback, the value of the d-c load of T_1 is the parallel combination of R_1 and R_3; the value of the a-c load is the parallel combination of R_1, R_2 and $R_3/(1 + G_2)$. Because distortion generated by T_1 due to a low value of $R_3/(1 + G_2)$ may be appreciable, a limitation on the amount of feedback that can be used is the distortion generated by T_1.

T_1 may be either a triode or a pentode. When T_1 is a low-r_p triode, the value of n is usually low because the comparatively low plate resistance of T_1 shunts R_1 and R_2. When an attempt is made to raise the value of n by decreasing the value of R_3, distortion generated by T_1 due to a low value of $R_3/(1 + G_2)$ may be appreciable. In a triode, a low value of $R_3/(1 + G_2)$ may cause the plate current to reduce to zero; the dynamic characteristic is then discontinuous.

When T_1 is a pentode, the value of n can be comparatively high with high values of R_3, because the plate resistance of a pentode is usually high compared to R_1. Moreover, a low value of $R_3/(1 + G_2)$ does not reduce the plate current to zero in a pentode, because plate-current curves of pentodes do not intersect the plate-voltage axis at high values of plate voltage; distortion may be generated by T_1 when it is a pentode due to a continuous non-linear dynamic characteristic. However, distortion due to a continuous non-linear characteristic is usually not as severe as that due to a discontinuous characteristic. When T_1 is a pentode, distortion due to a low value of $R_3/(1 + G_2)$ may be decreased by increasing the screen voltage on T_1.

Tests in Typical Receivers

Fig.2 shows the decrease in distortion obtained in a resistance-coupled amplifier using a 6B8 or 6J7 feeding a 6L6; no electrode potentials were changed after the feedback resistor was connected. These curves indicate that up to the grid-current point an appreciable reduction in distortion is obtained for the cost of a single resistor. In addition, low-frequency hang-over effects due to speaker resonance and high-frequency accentuation due to the rising impedance characteristic of the speaker are reduced. Some additional improvement can be obtained by adjusting R_c and R_d. The values of components used in the amplifier are shown in the figure.

The curves of Fig.3 show the improvements obtained in distortion by using parallel inverse feedback in an amplifier consisting of a 6Q7 and a 6Y6-G. The circuit of the a-f portion of the receiver is shown in the figure. Values of R_3 less than 1.25 megohms are not practical, because the grid-current point of the 6Q7 is reached before the grid-current point of the 6Y6-G. The impedance of the 6Q7 is reasonably high; hence, a worthwhile improvement in distortion is obtained. Inverse feedback in an amplifier that employs a 6Y6-G is desirable because of the high distortion obtained from this tube type.

The curves of Fig.4 show the frequency-response characteristic of the amplifier with and without inverse feedback. The curve corresponding to no feedback was taken with a 0.01-μf condenser connected from the plate of the 6Y6-G to ground; the curve corresponding to conditions with feedback was taken without any condenser in the plate circuit of the 6Y6-G. As shown by the curves, reduction in high-frequency response due to feedback was greater than that due to the by-pass condenser. The response at the resonant frequency of the speaker (about 180 cycles) was not reduced because of insufficient feedback. When the per cent voltage feedback (n) was increased to approximately twice the value indicated, low-frequency response with feedback was improved considerably. However, a value of R_3 less than 1.25 megohms is not recommended because, as previously mentioned, the grid-current point of the 6Q7 is reached before the grid-current point of the 6Y6-G. Thus, for the cost of a single resistor to provide feedback, the cost of a by-pass condenser is saved, distortion is reduced, and high-frequency response is improved.

Improvements in distortion and in frequency characteristic are obtained at a sacrifice in sensitivity which cannot be tolerated in many small receiver designs. In such cases, it is desirable to add an additional tube to the a-f amplifier. A suggested circuit is shown in Fig.5. The 6Q7 operates without degeneration and feeds a 6J5. Because the plate resistance of the 6J5 is too low to permit obtaining appreciable feedback, a cathode resistor is used in order to raise the effective plate impedance of the 6J5 to a reasonably high value. Parallel feedback between the plate of the 6J5 and the plate of the 6Y6-G is then used.

The gain of this amplifier can be made too high for use in a low-cost receiver. When the gain is too high, microphonic and hum problems require special consideration. Measurements on a number of receivers indicate that a good value of audio-frequency power sensitivity for a-c operated receivers is 200 mhos. Power sensitivity in mhos is defined as the ratio of power output in watts to the square of the input signal in volts (rms). The amplifier shown in Fig.5 has a power sensitivity of 200 mhos at 2 watts output; the power sensitivity of the 6Q7 - 6Y6-G amplifier without inverse feedback is 53 mhos. Thus, for the cost of a 6J5, a socket, five resistors, and a condenser, the power sensitivity of this receiver was increased nearly four times, the distortion at 2.5 watts was reduced to less than half its original value, and the frequency-response characteristic was improved.

PARALLEL INVERSE—FEEDBACK CIRCUIT

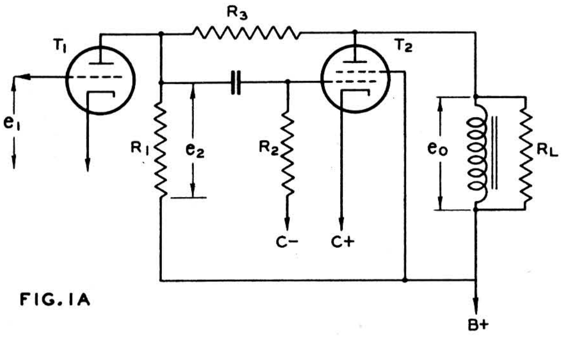


FIG. 1A

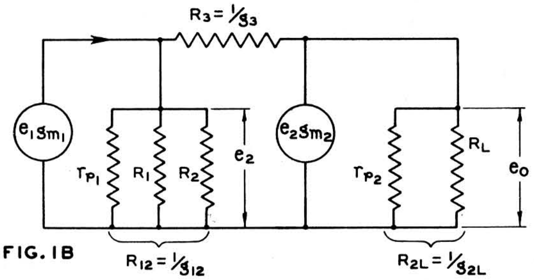


FIG. 1B

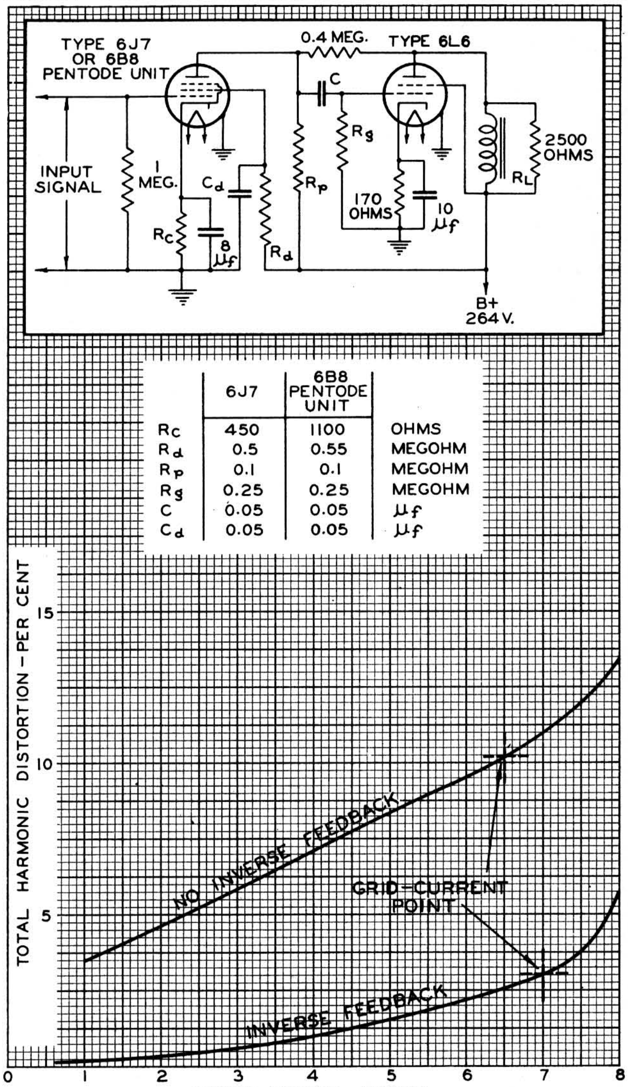
$$G_2 = \frac{e_0}{e_2} = \frac{g_{m_2} - g_3}{g_{2L} + g_3}$$

$$G_1 = \frac{e_2}{e_1} = \frac{g_{m_1}\,(g_{2L} + g_3)}{g_{12}\,(g_{2L} + g_3) + g_3\,(g_{m_2} + g_{2L})}$$

$$G = \frac{e_0}{e_1} = \frac{g_{m_1}\,(g_{m_2} - g_3)}{g_{12}\,g_{2L} + g_3\,(g_{m_2} + g_{2L} + g_{12})}$$

The license extended to the purchaser of tubes appears in the License Notice accompanying them. Information contained herein is furnished without assuming any obligations.

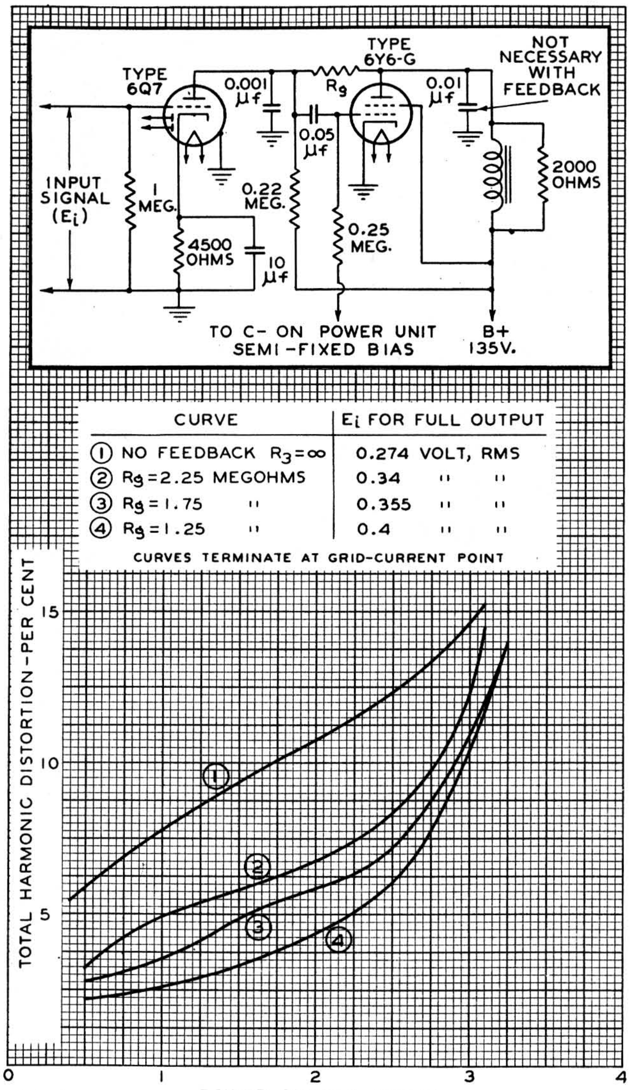
EFFECT OF PARALLEL INVERSE FEEDBACK IN CIRCUIT USING TYPE 6L6 AND TYPE 6J7 OR 6B8



	6J7	6B8 PENTODE UNIT	
Rc	450	1100	OHMS
Rd	0.5	0.55	MEGOHM
Rp	0.1	0.1	MEGOHM
Rg	0.25	0.25	MEGOHM
C	0.05	0.05	µf
Cd	0.05	0.05	µf

FIG. 2

EFFECT OF PARALLEL INVERSE FEEDBACK IN CIRCUIT USING TYPES 6Y6-G AND 6Q7



CURVE	Ei FOR FULL OUTPUT
① NO FEEDBACK R3=∞	0.274 VOLT, RMS
② Rg=2.25 MEGOHMS	0.34 " "
③ Rg=1.75 "	0.355 " "
④ Rg=1.25 "	0.4 " "

CURVES TERMINATE AT GRID-CURRENT POINT

FIG. 3

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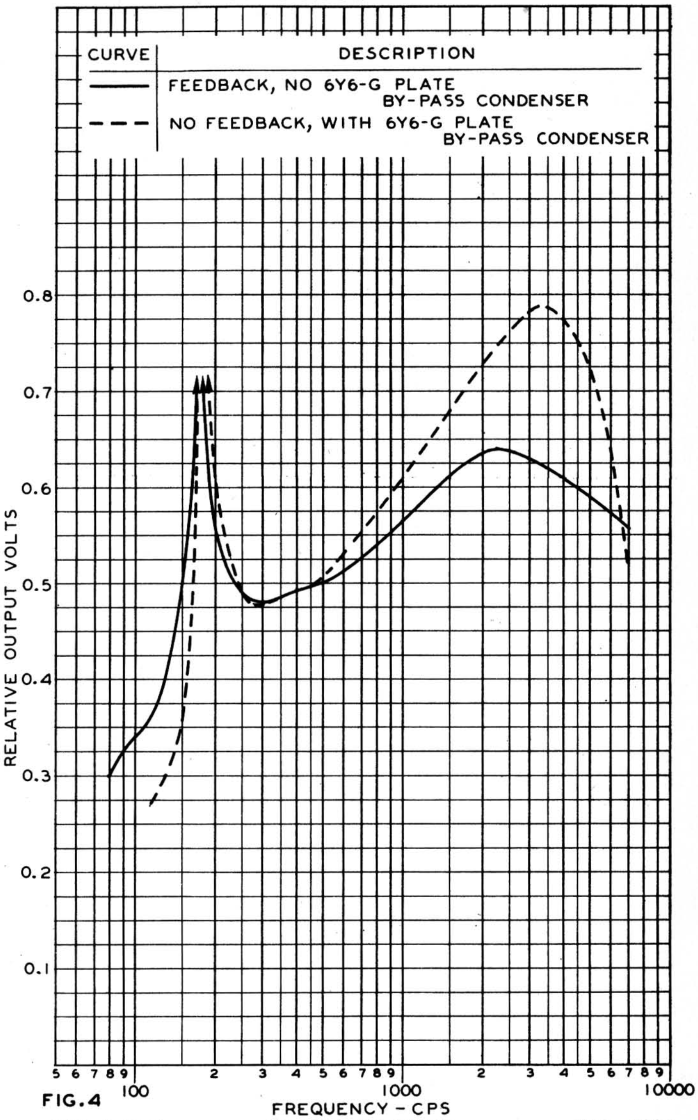
EFFECT ON FREQUENCY RESPONSE OF CIRCUIT IN FIG.3



CURVE	DESCRIPTION
———	FEEDBACK, NO 6Y6-G PLATE BY-PASS CONDENSER
– – –	NO FEEDBACK, WITH 6Y6-G PLATE BY-PASS CONDENSER

FIG. 4

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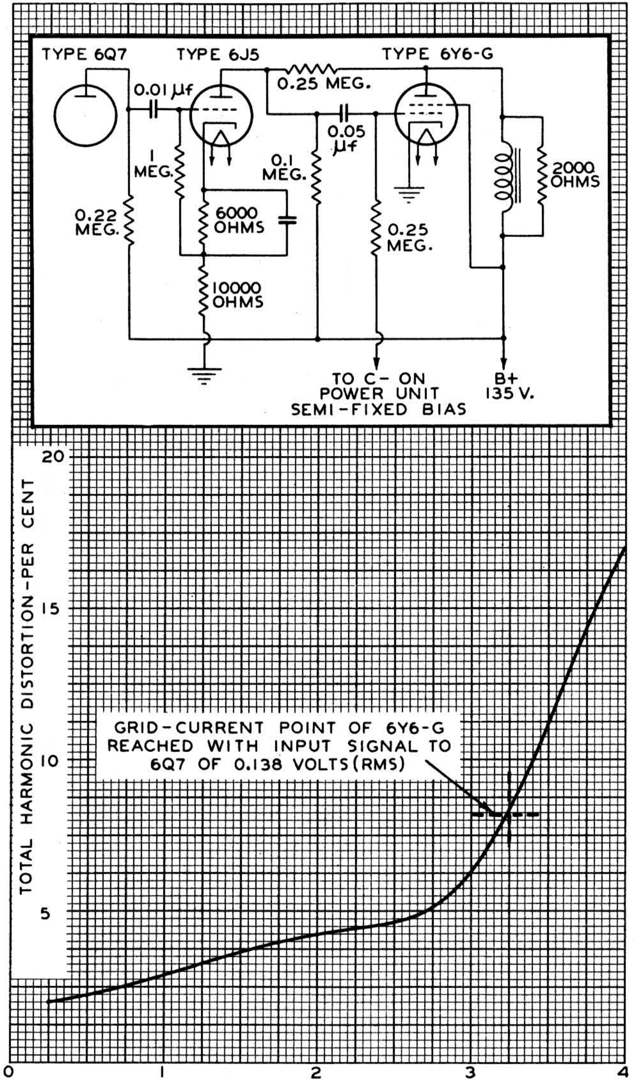
EFFECT OF PARALLEL INVERSE FEEDBACK IN CIRCUIT USING TYPES 6Y6-G, 6J5, AND 6Q7



GRID-CURRENT POINT OF 6Y6-G REACHED WITH INPUT SIGNAL TO 6Q7 OF 0.138 VOLTS (RMS)

FIG. 5

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