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RCA RADIOTRON DIVISION

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APPLICATION NOTE ON INVERSE-FEEDBACK CIRCUITS FOR A-F AMPLIFIERS

When power output and distortion characteristics of the final stage of an a-f amplifier are to be determined, it is customary to replace the loudspeaker by a fixed resistance of suitable value. Actually, a loudspeaker does not present the same impedance to an output tube at all audio frequencies. At the resonant frequency of the speaker, which is usually less than 100 cycles, the impedance of the speaker is high and resistive. At higher frequencies, the impedance of the speaker increases with frequency, because the voice coil has inductive reactance. Unless the variable effects of such a load are reduced by a low-resistance output tube, low frequencies "hang-over" and are accentuated by resonance effects in the speaker; high frequencies are accentuated by the rising impedance characteristic of the speaker.

The internal resistance (r_p) of an output tube shunts the plate load (Z_L). When r_p is appreciably less than Z_L, large variations in load impedance do not appreciably affect the output voltage, because the variable load impedance is shunted by the comparatively low resistance of the output tube. Hence, when a low-impedance triode is used in the output stage, the effects of the variable speaker impedance are reduced. When the internal resistance of the output tube is high compared to the load impedance, the effects of variable speaker impedance may seriously impair quality. This latter condition exists when tetrode- or pentode-type output tubes are used without compensating circuits. This Note describes the characteristics of two such circuits: (1) the familiar resistance-capacitance filter, which compensates for high-frequency effects, and (2) inverse-feedback circuits, which minimize the effects over the entire audio-frequency range.

Resistance-Capacitance Filter

Because the load impedance of a dynamic speaker acts like an inductance and resistance in series at frequencies higher than the resonant frequency of the speaker, a suitable resistance-capacitance filter, connected as shown in Fig. 1, can be used to compensate for the variable reactance of the load. Resistance (R) in Fig. 1 is made equal to the load impedance into which the output tube(s) should work; capacitance (C) is adjusted to give a frequency characteristic which is substantially flat over a desired frequency range.

When R and C are determined in this manner, considerable power may be dissipated in R, especially at the high audio frequencies. For this reason, it may be desirable to increase R and C until a suitable balance between high-frequency compensation and power loss is obtained. The effects of speaker resonance are not reduced by the filter method of compensation.

Inverse-Feedback Circuits

Inverse-feedback circuits can be used to decrease distortion at the expense of power sensitivity in an a-f amplifier. Some forms of inverse-feedback circuits cause an increase in the plate resistance of a tube and others cause a decrease in this resistance. In the following discussion, two forms of inverse-feedback circuits are analyzed. The reduction in distortion can be made equal in both forms, although one increases and the other decreases the plate resistance of the tube.

The plate resistance of a tube can be increased or decreased by feeding back to the grid circuit a portion of the alternating voltage appearing in the plate circuit. Thus, in Fig. 2, when the plate voltage is increased by an amount E by means of switch S, the control grid becomes more negative because of the increased voltage drop across the cathode resistor (R_c); this increase in negative bias reduces the plate-current change. When a signal is applied to the input and the battery (E) is replaced by a suitable load, the effect of the unby-passed cathode resistor is to increase the internal resistance of the tube as measured at the terminals of the load; therefore, the shunting effect of the tube on the load is decreased.

The a-c voltage developed across an unby-passed cathode resistor is in opposite phase to the input-signal voltage in a single-tube amplifier; hence, the circuit is degenerative. The effects of degeneration in a single-tube amplifier are to reduce distortion and power sensitivity; the power output is also somewhat reduced due to power dissipated in the cathode resistor. The fractional loss in power output is R_c/R_L, where R_c is the value of the cathode resistor and R_L is the value of the load resistance plus the cathode resistance. The input signal required for rated output with degeneration is approximately

$$E_d = E_o \left\{1 + [g_m R_c / (1 + R_L / r_p)]\right\}$$

where E_o is the input signal required for rated output without degeneration, and g_m is the grid-plate transconductance of the tube at the operating point. The distortion with degeneration is approximately

$$D_d = D_o / \left\{1 + [g_m R_c / (1 + R_L / r_p)]\right\}$$

where D_o is the distortion without degeneration. For example, when the by-pass condenser was removed from the cathode circuit of a typical single-tube amplifier using a type 6L6 tube, the distortion was reduced to approximately one-half its former value; the required input-signal voltage was doubled, and the power output was reduced by approximately 10 per cent. No other changes in circuit constants were made.

The cathode-resistor by-pass condenser should not be removed from over-biased push-pull circuits having a single cathode resistor for both tubes because the alternating plate currents of each tube do not cancel in this resistor; the resulting harmonic components of current cause an increase in distortion. The cathode-resistor by-pass condenser may be removed from over-biased push-pull circuits when each tube has its own resistor. However, the advantages of low tube resistance are not obtained.

When the entire load resistance is common to the plate and the cathode circuit, as shown in Fig. 3, a positive increment in plate voltage causes the same increment in grid voltage. Therefore, the internal resistance of the tube decreases. As in the circuit of Fig. 2, the feed-back voltage, which is the entire voltage developed across the load, is in opposite phase to the input-signal voltage. It follows that this circuit is also degenerative. When the circuit of Fig. 3 is used, the internal resistance of the tube, the distortion, and power sensitivity of the amplifier are reduced; the power output and efficiency are not changed.

The circuit of Fig. 3 alters the normal characteristics of the amplifier in such a manner that the output tube acts as though it were a low-resistance triode. The amplifier has all the advantages of a triode, plus the high efficiency obtainable from a good tetrode or pentode. In addition, the circuit may be made flexible enough to permit the tube characteristics to be changed in steps from those of a tetrode or pentode to those of a low-resistance triode.

The circuits of a practical single-tube and of a push-pull amplifier using partial inverse feedback to reduce the internal impedance of the tube are shown in Figs. 4a and 4b, respectively. Resistors (R_1) and (R_2) and condenser (C) are connected in series; the combination is connected from the plate of each tube to ground. Nearly all the a-c voltage developed across the load appears across R_1 and R_2 when the capacitance of C is high. Of this voltage, that due to $R_1/(R_1 + R_2)$ is applied in series with the input-signal voltage; this ratio is defined as the per cent degeneration (n). With any per cent degeneration, the tube acts as though its normal internal resistance (r_p) were shunted by a resistance $1/(n\ g_m)$, where g_m is the transconductance of the tube. The input signal required for rated output is approximately

$$E_d = E_o \{ 1 + [n\ g_m R_L / (1 + R_L / r_p)] \}$$

where E_o is the input signal required for rated output without inverse feedback. The distortion with inverse feedback is approximately

$$D_d = D_o / \{ 1 + [n\ g_m R_L / (1 + R_L / r_p)] \}$$

where D_o is the distortion without inverse feedback. The transconductance of the tube is not changed by the addition of this type of degeneration.

The cathode resistor (R_c) has the same value with and without inverse feedback, because electrode voltages are not changed when this circuit is used. Also, the load impedance into which the tube operates should not be changed when inverse feedback is added. The load resistance that is optimum without degeneration is also optimum with degeneration. Therefore, in order to use inverse feedback in some receivers, it may be necessary only to install R_1, R_2, and C.

Circuit Precautions

Although the inverse-feedback circuits of Figs. 4a and 4b offer certain advantages, the following precautions should be observed in the design and use of these circuits in order to avoid the possibility of instability, oscillation, or a marked divergence from expected results.

(1) A conventional resistance-coupled input circuit cannot be used with this type of degenerative circuit, because the input-signal voltage must be in series with the feedback voltage for proper operation.

(2) It may be desirable to connect small fixed condensers (C_1) across each secondary of the input transformer in order to avoid the possibility of oscillation due to leakage inductance and shunt capacitance in the input-transformer circuit. It is advisable to determine by test whether or not these condensers are necessary.

(3) The blocking condensers (C in Figs. 4a and 4b) should be placed between R_1 and R_2, as shown. When placed between R_2 and plate, the circuit may oscillate because of the capacitance of C to grid.

(4) It might appear that the primary of the output transformer could be tapped at the proper point or that a tertiary winding could be used to obtain the necessary feedback voltage. Attempts to use such schemes may be unsuccessful because of phase shifts due to leakage inductance.

(5) This type of circuit is not suitable for use in amplifiers that are designed for grid-current operation, because the relatively high values of R_1 cause appreciable grid-circuit distortion.

Results of Operating Tests - Circuit of Fig. 4b

Inverse feedback reduces the power sensitivity of an amplifier. In circuits having this feature it is, therefore, desirable to use an output tube that has high power sensitivity in order to obtain normal power output with reasonable signal voltage. For this reason, the 6L6 tube is well-suited for use in this type of circuit. Preliminary tests indicate that the shunting effect on a speaker load by two type 6L6 tubes with 10 per cent degeneration is comparable to that which can be obtained by two low-resistance triodes in a similar circuit without degeneration. At the same time, the power sensitivity of the 6L6 amplifier is approximately twice that of the triode amplifier and the inherently high efficiency of the type 6L6 tube is retained. In one test, a push-pull amplifier using two type 6L6 tubes without degeneration was set up under the following typical operating conditions: plate voltage, 400 volts; screen voltage, 300 volts; grid bias, -25 volts; plate-to-plate load, 6600 ohms. With a peak grid-to-grid signal of 50 volts, the power output was approximately 34 watts at 2 per cent distortion. When 10 per cent degeneration was added, using the circuit of Fig. 4b, an output of 34 watts was obtained from the tubes at the grid-current point with approximately 1 per cent distortion; grid current flowed with a peak grid-to-grid signal of 130 volts. No changes were made in electrode voltages or circuit constants.

The frequency characteristics of a typical amplifier with and without inverse feedback and with several values of shunt condensers for the same signal input are shown in Fig. 5. These curves indicate that the rise in power output at the resonant frequency of the speaker decreases and the high-frequency response flattens considerably when this form of degeneration is used. The effect of the shunt condensers on frequency response is small, because the secondaries of the input transformer have low impedance.

An interesting set of oscillograms which indicate the damping action of an inverse-feedback circuit are shown in Fig. 6. A short-impulse signal, shown in Fig. 6a, was fed to the grids of a push-pull amplifier. The output tubes were connected to a loudspeaker through an output transformer; the voice coil of the speaker was connected to a cathode-ray oscillograph in order to observe and to photograph the wave form of the voice-coil voltage. The slowly decaying output voltage in a 6L6 amplifier without degeneration is shown in Fig. 6b; the more rapid decay with 10 per cent degeneration is shown at (c). A slight improvement is obtained by using 16.6 per cent degeneration, as shown at (d). The output of a similar amplifier using low-impedance triodes is shown at (e).

From these pictures, it can be concluded that nearly the same amount of damping can be obtained from type 6L6 tubes with 10 per cent degeneration as from good triodes without degeneration. However, for approximately the same input-signal voltage and B-supply power, about twice the power output can be obtained from two 6L6 tubes as from two good triodes.

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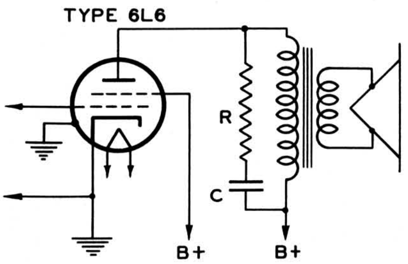
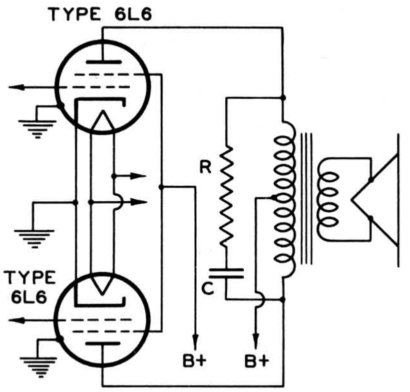
COMPENSATING CIRCUITS



SEE TEXT FOR VALUES OF R AND C

FIG. 1a



SEE TEXT FOR VALUES OF R AND C

FIG. 1b

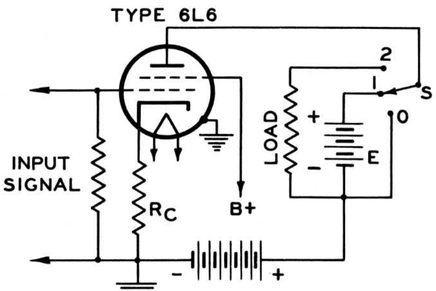


FIG. 2

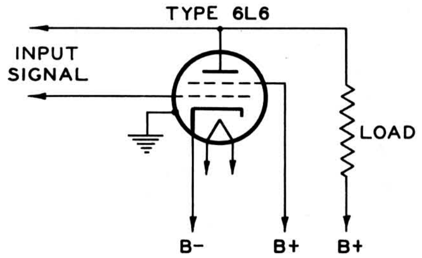


FIG. 3

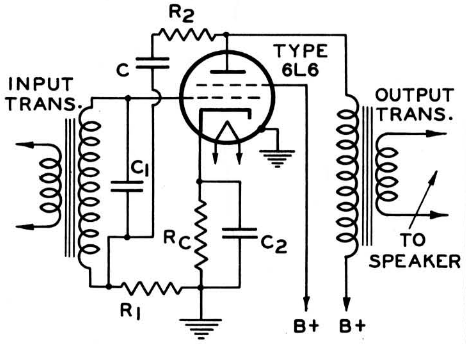


FIG. 4a

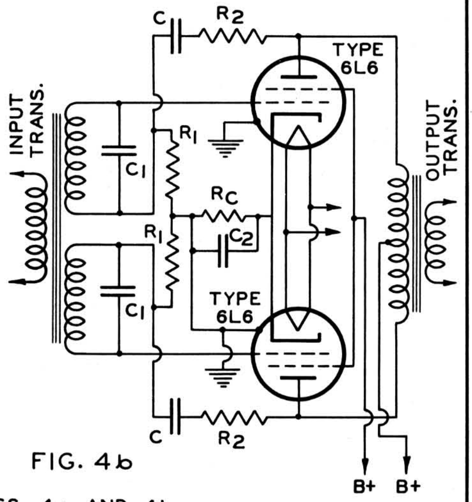


FIG. 4b

VALUES FOR FIGS. 4a AND 4b

R_C = CATHODE RESISTOR

C_2 = CATHODE-RESISTOR BY-PASS CONDENSER

	10% INVERSE FEEDBACK		16.6% INVERSE FEEDBACK	
R_1 =	5000 OHMS	10000 OHMS	8330 OHMS	16660 OHMS
R_2 =	45000 OHMS	90000 OHMS	41670 OHMS	83340 OHMS
C =	0.1 μf OR LARGER	0.1 μf OR LARGER	0.1 μf OR LARGER	0.1 μf OR LARGER
C_1 =	SEE TEXT	SEE TEXT	SEE TEXT	SEE TEXT

JULY 21, 1936

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TYPICAL FREQUENCY CHARACTERISTICS OF PUSH-PULL AMPLIFIER USING TYPE 6L6'S WITH AND WITHOUT INVERSE FEEDBACK

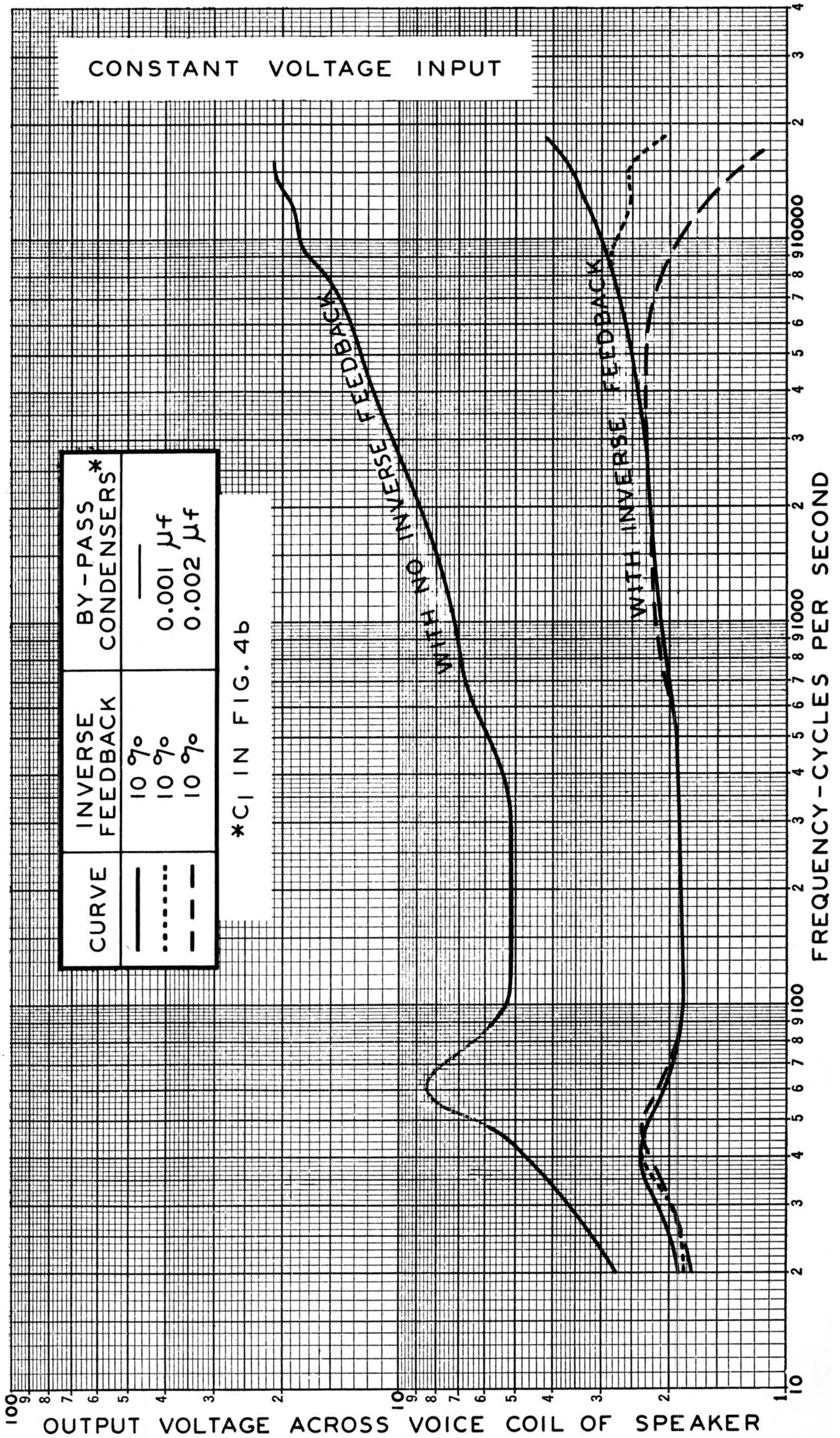

FIG. 5

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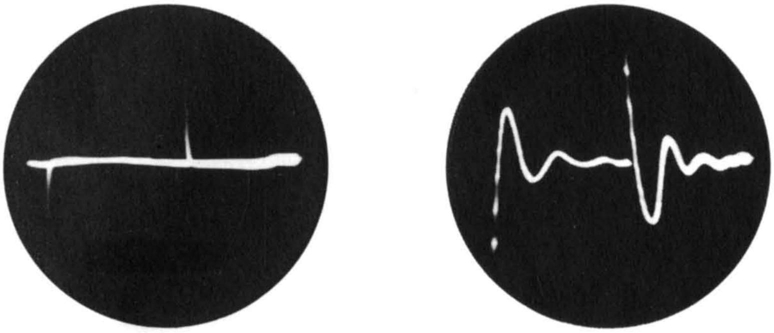
OSCILLOGRAMS SHOWING THE DAMPING ACTION OF INVERSE FEEDBACK

SEE FIG. 4b FOR CIRCUIT

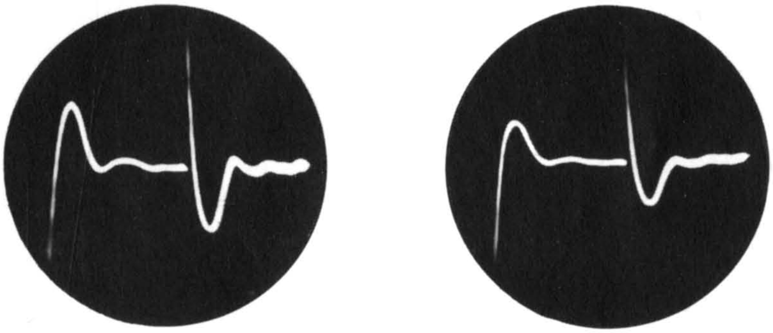


(a)

Input Signal

(b)

Output Voltage of 6L6 Amplifier:
No Inverse Feedback



(c)

Output Voltage of 6L6 Amplifier:
10% Inverse Feedback

(d)

Output Voltage of 6L6 Amplifier:
16.6% Inverse Feedback

(e)

Output Voltage of Amplifier Using
Low-Impedance Triodes:
No Inverse Feedback

FIG. 6