# the Cornell-Dubilier Capacitor

Vol. 9 NOVEMBER, 1944 No. 11

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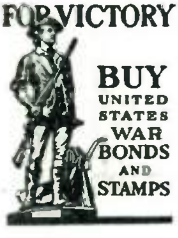

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(Continued on page 15)

# PHASE INVERTER CIRCUITS*

In the search for simplified and more economical circuits for radio receiver and amplifier construction, it was only natural that some means should be developed to eliminate the push-pull input transformer which is bulky, susceptible to hum pickup, and often a source of frequency discrimination. Without doubt, good transformers are available which are capable of supplying the desired results, but good transformers are far more costly than a few resistors and another tube. The development of the beam power with its high power sensitivity, and the general use of inverse feedback to eliminate the effects of cabinet resonance, speaker resonance, and deficiencies otherwise occurring in a production model, have advanced the use of phase inversion which eliminates the phase shift introduced by the input transformer. This effect is particularly vicious in the "driver" type of transformer.

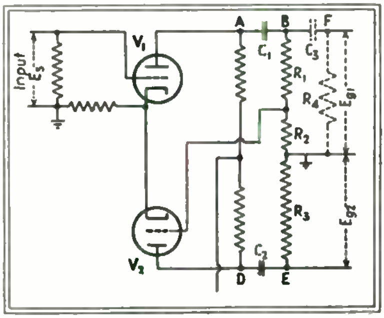

**Fig. 1. Conventional two-tube phase inverter circuit.**

Theoretically, a perfect phase inverter should be capable of taking a signal applied to its input and converting it to two signals of exactly equal magnitude which are exactly 180° out of phase, and which are exact facsimilies of the input signal. Actually, such perfect phase inversion is seldom obtained, nor is it absolutely necessary, for other considerations render it difficult to detect by ear slight differences in either phase or amplitude of a push-pull signal. This article has been written to point out the advantages and disadvantages of the more common types, and to present a new circuit, which, while not original with the writers, was investigated by them.

The most obvious circuit for phase inversion, and one in common use is that of Fig. 1. The signal is applied to the grid of $V_1$, is amplified, and appears at point B. which is to be connected to the grid of one of the output tubes. A portion of that signal is fed back to the grid of the second tube, $V_2$, that portion being tapped off at the junction of $R_1$ and $R_2$. $R_2$ can be determined from the formula

$$\frac{R_2}{R_1 + R_2} = A_2$$

where $A_2$ is the voltage gain of the stage $V_2$. $R_3$ is presumed to be equal to $R_1 + R_2$. The voltages available for the grids of the following tubes, $E_{g1}$ and $E_{g2}$, are equal, opposite in phase, and can be represented by $E_s \times A_1$, where $A_1$ is the voltage gain of $V_1$. With respect to the phase differential, there can be no doubt that there is

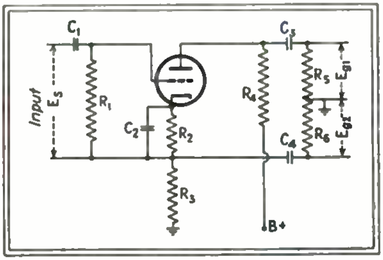

**Fig. 2. One-tube phase inverter with input above ground potential.**

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*By C. G. McProud and R. T. Wildermuth in "Electronics."*

180° shift between points B and D, but there is a slight shift between D and E, which is caused by $C_2$ and $R_3$. This could be corrected by the addition of another phase shifting element, $C_3$ and $R_4$. Granted that this phase shift is slight, in some cases where large amounts of inverse feedback are used, it contributes to the limiting of the maximum that can be used. The main disadvantage of the circuit lies in the fact that if $V_2$ should age, or should lose enough emission to seriously affect its amplification, the two output voltages are no longer equal, with attendant distortion. The main advantage lies in the gain obtained from the circuit in addition to the inversion. Variations of this circuit are common enough, in which $V_2$ is of a different type, or both $V_1$ and $V_2$ are in the same envelope, but the same factors apply to all of them.

A circuit which performs the inversion with only one tube is shown in Fig. 2. The main disadvantage here is the necessity for introducing the signal between points which are considerably above ground potential. Differences in capacity between ground and these points will affect the similarity between the signals appearing at the grids. The output voltages here will be seen to be

$$E_{g1} = E_{g2} = \tfrac{1}{2}\ A\,E_s$$

$R_3$ and $R_4$ are equal. The bias for the tube is developed across $R_2$, with the customary by-pass condenser, $C_2$.

This circuit can be improved by introducing the signal between grid and ground, which will remove one of the objections to it. Then the degeneration which occurs across resistor $R_3$ will reduce the gain of the stage to approximately zero. From the standpoint of cost, this circuit is a satisfactory solution, since, excluding the input condenser $C_1$ and the output condensers $C_3$ and $C_4$ which are common to all of these circuits, only one tube, four resistors, and one high-capacity, low-voltage electrolytic condenser are used.

As long ago as 1937, there appeared in print another circuit, Fig. 3, which is essentially the same as the one just discussed. In this case, the bias was obtained from a point on the voltage divider. Assuming that the voltage divider would be used anyway, the components are reduced to one tube and three resistors, though it is highly probable that some filtering would be required in the grid circuit. In the article cited, the tube used was a 76, with $R_2$ and $R_3$ 25,000 ohms each. It was claimed that the output voltages were approximately 0.8 $E_s$, resulting in a loss of 2 db. By increasing the values of $R_2$ and $R_3$ to 50,000 ohms, the output becomes equal to the input.

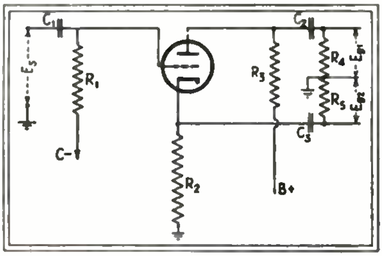

**Fig. 3. One-tube circuit with bias obtained from separate supply.**

In Fig. 4, the phase inverter of Fig. 2 has gone through another stage of simplication, and now requires the tube and four resistors. $R_3$ and $R_4$ are 50,000 ohms each. $R_1$, representing the input impedance of the stage,

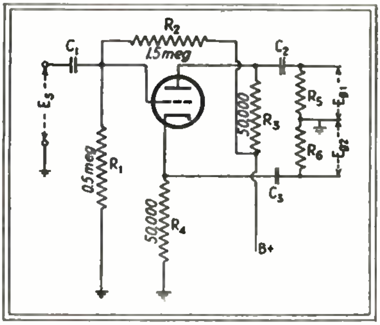

**Fig. 4. Method of obtaining bias from plate supply.**

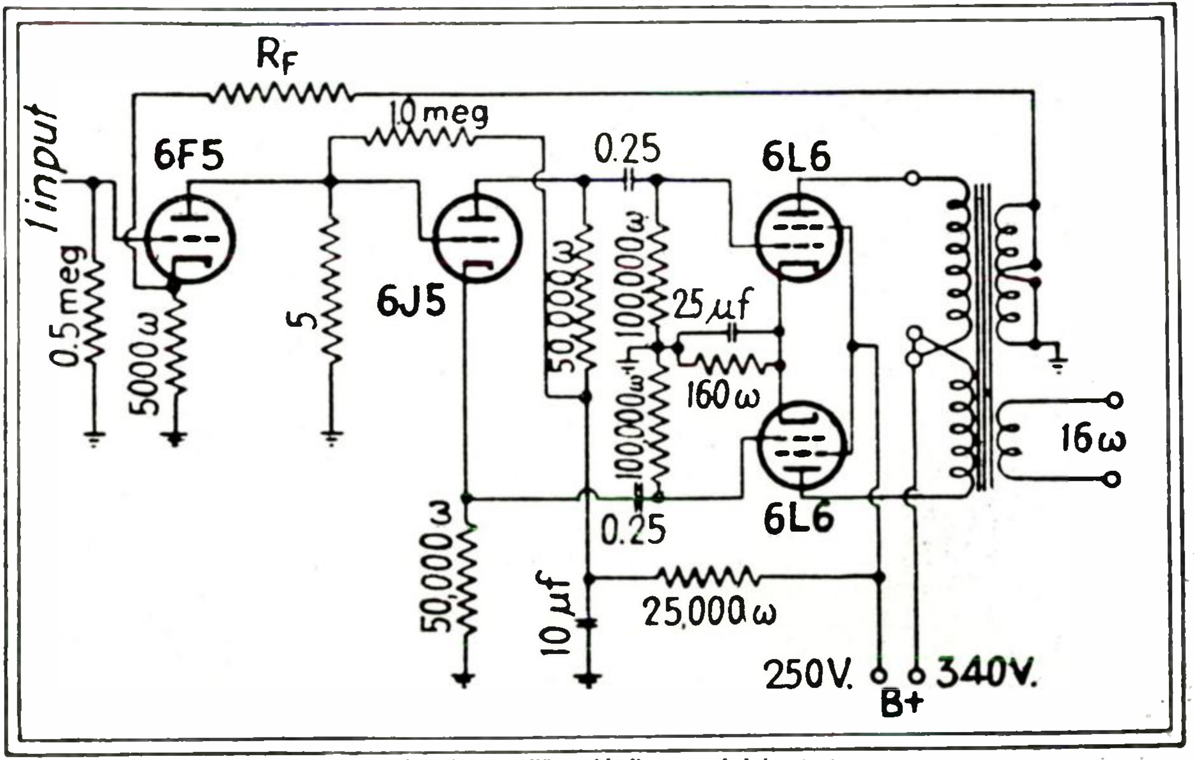

Fig. 5. Complete amplifier with direct-coupled input stage.

is set at 0.5 megohm. $R_2$ is selected to produce the proper grid bias. With the other values mentioned, $R_2$ comes out to be 1.5 megohms. This value is not at all critical, and the usual resistance tolerances will be close enough to make an excellent phase inverter. Nor is the circuit critical about what kind of tube is used, a low-mu or a high-mu triode, or a pentode, the output is still the same, equal to the input. The triode is naturally simpler, so a 6J5 or a 6SJ7, triode connected, is preferred. There is no amplication, since in adding up the voltage gain of several stages to obtain the overall of an amplifier, none should be considered as coming from the inverter. There is a slight differential in the phase shift occurring at the two output grids, which was thought to be due to the capacity between cathode and a normally grounded heater. Actually, the shift is around 2° at 8000 cps, which is slight enough to overlook. It can be corrected by decreasing the grid leak on the plate side, but that introduces other difficulties which are more objectionable. For exact equality in amplitude of the output voltages, $R_3$ and $R_4$ should be balanced as closely as possible.

At a plate supply potential of 200 volts applied at B+, the plate current is approximately 1.0 ma. Therefore the cathode is 50 volts above ground. The $R_2$ $R_1$ network applies 50 volts to the grid. The plate current increases sufficiently to place a bias of about 4.5 volts to the grid, automatically balancing itself to that operating condition, no delicate adjustments being necessary. Measurements show that with a 250-volt supply a r-m-s voltage of 45 volts can be obtained with 2 per cent distortion, which is more than enough to drive a pair of 45's in the 275-volt operating condition, in which they require 39 volts r-m-s. This requires an input voltage equal to that which can be supplied easily by a 6R7 with 250-volt supply and a load resistor of 0.25 megohm. The output voltages obtainable with a 6J5 in this circuit, with 2 per cent distortion are shown in the curve in Fig. 6.

With 50 volts available on the grid of the inverter tube, the next step is to couple the preceding tube directly to it, using that voltage for its plate supply. Normally, the other tube would be coupled to this grid through a condenser, using a separate load resistor with the attendant decoupling filter resistor and condenser. This has been found unnecessary, for the plate of a 6F5 or 6SF5 can be connected directly to the 6J5 grid with considerable improvement in overall operation, particularly if inverse feedback is to be used. The bias resistor of 5000 ohms, not bypassed, is a logical point for the introduction of the feedback voltage. Figure 5 shows the complete circuit of an amplifier using this system. The bias-balancing resistor has been reduced to 1.0 megohm to make up for the plate current of the 6F5. Without feedback, an input signal of 0.44 volts r-m-s is all that is required to drive the 6L6's to overload. With 17db of feedback, the input requirements increase to 3.1 volts r-m-s for maximum output. In the circuit shown, using two 500-ohm output transformer secondaries in shunt, the feedback resistor, $R_f$ will give 10 db of feedback when its value is 240,000 ohms. 100,000 ohms will give 17

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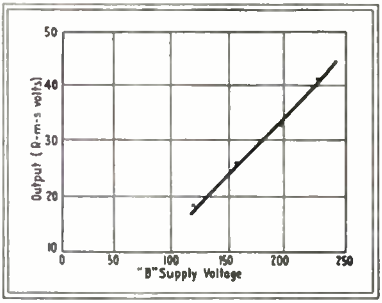

**Fig. 6. Output voltage from 6J5 as function of plate supply voltage.**

# OPEN-GRID TUBES IN LOW-LEVEL AMPLIFIERS*

For certain applications in amplifiers requiring a high input resistance and low noise level it has been found desirable to eliminate the grid leak, and no undesirable effects resulted from using the tubes in this manner. Examples of such applications are amplifiers operating from a low-level, high-impedance source, amplifiers that must present the smallest possible load to the preceding stage, and amplifiers that must handle signal voltages of the same order as the noise level. Actually, operation of a tube with an open grid is less noisy than operation with a grid leak.

## *Problems To Be Overcome*

Different objections to the use of open grid tubes can be summed up as follows:

(1) It has been suggested[1] that if the operating temperature of the tube is high enough, the grid will emit electrons. When this occurs in a conventional circuit, the resulting current through the grid leak (generally a resistance of about 2 megohms connected between grid and cathode) will make the grid less negative and increase the space current, thus increasing the temperature. If the grid becomes positive, electrons flowing to it will increase the grid temperature and might produce secondary emission. The grid will continue to become less negative as long as the number of electrons leaving the grid exceeds the number entering. This process is cumulative and may result in damage to the tube. The process might be aided initially by the flow of positive ions to the grid when it is negative. This effect would be most pronounced in a soft tube. It has been asserted that the use of extremely high cathode-to-grid resistance (such as an open grid) would tend to aid the process by producing large voltage drops in the grid circuit.

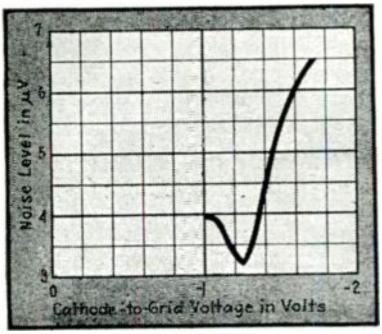

**FIG. 1—Noise level vs. cathode-to-grid voltage for a 6SJ7 tube connected as a triode, with 40 μμf in the grid circuit to simulate a high-impedance crystal pickup having no shunt resistance**

(2) If the grid leak is omitted, electrons will flow to the grid from the cathode and the grid will accumulate a negative charge.[2] Then any slight change in the grid capacitance would change the grid potential and produce fluctuations in the plate current.

(3) There is a small current flowing between the cathode and the grid through the leakage paths. However, these leakage paths are continually changing and thus there is a random fluctuation in the grid leakage current which produces noise in the tube. This effect should be most prominent during the time when the tube is heating.

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* *By Robert J. Meyer, "Electronics."*

## *Noise in Amplifier Circuits*

The three principal types of noise in an amplifier circuit are flicker, shot effect and thermal agitation. These noises can be considered as being developed by equivalent generators in the grid circuit of a noise-free tube.

The flicker voltage, which is produced by irregularities in the temperature of the heating element, is inversely proportional to the square of the frequency.

Shot noise is uniformly distributed throughout the frequency spectrum, independent of the electron velocity and independent of the manner in which the total current divides between the electrodes. The values of the shot voltage $E$ for triodes can be calculated from the formulas[3]

$$|E| = 2 \times 10^{-10} \sqrt{\Delta F / g_m} \tag{1}$$

For pentodes, the formula is

$$\left|E\right| = \frac{2 \times 10^{-10}}{g_m} \sqrt{\frac{I_b}{I_b + I_a} (g_m + 8 I_a) \Delta F} \tag{2}$$

The thermal agitation voltage developed by a resistor is

$$E^2 = 4KTR\,\Delta F \tag{3}$$

where $R$ is the resistance, $\Delta F$ is the frequency band passed, $T$ is the temperature in degrees Kelvin and $K$ is Boltzmann's constant ($1.39 \times 10^{-23}$).

If the impedance in the grid circuit is not a pure resistance, the resistive component is a function of the frequency and the voltage can be obtained from:

$$E^2 = 4KT \int_{F_1}^{F_2} R(f)\, dF \tag{4}$$

These formulas apply only to wirewound resistors or to carbon resistors in which no current is flowing.

There is always some capacitance across a resistor and this parallel combination forms a low-pass filter which affects the thermal agitation voltage $e$ as follows:

$$e = 1.28 \times 10^{-10} \sqrt{RF_0\left(\tan^{-1}\frac{F_2}{F_0} - \tan^{-1}\frac{F_1}{F_0}\right)} \tag{5}$$

where $F_0 = 1/2\pi RC$ and $F_2$ and $F_1$ are the upper and the lower frequency limits, respectively, being considered. It can be seen from Eq. (5) that the thermal agitation voltage output of an $RC$ combination is independent of the value of $R$, because $F_1 = 0$ and $F_2 = F_0$, reducing $e$ from a function of $R$ and $C$ to a function of $C$ only.

If the noise voltage from an $RC$ combination is applied to an amplifier, some of this voltage may be in a part of the frequency spectrum which is not passed by the amplifier. In this case the voltage passed by the amplifier would be a function of $R$ as expressed in Eq. (5), where $F_1$ and $F_2$ would now be the frequency limits of the amplifier, and $R$ and $C$ would be the grid leak and the input capacitance in the amplifier circuit. If $F_1$ is very much less than the upper frequency limit of the amplifier, Eq. (5) reduces to:

$$e = 1.28 \times 10^{-10} \sqrt{\frac{1}{2\pi C} \cot^{-1}\frac{F_1}{F_2}} \tag{6}$$

The form of Eq. (5) can be changed to show more clearly the relation between the thermal noise and the value of $R$.

$$e = 1.28 \times 10^{-10} \sqrt{\frac{1}{2\pi C}(\tan^{-1} 2\pi F_2 CR - \tan^{-1} 2\pi F_1 CR)} \tag{5a}$$

$$\tan\left[\frac{2\pi Ce^2}{(1.28 \times 10^{-10})^2}\right] = \frac{2\pi C\,(F_2 - F_1)\,R}{1 + 4\pi^2 F_1 F_2 C^2 R^2} \tag{5b}$$

Eq. 5 (b) shows that the noise increases as the value of *R* increases from zero, reaches a maximum at some finite value of *R*, and decreases as the value of *R* is increased beyond this value. This equation shows that operation of a tube with an open grid would be less noisy than operation with a grid leak. In an amplifier circuit, to obtain minimum noise, the grid leak is sufficiently high if the thermal noise is less than the shot effect.

Another source of noise is the flow of leakage current between the cathode and the grid. This noise would be at a minimum when the cathode-to-grid voltage is at a minimum. Thus the tube would be quietest with a proper value of bias and it remains to be shown that the open grid tube automatically biases itself to that bias voltage.

To aid in determining the desirability of an open grid, a low noise level, wide-range amplifier was built. The first stage had a 6SJ7, triode-connected, with a gain of 11 db. The next two stages, using 6SJ7 tubes, had a gain of 68 db. The output stage, using a 6J5, was a cathode follower. The frequency response was down 6 db at 200 cycles and at 200 kc. The entire amplifier was built in a copper box which gave excellent shielding. Because flicker noise is a low-frequency effect and not dependent upon the grid leak, a high-pass constant-K filter was placed at the output of the amplifier to suppress frequencies below about 650 cps and thus substantially eliminate the flicker effect.

### *Experiments With Open-Grid Tubes*

The first tests were made with a cathode resistor alternately in and out of the first stage. A 40-$\mu\mu$f capacitor was used in the grid circuit to simulate the condition of an open-grid tube operating from a high-impedance crystal. For the next two measurements a 35-megohm resistor was put in parallel with the capacitor to give the condition of operation with a high-value grid leak. Finally, the grid was shorted to obtain the value of the tube noises. The noise at the grid was obtained by dividing the noise output by the gain. Typical results are given in Table 1.

**TABLE 1. EFFECT OF CATHODE RESISTOR ON NOISE**

| Cathode Resistor | Grid Circuit Impedance | Noise at Grid ($\mu$v) |
|---|---|---|
| In | 40 $\mu\mu$f | 3.32 |
| Out | 40 $\mu\mu$f | 4.26 |
| In | 40 $\mu\mu$f and 35 meg. | 3.68 |
| Out | 40 $\mu\mu$f and 35 meg. | 8.40 |
| In | Short | 3.00 |
| Out | Short | 3.69 |

These results show that the noise is less with an open grid than with a grid leak. In all three cases the noise is less with a cathode resistor than without one. This result is to be expected, for the cathode resistor voltage drop reduces the voltage between the cathode and the grid, reducing the leakage current and the noise resulting from it. The value of noise obtained with a grid leak and no cathode resistor is exceptionally high, probably because the zero bias allows a comparatively high value of grid current to flow through the carbon grid leak, greatly increasing the noise across the resistor.

### *Effect of Cathode Resistor Value*

Noise measurements were taken with different sizes of cathode resistors. The test was made with 40 $\mu\mu$f in the grid circuit. The resulting curve of noise level vs. cathode voltage is not so important as the curve of noise level vs. Cathode-grid voltage. Since this voltage cannot be measured directly because any voltmeter would upset the circuit conditions, it was necessary to obtain a calibration curve of plate potential vs. grid voltage without a cathode resistor.

The curve of noise level vs. cathode-grid voltage is given in Fig. 1. Least noise is obtained for that value of cathode resistor which gives cathode-grid voltage of —1.2 volts. The

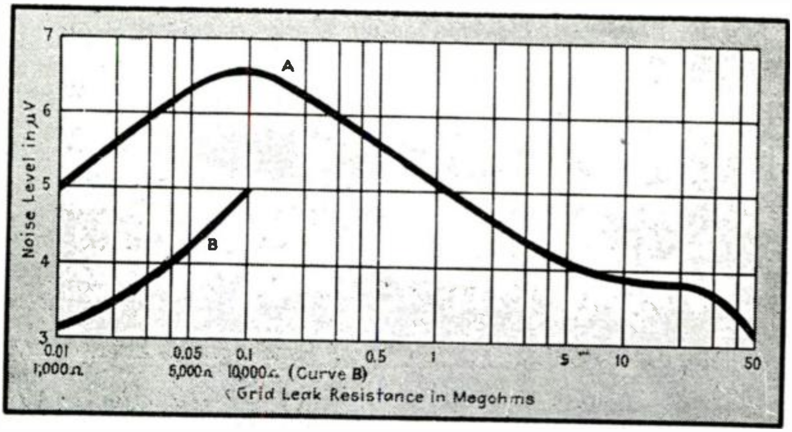

**FIG. 2**—Noise level vs. grid leak value for a triode-connected 6SJ7 tube. Curve B is for very low values of grid-cathode resistance

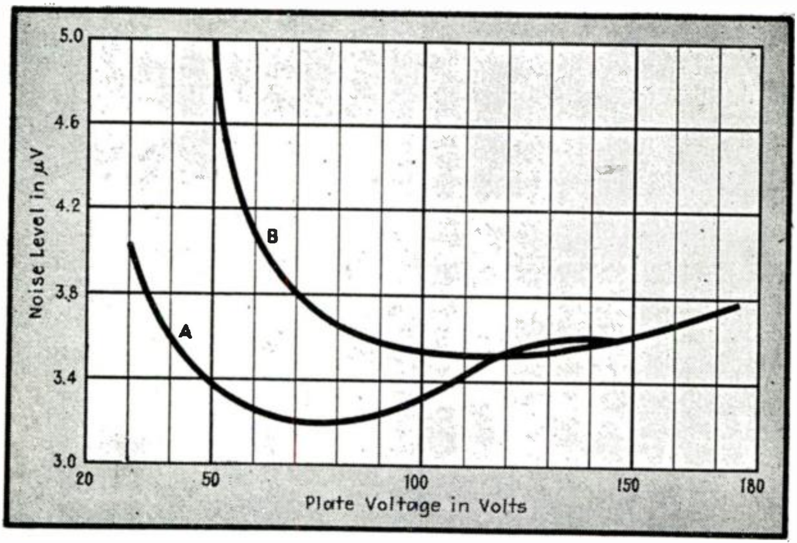

**FIG. 3**—Noise level vs. plate voltage for a triode-connected 6SJ7 tube with two different grid circuit arrangements. Curve A—40 μμf in grid circuit; curve B—40 μμf in parallel with 35 megohms in grid circuit

open-grid tube seems to automatically bias itself approximately to that value which gives the least noise. The effect of electron flow to the grid (which tends to make the grid negative) and the effects of emission from the grid and gas current to the grid (which tend to make the grid positive) balance each other to give the grid a small negative bias.

The foregoing test was repeated with a 35-megohm grid leak in addition to the 40 $\mu\mu f$ capacitor. The minimum noise obtained was greater than the minimum noise without the grid leak.

### *Effect of Grid Leak Value*

Figure 2 shows the relation between the noise level and the value of grid leak. These readings were taken with a 750-ohm cathode resistor. Except for a shorted or nearly shorted grid the best signal-to-noise ratio is obtained with an open grid. For the constants in this test, i.e., amplifier frequency response and input capacitance, the worst ratio is obtained for a grid leak around 100,000 ohms. For a different amplifier the worst ratio would occur at a different value of grid leak but the general shape of the curve would be the same. These results are in agreement with Eq. 5(b) and the discussion following it.

### *Effect of Plate Voltage*

The relation between the plate voltage on a tube and the noise level at the grid is given in Fig. 3. Again there is less noise without a grid leak than with a grid leak, but in both cases the best signal-to-noise ratio is obtained for a plate voltage of about 90 volts.

It would be expected from Eq. (1) that the noise would continue to decrease as the plate voltage is increased because the $g_m$ is increasing. However, the larger number of positive ions and secondary electrons present in the tube at higher plate voltages tends to make the tube slightly noisier.

### *Effect of Temperature and Time*

In various measurements it was noticed that the noise changed as the temperature of the tube changed, the noise in a cold tube being greater than the noise in a warm tube. This effect is undoubtedly due to leakage paths, which change as the tube is heated and become saturated when the tube is hot. The change in the noise level is just as great with a grid leak as without one, and thus the addition of a grid leak does not reduce the noise due to the random leakage paths. An attempt was made to reduce this transient effect by boiling the tube and its socket in wax, but this did not help nor did it reduce the noise level.

A long-time test was performed on five 6SJ7 tubes by continuously drawing plate current through the tubes and measuring the noise level at certain time intervals. Typical results are given in Fig. 4. It can be seen that the tubes have a general tendency to become noisier with age, but that in all cases, the noise is greater with a grid leak than without a grid leak.

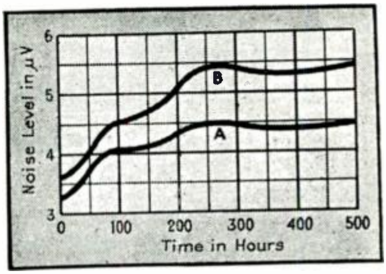

**FIG. 4—Noise level vs. number of hours of continuous operation for a triode-connected 6SJ7 tube. Curve A—40 $\mu\mu f$ in grid circuit; curve B—40 $\mu\mu f$ in parallel with 35 meg in grid circuit**

These tests show that tubes operated without a grid leak do not tend to become any more erratic than tubes operated with a grid leak.

### *Conclusions*

In the experiments performed, the noise level was always less without a grid leak than with one. In no case did omission of the grid leak lead to excessively high plate current or to high operating temperatures, nor did the grid bias become high enough to block the tube. In the aging test, open-grid tubes also performed better than tubes with a grid leak. The noise is also less with a cathode resistor (of proper size) than without one. With a fixed bias resistor and variable plate voltage the least noise was obtained with a plate voltage of about 90 volts for a 6SJ7 tube.

If the tubes are to be operated with nearly zero grid bias the lower noise level obtained by the omission of the grid leak is especially noticeable. From Table 1 it can be seen that for optimum grid bias the ratio of noise with a grid leak to the noise without a grid leak is 1.11, and for zero bias this same ratio is 1.97. This shows the advantage of operating without a grid leak for zero bias.

Operation of a tube without a grid leak seems practical in applications involving low-level operation, with no d-c potentials in the preceding stage, and a negative grid bias of not more than about 2 volts.

Tests were also performed on pentode-connected 6SJ7 tubes and on 6J5 tubes, and similar results were obtained.

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(2) Everitt, W. L., "Communications Engineering," McGraw-Hill Book Co., 1937, p. 241.

(3) Harris, W. A., Fluctuations in Vacuum Tube Amplifiers and Input Systems, *R. C. A. Review*, 5, April 1941, p. 505.

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(2) Moullin, E. B., "Spontaneous Fluctuations of Voltage," Oxford Univ. Press, 1938.

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# PHASE INVERTER CIRCUITS

(*Continued from page* 8)

db of feedback, 68,000 ohms 20 db, 52,000 ohms 22 db, and 36,000 ohms 24 db. The amplifier is perfectly stable with 22 db of feedback. When it was first constructed, the conventional method of coupling the 6F5 and the 6J5 was used, and with that connection, the amplifier became unstable with 17 db of feedback, due to phase turnover. With the slight change to direct coupling, the additional 5db became available, using the same parts throughout otherwise. It will be noted that the output transformer has its two 125 ohm secondaries strapped in parallel, a connection advanced by J. N. A. Hawkins to increase the available feedback due to the reduction in leakage reactance in the transformer, and consequent decrease in phase turnover.

The complete amplifier shown has a gain of 60 db, figured as most public address amplifiers are, from a 100,000 ohm source. Measured with a gainset terminated with 500 ohms, with the 500,000 ohm input bridged directly across it, it has a gain of 30 db; with the feedback resistor of 100,000 ohms removed, the gain increases to 47 db. With a suitable input transformer, and using the feedback of 17 db, it makes a very useful power amplifier to follow a pre-amplifier, mixer and booster or similar equipment with a nominal output level of 0 db. It is flat to within 0.2 db from 30 to 13,000 cycles, and has a power output of 35.2 db at 2 per cent distortion, that is, roughly, 20 watts.

# THE RADIO TRADING POST

(*Continued from page 4*)

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**WANTED**—VOM with 1000 ohms per volt sensitivity with zero adjustment. Also meters with same sensitivity. Will pay cash, or exchange with D5T model American dynamic mike, new. George Uyeda, 868 N. University Ave., Provo, Utah.

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**WANTED**—Any condition used Sept. movie cameras, for test equipment, parts, tubes. G. W. Deuchler, 1510 Monroe St., Omaha, Nebraska.

**WANTED**—Precision 920P tube and set tester or Supreme 504A tube and set tester, Hickok 188X signal generator or Hickok 510X tube set tester. Will pay cash or trade new Rider's Manuals, 7, 8, 9, 10, 11, 12 and cash. Leon S. Schall, 160 Abbott St., Plains, Pa.

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