Open-grid Tubes in Low-level Amplifiers

By ROBERT J. MEYER

Omission of the grid leak in a conventional low-level amplifier, leaving only surface leakage paths between the grid and cathode, reduces the noise due to shot effect and thermal agitation. A cathode resistor of proper size gives further lowering of noise level

For certain applications in amplifiers requiring a high input resistance and low noise level, it has been found desirable to eliminate the grid leak. 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. Operation of a tube with an open grid was found to be less noisy than operation with a grid leak.

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

$$|E| = 2 \times 10^{-10} \sqrt{\frac{\Delta F}{g_m}} \qquad (1)$$

For pentodes, the formula is

$$|E| = \frac{2 \times 10^{-10}}{g_m} \sqrt{\frac{I_b}{I_b + I_{c2}} (g_m + 8I_{c2}) \Delta F} \qquad (2)$$

The thermal agitation voltage developed by a resistor is

$$E^2 = 4KTR\,\Delta F \qquad (3)$$

where R = resistance
ΔF = frequency band passed
T = temperature, °K
K = Boltzmann's constant (1.39×10^{-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

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

These formulas apply only to wire-wound 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 that affects the thermal agitation voltage e as follows:

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

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

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

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

$$e = 1.28 \times 10^{-10} \sqrt{\frac{1}{2\pi C}(\tan^{-1} 2\pi F_2 CR - \tan^{-1} 2\pi F_1 CR)} \qquad (7)$$

$$\tan\left[\frac{2\pi Ce^2}{(1.28 \times 10^{-10})^2}\right] = \frac{2\pi C(F_2 - F_1)R}{1 + 4\pi^2 F_1 F_2 C^2 R^2} \qquad (8)$$

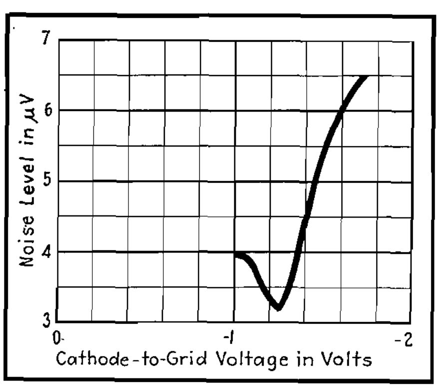

Fig. 1.—Noise level vs. cathode-to-grid voltage for a 6SJ7 tube connected as a triode, with 40 µµf in the grid circuit to simulate a high-impedance crystal pickup having no short resistance.

Equation (8) 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. The tube would thus be quietest with a proper value of bias, and the open-grid tube automatically biases itself to this bias voltage.

Experimental results confirmed that noise is less with an open grid than with a grid leak, and less with a cathode resistor than without one. This result is to be expected, for the cathode resistor voltage

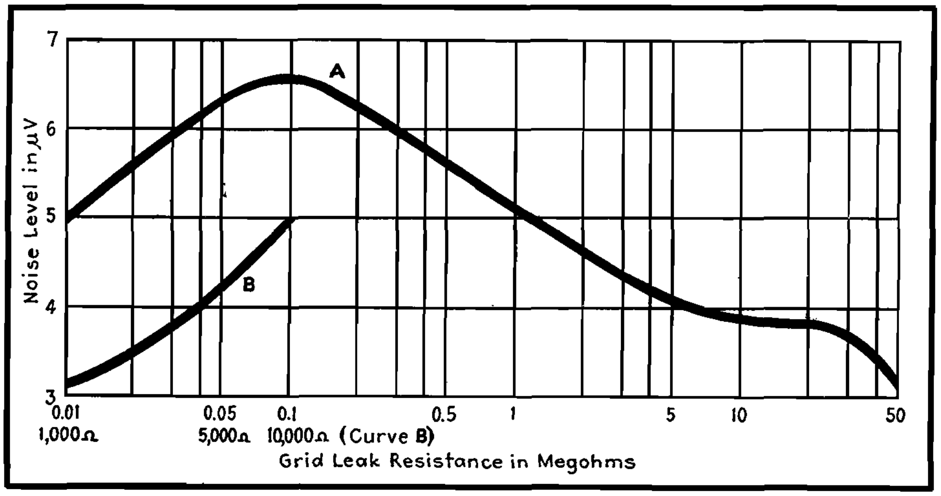

Fig. 2.—Noise level vs. grid-leak value for a triode-connected 6SJ7 tube. Curve B is for very low values of grid-cathode resistance.

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.

The curve of noise level vs. cathode-grid voltage is given for a 6SJ7 tube in Fig. 1. Least noise is obtained for that value of cathode resistor which gives a cathode-grid voltage of −1.2 volts. The open-grid tube seems automatically to 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.

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. (8) 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.

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.

Bibliography

(1) Reich, H. J., "Theory and Applications of Electron Tubes," p. 184, McGraw-Hill Book Company, Inc., New York, 1939.

(2) Everitt, W. L., "Communications Engineering," p. 241, McGraw-Hill Book Company, Inc., New York, 1937.

(3) Harris, W. A., Fluctuations in Vacuum Tube Amplifiers and Input Systems, *RCA Rev.*, **5**, 505, April, 1941.

(4) King, Ronald. A Screen Grid Voltmeter Without External Leak, *Proc. IRE*, **22**, 771, June, 1934.

(5) Moullin, E. B., "Spontaneous Fluctuations of Voltage," Oxford University Press, New York, 1938.

(6) Terman, F. E., "Radio Engineering," p. 228, McGraw-Hill Book Company, Inc., 1937.

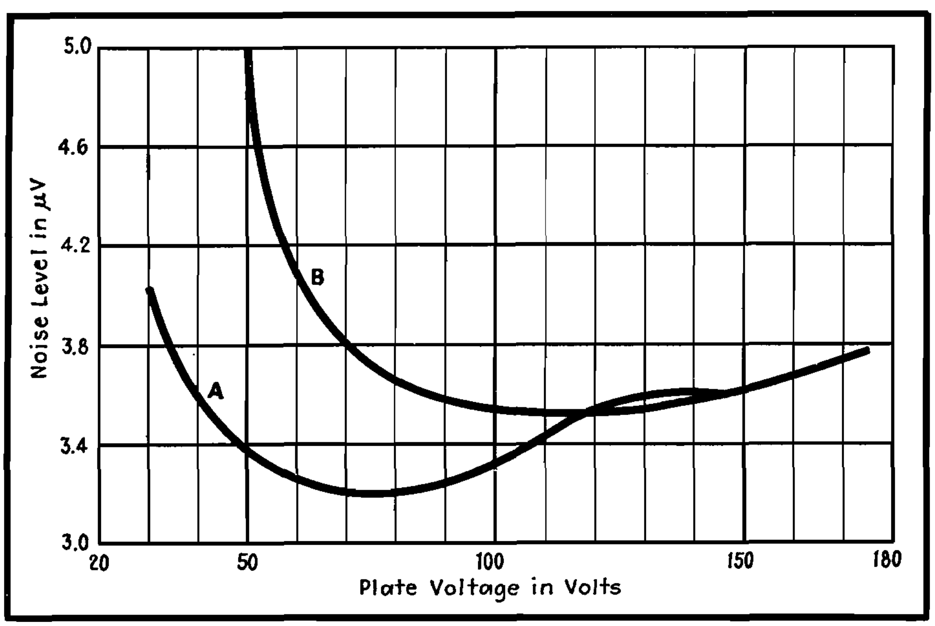

Fig. 3.—Noise level vs. plate voltage for a triode-connected 6SJ7 tube with two different grid-circuit arrangements. Curve A, 40 μμf in grid circuit; curve B, 40 μμf in parallel with 35 megohms in grid circuit.