

generator may be proven as follows:

Figure 3 shows an idealized plate characteristic for a triode tube (solid lines). Above a certain current value the characteristics are straight, parallel, and equally spaced for equal increments of voltage. Because of the absence of curvature, no distortion is assumed to take place above the I_{bmin} coordinate. The intersection of coordinates I_{b0} and E_{b0} determines Q_0 —the quiescent operating point. The vertical projection of Q_0 up to the $e_g = 0$ line gives the value marked I_0 on the graph. Since the slope of the lines above I_{bmin} is r_p , the equation for I_0 may be written readily with the use of elementary geometry.

$$I_0 = I_{bmin} + 2i_p + e_p/r_p \quad (3)$$

In any amplifier the following relations hold

$$R_l = e_p/i_p \quad (4)$$

$$P_o = \frac{1}{2}(e_p) i_p \quad (5)$$

The above equations may be rewritten through the use of the relation

$$e_p = \mu e_g$$

$$I_0 = I_{bmin} + 2i_p + \mu e_g/r_p \quad (3a)$$

$$R_l = \mu e_g/i_p \quad (4a)$$

$$P_o = \frac{1}{2}(\mu e_g) i_p \quad (5a)$$

To solve for maximum power output under the given restrictions, equations (3a) and (5a) are differentiated and the results set equal to zero. Implicit differentiation and solution of (3a) gives

$$-\mu \frac{de_g}{di_p} = 2r_p \quad (3b)$$

while differentiation with respect to i_p and solution of (5a) gives

$$\frac{\mu e_g}{i_p} = -\mu \frac{de_g}{di_p} \quad (5b)$$

It is easily seen from (4a) that the left member of (5b) is R_l and from (3b) that the right member is $2r_p$. The optimum load R_l for minimum distortion is therefore

$$R_l = 2r_p$$

This is the result for no feedback. If the same tube is used as a cathode follower,

the characteristics are changed, as shown in the graph by the dotted lines. For these curves, a new form of (1) may be written; (4) and (5), being general, are unaltered.

$$I_0 = I_{bmin} + 2i_p + \mu' e_g/r'_p \quad (1c)$$

For the cathode follower the effective plate resistance r'_p is

$$r'_p = r_p/(\mu + 1)$$

and the effective amplification factor μ'

$$\mu' = \mu/(\mu + 1)$$

Substitution of these values in (1c) gives

$$\begin{aligned} I_0 &= I_{bmin} + 2i_p + \frac{(\mu/\mu + 1)e_g}{r_p/(\mu + 1)} \\ &= I_{bmin} + 2i_p + \mu e_g/r_p \quad (3a) \end{aligned}$$

The final equation is (3a) of the original conditions. Consequently, solving it and (5a) for the optimum load will give the same result for the cathode follower that it did for the original tube, namely

$$R_l = 2r_p$$

In actual practice this value of load resistance is not strictly adhered to, and other, more complicated formulas may be used^{3,4}, or the optimum load may be determined by experiment.

Damping Properties

The superior damping ability of the cathode follower is generally one of the main reasons cited for its use as an output tube, and this damping quality attributed to its low effective generator impedance. It is not only the low effective plate resistance that provides the superior damping, however, but primarily the fact that the impedance matching is done on the basis of the original characteristics.

For example, the 6A5 triode has a μ of 4.2 and an r_p of 800 ohms. The optimum load on a $2r_p$ basis is therefore 1600 ohms. To match a 10-ohm speaker to this tube requires a transformer with an impedance ratio of 10:1600 or 1:160. The transformer also changes the im-

pedance that the speaker sees by the inverse of this ratio, i.e., 1/160. The effective generator reflected impedance is therefore 800/160 or 5 ohms. The same tube hooked up as a cathode follower has an effective plate resistance of $r_p/(\mu + 1) = 800/5.2 = 154$ ohms. To match a 10-ohm speaker to twice this value (308 ohms) would require a transformer ratio of 10:308 or 1:30.8. The reflected generator impedance seen by the speaker is 154/30.8 = 5 ohms, the same impedance that it saw in the original circuit, and therefore the damping factor has not been changed.

However, if the speaker is matched to twice the plate resistance of the original tube (the proper method), the same transformer is used as in the first case, and the speaker load looks like 10(160) = 1600 ohms to the tube. The tube looks like 154/160 = 0.96 ohms to the speaker, and the damping factor has been increased by 5/0.96 = 5.2 = $\mu + 1$ of the original tube. Since in general the optimum load given by manufacturers is greater than $2r_p$, the damping factor is further increased. The manufacturers' rating of 2500 ohms for the 6A5 would give an effective generator impedance of 154/250 = 0.61 ohms and a damping factor increase of 5/0.61 = 8.2 for cathode-follower operation.

The principal relations in cathode-follower operations may be summarized briefly as follows:

1. Bias point unchanged
2. Grid-current point unchanged
3. Effective amplification factor reduced
4. Effective plate resistance reduced
5. Optimum load unchanged
6. Damping factor increased (if 5. is followed).

The advantage of cathode follower operation are numerous and include good frequency response, low distortion, and good damping properties. The disadvantages are few, but in some cases serious enough to preclude use of the stage. Principal among these are lack of voltage amplification (which imposes extremely severe requirements on the preceding stage if distortion is to be avoided), very low efficiency (for most designs), and low power sensitivity.

³ K. R. Sturley, "Radio Receiver Design, Part II." New York: John Wiley and Sons, 1948, pp 56-64.

⁴ W. B. Nottingham, "Optimum Conditions for Maximum Power in Class A Amplifiers," *Proc. I. R. E.*, Dec. 1941, p 620.