

grid bias is made more negative to handle larger input signals, the electron flow from the sections of the cathode enclosed by the ends of the grid is cut off. The plate current and other tube characteristics are then dependent on the electron flow through the open section of the grid. This action changes the gain of the tube so that large signals may be handled with minimum distortion due to cross-modulation and modulation-distortion.

Fig. 38 shows a typical plate-current vs. grid-voltage curve for a remote-cutoff type compared with the curve

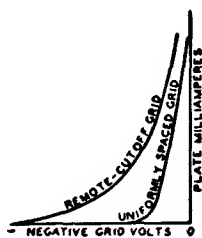


Fig. 38—Plate-current curves for triodes having remote-cutoff and uniformly spaced grids.

for a type having a uniformly spaced grid. It will be noted that while the curves are similar at small grid-bias voltages, the plate current of the remote-cutoff tube drops quite slowly with large values of bias voltage. This slow change makes it possible for the tube to handle large signals satisfactorily. Because remote-cutoff types can accommodate large and small signals, they are particularly suitable for use in sets having automatic volume control. Remote-cutoff tubes also are known as **variable-mu** types.

### Class A Power Amplifiers

As a class A power amplifier, an electron tube is used in the output stage of a radio or television receiver to supply a relatively large amount of power to the loudspeaker. For this application, large power output is of more importance than high voltage amplification; therefore, gain possibilities are sacrificed in the design of power tubes to obtain power-handling capability.

Triodes, pentodes, and beam power

tubes designed for power amplifier service have certain inherent features for each structure. Power tubes of the triode type for class A service are characterized by low power sensitivity, low plate-power efficiency, and low distortion. Power tubes of the pentode type are characterized by high power sensitivity, high plate-power efficiency and, usually, somewhat higher distortion than class A triodes. Beam power tubes have higher power sensitivity and efficiency than triode or conventional pentode types.

A class A power amplifier is also used as a driver to supply power to a class AB<sub>2</sub> or a class B stage. It is usually advisable to use a triode, rather than a pentode, in a driver stage because of the lower plate impedance of the triode.

Power tubes connected in either **parallel** or **push-pull** may be employed as class A amplifiers to obtain increased output. The parallel connection (Fig. 39) provides twice the output of a single tube with the same value of grid-signal voltage. With this connection, the effective transconductance of the stage is doubled, and the effective plate

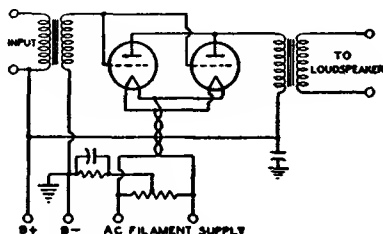


Fig. 39—Power amplifier with tubes connected in parallel.

resistance and the load resistance required are halved as compared with single-tube values.

The push-pull connection (Fig. 40), although it requires twice the grid-signal voltage, provides increased power and has other important advantages over single-tube operation. Distortion caused by even-order harmonics and hum caused by plate-voltage-supply fluctuations are either eliminated or decidedly reduced through cancellation.

Because distortion for push-pull operation is less than for single-tube operation, appreciably more than twice single-tube output can be obtained with triodes by decreasing the load resistance for the stage to a value approaching the load resistance for a single tube.

For either parallel or push-pull class A operation of two tubes, all electrode currents are doubled while all dc electrode voltages remain the same as for single-tube operation. If a cathode resistor is used, its value should be about one-half that for a single tube.

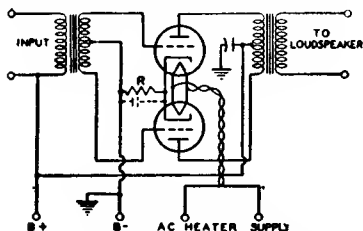


Fig. 40—Power amplifier with tubes connected in push-pull.

If oscillations occur with either type of connection, they can often be eliminated by the use of a non-inductive resistor of approximately 100 ohms connected in series with each grid at the socket terminal.

Operation of power tubes so that the grids run positive is inadvisable except under conditions such as those discussed in this section for class AB and class B amplifiers.

### Power-Output Calculations

Calculation of the power output of a triode used as a class A amplifier with either an output transformer or a choke having low dc resistance can be made

without serious error from the plate family of curves by assuming a resistance load. The proper plate current, grid bias, optimum load resistance, and per-cent second-harmonic distortion can also be determined. The calculations are made graphically and are illustrated in Fig. 41 for given conditions. The procedure is as follows:

(1) Locate the zero-signal bias point P by determining the zero-signal bias  $E_c$  from the formula:

$$\text{Zero-signal bias } (E_c) = -(0.68 \times E_b) / \mu$$

where  $E_b$  is the chosen value in volts of dc plate voltage at which the tube is to be operated, and  $\mu$  is the amplification factor of the tube. This quantity is shown as negative to indicate that a negative bias is used.

(2) Locate the value of zero-signal plate current,  $I_0$ , corresponding to point P.

(3) Locate the point  $2I_0$ , which is twice the value of  $I_0$  and corresponds to the value of the maximum-signal plate current  $I_{\max}$ .

(4) Locate the point X on the dc bias curve at zero volts,  $E_c = 0$ , corresponding to the value of  $I_{\max}$ .

(5) Draw a straight line XY through X and P.

Line XY is known as the load resistance line. Its slope corresponds to the value of the load resistance. The load resistance in ohms is equal to  $(E_{\max} - E_{\min})$  divided by  $(I_{\max} - I_{\min})$ , where E is in volts and I is in amperes.

It should be noted that in the case of filament types of tubes, the calculations are given on the basis of a dc-operated filament. When the filament is ac-operated, the calculated value of dc

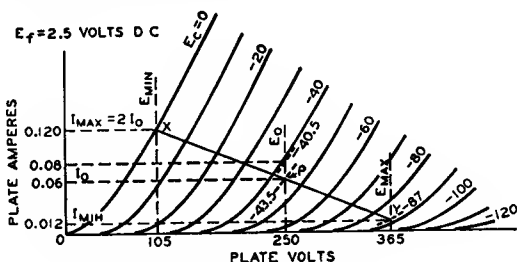


Fig. 41—Graphic calculations for class A amplifier using a power triode.

bias should be increased by approximately one-half the filament voltage rating of the tube.

The value of zero-signal plate current  $I_o$  should be used to determine the plate dissipation, an important factor influencing tube life. In a class A amplifier under zero-signal conditions, the plate dissipation is equal to the power input, *i.e.*, the product of the dc plate voltage  $E_o$  and the zero-signal dc plate current  $I_o$ . If it is found that the plate-dissipation rating of the tube is exceeded with the zero-signal bias  $E_o$ , calculated above, it will be necessary to increase the bias by a sufficient amount so that the actual plate dissipation does not exceed the rating before proceeding further with the remaining calculations.

For power-output calculations, it is assumed that the peak alternating grid voltage is sufficient (1) to swing the grid from the zero-signal bias value  $E_o$  to zero bias ( $E_c = 0$ ) on the positive swing and (2) to swing the grid to a value twice the zero-signal bias value on the negative swing. During the negative swing, the plate voltage and plate current reach values of  $E_{max}$  and  $I_{min}$ ; during the positive swing, they reach values of  $E_{min}$  and  $I_{max}$ . Because power is the product of voltage and current, the power output  $P_o$  as shown by a watt-meter is given by

$$P_o = \frac{(I_{max} - I_{min}) \times (E_{max} - E_{min})}{8}$$

where  $E$  is in volts,  $I$  is in amperes, and  $P_o$  is in watts.

In the output of power-amplifier triodes, some distortion is present. This distortion is due predominantly to second harmonics in single-tube amplifiers. The percentage of second-harmonic distortion may be calculated by the following formula:

$$\% \text{ distortion} = \frac{\frac{I_{max} + I_{min}}{2} - I_o}{I_{max} - I_{min}} \times 100$$

where  $I_o$  is the zero-signal plate current in amperes. If the distortion is excessive, the load resistance should be increased or, occasionally, decreased slightly and the calculations repeated.

**Example:** Determine the load resistance, power output, and distortion

of a triode having an amplification factor of 4.2, a plate-dissipation rating of 15 watts, and plate-characteristics curves as shown in Fig. 41. The tube is to be operated at 250 volts on the plate.

**Procedure:** For a first approximation, determine the operating point  $P$  from the zero-signal bias formula,  $E_c = -(0.68 \times 250) / 4.2 = -40.5$  volts. From the curve for this voltage, it is found that the zero-signal plate current is 0.08 ampere and, therefore, the plate-dissipation rating is exceeded ( $0.08 \times 250 = 20$  watts). Consequently, it is necessary to reduce the zero-signal plate current to 0.06 ampere at 250 volts. The grid bias is then  $-43.5$  volts. Note that the curve was taken with a dc filament supply; if the filament is to be operated on an ac supply, the bias must be increased by about one-half the filament voltage, or to  $-45$  volts, and the circuit returns made to the mid-point of the filament circuit.

Point  $X$  can then be determined. Point  $X$  is at the intersection of the dc bias curve at zero volts with  $I_{max}$ , where  $I_{max} = 2I_o = 2 \times 0.06 = 0.12$  ampere. Line  $XY$  is drawn through points  $P$  and  $X$ .  $E_{max}$ ,  $E_{min}$ , and  $I_{min}$  are then found from the curves. When these values are substituted in the power-output formula, the following result is obtained:

$$P_o = \frac{(0.12 - 0.012) \times (365 - 105)}{8} = 3.52 \text{ watts}$$

The resistance represented by load line  $XY$  is

$$\frac{(365 - 105)}{(0.12 - 0.012)} = 2410 \text{ ohms}$$

When the values from the curves are substituted in the distortion formula, the following result is obtained:

$$\% \text{ distortion} = \frac{\frac{0.12 + 0.012}{2} - 0.06}{0.12 - 0.012} \times 100 = 5.5\%$$

It is customary to select the load resistance so that the distortion does not exceed five per cent. When the method shown is used to determine the slope of the load-resistance line, the second-harmonic distortion generally does not exceed five per cent. In the example, however, the distortion is excessive and it is desirable, therefore, to use a slightly higher load resistance. A load resistance

of 2500 ohms will provide a distortion of about 4.9 per cent. The power output is reduced only slightly to 3.5 watts.

Operating conditions for **triodes in push-pull** depend on the type of operation desired. Under class A conditions, distortion, power output, and efficiency are all relatively low. The operating bias can be anywhere between that specified for single-tube operation and that equal to one-half the grid-bias voltage required to produce plate-current cutoff at a plate voltage of  $1.4E_o$ , where  $E_o$  is the operating plate voltage. Higher bias than this value requires higher grid-signal voltage and results in class AB<sub>1</sub> operation, which is discussed later.

The method for calculating maximum power output for triodes in **push-pull class A operation** is as follows: Erect a vertical line at  $0.6 E_o$  (see Fig. 42), intersecting the  $E_c = 0$  curve at the point  $I_{max}$ . Then,  $I_{max}$  is determined from the curve for use in the formula

$$P_o = (I_{max} \times E_o)/5$$

If  $I_{max}$  is expressed in amperes and  $E_o$  in volts, power output is in watts.

**Example:** Assume that the plate voltage ( $E_o$ ) is to be 300 volts, and the plate-dissipation rating of the tube is 15 watts. Then, for class A operation, the operating bias can be equal to, but not more than, one-half the grid bias for cutoff with a plate voltage of  $1.4 \times 300 = 420$  volts. (Since cutoff bias is approximately  $-115$  volts at a plate voltage of 420 volts, one-half of this value is  $-57.5$  volts bias.) At this bias, the plate current is found from the plate family to be 0.054 ampere and, therefore, the plate dissipation is  $0.054 \times 300$  or 16.2 watts. Since  $-57.5$  volts is the limit of bias for class A operation of these tubes at a plate voltage of 300 volts, the dissipation cannot be reduced by increasing the bias and it becomes necessary to reduce the plate voltage.

If the plate voltage is reduced to 250 volts, the bias will be found to be  $-43.5$  volts. For this value, the plate current is 0.06 ampere, and the plate dissipation is 15 watts. Then, following the method for calculating power output, erect a vertical line at  $0.6E_o = 150$

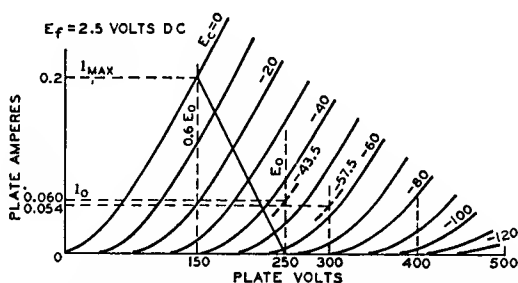


Fig. 42—Graphic calculations for push-pull class A amplifier using a power triode.

The method for determining the proper load resistance for triodes in push-pull is as follows: Draw a load line through  $I_{max}$  on the zero-bias curve and through the  $E_o$  point on the zero-current axis. Four times the resistance represented by this load line is the plate-to-plate load ( $R_{pp}$ ) for two triodes in a class A push-pull amplifier. Expressed as a formula,

$$R_{pp} = 4 \times (E_o - 0.6E_o)/I_{max}$$

where  $E_o$  is expressed in volts,  $I_{max}$  in amperes, and  $R_{pp}$  in ohms.

The intersection of the line with the curve  $E_c = 0$  is  $I_{max}$  or 0.2 ampere. When this value is substituted in the power formula, the power output is  $(0.2 \times 250)/5 = 10$  watts. The load resistance is determined from the load formula: Plate-to-plate load ( $R_{pp}$ ) =  $4 \times (250 - 150)/0.2 = 2000$  ohms.

**Power output for a pentode or a beam power tube as a class A amplifier** can be calculated in much the same way as for triodes. Calculations can be made graphically from a special plate family of curves, as shown in Fig. 43.

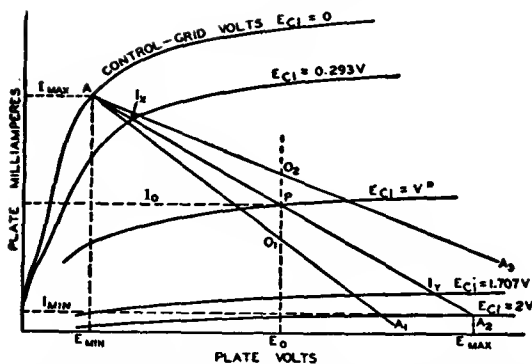


Fig. 43—Graphic calculations for class A amplifier using a pentode or beam power tube.

From a point A at or just below the knee of the zero-bias curve, draw arbitrarily selected load lines to intersect the zero-plate-current axis. These lines should be on both sides of the operating point P, whose position is determined by the desired operating plate voltage,  $E_0$ , and one-half the maximum-signal plate current. Along any load line, say  $AA_1$ , measure the distance  $AO_1$ . On the same line, lay off an equal distance,  $O_1A_1$ . For optimum operation, the change in bias from A to  $O_1$  should be nearly equal to the change in bias from  $O_1$  to  $A_1$ . If this condition can not be met with one line, as is the case for the line first chosen, then another should be chosen. When the most satisfactory line has been selected, its resistance may be determined by the following formula:

$$\text{Load resistance (R}_L\text{)} = \frac{E_{\max} - E_{\min}}{I_{\max} - I_{\min}}$$

The value of  $R_L$  may then be substituted in the following formula for calculating power output.

$$P_o = \frac{[I_{\max} - I_{\min} + 1.41 (I_x - I_y)]^2 R_L}{32}$$

In both of these formulas,  $I$  is in amperes,  $E$  is in volts,  $R_L$  is in ohms, and  $P_o$  is in watts.  $I_x$  and  $I_y$  are the current values on the load line at bias voltages of  $E_{c1} = V - 0.707V = 0.293V$  and  $E_{c1} = V + 0.707V = 1.707V$ , respectively.

Calculations for distortion may be made by means of the following formula.

The terms used have already been defined.

% 2nd-harmonic distortion =

$$\frac{I_{\max} + I_{\min} - 2 I_0}{I_{\max} - I_{\min} + 1.41 (I_x - I_y)} \times 100$$

% 3rd-harmonic distortion =

$$\frac{I_{\max} - I_{\min} - 1.41 (I_x - I_y)}{I_{\max} - I_{\min} + 1.41 (I_x - I_y)} \times 100$$

% total (2nd and 3rd) harmonic distortion =

$$\sqrt{(\% \text{ 2nd})^2 + (\% \text{ 3rd})^2}$$

### Conversion Factors

Operating conditions for voltage values other than those shown in the published data can be obtained by use of the nomograph shown in Fig. 44 when all electrode voltages are changed simultaneously in the same ratio. The nomograph includes conversion factors for current ( $F_i$ ), power output ( $F_p$ ), plate resistance or load resistance ( $F_r$ ), and transconductance ( $F_{gm}$ ) for voltage ratios between 0.5 and 2.0. These factors are expressed as functions of the ratio between the desired or new voltage for any electrode ( $E_{daa}$ ) and the published or original value of that voltage ( $E_{pub}$ ). The relations shown are applicable to triodes and multigrid tubes in all classes of service.

To use the nomograph, simply place a straight-edge across the page so that it intersects the scales for  $E_{daa}$  and  $E_{pub}$  at the desired values. The desired conversion factor may then be read directly or estimated at the point where the straight-edge intersects the  $F_i$ ,  $F_p$ ,  $F_r$ , or  $F_{gm}$  scale.

For example, suppose it is desired to operate two 6L6GC's in class A<sub>1</sub> push-pull, fixed bias, with a plate voltage of 200 volts. The nearest published operating conditions for this class of service are for a plate voltage of 250 volts. The operating conditions for the new plate voltage can be determined as follows:

The voltage conversion factor,  $F_v$ , is equal to 200/250 or 0.8. The dashed lines on the nomograph of Fig. 44 indicate that for this voltage ratio  $F_v$  is approximately 0.72,  $F_p$  is approximately 0.57,  $F_r$  is 1.12, and  $F_{gm}$  is approximately 0.892. These factors may be applied directly to operating values shown in the tube data, or to values calculated by the methods described previously.

Because this method for conversion

of characteristics is necessarily an approximation, the accuracy of the nomograph decreases progressively as the ratio  $E_{des}/E_{pub}$  departs from unity. In general, results are substantially correct when the value of the ratio  $E_{des}/E_{pub}$  is between 0.7 and 1.5. Beyond these limits, the accuracy decreases rapidly, and the results obtained must be considered rough approximations.

The nomograph does not take into consideration the effects of contact potential or secondary emission in tubes. Because contact-potential effects become noticeable only at very small dc grid-No. 1 (bias) voltages, they are generally negligible in power tubes. Secondary emission may occur in conventional tetrodes, however, if the plate voltage swings below the grid-No. 2 voltage. Consequently, the conversion

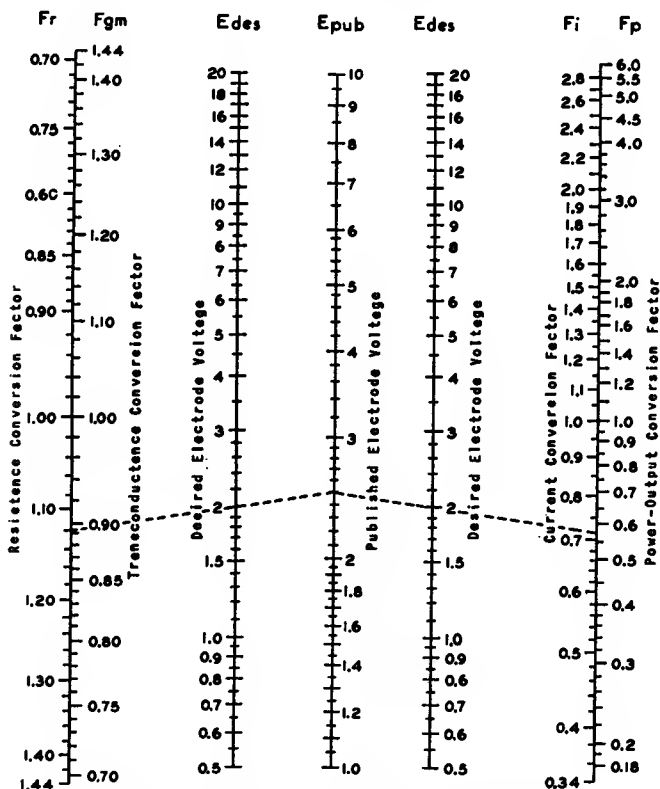


Fig. 44—Nomograph of tube conversion factors.