

CALCULATION OF TUBE OPERATING CONDITIONS (CONT'D)

ing at the peak of the audio cycle, it will be necessary to work to rather high peak currents. This will require that the grid be driven to a considerably higher positive peak than for the carrier conditions. It is not generally desirable to modulate the grid drive, but the higher positive grid drive may be accomplished in practice by two factors. If a combination fixed and grid resistor bias is used, the bias voltage developed will be reduced at the peak of the audio cycle. This will be true since the minimum plate voltage on this operating line is higher than for the carrier operating line, which results in working the tube in a lower grid current region. This reduces the grid current, and hence the bias voltage. Thus, with constant grid excitation the positive grid voltage peak will be raised by the amount of reduced grid bias. In actual practice, with reduced loading of the grid excitation supply, the grid drive voltage will increase to some extent, thus increasing further the positive peak grid voltage.

For Class B Audio Amplifiers

Operating conditions and calculations are those for a two-tube push-pull amplifier, since this is the type of circuit generally encountered in this class of service.

The applied conditions of operation must first be determined as follows:

- (1) The d-c plate voltage is arbitrarily assigned to be 7500 volts.
- (2) The plate current is to be chosen for zero signal input.

Fig. 11 represents a composite plate characteristic curve for two tubes.¹ Use of this curve clarifies the analysis which is complicated by the fact that the plate currents of the two tubes act on a common magnetic circuit in the output transformer. The composite curve is formed by placing two sets of static plate characteristic curves back to back as indicated in the figure.

Since the plate currents for the two tubes act through the output transformer in opposite directions, only their differences contribute to useful output. Therefore, the dotted lines indicate useful composite plate characteristics for the two tubes, the grid voltage lines now corresponding to signal voltages.

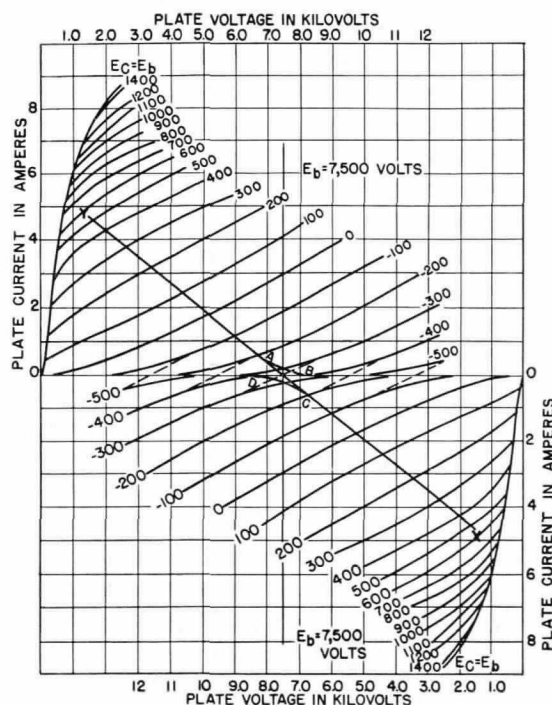
The output operating line is shown as X-Y. The individual tube operating lines are YAB and XCD.

The individual tube operating lines of Fig. 11 are based on a zero signal plate current of 0.2 ampere. In general a value of 10 to 15 per cent of the average plate current is used. If too high a value of zero signal current is used, the distortion, and plate dissipation will be excessive.

(3) The grid bias voltage is established, since a d-c plate voltage of 7500 volts, and a zero signal plate current of 0.2 ampere has been chosen for this set of calculations. From the plate current curves, this would require -300 volts bias.

(4) Assume a peak positive grid voltage of 550 volts. This is an arbitrary value, and may be applied by a suitable driving stage. The peak grid swing is then 850 volts. If too high a value of positive grid voltage is chosen, the driving power will be greatly increased with little increase in power output.

(5) For this set of calculations a plate voltage swing of 6000 volts will be used. This again is an arbitrary value, and ordinarily is approximately 80 per cent of the d-c plate voltage. If too low a minimum plate voltage dip is used, excessive distortion and grid drive will result. If too high a minimum plate voltage dip is used, plate efficiency is sacrificed. The value of the load impedance in the plate output circuit to give this swing will be determined from the ratio of the plate voltage swing to the peak plate current as determined later in the calculations.



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Fig. 11—Composite Plate Characteristic Curve for Combined Tubes and Transformer (Class B Audio Service)

¹ B. J. Thompson, "Push-Pull Audio Amplifier," Proceedings of the I.R.E. (April, 1933), p. 591.

Summarizing the above, the following conditions of operation have been established thus far:

- (1) D-c plate voltage = 7500 volts
- (2) Grid bias voltage = -300 volts
- (3) Peak grid voltage swing = 850 volts. This results in a maximum positive grid voltage of 550 volts, at maximum signal.
- (4) Peak plate voltage swing = 6000 volts. This results in a minimum plate voltage dip of 1500 volts at maximum signal.

The above conditions completely determine the operating line X-Y, Fig. 11.

Efficient operating conditions for Class B audio amplifiers normally result in some distortion. This can be tolerated since the even order harmonics are eliminated from the output in the push-pull amplifier. However, this makes it impossible to draw a straight operating line between points A and B of Fig. 12, as was done in the case of the Class C amplifier for calculation of operating conditions. However, items 1 through 4 above do define the extreme points of grid and plate voltage and current excursions as shown by points X and Y, of Fig. 11, and A and B, Fig. 12.

Reference is again made to Fig. 11. The load line X-Y must be straight, since the load current must vary directly with the plate voltage, the load impedance being constant. Working from Fig. 11, the operating line A-B of Fig. 12, is laid out so that the grid voltage for any value of plate voltage correspond on the two curves. For example, on Fig. 11 for a grid of voltage plus 300 the plate voltage is 2700. This then deter-

mined one of the points, P along which the curve A-B, Fig. 12, was to lie. Having laid out the operating line A-B, Fig. 12, it remains to calculate the tube operation as shown in the chart of Fig. 13.

Complete tube performance may thus be determined for the chosen set of conditions, as follows:

- (1) D-c plate input kw (per tube)
- (2) Plate output power (per tube)
- (3) Plate dissipation
- (4) Plate efficiency
- (5) Grid excitation power
- (6) Load resistance—plate to plate
- (7) D-c grid current
- (8) Grid bias loss

All of the above results are for maximum signal operation. The maximum anode dissipation, however, will be found to occur at a signal less than unity, approximately at $S = \frac{2}{K}$ where:

K = ratio of plate voltage swing to the d-c plate voltage, at maximum signal
 $S = 1$.

S = ratio of the signal under consideration (grid swing), to the maximum signal, as used in the sample calculation.

Thus for the conditions of operation chosen for the sample calculation the signal for maximum anode dissipation is determined as follows:

$$K = \frac{6000}{7500} = 0.80$$

$$S = \frac{2}{0.8 \times 3.14} = 0.794$$

The maximum signal grid swing ($S = 1$), in the example, Fig. 13, was 850 volts. For $S = 0.794$, the grid swing will be 675 volts, with a maximum positive grid voltage peak of 375 volts. The operating line for $S = 0.794$ is then A-C, Fig. 12. Carrying through calculations for this operating line, similar to those in the chart of Fig. 13, it will be found that the anode dissipation is 4.42 kilowatts. Since this value is within the rated anode dissipation of the tube, the conditions chosen for operating line A-B are satisfactory.

If the operating line A-B deviates greatly from a straight line, it is an indication that distortion is present, and the output should be checked for harmonic content.

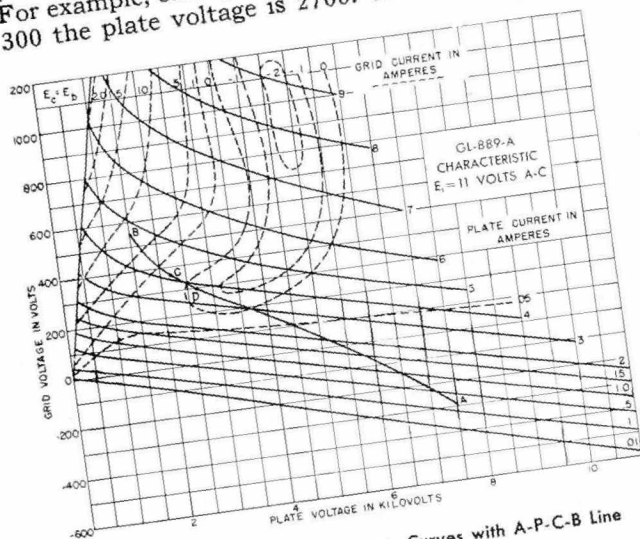


Fig. 12—GL-889-A Characteristic Curves with A-P-C-B Line

CALCULATION OF TUBE OPERATING CONDITIONS (CONT'D)

TYPE GL-889A CALCULATION OF TYPICAL OPERATING CONDITIONS BY _____ DATE _____
CLASS B AUDIO AMPLIFIER SERVICE

Angle Degrees	Sine	e_p Volts	Plate Swing Volts	i_p Amperes	Product Plate Swing and i_p	e_g Volts	i_g Amperes	Product Sine Amperes
0	0	7500			—	-300		—
5	0.087	7000	500	.5	250	-226		
15	0.258	5900	1900	1.3	2,080	-81		
25	0.423	4800	2700	2.1	5,670	+59	0.05	0.021
35	0.574	3700	3800	2.95	11,200	187		
45	0.707	2700	4800	3.8	18,250	300		
55	0.819	2100	5400	4.2	22,700	395	0.10	0.082
65	0.906	1800	5700	4.5	25,700	470	0.40	0.362
75	0.966	1600	5900	4.6	27,100	520	0.70	0.676
85	0.996	1500	6000	4.7	28,200	547	0.75	0.746
90	1.00	1500		(*)	—	550	(*)	—

5-85 Incl. Summation
Divided By
Average Current $I_b =$
0° $E_b = 7500$
90° $e_p = 1500$
Difference (Swing) 6000

28.65
18
159
141,150
18
(I_g) =
 $E_c = -300$
 $e_g = 550$
(Swing) 850

2.00
18
0.111
1.887
18
0.105

Plate Input = $E_b \times I_b = 7500 \times 1.59$ = 11.92 kilowatts
Plate Output = 141.50
..... = 7.83 kilowatts
Plate Dissipation = Plate Input - Plate Output = 4.09 kilowatts
Efficiency = $\frac{\text{Output}}{\text{Input}} = \frac{850}{11.92}$ 105 = 65.6%
Total Grid Excitation Power = Grid Swing $\times$ Average Product Sine Amperes = ... = 89.2 watts
Grid Bias Loss = $I_g \times E_c = .111 \times 300$ = 33 watts

* Peak value—for reference only—omit from calculation of average currents.

Load Resistance = $\frac{\text{Peak plate voltage swing}}{\text{Peak plate current}} = \frac{6000}{4.7}$
= 1276 ohms

Effective load, plate to plate = $4 \times 1305 = 5220$ ohms

Fig. 13—Chart Showing Calculation of Typical Operating Conditions for Class B Audio Amplifier

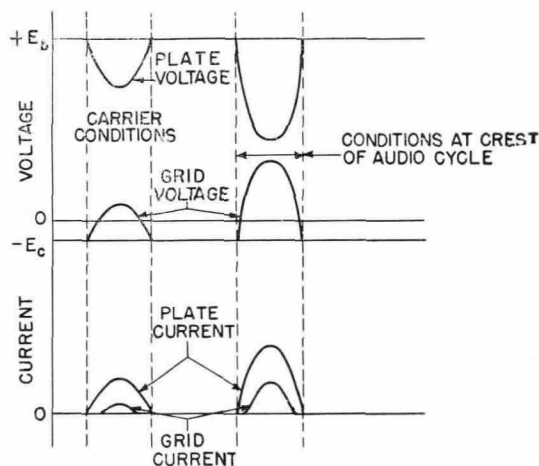
FOR CLASS B RADIO-FREQUENCY AMPLIFIERS

In Class B radio-frequency amplifier service, the radio-frequency current and voltage relations are as indicated in Fig. 14 below.

If the amplifier output is free from distortion, the plate voltage and plate current will vary linearly with the grid swing. Thus for a maximum modulation factor of 1.0 at the crest of the audio cycle the radio-frequency voltage and currents will be double those for the carrier conditions.

In calculating the performance of the Class B radio-frequency amplifier, the operating line A-B, Fig. 15, must be established by the following steps:

(1) Point A depends upon the value of d-c plate voltage and grid bias chosen. The higher the plate voltage the greater the power capa-



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Fig. 14—Instantaneous Radio-frequency Voltage and Current Relations

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bilities of the tube. The grid bias voltage is such as to allow a zero signal plate current of 10 to 15 per cent of the average d-c plate current under carrier conditions. The same factors apply as explained under Class B audio service. In the curve, Fig. 15, the point A is located at a plate voltage of 7500 volts, and a grid voltage of -300 volts.

(2) The location of point B depends upon a number of considerations. If it approaches too close to the diode line the grid drive and distortion are likely to become excessive for maximum modulation. If B is located too high in the positive grid region the grid drive would be increased at maximum modulation. It is usually necessary to make several sets of calculations to determine the optimum conditions for minimum distortion at the desired power output and maximum efficiency. Taking the above factors into account the point B for the curve on Fig. 15 was located at a plate voltage of 2500 volts and a grid voltage of 700 volts.

As in the case of the Class C oscillator the operating line on Fig. 15 is a straight line connecting points A and B.

Calculations for maximum modulation conditions will then be identical to those described for Class C operation, operating over the entire line from A to B.

Under carrier conditions, the tube operates over the same line, but the grid and plate swing are only one half that for maximum modulation. Therefore, for carrier conditions, calculations are similar to those for maximum modulation are made, but the operating line extends only from A to C. Maximum plate dissipation occurs under carrier conditions so the value of dissipation calculated should be checked to see that the maximum ratings are not exceeded.

It is advisable to plot the rms value of the plate current versus the grid voltage for the conditions chosen for maximum modulation and to analyze the current wave for excessive distortion.

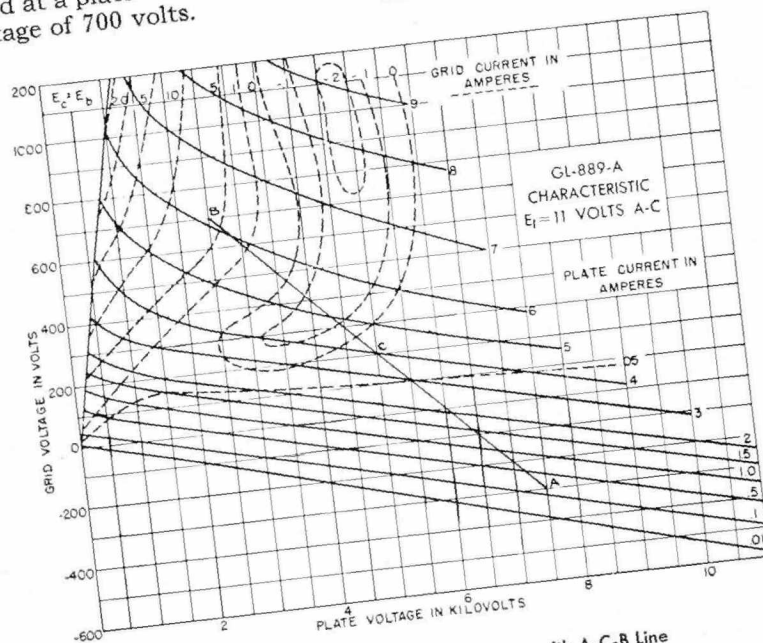


Fig. 15—GL-889-A Characteristic Curves with A-C-B Line

APPLICATIONS

General

Although the number and variety of tube types presented in this manual may seem somewhat bewildering at first glance, the selection of the most suitable tubes for a specific application is not difficult. The "Quick Selection Chart," included in the manual, provides a breakdown of tube types by method of cooling and maximum power input at various frequencies. Correlating

design considerations such as size, cost, and mobility must be taken into account, but are too varied and complex for treatment here.

A number of circuits are included to cover typical installations for rectifiers, oscillators, multipliers, and power amplifiers. Each circuit represents only one of the many accepted approaches to the problem involved, and is intended only as a guide to the designer.

Circuits shown in ETX-108 are examples of possible tube applications and the description and illustration of them does not convey to the purchaser of tubes any license under patent rights of General Electric Company.