

tion are of primary importance. Almost all commercial installations are designed by these ratings. Where factors of weight, cost, and size vs. power output appear most important, the ICAS (Intermittent Commercial and Amateur Service), rating may be applied. Intermittent service is generally considered to be service in which the operating period never exceeds five minutes, and the stand-by interval is at least equal to this operating period.

Filament Circuit—Filament and heater ratings are invariably given in terms of average voltage. Nominal current at rated voltage is included only as an aid in equipment design. The filament circuit should be so regulated as to limit the possible voltage deviation to  $\pm 5$  per cent of the

rated value unless otherwise specified on the data sheet.

Plate Circuit—In the plate ratings of transmitting tubes, the operating frequency of the tubes is an important parameter. Wherever a tube is designed for high-frequency operation, the data sheet includes a tabulation of the maximum permissible percentage of maximum rated plate voltage and plate input as a function of frequency.

It will be noted that in most cases the product of maximum plate voltage and maximum plate current is higher than the maximum permissible plate dissipation. Plate current as a function of plate voltage, or voltage as a function of current should be determined on the basis of the rated maximum dissipation.

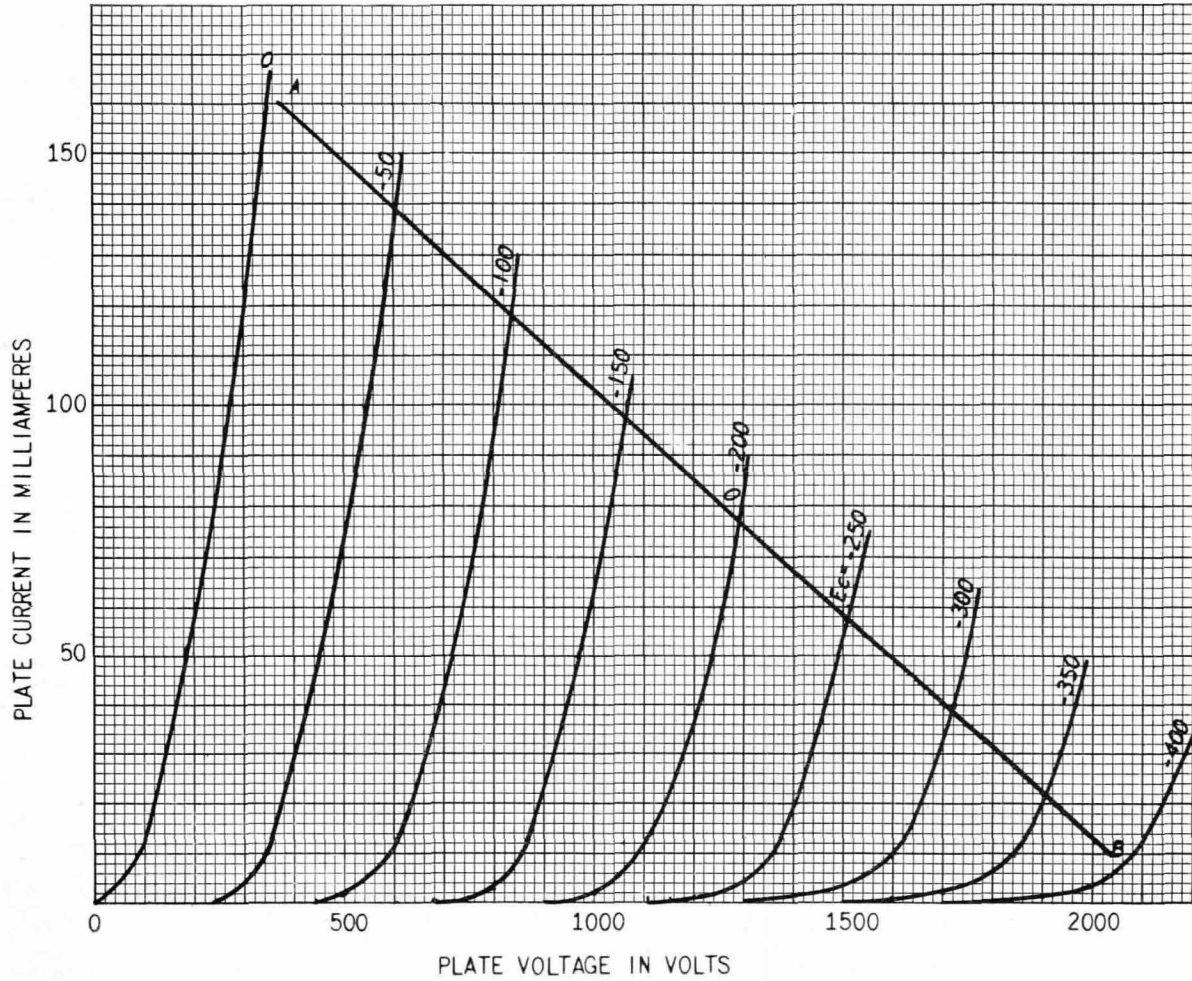
CALCULATION OF TUBE OPERATING CONDITIONS

**General**

In order to make optimum adjustment of transmitting tube operating conditions, it is necessary to visualize clearly the effect on tube

operation, and hence on circuit output, of varying grid bias voltage, grid drive, plate voltage and plate circuit impedance.

A complete sample set of calculations will



K-9186120 Fig. 6—GL-845 Characteristics with A-B Operating Line 12-31-45

be made for the various classes of operation, using the GL-889-A as an example except for the Class A amplifier analysis in which the GL-845 is used. All of the work for Class B and C operation is based on use of the "constant-current" curves. Experience has shown that the results so obtained compare closely with actual operating test results.

Several sets of calculations should be made for any particular class of operation to be sure that the optimum conditions are met as far as plate efficiency and grid drive are concerned. Operating conditions should be chosen so as to always fall within the maximum ratings.

#### For Class A Amplifiers (Resistance Loads)

The Class A amplifier analysis is based on characteristic curves of the GL-845 tube which is particularly suited for Class A operation, rather than on the curves of the GL-889-A which is designed for other classes of service. Also tube applications do not generally require a tube of high-power rating for Class A service, since operating efficiency of high-power tubes becomes an important factor and Class B linear service is desirable.

Referring to Fig. 6 of page 8, it is first necessary to draw the load line A-B about the operating point O. The following factors should be considered in locating the operating line:

- (1) The point O must be located so that the product of the plate current and plate voltage at that location does not exceed the maximum rated anode dissipation.
- (2) The position of point O on a proposed operating line must be such that the grid swing does not go past the zero bias curve, as shown at A. At the extreme negative grid swing, point B, operation should not extend appreciably into the non-linear portion of the curves. In general, point B should not be below 10 to 15 per cent of the plate current at point O. The grid swing from O to A is equal to the grid swing from O to B.
- (3) The calculations will show that the power output is proportional to the product of the total plate current and plate voltage change when operating over the load line from A to B. Thus it is apparent that lowering the point O would reduce the possible plate current swing and therefore the power output. To raise it, would cause the anode dissipation rating to be exceeded, as explained above.

Having thus located the line A-B, Fig. 6, it is possible to calculate specific conditions of tube operation, as follows:

$$(1) \text{ Power output} = \frac{(E_{\max} - E_{\min})(I_{\max} + I_{\min})}{8}$$

From Fig. 6:

$E_{\max}$  = plate voltage at B = 2030 volts

$E_{\min}$  = plate voltage at A = 380 volts

$I_{\max}$  = plate current at A = 0.159 amperes

$I_{\min}$  = plate current at B = 0.010 amperes

$$\text{Power output} = \frac{(2030 - 380)(0.159 + 0.010)}{8} = 30.6 \text{ watts}$$

- (2) Plate dissipation is the product of the plate current and the plate voltage at operating point O. Plate dissipation, from Fig. 6 =  $0.080 \times 1250 = 100$  watts.
- (3) Required load resistance is equal to the ratio of the plate voltage change to the plate current change, on the load line A-B. From Fig. 6 the load resistance is calculated as follows:
 

Plate current at A = 159 milliamperes  
 Plate current at O = 80 milliamperes  
 Plate voltage at A = 380 volts  
 Plate voltage at O = 1250 volts

$$R_L = \frac{1250 - 380}{159 - 80} = 11,000 \text{ ohms}$$
- (4) The d-c plate current will be equal to the value of plate current at the point O, or from Fig. 6, this value is 80 milliamperes.
- (5) Some distortion is always present due to non-linearity. This distortion is comprised almost entirely of a second harmonic. The allowable percentage of second harmonic is generally specified at 5 per cent maximum and may be calculated from the following relation:

$$\text{Percentage 2nd harmonic} = \frac{\frac{1}{2}(I_{\max} + I_{\min}) - I_o \times 100}{I_{\max} - I_{\min}}$$

Where, referring to Fig. 6:

$I_{\max}$  = plate current at A = 159 ma.

$I_{\min}$  = plate current at B = 10 ma.

$I_o$  = plate current at O = 80 ma.

then percentage second harmonic is:

$$\frac{\frac{1}{2}(159 + 10) - 80}{159 - 10} \times 100 = 2.8 \text{ per cent}$$

The above calculations set up conditions of operation which would deliver the maximum power possible, yet not exceed any of the maximum ratings of the tube. Several sets of calculations may be required to obtain the optimum operating conditions to fulfill other special requirements, such as operation at reduced power output, reduced plate voltage, different load impedance or combination of the above.

CALCULATION OF TUBE OPERATING CONDITIONS (CONT'D)

For Class C Radio-frequency Amplifiers and Oscillators

Certain conditions of operation are arbitrarily assigned, as follows:

- 1. D-c plate voltage = 7500 volts
- 2. Grid bias voltage = -800 volts
- 3. Peak grid voltage swing = 1800 volts
- 4. Plate voltage swing = 6000 volts

All the above values may be obtained in practice by applying them directly or by varying the grid drive or load impedance.

Referring to Fig. 7, the first step is to determine the operating line A-A', as established by the four assigned conditions of operation. The point A is determined by the d-c plate voltage and grid bias voltage. As the plate voltage swings down and the grid voltage rises in sinusoidal fashion, their instantaneous values describe a straight line, terminated at A'. The point A' is automatically determined, having chosen A as the starting point and having previously determined the amplitude of grid and plate voltage swing.

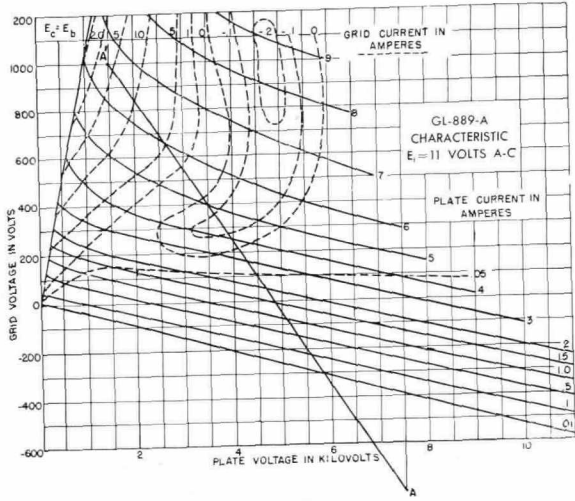


Fig. 7—GL-889-A Characteristic Curves with A-A' Line

CLASS C AMPLIFIER AND OSCILLATOR SERVICE

| Angle Degrees                                                           | Sine | $e_p$ Volts  | $i_p$ Amperes | Product Sine Amperes | $e_g$ Volts  | $i_g$ Amperes | Product Sine Amperes |
|-------------------------------------------------------------------------|------|--------------|---------------|----------------------|--------------|---------------|----------------------|
| 0                                                                       | 0    | 7500         |               | —                    | -800         |               | —                    |
| 5                                                                       | .087 | 6978         |               |                      | -643         |               |                      |
| 15                                                                      | .258 | 5950         |               |                      | -335         |               |                      |
| 25                                                                      | .423 | 4960         | 1.25          | .529                 | -40          |               |                      |
| 35                                                                      | .574 | 4060         | 3.80          | 2.18                 | 230          | -0.020        | -0.0115              |
| 45                                                                      | .707 | 3260         | 5.20          | 3.68                 | 470          | 0.020         | 0.0141               |
| 55                                                                      | .819 | 2600         | 6.0           | 4.91                 | 670          | 0.50          | 0.409                |
| 65                                                                      | .906 | 2070         | 6.4           | 5.80                 | 830          | 0.90          | 0.815                |
| 75                                                                      | .966 | 1700         | 6.5           | 6.28                 | 940          | 1.25          | 1.208                |
| 85                                                                      | .996 | 1520         | 6.5           | 6.48                 | 990          | 1.70          | 1.692                |
| 90                                                                      | 1.00 | 1500         | (*)           | —                    | 1000         | (*)           | —                    |
|                                                                         |      | Summation    | 35.65         | 29.85                |              | 4.35          | 4.126                |
| 5-85 Incl.                                                              |      | Divide By    | 18            | 18                   |              | 18            | 18                   |
| Average Current                                                         |      |              | $I_b = 1.98$  | 1.66                 | $(I_g) =$    | .242          | .229                 |
| 0°                                                                      |      | $E_b = 7500$ |               |                      | $E_c = -800$ |               |                      |
| 90°                                                                     |      | $e_p = 1500$ |               |                      | $e_g = 1000$ |               |                      |
| Difference (Swing)                                                      |      | 6000         |               | (Swing)              | 1800         |               |                      |
| Plate Input = $E_b \times I_b =$                                        |      | 7500         | ×             | 1.98                 |              |               | = 14.85 kilowatts    |
| Plate Output = Plate Swing × Average Product Sine Amperes =             |      | 6000         | ×             | 1.66                 |              |               | = 9.95 kilowatts     |
| Efficiency = $\frac{\text{Output}}{\text{Input}} =$                     |      |              |               | 9.95                 |              |               | = 67 per cent        |
| Total Grid Excitation Power = Grid Swing × Average Product Sine Amperes |      |              |               |                      |              |               | = 410                |
| Grid Bias Loss = $I_g \times E_c = 800 \times .242$                     |      |              |               |                      |              |               | = 193                |

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

Fig. 8—Chart Showing Calculation of GL-889-A Typical Operating Conditions

The point A is set at a point corresponding to a plate voltage of 7500 volts and grid bias of -800 volts. With a grid swing of 1800 volts and a plate swing of 6000 volts, the point A' is located at a grid voltage of 1000 volts and a plate voltage of 1500 volts. Thus the operating line A-A' is determined.

The rest of the work is simply mechanical integration. The instantaneous values of plate voltage and current, and grid voltage and current are tabulated as shown in table of Fig. 8, page 10. By simple relations indicated in Fig. 8, the operating conditions are completely determined.

By studying this set of calculations, it is possible to determine:

1. D-c plate input power
2. Plate output power
3. Plate efficiency
4. Grid excitation power
5. Grid bias loss
6. D-c grid current

It will be found that the location of the point A' on the curves of Fig. 7, affects the tube operation very greatly since a small change in its position changes the working range in the high grid current and plate current region.

A few sets of calculations will indicate the optimum operating conditions for a particular installation. By referring to Fig. 9, a general idea may be gained as to the relation of the performance factors involved.

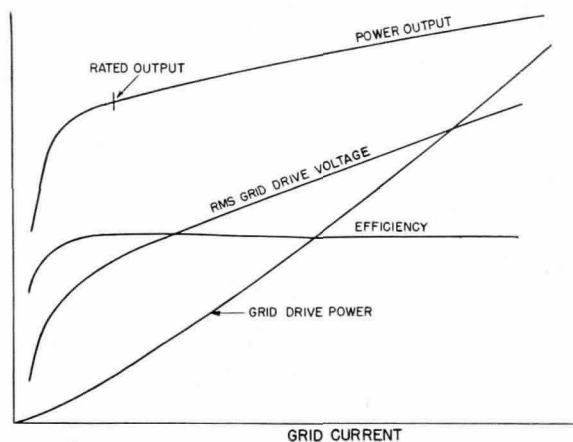
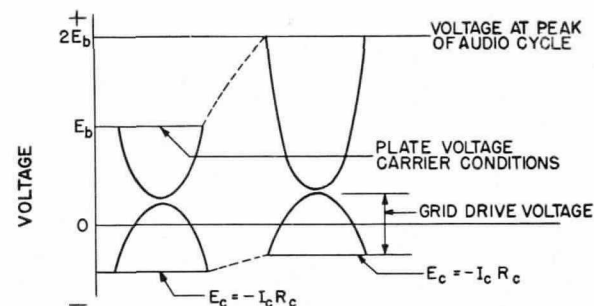


Fig. 9—Performance Curves for Class C Amplifier and Oscillator  
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### For Class C Radio-frequency Power Amplifiers, Plate Modulated

The operation of a tube under plate modulation conditions may be analyzed in a manner similar to that for a Class C oscillator, unmodulated. In this type of service, operating conditions are specified for carrier conditions. Modulation is used by superimposing the signal voltage on the applied d-c plate potential. 100

per cent modulation means that the applied plate potential varies from zero to twice the d-c applied voltage throughout the audio cycle as shown in Fig. 10.



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Fig. 10—Wave Shapes Showing Plate Voltage Variation

In establishing the operating lines for plate modulated service, the carrier conditions are determined. It will be noted that the maximum anode dissipation for carrier conditions is less than that for Class C oscillator rating. This must be so since 100 per cent modulation causes the plate input and plate dissipation to increase 50 per cent, the additional plate input being supplied by the modulator.

When establishing the operating line for carrier conditions, it must be borne in mind that a second line must be drawn for conditions obtained at double the d-c plate voltage. This second line corresponds to the conditions under which the tube is operating, at the peak of the modulating voltage. Certain relations, as enumerated below, must exist between these two lines in order that the output be free from distortion.

(1) If the modulation is to be free from distortion, a linear relation must exist between the radio-frequency voltage and current. Therefore, for 100 per cent modulation, at the peak of the modulation cycle, the radio-frequency voltage and current must be double that of the carrier condition, while at the other extreme of the modulation cycle the radio-frequency voltage and current are zero. It should be noted that the r-f current is proportional to the average current calculated under the column "Product Sine Amperes" in Fig. 8.

(2) The operating line for the peak of the modulation cycle must be drawn so that the load impedance will be the same as that for the operating line at carrier conditions. The load impedance may be expressed by the relation  $\frac{E_p^2}{2P_o}$ ,

where  $E_p$  = plate voltage swing, and  $P_o$  = power output in watts.

(3) It will be found upon examination of the constant current curves that in order to double the current, at double the voltage when operat-