RCA RADIOTRON COMPANY, INC.
A RADIO CORPORATION OF AMERICA SUBSIDIARY
HARRISON
NEW JERSEY

OFFICE OF MANAGER
201 N. Front Street
CAMDEN, N. J.

EQUIPMENT SALES
ENGINEERING SERVICE DIVISION

APPLICATION NOTE No. 42

Sept. 5, 1934.

# APPLICATION NOTE ON SHORT-CUT METHOD FOR DETERMINING OPERATING CONDITIONS OF POWER OUTPUT TRIODES

The approximate operating conditions for output triodes can be readily obtained by graphical methods. In this Application Note, the Power Output Rule is described and simple formulas are given for obtaining the operating current, bias, and load for both single and push-pull triodes. Other formulas are included for converting power output, load, and plate current from one set of plate voltage conditions to another. These formulas are based upon the assumption that the $E_c = 0$ curve of the plate family follows the three-halves power law.

## The Power Output Rule

The Power Output Rule (frequently referred to as the Distortion Rule) is used to obtain the plate load and the corresponding power output. This rule was first described by K. S. Weaver in QST of November, 1929. It is the double-scaled rule illustrated in Figure 1. $L_1$ and $L_2$ have a ratio of 11 to 9, since this is the ratio corresponding to 5% distortion. The zero of the rule is placed at the point on a plate family corresponding to the values of plate voltage and plate current or grid bias under consideration. The slope of the rule is then adjusted so that the reading of the rule at one extreme of the assumed grid swing is the same as that at the other extreme of the grid swing. The slope of the rule when so adjusted corresponds to the load line for 5% distortion.

## Selection of the Load for a Single-Triode Output Tube

The plate circuit load for a triode is determined from its plate characteristics curves. If the operating point $I_o$ of Figure 2 is

known, the distortion rule can be used directly to obtain the load. If $I_o$ is not known, it can be determined from the simple relation, $I_o = 1/4\ I_m$. $I_m$ is obtained by drawing a vertical at the desired operating plate voltage and extending the $E_c = 0$ curve until it intersects the vertical line. One quarter of this value, $I_m$, locates $I_o$, the operating point. The Distortion Rule is then applied with its zero placed at $I_o$ and adjusted until L1 reads for the intersection with the zero bias the same as L2 reads for the intersection with the curve for twice the operating bias. The slope of this line represents the load resistance. The power output can be obtained from the formula:

$$P = \frac{(I_{max.} - I_{min.})\ (E_{max.} - E_{min.})}{8}$$

Limitations of Method

The only limitation to the general use of this method is that conditions should not be chosen which exceed recommended maximum plate dissipation of the tube. The best guide to this value is the product of the maximum recommended plate voltage and the maximum recommended plate current. When a value of $I_o$ giving too high a plate dissipation is obtained, $I_o$ should be arbitrarily lowered to bring the plate dissipation within limits. Tubes such as the 112-A, 71-A, 45, and 2A3 are generally operated with control-grid voltages somewhat greater than the theoretical bias value for their maximum plate voltage rating in order that plate dissipation may be kept down. The operating points ($I_o$ values) obtained by this method will be found to check the established operating points for types 10, 31, 50, and 89 with triode connection, and to be fairly close for the 112-A and the 71-A. Some readjustment of the grid bias is required for the 45 and 2A3 when used above 180 plate volts.

Conversion Formulas for Single and Push-Pull Triodes

When a set of conditions for single or push-pull operation of power triodes is known and when operation under some other plate voltage condition is desired, the power output, load resistance, and plate current can be quickly computed by means of the following conversion formulas:

For power output

$$P = A(E)^{5/2}$$

where

P = the power output for the new operating conditions,
A = the power output for the old operating conditions,
E = the ratio of the old and the new plate voltage.

For load resistance

$$R = B(E)^{-1/2}$$

where

R = the load resistance for the new operating conditions,
B = the load resistance for the old operating conditions,
E = the ratio of the old and the new plate voltage.

For plate current

$$I_b = C(E)^{3/2}$$

where

$I_b$ = the plate current for the new operating conditions,
C = the plate current for the old operating conditions,
E = the ratio of the old and the new plate voltage.

The practicability of these formulas is shown by the following example of a triode-connected 89.

| | Known Values | Conversion Factors | Calculated Values | Actual Values |
|---|---|---|---|---|
| Plate Volts | 180 | 1.39* | 250 | 250 |
| Grid Volts | 22.5 | 1.39 | 31.4 | 31 |
| Plate Milliamperes | 20 | $(1.39)^{3/2}$ | 32.7 | 32 |
| Plate Load (ohms) | 6500 | $(1.39)^{-1/2}$ | 5500 | 5500 |
| Power Output (watts) | 0.4 | $(1.39)^{5/2}$ | 0.91 | 0.9 |

* 250/180 = 1.39

For filament types of tubes, such as the 10, 45, 50, 71-A, and 2A3, the plate characteristics curves are given for d-c filament excitation, although operating characteristics are generally shown for a-c filament excitation. For these types, conversion calculations are made on a d-c excitation basis. To adjust a-c excitation bias values to corresponding d-c values, reduce the a-c value by 1/2 the peak value of the RMS filament voltage. To adjust d-c values to a-c values, add 1/2 the peak value of the RMS filament voltage to the d-c value of grid bias.

## Limitations of Formulas

The conversion formulas are accurate except for over-biased operation. Thus, for the 45 and 2A3 at voltages greater than 180 volts, these conversion formulas can not be used unless adjustment is made to keep plate dissipation within limits.

## Selection of Load for Triodes in Push-Pull

To obtain the proper load for triodes in push-pull, the relation $E = 0.6E_o$ is used (see Figure 3). Plate characteristics curves for the triode are required. An operating plate voltage $E_b$ is then selected. A vertical is erected at $E = 0.6E_o$ and the intersection of this vertical with the $E_c = 0$ curve determines one end of the load line. The other end is at $E_b$, the operating plate voltage. The slope of this line multiplied by four is the correct value of plate-to-plate load for two triodes operating in a Class A push-pull amplifier. Thus, for the 45 (see Figure 3), the plate-to-plate load is equal to

$$\left(\frac{250 - 150}{0.096}\right) \times 4, \text{ or } 4160 \text{ ohms.}$$

This simple method for determining the plate-to-plate load is applicable to all power output triodes. The operating point can be anywhere between the bias voltage specified for single-tube operation and the bias voltage obtained by taking one-half of the control-grid bias at plate current cut-off for a plate voltage value of 1.4 $E_o$. Figure 3 shows the plate family of a 45 tube. The recommended operating point as a single triode is -50 volts. The maximum bias that can be used without departing from Class A operation is -55 volts. Plate current cut-off at 1.4 x 250 volts, or 350 volts, occurs with a control-grid bias of -110 volts. One-half of this value is -55 volts, the maximum bias. Operation beyond this value of grid bias will be accompanied by rectification and will no longer be representative of a Class A amplifier.

Power Output Formula for Push-Pull Triodes

The method just described of determining the plate-to-plate load also makes it possible to determine the power output for push-pull triodes by means of the following simple formula:

$$P = \frac{I_m E_o}{5}$$

Thus, for the 45's of Figure 3, power output is equal to

$$\frac{0.096 \times 250}{5}, \text{ or } 4.8 \text{ watts.}$$

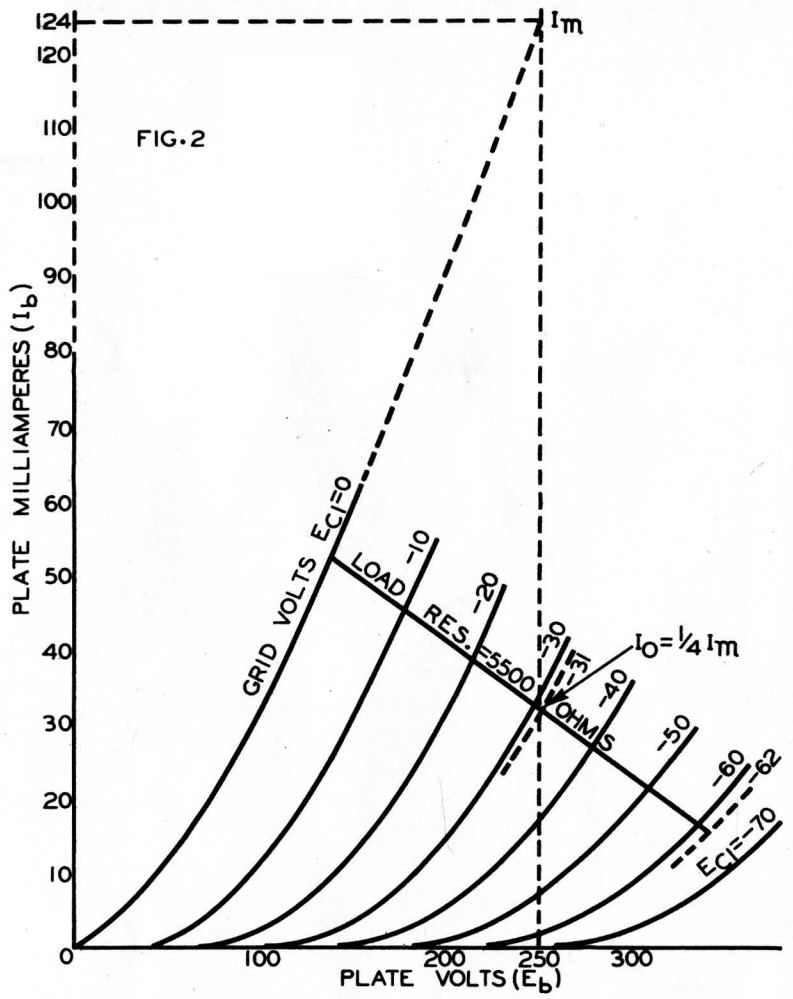


FIG. 2
PLATE MILLIAMPERES ($I_b$)
PLATE VOLTS ($E_b$)
$I_m$
GRID VOLTS $E_{C1}$=0
-10
-20
-30
-31
-40
-50
-60
-62
$E_{C1}$=-70
LOAD RES. =5500 OHMS
$I_O = \frac{1}{4} I_m$
0
10
20
30
40
50
60
70
80
90
100
110
120
124
100
200
250
300

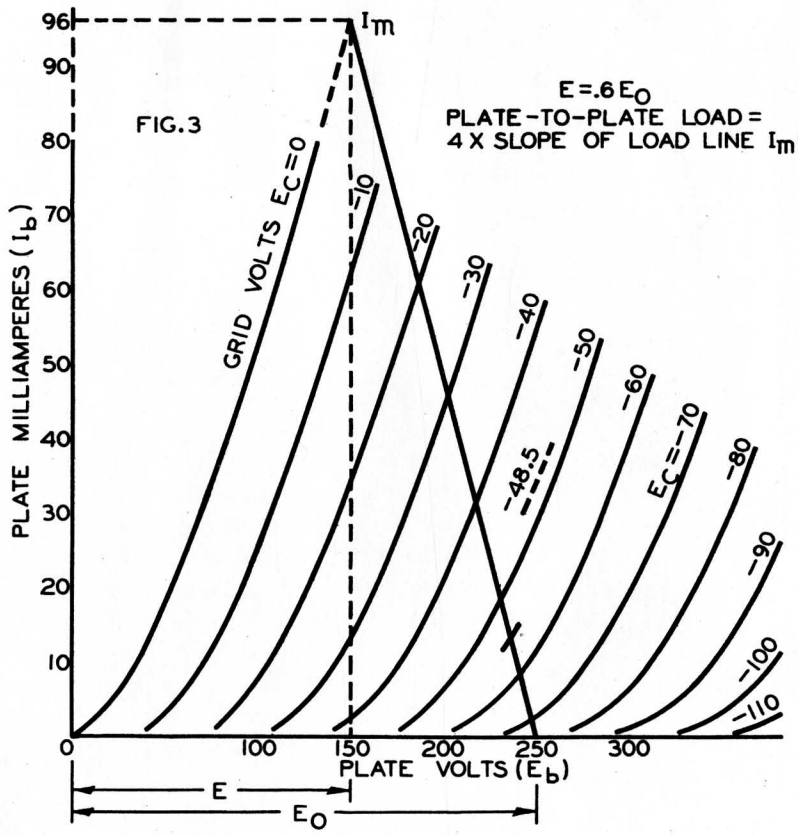
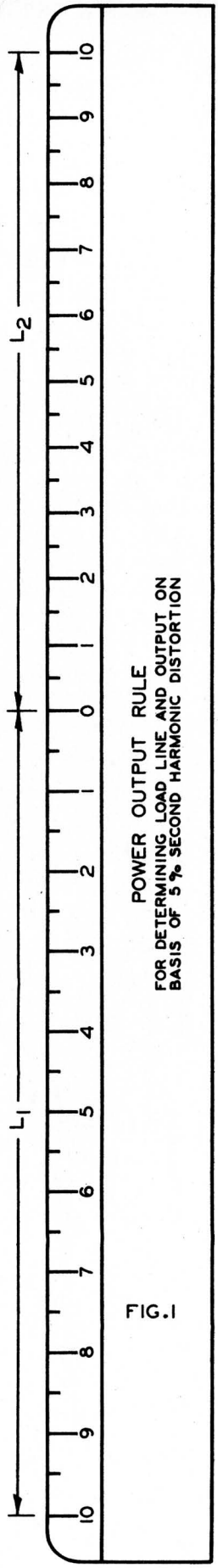


FIG. 3
PLATE MILLIAMPERES ($I_b$)
PLATE VOLTS ($E_b$)
$I_m$
E=.6 $E_O$
PLATE-TO-PLATE LOAD =
4 X SLOPE OF LOAD LINE $I_m E_b$
GRID VOLTS $E_C$=0
-10
-20
-30
-40
-50
-60
$E_C$=-70
-80
-90
-100
-110
-48.5
0
10
20
30
40
50
60
70
80
90
96
100
150
200
250
300
E
$E_O$


$L_2$
$L_1$
POWER OUTPUT RULE
FOR DETERMINING LOAD LINE AND OUTPUT ON
BASIS OF 5% SECOND HARMONIC DISTORTION
FIG. 1

We are pleased to send you the enclosed POWER TUBE RULE as a supplement to APPLICATION NOTES #42. We regret that the sheet 92S-5556 was not correctly placed. It should follow the text and be the last page of the NOTE.

9-6-34