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 $E_o = 0$ 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

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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,
\( I_o = \frac{1}{4} I_m \). \( I_m \) is obtained by drawing a vertical at the desired oper-
ating 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 oper-
ating point. The Distortion Rule is then applied with its zero placed
at \( I_o \) and adjusted until \( I_o \) reads for the intersection with the zero
bias the same as \( I_o \) reads for the intersection with the curve for twice
the operating bias. The slope of this line represents the load resist-
ance. The power output can be obtained from the formula:
\[
P = \frac{(I_{\text{max}} - I_{\text{min}})(E_{\text{max}} - E_{\text{min}})}{8}
\]

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 ob-
tained, \( I_o \) 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.

<table>
<thead>
<tr>
<th>Known</th>
<th>Conversion Factors</th>
<th>Calculated Values</th>
<th>Actual Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plate Volts</td>
<td>180</td>
<td>1.39*</td>
<td>250</td>
</tr>
<tr>
<td>Grid Volts</td>
<td>22.5</td>
<td>1.39</td>
<td>31.4</td>
</tr>
<tr>
<td>Plate Milliamperes</td>
<td>20</td>
<td>(1.39)^{3/2}</td>
<td>32.7</td>
</tr>
<tr>
<td>Plate Load (ohms)</td>
<td>6500</td>
<td>(1.39)^{-1/2}</td>
<td>5500</td>
</tr>
<tr>
<td>Power Output (watts)</td>
<td>0.4</td>
<td>(1.39)^{5/2}</td>
<td>0.91</td>
</tr>
</tbody>
</table>

\* 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 ac filament excitation. For these types, conversion calculations are made on a d-c excitation basis. To adjust ac excitation bias values to corresponding d-c values, reduce the ac value by 1/2 the peak value of the RMS filament voltage. To adjust d-c values to ac 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 \( E = 0.6E_0 \) 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 \( E = 0.6E_0 \) 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 any-
where 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 \( E_0 \). 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 \( \times \) 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 ampli-
fier.

**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:

\[
P = \frac{I_m E_0}{5}
\]

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

\[
0.096 \times 250 \div 5 , \text{ or } 4.8 \text{ watts}.
\]
We are pleased to send you the enclosed POWER TUBE RULE as a supplement to APPLICATION NOTES #42. We regret that the sheet 928-5556 was not correctly placed. It should follow the text and be the last page of the NOTE.

9-6-34