Two-Resistor Class AB Amp Model …by Earles L. McCaul

• The Two-Resistor Model

The operating parameters of a push-pull, Class-AB, audio power amplifier are traditionally analyzed by plotting a loadline on the tube's composite characteristic curves. If you're comfortable with this approach, and an alternative method doesn't interest you, then read no further. If you're like most people, however, the tedium of mirror-imaging the plate voltage relative to the supply voltage and subtracting the two currents makes your head spin, so this article is for you. There happens to be another way to determine the maximum plate voltage swing, the plate dissipation, and the plate efficiency. The alternative method uses the ratio of two representative resistance values.

A tube's diode line is the characteristic curve that corresponds to a grid voltage of zero. Along this curve the tube is in saturation and acts as a diode. The diode line represents the minimum plate voltage at which the tube can conduct at a specified level of plate current. The voltage at any point along it represents the plate saturation voltage $\mathbf{V_{sat}}$ for the given plate current.

With Class-AB operation, the most important point along the diode line is the plate voltage "knee," the point where the plate current at a control grid voltage of zero (**Ec1 = 0**) intersects the diode line. The graph in Figure 1 shows the diode line (**red**), loadline (**brown**) and "knee" overlaid on a 6L6GC plate/screen curve with Ec1 = 0.

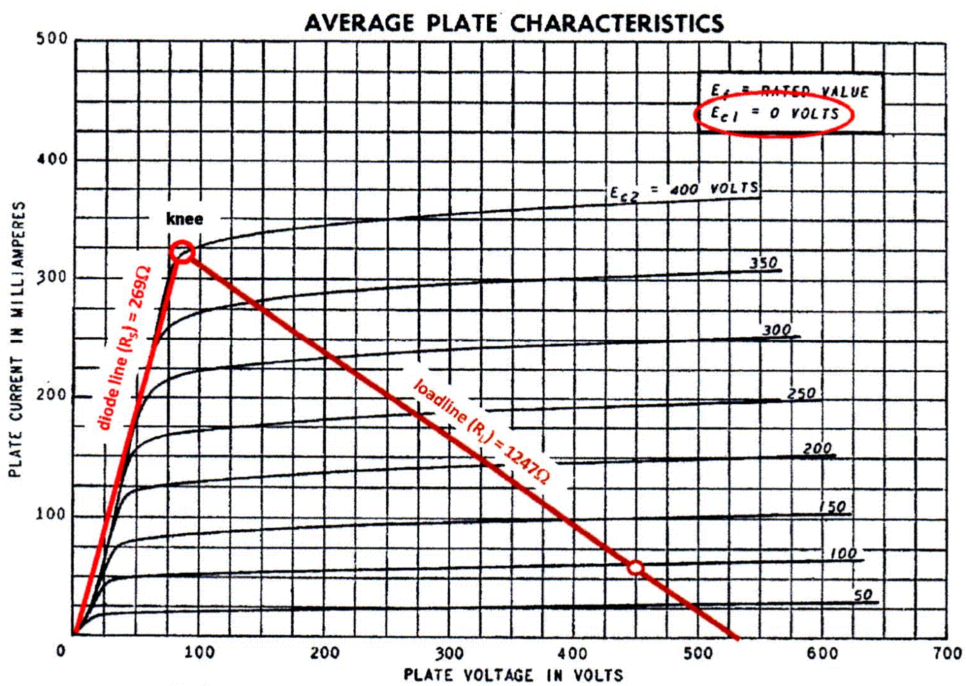

Figure 1 - Diode line (R_s), load line (R_L) and "knee."

Functionally, having the loadline pass through the middle of the knee provides the longest possible distance between the plate supply voltage $\mathbf{V_{bb}}$ and minimum plate voltage $\mathbf{V_{sat}}$ without the grid voltage of either tube exceeding zero, a limiting criteria for Class-AB$_1$ operation. This ensures the maximum possible plate voltage swing:

$$\mathbf{V_{Ppk} = V_{bb} - V_{sat}}$$

Thus $\mathbf{V_{bb}}$ and $\mathbf{V_{sat}}$ determine the high- and low-voltage limits for the Class-AB circuit.

Interestingly, $\mathbf{V_{sat}}$ is a function of the screen grid voltage $\mathbf{V_S}$ and not the plate voltage $\mathbf{V_P}$. From the 6L6GC datasheet [1], for example, we see that $\mathbf{V_{sat}}$ is typically about 80 volts at $\mathbf{V_S = 400}$ and 50 volts at $\mathbf{V_S = 250}$.

The plate current-versus-voltage characteristic curve corresponding to $\mathbf{V_{sat}}$ is actually a power function:

$$\mathbf{I_P = KV_P^{3/2}}$$

where **K** is a constant (Perveance), but any point on the curve can readily be determined by the equivalent resistance at that point. The equivalent resistance for $\mathbf{V_{sat}}$ at the knee is called the plate saturation resistance $\mathbf{R_S}$. Note that while it is not accurate over the whole length of the diode line, $\mathbf{R_S}$ does exactly represent the $\mathbf{V_{sat}}$ point.

The saturation resistance can be determined by dividing the plate supply voltage by the peak plate current according to Ohm's Law,

$$\mathbf{R_S = V_{bb}/I_{Ppk}}$$

In its simplest form, the Class-AB circuit can be viewed as being a simple, two resistor, voltage divider:

$$\mathbf{V_{sat} = V_{bb}[R_S/(R_L+R_S)]}$$

We can use this equation to solve for the saturation resistance:

$$\mathbf{R_S = R_L V_{sat}/(V_{bb}-V_{sat}) = R_L V_{sat}/V_{Ppk}}$$

and therefore the ratio of load resistance to saturation resistance is $\mathbf{R_L/R_S = V_{Ppk}/V_{sat}}$.

This ratio has been used by earlier authors[2] [3] to derive equations for estimating the tube plate dissipation for the two tubes added together and the plate conversion efficiency:

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[1] GE 7581-A data sheet, 4/63.

[2] Leonard Baker, "Power Dissipation in Class B Amplifiers," PROC IRE, 1962, pp. 139-145 (IEEE doc: 1161654).

$$\mathbf{P_d/P_o = [2/\pi]^2[(R_L/R_S + 1)/(R_L/R_S)]^2}$$
$$\mathbf{E_f = (\pi/4)[(R_L/R_S)/(R_L/R_S + 1)]}$$

Let's try these equations using the 55W Class-AB amplifier example in the RCA Manual[4]. From the 6L6GC datasheet we get the output power, plate supply voltage, screen voltage, quiescent plate current, and the peak (RMS) plate current at maximum power:

$\mathbf{P_o = 55W}$
$\mathbf{V_{bb} = 450V}$
$\mathbf{V_S = 400V}$
$\mathbf{I_{PQ} = 0.058A}$
$\mathbf{I_{Pm} = 0.210A}$

From this we can calculate the load resistance, the peak plate current, the RMS plate voltage, the peak plate voltage, and the idle plate dissipation:

$\mathbf{R_L = P_o/(I_{Pm}^2) = 1247\Omega}$
$\mathbf{I_{Ppk} = SQRT[2]I_{Pm} = 0.297A}$
$\mathbf{V_P = P_o/I_{Pm} = 262V}$
$\mathbf{V_{Ppk} = SQRT[2]V_{Pm} = 370V}$
$\mathbf{P_{PQ} = I_{PQ}V_{PQ} = 26.1W}$

We can then calculate the saturation resistance (**R_s**) load resistance (**R_L**) for the RCA amplifier:

$\mathbf{R_S = V_{sat}/I_{Ppk} = 269\ \Omega}$
$\mathbf{R_L = V_{Ppk}/I_{Ppk} = 1247\ \Omega}$

from which we can calculate the plate dissipation for two tubes and the plate efficiency:

$$\mathbf{P_d/P_o = [2/\pi]^2[(R_L/R_S + 1)/(R_L/R_S)]^2 = 0.6}$$
$$\mathbf{P_d = (0.6)P_o = 33W}$$
$$\mathbf{E_f = (\pi/4)[(R_L/R_S)/(R_L/R_S + 1)] = 65\ percent}$$

• Summary

We conclude that while the Class-AB amplifier circuit is normally represented by a loadline and its characteristic curves, it can also be represented by two resistance values: **R_L,** which represents its *loadline*, and **R_S,** which represents its *diode line*. This equivalence makes sense when we recall that a Class-AB circuit behaves essentially like a two-resistor voltage divider and that any

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[3] K. A. Macfadyen, "Modifications of the push-pull output stage Part I," WIRELESS ENGR, vol. 12, p. 532; October 1935.

[4] RCA Receiving Tube Manual, RC-26, 5/68, pp. 360-361.

point on the characteristic curves is defined by knowing two of its three parameters: voltage, current, and resistance. The method we have just described merely applies Ohm's Law so that we can use resistance and current instead of voltage and current. Thus we have demonstrated an alternative to loadlines and characteristic curves that achieves the same results.