Load impedance and operating points for single-ended triode amplifier stages

Part One: What's Really Going On Here?

by Paul Joppa

As long-time readers might remember, I wrote on this subject some time ago (VALVE v2 n5). This series of articles is the result of some further thinking and analyses, which I presented in somewhat rougher form at the VSAC 97 seminars. In Part 1, I will outline the approach and make some observations on how load lines relate to tube voltages and currents. In Part 2 I will present an analysis of highly linear triodes, including my rules of thumb for a pretty good starting point design for most triode amplifiers. Finally in Part 3 I will discuss the more difficult problem of nonlinear triodes, including a proposed new nonlinearity parameter and some tables and graphs that provide a good estimate of performance.

The first order of business is to look at operating points and load lines. I will do this graphically, mostly because I'm more used to looking at the pictures than reading the articles. The plots shown here illustrate how the tube operates into a resistive load, and are the usual starting point for tube circuit design. The object of this exercise is to understand qualitatively the physics behind selection of operating points. Numerical details will be developed in Parts 2 and 3.

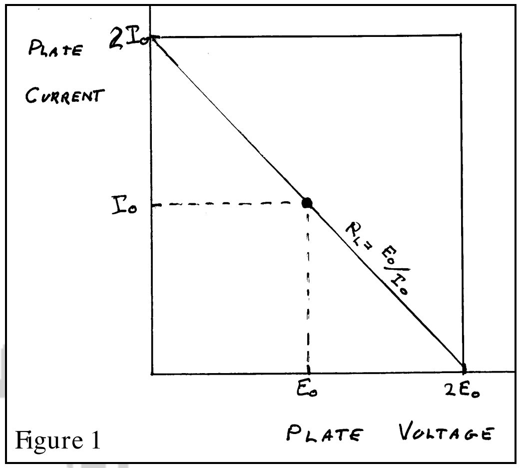


Figure 1

On a graph of plate voltage (Eb) and current (Ib), suppose you choose some operating point (Eo,Io). If you don't know anything except Eo and Io, you can still make some estimate of the performance. The smallest voltage you could generate is zero, so the largest must be the same amount in the positive direction, or 2Eo. Similarly, the most current you can swing must be 0 to 2Io. Think of this as a box that defines the operating region. The resistive load that gets the most power out of this box goes from E = 0, I = 2Io to E = 2Eo, I = 0. So the first guess for a plate load impedance is R0 = 2Eo/ 2Io = Eo/ Io. In fact, you could stop here and just use this load; it's often close enough to the optimum anyhow. If you could actually drive the tube to the ends of this line, you would find a maximum sine-wave output of 0.5Eb*Ib. Since the plate dissipation PD is Eb*Ib, the efficiency is 50%. This is the highest efficiency you can theoretically get with Class A operation.

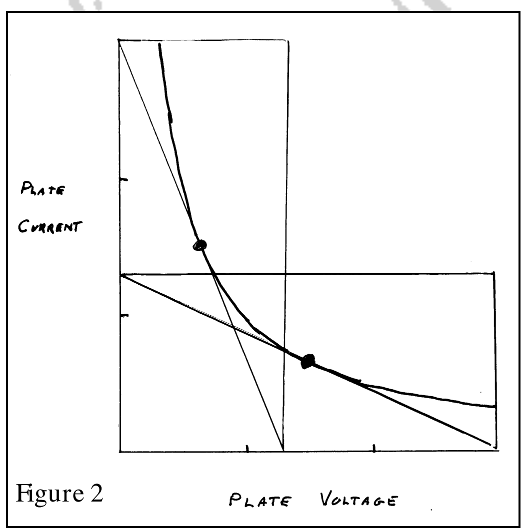


Figure 2

Now a word about choosing that operating point. The output power is proportional to the

plate dissipation PD = Eo*Io. Therefore, to get the most power out, you want to set the operating point somewhere along the line of maximum plate dissipation, Io = PD/ Eo.
Figure 3
Usually there are some other constraints on where you can place the operating point along

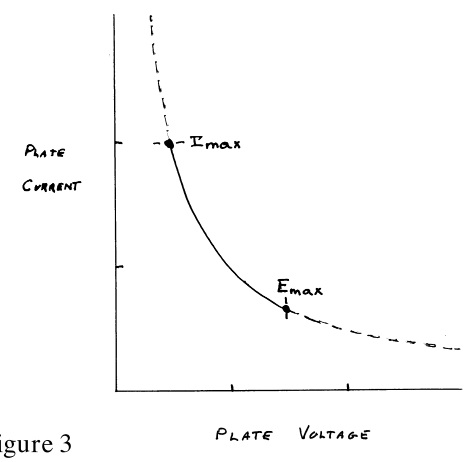


Figure 3

the PD line. There will be a maximum plate current and/ or voltage. The operating point will have to be less than the maximum continuous current or voltage, and if there are also instantaneous limits then the operating box will have to stay within them. This confines the operating point to a certain region of the max-dissipation line.
Figure 4

Usually, there is also a sort of triangular region of high current and low plate voltage that you want to avoid. Here are three possible reasons

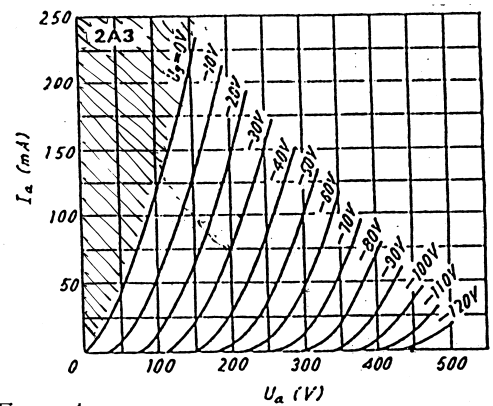


Figure 4

for this:

- Triode operation in Class A1 is limited to operation to the right of the zero-grid-voltage line. This avoids grid current, allowing the grid to be driven from a high impedance source, plus since the grid is not acting as a rectifier, it can also be driven through a capacitor without shifting the operating point.
Figure 5
- Even for triodes in Class A2, grid current can become excessive if the grid is more positive than the plate. This marks off a similar but narrower region on the left side of the plot. (It is especially narrow for high-mu tubes,

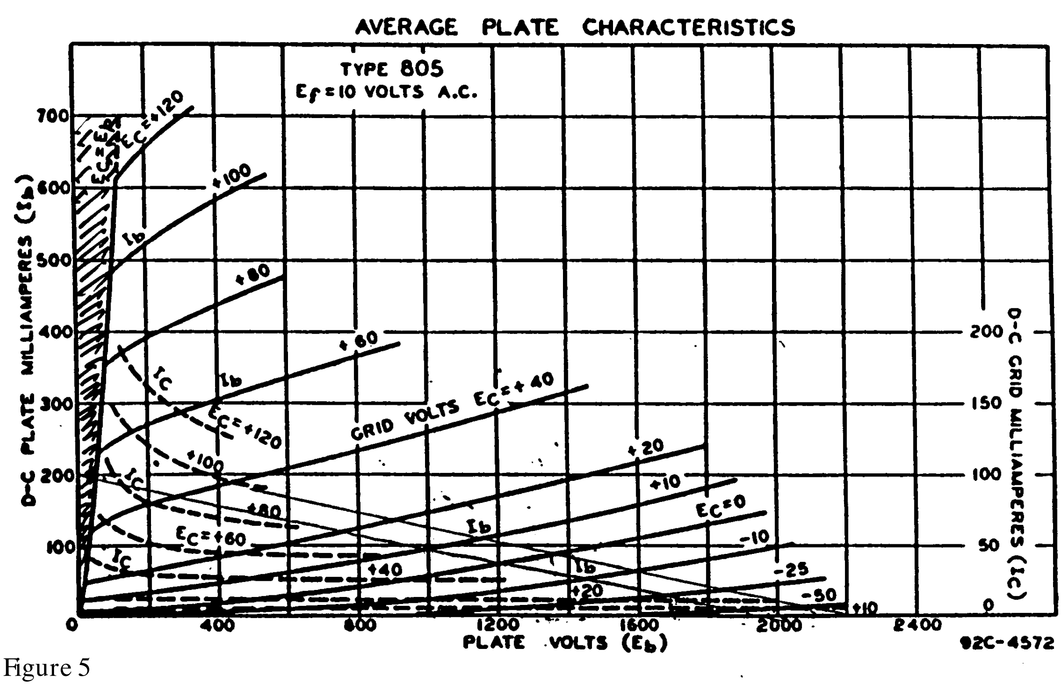


Figure 5

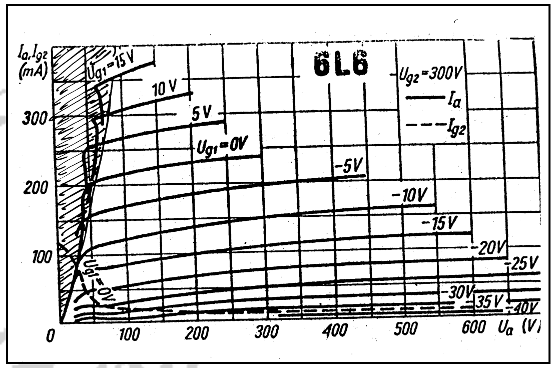
which is why Class A2 tubes often have high mu even though lower mu might allow lower plate resistance.)

Figure 6

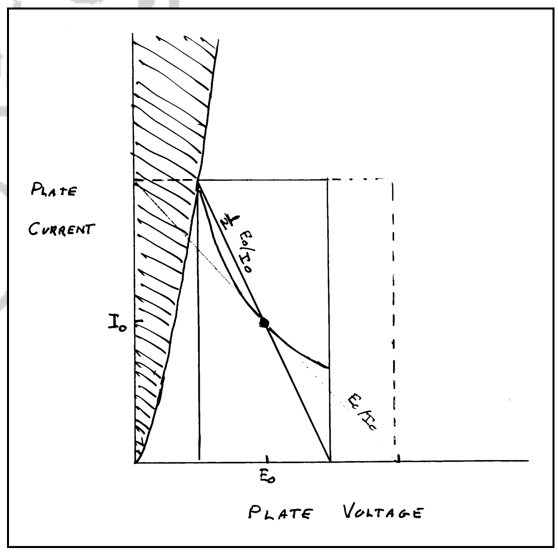
• Pentodes also have a region near the left edge where operation is nonlinear and screen grid current is excessive.

Figure 7

In all of these cases, the left edge of the operating box must be moved away from the axis so that



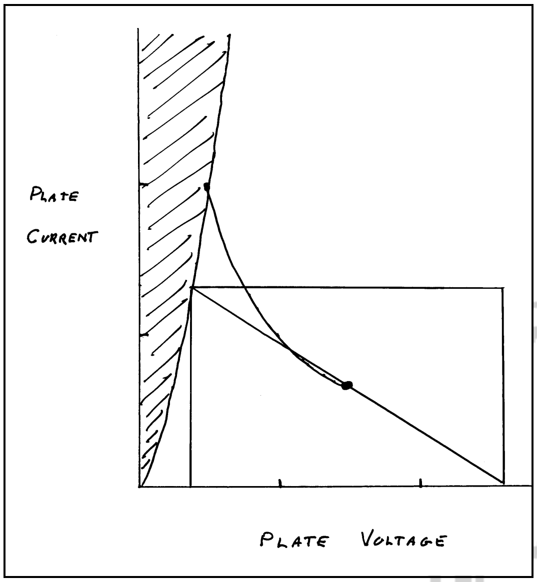
the top left corner is clear of the region. Since undistorted output is symmetrical about the operating point, the right side also moves in, so the load resistance for maximum power is lower.



The maximum power is also lower for the same operating point, so the efficiency is reduced. For example, the most common operating point for Class A1 triodes is from 0.5Eo to 1.5Eo with a load impedance of 0.5Eo/ Io=0.5R0 and an efficiency around 25%.

Figure 8

To get the most efficiency with this constraint you want a wide, short operating box, so the optimum here is with Eo set at the maximum continuous value. As will be shown later, there are some problems with going too high, especially for the less linear triodes, but overall



the conclusions so far will be seen to hold up pretty well - you get the best efficiency at high voltage and low current, and the load resistance depends on Eo/Io rather than plate resistance as is often claimed.

Next issue:

- *Paul continues his examination of operating points*
- *Alan Douglas examines the accuracy of some of the more popular tube testers*
- *Eric Barbour builds a preamp based on the Svetlana 572-10*
- *and lots more!*