Loadlines Made Simple

by Carl B. and Matthias M.

Hey Guys,

I know there´s some good info out there already on load lines and power estimation, but everything I´ve seen is more complicated than it needs to be. I think it can be simplified a bit.

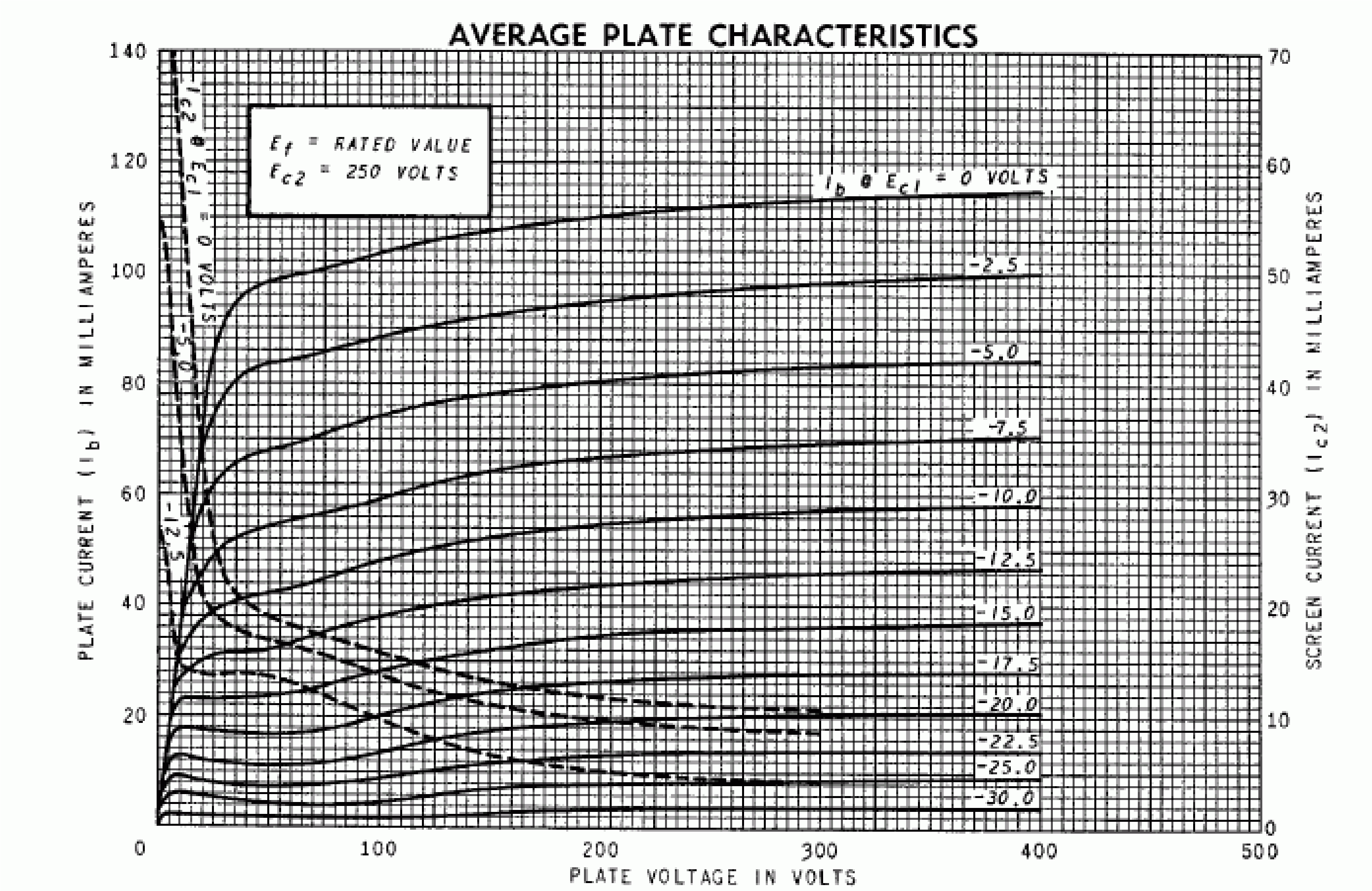
It always boils down to two points of interest. The first is the bias point. Second is the maximum swing point.

The bias point is the (x,y) point given by the plate voltage (x) and the plate current (y). The maximum swing point occurs in the leftest-uppermost point where the load line intersects the plate curve for Vg = 0V (the curve that´s the "leftest" usually, unless they put some positive grid voltage curves in there too. Ignore the positive grid voltage curves for now, that´ll be for a later post).

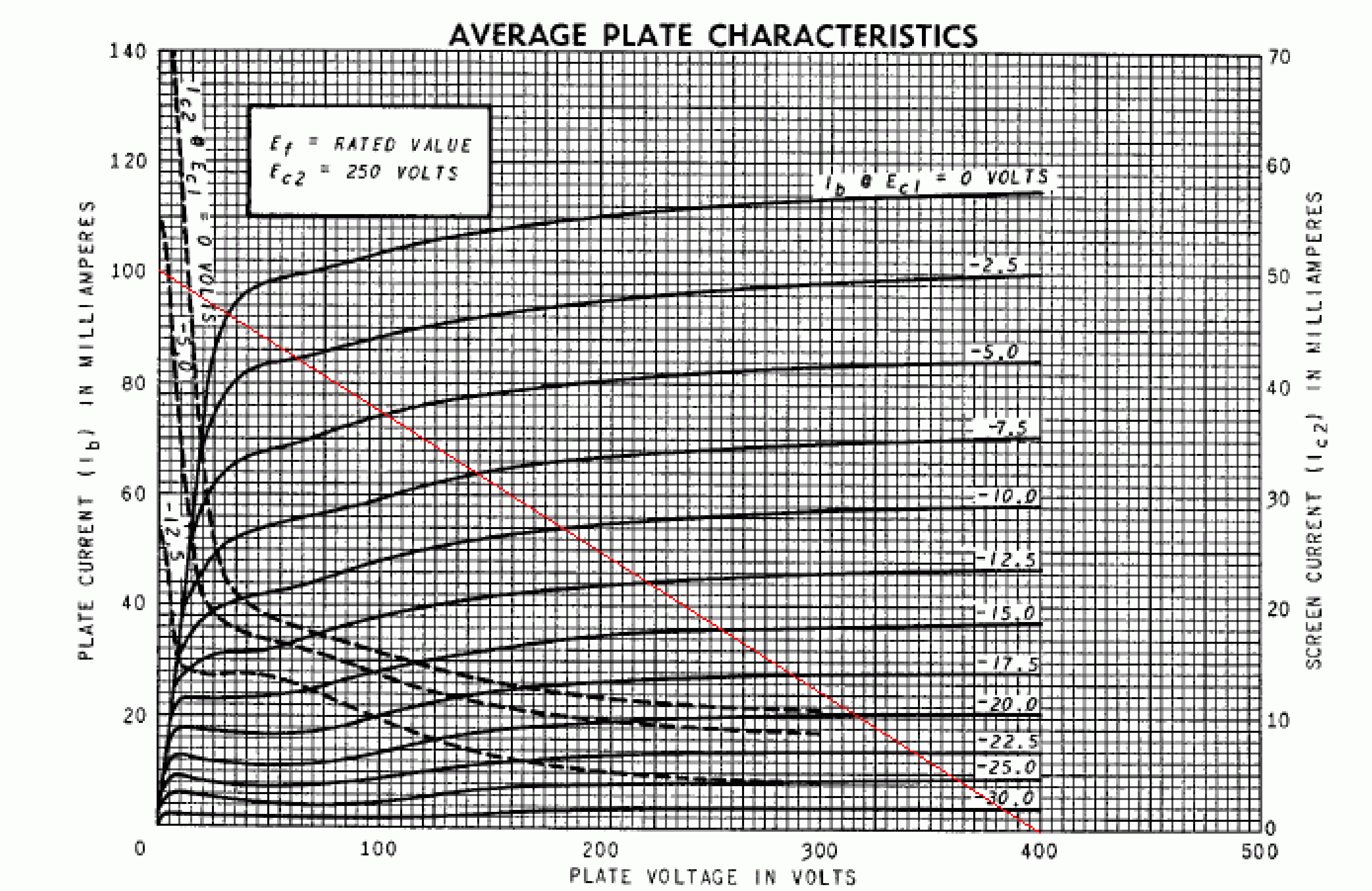
Now, how do we come up with that imfamous load-line? Read on.

Single-ended amp load-lines:

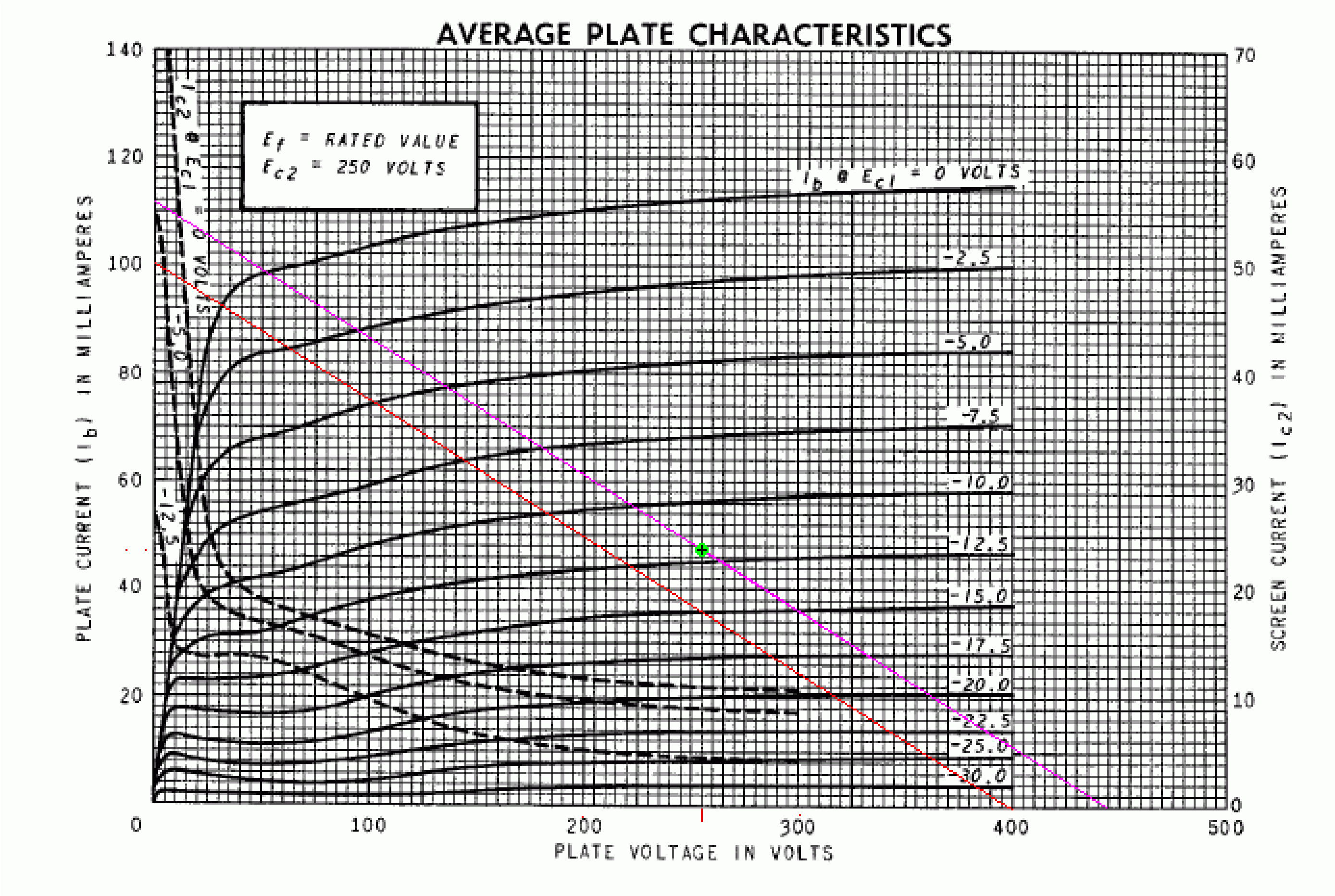
Make sure to plot on a graph that notes a screen (Vg2) voltage close to what you´re going to have. For guitar amps, try to find the graph where Vg2 is about the same as your main B+ voltage (unless you´re getting fancy with a dual-voltage B+). Let´s start with Vg2 = 250Vdc, and assume our plate voltage will be the same. While we´re assuming, let´s figure on a 6V6GT, the 250Vdc curves of which are given by cross-referencing to the 6AQ5.



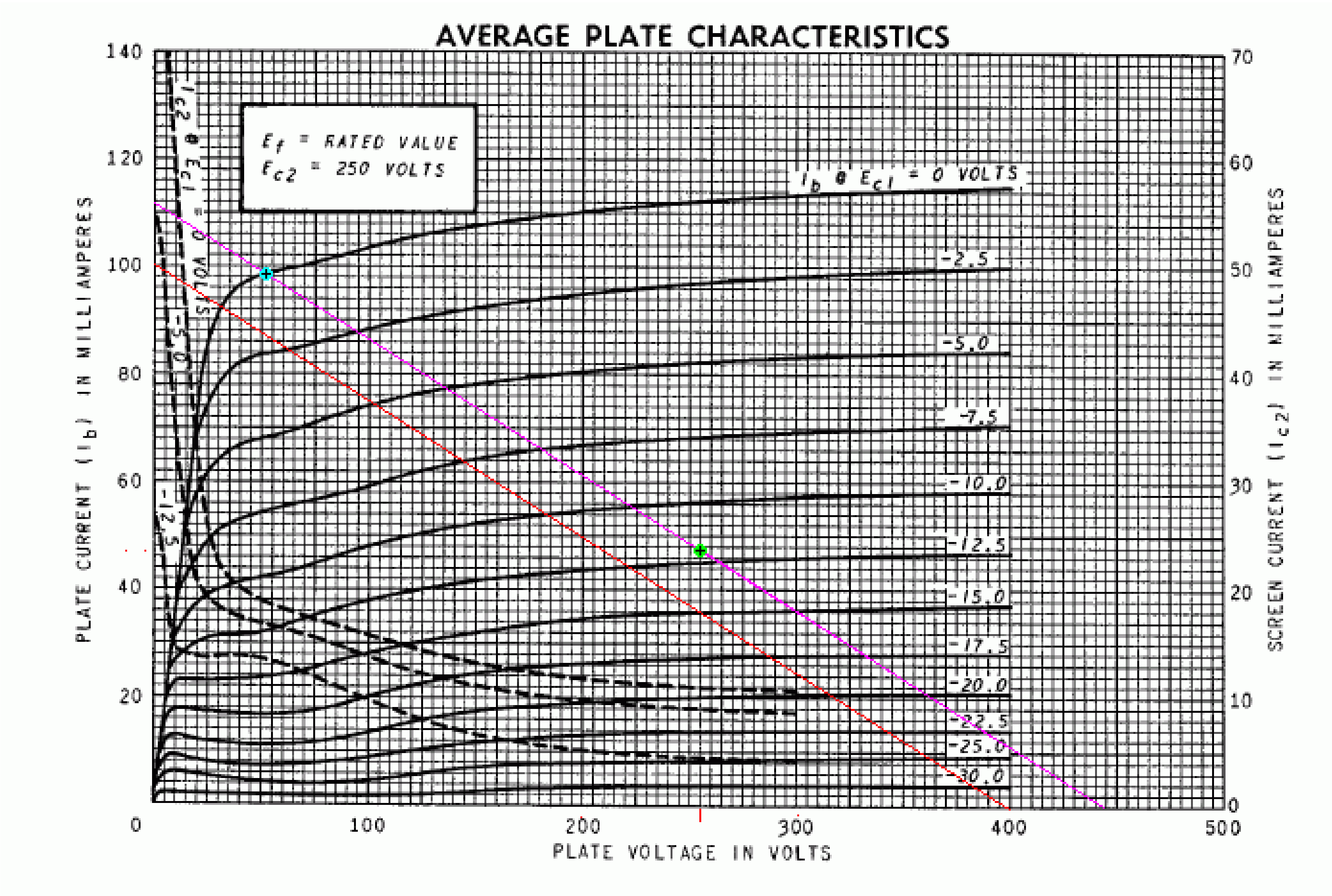
Now, to zero-in on that that load-line, take an arbitrary voltage on the x-axis, fairly far-out towards the right. For this example, 400Vdc. Now, use good old I=V/R to come up with a current point on the y-axis. Let´s say we´ve a 4000 ohm SE OT, classic for that 6V6 SE operation. Well, the corresponding current intercept on the y-axis is 400/4000 = 100mA. The line from 400V on the x-axis out to 100mA on the y-axis (——) has the slope of our load line.



Now draw a line (——) through your bias point (●), with this angle. (Bias point for SE: a point on the graph that will have roughly half of the load line above it, half below it, and not exceed the plate dissipation at idle.)



Note that maximum RMS voltage swings across this load line is .71 times the voltage from the bias point up to the voltage at intercept with the "Vg1=0" curve (+).



For a 6V6 with 250Vdc on the screen, the maximum RMS swing is about (250 - 50) * .71 = 140Vrms. Note that the maximum RMS current swing across this load line is .71 times the current from the bias point up to the current intercept with the "Vg1= 0"curve. For a 6V6 with 250Vdc on the screen, the maximum RMS current swing is about (100 - 50) * .71 = 35mA rms.

So, the maximum expected output before serious clipping here is P= I(rms) * V(rms) = .035 * 140 = 4.9 watts. Very consistent with empirical results.

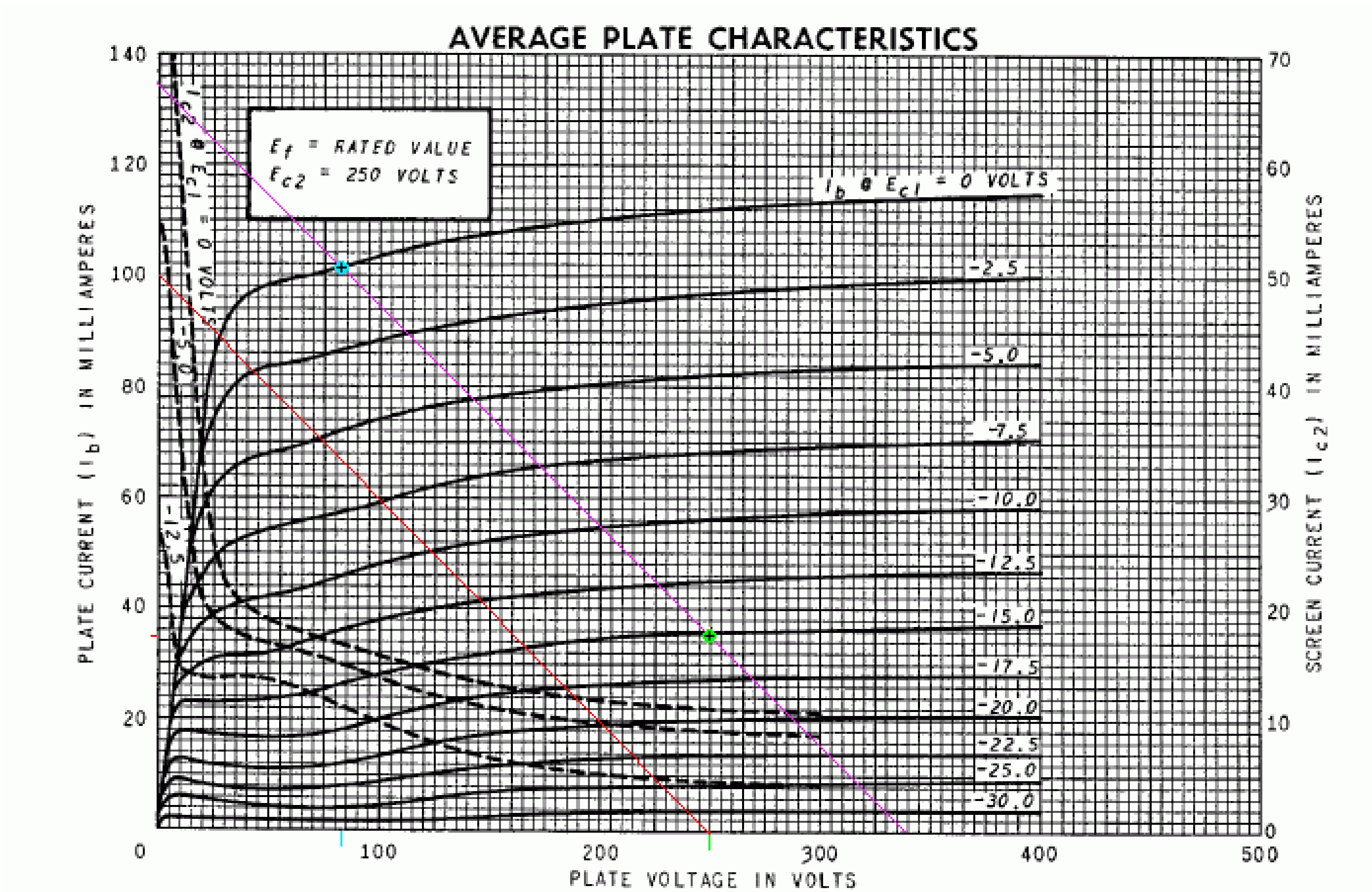
Push-Pull amp load-lines:

There are two big things different about push-pull:
1) the bias point can be a heck of a lot lower, and
2) the plate impedance will throw us a "gotchya" if you´re not thinking.

Number 1): Use a bias point that´s fairly low and to the right to maximize power. Whatever can be tolerated without the amp sounding "cold" or "life-less." Next draw the load line through that point and up to the intercept with the "Vg1=0" curve, same as before. But wait, there´s a "gotchya" on the load line.

Number 2): For push-pull, the number of OT turns that either output tube sees is one-half the total primary turns. Because the impedance is the square of the turns, the impedance that either tube will see is one-quarter of the PP OT´s primary impedance.

So, let´s look at a push-pull example:



For a 10k plate to plate PP OT primary, each 6V6 sees a 2500 ohm load. Drawing that 2500 ohm load onto the Vg2=250Vdc graph, and using a bias point of 35mA @ 250Vdc per tube, we get the following RMS figures:
Vrms = (250 - 83) * .71 = 119Vrms
Irms = (102mA - 35mA) * .71 = 48mA rms
P = Vrms * Irms = 5.7 watts.

This is under the 10 watt figure that RCA touts for the above specs. But you know what? without a bit of positive grid drive, you´re not going to get 10 watts without some clipping. Hmmm, they´re quoting 5% distortion at that 10 watts. So there you go: 5.7 watts without clipping, and 10 watts at 5% grid-clipping distortion.

There may even be one thing to make this slightly simpler: use "V Squared divided by R" to get the power. For example, that 2500 ohm load line for the push pull 6V6, 250Vdc plate at idle, 50Vdc max swing yields: (142^2)/2500 = 5.7 watts.

[Carl´s first results were a bit different (6.5 and 7.8w).] That´s because I´m using a very small graph (the one for 6AQ5s in the RCA manuals). My intercept guestimates just can't be all that good with such a small graph. And that shows you the imprecision of this (unless you get a large, very detailed graph). Don´t sweat the imprecision, however. Because any given tube is going to have slightly different curves than that "bogey" 6V6GT graph anyway (that's actually an average of many different 6V6s that they got off the production line).

By the way, guess what happens when a tube starts wearing out? The slope of that initial rise (i.e. the more vertical, left-hand part of the curve) starts to relax, and instead of getting up to 100mA at 50Vdc at Vg1=0, it may take 75Vdc to get up there. Doing the calculations on that, you can see that your output power starts to drop! Just like you experience in "real-life," and why you finally replace your tubes after the amp starts losing too much life. Makes sense, eh?

Hope that helps anyone who was afraid of using load-lines to calculate power. Need a reverb driver at 2 watts? Heck the above works with triodes too, just figure out the Vrms and Irms between the bias point on up to the "Vg1=0" curve, via that load line.

- Carl

Please post questions, suggestions, corrections etc. on the AX84 Discussion Forum.

Text and idea by Carl B., drawings and editing by Matthias M.