

Output Load Factor

...by Earles L. McCaul

• When $Z_{o0}/4$ isn't the Correct Answer

When computing the output power in a power amp, a common mistake is to view the circuit as a simple parallel load calculation. For example, a 23.5k ohm plate resistance (r_p) driving a 1.4k ohm load (i.e., $Z_{o0}/4$) is often misconstrued as an effective load of 1.32k ohms, equal to the two resistances in parallel (i.e., $r_p \parallel Z_{o0}/4$). This mistake usually leads to an error of ten percent or more. In this case, for example, the effective load is actually 1.25k ohms^[1]. Here is an explanation^{[2][3]} for why the effective load is less than what it seems.

Imagine we have a power amplifier with a plate resistance of r_p and a load of Z_o . The current through the load is the current generated by the tube, which is equal to the product of the transconductance g_m and the grid voltage v_g , *reduced* by the current divider formed by the plate resistance and the output load:

$$i_o = g_m v_g [r_p / (r_p + Z_o)]$$

By Ohm's Law, the voltage across the load is the current times the impedance:

$$v_o = g_m v_g [r_p / (r_p + Z_o)] Z_o$$

The power generated in the load is then simply the product of the voltage across it times the current through it:

$$P_o = [g_m v_g]^2 [r_p / (r_p + Z_o)]^2 Z_o$$

This equation is of the form $P = I^2 R$, where I is the driving current and R is the effective resistance through which it flows. In this case the driving current is $I = g_m v_g$, so the effective impedance of the load is

$$[r_p / (r_p + Z_o)]^2 Z_o$$

where $[r_p / (r_p + Z_o)]^2$ is the *load factor* [%]. It is important to note that this term is squared, an aspect that is often overlooked, and the primary source of confusion.

¹ See for example, "Getting More from Tube Data Sheets."

² Slerzberg and Osterberg, **Essentials of Radio Electronics**, 2nd ed., (New York: McGraw-Hill, 1961), pp. 261, 262.

³ Samuel Seeley, **Electron Tube Circuits**, 2nd ed., (New York: McGraw-Hill, 1958), p. 314.

• **Class-AB₁ example**

Using the values from the GE 6L6GC 55W Class-AB₁ data sheet example^[4], $r_p = 23.5k$ ohms and $Z_o = 1.4k$ ohms, we thus get an effective load of $Z_o' = 1.25k$ ohms:

$$[\%] = [r_p / (r_p + Z_o)]^2 = [23.5k / (23.5k + 1.4k)]^2 = 0.8907 \approx 0.89$$

$$Z_o' = [\%] \times Z_o = [0.8907] \times 1.4k = 1,247\Omega \approx 1.25k\Omega$$

The graph in Figure 1 below shows the relative power output P_o (solid purple) and equivalent dB value (dashed black) as a function of the ratio Z_o/r_p . It is important to notice how the effective impedance of the load is the same when $Z_o = 2r_p$ as when $Z_o = r_p/2$. In either case we get an effective impedance of $2r_p/3$.

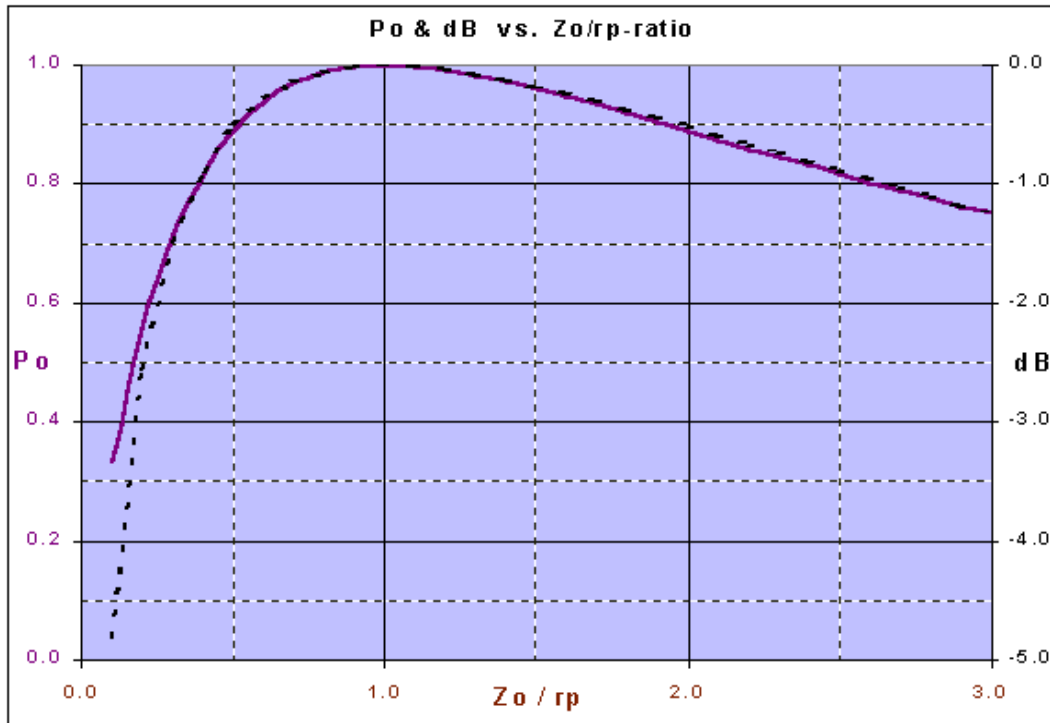


Figure 1 – Power Output and dB vs. Z_o/r_p -ratio.

Moreover, the effective impedance reaches a maximum of $r_p/4$ when $Z_o = r_p$, where the greatest power output is achieved. Important points to observe are: (1) the power declines much faster below $Z_o/r_p = 1$ than above this point; and, (2) the power is *at least* 88 percent of maximum, and attenuated by less than 0.5dB, when the ratio is between 0.5 and 2.0.

• **Summary**

⁴ GE 6L6-GC Beam Pentode, data sheet ET-T1515A (3-59).

Theory says the effective impedance of a push-pull output transformer is $Z_{o0}/4$ but the effects of real-world plate resistance and output load create a *load factor* [%] that says it's something lower, and that reduction is proportional to the current-divider ratio of the r_p and Z_o loads, *squared!*