
Subject: 300B SET Project - Part 1: The output stage

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One of the most important factors in designing a SET output stage is choosing the operating point, closely connected with determining a primary OPT load, R_a for our output tube. We'll use some simplified methods - for the start, we can say that our tube is "perfect" - linear, that its static anode characteristics are parallel and equidistant lines (μ and r_p are constants). Then our OPT is "perfect", or without losses, winding resistances are neglected, as well as L_p (primary inductance in parallel with R_a), C_w and L_w too (winding capacitances and leakage inductance - affects the high frequencies), speaker is a resistor, we'll neglect "rectification" effect ("lifting" of the OP on max. power - enlargement of I_a because of the distortion), etc. From Fig. 1 we have a few important things to observe: 1.) From 300B $U_a/I_a/U_g$ characteristics we choose an operating point somewhere in the middle of its (linear) characteristics, with respect for max. values of U_a , I_a , P_a . We can choose $U_a=350V$, $I_a=80mA$, $U_g=-70V$. 2.) The peak input AC voltage for max. power is equal to the bias voltage, or in our example $U_{in} = U_{gk} = 70V_p = 140V_{pp} = 49,5V_{rms}$. 3.) Our primary load R_a is reflected resistance of the speaker R_{sp} , connected at the secondary, where turns ratio is $n=N_{pr}/N_{sec}$, and then $U_{prim}=U_a=U_{sec}*n$, and $I_{pr}=I_a=I_{sec}/n$, and then $R_a=n^2*R_{sec}$. 4.) Theoretical U_a "across" our R_a is $\mu*U_{gk}$, or input voltage multiplied with tube amplification factor. However, the internal anode resistance r_p makes voltage divider with R_a , and U_a "across" R_a is actually smaller than $\mu*U_{gk}$, or $U_a=(\mu*U_{gk})/(1+r_p/R_a)$, then our stage amplification is lower than μ , or $A=\mu/(1+r_p/R_a)$. 5.) By Ohm's Law, AC voltage divided with AC current through the load gives the value of $R_a = U_a_{pp} / I_a_{pp} = U_a_p / I_a_p = U_a_{rms} / I_a_{rms}$. The power at the primary ("through" R_a) is $P_a=U_a^2/R_a=I_a^2*R_a=U_a*I_a$, where U_a and I_a are in rms values. 6.) AC current through the load R_a can "swing" around its quiescent value, $I_{a0}=80mA$ in our case, in a way that can't be lower than 0 mA, or higher than $2*I_{a0}=160mA$. In other words, I_a can be max. $160mA_{pp} = 80mA_p = 56,56mA_{rms}$. 7.) The "optimum" load R_a can be the load where max. voltage "swing" is "divided" with max. current "swing" for concrete OP, or where tube "runs out" from current and voltage swing at the same time. I developed the simple formula for $R_a=(\mu*U_{gk})/I_a - r_p$, or in our case $R_a=(3,9*70)/0,08 - 650 = 2762,5$ Ohms. Then we have $U_a=(\mu*U_{gk})/(1+r_p/R_a)=(3,9*70)/(1+650/2762,5) = 221V_p = 442V_{pp} = 156,27V_{rms}$. And then we have the power across the primary load $R_a=U_a^2/R_a = 156,27^2/2762,5 = 8,84W$. Or in other ways, $P_a=I_a^2*R_a=0,05656^2*2762,5 = 8,84W$ or $P_a=U_a * I_a = 156,27 * 0,05656 = 8,84W$. 8.) We can examine this graphically, see the Fig. 2 & 3. Our OP (350V/-70V/80mA) is the point O. We can find the point A, where the $U_g=0V$ line intersects max. current, 160mA in our case. If we draw the line through A&O to the abscisse U_a , we'll get point B ($I_a=0$) - and then our AB line is our R_a . Generally, $R_a=(U_a_{max} - U_a_{min}) / (I_a_{max} - I_a_{min})$, or in our case, $R_a = (570-130)/(0,160-0) = 440/0,16 = 2750$ Ohms. We can see that in our "ideal" case, input signal "swings" + and - 70V "around" -70V "bias" (0-140Vpp). That changing voltage "produces" varying I_a , symmetrical from 0-160 mA "around" the quiescent value of 80mA, and respectively - output voltage U_a across the load R_a , 220Vp on "both sides" of the quiescent 350V value. Power $P_a = 155,56^2/2750 = 8,8W$. No distortion:-). 9.) When we examine that conditions on the real 300B graphs, the things are little worse. Our point A= 160mA/117V/ $U_g=0V$, and point B= 535V/15mA/ $U_g=-140V$. According to the above, and Fig. 4, we have: $r_a=(535-117)/(0,160-0,015) = 418/0,145 = 2882,7$ Ohms. That's not such a large difference then the theoretical (ideal) analysis, but now, we can see that both "halves" of our output U_a

sinusoide are unequal, and that means

distortion: $K_2 \sim [U_{a0} - (U_{max} + U_{min})/2] / (U_{max} - U_{min})$
 $K_2 \sim [350 - (535 + 117)/2] / (535 - 117) = 0,057$ or 5,7 % Or expressed with

currents: $K_2 \sim [(I_{max} + I_{min})/2 - I_{a0}] / (I_{max} - I_{min})$
 $K_2 \sim [(0,16 + 0,015)/2 - 0,08] / (0,16 - 0,015) = 5,2\%$ - little difference because of not so precise graph reading... Rather then transform peak-to-peak values of U_a and I_a in rms values, we can calculate our P_a from pp values by

formula: $P_a = [(I_{max} - I_{min}) * (U_{max} - U_{min})] / 8$
 $P_a = [(0,16 - 0,015) * (535 - 117)] / 8 = 7,58W$ To be continued...
