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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 ( $\mu$  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  $\mu$ , 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  $R_a = U_a / I_a = U_a_{pp} / I_a_{pp} = U_a_{rms} / I_a_{rms}$ . 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  $U_a$

sinusoids are unequal, and that means

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

currents:  $K_2 \sim \frac{(I_{max} + I_{min})/2 - I_{a0}}{(I_{max} - I_{min})}$   $K_2 \sim \frac{(0,16 + 0,015)/2 - 0,08}{(0,16 - 0,015)} = 5,2\%$  - little difference because of not so precise graph reading... Rather than 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:  $P_a = \frac{(I_{max} - I_{min}) * (U_{max} - U_{min})}{8}$   $P_a = \frac{(0,16 - 0,015) * (535 - 117)}{8} = 7,58W$  To be continued...

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