
Subject: 300B SET Project - Part 2: The output stage some more

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At the end of the Part 1, there are some typing errors, the proper formulas are:

$$K2 \sim [U_{a0} - (U_{max} + U_{min})/2] / (U_{max} - U_{min})$$

$P_a = [(I_{max} - I_{min}) * (U_{max} - U_{min})] / 8$ (We can examine various other load-lines through our OP, for example, $R_{a2} = 6k\Omega$ and $R_{a3} = 1,5k\Omega$ in addition with $R_{a1} = 3k\Omega$ load line we determined (we "rounded" r_a on the first "standard" value). See Fig. 5.

Using "general" formula $R_a = (U_{a \max} - U_{a \min}) / (I_{a \max} - I_{a \min})$, we can draw the various load-lines by the little geometry, see Fig. 6.

We have the triangle, with U_a , I_a , R_a sides. We must find a "slope" of R_a , or angle β . Very easy - for $R_a = 3000 \Omega$, we can draw the line through, say $A' = 100mA$ and $B' = 300V$, using $U_{a \min} = 0$ and $I_{a \min} = 0$, $R_a = 300V/0,1A = 3000 \Omega$. Our $R_{a1} = 3k$ line through op. point $O = 350V/-70V/80mA$ we can draw like a parallel line to the line $A'B'$ we just got, "preserving" the angle β .

Back to Fig.5 - our point A_1 is intersection of the $U_g = 0$ line and $R_{a1} = 3k$ line, and correspond to $115V/158mA$. Point B_1 is intersection of the R_{a1} line and $U_g = -140V$ line, and correspond to $540V/16mA$.

Verification: $R_{a1} = (540 - 115) / (0,158 - 0,016) = 2993 \Omega$

Then $U_{a1} = 425V_{pp} = 212,5V_p = 150,26V_{rms}$, and then

$P_{a1} = U_{a1}^2 / R_{a1} = 150,26^2 / 3000 = 7,53W$, or

$P_{a1} = I_{a1}^2 * R_{a1} = 0,0502^2 * 3000 = 7,56W$, or $a_1 = U_{a1} * I_{a1} = 150,26 * 0,0502 = 7,54 W$, or "direct", in pp values:

$$P_a = [(540 - 115) * (0,158 - 0,016)] / 8 = 7,54W$$

In the similar way we can determine $R_{a2} = 6k$ load-line, first find the temporary A_2' and B_2' points, say from $R_{a2} = 600V/100mA = 6k\Omega$, parallel line through O , and then our point A_2 "says" $100V/122mA/U_g = 0V$, and point B_2 $580V/42mA/-140V$.

Verification: $R_{a2} = (580 - 100) / (0,122 - 0,042) = 6000 \Omega$

$P_{a2} = U_{a2}^2 / R_{a2} = 169,7^2 / 6000 = 4,8W$, or $P_{a2} = I_{a2}^2 * R_{a2} = 0,028^2 * 6000 = 4,8W$.

Or $P_{a2} = I_{a2} * R_{a2} = 169,7 * 0,028 = 4,8W$, or $P_{a2} = [(580 - 100) * (0,122 - 0,042)] / 8 = 4,8 W$. Much lower power, but the distortion is much smaller, too:

$$K2 \sim [350 - (580 + 100)/2] / (580 - 100) = 2 \%$$

Interesting is the $R_{a3} = 1,5k\Omega$ case, smaller then "optimum" $R_{a1} = 3k$. We can see that sinusoidal input signal around $-70V$, from $-30V$ up to $-110V$ ($80V_{pp}$) "produces" resonably "clean" output U_{a3} , from about $230V$ to about $440V$ ($210V_{pp}$), or $P_{a3} = U_{a3}^2 / R_{a3} = 74,25^2 / 1500 = 3,68 W$, but then our tube "runs out of current", or in another words, we "crossed" $160 mA$ "upper" limit. The consequences are that with full input "swing" from $U_{gk} = 0v$ to $U_{gk} = -140V$, our output sinusoid is limited, or part of it is "clipped off" - large distortion (of course, we talk about

"theoretical" class A1 here). Actually, $R_a=1k\Omega$ condition can be reached if $R_{sp}=4\ \Omega$, instead of the "nominal" $8\ \Omega$. See Fig. 7.

11.) We can now examine some properties of the real OPT, I have a pair of "Lundahl" LL1664/80mA, 3k:8 Ω . Its data are somewhat limited, but here are some:

- max. output power $P_{out}=10W/30Hz$
- primary inductance $L_p=22H$
- primary leakage inductance $L_w=8mH$
- primary "static" resistance $R_{wpr} = 148\ \Omega$
- secondary "static" resistance $R_{ws} = 0,5\ \Omega$
- turns ratio $n=19,2:1$

-We can calculate the LF power bandwidth: $f_{pb} = R_a / 2 * \pi * L_p = 21,3\ Hz/-3dB$, or in other words, OPT can "handle" half the power (5W) on the 21,7 Hz - where the load R_a is equal to the reactive impedance of the OPT. Or from 30Hz/10W (full power data), we can find -3dB power bandwidth $f_{pb} = 30/1,4142021,2\ Hz$.

Small signal frequency response is larger, $f_{ss} \sim r_p/2\pi * L_p \sim 4,7\ Hz$.

The high frequency response depends on the L_w and C_w , but we don't have the value of the winding capacitance, C_w ...

-Theoretical damping factor is the ratio between the primary load and tube internal anode resistance, $DF = R_a/r_p$, and in our case $DF = 3000/650 = 4,6$. But, winding resistances are actually in series with r_p , and referred to the primary, $R_w=R_{wpr} + R_{ws} * n^2 = 148 + 0,5 * 19,2^2 = 332,3\ \Omega$. Then our $DF=3000/(650+332,3) \sim 3$ times.

-Winding resistances have another bad feature - we have loss of our output power. The OPT efficiency is the ratio between the power at the speaker, P_{sp} and "input" power $P_a=P_{sp}+P_{rw}$. We can examine both R_{ws} and R_{wpr} in a series with the speaker, and then we have $R_{sec} = R_{sp} + R_w$. In our case, when we R_w "referred" to the secondary side, we have $R_w=R_{ws} + R_{wpr}/n^2 = 0,9\ \Omega$.

$E = P_{sp}/P_{sec} = U_{sp} * I_{sec} / U_{sec} * I_{sec} = U_{sp}/U_{sec}$

$U_{sp}=U_{sec}/(1+R_w/R_{sp})$, and then $E = 1/(1+R_w/R_{sp})$.

In our case, $E = 1/(1+0,9/8) = 0,9$ or 90 %. It means that 10% of our theoretical $P_a=7,54W$ (determined in chapter 10) would be heat in the winding resistances, $P_{rw}=0,75\ W$, and 90 % or about 6,8W would reach the speaker.

-We can try to find another OP for our 3k OPTs... For example, OP: $U_{ak}=320V$, $U_{gk}=-64,5V$, $I_a=80\ mA$. Plotting the $R_a=3k$ line through this OP gives $U_a=510-110=400V_{pp}$, and $I_a=0,15-0,02=0,13A_{pp}$. Then our $P_a=6,5W$, and $K_2 \sim 2,5\ %$, not bad...

Interestingly, our theoretical R_a formula gives

$R_a=64,5^2 * 3,9/0,08 - 650 \sim 2,5\ k\Omega$.

12.) CONCLUSION:

Although our analysis is simplified, we can see that the "theoretical" R_a formula or load line analysis where I_a is "allowed" to swing from $0-2 * I_{a0}$ gives R_a with no "current limiting" and P_a close to the max. power for chosen OP. With linear tubes in the "middle" of their $U_a/I_a/U_{gk}$ characteristics, "real" graphical analysis gives the results close to the theoretical values, based on voltage source model in series with r_p , and max. current swing.

However, it is "wise" to look at the resultant R_a like the minimum, or in another words, we can use a larger R_a with somewhat lower power, but with lower distortion and larger damping factor. In our case, we get $R_a \sim 2k8$, and round it on the first "standard" value, $R_a = 3k$ like the minimum we'd like to use.

Although we only "touched" some of the OPT properties, we can see that the quality of the OPT (high L_p , low $C_w, L_w, R_w \dots$) is important.

13.) F A Q :

Q) Frankly - from all those graphs, math and formulas I understand absolutely nothing. However, I'd like to find the "best" OPT primary impedance for the 300B OP I really like: $U_{ak} = 350V$, $I_a = 60mA$, $U_{gk} = -74V$. Please, answer in one sentence, and one formula max!

A) Use my formula $R_a = \mu * U_{gk} / I_a - r_p = 3,9 * 74 / 0,06 - 700 = 4110 \text{ Ohms}$, and "round" it on the larger "standard" value of 5 kOhms.

Q) Huh, but I'd like to use OPTs I have, 2k5/60mA/17H. My buddy says that I can do it, you can't go wrong with $R_a > 3 * r_p$ with 300B, and if I really need 5k OPT that I can connect 8 Ohms speaker on the 4 Ohms taps on my OPT.

A) Your buddy can be right, SE is a very subjective thing, but see "chapter" 10 once more... And yes, your 2k5 OPT is now $R_a = 5k$ OPT by changing the turns ratio with connection of the 8 Ohms speaker to the 4 hms taps. But, it's not quite the same like the "proper" 5k OPT, for example L_p is now too small for $R_a = 5k$, and LF can be limited and more distorted. But, you can try it, your friend can be right again, SE is very subjective thing, etc.