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

Posted by [Damir](#) on Sun, 01 May 2005 14:20:12 GMT

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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  $\beta$ . 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  $\beta$ .

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" reasonably "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  $\Omega$ . It's 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  $R_w=R_{ws} + R_{wpr}/n^2 = 0,9\ \Omega$ .

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

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

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 analyse 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.

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Subject: Re: 300B SET Project - Part 2: The output stage some more  
Posted by [Wayne Parham](#) on Sun, 01 May 2005 21:52:04 GMT  
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Looks like the primary will need to be 4k-5k ohms, yes? And B+ should be 450V, is that right?  
Thanks for all the groundwork!

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Subject: Re: 300B SET Project - Part 2: The output stage some more  
Posted by [Forty2wo](#) on Mon, 02 May 2005 01:14:14 GMT  
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Wow. Great reading. Thank you for taking the time and effort to present it...John

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

Posted by [Damir](#) on Mon, 02 May 2005 04:41:15 GMT

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For cathode biased amp,  $U_{ak}=350V$ ,  $U_{gk}=70V$  and voltage drop on the primary winding resistance  $U_{rp} = 148 * 0,08 = 11,84V$ . Then our B+ is  $350+70+12=432V$  DC. I'd "play" with similar OPs, but this is "working" version. And for the "optimum" Ra... depends of what OPT you have /can find:-) I have a LL1664 (3k:8 Ohms), but better solution would be LL1623 (3k/5k6:4,8,16 Ohms, 90mA), then you have more options to try:-)

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

Posted by [hungnv](#) on Fri, 19 Jul 2013 08:09:47 GMT

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Damir

Can you post the picture of Part 2 again , it was disappeared.

Thanks

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

Posted by [horny](#) on Tue, 06 Jan 2015 15:14:10 GMT

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hello i am new here and really interested in de 300b project  
but i can't see the pictures in all the 300b set projects  
is this some thing in my pc or are they really gone?

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

Posted by [FL152](#) on Sun, 11 Jan 2015 18:09:16 GMT

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Gone, but the final schematic is in the "Projects" files.

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