Subject: The Introduction of Push - Pull Theory
Posted by Damir on Thu, 30 Dec 2004 19:05:10 GMT
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During a heated "PP" debate on another forum, I tried to describe PP-model in a simplified way. I finally put together and extend some posts of mine about that subject. Enjoy!   THE INTRODUCTION OF PUSH - PULL THEORY1. FOREWORD:We`d introduce some simplifications - the transformer is ideal (no losses, the effects of Rw, Lp, Cw, etc. are negligible, tubes are identical and "expressed" as AC generators/voltage sources with their internal resistances, the effects of non-linearity is negligible (rp and mu are constant), speaker load is resistor, etc.We`ll neglect DC conditions, too.2. SINGLE ENDED (SE) OUTPUT STAGEWe have output transformer with N1=300 turns on the primary, and N2=10 turns on the secondary. The turns ratio n=N1/N2=300/10=30. If we connect the speaker of Rs=4 Ohms on the secondary, then our tube, connected at the primary "see" the load Rpr=(N1/N2)^2*Rs=30^2*4=3600 Ohms. Our tube/AC generator has mu=3,75, rp=700 Ohms and with Ugk=32 Vrms "input" our Ugen=mu*Ugk=3,75*32=120Vrms, then current that flows through the circuit (rp and Rpr in series) is I=120/(3600+700)=27,9mA, and the voltage drop across rp is Urp=700*0,0279=19,5Vrms - then voltage through our Rpr is 100,5Vrms. Note that the conditions are similar to the "ideal" 2A3 or 300B tube, working on the linear part of its anode characteristics.From now on, we`d simplify things even more - we`ll neglect our internal tube/generator resistance, and just say that our generator 2gives" 100vrms across the 3600 Ohms resistance. Then power at the primary is: Ppr=Upr^2/Rpr=100^2/3600=2,77W.The AC current through primary load is Ipr=Upr/Rpr=(Ppr/Rpr)^0,5= 27,77mA. Our speaker, connected at the secondary gets this power, or Ppr=Ps, voltage on the speaker Us=Upr/n=100/30=3,33Vrms, and current Is=Us/Rs=(Ps/Rs)^0,5=Ipr*n=0,833A. See the schematic Nr.1.If we have another secondary, again with N3=N2=10 turns, and connect them in a series, then: (see the schematics Nr.2)-we can connect Rs=4 Ohms speaker across one or the other secondary, our tube "sees" 3600 ohms reflected load, and the power is 2,77W - see above and Figure 2a.-if we connect one speaker across the whole secondary (center tap is unconnected), then we have turns ratio n`=300/(10+10)=15. if we want our tube to "see" the same 3600 Ohms reflected resistance at the primary (and give the same power), then we must connect Rs`=Rpr/n`^2=3600/15^2=16 Ohms speaker. Our Us`=Upr/n`=100/15=6,667Vrms and Ps`=Us`^2/Rs`=6,667^2/16=2,77W.And Is`=Is*n`=0,416A, and Ps`=Is`^2*Rs=0,416^2*16=2,77W. See Figure 2b.-but, if we want to connect the two identical speakers, each one across one and another half of the secondary, and want the same reflected load on the primary (3600 Ohms) and the same power at the primary (2,77W)that`ll be "transferred" to the secondary loads - what is the resistances of the two speakers?We know that Rs1=Rs2=Rs``, and we know that Us1=Us2=Us``= Upr/n=3,33Vrms. From the Law of the energy conservation, Ppr=Ps1+Ps2, and Upr^2/Rpr=Us1^2/Rs1 + Us2^2/Rs2Upr^2/Rpr=2Us^2/Rs``2,77=2*3,33^2/Rs`` and Rs``=22,22/2,77= 8 Ohms.The power at the loads Rs1=Rs2=Rs``=3,33^2/8=1,389W, or each 8-Ohms resistor gets Ppr/2.The AC current through the load(s) Is1=Is2=IS``=Us``/Rs``=3,33/8=0,416A.We have n1=n2, Rs1=Rs2, Us1=Us2 - then our center tap "dissapeared" (it doesn`t carry any current). We can see the similarity between 8+8 Ohms series connected speakers - Figure 2c, and 16-Ohms speaker example - Figure 2b.2.1 SUMMARY AND CONCLUSION:We have the SE output stage, our output tube connected at the primary, and two series connected secondary windings. We can connect one 4-Ohms speaker across the one or another secondary, we can connect 16-Ohms speaker across the whole secondary, or we can connect two 8-Ohms speakers across each secondary. In all three cases the reflected primary load is the same (3600 Ohms), and power in the primary that is transferred to the secondaries is the same (2,77W).We can look at the series connected secondaries like one center tapped secondary. t`s Rsec=16 Ohms when both windings are used with 16-Ohms load across the whole secondary. It`s the 4-Ohms (Rsec/4), when halfof the secondary is used (with 4-Ohms load), other half unconnected. and it`s the 8+8 Ohms, when both windings are used at the same time, with 8-Ohms speaker across each winding (Rsec/2).The ratio of Rpr/rp (neglecting Rw-in series with rp, and neglecting Cw, Lsp) is our damping factor DF=Rpr/rp=3600/700=5,1.3. THE PUSH - PULL (PP) OUTPUT STAGESee figure 3a - we have PP OPT with, say, 300 turns center taped primary, or two primary windings N1=N2=150 turns connected in series. We have the secondary, with Ns=10 turns. Then turns ratio from the whole primary to the secondary is n=(N1+N2)/Ns=300/10 = 30. From one or another half of the primary, the turns ratios are n1=n2=N1/Ns = N2/Ns = 15010 =15.If we connect the speaker Rs=8 Ohms on the secondary, then our reflected impedance to the whole primary (from anode to anode, or from the points A&B) is Raa=n^2*Rs=(30^2)*8=7200 Ohms.The reflected secondary impedance to the one or another half of the primary (between the points A&C or between B&C) is Rp1=Rp2= n1^2*Rs = n2^2*Rs = 15^2*8 = 1800 Ohms, or Raa/4.In the 2nd chapter (SE), we saw, when we connect our tube/generator across the whole primary, then we have a potential divider between the primary load and rp, and our Raa=7200 Ohms "see" Upr`=Ugen/(1+rp/Raa) = 120/(1+700/7200)=109,37Vrms. The current through the load, Raa, is Ip`=Up`/Raa=109,37/7200=15,19mA. Then we have Ppr`=Upr`^2/Raa=109,37^2/7200=1,66W or in another ways, Ppr`=Upr`*Ipr`=Ipr`^2*Raa=1,66W. See figure 3b.When we connect our tube across the only half of the primary, lets say between the points B&C, our load is now Rpr2=1800 Ohms, and Upr2=120/(1+700/1800)=86,4rms, Ipr1=48mA, and power 4,15W, Figure 3c.3.1 PUSH PULL:Now, we feel like goin` PP, and connect two identical generators/tubes, but in antiphase, see Figure 4. The center tap (point C) is connected to the DC B+ (and AC ground!), but no AC current flows through it, and can be "ommited". Each generator "sees" the equal load - but the question is - which load each tube "see" in class A (both tubes work all the time in the equal loads and both give, say 100Vrms). When we measure the AC voltage between the points A&C, and B&C, we`d get 100Vrms. But, the AC voltage across the whole primary, points A&B is 200Vrms (two 100Vrms generators in antiphase).then we can calculate the current through the primary, Ipr=Upr/Raa = 200/7200 = 27,77 mA. And our power that both tubes "give" to the primary is Ppr=Upr^2/Raa = Ipr^2*Raa = Upr*Ipr = 5,55W. Each tube "gives" half of the voltage (100Vrms), and apparently - half of the primary power.This power is "transferred" to the secondary load, when Usec=Upr/n= 200/30=6,66Vrms and Isec=Ipr*n=0,0277*30=0,833A. Power is the same, or Ppr=Psec, or Psec=Usec*Isec=6,66*0,833=5,55W.The Law of energy conservation says Ppr=Psec, or in this case, Psec=Ppr1+Ppr2, then Usec^2/Rsec = Upr1^2/Rpr1 + Upr2^2/Rsec = 5,55W.We know that Upr1=Upr2=100vrms. we know Usec^2/Rsec=5,55W. We know that our Rpr1=Rpr2=Rpr1,2 - unknown resistance(s) of one or another half of the primary, that each tube from PP pair "sees".5,55 = 100^2/Rpr1 + 100^2/Rpr25,55 = 2*(100^2)/Rpr1,2 andRpr1,2 = 3600 ohms or half of the total Raa=7200 ohms.We can express this with turn ratios, the result is the same:1/Rs = 1/(Rpr1*(Ns/N1)^2 + 1/(Rpr2*(Ns/N2)^21/8 = 1/(Rpr1,2*(10/150)^2 + 1/(Rpr1,2*(10/150)^2)and from that Rpr1,2 = 3600 Ohms.Our damping factor DF=Raa/2rp = 7200/2*700 = 5,1 (neglecting Rw in series with rp, and influences of Lp, Lsp, Cw).4. SUMMARY AND CONCLUSION:A tube connected across the whole primary "sees" the reflected resistance of the secondary, or square of the turns ratio times secondary load, Raa=((N1+N2)/Nsec)^2 * Rsec. When we connect our tube across the half of the primary, then our tube "sees" the reflected load Ra=((N1/Nsec)^2 * Rsec, or Raa/4.When we connect two tubes in PP A class (both tube s working all the time), each tube from PP pair "sees" half of the total primary resistance, or Raa/2.When we use the same DC conditions, and Raa that is twice Ra for the one tube in SE, then our resultant power from PP pair is double then from one tube in SE.When one tube reaches anode current cut-off, we can say that`s the same as removing this tube from its socket. The "remaining" tube then "sees" Raa/4 - class B (anode current flows one half of the cycle).We can say that in the class AB anode current flows less then the entire cycle (but more then half), at the voltage peaks one or another tube switchess off.