

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 THEORY

1. FOREWORD:We`d introduce some simplifications - the transformer is ideal (no losses, the effects of R_w , L_p , C_w , etc. are negligible, tubes are identical and "expressed" as AC generators/voltage sources with their internal resistances, the effects of non-linearity is negligible (r_p and μ are constant), speaker load is resistor, etc.We`ll neglect DC conditions, too.

2. SINGLE ENDED (SE) OUTPUT STAGEWe have output transformer with $N_1=300$ turns on the primary, and $N_2=10$ turns on the secondary. The turns ratio $n=N_1/N_2=300/10=30$. If we connect the speaker of $R_s=4$ Ohms on the secondary, then our tube, connected at the primary "see" the load $R_{pr}=(N_1/N_2)^2 \cdot R_s=30^2 \cdot 4=3600$ Ohms. Our tube/AC generator has $\mu=3,75$, $r_p=700$ Ohms and with $U_{gk}=32$ Vrms "input" our $U_{gen}=\mu \cdot U_{gk}=3,75 \cdot 32=120$ Vrms, then current that flows through the circuit (r_p and R_{pr} in series) is $I=120/(3600+700)=27,9$ mA, and the voltage drop across r_p is $U_{rp}=700 \cdot 0,0279=19,5$ Vrms - then voltage through our R_{pr} is $100,5$ Vrms. 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 "gives" 100vrms across the 3600 Ohms resistance. Then power at the primary is: $P_{pr}=U_{pr}^2/R_{pr}=100^2/3600=2,77$ W. The AC current through primary load is $I_{pr}=U_{pr}/R_{pr}=(P_{pr}/R_{pr})^{0,5}=27,77$ mA. Our speaker, connected at the secondary gets this power, or $P_{pr}=P_s$, voltage on the speaker $U_s=U_{pr}/n=100/30=3,33$ Vrms, and current $I_s=U_s/R_s=(P_s/R_s)^{0,5}=I_{pr} \cdot n=0,833$ A. See the schematic Nr.1. If we have another secondary, again with $N_3=N_2=10$ turns, and connect them in a series, then: (see the schematics Nr.2)-we can connect $R_s=4$ 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 $R_s`=R_{pr}/n`^2=3600/15^2=16$ Ohms speaker. Our $U_s`=U_{pr}/n`=100/15=6,667$ Vrms and $P_s`=U_s`^2/R_s`=6,667^2/16=2,77$ W. And $I_s`=I_s \cdot n`=0,416$ A, and $P_s`=I_s`^2 \cdot R_s=0,416^2 \cdot 16=2,77$ W. 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 $R_{s1}=R_{s2}=R_s`$, and we know that $U_{s1}=U_{s2}=U_s`=U_{pr}/n=3,33$ Vrms. From the Law of the energy conservation, $P_{pr}=P_{s1}+P_{s2}$, and $U_{pr}^2/R_{pr}=U_{s1}^2/R_{s1} + U_{s2}^2/R_{s2}$ $U_{pr}^2/R_{pr}=2U_s`^2/R_s`$ $2,77=2 \cdot 3,33^2/R_s`$ and $R_s`=22,22/2,77=8$ Ohms. The power at the loads $R_{s1}=R_{s2}=R_s`=3,33^2/8=1,389$ W, or each 8-Ohms resistor gets $P_{pr}/2$. The AC current through the load(s) $I_{s1}=I_{s2}=I_s`=U_s`/R_s`=3,33/8=0,416$ A. We have $n_1=n_2$, $R_{s1}=R_{s2}$, $U_{s1}=U_{s2}$ - then our center tap "disappeared" (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. It's $R_{sec}=16$ Ohms when both windings are used with 16-Ohms load across the whole secondary. It's the 4-Ohms ($R_{sec}/4$), when half of 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 ($R_{sec}/2$). The ratio of R_{pr}/r_p (neglecting R_w in series with r_p , and neglecting C_w , L_{sp}) is our damping factor $DF=R_{pr}/r_p=3600/700=5,13$. THE PUSH - PULL (PP) OUTPUT STAGES See figure 3a - we have PP OPT with, say, 300 turns center taped primary, or two primary windings $N_1=N_2=150$ turns connected in series. We have the secondary, with $N_s=10$ turns. Then turns ratio from the whole primary to the secondary is $n=(N_1+N_2)/N_s=300/10 = 30$. From one or another half of the primary, the turns ratios are $n_1=n_2=N_1/N_s = N_2/N_s = 150/10 = 15$. If we connect the speaker $R_s=8$ Ohms on the secondary, then our reflected impedance to the whole primary (from anode to anode, or from the points A&B) is $R_{aa}=n^2*R_s=(30^2)*8=7200$ Ohms. The reflected secondary impedance to the one or another half of the primary (between the points A&C or between B&C) is $R_{p1}=R_{p2}=n_1^2*R_s = n_2^2*R_s = 15^2*8 = 1800$ Ohms, or $R_{aa}/4$. 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 r_p , and our $R_{aa}=7200$ Ohms "see" $U_{pr} = U_{gen}/(1+r_p/R_{aa}) = 120/(1+700/7200)=109,37$ Vrms. The current through the load, R_{aa} , is $I_p = U_p/R_{aa}=109,37/7200=15,19$ mA. Then we have $P_{pr} = U_{pr}^2/R_{aa}=109,37^2/7200=1,66$ W or in another ways, $P_{pr} = U_{pr} * I_{pr} = I_{pr}^2 * R_{aa}=1,66$ W. See figure 3b. When we connect our tube across the only half of the primary, let's say between the points B&C, our load is now $R_{pr2}=1800$ Ohms, and $U_{pr2}=120/(1+700/1800)=86,4$ rms, $I_{pr1}=48$ mA, and power 4,15W, Figure 3c. 3.1 PUSH PULL: Now, we feel like going 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 "omitted". 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, $I_{pr}=U_{pr}/R_{aa} = 200/7200 = 27,77$ mA. And our power that both tubes "give" to the primary is $P_{pr}=U_{pr}^2/R_{aa} = I_{pr}^2 * R_{aa} = U_{pr} * I_{pr} = 5,55$ W. Each tube "gives" half of the voltage (100Vrms), and apparently - half of the primary power. This power is "transferred" to the secondary load, when $U_{sec}=U_{pr}/n= 200/30=6,66$ Vrms and $I_{sec}=I_{pr}*n=0,0277*30=0,833$ A. Power is the same, or $P_{pr}=P_{sec}$, or $P_{sec}=U_{sec} * I_{sec}=6,66*0,833=5,55$ W. The Law of energy conservation says $P_{pr}=P_{sec}$, or in this case, $P_{sec}=P_{pr1}+P_{pr2}$, then $U_{sec}^2/R_{sec} = U_{pr1}^2/R_{pr1} + U_{pr2}^2/R_{pr2} = 5,55$ W. We know that $U_{pr1}=U_{pr2}=100$ rms. we know $U_{sec}^2/R_{sec}=5,55$ W. We know that our $R_{pr1}=R_{pr2}=R_{pr1,2}$ - unknown resistance(s) of one or another half of the primary, that each tube from PP pair "sees". $5,55 = 100^2/R_{pr1} + 100^2/R_{pr2}$, $5,55 = 2*(100^2)/R_{pr1,2}$ and $R_{pr1,2} = 3600$ ohms or half of the total $R_{aa}=7200$ ohms. We can express this with turn ratios, the result is the same: $1/R_s = 1/(R_{pr1} * (N_s/N_1)^2 + 1/(R_{pr2} * (N_s/N_2)^2)$, $1/8 = 1/(R_{pr1,2} * (10/150)^2 + 1/(R_{pr1,2} * (10/150)^2)$ and from that $R_{pr1,2} = 3600$ Ohms. Our damping factor $DF=R_{aa}/2r_p = 7200/2*700 = 5,1$ (neglecting R_w in series with r_p , and influences of L_p , L_{sp} , C_w). 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, $R_{aa}=(N_1+N_2)/N_{sec})^2 * R_{sec}$. When we connect our tube across the half of the primary, then our tube "sees" the reflected load $R_a=(N_1/N_{sec})^2 * R_{sec}$, or $R_{aa}/4$. 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 $R_{aa}/2$. When we use the same DC conditions, and R_{aa} that is twice R_a 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" $R_{aa}/4$ - 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.
