Subject: 300B SET Project - Part 1: The output stage
Posted by Damir on Thu, 28 Apr 2005 13:23:44 GMT
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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, Ra 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 (µ and rp are constants). Then our OPT is "perfect", or without losses, winding resistances are neglected, as well as Lp (primary inductance in parallel with Ra), Cw and Lw 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 Ia because of the distortion), etc.From Fig. 1 we have a few important things to observe:1.)From 300B Ua/Ia/Ug characteristics we choose an operating point somewhere in the middle of its (linear) characteristics, with respect for max. values of Ua, Ia, Pa. We can choose Ua=350V, Ia=80mA, Ug=-70V2.)The peak input AC voltage for max. power is equal to the bias voltage, or in our example Uin = Ugk = 70Vp = 140Vpp = 49,5Vrms3.)Our primary load Ra is reflected resistance of the speaker Rsp, connected at the secondary, where turns ratio is n=Npr/Nsec, and then Uprim=Ua=Usec*n, and Ipr=Ia=Isec/n, and then Ra=n^2*Rsec4.)Theoretical Ua "across" our Ra is µ*Ugk, or input voltage multiplied with tube amplification factor. However, the internal anode resistance rp makes voltage divider with Ra, and Ua "across" Ra is actually smaller then µ*Ugk, or Ua=(µ*Ugk)/(1+rp/Ra), then our stage amplification is lower then µ, or A=µ/(1+rp/Ra)5.)By Ohm`s Law, AC voltage divided with AC current through the load gives the value of Ra = Ua pp / Ia pp = Ua p / Ia p = Ua rms / Ia rms.The power at the primary ("through" Ra) is Pa=Ua^2/Ra=Ia^2*Ra=Ua*Ia, where Ua and Ia are in rms values.6.)AC current through the load Ra can "swing" around its quiescent value, Ia0=80mA in our case, in a way that can`t be lower then 0 mA, or higher then 2*Ia0=160mA. In other words, Ia can be max. 160mApp = 80 mAp = 56,56 mArms7.)The "optimum" load Ra 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 Ra=(µ*Ugk)/Ia - rp, or in our case Ra=(3,9*70)/0,08 - 650 = 2762,5 Ohms.Then we have Ua=(µ*Ugk)/(1+rp/Ra)=(3,9*70)/(1+650/2762,5) = 221Vp = 442 Vpp = 156,27 Vrms.And then we have the power across the primary load Ra=Ua^2/Ra = 156,27^2/2762,5 = 8,84W. Or in other ways, Pa=Ia^2*Ra=0,05656^2*2762,5 = 8,84WOr Pa= Ua * Ia = 156,27 * 0,05656 = 8,84W8.)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 Ug=0V line intersects max. current, 160mA in our case. If we draw the line through A&O to the abscisse Ua, we`ll get point B (Ia=0) - and then our AB line is our Ra. Generally, Ra=(Ua max - Ua min) / (Ia max - Ia min), or in our case, Ra = (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 Ia, symetrical from 0-160 mA "around" the quiescent value of 80mA, and respectively - output voltage Ua across the load Ra, 220Vp on "both sides" of the quiescent 350V value.Power Pa = 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/Ug=0V, and point B= 535V/15mA/Ug=-140V.According to the above, and Fig. 4, we have:ra=(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 Ua sinusoide are unequal, and that means distortion:K2~[Ua0-(Umax+Umin)/2]/(Umax-Imin)K2~[350-(535+117)/2]/(535-117) = 0,057 or 5,7 % Or expressed with currents:K2~[(Imax+Imin)/2-Ia0]/(Imax-Imin)K2~[(0,16+0,015)/2-0,08]/(0,16-0,015)= 5,2% - little difference because of not so precise graph reading...Rather then transform peak-to-peak values of Ua and Ia in rms values, we can calculate our Pa from pp values by formula:Pa=[(Imax-Imin)*(Umax-Imin)]/8Pa=[(0,16-0,015)*(535-117)]/8 = 7,58WTo be continued...