EE 210

Sol^n to HA # 3

1 i) $V_{SB} = 0 \Rightarrow V_{TN} = V_{TNO} = \underline{1V}$

ii) $V_{SB} = +1V \Rightarrow V_{TN} = V_{TNO} + \gamma\left(\sqrt{2\phi_F + V_{SB}} - \sqrt{2\phi_F}\right)$

$= 1 + 0.4\left(\sqrt{0.6+1} - \sqrt{0.6}\right) = \underline{1.2V}$

iii) $V_{SB} = +5V \Rightarrow V_{TN} = 1 + 0.4\left(\sqrt{0.6+5} - \sqrt{0.6}\right) = \underline{1.64V}$

If body were tied to a +ve potential, then the SB jn. would become forward biased, & the jn. would carry large forward current, totally overshadowing the surface current due to field effect. ⇒ MOS operation will be lost.

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2 a) i) $V_{DS} = \underline{1V}$ $\quad V_{GS} - V_{TN} = 2 - 0.7 = \underline{1.3V} \Rightarrow V_{DS} < V_{GS} - V_{TN} \Rightarrow$ non-saturation

$\therefore I_D = \frac{K_n'}{2}\left(\frac{W}{L}\right)\left[2(V_{GS}-V_{TN})V_{DS} - V_{DS}^2\right] = \frac{40\times10^{-6}}{2} \times \frac{20}{1} \times \left[2(2-0.7)1 - 1^2\right]$

$= \underline{0.64\,mA}$

ii) $V_{DS} = \underline{5V}$ $\quad V_{GS} - V_{TN} = \underline{1.3V} \Rightarrow V_{DS} > V_{GS} - V_{TN} \Rightarrow$ saturation

$\therefore I_D = \frac{K_n'}{2}\left(\frac{W}{L}\right)(V_{GS}-V_T)^2 = \underline{0.676\,mA}$

b) i) With $\lambda = 0.1\,V^{-1}$, the result of part i) will remain unaltered, ∵ λ has no meaning in non-saturation region (as the channel is yet to pinch off).

ii) $I_D = 0.676\,mA \times (1 + \lambda V_{DS}) = \underline{1.014\,mA}$

Note: I_D increases significantly in saturation region due to the channel length modulation effect, compounded by a high value of λ.

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3 $V_{TNO} = -1V \Rightarrow$ Depletion mode device, operated with $V_G = V_S = 0 \Rightarrow V_{GS} = 0$ & $V_{DS} = 0.5V$.

a) If $V_B = 0$, $V_{BS} = 0$, $V_{TN} = V_{TNO} = -1V$, $V_{GS} - V_{TN} = 1V$, $V_{DS} = 0.5V \Rightarrow$ non-sat.

$\therefore I_D = \frac{K_n'}{2}\left(\frac{W}{L}\right)\left[2(V_{GS}-V_{TN})V_{DS} - V_{DS}^2\right] = \underline{0.3\,mA}$

b) V_B can only be −ve, ∵ $V_S = 0$, & the device is n-channel (p-substrate). With V_{BS} becoming more −ve, V_{TN} would keep on increasing due to body effect. When V_{TN} equals $-0.5V$, $V_{GS} - V_{TN} = 0.5V = V_{DS}$, & the device would be at the cross-over point betn. non-sat. & sat. regions.

$\therefore V_{TN} = -0.5V = -1 + \gamma\left(\sqrt{2\phi_F + V_{SB}} - \sqrt{2\phi_F}\right) \Rightarrow 0.5 = 0.4\left(\sqrt{0.6+V_{SB}} - \sqrt{0.6}\right)$

which gives $V_{SB} = 3.5V \Rightarrow V_B = -\underline{3.5V}$.

& $I_D = \frac{K_n'}{2}\left(\frac{W}{L}\right)(V_{GS}-V_{TN})^2 = \underline{0.1\,mA}$.

c) For I_D to go to zero, the device must cutoff, i.e., $V_{GS}-V_{TN}$ must be zero, (2)
or $V_{GS}=V_{TN}=\underline{0}$ (for this case) (∵ $V_G=V_S=0$ & $V_{GS}=0$).

∴ $V_{TN}=0=-1+0.4(\sqrt{0.6+V_{SB}}-\sqrt{0.6}) \Rightarrow V_{SB}=\underline{10.12\,V} \Rightarrow V_B=-\underline{10.12\,V}$.

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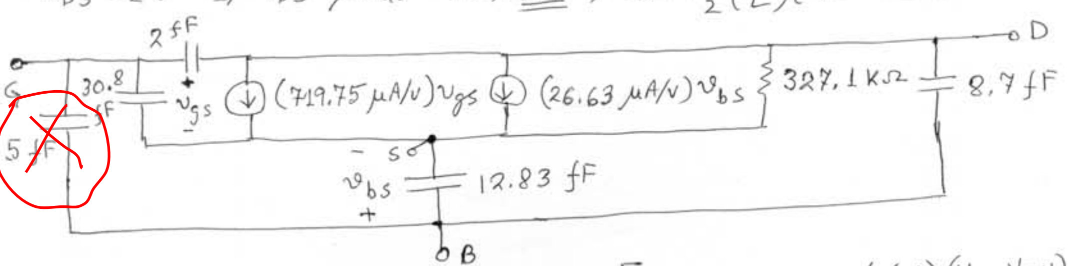
4. $C'_{ox}=\frac{\epsilon_{ox}}{t_{ox}}=\underline{4.32\times10^{-7}\,F/cm^2}$, $\gamma=\frac{\sqrt{2q\epsilon_s N_A}}{C'_{ox}}=\underline{0.094\,V^{1/2}}$

$V_{TN}=V_{TNO}+\gamma(\sqrt{2\phi_F+V_{SB}}-\sqrt{2\phi_F})=\underline{0.646\,V}$, $V_{GS}-V_{TN}=\underline{0.354\,V}$

$V_{DS}=2V \Rightarrow V_{DS}>V_{GS}-V_{TN} \Rightarrow \underline{sat} \Rightarrow I_D=\frac{K_n'}{2}\left(\frac{W}{L}\right)(V_{GS}-V_{TN})^2(1+\lambda V_{DS})=\underline{127.4\,\mu A}$



$g_m=\sqrt{2K_n'\left(\frac{W}{L}\right)I_D(1+\lambda V_{DS})}=\underline{719.75\,\mu A/V}$ [Alternately, $g_m=K_n'\left(\frac{W}{L}\right)(V_{GS}-V_{TN})(1+\lambda V_{DS})$
$=\underline{719.75\,\mu A/V}$]

$\chi=\frac{\gamma}{2\sqrt{2\phi_F+V_{SB}}}=0.037$, $g_{mb}=\chi g_m=\underline{26.63\,\mu A/V}$

$r_o=\frac{1}{\lambda I_D}=\underline{327.1\,k\Omega}$, $C_{sb}=\frac{C_{sbo}}{\left(1+\frac{V_{SB}}{V_0}\right)^{1/2}}=\underline{12.83\,fF}$ $\quad V_{DB}=V_{DS}+V_{SB}=\underline{3V}$

∴ $C_{db}=\frac{C_{dbo}}{\left(1+\frac{V_{DB}}{V_0}\right)^{1/2}}=\underline{8.7\,fF}$, $C_{gso}=C'_{gso}W=\underline{2\,fF}=C_{gdo}=C'_{gdo}W$

$\Rightarrow C_{gs}=\frac{2}{3}WLC'_{ox}+C_{gso}=\underline{30.8\,fF}$, $C_{gd}\approx C_{gdo}=\underline{2\,fF}$, ~~$C_{gb}=5\,fF$~~

Eqv. ckt. as shown. [Check all the calculations for corrections]

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5. Note: C_{gs}, C_{gd}, C_{gb} are to a first-order, independent of V_{GS}, & for the given data, the device remains saturated for all values of V_{GS}.

$f_T=\frac{g_m}{2\pi(C_{gs}+C_{gd}+\cancel{C_{gb}})}$ & $f_{max}=\frac{1.5\mu_n}{2\pi L^2}(V_{GS}-V_{TN})$ $\quad \mu_n=\frac{K_n'}{C'_{ox}}=\underline{449.1\,\frac{cm^2}{V\,sec}}$

$\underline{V_{GS}=1V}$: $g_m=K_n'\left(\frac{W}{L}\right)(V_{GS}-V_{TNO})(1+\lambda V_{DS})=\underline{831.87\,\mu A/V}$

$C_{gs}+C_{gd}+\cancel{C_{gb}}=\underline{37.8\,fF}$ $\quad f_T=\underline{3.5\,GHz}$ & $f_{max}=\underline{4.3\,GHz}$

$\underline{V_{GS}=1.5V}$: $g_m=\underline{1.87\,mA/V} \Rightarrow f_T=\underline{7.87\,GHz}$ & $f_{max}=\underline{9.65\,GHz}$

$\underline{V_{GS}=2V}$: $g_m=\underline{2.9\,mA/V} \Rightarrow f_T=\underline{12.2\,GHz}$ & $f_{max}=\underline{15\,GHz}$

[Check all calculations for corrections]
