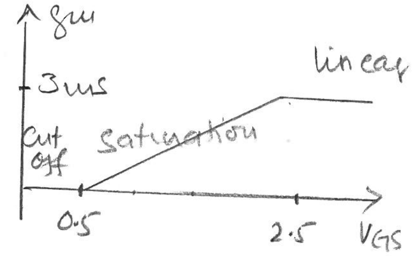
ECE Midterm Solutions (3150)



1a) $g_m = k_n (V_{GS} - V_{TN})$ Saturation
$\quad = k_n V_{DS}$ Linear
From Fig. $V_{TN} = 0.5\,V$

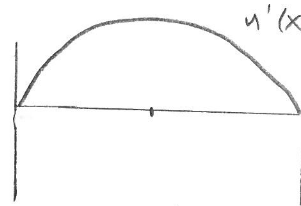
b) $V_{DS} = 0 \Rightarrow$ MOS Cap in inversion $\quad C_{gs} = C_{ox} WL$

$\Rightarrow WL \dfrac{\epsilon_{ox}}{t_{ox}} = 172.5\ fF \quad \Rightarrow t_{ox} = 20\ Å$

c) $\dfrac{dg_m}{dV_{GS}} = k_n = \dfrac{W}{L}\mu_n C_{ox}$ } in Saturation $\Rightarrow \dfrac{W}{L}\mu_n C_{ox} = 1500\ \mu A/V^2$

$\Rightarrow \mu_n =$ 87 $cm^2/V\text{-}s$

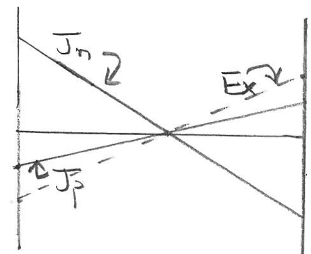
2 a) $n'(0) = 0$ b) $p'(L) = 0$



c) $\dfrac{\partial^2 n'(x)}{\partial x^2} = -\dfrac{G_L}{D_n}$ d) $n'(x) = -\dfrac{G_L}{2D_n}(x-L)x$

e) $p'(x) = n'(x) = -\dfrac{G_L}{2D_n}(x-L)x$ f) $J_n^{diff} = q D_n \dfrac{\partial n'}{\partial x} = -q G_L (x - L/2)$

g) $J_p^{diff} = -q D_p \dfrac{\partial p'(x)}{\partial x} = +q \dfrac{D_p}{D_n} G_L (x - L/2)$



h) $J_n^{diff} + J_p^{diff} + J_p^{drift} = J_T = 0 \Rightarrow J_p^{drift} = q\left(1 - \dfrac{D_p}{D_n}\right) G_L \left(x - \dfrac{L}{2}\right)$

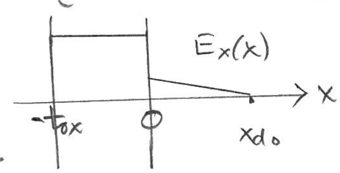
$J_p^{drift} = q \mu_p P_0 E = q\left(1 - \dfrac{D_p}{D_n}\right) G_L \left(x - \dfrac{L}{2}\right)$

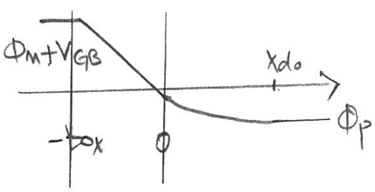
i) $I_L = A J_T = 0$

3 a) For $0 \le x < x_{do}$ $\quad E_x(x) = -\dfrac{q N_a}{\epsilon_s}(x - x_{do})$ as in the lecture notes.

At the oxide-sem interface $\epsilon_s E_x(x = 0^+) - \epsilon_{ox} E_x(x = 0^-) = Q_I$

$\Rightarrow E_x(x = 0^-) = -\dfrac{Q_I}{\epsilon_{ox}} + \dfrac{q N_a x_{do}}{\epsilon_{ox}}$





b) For $0 \le x \le x_{do}$ $\quad \phi(x) = \phi_p + \dfrac{q N_a}{2\epsilon_s}(x - x_{do})^2$

For $-t_{ox} \le x \le 0$ $\quad \phi(x) = \phi_p + \dfrac{q N_a x_{do}^2}{2\epsilon_s} + \dfrac{Q_I}{\epsilon_{ox}} x - \dfrac{q N_a}{\epsilon_{ox}} x_{do}\, x$.

c) Part (b) implies $\quad \phi_B + V_{GB} = \dfrac{q N_a x_{do}^2}{2\epsilon_s} - \dfrac{Q_I}{\epsilon_{ox}} t_{ox} + \dfrac{q N_a x_{do}}{\epsilon_{ox}} t_{ox}$.

$x_{do} = 0$ when $V_{GB} = V_{FB} = -\phi_B - \dfrac{Q_I}{\epsilon_{ox}} t_{ox}$

4 a) $\dfrac{k_p}{2}(V_{OUT} - V_{DD} - V_{TP})^2 (1 - \lambda_p (V_{OUT} - V_{DD})) = \dfrac{k_n}{2}(V_{BIAS} - V_{TN})^2 (1 + \lambda_n V_{OUT})$

$k_p = k_n$ and $V_{OUT} = 1.5 \Rightarrow V_{BIAS} = 0.99\ V$

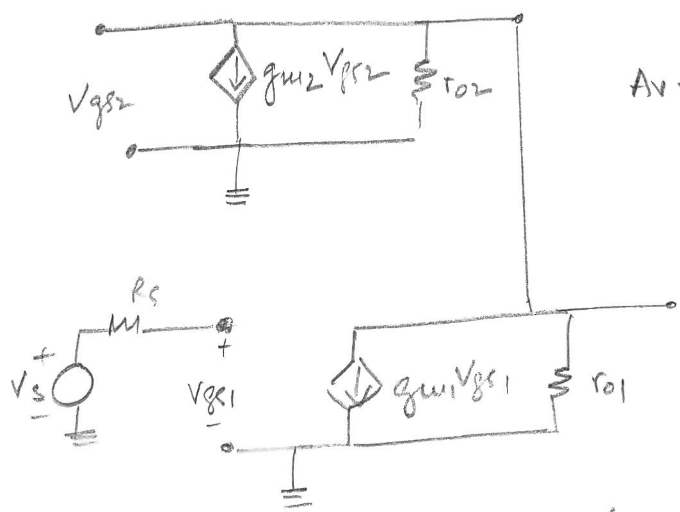
c) When V_{OUT} goes too low, M1 goes into linear region. Therefore

$$\frac{k_P}{2}(V_{OUT}-V_{DD}-V_{TP})^2(1-\lambda_P(V_{OUT}-V_{DD})) = \frac{k_n}{2}(V_{OUT})^2(1+\lambda_n V_{OUT})$$

$\Rightarrow V_{OUT} \approx 1$ Volt.

b). Highest V_{OUT} can be Calculated by seeing when M2 goes into cut-off. This happens when $V_{OUT} = 2.0$ V.

d)



$$A_V = -g_{m1}\left(r_{o1}\|r_{o2}\|\frac{1}{g_{m2}}\right)$$

$$\sim -\frac{g_{m1}}{g_{m2}} \sim -1 \quad \text{(small)}$$

e) Looking in from the output node, $R_{out} = \left(r_{o1}\|r_{o2}\|\frac{1}{g_{m2}}\right)$.

$$\sim \frac{1}{g_{m2}}$$