ECE 3150 Homework 6 Solutions

6.1)

a) We need to have no current going through the resistor. So

$$-I_D = \frac{k_P}{2}\left(V_{IN} - V_{DD} - V_{TP}\right)^2\left(1 - \lambda_P\left(V_{OUT} - V_{DD}\right)\right) = I_{BIAS} = 100\ \mu A$$

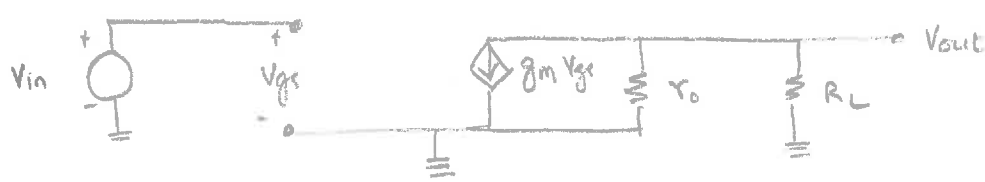
$$\Rightarrow \left(250\ \mu A/V^2\right)\left(V_{IN} - 2\right)^2\left(1 + \lambda_P (2.5)\right) = 100\ \mu A$$

$$\Rightarrow V_{IN} = 1.417 \text{ Volts}$$

Check: Since $V_{DS} = V_{OUT} - V_{DD} = -2.5\ V < V_{GS} - V_{TP} = V_{IN} - V_{DD} - V_{TP} = -0.585$

the FET is in saturation.

b)



c) $A_V = -g_m\left(r_o \| R_L\right)$

$$g_m = \frac{\partial I_D}{\partial V_{GS}} = -k_P\left(V_{IN} - V_{DD} - V_{TP}\right)\left(1 + \lambda_P V_{DD}\right) = +3.4 \times 10^{-4}\ A/V$$

$$g_o = \frac{1}{r_o} = \frac{\partial I_D}{\partial V_{DS}} = \frac{k_P}{2}\left(V_{IN} - V_{DD} - V_{TP}\right)^2 \lambda_P = 5.74 \times 10^{-6}\ S$$

$$\Rightarrow r_o = 1.74 \times 10^5\ \Omega$$

$$\Rightarrow \left(r_o \| R_L\right) = 9.46 \times 10^3\ \Omega.$$

$$\Rightarrow A_V = -3.21$$

d) & e) PFET will remain in saturation provided:

$V_{DS} < V_{GS} - V_{TP}$ and $V_{GS} < V_{TP}$

$$\Rightarrow V_{IN} - V_{DD} < V_{TP}$$

$$\Rightarrow V_{IN} < 2.0$$

We also have

$$V_{OUT} = (-I_D - I_{BIAS}) R_L$$

$$\Rightarrow \frac{V_{OUT}}{R_L} + I_{BIAS} = -I_D = \frac{k_p}{2}\left(V_{IN} - V_{DD} - V_{TP}\right)^2 \left(1 - \lambda_p (V_{OUT} - V_{DD})\right)$$

$$\Rightarrow \frac{\frac{V_{OUT}}{R_L} + I_{BIAS}}{1 - \lambda_p (V_{OUT} - V_{DD})} = \frac{k_p}{2}\left(V_{IN} - V_{DD} - V_{TP}\right)^2 \quad \text{——— (1)}$$

The above equation can be used to figure out V_{OUT} for every V_{IN} provided the PFET is in saturation, which would be the case provided $V_{DS} < V_{GS} - V_{TP}$

$$\Rightarrow V_{OUT} < V_{IN} + 0.5 \quad \text{——— (2)}$$

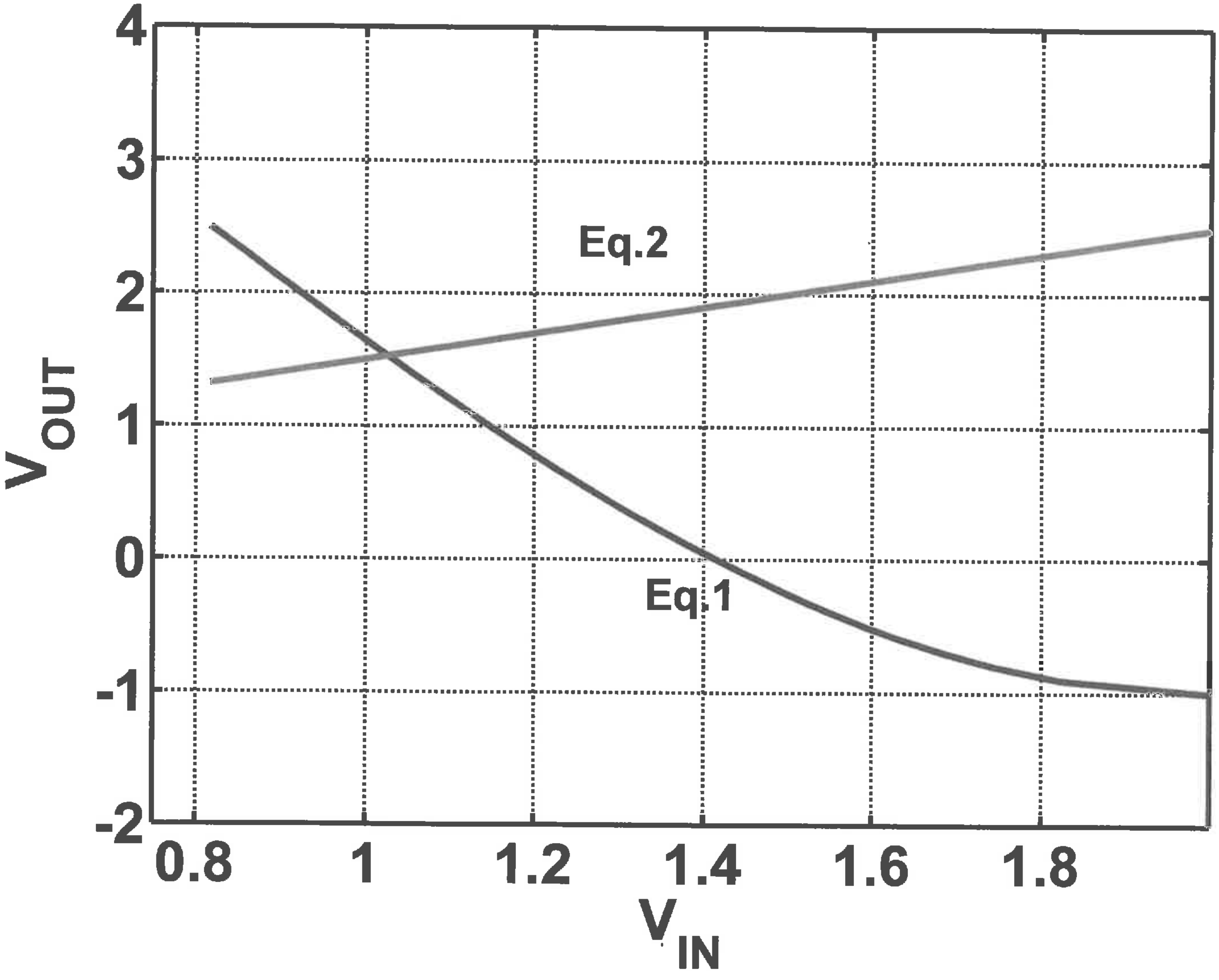
and provided $V_{GS} < V_{TP}$

$$\Rightarrow V_{IN} < 2.0$$

One can plot V_{OUT} vs V_{IN} using eq. (1) and also plot $V_{OUT} = V_{IN} + 0.5$ {eq (2)}. The portion of curve of eq (1) below eq (2) curve will give the range of values for V_{OUT} and V_{IN} for which the PFET will be in saturation. The graph is plotted on the next page

$V_{OUT}\big|_{max} = +1.526\ V$ $\qquad$ $V_{OUT}\big|_{min} = -1\ V$

$V_{IN}\big|_{max} = +2.0\ V$ $\qquad$ $V_{IN}\big|_{min} = 1.026\ V$


4
3
2
1
0
-1
-2
0.8
1
1.2
1.4
1.6
1.8
V_OUT
V_IN
Eq.2
Eq.1

6.2)

a) $V_{DS-sat} = V_{GS} - V_{TN} = 4 - 1 = 3\ V$

b) $I_D = \frac{W}{2L} \mu_n C_{ox} (V_{GS} - V_{TN})^2 = 2\ mA$ for $V_{GS} - V_{TN} = 3\ V$

$\Rightarrow \mu_n = 515 \ \frac{cm^2}{V\text{-}s}$

c) $Q_N = -C_{ox}(V_{GS} - V_{TN}) = -10^{-6}\ C/cm^2$

d) $Q_N = -C_{ox}(V_{GS} - V_{TN} - V_{DS}) = -0.6 \times 10^{-6}\ C/cm^2$

e) $I_D = -W Q_N V_{dn} = 2 \times 10^{-3}\ A$ $\{Q_N = -10^{-6}\ C/cm^2\}$ source end

$\Rightarrow V_{dn} = 8 \times 10^5\ cm/s$

f) $I_D = -W Q_N V_{dn} = 2 \times 10^{-3}\ A$ $\{Q_N = -0.6 \times 10^{-6}\ C/cm^2\}$ drain end

$\Rightarrow V_{dn} = 1.33 \times 10^6\ cm/s$

g) $Q_N = -C_{ox}(V_{GS} - V_{TN}) = -10^{-6}\ C/cm^2$

h) $Q_N = -C_{ox}(V_{GS} - V_{TN} - V_{DS})$ will give a positive inversion layer density at the drain which is nonsense. The device is in saturation and the channel near the drain end has been pinched off. Therefore, $Q_N \approx 0$

i) $V_{TN} = V_{TN}(V_{SB} = 0) + \gamma_n \left[\sqrt{-2\phi_p + V_{SB}} - \sqrt{-2\phi_p} \right]$

$\phi_p = -0.416$ $\quad \gamma_n = \frac{\sqrt{2 \varepsilon_s q N_a}}{C_{ox}} = 0.527\ \sqrt{V}$

$\Rightarrow V_{TN} = 1 + 0.79 = 1.79\ V$ $\quad \Rightarrow I_D = 1.1\ mA$