Homework From Chapter 4

4.9

- $V_{GS} = 0 < V_{TN} \Rightarrow$ FET is off $\therefore I_D = 0$
- $V_{GS} = 1V < V_{TN} \Rightarrow$ FET is off $\therefore I_D = 0$
- $V_{GS} = 2V > V_{TN} \Rightarrow$ FET is on $V_{GS} - V_{TN} = 0.5 > V_{DS} \Rightarrow$ linear region

  $\therefore I_D = K_n' \frac{W}{L} \left(V_{GS} - V_{TN} - \frac{V_{DS}}{2} \right) V_{DS} = 112.5 \mu A$
- $V_{GS} = 3V > V_{TN} \Rightarrow$ FET is on $V_{GS} - V_{TN} = 1.5 > V_{DS} \Rightarrow$ linear region

  $\therefore I_D = 362.5 \mu A$
- $K_n = K_n' \frac{W}{L} = 2.5 \ mA / V^2$

4.15

a. $R_{on} = \dfrac{1}{K_n' \frac{W}{L} (V_{GS} - V_{TN})} = 94.12 \ \Omega$

b. $R_{on} = 148.15 \ \Omega$

4.27

a. $V_{GS} - V_{TN} = 4V < V_{DS} \Rightarrow$ saturation region

b. $V_{GS} - V_{TN} = -1V \Rightarrow$ cutoff region

c. $V_{GS} - V_{TN} = 1V < V_{DS} \Rightarrow$ saturation region

d. $V_{GS} - V_{TN} = 0.5V = V_{DS} \Rightarrow$ boundary bet. linear & saturation regions

e. $\because V_{DS} < 0 \Rightarrow$ both source & drain are exchanged (reversed) & still we can consider the new $V_{DS}' = 0.5V$, but now V_{GS} is V_{GD}'

$\therefore V_{GS}' = V_{GD}' + V_{DS}' = 2.5V$

$\therefore V_{GS}' - V_{TN} = 1.5V > V_{DS}' \Rightarrow$ saturation region

f. $V_{GS}' = V_{GD}' + V_{DS}' = 3 + 6 = 9V$

$\therefore V_{GS}' - V_{TN} = 8V > V_{DS}' \Rightarrow$ saturation region

4.35

a. The transistor is connected such that $V_{DS} = V_{GS}$

$\therefore V_{DS} > V_{GS} - V_{TN} \Rightarrow$ The transistor is saturated

$$I_D = \frac{12 - V_{GS}}{100K} = \frac{25\times10^{-6}}{2}\left(\frac{10}{1}\right)(V_{GS} - 0.75)^2$$

$\therefore 12.5\, V_{GS}^2 - 17.8\, V_{GS} - 4.97 = 0 \Rightarrow V_{GS} = -0.24\,V$ or $1.66\,V$

but V_{GS} can't be negative $\Rightarrow V_{GS} = 1.66\,V$ & $I_D = 103.4\,\mu A$

b. $$I_D = \frac{12 - V_{GS}}{10^5} = 125\times10^{-5}\,(V_{GS} - 0.75)^2\,(1 + 0.025\, V_{GS})$$

To solve this cubic eq., we'll use trial & error & let the first trial be $V_{GS} = 1.66\,V$ calculated in part (a)

$\Rightarrow V_{GS} = 1.64\,V$ & $I_D = 104\,\mu A$

c. $$I_D = \frac{12 - V_{GS}}{10^5} = \frac{25\times10^{-6}}{2}\left(\frac{25}{1}\right)(V_{GS} - 0.75)^2$$

$\therefore 62.5\, V_{GS}^2 - 91.75\, V_{GS} + 11.16 = 0 \Rightarrow V_{GS} = 0.134\,V$ or $1.334\,V$

but V_{GS} can't be less than $V_{TN} \Rightarrow V_{GS} = 1.334\,V$ & $I_D = 107\,\mu A$

4.41

a. $V_{GS} = 0V$ $\therefore V_{D\,sat} = V_{GS} - V_{TN} = 2V$

Assume $V_{DS} \geq V_{D\,sat} \Rightarrow$ transistor is saturated

$$\therefore I_{D\,sat} = \frac{25\times10^{-6}}{2}\left(\frac{10}{1}\right)(0+2)^2 = 500\,\mu A$$

$\therefore V_{DS} = 10V - 100K \times 500\,\mu A = -40V < V_{D\,sat}$

$\therefore$ we used a wrong assumption.

So the transistor is in linear region

$$\Rightarrow I_D = \frac{10 - V_{DS}}{10^5} = 25\times10^{-6}\left(\frac{10}{1}\right)\left(0 + 2 - \frac{V_{DS}}{2}\right)V_{DS}$$

$\Rightarrow V_{DS} = 0.2065\,V$ & $I_D = 97.9\,\mu A$ $\quad (V_{DS} < V_{D\,sat})$

b. Assume directly that the transistor is in linear region.

$$\therefore \frac{10-V_{DS}}{5\times10^4} = 25\times10^{-6}\left(\frac{20}{1}\right)\left(2-\frac{V_{DS}}{2}\right)V_{DS}$$

$$\Rightarrow V_{DS} = 0.2065\,V \quad (< V_{Dsat}) \quad \& \quad I_D = 195.8\,\mu A$$

c. In this case, both drain & source will be reversed & $V_{DS} = V_{GS}$

$\because$ This is a depletion mode device (V_{TN} is $-$ve)

$\therefore$ It's working in linear region ($V_{DS} < V_{GS} - V_{TN}$)

$$\therefore \frac{10-V_{DS}}{10^5} = 25\times10^{-6}\left(\frac{10}{1}\right)\left(V_{DS}-(-2)-\frac{V_{DS}}{2}\right)V_{DS}$$

$$\Rightarrow V_{DS} = 0.1876\,V \quad \& \quad I_D = 98.1\,\mu A$$

4.45

$$V_{TN} = V_{TO} + \gamma\left(\sqrt{V_{SB}+2\phi_F} - \sqrt{2\phi_F}\right) = 2.266\,V$$

$\because V_{GS} < V_{TN} \Rightarrow$ Transistor is off & $I_D = 0$

4.51

a. $V_{GS} - V_{TP} = -1.1 - (-0.75) = -0.35\,V$, $|V_{DS}| < |V_{GS} - V_{TP}| \Rightarrow$ linear region

$$I_D = 10\times10^{-6}\left(\frac{10}{1}\right)\left(-1.1-(-0.75)-\frac{(-0.2)}{2}\right)(-0.2) = 5\,\mu A$$

b. $V_{GS} - V_{TP} = -0.55\,V$, $|V_{DS}| < |V_{GS} - V_{TP}| \Rightarrow$ linear region

$I_D = 9\,\mu A$

c. $V_{TP} = -\left[0.75 + 0.5\left(\sqrt{1+0.6} - \sqrt{0.6}\right)\right] = -0.995\,V$

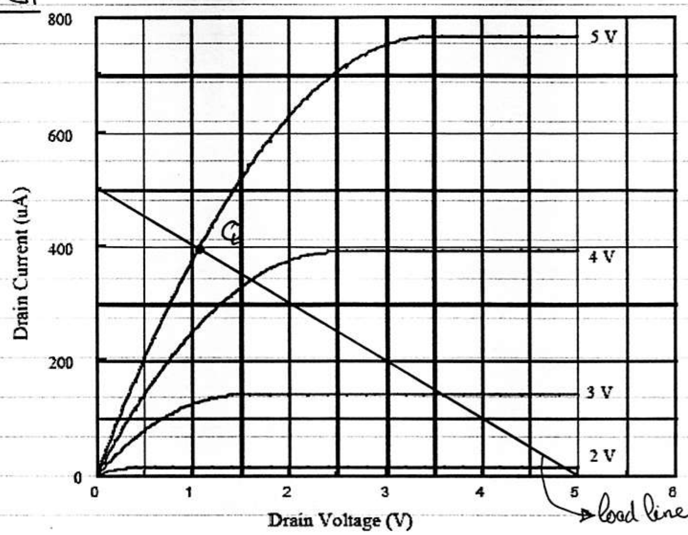
$\underline{V_{GS} = -1.1\,V}$ $\quad |V_{DS}| > |V_{GS} - V_{TP}| \Rightarrow$ saturation region

$\therefore I_D = 0.551\,\mu A$

$\underline{V_{GS} = -1.3\,V}$ $\quad |V_{DS}| < |V_{GS} - V_{TP}| \Rightarrow$ linear region

$\therefore I_D = 4.1\,\mu A$

4.81



For the loadline: $V_{DS}=0 \Rightarrow I_D = V_{DD}/\overset{10}{\cancel{\ }}k = 0.5\,mA$

$I_{DS}=0 \Rightarrow V_{DS} = V_{DD} = 5V$

Now check the intersection with $V_{GS}=5V \Rightarrow Q \simeq (390\mu A, 1.1V)$

4.82

$V_{GS} = \frac{V_{DD}}{2} = 3V$

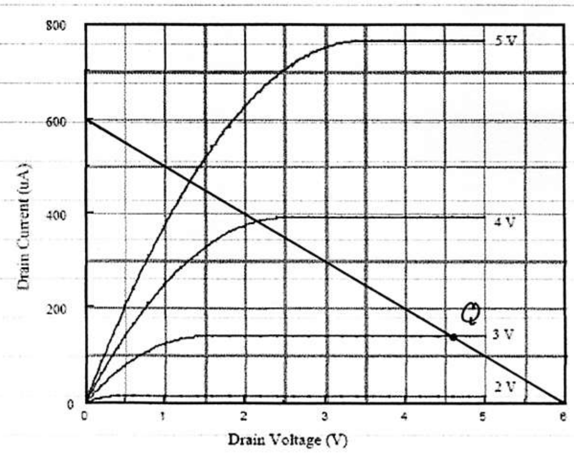
The loadline eq is

$V_{DD} = 10k \cdot I_D + V_{DS}$

$I_D = 0 \Rightarrow V_{DS} = 6V$

$V_{DS} = 0 \Rightarrow I_D = 0.6\,mA$

$Q \simeq (140\mu A, 4.6V)$



4.86

$$V_{G} = \frac{V_{DD} R_1}{R_1 + R_2} = 3.81\,V$$

Assume saturation $3.81\,V = V_{GS} + R_3 I_D = V_{GS} + R_3 \frac{K_n'}{2} \left(\frac{W}{L}\right) (V_{GS} - V_{TO})^2$

$\therefore\ 3.81 = V_{GS} + 47 \times 10^3 \times \left(\frac{25 \times 10^{-6}}{2}\right) \times \left(\frac{5}{1}\right) (V_{GS} - 1)^2$

Solving for V_{GS} gives $V_{GS} = 1.81V$ & $I_D = 42.3\,\mu A$

Then from circuit analysis: $V_{DS} = 12 - (R_3 + R_4) I_D = 9V$

$\because V_D > V_{GS} - V_{TO}$

$\therefore$ The saturation assumption is correct

$\Rightarrow\ Q \simeq (42.3\mu A, 9V)$

4.102

a. $I_D = \frac{K_n'}{2} \cdot \frac{W}{L} (V_{GS} - V_{TN})^2 = \left(\frac{25 \times 10^{-6}}{2}\right)\left(\frac{10}{1}\right)(V_{GS} - 0.75)^2$

$\because I_G = 0 \Rightarrow$ no current in the $10\,M\Omega \Rightarrow V_{GS} = V_{DS} = V_{DD} - 330K \times I_D$

Solving both eq. for $V_{GS} \Rightarrow V_{GS} = 1.326V$ or $0.15V$ ($< V_{TO}$ so refused)

$\therefore\ I_D = 41.5\,\mu A$ & $V_{DS} = V_{GS} = 1.326\,V$

$\Rightarrow\ Q \simeq (41.5\mu A, 1.326\,V)$

b. Repeating the same procedure $\Rightarrow Q \simeq (42.1\mu A, 1.117\,V)$

4.116

a. This a PMOS & since G & D are connected $\Rightarrow$ saturation ($V_{GS} = V_{DS}$)

Circuit eq $V_{DS} = V_{GS} = V_{DD} + I_D R = -15 + 75 \times 10^3 I_D$

Trans eq $I_D = \frac{10^{-5}}{2} (V_{GS} + V_{TP})^2 = \frac{10^{-5}}{2} (-15 + 75000 I_D + 0.75)^2$

$\Rightarrow I_D = 124\,\mu A$ & $V_{DS} = -5.7V \Rightarrow Q \simeq (124\mu A, -5.7V)$

b. $V_G = -15V$

$\because V_G$ is equal to largest voltage $\Rightarrow V_{GS} \gg V_{DS}$

$\therefore$ Most probably the transistor is in the linear region

$$I_D = \frac{V_{DS} - (-15)}{75000} = 10^{-5}\left(-15 - (-0.75) - \frac{V_{DS}}{2}\right) V_{DS}$$

$\Rightarrow V_{DS} = -1.3V$ & $I_D = 182\mu A$ $\Rightarrow$ $Q = (182\mu A, -1.3V)$

$\therefore V_{DS} > V_{GS} - V_{TP}$ $\Rightarrow$ assumption was correct

4.118

a. Both transistors are saturated by the way they are connected

& $I_{Dp} = I_{DN}$, $10 = -V_{GSp} + V_{GSN}$

$$\frac{10\times10^{-6}}{2}\left(\frac{20}{1}\right)(-10 + V_{GSN} + 0.75)^2 = \frac{25\times10^{-6}}{2}\left(\frac{20}{1}\right)(V_{GSN} - 0.75)^2$$

$\Rightarrow V_{GSN} = 4.04V$ & $V_{GSp} = -5.96V$ & $I_{DN} = I_{Dp} = 2.71mA$

$V_o = V_{GSN} = 4.04V$

b. The voltages remain the same, but the currents are scaled by 80:20

$\Rightarrow I_{Dp} = I_{DN} = 10.8\ mA$

4.142 (read section 4.10.4 for current mirror circuits)

This is a normal current mirror circuit with all transistors working in saturatio[n]
But here the pinch off effect is considered.

So for any transistor x

$$I_{Ox} = \frac{(W/L)_x}{(W/L)_1} I_{Ref} \frac{1 + \lambda V_{DSx}}{1 + \lambda V_{DS1}} \quad \& \quad R_{Ox} = \frac{\frac{1}{\lambda} + V_{DSx}}{I_{Ox}}$$

$$V_{DS1} = V_{GS1} = V_{TN} + \sqrt{\frac{2 I_{D1}}{K_n}} = 0.75 + \sqrt{\frac{2(30\times10^{-6})}{4\,(25\times10^{-6})}} = 1.52\,V$$

$$\therefore I_{O2} = \frac{10}{4}\cdot(30\mu A)\cdot\frac{1 + 0.015(10)}{1 + 0.015(1.52)} = 84.3\mu A, \quad R_{O2} = \frac{\frac{1}{0.015} + 8}{84.3\mu A} = 909\ K\Omega$$

Similarly $I_{O3} = 164\ \mu A$, $R_{O3} = 455\ K\Omega$

$I_{O4} = 346\mu A$, $R_{O4} = 227\ K\Omega$