EECS 311 - F08 - HW4 sol'ns

P4.1

find I_D for an NMOS

$V_{GS} = 0, 1, 2, 3\,V$

$V_{DS} = 0.25\,V$

$W = 5\,\mu m$, $L = 0.5\,\mu m$

$V_{TN} = 0.80\,V$

$K_n' = 200\,\mu A/V^2$

$K_n = K_n' \frac{W}{L} = 2000\,\frac{\mu A}{V^2}$

for $V_{GS} = 0\,V$: $I_D = 0\,\mu A$ (off)

for $V_{GS} = 1\,V \Rightarrow V_{GS} - V_{TN} = 0.20\,V < V_{DS}$ (sat.)

$$I_D = \frac{1}{2} K_n (V_{GS} - V_{TN})^2 \approx 40\,\mu A$$

for $V_{GS} = 2\,V \Rightarrow V_{GS} - V_{TN} > V_{DS}$ (linear)

$$I_D = K_n\left[(V_{GS} - V_{TN}) V_{DS} - \frac{1}{2} V_{DS}^2\right] \approx 537.5\,\mu A$$

for $V_{GS} = 3\,V \Rightarrow V_{GS} - V_{TN} > V_{DS}$ (linear)

$$I_D = K_n\left[(V_{GS} - V_{TN}) V_{DS} - \frac{1}{2} V_{DS}^2\right] \approx 1.038\,mA$$

P4.2

for a MOSFET in linear,

$$i_{ds} = \mu_n C_{ox} \frac{W}{L}\left[(V_{GS} - V_T) V_{DS} - \frac{1}{2} V_{DS}^2\right]$$

for $\frac{1}{2} V_{DS}^2 << (V_{GS} - V_T) V_{DS}$

$$i_{ds} \approx \mu_n C_{ox} \frac{W}{L}\left[(V_{GS} - V_T) V_{DS}\right] \Rightarrow \frac{V_{DS}}{i_{ds}} \approx \left[\mu_n C_{ox} \frac{W}{L} (V_{GS} - V_T)\right]$$

$$\frac{1}{2} V_{DS} << (V_{GS} - V_T)$$

$$V_{DS} << 2(V_{GS} - V_T)$$

P4.3 Assuming the on-resistance is measured in linear mode (The FET has quite a bit of overdrive)

a) $R_{DS} \approx \left[\mu_n C_{ox} \frac{W}{L}(V_{GS}-V_{th})\right]^{-1} \Rightarrow \mu_n C_{ox} = K' = 100\ \mu A/V^2$

$W/L = 100$

$\approx \left[100\times10^{-6}(100)(5-0.65)\right]^{-1}\Omega \approx 22.99\ \Omega$

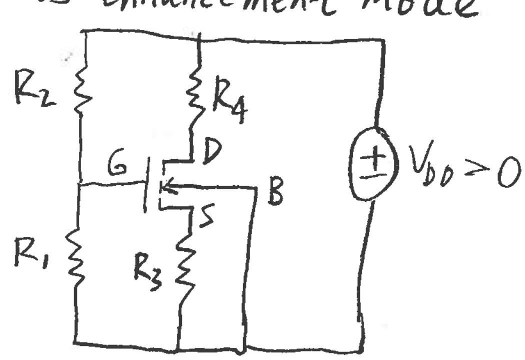
b) $R_{DS} \approx \left[100\times10^{-6}(100)(3.3-0.50)\right]^{-1}\Omega \approx 35.71\ \Omega$

P4.4 NMOS, $V_{TN} = 0.75\ V$, $K_n' = 200\ \mu A/V^2$, $W/L = 10$

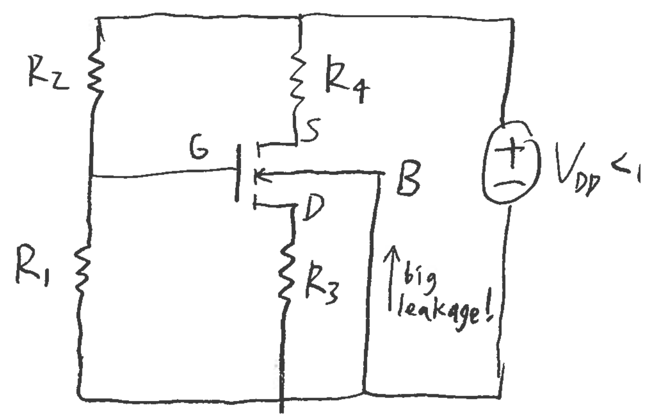
	V_{GS} (V)	V_{DS} (V)	$V_{GS}-V_{TN}$	mode	I_D
$K_n' = 200\frac{\mu A}{V^2}$	2	0.2	1.25	linear	$K_n' \frac{W}{L}\left[(V_{GS}-V_{TN})V_{DS} - \frac{1}{2}V_{DS}^2\right] = 460\ \mu A$
	2	2.5	1.25	sat.	$\frac{1}{2}K_n' \frac{W}{L}(V_{GS}-V_{TN})^2 \approx 1.563\ mA$
	0	4	−0.75	cutoff	0
$K_n' = 300\frac{\mu A}{V^2}$	2	0.2	↓	↓	$= 690\ \mu A$
	2	2.5			$\approx 2.344\ mA$
	0	4			≈ 0

P4.5 NMOS-enhancement mode

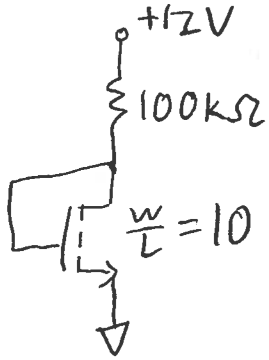
a)



b)



P4.6 a)



$\underline{\lambda = 0}$ $\quad V_{TN} = 0.75\,V \quad K_n' = 100\,\frac{\mu A}{V^2}$

mode: $\underline{\text{sat}}$ (diode connected)

$$I_D = \frac{1}{2} K_n' \frac{W}{L}(V_{GS} - V_{TN})^2 \underbrace{(1 + \lambda V_{DS})}_{=0}$$

$$= \frac{12 - V_{GS}}{100\,k}$$

$$12 - V_{GS} = 50{,}000\,(100\times10^{-6})(10)(V_{GS} - 0.75)^2 \Rightarrow V_{GS} \approx 1.21445\,V$$

$$I_D = 50\times10^{-6}(10)(\quad - 0.75)^2 \approx 107.86\,\mu A$$

b) $\lambda = 0.02\,V^{-1}$

$$12 - V_{GS} = 50{,}000(100\times10^{-6})(10)(V_{GS} - 0.75)^2(1 + 0.02\,\underset{V_{DS}\,\parallel}{V_{GS}})$$

$$V_{GS} \approx 1.209046\,V$$

$$I_D = 50\times10^{-6}(10)(\quad - 0.75)^2(1 + 0.02(\quad)) \approx 107.91\,\mu A$$

c) $12 - V_{GS} = 50{,}000\,(100\times10^{-6})(25)(V_{GS} - 0.75)^2 \Rightarrow V_{GS} \approx 1.04603\,V$

$$I_D = 50\times10^{-6}(25)(\quad - 0.75)^2 \approx 109.54\,\mu A$$

P4.7 NMOS, $\frac{W}{L}=8$, $V_{T0}=1V$, $2\phi_F=0.6V$, $\gamma=0.7\sqrt{V}$, $K_n'=100\ \mu A/V^2$

a) $V_{SB}=3V$, $V_{GS}=2.5V$, $V_{DS}=5V$, find I_D

$$V_{TN}=V_{T0}+\gamma\left(\sqrt{V_{SB}+2\phi_F}-\sqrt{2\phi_F}\right)=1+0.7\left(\sqrt{3+0.6}-\sqrt{0.6}\right)\approx 1.7859\ V$$

$V_{GS}-V_{TN}<V_{DS}$ (sat.)

$$I_D=\frac{1}{2}K_n'\left(\frac{W}{L}\right)(V_{GS}-V_{TN})^2\approx 203.95\ \mu A$$

b) $V_{DS}=0.5V$

$V_{GS}-V_{TN}>V_{DS}$ (linear)

$$I_D=K_n'\left(\frac{W}{L}\right)\left[(V_{GS}-V_{TN})V_{DS}-\frac{1}{2}V_{DS}^2\right]\approx 185.62\ \mu A$$

P4.8 PMOS, $W/L=20$, $V_{BS}=0V$, $V_{T0}=-0.75V$, $\gamma=0.5\sqrt{V}$, $2\phi_F=0.6V$

a) $V_{GS}=-1.1V$, $V_{DS}=-0.2V$

$K_p'=40\ \mu A/V^2$

	V_{BS}	V_{TP}	V_{GS}	V_{DS}	mode	I_D
a)	0	$=V_{T0}=-0.75V$	$-1.1V$	$-0.2V$	linear	$K_p'\frac{W}{L}\left[(V_{GS}-V_{Tp})V_{DS}-\frac{1}{2}V_{DS}^2\right]=40\ \mu A$
b)	0	$=V_{T0}$	$-1.3V$	$-0.2V$	linear	$\downarrow$ $=72\ \mu A$
c)	1	-0.99516	$-1.1V$	$-0.2V$	sat.	$\frac{1}{2}K_p'\frac{W}{L}(V_{GS}-V_{Tp})^2\approx 4.397\ \mu A$
	1	-0.99516	$-1.3V$	$-0.2V$	linear	$K_p'\frac{W}{L}\left[(V_{GS}-V_{Tp})V_{DS}-\frac{1}{2}V_{DS}^2\right]\approx 32.77\ \mu A$

$$V_{TP}=V_{T0}-\gamma\left(\sqrt{V_{BS}+2\phi}-\sqrt{2\phi}\right)$$