Homework 5 Solutions

1. J&B P4.27

$$g_m = K_n' \frac{W}{L}(V_{GS} - V_{TN})$$

$V_{GS} = 2\ V$, $0 \le V_{GS} - V_{TN} \le V_{DS}$, NMOS is in the saturation region, $g_m = 6.5\ mS$,

$V_{GS} = 3.3\ V$, $0 \le V_{GS} - V_{TN} \le V_{DS}$, NMOS is in the saturation region, $g_m = 13\ mS$

2. J&B P4.40

(a) The +10 V supply makes the source the pin with the arrow, as labeled in the figure. $V_{GS} = 0$. Guess saturation to start with:

$$I_D = \frac{K_n'}{2}\frac{W}{L}(V_{GS} - V_{TN})^2 = 2\ mA$$

$$V_{DS} = 10 - I_D R = -190\ V$$

This can't be, so guess nonsaturated instead. Equate current and solve for V_{DS} (you can use iterative analysis or use root finder function in a software for complex calculation, e.g. Matlab).

$$V_{DS} = 0.2\ V\,(initial\ guess)$$

$$\frac{10 - V_{DS}}{R} = K_n' \frac{W}{L}\left(V_{GS} - V_{TN} - \frac{1}{2}V_{DS}\right)V_{DS}$$

$$V_{DS} = 0.0504\ V$$

This is reasonable and is less than $V_{DSsat} = 2\ V$, so nonsat is right.

$$I_D = \frac{10 - V_{DS}}{R} = 99.5\ \mu A$$

(b) Similar method as applied to (a)

$$V_{DS} = 0.0504\ V$$

$$I_D = \frac{10 - V_{DS}}{R} = 199\ \mu A$$

(c) The -10 V supply makes the source the upper connection, then, the lower connection which is shorted to gate is drain. Note that for three terminal NMOS symbols, the substrate terminal is always assumed to connected with the terminal labeled with arrow as source. In this part, the lower connection is drain now, so the substrate terminal is connected with drain. Then $V_B = V_G = V_D = 0$ V and hence $V_{SB} = V_S - V_B = V_S = -V_{GS} = -V_{DS}$ is negative and unknown now. We have to consider the body effect in such case. Anyway, this problem doesn't provide any related parameters, so we assume $V_{TO} = -2\,V$, $\gamma = 0.75\sqrt{V}$ and $2\varphi_F = 0.6\,V$, then

$$V_{TN} = V_{TO} + \gamma\left(\sqrt{V_S + 2\varphi_F} - \sqrt{2\varphi_F}\right)$$

We can observe that, V_S is negative, and this makes V_{TN} more negative (body effect).

Next we list equation and solve unknowns. Note that in this case

$$-V_S = V_{DS} = V_{GS} < V_{GS} - V_{TN}$$

the MOSFET should work in the triode region. We also assume $I_S = I_D$, then

$$I_D R + V_{DS} = 0 - (-10\,V)$$

Note that $V_{DS} = V_{GS}$, then

$$I_D = K_n' \frac{W}{L}\left(V_{DS} - V_{TN} - \frac{1}{2}V_{DS}\right)V_{DS}$$

Similar method as applied to (a) to solve for the equation

$$\frac{10 - V_{DS}}{R} = K_n' \frac{W}{L}\left(\frac{1}{2}V_{DS} - \left(V_{TO} + \gamma\left(\sqrt{-V_{DS} + 2\varphi_F} - \sqrt{2\varphi_F}\right)\right)\right)V_{DS}$$

For $\frac{W}{L} = 10$ case

$$V_{DS} = V_{GS} = 0.0486\,V$$

$$I_D = \frac{10 - V_{DS}}{R} = 99.5\,\mu A$$

For $\frac{W}{L} = 20, R = 50\,k\Omega$ case

$$V_{DS} = V_{GS} = 0.0486\,V$$

$$I_D = \frac{10 - V_{DS}}{R} = 199\,\mu A$$

We can see the body effect is not significant in this case since V_{SB} is small. The source to body diode is forward biased, but as long as $V_{on} > V_{DS} = V_{BS} = 0.0486$, then diode is still off and can be neglected.

3. J&B P4.44

$$V_{TN} = V_{TO} + \gamma\left(\sqrt{V_{SB} + 2\varphi_F} - \sqrt{2\varphi_F}\right) = 1.79\,V$$

$$V_{DSsat} = V_{GS} - V_{TN} = 0.714\,V$$

See that the MOSFET is saturated

$$I_D = \frac{K_n}{2}(V_{GS} - V_{TN})^2 = 204\ \mu A$$

(b)

$$V_{DS} = 0.5\ V$$

$$I_D = K_n\left(V_{GS} - V_{TN} - \frac{1}{2}V_{DS}\right)V_{DS} = 185.6\ \mu A$$

4. J&B P4.57

$$R_{on\_max} = \frac{V_{SD}}{I_D} = 0.2\ \Omega$$

$$K_{p\_min} = \frac{1}{R_{on\_max}(V_{SG} + V_{TP})} = 625\ mA/V^2$$

5. J&B P4.71 (a)

Triode region

$$C_{GS} = C''_{ox}\frac{WL}{2} + C_{GSO}W = \frac{\varepsilon_{ox}}{T_{ox}}\frac{WL}{2} + C_{GSO}W = 1.35\ fF$$

$$C_{GD} = C''_{ox}\frac{WL}{2} + C_{GDO}W = \frac{\varepsilon_{ox}}{T_{ox}}\frac{WL}{2} + C_{GDO}W = 1.35\ fF$$

Saturation region

$$C_{GS} = \frac{2}{3}C''_{ox}\frac{WL}{2} + C_{GSO}W = \frac{2}{3}\frac{\varepsilon_{ox}}{T_{ox}}\frac{WL}{2} + C_{GSO}W = 0.97\ fF$$

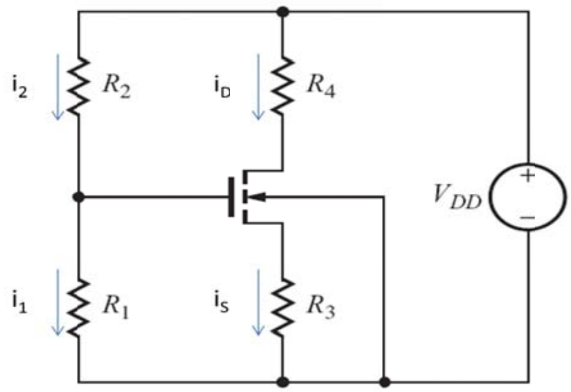
$$C_{GD} = C_{DSO}W = 0.2\ fF$$

Cutoff region

$$C_{GS} = C_{GSO}W = 0.2\ fF$$

$$C_{GD} = C_{DSO}W = 0.2\ fF$$

6. J&B P4.93 (a)



, means , , we can apply voltage divider rule in the left branch:

Assume MOSFET is in saturation region

KVL

Solve the above equations, then

Check

In saturation region, then Q point is with .

7. J&B P4.111 (b)

, , in saturation region.

Solve for above qeuations

$$V_{GS} = 0.93\ V\ and\ 0.56\ V$$

We need $V_{GS} > V_{TN}$ (on), then $V_{GS} = V_{DS} = 0.93\ V$, $i_D = 33.5\ mA$, Q point is $(33.5\ mA, 0.93\ V)$ with $V_{GS} = 0.93\ V$.

8. Jaeger & Blalock Problem 4.127. Use the NMOS transistor parameters listed in Table 4.6 on p. 204.

The gate voltage is coupled to the output in this circuit, so the input and output halves of the circuit must be solved simultaneously. It should be evident that the transistor is ON with the gate pulled high, so first guess SATURATION and then see if this is correct.

Guess saturation to start with:

$$V_{GS} = 2\ V (initial\ guess)$$

$$\frac{V_{DD} - V_{DS}}{R_{top}} = \frac{K_n'}{2}\frac{W}{L}(V_{GS} - V_{TN})^2$$

$$V_{GS} = 2.89\ V$$

$$I_D = 355.7\ \mu A$$

$$V_{DS} = V_{GS} - I_D R_{bottom} = -4.23\ V$$

This cannot be right.

Try guess of non-saturation instead

$$I_D = 400\ \mu A (initial\ guess)$$

$$\frac{I_D}{K_n'}\frac{L}{W} - \left(V_{DD} - I_D R_{top} - V_{TN}\right)(V_{DD} - I_D R_{tb}) + \frac{1}{2}(V_{DD} - I_D R_{tb})^2$$

$$I_D = 242.4\ \mu A$$

$$V_{GS} = 5.15\ V$$

$$V_{DS} = 0.3\ V$$

$$V_{DSsat} = V_{GS} - V_{TN} = 4.152\ V$$

So the MOSFET is non-saturated.

9. Jaeger & Blalock Problem 4.134.

$K_p' = 40\ \mu A/V^2, K_n' = 100\ \mu A/V^2, V_{TP} = -0.75\ V, V_{TN} = 0.75\ V.$

For both PMOS and NMOS, $V_{GS} = V_{DS}$, then both are saturated.

For PMOS,

$$i_D = \frac{K_p'}{2}\frac{W}{L}(V_{GS} - V_{TP})^2 = \frac{K_p'}{2}\frac{W}{L}(V_{DS} - V_{TP})^2 = \frac{K_p'}{2}\frac{W}{L}(V_o - V_{DD} - V_{TP})^2$$

For NMOS,

$$i_D = \frac{K_n'}{2}\frac{W}{L}(V_{GS} - V_{TN})^2 = \frac{K_n'}{2}\frac{W}{L}(V_{DS} - V_{TN})^2 = \frac{K_n'}{2}\frac{W}{L}(V_o - V_{TN})^2$$

then

$$\frac{K_p'}{2}\frac{W}{L}(V_o - V_{DD} - V_{TP})^2 = \frac{K_n'}{2}\frac{W}{L}(V_o - V_{TN})^2$$

$$V_o = -13.9\,V(dropped), 4.04\,V\ (for\ NOMS, V_{GS} > V_{TN}, ON)$$

$$i_D = 10.8\,mA$$

(b)

$$i_D = 43.2\,mA$$

(c) For NMOS, $V_G = V_D$, it is always in saturation. For PMOS, $V_G = 0, V_D = V_{DD}$, $V_{GS} = -V_{DD} = -10\,V < V_{TP}$, PMOS is on. We first guess PMOS is in saturation.

$$\frac{K_p'}{2}\frac{W}{L}(V_{GSP} - V_{TP})^2 = \frac{K_n'}{2}\frac{W}{L}(V_O - V_{TN})^2$$

$$V_O = 6.6\,V(for\ NOMS, V_{GSN} > V_{TN}, ON), -5.1\,V(dropped)$$

Check:

NMOS, $V_{GSN} - V_{TN} = 5.85\,V < V_{DSN} = 6.6\,V$, saturation.

PMOS, $V_{DSP} = V_O - V_{DD} = -3.4\,V$, $V_{GSP} - V_{TP} = -9.25\,V < V_{DSP}$, not in saturation.

Assumption is not correct.

Try guess PMOS is in triode region,

$$\frac{K_p'}{2}\frac{W}{L}\left(V_{GSP} - V_{TP} - \frac{1}{2}V_{DSP}\right)V_{DSP} = \frac{K_n'}{2}\frac{W}{L}(V_O - V_{TN})^2$$

$$V_{DSP} = V_O - V_{DD}$$

$$V_O = 5.69\,V(for\ NOMS, V_{GSN} > V_{TN}, ON)\ and - 4.19\,V(dropped)$$

Check:

NMOS, $V_{GSN} - V_{TN} = 4.94\,V < V_{DSN} = 5.69\,V$, saturation.

PMOS, $V_{DSP} = V_O - V_{DD} = -3.4\,V$, $V_{GSP} - V_{TP} = -9.25\,V < V_{DSP} = -4.31$, triode.

Assumption is correct, $V_O = 5.69\ V$.

For $\frac{W}{L} = 20$,

$$i_D = 24.4\ mA$$

For $\frac{W}{L} = 80$,

$$i_D = 97.6\ mA$$

10. Jaeger & Blalock Problem 6.11.

$V_H = 3.3\ V$, $V_L = 0\ V$, $V_{OH} = 3.0\ V$, $V_{OL} = 0.25\ V$, $V_{IH} = 1.8\ V$, $V_{IL} = 1.5\ V$, $N_{MH} = 1.2\ V$, $N_{ML} = 1.25\ V$. (Results can be within 0.1 V difference).