Homework 3 – Solutions

Problems (not review questions) : 5.18, 5.19, 5.27, 5.38, 5.39, 5.44, 5.45

5.18 A particular MOSFET for which $V_{tn} = 0.5$ V and $k_n'(W/L) = 1.6$ mA/V^2 is to be operated in the saturation region. If i_D is to be 50 μA, find the required v_{GS} and the minimum required v_{DS}. Repeat for $i_D = 200$ μA.

5.18 $V_{tn} = 0.5$ V, $\quad k_n = 1.6$ mA/V^2

$$I_D = 0.05 = \frac{1}{2} \times 1.6 \times V_{OV}^2$$

$$\Rightarrow V_{OV} = 0.25 \text{ V and } V_{DS} \geq 0.25 \text{ V}$$

$$V_{GS} = 0.5 + 0.25 = 0.75 \text{ V}$$

$$I_D = 0.2 = \frac{1}{2} \times 1.6 \times V_{OV}^2$$

$$\Rightarrow V_{OV} = 0.5 \text{ V and } V_{DS} \geq 0.5 \text{ V}$$

$$V_{GS} = 0.5 + 0.5 = 1 \text{ V}$$

5.19 A particular n-channel MOSFET is measured to have a drain current of 0.4 mA at $V_{GS} = V_{DS} = 1$ V and of 0.1 mA at $V_{GS} = V_{DS} = 0.8$ V. What are the values of k_n and V_t for this device?

5.19 For $V_{GS} = V_{DS} = 1$ V, the MOSFET is operating in saturation,

$$I_D = \frac{1}{2} k_n (V_{GS} - V_t)^2$$

$$0.4 = \frac{1}{2} k_n (1 - V_t)^2 \qquad (1)$$

$$0.1 = \frac{1}{2} k_n (0.8 - V_t)^2 \qquad (2)$$

Dividing Eq. (1) by Eq. (2) and taking square roots gives

$$2 = \frac{1 - V_t}{0.8 - V_t}$$

$$\Rightarrow V_t = 0.6 \text{ V}$$

Substituting in Eq. (1), we have

$$0.4 = \frac{1}{2} k_n \times 0.4^2$$

$$\Rightarrow k_n = 5 \text{ mA/V}^2$$

*5.27 The table above lists 10 different cases labeled (a) to (j) for operating an NMOS transistor with $V_t = 1$ V. In each case the voltages at the source, gate, and drain (relative to the circuit ground) are specified. You are required to complete the table entries. Note that if you encounter a case for which v_{DS} is negative, you should exchange the drain and source before solving the problem. You can do this because the MOSFET is a symmetric device.

5.27 $V_{DS} = V_D - V_S \qquad V_{GS} = V_G - V_S$

$V_{OV} = V_{GS} - V_t = V_{GS} - 1.0$

According to Table 5.1, three regions are possible.

Case	V_S	V_G	V_D	V_{GS}	V_{OV}	V_{DS}	Region of operation
a	+1.0	+1.0	+2.0	0	–1.0	+1.0	Cutoff
b	+1.0	+2.5	+2.0	+1.5	+0.5	+1.0	Sat.
c	+1.0	+2.5	+1.5	+1.5	+0.5	+0.5	Sat.
d	+1.0	+1.5	0	+0.5	–0.5	–1.0	Sat.*
e	0	+2.5	1.0	+2.5	+1.5	+1.0	Triode
f	+1.0	+1.0	+1.0	0	–1.0	0	Cutoff
g	–1.0	0	0	+1.0	0	+1.0	Sat.
h	–1.5	0	0	+1.5	+0.5	+1.5	Sat.
i	–1.0	0	+1.0	+1.0	0	+2.0	Sat.
j	+0.5	+2.0	+0.5	+1.5	+0.5	0	Triode

* With the source and drain interchanged.

5.38 A PMOS transistor has $k_p'(W/L) = 100\ \mu A/V^2$, $V_t = -1.0$ V, and $\lambda = -0.02\ V^{-1}$. The gate is connected to ground and the source to +5 V. Find the drain current for $v_D = +4$ V, +2 V, +1 V, 0 V, and –5 V.

5.38

$$k_p = k_p'\left(\frac{W}{L}\right) = 100\ \mu A/V^2$$

$$V_{tp} = -1\ V \quad \lambda = -0.02\ V^{-1}$$

$$V_G = 0, \quad V_S = +5\ V \Rightarrow V_{SG} = 5\ V$$

$$|V_{OV}| = V_{SG} - |V_{tp}| = 5 - 1 = 4$$

• For $v_D = +4$ V, $v_{SD} = 1\ V < |V_{OV}| \Rightarrow$ triode-region operation,

$$i_D = k_p\left[v_{SD}|V_{OV}| - \frac{1}{2}v_{SD}^2\right]$$

$$= 100\left(1 \times 4 - \frac{1}{2} \times 1\right) = 350\ \mu A$$

• For $v_D = +2$ V, $v_{SD} = 3\ V < |V_{OV}| \Rightarrow$ triode-region operation,

$$i_D = k_p\left[v_{SD}|V_{OV}| - \frac{1}{2}v_{SD}^2\right]$$

$$= 100\left(3 \times 4 - \frac{1}{2} \times 9\right) = 750\ \mu A$$

• For $v_D = +1$ V, $v_{SD} = 4\ V = |V_{OV}| \Rightarrow$ saturation-mode operation,

$$i_D = \frac{1}{2}k_p|V_{OV}|^2(1 + |\lambda|v_{SD})$$

$$= \frac{1}{2} \times 100 \times 16(1 + 0.02 \times 4) = 864\ \mu A$$

• For $v_D = 0$ V, $v_{SD} = 5\ V > |V_{OV}| \Rightarrow$ saturation-mode operation,

$$i_D = \frac{1}{2} \times 100 \times 16(1 + 0.02 \times 5) = 880\ \mu A$$

• For $v_D = -5$ V, $v_{SD} = 10\ V > |V_{OV}| \Rightarrow$ saturation-mode operation,

$$i_D = \frac{1}{2} \times 100 \times 16(1 + 0.02 \times 10) = 960\ \mu A$$

5.39 A p-channel transistor for which $|V_t| = 0.8$ V and $|V_A| =$ 40 V operates in saturation with $|v_{GS}| = 3$ V, $|v_{DS}| = 4$ V, and $i_D = 3$ mA. Find corresponding signed values for v_{GS}, v_{SG}, v_{DS}, v_{SD}, V_t, V_A, λ, and $k_p'(W/L)$.

5.39 $V_{tp} = 0.8$ V, $\quad |V_A| = 40$ V

$|v_{GS}| = 3$ V, $\quad |v_{DS}| = 4$ V

$i_D = 3$ mA

$|V_{OV}| = |v_{GS}| - |V_{tp}| = 2.2$ V

$|v_{DS}| > |V_{OV}| \Rightarrow$ saturation mode

$v_{GS} = -3$ V

$v_{SG} = +3$ V

$v_{DS} = -4$ V

$v_{SD} = 4$ V

$V_{tp} = -0.8$ V

$V_A = -40$ V

$\lambda = -0.025\ \mathrm{V}^{-1}$

$$i_D = \frac{1}{2}k_p(v_{GS} - V_{tp})^2(1 + \lambda\ v_{DS})$$

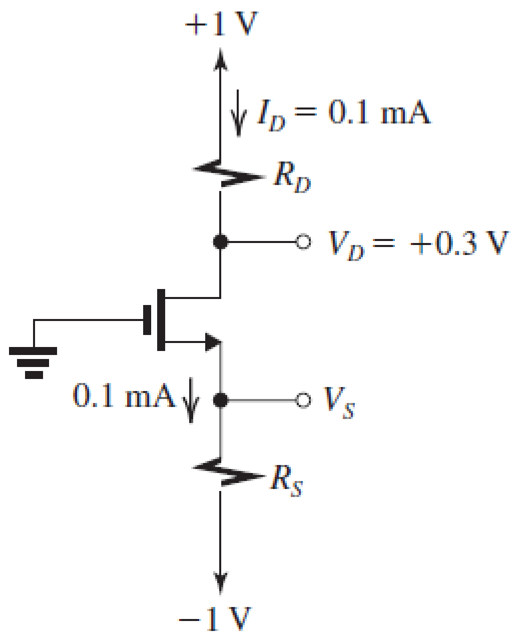
$$3 = \frac{1}{2}k_p[-3 - (-0.8)]^2(1 - 0.025 \times -4)$$

$\Rightarrow k_p = 1.137\ \mathrm{mA/V^2}$

Note: If λ is not specified, assume it is zero.

D 5.44 Design the circuit of Fig. P5.44 to establish a drain current of 0.1 mA and a drain voltage of +0.3 V. The MOSFET has $V_t = 0.5$ V, $\mu_n C_{ox} = 400\ \mu\text{A/V}^2$, $L = 0.4\ \mu\text{m}$, and $W = 5\ \mu\text{m}$. Specify the required values for R_S and R_D.

5.44



Since $V_{DG} > 0$, the MOSFET is in saturation.

$$I_D = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}V_{OV}^2$$

$$0.1 = \frac{1}{2} \times 0.4 \times \frac{5}{0.4} \times V_{OV}^2$$

$$\Rightarrow V_{OV} = 0.2 \text{ V}$$

$$V_{GS} = V_t + V_{OV} = 0.5 + 0.2 = 0.7$$

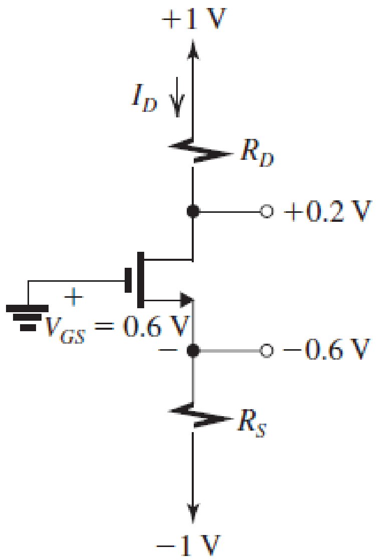
$$V_S = 0 - V_{GS} = -0.7 \text{ V}$$

$$R_S = \frac{V_S - (-1)}{I_D} = \frac{-0.7 + 1}{0.1} = 3 \text{ k}\Omega$$

$$R_D = \frac{1 - V_D}{I_D} = \frac{1 - 0.3}{0.1} = \frac{0.7}{0.1} = 7 \text{ k}\Omega$$

5.45 The NMOS transistor in the circuit of Fig. P5.44 has $V_t = 0.4$ V and $k_n = 4$ mA/V^2. The voltages at the source and the drain are measured and found to be -0.6 V and $+0.2$ V, respectively. What current I_D is flowing, and what must the values of R_D and R_S be? What is the largest value for R_D for which I_D remains unchanged from the value found?

5.45



Since $V_{DG} > 0$, the MOSFET is operating in saturation. Thus

$$I_D = \frac{1}{2} k_n (V_{GS} - V_t)^2$$

$$= \frac{1}{2} \times 4 \times (0.6 - 0.4)^2$$

$$= 0.08 \text{ mA}$$

$$R_D = \frac{1 - V_D}{I_D} = \frac{1 - 0.2}{0.08} = \frac{0.8}{0.08} = 10 \text{ k}\Omega$$

$$R_S = \frac{-0.6 - (-1)}{I_D} = \frac{-0.6 + 1}{0.08} = 5 \text{ k}\Omega$$

For I_D to remain unchanged from 0.08 mA, the MOSFET must remain in saturation. This in turn can be achieved by ensuring that V_D does not fall below V_G (which is zero) by more than V_t (0.4 V). Thus

$$1 - I_D R_{D\max} = -0.4$$

$$R_{D\max} = \frac{1.4}{0.08} = 17.5 \text{ k}\Omega$$