Homework #9

Solutions

MOSFET Circuits: DC Biasing and Common Source Amplifier – *100 points*

DUE @ Beginning of Class: Thursday, November 16

1) E-Book, problem 3.26 (10 points)

2) E-Book, problem D3.28 (find R_1 and R_2) (10 points)

3) E-Book, problem 3.29 (20 points)

4) E-Book, problem 3.40 (10 points)

5) E-Book, problem 4.8 (10 points)

6) E-Book, problem 4.15 (12 points)

7) E-Book, problem 4.18 (10 points)

8) E-Book, problem D4.26 (18 points)

1) E-Book, problem 3.26 (10 points)

3.26 In the circuit in Figure P3.26, the transistor parameters are $V_{TN} = 0.8$ V and $K_n = 0.5$ mA/V^2. Calculate V_{GS}, I_D, and V_{DS}.

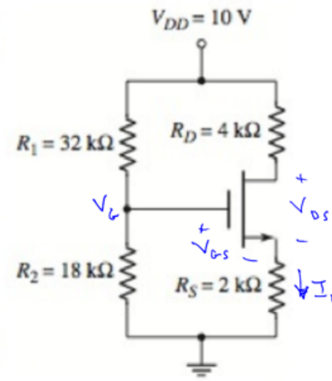


Figure P3.26

$$V_G = \left(\frac{R_2}{R_1 + R_2}\right) V_{DD} = \left(\frac{18\,k\Omega}{18\,k\Omega + 32\,k\Omega}\right)(10\,V) = 3.6\,V$$

→ assume biased in sat.

$$I_D = \frac{V_S}{R_S} = \frac{V_G - V_{GS}}{R_S} = K_n (V_{GS} - V_{TN})^2$$

$$V_G - V_{GS} = R_S K_n (V_{GS} - V_{TN})^2$$

$$3.6\,V - V_{GS} = (2\,k\Omega)(0.5\,mA/V^2)(V_{GS} - 0.8\,V)^2$$

$$V_{GS}^2 - 0.6 V_{GS} - 2.96 = 0$$

Solve quadratic: $\boxed{V_{GS} = 2.046\,V}$ 3

$$I_D = \frac{V_G - V_{GS}}{R_S} = \frac{3.6\,V - 2.046\,V}{2\,k\Omega} = \boxed{0.777\,mA}$$ 3

KVL gives:

$$V_{DS} = V_{DD} - I_D (R_D + R_S) = 10\,V - (0.777\,mA)(4\,k\Omega + 2\,k\Omega) = \boxed{5.34\,V}$$ 2

is $V_{DS} > V_{DS}(sat) = V_{GS} - V_{TN} = 2.046\,V - 0.8\,V$? YES ✓

2) E-Book, problem D3.28 (find R_1 and R_2) (10 points)

D3.28 The transistor in Figure P3.28 has parameters $V_{TN} = 0.4$ V, $k_n' = 120$ μA/V^2, and $W/L = 80$. Design the circuit such that $I_Q = 0.8$ mA and $R_{in} = 200$ kΩ.

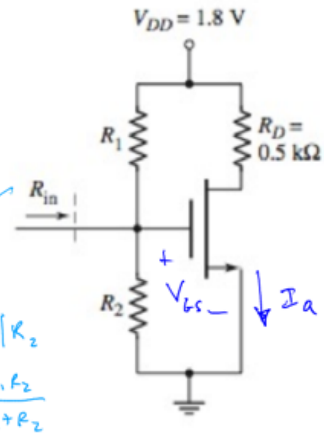


Figure P3.28

assuming operation in saturation:

$$I_Q = \frac{k_n'}{2}\left(\frac{W}{L}\right)(V_{GS} - V_{TN})^2$$

$$0.8\text{ mA} = \frac{0.12\text{ mA/V}^2}{2}(80)(V_{GS} - 0.4\text{V})^2$$

$$\Rightarrow V_{GS} = 0.808\text{ V} \quad 2$$

$$R_{in} = R_1 || R_2 = \frac{R_1 R_2}{R_1 + R_2}$$

voltage divider:

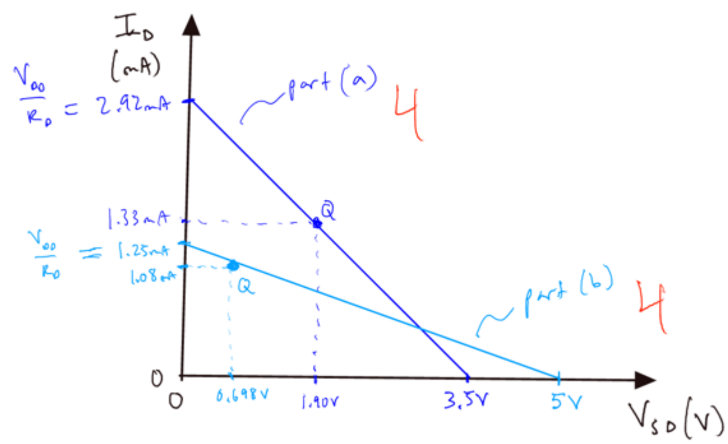
$$V_{GS} = \frac{R_2}{R_1 + R_2} V_{DD} = \frac{1}{R_1} R_{in} V_{DD}$$

$$0.808\text{V} = \frac{1}{R_1}(200\text{k}\Omega)(1.8\text{V}) \Rightarrow \boxed{R_1 = 445\text{ k}\Omega} \quad 3$$

$$R_{in} = R_1 || R_2 = 200\text{ k}\Omega = \frac{(445\text{k}\Omega) R_2}{445\text{k}\Omega + R_2} \Rightarrow \boxed{R_2 = 363\text{ k}\Omega} \quad 3$$

3) E-Book, problem 3.29 (20 points)

3.29 The transistor in the circuit in Figure P3.29 has parameters $V_{TP} = -0.8$ V and $K_p = 0.20$ mA/V^2. Sketch the load line and plot the Q-point for (a) $V_{DD} = 3.5$ V, $R_D = 1.2$ kΩ and (b) $V_{DD} = 5$ V, $R_D = 4$ kΩ. What is the operating bias region for each condition?



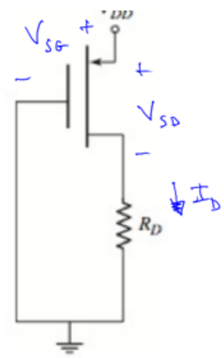


Figure P3.29

a) $V_{SG} = V_{DD} = 3.5\text{V}$, $V_{SD}(\text{sat}) = V_{SG} + V_{TP} = 3.5\text{V} - 0.8\text{V} = 2.7\text{V}$

If biased in sat: $I_D = K_p(V_{SG}+V_{TP})^2 = (0.2\,\text{mA/V}^2)(2.7\text{V})^2 = 1.46\,\text{mA}$

$V_{SD} = V_{DD} - I_D R_D = 3.5\text{V} - (1.46\text{mA})(1.2\text{k}\Omega) = 1.75\text{V} < V_{SD}(\text{sat})$

$\Rightarrow$ NOT in sat.

Non-sat:

$V_{DD} = V_{SD} + I_D R_D = V_{SD} + K_p R_D\left[2(V_{SG}+V_{TP})V_{SD} - V_{SD}^2\right]$

$\boxed{\text{Linear or non. sat. region}}$ 2

$3.5\text{V} = V_{SD} + 1.296\,V_{SD} - 0.24\,V_{SD}^2$

solve quadratic: $V_{SD} = 1.90\text{V}$ operating point 2

$I_D = \frac{V_{DD} - V_{SD}}{R_D} = \frac{3.5\text{V} - 1.90\text{V}}{1.2\text{k}\Omega} = 1.33\,\text{mA}$

b) $V_{SG} = V_{DD} = 5\text{V}$, $V_{SD}(\text{sat}) = 5\text{V} - 0.8\text{V} = 4.2\text{V}$

assume sat.: $I_D = (0.2)(4.2\text{V})^2 = 3.53\,\text{mA}$ .... would result in $V_{SD} < 0$ $\Rightarrow$ $\boxed{\text{non-sat. region}}$ 2

non-sat:

$V_{DD} = V_{SD} + I_D R_D = V_{SD} + K_p R_D\left[2(V_{SG}+V_{TP})V_{SD} - V_{SD}^2\right]$

and

$I_D = \frac{V_{DD} - V_{SD}}{R_D}$

Same approach as in part a) gives: $V_{SD} = 0.698\text{V}$, $I_D = 1.08\,\text{mA}$ operating point 2

4) E-Book, problem 3.40 (10 points)

3.40 The PMOS transistor in Figure P3.40 has parameters $V_{TP} = -0.7$ V, $k'_p = 50\ \mu\text{A/V}^2$, $L = 0.8\ \mu$m, and $\lambda = 0$. Determine the values of W and R such that $I_D = 0.1$ mA and $V_{SD} = 2.5$ V.

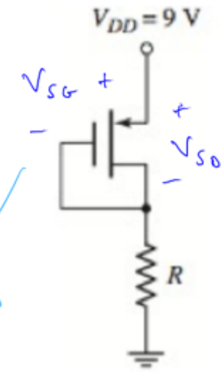


Figure P3.40

$$I_D = 0.1\ \text{mA} = \frac{V_{DD} - V_{SD}}{R} = \frac{9\text{V} - 2.5\text{V}}{R}$$

$$\Rightarrow \boxed{R = 65\,\text{k}\Omega}$$ 2

assume sat.

$V_{SG} = V_{SD}$

$$I_D = \frac{k_p'}{2}\left(\frac{W}{L}\right)(V_{SG} + V_{TP})^2$$

$$0.1\ \text{mA} = \frac{0.05\ \text{mA/V}^2}{2}\left(\frac{W}{L}\right)(2.5\text{V} - 0.7\text{V})^2$$

$$\Rightarrow \left(\frac{W}{L}\right) = 1.235 = \frac{W}{0.8\,\mu\text{m}} \Rightarrow \boxed{W = 0.988\,\mu\text{m}}$$ 6

5) E-Book, problem 4.8 (10 points)

4.8 The parameters of the circuit in Figure 4.1 are $V_{DD} = 3.3$ V and $R_D = 5$ kΩ. The transistor parameters are $k_n' = 100\,\mu$A/V^2, $W/L = 40$, $V_{TN} = 0.4$ V, and $\lambda = 0.025$ V^{-1}. (a) Find I_{DQ} and V_{GSQ} such that $V_{DSQ} = 1.5$ V. (b) Determine the small-signal voltage gain.

a) $V_{DD} = I_{DQ} R_D + V_{DSQ}$ (voltage loop)

$3.3\text{v} = I_{DQ}(5\text{k}\Omega) + 1.5\text{v} \Rightarrow \boxed{I_{DQ} = 0.36\text{mA}}$ 3

$I_{DQ} = \frac{k_n'}{2}\left(\frac{W}{L}\right)(V_{GSQ} - V_{TN})^2$

$0.36\text{mA} = \frac{0.1\text{mA/V}^2}{2}(40)(V_{GSQ} - 0.4\text{v})^2 \Rightarrow \boxed{V_{GSQ} = 0.824\text{ V}}$ 3

b) $g_m = 2\sqrt{K_n I_{DQ}} = 2\sqrt{\frac{k_n'}{2}\left(\frac{W}{L}\right) I_{DQ}} = 2\sqrt{\frac{0.1\text{mA/V}^2}{2}(40)(0.36\text{mA})} = 1.697\text{ mA/V}$

$r_o = \frac{1}{\lambda I_{DQ}} = \frac{1}{(0.025\text{ V}^{-1})(0.36\text{mA})} = 111\text{ k}\Omega$

$A_v = -g_m(r_o \| R_D) = -(1.697\text{ mA/V})(111\text{ k}\Omega \| 5\text{ k}\Omega) = \boxed{-8.12}$ 4

6) E-Book, problem 4.15 (12 points)

4.15 For the NMOS common-source amplifier in Figure P4.15, the transistor parameters are: $V_{TN} = 0.8$ V, $K_n = 1$ mA/V^2, and $\lambda = 0$. The circuit parameters are $V_{DD} = 5$ V, $R_S = 1$ kΩ, $R_D = 4$ kΩ, $R_1 = 225$ kΩ, and $R_2 = 175$ kΩ. (a) Calculate the quiescent values I_{DQ} and V_{DSQ}. (b) Determine the small-signal voltage gain for $R_L = \infty$. (c) Determine the value of R_L that will reduce the small-signal voltage gain to 75 percent of the value found in part (b).

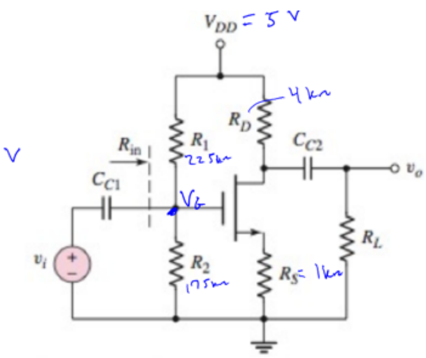


Figure P4.15

a) Voltage divider:

$$V_G = \left(\frac{R_2}{R_1+R_2}\right)V_{DD} = \left(\frac{175\text{k}\Omega}{175\text{k}\Omega + 225\text{k}\Omega}\right)(5\text{V}) = 2.19\text{V}$$

$$V_G = V_{GS} + I_D R_S = V_{GS} + K_n R_S (V_{GS} - V_{TN})^2$$

$$2.19\text{V} = V_{GS} + (1\text{mA/V}^2)(1\text{k}\Omega)(V_{GS} - 0.8\text{V})^2$$

$$\Rightarrow V_{GS} = 1.58\text{V}$$

$$I_{DQ} = K_n (V_{GS} - V_{TN})^2 = (1\text{mA/V}^2)(1.58\text{V} - 0.8\text{V})^2 = \boxed{0.608\text{ mA}}$$ 2

$$V_{DSQ} = V_{DD} - I_{DQ}(R_S + R_D) = 5\text{V} - (0.608\text{mA})(1\text{k}\Omega + 4\text{k}\Omega) = \boxed{1.96\text{V}}$$ 2

b) with $R_L = \infty$, then: $A_v = \dfrac{-g_m R_D}{1 + g_m R_S}$ (from pg. 605, Eq. 4.5)

$$g_m = 2\sqrt{K_n I_{DQ}} = 2\sqrt{(1\text{mA/V}^2)(0.608\text{mA})} = 1.56\text{ mA/V}$$

$$A_v = \frac{-(1.56\text{mA/V})(4\text{k}\Omega)}{1 + (1.56\text{mA/V})(1\text{k}\Omega)} = \boxed{-2.44}$$ 4

c) If $R_L \neq \infty$, then A_v:

$$A_v = \frac{-g_m R_D || R_L}{1 + g_m R_S} = \frac{-(1.56\text{ mA/V})\, R_D || R_L}{1 + (1.56\text{ mA/V})(1\text{k}\Omega)} = -0.609 (R_D || R_L)$$

75% of -2.44: $-(0.75)(2.44) = -0.609\, R_D || R_L$

$$\Rightarrow \boxed{R_L = 12\text{k}\Omega}$$ 4

7) E-Book, problem 4.18 (10 points)

4.18 The ac equivalent circuit of a common-source amplifier is shown in Figure P4.18. The small-signal parameters of the transistor are $g_m = 2$ mA/V and $r_o = \infty$. (a) The voltage gain is found to be $A_v = V_o/V_i = -15$ with $R_S = 0$. What is the value of R_D? (b) A source resistor R_S is inserted. Assuming the transistor parameters do not change, what is the value of R_S if the voltage gain is reduced to $A_v = -5$.

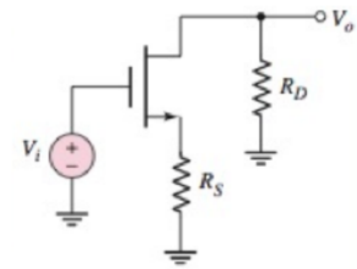


Figure P4.18

a) $A_v = -g_m R_D$

$-15 = -(2\,\text{mA/V})\,R_D$

$\Rightarrow \boxed{R_D = 7.5\,\text{k}\Omega}$ 2

b) with R_S:

$$A_v = \frac{-g_m R_D}{1 + g_m R_S}$$

$$-5 = \frac{-(2\,\text{mA/V})(7.5\,\text{k}\Omega)}{1 + (2\,\text{mA/V})\,R_S} \Longrightarrow \boxed{R_S = 1\,\text{k}\Omega}$$ 4

8) E-Book, problem D4.26 (18 points)

*D4.26 Design the common-source circuit in Figure P4.26 using an n-channel MOSFET with $\lambda = 0$. The quiescent values are to be $I_{DQ} = 6$ mA, $V_{GSQ} = 2.8$ V, and $V_{DSQ} = 10$ V. The transconductance is $g_m = 2.2$ mA/V. Let $R_L = 1$ kΩ, $A_v = -1$, and $R_{in} = 100$ kΩ. Find R_1, R_2, R_S, R_D, K_n, and V_{TN}.

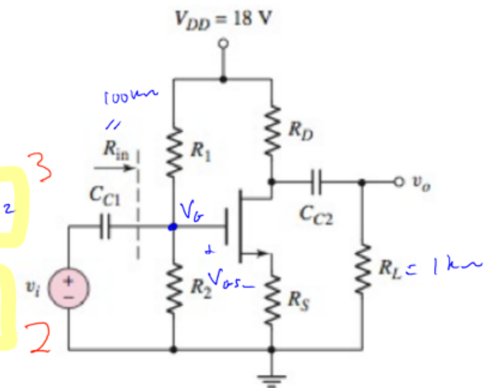


Figure P4.26

$$I_{DQ} = K_n (V_{GSQ} - V_{TN})^2$$

$$g_m = 2\sqrt{K_n I_{DQ}}$$

$$2.2\,\text{mA/V} = 2\sqrt{K_n (6\,\text{mA})} \Rightarrow \boxed{K_n = 0.202\ \text{mA/V}^2} \quad 3$$

$$6\,\text{mA} = (0.202\,\text{mA/V}^2)(2.8\,\text{V} - V_{TN})^2 \Rightarrow \boxed{V_{TN} = -2.65\,\text{V}} \quad 2$$

$$V_{DSQ} = V_{DD} - I_{DQ}(R_S + R_D)$$

$$R_S + R_D = \frac{18\,\text{V} - 10\,\text{V}}{6\,\text{mA}} = 1.33\,\text{k}\Omega \Rightarrow R_S = 1.33\,\text{k}\Omega - R_D$$

$$A_v = \frac{g_m (R_D \| R_L)}{1 + g_m R_S} \longrightarrow -1 = \frac{-(2.2\,\text{mA/V})\left(\frac{R_D (1\,\text{k}\Omega)}{R_D + 1\,\text{k}\Omega}\right)}{1 + (2.2\,\text{mA/V})(1.33\,\text{k}\Omega - R_D)} \Rightarrow \boxed{R_D = 1.23\,\text{k}\Omega} \quad 4$$

and

$$\boxed{R_S = 0.10\,\text{k}\Omega} \quad 2$$

$$V_G = V_{GS} + V_S = 2.8\,\text{V} + \underbrace{(6\,\text{mA})}_{I_{DQ}}\underbrace{(0.10\,\text{k}\Omega)}_{R_S} = 3.4\,\text{V}$$

$$V_G = \left(\frac{R_2}{R_1 + R_2}\right) V_{DD} = \frac{1}{R_1} R_{in} V_{DD} = \frac{1}{R_1}(100\,\text{k}\Omega)(18\,\text{V}) = 3.4\,\text{V} \Rightarrow \boxed{R_1 = 529\,\text{k}\Omega} \quad 3$$

$$R_{in} = 100\,\text{k}\Omega = R_1 \| R_2 = (529\,\text{k}\Omega) \| R_2 \Rightarrow \boxed{R_2 = 123\,\text{k}\Omega} \quad 2$$