Homework #10

Solutions

MOSFET Amplifiers and Single-Stage MOSFET IC – *100 points*

DUE @ Beginning of Class: Tuesday, November 28

1) E-Book, problem 4.31 (10 points)

2) E-Book, problem 4.44 (15 points)

3) E-Book, problem 4.52 (10 points)

4) E-Book, problem 4.53; hint: see Ex. 4.11 (15 points)

5) E-Book, problem 4.59 (20 points)

6) E-Book, problem 4.61 (15 points)

7) E-Book, problem 4.65; hint: $I_{dD} = I_Q = I_{dL}$ (15 points)

1) E-Book, problem 4.31 (10 points)

4.31 The open-circuit ($R_L = \infty$) voltage gain of the ac equivalent source-follower circuit shown in Figure P4.31 is $A_v = 0.98$. When R_L is set to 1 kΩ, the voltage gain is reduced to $A_v = 0.49$. What are the values of g_m and r_o?

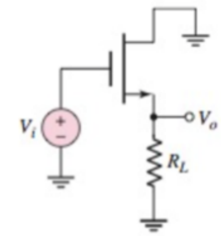


Figure P4.31

Source-follower, so:

$$A_v = \frac{g_m(R_s \| r_o)}{1+g_m(R_s\|r_o)}\left(\frac{R_i}{R_i+R_{si}}\right), \quad R_s = R_L$$

$$\therefore A_v = \frac{g_m(R_L\|r_o)}{1+g_m(R_L\|r_o)} \quad 2$$

If $R_L = \infty$ then:

$$0.98 = \frac{g_m r_o}{1+g_m r_o} \Rightarrow g_m r_o = 49 \quad 2$$

If $R_L = 1k\Omega$:

$$0.49 = \frac{g_m(R_L\|r_o)}{1+g_m(R_L\|r_o)} = \frac{g_m\left(\frac{R_L r_o}{R_L+r_o}\right)}{1+g_m\left(\frac{R_L r_o}{R_L+r_o}\right)} = \frac{g_m(R_L r_o)}{R_L+r_o+g_m(R_L r_o)}$$

$$0.49 = \frac{(49)(1k\Omega)}{1k\Omega + r_o + (49)(1k\Omega)} = \frac{49k\Omega}{50k\Omega + r_o}$$

$$\Rightarrow \boxed{r_o = 50k\Omega} \quad 4$$

$$\boxed{g_m = \frac{49}{r_o} = 0.98\ mA/V} \quad 2$$

2) E-Book, problem 4.44 (15 points)

4.44 The transistor in the circuit in Figure P4.44 has parameters $V_{TN} = 0.4$ V, $K_n = 0.5$ mA/V^2, and $\lambda = 0$. The circuit parameters are $V_{DD} = 3$ V and $R_i = 300\,\text{k}\Omega$. (a) Design the circuit such that $I_{DQ} = 0.25$ mA and $V_{DSQ} = 1.5$ V. (b) Determine the small-signal voltage gain and the output resistance R_o.

Source-follower amplifier

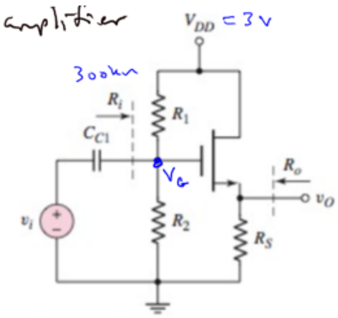


Figure P4.44

a) DC analysis, KVL:

$V_{DD} = V_{DSQ} + I_{DQ} R_S$

$3\text{ V} = 1.5\text{ V} + (0.25\text{ mA}) R_S$

$\Rightarrow \boxed{R_S = 6\text{ k}\Omega}$ 3

$V_S = (0.25\text{ mA})(6\text{ k}\Omega) = 1.5\text{ V}$

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

$0.25\text{ mA} = (0.5\text{ mA/V}^2)(V_{GSQ} - 0.4\text{ V})^2$

$\Rightarrow V_{GSQ} = 1.107\text{ V}$

KVL: $V_G = V_{GSQ} + V_S = 1.107\text{ V} + 1.5\text{ V} = 2.607\text{ V}$

Voltage divider:

$V_G = \left(\frac{R_2}{R_1 + R_2}\right) V_{DD} = \frac{1}{R_1} R_{in} V_{DD}$

$2.607\text{ V} = \frac{1}{R_1}(300\text{ k}\Omega)(3\text{ V}) \Rightarrow \boxed{R_1 = 345.2\text{ k}\Omega}$ 4

$\therefore \boxed{R_2 = 2.29\text{ M}\Omega}$ 4

b) Assuming no r_o; also there is no R_S:

$\therefore A_v = \frac{g_m R_S}{1 + g_m R_S}$

$g_m = 2\sqrt{K_n I_{DQ}} = 2\sqrt{(0.5\text{ mA/V}^2)(0.25\text{ mA})} = 0.707\text{ mA/V}$

$A_v = \frac{(0.707\text{ mA/V})(6\text{ k}\Omega)}{1 + (0.707\text{ mA/V})(6\text{ k}\Omega)} = \boxed{0.809}$ 2

$R_o = \frac{1}{g_m} \| R_S = \frac{1}{0.707\text{ mA/V}} \| 6\text{ k}\Omega = \boxed{1.14\text{ k}\Omega}$ 2

3) E-Book, problem 4.52 (10 points)

4.52 For the common-gate amplifier in Figure 4.35 in the text, the PMOS transistor parameters are $V_{TP} = -0.8$ V, $K_p = 2.5\ \text{mA/V}^2$, and $\lambda = 0$. The circuit parameters are $V^+ = 3.3$ V, $V^- = -3.3$, $R_G = 100\ \text{k}\Omega$, and $R_L = 4\ \text{k}\Omega$. (a) Determine R_S and R_D such that $I_{DQ} = 1.2$ mA and $V_{SDQ} = 3$ V. (b) Determine the small-signal voltage gain $A_v = v_o/v_i$.

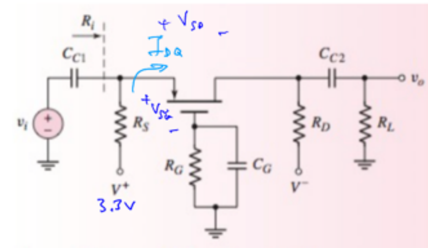


Figure 4.35 Figure for Exercise Ex 4.10

a) DC Analysis:

$$I_{DQ} = K_p \left(V_{SGQ} + V_{TP}\right)^2$$

$$1.2\ \text{mA} = \left(2.5\ \text{mA/V}^2\right)\left(V_{SGQ} - 0.8\ \text{V}\right)^2$$

$$\Rightarrow V_{SGQ} = 1.493\ \text{V}$$

$$R_S = \frac{V^+ - V_{SGQ}}{I_{DQ}} = \frac{3.3\ \text{V} - 1.493\ \text{V}}{1.2\ \text{mA}} = \boxed{1.51\ \text{k}\Omega} \quad 4$$

KVL:

$$V_{SDQ} = V^+ - V^- - I_{DQ}\left(R_S + R_D\right)$$

$$3\ \text{V} = 6.6\ \text{V} - (1.2\ \text{mA})\left(1.51\ \text{k}\Omega + R_D\right) \Rightarrow \boxed{R_D = 1.49\ \text{k}\Omega} \quad 2$$

b)

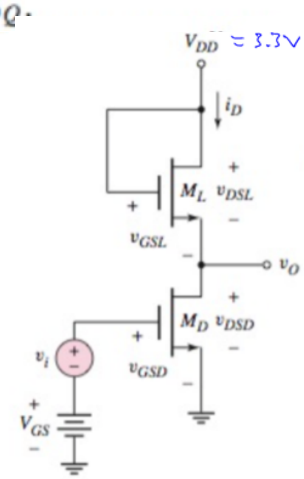
$$A_v = \frac{g_m (R_D \| R_L)}{1 + g_m R_{Si}} \quad (R_{Si} = 0 \text{ in this case}) = g_m (R_D \| R_L)$$

$$g_m = 2\sqrt{K_p I_{DQ}} = 2\sqrt{(2.5\ \text{mA/V}^2)(1.2\ \text{mA})} = 3.46\ \text{mA/V}$$

$$A_v = (3.46\ \text{mA/V})(1.49\ \text{k}\Omega \,\|\, 4\ \text{k}\Omega) = \boxed{3.76} \quad 4$$

4) E-Book, problem 4.53; hint: see Ex. 4.11 (15 points)

4.53 Consider the NMOS amplifier with saturated load in Figure 4.39(a). The transistor parameters are $V_{TND} = V_{TNL} = 0.6$ V, $k_n' = 100\,\mu A/V^2$, $\lambda = 0$, and $(W/L)_L = 1$. Let $V_{DD} = 3.3$ V. (a) Design the circuit such that the small-signal voltage gain is $|A_v| = 5$ and the Q-point is in the center of the saturation region. (b) Determine I_{DQ} and V_{DSDQ}.



(a)

a) $|A_v| = \sqrt{\dfrac{(W/L)_D}{(W/L)_L}} = 5 \Rightarrow \boxed{(W/L)_D = 25}$ 2

$(W/L)_L \to 1$

From Ex. 4.11:

$$V_{GSDt} = \frac{(V_{DD} - V_{TNL}) + V_{TND}(1 + |A_v|)}{1 + |A_v|} = 1.05V$$

$$V_{GSDQ} = \frac{V_{GSDt} - V_{TND}}{2} + V_{TND} = \boxed{0.825V}$$ 3

Cut-off point

Q-point centered in sat. region of driver

b) $I_{DQ} = \left(\frac{k_n'}{2}\right)\left(\frac{W}{L}\right)_D (V_{GSDQ} - V_{TN})^2 = \left(\frac{0.1\,mA/V^2}{2}\right)(25)(0.825V - 0.6V)^2 = \boxed{0.063\ mA}$ 4

Since $I_{DD} = I_{DL}$

$$\left(\frac{W}{L}\right)_D (V_{GSDQ} - V_{TN})^2 = \left(\frac{W}{L}\right)_L (V_{GSLQ} - V_{TN})^2$$

$$5(V_{GSDQ} - V_{TN}) = V_{DD} - V_o - V_{TN}$$ KVL

$$5(0.825V - 0.6V) = 3.3V - V_o - 0.6V$$

$$\Rightarrow V_o = \boxed{V_{DSDQ} = 1.575V}$$ 6

5) E-Book, problem 4.59 (20 points)

4.59 The transistor parameters for the common-source circuit in Figure P4.59 are $V_{TND} = 0.4\,\text{V}$, $V_{TPL} = -0.4\,\text{V}$, $(W/L)_L = 50$, $\lambda_D = 0.02\,\text{V}^{-1}$, $\lambda_L = 0.04\,\text{V}^{-1}$, $k_n' = 100\,\mu\text{A/V}^2$, and $k_p' = 40\,\mu\text{A/V}^2$. At the Q-point, $I_{DQ} = 0.5\,\text{mA}$. (a) Determine $(W/L)_D$ such that the small-signal voltage gain is $A_v = V_o/V_i = -40$. (b) What is the required value of V_B? (c) What is the value of V_{GSDQ}?

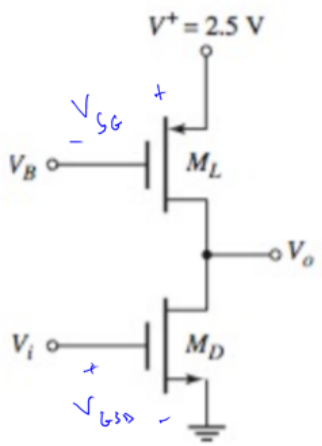


Figure P4.59

a) $A_v = -\underbrace{g_{mn}}_{g_{mD}}\left(\underbrace{r_{on}}_{r_{oD}} \| \underbrace{r_{op}}_{r_{oL}}\right) = -40$

$r_{oD} = \dfrac{1}{\lambda_D I_{DQ}} = \dfrac{1}{(0.02\,\text{V}^{-1})(0.5\,\text{mA})} = 100\,\text{k}\Omega$

$r_{oL} = \dfrac{1}{\lambda_L I_{DQ}} = 50\,\text{k}\Omega$

$r_{oD} \| r_{oL} = 33.3\,\text{k}\Omega$

$-g_{mD}(33.3\,\text{k}\Omega) = -40 \Rightarrow g_{mD} = 1.20\,\text{mA/V}$

$g_{mD} = 2\sqrt{\left(\dfrac{k_n'}{2}\right)\left(\dfrac{W}{L}\right)_D I_{DQ}}$

$1.20\,\text{mA/V} = 2\sqrt{\left(\dfrac{0.1\,\text{mA/V}^2}{2}\right)\left(\dfrac{W}{L}\right)_D (0.5\,\text{mA})}$

$\Rightarrow \boxed{\left(\dfrac{W}{L}\right)_D = 14.4}$ 8

assume lamda neglibigle contribution

b) DC analysis:

$I_{DQ} = \left(\dfrac{k_p'}{2}\right)\left(\dfrac{W}{L}\right)_L (V_{SGQ} + V_{TP})^2$

$0.5\,\text{mA} = \left(\dfrac{0.04\,\text{mA/V}^2}{2}\right)(50)(V_{SGQ} - 0.4\,\text{V})^2$

$\Rightarrow V_{SGQ} = 1.107\,\text{V} = V^+ - V_B$

$1.107\,\text{V} = 2.5\,\text{V} - V_B$

$\Rightarrow \boxed{V_B = 1.393\,\text{V}}$ 8

c) $I_{DQ} = \left(\dfrac{k_n'}{2}\right)\left(\dfrac{W}{L}\right)_D (V_{GSDQ} - V_{TN})^2$

$\Rightarrow \boxed{V_{GSDQ} = 1.233\,\text{V}}$ 4

6) E-Book, problem 4.61 (15 points)

4.61 The ac equivalent circuit of a CMOS common-source amplifier is shown in Figure P4.61. The transistor parameters for M_1 are $V_{TN} = 0.5$ V, $k_n' = 85\ \mu A/V^2$, $(W/L)_1 = 50$, and $\lambda = 0.05\ V^{-1}$, and for M_2 and M_3 are

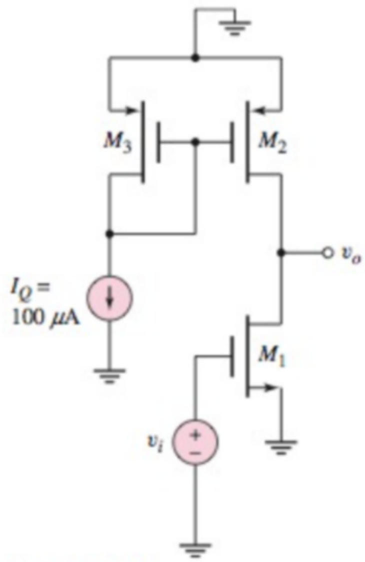


Figure P4.61

Determine A_v.

$$A_v = -g_{m1}(r_{o1} \| r_{o2})$$

$$g_{m1} = 2\sqrt{K_{n1} I_{D1}}$$

$$= 2\sqrt{\left(\frac{85\,\mu A/V^2}{2}\right)(50)(100\,\mu A)} = 0.922\ mA/V$$ 2

$$r_{o1} = \frac{1}{\lambda_1 I_{D1}} = \frac{1}{(0.05\,V^{-1})(0.1\,mA)} = 200\,k\Omega$$ 2

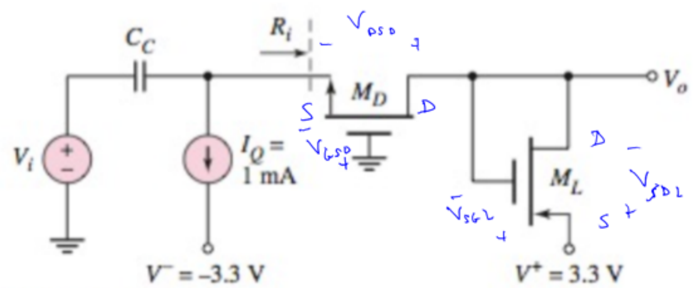
$$r_{o2} = \frac{1}{\lambda_2 I_{D2}} = \frac{1}{(0.075\,V^{-1})(0.1\,mA)} = 133.3\,k\Omega$$ 2

$$A_v = -(0.922\ mA/V)(200\,k\Omega \| 133.3\,k\Omega)$$

$$= \boxed{-73.7}$$ 9

7) E-Book, problem 4.65; hint: $I_{dD} = I_Q = I_{dL}$ (15 points)

4.65 Figure P4.65 shows a common-gate amplifier. The transistor parameters are $V_{TN} = 0.6$ V, $V_{TP} = -0.6$ V, $K_n = 2\text{ mA/V}^2$, $K_p = 0.5\text{ mA/V}^2$, and $\lambda_n = \lambda_p = 0$. (a) Find the values of V_{SGLQ}, V_{GSDQ}, and V_{DSDQ}. (b) Derive the expression for the small-signal voltage gain in terms of K_n and K_p. (c) Calculate the value of the small-signal voltage gain $A_v = V_o/V_i$.



$V_{SGL} = V_{SDL}$

Figure P4.65

a) $I_{DQ} = K_n (V_{GSDQ} - V_{TN})^2 = I_Q$

$1\text{mA} = (2\text{ mA/V}^2)(V_{GSDQ} - 0.6\text{V})^2 \Rightarrow \boxed{V_{GSDQ} = 1.307\text{V}}$ 3

$I_{DQ} = K_p (V_{SGLQ} + V_{TP})^2$

$1\text{mA} = (0.5\text{ mA/V}^2)(V_{SGLQ} - 0.6\text{V})^2 \Rightarrow \boxed{V_{SGLQ} = 2.014\text{ V}}$ 3

$V_o = 3.3\text{V} - V_{SDL} = 3.3\text{V} - 2.014\text{V} = 1.286\text{V}$

KVL: $V_{DSDQ} = V_o + V_{GSDQ} = 1.286\text{V} + 1.307\text{V} = \boxed{2.593\text{V}}$ 3

b) $i_D = i_L$ from small signal equiv. circuit

$g_{mD} v_i = g_{mL} v_o$

$A_v = \dfrac{v_o}{v_i} = \dfrac{g_{mD}}{g_{mL}} = \boxed{\sqrt{\dfrac{K_n}{K_p}}}$ 4

c) $A_v = \sqrt{\dfrac{2}{0.5}} = \boxed{2}$ 2