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Homework 3 (Due Date: Thursday, Feb 7th In Class)

Problem 4.5

An n-channel MOSFET is biased in the saturation region at a constant V_{GS}. (a) The drain current is $I_D = 0.250$ mA at $V_{DS} = 1.5$ V and $I_D = 0.258$ mA at $V_{DS} = 3.3$ V. Determine the value of λ and r_o. (b) Using the results of part (a), determine I_D at $V_{DS} = 5$ V.

a)

$$I_D = K_n(V_{GS} - V_{TN})^2(1 + \lambda V_{DS}) \Rightarrow K_n = \frac{I_D}{(V_{GS}-V_{TN})^2(1+\lambda V_{DS})}$$

$$\frac{0.25mA}{\cancel{(V_{GS}-V_{TN})^2}(1+\lambda(1.5))} = \frac{0.258mA}{\cancel{(V_{GS}-V_{TN})^2}(1+\lambda(3.3v))}$$

$$0.25mA(1+\lambda(3.3v)) = 0.258mA(1+\lambda(1.5V))$$

$$0.25mA + \lambda 825\mu = 0.258mA + \lambda(387\mu) \Rightarrow 8\mu = \lambda 438\mu$$

$$\lambda = \frac{8\mu}{438\mu} \Rightarrow \boxed{\lambda = 0.0183\ v^{-1}}$$

$$r_o = \frac{\Delta V}{\Delta I} \Rightarrow \frac{3.3v - 1.5v}{0.258mA - 0.25mA} \Rightarrow \frac{1.8}{8\mu} \Rightarrow \boxed{r_o = 225k\Omega}$$

b)

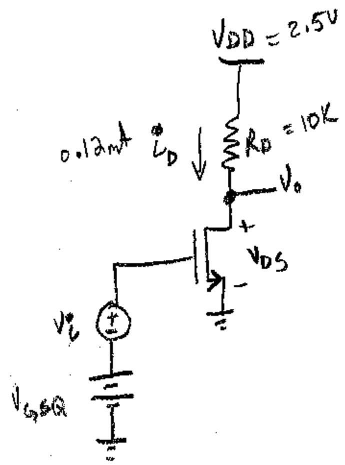
$$0.258mA = K_n(V_{GS} - V_{TN})^2(1 + \lambda V_{DS}) \Rightarrow K_n(V_{GS}-V_{TN})^2 = \frac{0.258mA}{1+3.3(0.0183)}$$

$$\Rightarrow 0.243m = K_n(V_{GS}-V_{TN})^2$$

$$I_D = 0.243m(1+(0.0183)(5)) \Rightarrow \boxed{I_D = 0.2655mA}$$

Problem 4.9

The circuit shown in Figure 4.1 has parameters $V_{DD} = 2.5$ V and $R_D = 10\ \text{k}\Omega$. The transistor is biased at $I_{DQ} = 0.12$ mA. The transistor parameters are $V_{TN} = 0.3$ V, $k_n' = 100\ \mu\text{A/V}^2$, and $\lambda = 0$. (a) Design the W/L ratio of the transistor such that the small-signal voltage gain is $A_\upsilon = -3.8$. (b) Repeat part (a) for $A_\upsilon = -5.0$.



a) $V_o = 2.5V - 0.12mA(10K) \Rightarrow V_o = 1.3V$

$A_V = -3.8 = \frac{V_o}{V_i} \Rightarrow V_i = \frac{1.3}{-3.8} \Rightarrow V_i = -0.342\,V = V_{GS}$

$1.3 \boxed{>} -0.342V - 0.3V$ sat

$0.12mA = \frac{100\mu A}{2}\left(\frac{W}{L}\right)(-0.342 - 0.3V)^2$

$\frac{W}{L} = \frac{0.12mA(2)}{100\mu A(-0.642)^2} \Rightarrow \boxed{\frac{W}{L} = 5.823}$

b) $A_V = -5.0 = \frac{V_o}{V_i} \Rightarrow V_i = \frac{1.3V}{-5} \Rightarrow V_i = -0.26 = V_{GS}$

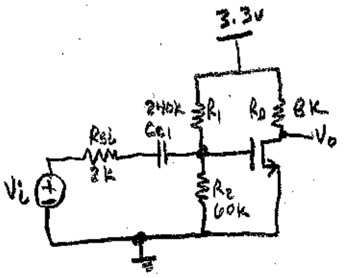
$1.3 \boxed{>} -0.26 - 0.3$ sat

$0.12mA = \frac{100\mu A}{2}\left(\frac{W}{L}\right)(-0.26 - 0.3)^2$

$\frac{W}{L} = \frac{0.12mA(2)}{100\mu A(-0.56)^2} \Rightarrow \boxed{\frac{W}{L} = 7.653}$

Problem 4.13

Consider the circuit in Figure 4.14 in the text. The circuit parameters are $V_{DD} = 3.3$ V, $R_D = 8\ \text{k}\Omega$, $R_1 = 240\ \text{k}\Omega$, $R_2 = 60\ \text{k}\Omega$, and $R_{Si} = 2\ \text{k}\Omega$. The transistor parameters are $V_{TN} = 0.4$ V, $k_n' = 100\ \mu\text{A/V}^2$, $W/L = 80$, and $\lambda = 0.02\ \text{V}^{-1}$. (a) Determine the quiescent values I_{DQ} and V_{DSQ}. (b) Find the small-signal parameters g_m and r_o. (c) Determine the small-signal voltage gain.



a) $V_{GS} = 3.3v\left(\frac{60K}{60K + 240K}\right) \Rightarrow V_{GS} = 0.66V$

Assume sat

$I_{DQ} = \frac{100\mu A}{2}(80)(0.66 - 0.4)^2 \Rightarrow \boxed{I_{DQ} = 270.4\mu A}$

$V_{DS} = 3.3v - 270.4\mu A(8k) \Rightarrow \boxed{V_{DSQ} = 1.1368\ v}$

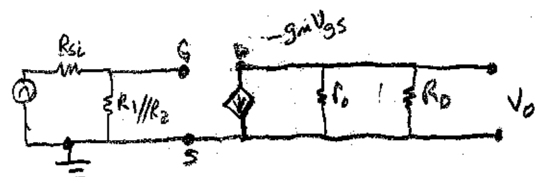
$1.1368v\ \boxed{>}\ 0.66v - 0.4$ Sat ✓

b) $g_m = 2\sqrt{k_n I_{DQ}}$ $k_n = \frac{k'_n}{2}\left(\frac{W}{L}\right) = \frac{100\mu A}{2}(80) = k_n = 4m$

$g_m = 2\sqrt{(4m)(270.4\mu A)} = \boxed{g_m = 2.08\ mA/V}$

$r_o = \frac{1}{\lambda I_{DQ}} \Rightarrow \frac{1}{(0.02)(270.4\mu A)} \Rightarrow \boxed{r_o = 184.911\ K\Omega}$

c)



$V_o = -g_m V_{gs}(R_o // R_D)$ $V_{gs} = V_i\left(\frac{R_1//R_2}{R_{si} + R_1//R_2}\right)$

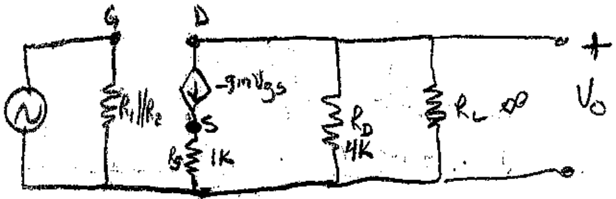
$A_V = \frac{V_o}{V_i} = \frac{-g_m\left(\cancel{V_i}\left(\frac{R_1//R_2}{R_{si} + R_1//R_2}\right)\right)(R_o//R_D)}{\cancel{V_i}} \Rightarrow -g_m\left(\frac{R_1//R_2}{R_{si} + R_1//R_2}\right)(R_o//R_D) = A_V$

$R_1//R_2 = 48K\Omega$ $R_o//R_D = 7.668K\Omega$

$A_V = -2.08mA/V\left(\frac{48K}{2K + 48K}\right)(7.668K\Omega) = \boxed{A_V = -15.312}$

Problem 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).



a) $V_G = 5\left(\frac{175K}{175K + 225K}\right) \Rightarrow V_G = 2.1875$

$I_{DQ} = 1mA\left(2.1875 - I_{DQ}(1K) - 0.8\right)^2$

$\boxed{I_{DQ} = 607.852\mu A}$

$V_{DS} = 5 - (607.852\mu A)(4K) - (607.852\mu A)(1K)$

$\boxed{V_{DSQ} = 1.9607V}$

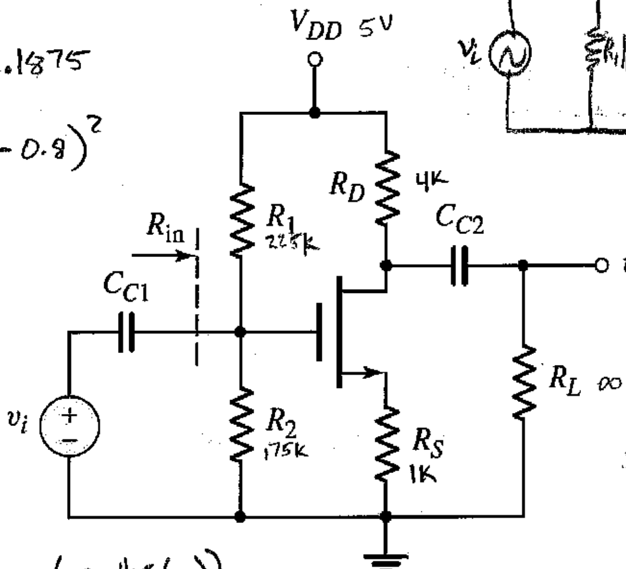


Figure P4.15

b) $V_{gs} = V_G - V_s \Rightarrow V_i - V_s = V_{GS}$

$V_i = V_{GS} - V_S \Rightarrow V_i = V_{GS} - (-g_m V_{gs}(1K))$

$V_i = V_{GS}(1 + g_m(1K))$

$V_o = -g_m V_{gs}(R_D \| R_L)$

$A_V = \frac{V_o}{V_i} = \frac{-g_m(R_D \| R_L)}{1 + g_m(1K)}$

$g_m = 2\sqrt{k_n I_{DQ}} \Rightarrow g_m = 2\sqrt{(1mA)(607.852\mu A)}$

$\boxed{g_m = 1.559m}$

$A_V = \frac{-1.559m(4K \| \infty)}{1 + (1.559m)(1K)} \Rightarrow \boxed{A_V = -2.437}$

c) $0.75(-2.437) = -1.828 = A_V$

$-1.828 = \frac{-g_m(R_D \| R_L)}{1 + g_m(1K)}$

$R_D \| R_L = \frac{-1.828(1 + g_m(1K))}{-g_m}$

$\frac{1}{\frac{1}{R_D} + \frac{1}{R_L}} = \frac{1.828(1 + g_m(1K))}{g_m}$

$\frac{g_m}{1.828(1 + g_m(1K))} - \frac{1}{R_D} = \frac{1}{R_L}$

$R_L = \frac{1}{\frac{1.559m}{1.828(1 + 1.559m(1K))} - \frac{1}{4K}}$

$\boxed{R_L = 12K\Omega}$

Problem 4.19

Consider the ac equivalent circuit shown in Figure P4.18. Assume $r_o = \infty$ for the transistor. The small-signal voltage gain is $A_v = -8$ for the case when $R_S = 1\ \text{k}\Omega$. (a) When R_S is shorted ($R_S = 0$), the magnitude of the voltage gain doubles. Assuming the small-signal transistor parameters do not change, what are the values of g_m and R_D? (b) A new value of R_S is inserted into the circuit and the voltage gain becomes $A_v = -10$. Using the results of part (a), determine the value of R_S.

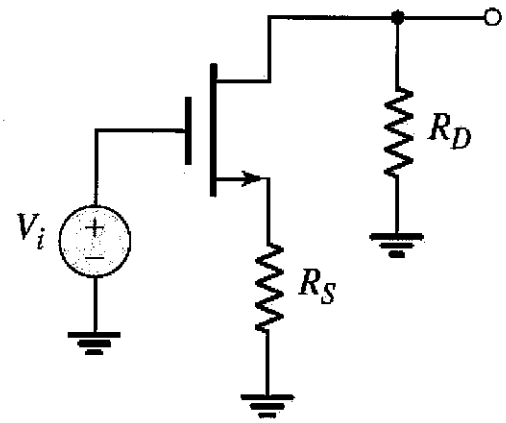
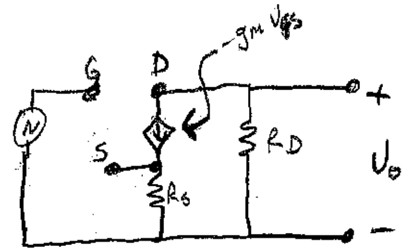


Figure P4.18



a) $A_v = \frac{V_o}{V_i}$

$V_{GS} = V_G - V_S$

$V_{GS} = V_i - (g_m V_{GS})(R_S)$

$V_i = V_{GS} + g_m V_{GS} R_S$

$V_i = V_{GS}(1 + g_m R_S)$

$V_o = -g_m V_{GS} R_D$

$A_{v_1} = \frac{-g_m R_D}{1 + g_m R_S}$

$2A_{v_2} = \frac{-g_m R_D}{1 + g_m(\emptyset)} \Rightarrow A_{v_2} = \frac{-g_m R_D}{2}$

$A_{v_1} = A_{v_2}$

$\frac{-g_m R_D}{1 + g_m R_S} = \frac{-g_m R_D}{2} \Rightarrow \frac{-2g_m \cancel{R_D}}{-g_m \cancel{R_D}} = 1 + g_m R_S$

$2 = 1 + g_m R_S \Rightarrow 1 = g_m R_S \Rightarrow g_m = \frac{1}{1K}$

$\boxed{g_m = 1mA/V}$

$2(-8) = -(1mA)(R_D) \Rightarrow \frac{-16}{-1mA} = \boxed{R_D = 16K\Omega}$

b)

$-10 = \frac{-1mA(16K)}{1 + (1mA)(R_S)} \Rightarrow 1 + 1mA(R_S) = \frac{-1mA(16K)}{-10}$

$R_S = \frac{1.6 - 1}{1mA} \Rightarrow \boxed{R_S = 600\Omega}$