Homework 4, Due Date (Thursday, Feb 21st, 2013, In Class)

Problem 4.25

For the common-source circuit in Figure P4.24, the bias voltages are changed to $V^+ = 3$ V and $V^- = -3$ V. The PMOS transistor parameters are: $V_{TP} = -0.5$ V, $K_p = 0.8$ mA/V^2, and $\lambda = 0$. The load resistor is $R_L = 2$ k Ω. (a) Design the circuit such that $I_{DQ} = 0.25$ mA and $V_{SDQ} = 1.5$ V. (b) Determine the small-signal voltage gain $A_v = v_o/v_i$.

$0.25mA = 0.8mA/V^2(|V_{GS}| - |0.5V|)^2$

$0.25mA = 0.8mA(|0-(3-0.25mA(R_S))| - |-0.5|)^2$

$\boxed{R_S = 7.764k\Omega}$

$V_{RS} = 0.25mA(7.764k) \Rightarrow V_{RS} = 1.941V$

$V_S = 3 - 1.941V \Rightarrow V_S = 1.059V$

$V_{RD} = 6 - 1.941 - 1.5$

$V_{RD} = 2.56V$

$R_D = \frac{2.56V}{0.25mA} = \boxed{10.24k\Omega = R_D}$

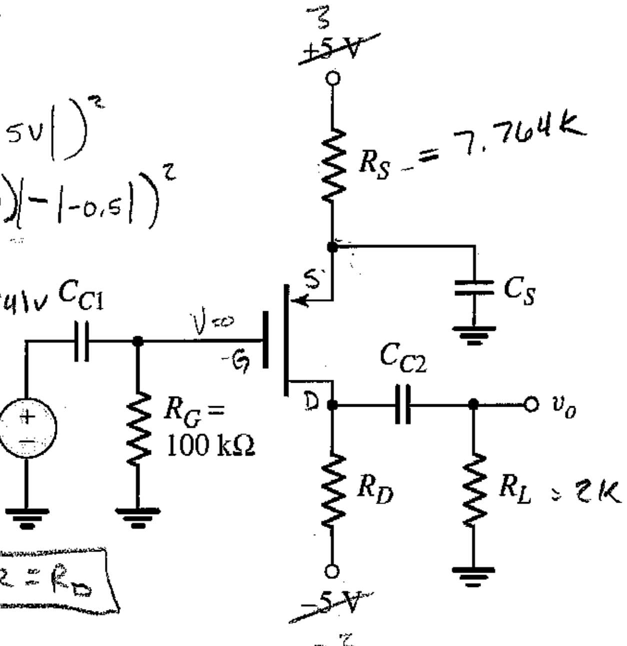
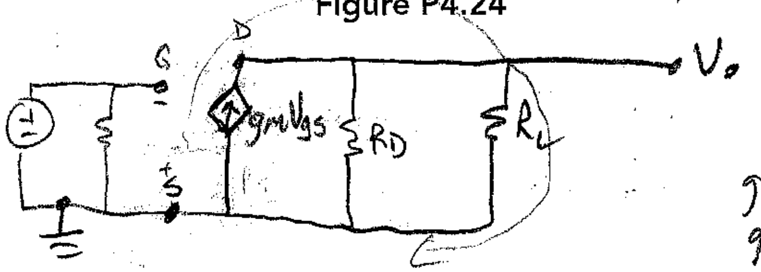


Figure P4.24



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

$g_m = 2\sqrt{0.8mA(0.25mA)} \Rightarrow g_m = 894.427\mu$

$A_V = \frac{V_o}{V_{in}} \Rightarrow$

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

$V_{gs} = V_g - V_s \Rightarrow V_g = V_{gs} + \cancel{V_s}^{0} = V_i$

$A_V = \frac{-g_m \cancel{V_{gs}}(R_D//R_L)}{\cancel{V_{gs}}} \Rightarrow A_V = -g_m(R_D//R_L) = -894.427\mu\left(\frac{1}{\frac{1}{7.764k} + \frac{1}{2k}}\right)$

$\boxed{A_V = -1.422}$

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Problem 4.31

The open-circuit ($RL = \infty$) 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 k Ω, the voltage gain is reduced to $A_v = 0.49$. What are the values of g_m and r_o?

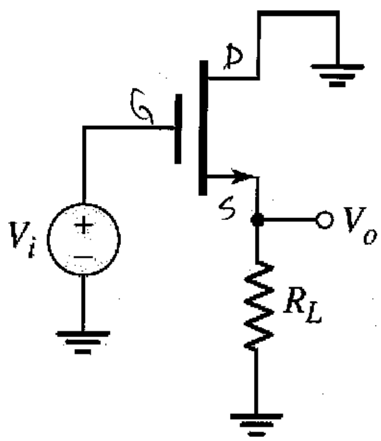
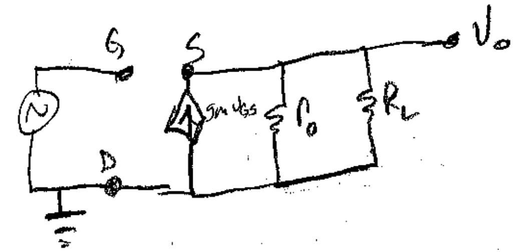


Figure P4.31



$$A_v = \frac{V_o}{V_{in}} \Rightarrow$$

$$V_o = g_m V_{GS}(r_o // R_L)$$

$$V_{GS} = V_G - V_S \Rightarrow V_G = V_{GS} + V_S$$

$$V_{in} = V_G = V_{GS} + V_S \qquad V_S = V_o$$

$$V_{in} = V_{GS} + g_m V_{GS}(r_o//R_L) = V_{GS}(1 + g_m(r_o//R_L))$$

$$A_v = \frac{g_m(r_o//R_L)}{1 + g_m(r_o//R_L)}$$

$A_v = 0.98$, $R_L = \infty$

$$0.98 = \frac{g_m(r_o)}{1 + g_m(r_o)} \Rightarrow 0.98 + 0.98 g_m(r_o) = g_m(r_o)$$

$$0.98 = 0.02 g_m(r_o)$$

$$g_m(r_o) = 49$$

$$g_m = \frac{49}{r_o}$$

$A_v = 0.49$ $\quad R_L = 1K$

$$0.49 = \frac{g_m(r_o // 1K)}{1 + g_m(r_o//1K)}$$

$$0.49 + 0.49 g_m(r_o//1K) = g_m(r_o//1K)$$

$$0.49 = 0.51 g_m(r_o//1K)$$

$$0.49 = 0.51\left(\frac{49}{r_o}\right)\left(\frac{1}{\frac{1}{r_o} + \frac{1}{1K}}\right)$$

$$\frac{0.49 r_o}{(0.51)(49)} = \frac{1}{\frac{1}{r_o} + \frac{1}{1K}} \Rightarrow r_o\left(\frac{1}{r_o} + \frac{1}{1K}\right) = \frac{0.51(49)}{0.49}$$

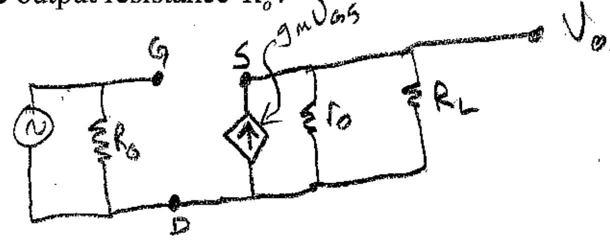
$$1 + \frac{r_o}{1K} = 51 \Rightarrow \frac{r_o}{1K} = 50 \Rightarrow \boxed{r_o = 50k}$$

$$g_m = \frac{49}{r_o} \Rightarrow g_m = \frac{49}{50K}$$

$$\boxed{g_m = 0.98\,mA/V}$$

Problem 4.37

Consider the source follower circuit in Figure P4.37 with transistor parameters $V_{TN} = 0.8$ V, $k_n' = 100\ \mu$A/V^2, $W/L = 20$, and $\lambda = 0.02$ V^{-1}. (a) Let $I_Q = 5$ mA. (i) Determine the small-signal voltage gain. (ii) Find the output resistance R_o. (b) Repeat part (a) for $I_Q = 2$ mA.



$K_n = \frac{K'_n}{2}\left(\frac{W}{L}\right) \Rightarrow K_n = \frac{100\mu A}{2}(20) = 1mA/V^2$

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

$g_m = 2\sqrt{1mA(5mA)}$

$\boxed{g_m = 4.47mA/V}$

$r_o = \frac{1}{\lambda I_{DQ}} = \frac{1}{(0.02)(5mA)}$

$\boxed{r_o = 10K}$

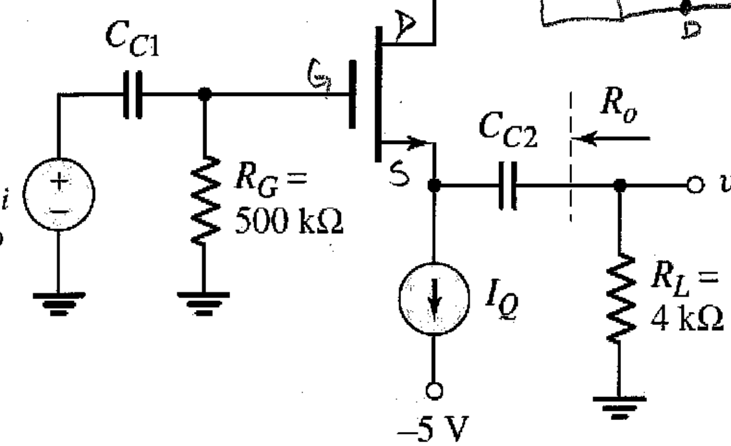


Figure P4.37

$A_v = \frac{V_o}{V_{in}}$

$V_{GS} = V_G - V_S \Rightarrow V_{in} = V_{GS} + V_S$

$V_{in} = V_{GS} + V_o$

$V_o = g_m V_{GS}(r_o // R_L)$

$A_v = \frac{g_m V_{GS}(r_o//R_L)}{V_{GS} + (g_m V_{GS}(r_o//R_L))}$

$A_v = \frac{g_m(r_o//R_L)}{1 + g_m(r_o//R_L)}$

$A_v = \frac{4.47mA\left(\frac{1}{\frac{1}{10K}+\frac{1}{4K}}\right)}{1 + 4.47mA\left(\frac{1}{\frac{1}{10K}+\frac{1}{4K}}\right)}$

$\boxed{A_v = 0.927m}$

$V = IR \Rightarrow \frac{V}{R} = I = V\left(\frac{1}{R}\right)$ (g_m)

$R_o = \left(\frac{1}{g_m} // r_o\right) \Rightarrow \frac{1}{g_m + \frac{1}{r_o}} = \frac{1}{4.47m + \frac{1}{10k}}$

$\boxed{R_o = 218.716\ \Omega}$

b) $g_m = 2\sqrt{1mA(2mA)} \Rightarrow \boxed{g_m = 2.828m}$

$r_o = \frac{1}{(0.02)(2mA)} \Rightarrow \boxed{r_o = 25K\Omega}$

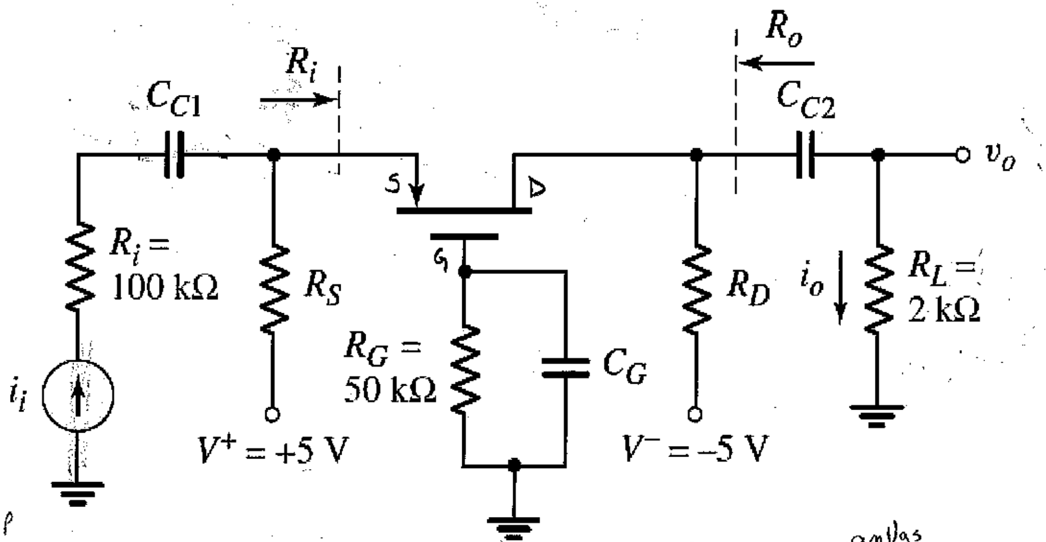
$A_v = \frac{2.828m\left(\frac{1}{\frac{1}{25k}+\frac{1}{4k}}\right)}{1 + 2.828m\left(\frac{1}{25k}+\frac{1}{4k}\right)}$

$\boxed{A_v = 0.907}$

$R_o = \frac{1}{g_m} // r_o \Rightarrow R_o = \frac{1}{(2.828m)(\frac{1}{25k})} \Rightarrow \boxed{R_o = 348.623\ \Omega}$

Problem 4.49

Consider the PMOS common-gate circuit in Figure P4.49. The transistor parameters are: $V_{TP} = -1$V, $K_p = 0.5$ mA/V^2, and $\lambda = 0$. (a) Determine R_S and R_D such that $I_{DQ} = 0.75$ mA and $V_{SDQ} = 6$ V. (b) Determine the input impedance R_i and the output impedance R_o. (c) Determine the load current i_o and the output voltage v_o, if $i_i = 5 \sin \omega t$ μA.



$V_{DS} \square V_{GS} - V_{TP}$

Figure P4.49

$0.75\text{mA} = 0.5\,\text{mA/V}^2 \left(|V_{GS}| - |-1|\right)^2$

$V_{GS} = \sqrt{\frac{0.75\text{mA}}{0.5\text{mA}}} + 1 \Rightarrow V_{GS} = -2.225\text{V}$

$V_{GS} = \cancel{V_G}^{\,0} - V_S \qquad V_S = -V_{GS} = 2.225\text{V}$

$R_S = \frac{5 - 2.225\text{V}}{0.75\text{mA}} \Rightarrow \boxed{R_S = 3.7\text{k}\Omega}$

$V_{DS} = V_D - V_S$

$-6 + V_S = V_D = 2.225 - 6 = V_D = -3.775\text{V}$

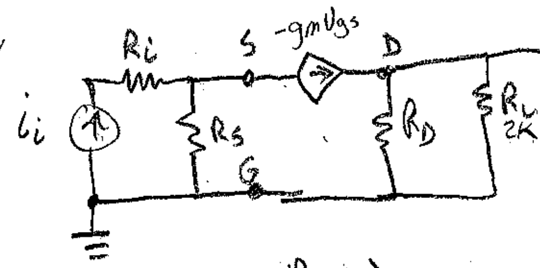
$R_D = \frac{-3.775 - (-5)}{0.75\text{mA}} \Rightarrow \boxed{R_D = 1.633\text{k}\Omega}$

$g_m = 2\sqrt{K_p I_{DQ}} = 2\sqrt{0.5\text{mA}(0.75\text{mA})} \Rightarrow g_m = 1.225\text{m}$

for open Gate circuits

$R_i = \frac{1}{g_m} \Rightarrow \boxed{R_i = 816.5\,\Omega}$

$R_o = R_D \Rightarrow \boxed{R_o = 1.633\text{K}}$



$-g_m V_{gs}\left(\frac{R_D}{R_D + R_L}\right)$

$i_i = \frac{V_S - V_G}{R_S} + (-g_m V_{GS})$

$i_i = \frac{V_{SG}}{R_S} + g_m V_{SG}$

$i_i = V_{SG}\left(\frac{1}{R_S} + g_m\right)$

$V_{SG} = \frac{i_i}{\frac{1}{R_S} + g_m} = -V_{GS}$

Current Divider

$-g_m\left(\frac{-i_i}{\frac{1}{R_S} + g_m}\right)\left(\frac{R_D}{R_D + R_L}\right) = i_o$

$i_o = 1.225\text{m}\left(\frac{5\sin(wt)\,\mu\text{A}}{\frac{1}{3.7\text{k}} + 1.225\text{m}}\right)\left(\frac{1.633\text{k}}{1.633\text{k} + 2\text{k}}\right)$

$\boxed{i_o = 1.84\sin(wt)\,\mu\text{A}}$

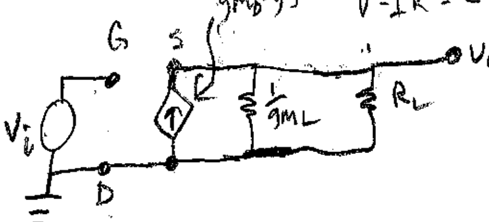
$V_o = 1.84\sin(wt)(2\text{K}) \Rightarrow \boxed{V_o = 3.68\sin(wt)\,\text{mV}}$

Problem 4.57

A source-follower circuit with a saturated load is shown in Figure P4.57. The transistor parameters are $V_{TND} = 1$ V, $K_{nD} = 1$ mA/V^2 for M_D, and $V_{TNL} = 1$ V, $K_{nL} = 0.1$ mA/V^2 for M_L. Assume $\lambda = 0$ for both transistors. Let $V_{DD} = 9$ V. (a) Determine V_{GG} such that the quiescent value of v_{DSL} is 4 V. (b) Show that the small-signal open-circuit ($R_L = \infty$) voltage gain about this Q-point is given by $A_v = 1/[1 + \sqrt{(K_{nl}/K_{nD})}]$. (c) Calculate the small-signal voltage gain for $R_L = 4$ k Ω.

$R = g_m$

$V = IR \Rightarrow I = \frac{V}{R} = V(\frac{1}{R}) \Rightarrow I = V(\frac{1}{g_m})$



a)

$V_{GSD} = V_{GG} - V_{DSL}$ $\quad V_{GSL} = V_{DSL}$

$K_{nD}(V_{GSD} - V_{TND})^2 = K_{nL}(V_{GSL} - V_{TNL})^2$

$K_{nD}(V_{GG} - V_{DSL} - V_{TND})^2 = K_{nL}(V_{DSL} - V_{TNL})^2$

$1\frac{mA}{V^2}(V_{GG} - 4 - 1)^2 = 0.1\frac{mA}{V^2}(4-1)^2$

$\frac{0.1mA(9V)}{1mA} = (V_{GS} - 5)^2$

$V_{GG} = \sqrt{\frac{.9mA}{1mA}} + 5$

$\boxed{V_{GG} = 5.949V}$

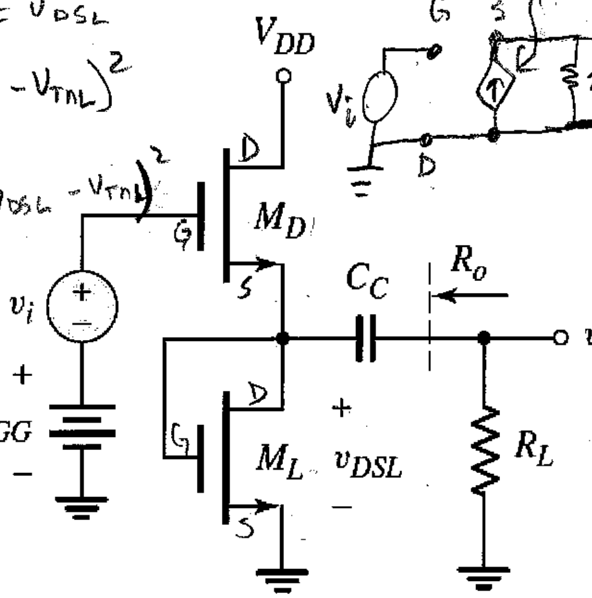


Figure P4.57

b) $A_v = \frac{V_o}{V_{in}}$

$V_o = g_{mD}V_{gs}(\frac{1}{g_{mL}})$

$V_{gs} = V_G - V_S \Rightarrow V_S = V_o$

$V_i = V_G = V_{gs} + V_o$

$V_{in} = V_{gs} + (g_{mD}V_{gs}(\frac{1}{g_{mL}}))$

$V_{in} = V_{gs}(1 + \frac{g_{mD}}{g_{mL}})$

$\boxed{A_v = \frac{(\frac{g_{mD}}{g_{mL}})}{1 + (\frac{g_{mD}}{g_{mL}})}}$

$g_{mD} = 2\sqrt{K_{nD}I_{DQ}}$

$g_{mL} = 2\sqrt{K_{nL}I_{DQ}}$

$\frac{g_{mD}}{g_{mL}} = \frac{\cancel{2}\sqrt{K_{nD}I_{DQ}}}{\cancel{2}\sqrt{K_{nL}I_{DQ}}}$

$\frac{g_{mD}}{g_{mL}} = \sqrt{\frac{K_{nD}\cancel{I_{DQ}}}{K_{nL}\cancel{I_{DQ}}}}$

$\frac{g_{mD}}{g_{mL}} = \sqrt{\frac{K_{nD}}{K_{nL}}}$

$A_v = \frac{\sqrt{\frac{K_{nD}}{K_{nL}}}}{1 + \sqrt{\frac{K_{nD}}{K_{nL}}}} \left(\frac{\frac{1}{\sqrt{\frac{K_{nD}}{K_{nL}}}}}{\frac{1}{\sqrt{\frac{K_{nD}}{K_{nL}}}}} \right)$

$\boxed{A_v = \frac{1}{\frac{1}{\sqrt{\frac{K_{nD}}{K_{nL}}}} + 1}}$

c) $V_o = g_{mD}V_{gs}(\frac{1}{g_{mL}} \| R_L)$

$V_{gs} = V_g - V_s$

$V_G = V_{gs} + V_s \quad V_s = V_o, \; V_G = V_{in}$

$V_{in} = V_{gs} + V_o$

$A_v = \frac{V_o}{V_{in}} = \frac{g_{mD}(\frac{1}{g_{mL}} \| R_L)}{1 + g_{mD}(\frac{1}{g_{mL}} \| R_L)}$

$I_D = K_{nL}(V_{GSL} - V_{TNL})^2 = K_{nL}(V_{DSL} - V_{TNL})^2$

$I_D = 0.1mA(4-1)^2 \Rightarrow I_D = 0.9mA$

$g_{mL} = 2\sqrt{0.1mA(0.9mA)} \Rightarrow g_{mL} = 600\mu$

$g_{mD} = 2\sqrt{1mA(0.9mA)} \Rightarrow g_{mD} = 1.897m$

$A_v = \frac{1.897m(\frac{1}{600\mu} \| 4k)}{1 + 1.897m(\frac{1}{600\mu} \| 4k)} = \frac{2.232}{3.232}$

$\boxed{A_v = 690.61m}$

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