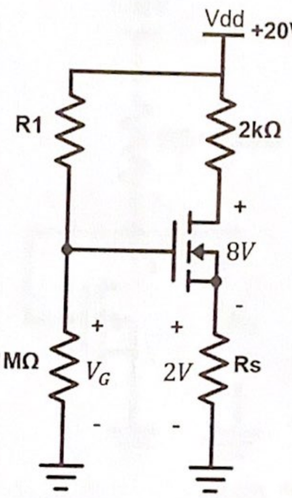
Part 2 (Graded):

Q1. Problem 11.29

The transistor in the figure below has $KP = 50\mu A/V^2$, $W = 600\mu m$, $L = 20\mu m$, and $V_{to} = 1V$. Determine the values of R_1 and R_s.



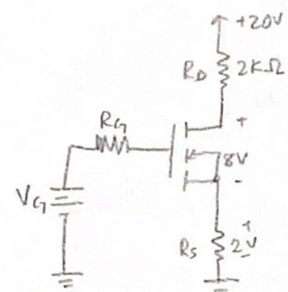
Device Constant

$K = \frac{W}{L}\frac{KP}{2}$

$K = \left(\frac{600\times10^{-6}}{20\times10^{-6}}\right)\frac{50}{2}\times10^{-6}$

$K = 0.75 \frac{mA}{V^2}$

Redraw Circuit ($R_G = R_1 || 1M\Omega$)



$V_G = V_{DD}\left[\frac{10^6}{R_1+10^6}\right]$

$V_{DD} = I_{DQ}R_D + 8 + 2$ (Q: Quiescent)

$20 = 2000 I_{DQ} + 10$

$I_{DQ} = 5mA$

$R_s = \frac{V_s}{I_{DQ}} =$

$R_s = \frac{2}{5\times10^{-3}}$

$\boxed{R_s = 400\Omega}$

We want to bias the transistor in saturation region.

$I_{DQ} = K(V_{GSQ} - V_{to})^2$

$5\times10^{-3} = 0.75\times10^3 (V_{GSQ} - 1)^2$

$V_{GSQ}^2 - 2V_{GSQ} - 5.67 = 0$

$V_{GSQ} = 3.582V$, $V_{GSQ} = -1.582V$

For saturation, $V_{GSQ} > V_{to}$: $V_{GS} = 3.582V$

$V_G = V_{GSQ} + R_s I_{DQ}$

$V_G = 3.582 + 400(0.005)$

$V_G = 5.582\,V$

$V_G = V_{DD}\left[\frac{10^6}{R_1+10^6}\right]$

$5.582 = 20\left[\frac{10^6}{R_1+10^6}\right]$

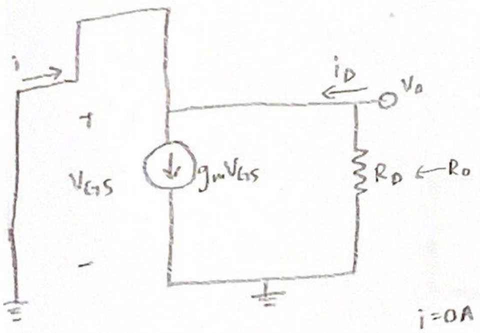
$\boxed{R_1 = 2.618\times10^6\Omega}$

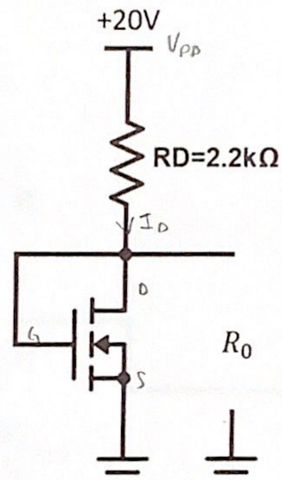
$\boxed{\begin{array}{l} R_s = 400\Omega \\ R_1 = 2.618\times10^6\Omega \end{array}}$

Q2. Problem 11.53

Find V_{DSQ} and I_{DQ} for the FET shown in the figure below, given $V_{t0} = 3V$ and $K = 0.5mA/V^2$. Find the value of g_m at the operating point. Draw the small-signal equivalent circuit, assuming that $r_d = \infty$. Derive an expression for the resistance R_0 in terms of R_D and g_m. Evaluate the expression for the values given.

Small-signal Equivalent Circuit





G and S are both shorted.

$V_{DS} = V_{GS}$

At quiescent point:

$V_{DS} = V_{DSQ}$, $V_{GS} = V_{GSQ}$, $I_D = I_{DQ}$

$V_{DSQ} = V_{GS}$, $V_{DSQ} = V_{GSQ}$

$V_{DSQ} = V_{DD} - R_D I_{DQ}$

$I_{DQ} = \frac{V_{DD} - V_{DSQ}}{R_D}$

Saturation: $V_{DS} \geq V_{GS} - V_{to}$

- This is true, since $V_{DS} = V_{GS}$

↳ Transistor in saturation!

$I_{DQ} = K(V_{GS} - V_{to})^2$

$I_{DQ} = K(V_{DSQ} - 3)^2$

Combining equations for I_{DQ}:

$\frac{V_{DD} - V_{DSQ}}{R_D} = K(V_{DSQ} - 3)^2$

$\frac{20 - V_{DSQ}}{2200} = 0.0005(V_{DSQ} - 3)^2$

$\boxed{V_{DSQ} = 6.616V}$

$V_{DSQ} = -1.5252V$

(must be positive)

$I_{DQ} = K(V_{DSQ} - 3)^2$

$I_{DQ} = 0.0005(6.616 - 3)^2$

$\boxed{I_{DQ} = 6.54\ mA}$

$I_{DQ} = K(V_{DSQ} - V_{to})^2$

$g_m = \frac{\partial I_D}{\partial V_{GS}}$

$g_m = 2K(V_{GSQ} - V_{to})$

$g_m = 0.001(6.616 - 3)$

$\boxed{g_m = 3.616 \frac{mA}{V}}$

Looking at equivalent circuit

$V_o = V_{gs}$

$i_D = g_m V_{gs} + \frac{V_o}{R_D}$

$R_o = \frac{V_o}{i_D}$

$R_o = \frac{V_o}{g_m V_{gs} + \frac{V_o}{R_D}} = \frac{V_{gs}}{g_m V_{gs} + \frac{V_o}{R_D}}$

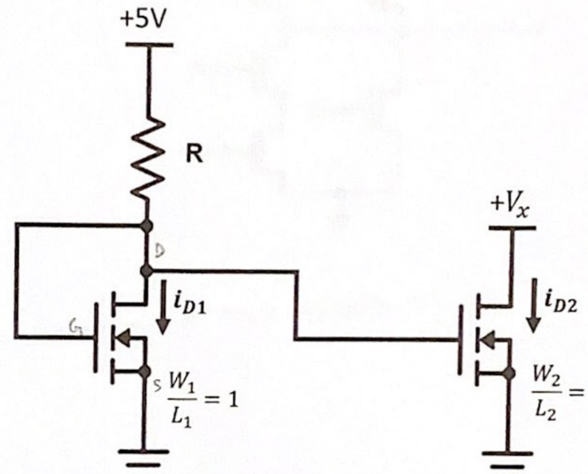
$\boxed{R_o = \frac{1}{g_m + \frac{1}{R_D}}}$

$R_o = \frac{1}{3.616 \times 10^{-3} + (2200)^{-1}}$

$\boxed{R_o = 245\Omega}$

Q3. Problem 11.35

Both transistors shown in the figure below have $KP = 100\mu A/V^2$ and $V_{t0} = 0.5V$. Determine the value of R needed so that $i_{D1} = 0.2mA$. For what range of V_x is the second transistor operating in the saturation region? What is the resulting value of i_{D2}? Provided that V_x is large enough so that the second transistor operates in saturation, to what ideal circuit element is the transistor equivalent?



$V_{GD_1} = 0V \rightarrow$ Transistor #1 in saturation

$K_1 = \frac{1}{2} KP \left(\frac{W_1}{L_1}\right)$

$K_1 = \frac{1}{2} (100 \times 10^{-6})$

$K_1 = 50 \times 10^{-6} A/V^2$

$I_{D_1} = K_1 (V_{GSQ} - V_{to})^2$

$0.2 \times 10^{-3} = 50 \times 10^{-6} (V_{GSQ} - 0.5)^2$

$V_{GSQ} = -1.5V$, $V_{GSQ} = 2.5V$

In saturation, must be positive

$V_{GSQ} = 2.5V$

$R = \frac{V_{DD} - V_{GSQ}}{i_{D_1}}$

$R = \frac{5 - 2.5}{0.2 \times 10^{-3}}$

$\boxed{R = 12,500\Omega}$

Transistor #2

$K_2 = \frac{1}{2} KP \left(\frac{W_2}{L_2}\right)$

$K_2 = \frac{1}{2} (100 \times 10^{-6})$

$K_2 = 50 \times 10^{-6} A/V^2$

$i_{D2} = K_2 (V_{GSQ} - V_{to})^2$

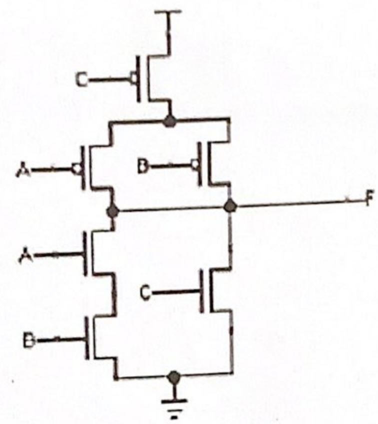
$i_{D2} = 50 \times 10^{-6} (2.5 - 0.5)^2$

[V_{GSQ} is same in both transistors because they share the same KP and V_{to}]

$\boxed{i_{D2} = 0.4\,mA}$

As long as $V_x > 2V$, then transistor #2 will be in saturation. This allows i_{D2} to be constant at 0.4mA. Thus, i_{D2} essentially behaves as a 0.4 mA current source.

Q4. Analyze the CMOS circuit below (triode region equivalent) and fill out the "truth table" for it.



This CMOS circuit is equivalent to the logic equation

$F = \overline{AB + C}$

$F = \neg[(A \wedge B) \vee C]$

A	B	C	F
0	0	0	1
0	0	1	0
0	1	0	1
0	1	1	0
1	0	0	1
1	0	1	0
1	1	0	0
1	1	1	0