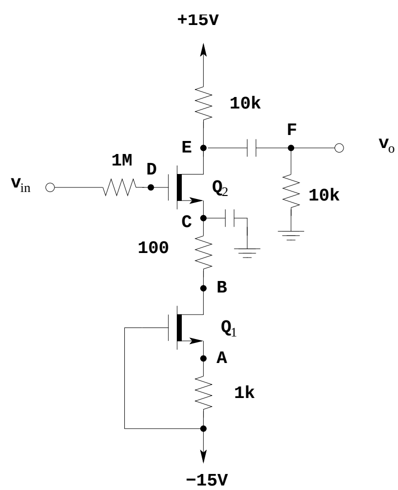
EE 321 - Exam 3

April 18, 1989

Name: ____

Closed book. One page of notes and a calculator are allowed. Show all work. Partial credit will be given. No credit will be given if an answer appears with no supporting work.

1. Consider the following circuit:



The MOSFET's are matched, and $k_n'(W/L) = 2$ mA/V^2, and $V_t = -2$ V. Ignore the output resistance r_o, and assume all capacitors are large (all AC signals are passed through, all DC signals are blocked).

(a) Find I_{D_1}, the drain current through Q_1.

(b) What are the bias voltages V_A, V_B, V_C, V_D, V_E and V_F?

(c) Draw the small-signal equivalent circuit for the amplifier.

(d) What is g_{m_2}, the transconductance of Q_2?

(e) What is the input resistance?

(f) What is the voltage gain v_o/v_i?

(a) $I_{D_1} = \frac{1}{2} k_n'\left(\frac{W}{L}\right)(V_{GS_1} - V_{t_1})^2$ (assuming sat.)

and $I_{D_1} = (V_A - (-15V))/1k$

$V_{GS_1} = V_{G_1} - V_{S_1} = -15V - V_A$

$\therefore \frac{1}{2} k_n'\left(\frac{W}{L}\right)(-15V - V_A - (-2V))^2 = (V_A - (-15V))/1k$

$\frac{1}{2}(2\,mA/V^2)(-13V - V_A)^2 = (V_A + 15V)/1k$

Multiply through by 1k

$1\,V^{-1}(-13V - V_A)^2 = (V_A + 15V)$

$169 + 26V_A + V_A^2 = V_A + 15$

$V_A^2 + 25V_A + 154 = 0$

$$V_A = \frac{-25 \pm \sqrt{(25)^2 - 4(154)}}{2} = \frac{-25 \pm 3}{2} = -11, -14$$

If $V_A = -11V$, then $V_{GS_1} = V_{G_1} - V_A = -15 - (-11) = -4V$.

$V_{GS_1} < V_{t_1}$, so Q is off - cannot be

If $V_A = -14V$, then $V_{GS_1} = V_{G_1} - V_A = -15 - (-14) = -1V$

$V_{GS_1} > V_{t_1}$, so Q on - correct

$\therefore V_A = -14V$

$$I_{D_1} = \frac{V_A - (-15V)}{1k} = \frac{-14V + 15V}{1k} = 1mA$$

$I_{D_1} = 1mA$

(b) $V_A = -14V$ (from (a))

$V_D = 0V$ (cap open for DC)

$V_F = 0V$ (")

$I_{D_2} = I_{D_1} \Rightarrow V_{GS_2} = V_{GS_1} = -1V$

$V_{GS_2} = V_D - V_C \Rightarrow V_C = V_D - V_{GS_2} = 0 - (-1V) = 1V$

$\therefore V_C = +1V$

$$\frac{V_C - V_B}{100} = I_D = 1mA$$

$V_B = V_C - I_D(100) = 1V - (1mA)(100\Omega) = 0.9V$

$$\frac{15V - V_E}{10k} = I_D$$

$V_E = 15V - I_D(10k) = 15V - (1mA)(10k) = 5V$

$V_A = -14V$

$V_B = 0.9V$

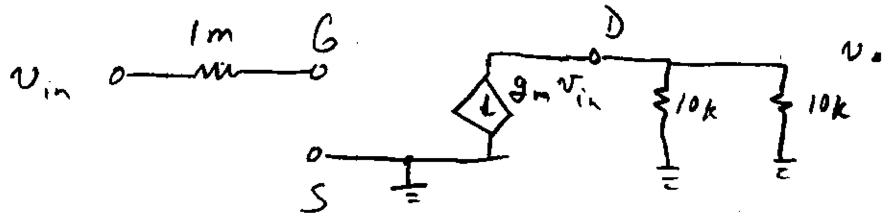
$V_C = 1V$

$V_D = 0V$

$V_E = 5V$

$V_F = 0V$

(c)



(d) $g_m = \frac{I_D}{(V_{GS_2} - V_{t_2})/2} = \frac{1\,mA}{(-1V - (-2V))/2} = 2\,mA/V$

(e) No current flows into gate, so $R_{in} = \infty$

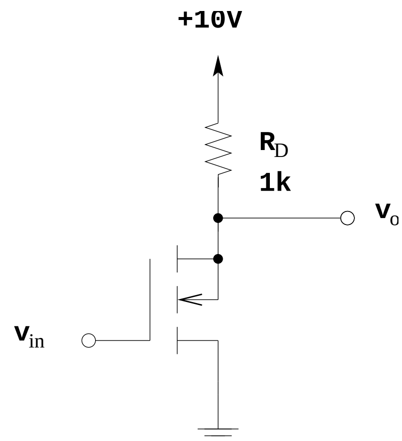
(f) From small signal model

$$v_o = -g_m v_{in} (10k \parallel 10k)$$

$$\frac{v_o}{v_i} = -g_m (5k) = -(2mA/V)(5k) = -10$$

2. For the following problem it is known that $V_t = 2$ V for the NMOS FET, but $k_n'(W/l)$ is not known.

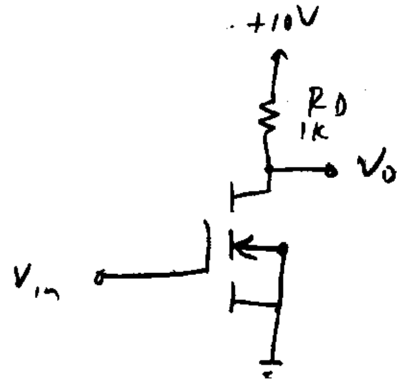
   (a) Your lab partner builds the following circuit using the MOSFET, but the circuit fails to function. What mistake has been made, and how would you correct it?



   (b) After making the correction, you find that $V_o = 6$ V when $V_{in} = 4$V. Determine $k_n'(W/L)$ for the MOSFET.

   (c) The MOSFET is next used as a switch by changing R_D from 1 kΩ to 100 kΩ. Find V_D when $v_{in} = 0$ V, and and when $v_{in} = 4$ V.

(a) Need to connect body to source, not drain



← Fixed

(b) $V_{in} = 4V \Rightarrow V_{GS} = 4V$

$V_o = 6V \Rightarrow I_D = \frac{10V - 6V}{1k} = 4mA$

$V_{DS} = V_o = 6V$

$V_{DS} > V_{GS} - V_t$ so Q in saturation

$$I_D = \frac{1}{2} k_n' \left(\frac{W}{L}\right) (V_{GS} - V_t)^2$$

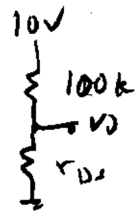
$$4mA = \frac{1}{2} k_n' \left(\frac{W}{L}\right) (4 - 2)^2$$

$$k_n' \left(\frac{W}{L}\right) = 2 mA/V^2$$

(c) $V_{in} = 0 \Rightarrow V_{GS} = 0 \Rightarrow$ Q off $\Rightarrow I_D \approx 0 \Rightarrow V_o = 10V$

$V_{in} = 4V \Rightarrow V_{GS} > V_t$; Q will be in triode

Q will act like a resistor



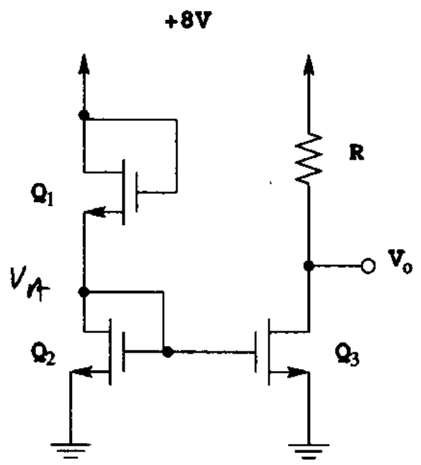
$$V_o = \frac{r_{DS}}{10k + r_{DS}} 10V$$

$$r_{DS} = \frac{1}{k_n' \left(\frac{W}{L}\right)(V_{GS} - V_t)} = \frac{1}{(2mA/V^2)(4V - 2V)}$$

$$= 250\Omega$$

$$V_o = \frac{250\Omega}{10k + 250} 10V = 0.24V$$

3. For the MOSFETs in the circuit below $k_n'(W/L) = 5\ \mu A/V2$, and $V_t = 2$ V. Select R to obtain $V_o = 6$ V. Neglect the effect of r_o.



$Q_1 + Q_2$ identical

$I_{D_1} = I_{D_2} \Rightarrow V_{GS_1} = V_{GS_2} \Rightarrow 8 - V_A = V_A \Rightarrow V_A = 4V$

$I_{D_1} = \frac{1}{2} k_n' \left(\frac{W}{L}\right) (V_{GS_1} - V_{t_1}) = \frac{1}{2} (5 \mu A/V^2)(4v - 2v)^2$

$= 20 \mu A$

Q_3 and Q_2 identical, and $V_{GS_3} = V_{GS_2}$, so

$I_{D_3} = I_{D_2} = I_{D_1} = 20\ \mu A$

$I_{D_3} = \frac{8V - V_o}{R} \Rightarrow R = \frac{8V - V_o}{I_{D_3}} = \frac{8V - 6V}{20 \mu A} = 100\ k\Omega$