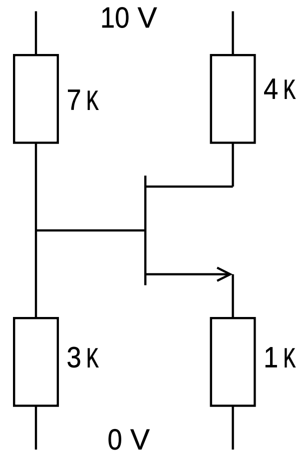
EE 321 Analog Electronics, Fall 2012
Exam 3 November 30, 2012
solution

This is a closed-book exam. Calculators allowed. The exam is designed for conceptual understanding not long derivations. You MUST box your answer. When there are multiples values in an answer summarize them in a single box. Correct answer boxed and derivation gives you 10 points. Either is 5 points. Neither is 0 points.

1. Find i_D, v_D, v_S, and v_G for this circuit, with $V_t = 1\,\text{V}$, and $k_n' \frac{W}{L} = 1\,\text{mA/V}^2$



$v_G = 3V$. GUESS SATURATION.

$i_D = \frac{1}{2}(v_{GS} - V_t)^2 = \frac{1}{2}(v_G - V_t - i_D R_S)^2$

$2i_D = (v_G - V_t)^2 + i_D^2 R_S^2 - 2 i_D R_S (v_G - V_t)$

$2i_D = 4 + i_D^2 - 4 i_D$ $\qquad i_D^2 - 6 i_D + 4 = 0$

$i_D = \frac{6 \pm \sqrt{20}}{2} = 0.76$ OR $5.23mA$

MUST BE FIRST. THEN

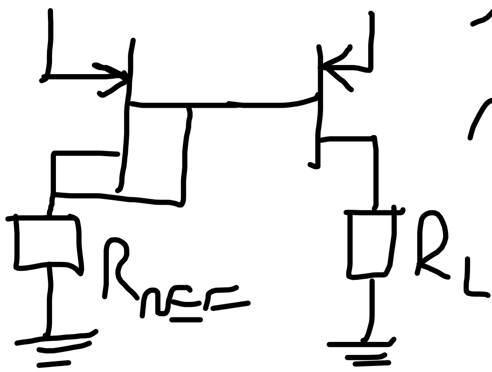
$\boxed{v_S = 0.76V \quad v_G = 3V \quad v_D = 6.94V \quad i_D = 0.76mA}$

2. Replace the $4\,\text{k}\Omega$ with a $10\,\text{k}\Omega$ and find the same quantities.

GUESS SATURATION MODE. THEN i_D IS THE SAME, AND $v_D = V_{DD} - i_D R_D = 10 - 0.76 \cdot 10 = 2.4V$. v_G IS ALSO THE SAME, SO WE FIND THAT $v_{DS} > v_{GS} - V_t$ WHICH VERIFIES SATURATION MODE.

$\boxed{v_S = 0.76V \quad v_G = 3V \quad v_D = 2.4V \quad i_D = 0.76mA}$

3. Make a MOSFET current mirror which provides 1 mA to a load connected between ground and the current mirror output. Assume $V_t = 1\,\text{V}$, and $k_p' \frac{W}{L} = 1\,\text{mA/V}^2$, and 10 V supplies.



$i_D = \frac{1}{2}(v_{SG} - V_t)^2$

$v_{SG} = \sqrt{2 i_D} + V_t = 2.41\,V$

$R_{REF} = \frac{10\,V - v_{SG}}{i_D} = 7.5\,k\Omega$

$\boxed{\Rightarrow 7.58\,k\Omega}$

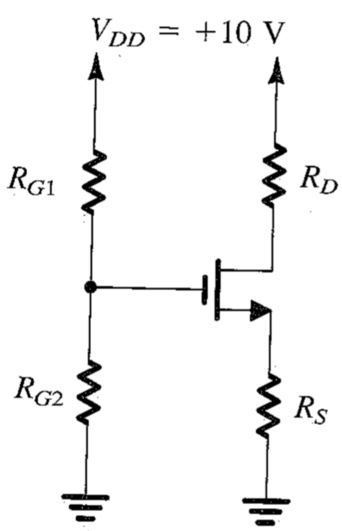
4. For the current mirror in the previous circuit what is the largest value of the load resistor that will maintain saturation mode operation of the MOSFETs?

MAX VOLTAGE IS $10V - (v_{SG} - V_t) = 10V - 1.41V = 8.59V$

MAX RESISTANCE

$\boxed{R_{LMAX} = 8.59\,k\Omega}$

5. Pick resistors in this circuit such that a CS amplifier is implemented (not a CS with R_S) which has (a) output biased at 5 V, (b) $A_{vo} = -10$, (c) smallest gate resistor of 1 MΩ. Assume $k_n' \frac{W}{L} = 1\,\frac{\text{mA}}{\text{V}^2}$ and $V_t = 1\,\text{V}$.



$R_S = 0 \quad A_{vo} = -\frac{2 I_D R_D}{V_{GS} - V_t}$

$I_D R_D = 5V \Rightarrow V_{GS} = -\frac{2 I_D R_D}{A_{vo}} + V_t = \frac{10}{-10} + 1$

$= 2V$

$\Rightarrow R_{G2} = 1M\Omega,\ R_{G1} = 5M\Omega$

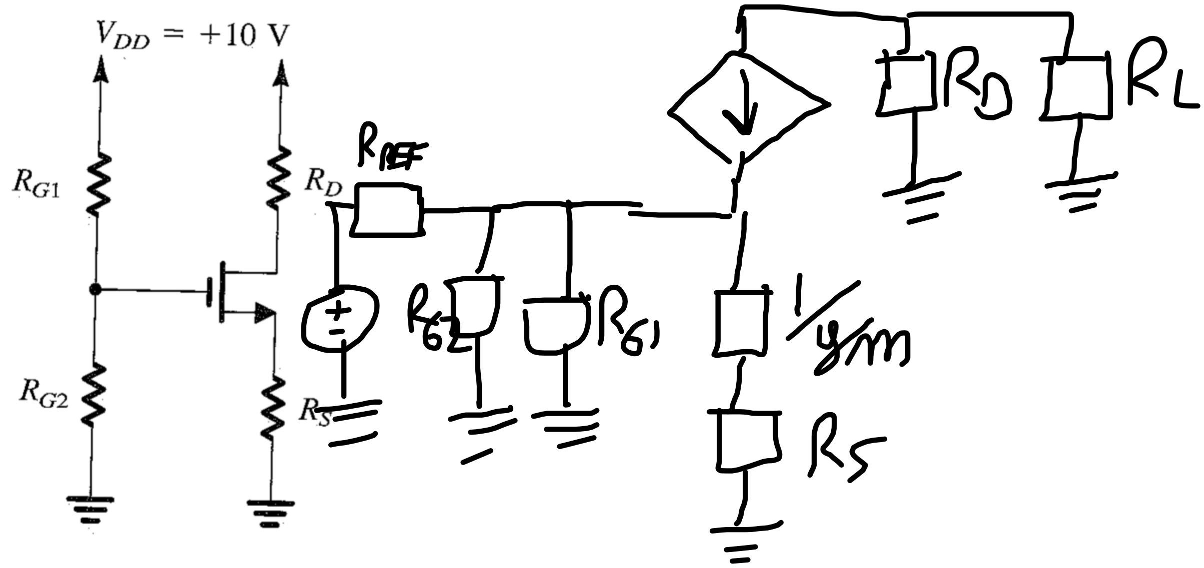
$I_D = \frac{1}{2}(V_{GS} - V_t)^2$

$= 0.5\,mA$

$\Rightarrow R_D = 10\,k\Omega$

$\boxed{\begin{array}{l} R_S = 0 \\ R_D = 10\,k\Omega \\ R_{G1} = 5M\Omega \\ R_{G2} = 1M\Omega \end{array}}$

6. Draw the small-signal model for this amplifier, adding also a source (with R_{src}) and a load (R_L).



7. If $R_{G1} = 200\,\text{k}\Omega$, $R_{G2} = 800\,\text{k}\Omega$, $R_S = 1\,\text{k}\Omega$, $R_D = 5\,\text{k}\Omega$, $V_t = 1\,\text{V}$, $k_n'\frac{W}{L} = 1\,\text{mA/V}^2$, $R_{\text{src}} = 100\,\text{k}\Omega$, and $R_L = 3\,\text{k}\Omega$, what are A_{vo}, A_v, G_v, R_{in}, and R_{out}?

$$I_D = \frac{1}{2}(V_G - V_t - I_D R_S)^2$$

$$g_m = \frac{2I_D}{V_{GS} - V_t} = \frac{2 \cdot 0.27}{1} = 0.54 \cdot 10^{-3}\,\Omega^{-1}$$

$$2I_D = (V_G - V_t)^2 + I_D^2 R_S^2 - 2 I_D R_S (V_G - V_t)$$

$$2I_D = 1 + I_D^2 - 2I_D$$

$$I_D^2 - 4I_D + 1 = 0 \qquad I_D = \frac{4 \pm \sqrt{16-4}}{2} = \underline{0.27\,\text{mA}} \text{ OR } 3.73\,\text{mA}$$

$$\boxed{\begin{aligned} A_{vo} &= -27 \\ A_v &= -1.0 \\ G_{vo} &= -1.66 \\ G_v &= -0.62 \end{aligned}}$$

$$A_{vo} = -g_m R_D = -2.7$$

$$A_v = -g_m (R_D \| R_L) = -1.0$$

$$G_v = \frac{R_{G1} \| R_{G2}}{R_{src} + R_{G1} \| R_{G2}} A_v = \frac{160}{100+160}(-1.0) = -0.62$$

$$G_{vo} = \frac{R_{G1} \| R_{G2}}{R_{src} + R_{G1} \| R_{G2}} = -1.66$$

$$R_{IN} = R_{G1} \| R_{G2} = 160\,\text{k}\Omega$$

$$R_{OUT} = R_D = 5\,\text{k}\Omega$$

IF WE DO THE SIMPLE APPROXIMATION: $A_{vo} = -\frac{R_D}{R_S} = -5$, $A_v = -\frac{5 \| 3}{1} = -1.88$

$$G_{vo} = A_{vo} \frac{R_{IN}}{R_{IN} + R_{SRC}} = -3.1 \qquad G_v = -1.16$$

$$\boxed{\begin{aligned} A_{vo} &= -5 & G_{vo} &= -3.1 \\ A_v &= -1.88 & G_v &= -1.16 \end{aligned}}$$