ECE 422 Fall 2008

Test 1 (10/28/08)

Total # Pages 6 **Total # Problems 5**

Attach your one page of notes to this test

Name SOLUTION

1.	**(20 points)**	________
2.	**(25 points)**	________
3.	**(30 points)**	________
4.	**(10 points)**	________
5.	**(15 points)**	________
Total	**(100 points)**	________

GOOD LUCK

Note: All bulk connections that are not shown are tied to the appropriate supply voltage.

$$I_d = \begin{cases} k'\frac{W}{L}\left[(V_{gs}-V_T)V_{ds}-\frac{V_{ds}^2}{2}\right](1+\lambda V_{ds}) & V_{gs}\ge V_T, V_{ds}\le V_{gs}-V_T, \text{linear} \\ \frac{k'}{2}\frac{W}{L}(V_{gs}-V_T)^2(1+\lambda V_{ds}) & V_{gs}\ge V_T, V_{ds}\ge V_{gs}-V_T, \text{saturation} \\ 0 & V_{gs}<V_T, \quad \text{cutoff} \end{cases}$$

$$V_T = V_{To} + \gamma\left(\sqrt{V_{sb}+\varphi}-\sqrt{\varphi}\right)$$

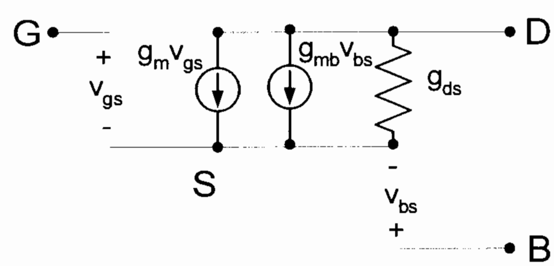
$$\text{In saturation}, V_{gs} = V_T + \sqrt{\frac{2I_d}{k'\frac{W}{L}}}$$

Small − signal parameters in saturation :

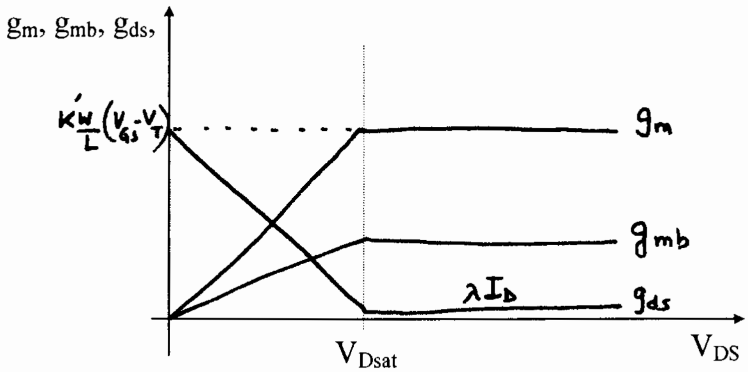
$$g_{ds} = g_o = \lambda I_d$$

$$g_m = \sqrt{2I_d k'\frac{W}{L}} = \frac{2I_d}{V_{gs}-V_T}$$

$$g_{mb} = \eta g_m \quad \text{where } \eta = \frac{\gamma}{2\sqrt{V_{sb}+\varphi}}$$



1. a) Plot the g_m, g_{mb}, g_{ds}, for an n-channel MOSFET as a function of V_{DS} for a value of $V_{GS} > V_T$. **(20 points)**

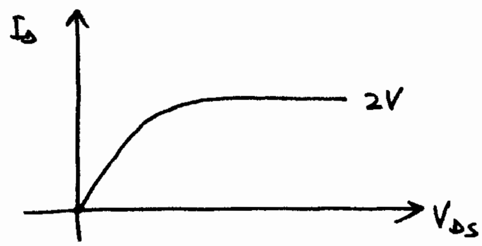


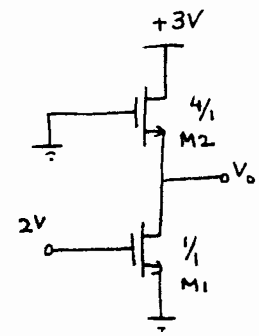
b) Identify the regions of operation for M1 and M2 and calculate the voltage V_o as shown. $V_{TO} = 0.7$ V, $k' = 100\,\mu A/V^2$, $\gamma = 0, \lambda = 0$.

M2 cut off

M1 linear (nonsat, triode)

$V_o = 0$ V

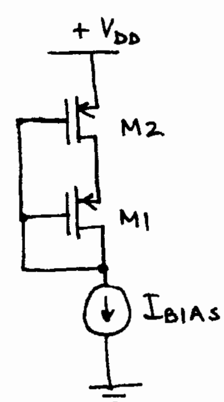




c) Identify the regions of operation for M1 and M2.

M2 linear (triode, nonsat)

M1 Saturation



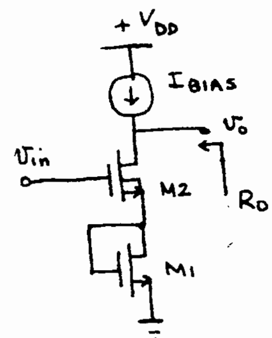
2. Write the expressions for the small-signal low-frequency quantities as shown. ***Assume all transistors are biased in saturation and have identical small-signal parameters. Ignore the body effect and assume that $g_m r_o >> 1$* (25 points).**

G_m (effective g_m) = $g_m/2$

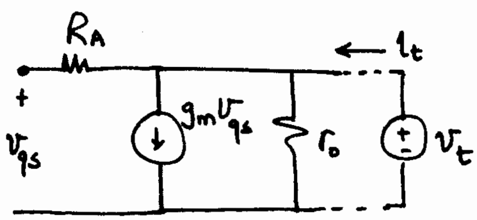
R_o = $2r_o$

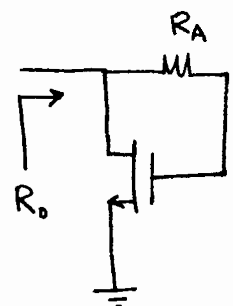
$$G_m = \frac{g_m}{1+1} = \frac{g_m}{2}$$

$$R_o = \left(1 + g_m \cdot \frac{1}{g_m}\right) r_o = 2r_o$$



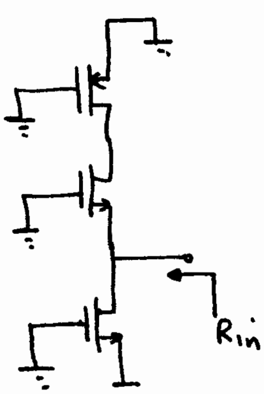
R_o = $1/g_m$

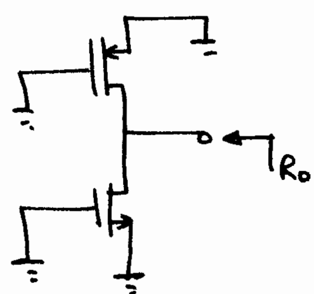


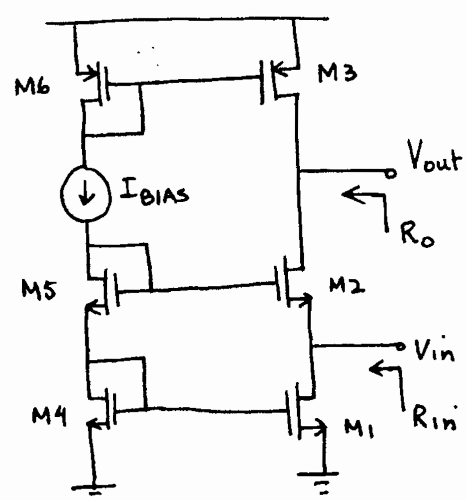


R_{in} = $2/g_m$

R_o = $r_o/2$







$$R_o = r_o \| r_o = \frac{r_o}{2}$$

$$R_{in} = r_o \| \frac{1}{g_m}\left(1 + \frac{r_o}{r_o}\right)$$

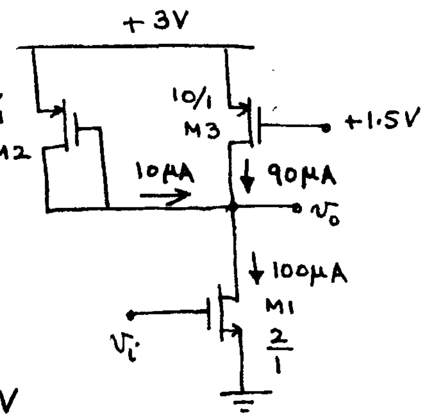
$$= \frac{2}{g_m}$$

3. a) For the amplifier shown <u>calculate</u> the dc gate bias V_{GS} for M1 to have a bias current of 100 μA. Also <u>calculate</u> the values of the dc drain current of M3 and the drain voltage of M1 for this bias condition **(15 points)**.

n-ch: $V_{TO} = 0.7$ V, $k' = 100\,\mu A/V^2$, $\gamma = 0.6\,V^{1/2}$, $\varphi = 0.7$ V, $\lambda = 0.02\,V^{-1}$

p-ch: $V_{TO} = -0.9$ V, $k' = 50\,\mu A/V^2$, $\gamma = 0.5\,V^{1/2}$, $\varphi = 0.7$ V, $\lambda = 0.02\,V^{-1}$

$V_{GS(M1)} =$ 1.7V $I_{D(M3)} =$ 90 μA $V_{D(M1)} =$ 1.9 V



$V_{GS} = V_T + \sqrt{\frac{2I_D}{K'W/L}}$; $V_{GS1} = 0.7 + \sqrt{\frac{2\times100}{100\times2}} = 1.7V$

$I_{DM3} = \frac{k'}{2}\frac{W}{L}\left(|V_{GS}| - |V_T|\right)^2 = \frac{50}{2}\times 10\,(1.5-0.9)^2$

$= 90\ \mu A$

$|V_{GS2}| = 0.9 + \sqrt{\frac{2\times10}{50\times10}} = 1.1\ V \Rightarrow V_o = 1.9V$

Check: M1 in saturation!

b) <u>Calculate</u> the low frequency small-signal voltage gain $A_v = v_o/v_i$ **(10 points)**.

$A_v = -g_{m1} \cdot r_{o1} \| r_{o3} \| 1/g_{m2}$

$\cong -\frac{g_{m1}}{g_{m2}}$ $g_{m1} = \sqrt{2 I_D K' W/L} = \sqrt{2\times100\times100\times2}\ \mu A/V = 200\mu A/V$

$g_{m2} = \sqrt{2\times10\times50\times10} = 100\,\mu A/V$

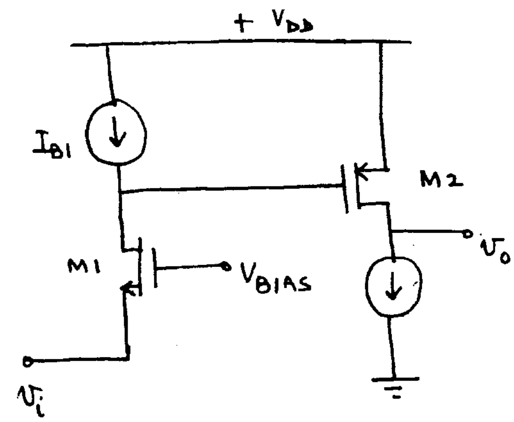
$\therefore A_v = -2$

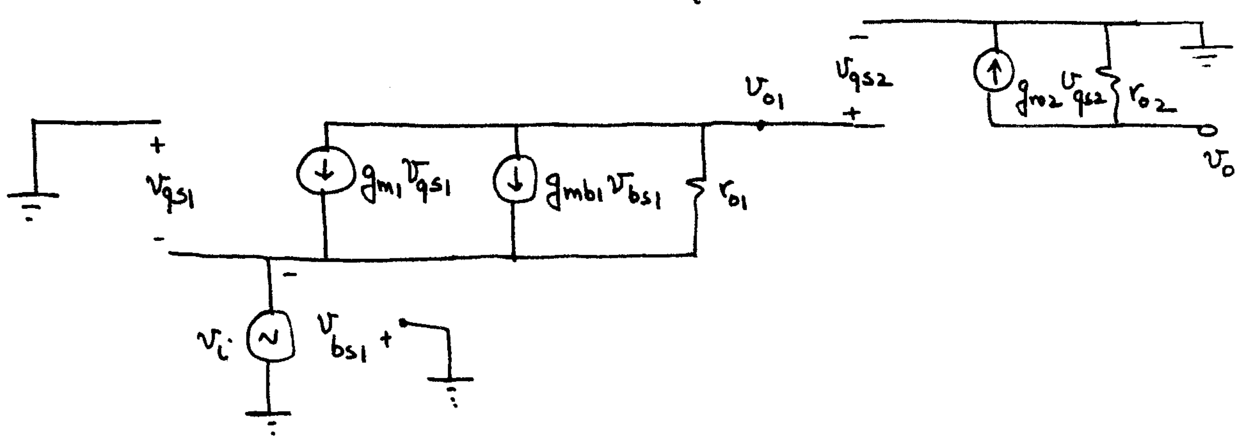
c) <u>Calculate</u> the output resistance of this amplifier **(5 points)**.

$R_o = r_{o1} \| r_{o3} \| \frac{1}{g_{m2}} \cong \frac{1}{g_{m2}} = 10\ k\Omega$

4. Draw the low frequency small-signal circuit for the configuration shown and derive an expression for the voltage gain of this circuit. ***Assume*** $g_{mb} = \eta g_m$ ***and*** $g_m r_o >> 1$ **(10 points).**

$A_v = v_o/v_i =$ $-(1+\eta)\, g_{m1} r_{o1} g_{m2} r_{o2}$





$$\frac{v_{o1}}{v_i} = (g_{m1} + g_{mb1})\, r_{o1} \qquad \text{(CG stage)}$$

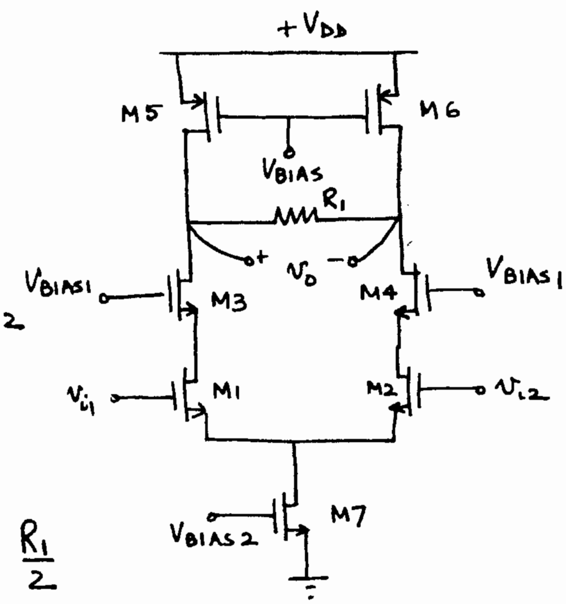
$$\frac{v_o}{v_{o1}} = -g_{m2} r_{o2} \qquad \text{(CS stage)}$$

$$A_v = \frac{v_o}{v_i} = -(g_{m1} + g_{mb1})\, r_{o1}\, g_{m2} r_{o2}$$

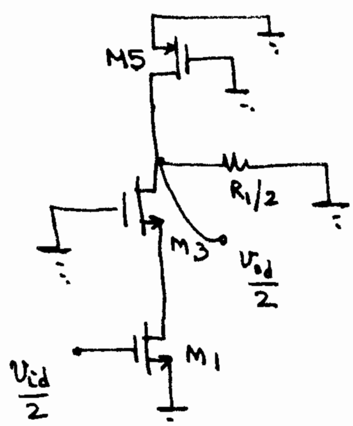
$$= -(1+\eta)\, g_{m1} r_{o1}\, g_{m2} r_{o2}$$

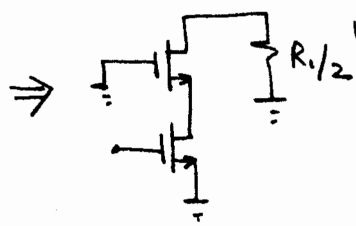
5. a) Derive the expression for the **differential** mode low frequency small-signal voltage gain for the amplifier as shown. Assume $g_{m1} = g_{m2} = g_{mx}$, $g_{m3} = g_{m4} = g_{my}$, $g_{m5} = g_{m6} = g_{mz}$. ***Take r_o to be infinity and ignore the body effect*** **(10 points)**.

$A_{dm} =$ $-g_{m1}R_1/2$



differential half circuit:





$$A_{dm} = \frac{v_{od}}{v_{id}} = -g_{m1}\frac{R_1}{2}$$

b) Draw the half circuit for calculating the common-mode gain. ***Assume $g_m r_o \gg 1$ and ignore the body effect*** **(5 points).**