Texas A&M University
Department of Electrical and Computer Engineering

ECEN 474 – (Analog) VLSI Circuit Design

Fall 2012

Exam #3

Instructor: Sam Palermo

- Please write your name in the space provided below
- Please verify that there are **5** pages (1 blank) in your exam
- You may use one double-sided page of notes and equations for the exam
- Good Luck!

Problem	Score	Max Score
1		35
2		30
3		35
Total		**100**

Name: SAM PALERMO

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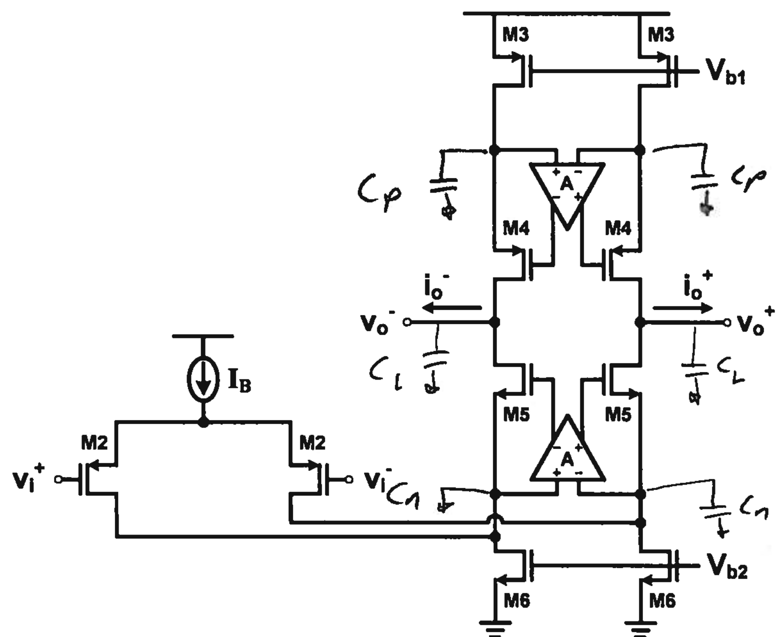
Problem 1 (35 points)

For the fully-differential amplifier below, assume all transistors are operating in saturation, the internal amplifier blocks have finite gain A and infinite bandwidth, and obtain expressions for the following:

a) Small-signal differential transconductance, $(i_o^+ - i_o^-)/(v_i^+ - v_i^-)$.

b) Fully differential amplifier DC gain, $A_{vd}=(v_o^+ - v_o^-)/(v_i^+ - v_i^-)$.

c) The amplifier's ~~two~~ 3 main poles. Note, it's OK here to state this as a function of an effective capacitance at a certain node, but make sure to appropriately label the nodes.



a. $G_m = g_{m2}$

$R_{out} = \left[r_{o5}\, g_{m5}(1+A)(r_{o6} \| r_{o2})\right] \| \left[r_{o4}\, g_{m4}(1+A)\, r_{o3}\right]$

b. $A_V = g_{m2}\left\{\left[r_{o5}\, g_{m5}(1+A)(r_{o6} \| r_{o2})\right] \| \left[r_{o4}\, g_{m4}(1+A)\, r_{o3}\right]\right\}$

c. $p_1 = -\dfrac{1}{R_{out} C_L}$, $p_2 = -\dfrac{g_{m4}(1+A)}{C_p}$, $p_3 = -\dfrac{g_{m5}(1+A)}{C_n}$

Problem 2 (30 points)

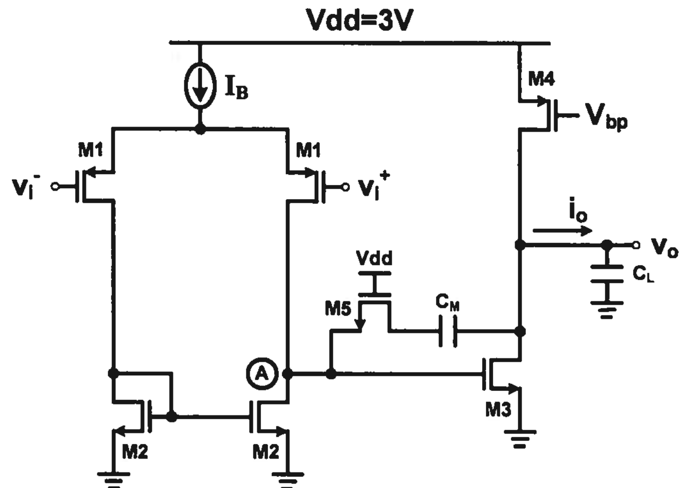
For the amplifier below, assume all transistors are operating in saturation **except for M5, which is in triode,** and obtain expressions for the following:

a) Small-signal transconductance.

b) The amplifier's two main poles. Note, it's OK to neglect the transistor capacitors here.

c) What is the value of $(W/L)_5$ that sets the main compensation zero to infinity? For this calculation, use the following:

$(W/L)_3=(6\mu/0.6\mu)$, $V_{T0}=1V$, $\gamma=0V^{1/2}$, $\mu C_{ox}=100\mu A/V^2$, Vdd=3V, Node A DC operating point = 1.5V



a. $$G_m = \left(-\frac{g_{m1}}{g_{o1}+g_{o2}}\right)\left(-g_{m3}\right) = \frac{g_{m1}\,g_{m3}}{g_{o1}+g_{o2}}$$

b. $$p_1 \cong -\frac{(g_{o1}+g_{o2})(g_{o3}+g_{o4})}{C_M\, g_{m3}}$$

$$p_2 \cong -\frac{g_{m3}}{C_L}$$

c. $$\omega_z = \frac{1}{\left(\frac{1}{g_{m3}} - R_z\right) C_M}$$

For $\omega_z \Rightarrow \infty$, need $R_z = \frac{1}{g_{m3}}$

$$R_z = \frac{1}{\mu_n C_{ox}\left(\frac{W}{L}\right)_5 (V_{GS5}-V_T)}, \quad g_{m3} = \mu_n C_{ox}\left(\frac{W}{L}\right)_3 (V_{GS3}-V_T)$$

$$\frac{1}{\mu_n C_{ox}\left(\frac{W}{L}\right)_5 (V_{GS5}-V_T)} = \frac{1}{\mu_n C_{ox}\left(\frac{W}{L}\right)_3 (V_{GS3}-V_T)}$$

$$\left(\frac{W}{L}\right)_5 = \left(\frac{W}{L}\right)_3 \left(\frac{V_{GS3}-V_T}{V_{GS5}-V_T}\right) = \left(\frac{6}{0.6}\right)\left(\frac{1.5-1}{1.5-1}\right)$$

$$\boxed{\left(\frac{W}{L}\right)_5 = \frac{6\mu}{0.6\mu}}$$

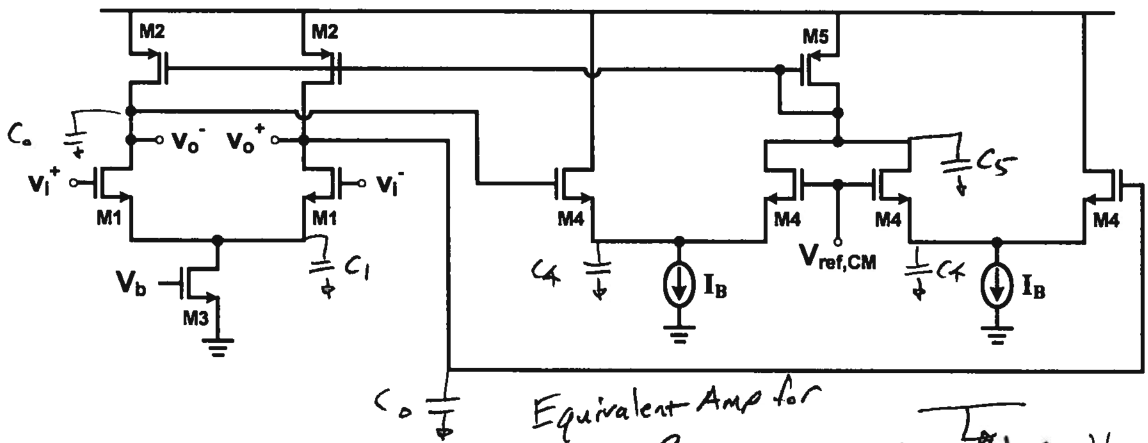
Problem 3 (35 points)

For the fully differential amplifier with common-mode feedback (CMFB) below, assume all transistors are operating in saturation, and obtain the following:

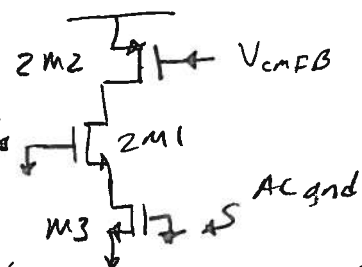
a) Neglecting the CMFB network, give an expression for the fully differential amplifier DC gain, $A_{vd}=(v_o^+ - v_o^-)/(v_i^+ - v_i^-)$.

b) Give an expression for the CMFB loop DC gain.

c) Give expressions for the poles of the CMFB loop. Note, it's OK here to state this as a function of an effective capacitance at a certain node, but make sure to appropriately label the nodes.



Equivalent Amp for CMFB



a. $$A_{vd} = \frac{g_{m1}}{g_{o1} + g_{o2}}$$

b. $$\text{CMFB Loop Gain} = \left(\frac{g_{m4}}{g_{m5}}\right)\left(-2g_{m2}\right)\left(\frac{r_{o1}}{2}(2g_{m1} r_{o3}) \,\|\, \frac{r_{o2}}{2}\right)$$

$$\simeq -\frac{g_{m4}\, g_{m2}\, r_{o2}}{g_{m5}}$$

c. $$p_1 = -\frac{g_{o2}}{C_o}, \quad p_2 = -\frac{2g_{m4}}{C_4}, \quad p_3 = -\frac{g_{m5}}{C_5}$$

$\Rightarrow$ There is also a pole at $-\frac{2g_{m1}}{C_1}$ which will reduce the "bottom" output impedance $\frac{r_{o1}}{2}(2g_{m1} r_{o2})$

However, the above 3 poles are enough for full credit

Scratch Paper