Texas A&M University
Department of Electrical and Computer Engineering

ECEN 474/704 – (Analog) VLSI Circuit Design

Fall 2016

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		35
3		30
Total		**100**

Name: SAM PALERMO

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Problem 1 (35 points)

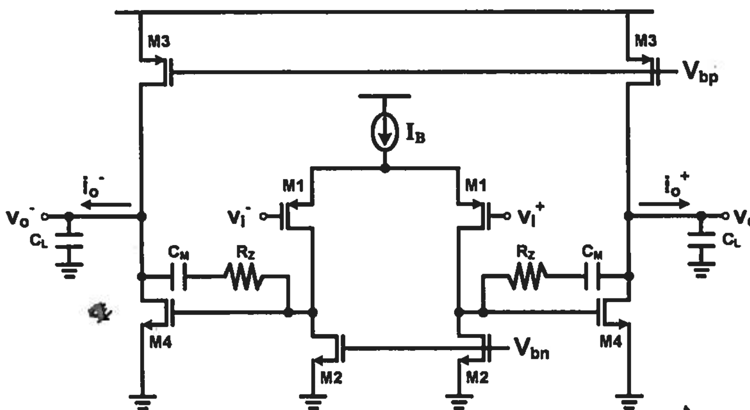
For the fully-differential amplifier below, assume all transistors are operating in saturation and obtain expressions for the following:

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 main poles. Note, it's OK to neglect the transistor capacitors here.

d) What is the value of R_z that sets the main compensation zero to infinity?



a. $G_m = \left(\frac{g_{m1}}{g_{o1}+g_{o2}}\right) g_{m4}$

$R_{out} = \frac{1}{g_{o3}+g_{o4}}$

b. $A_v = G_m R_{out}$

$= \frac{g_{m1}\, g_{m4}}{(g_{o1}+g_{o2})(g_{o3}+g_{o4})}$

c. $\omega_{p1} \simeq - \frac{(g_{o3}+g_{o4})(g_{o1}+g_{o2})}{C_M\, g_{m4}}$ $\omega_{p2} \simeq - \frac{g_{m4}}{C_L}$

d. $\omega_z = \frac{1}{\left(\frac{1}{g_{m4}} - R_z\right)C_M} = \infty$

$\Rightarrow \frac{1}{g_{m4}} - R_z = 0$

$\boxed{R_z = \frac{1}{g_{m4}}}$

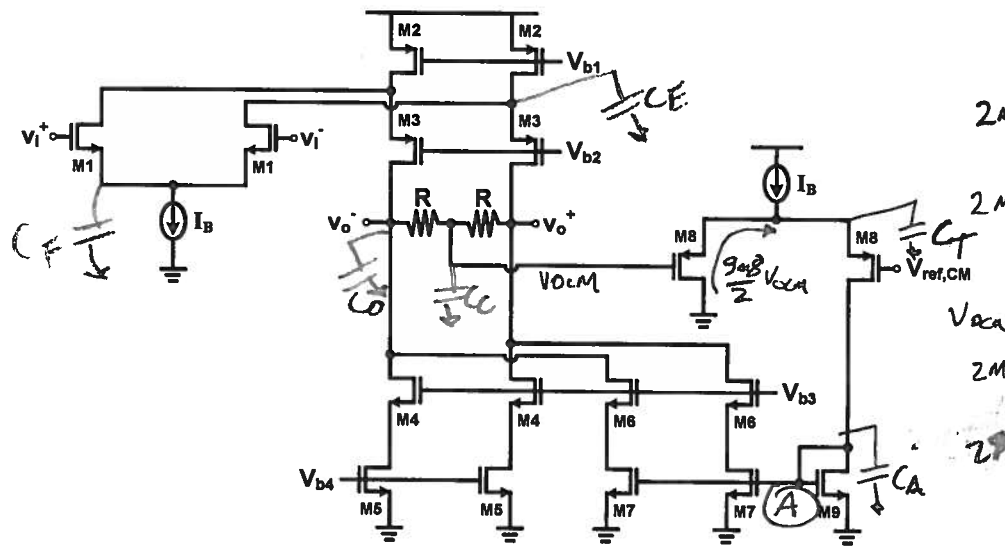
Problem 2 (35 points)

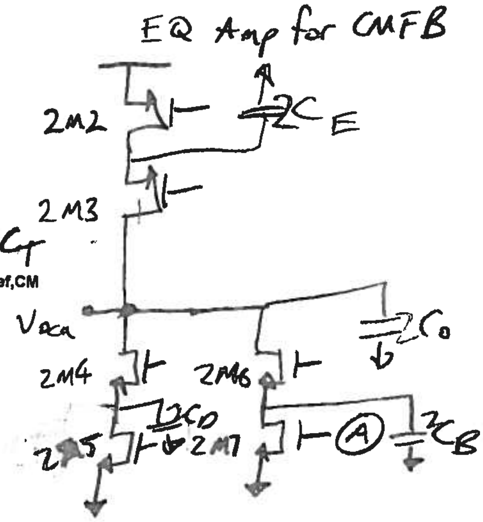
For the fully differential amplifier with common-mode feedback (CMFB) below, assume all transistors are operating in saturation, and obtain the following:

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.





a. $A_{vd} = g_{m1}\left[g_{m3}r_{o3}(r_{o2}||r_{o1}) \,||\, g_{m4}r_{o4}r_{o5} \,||\, g_{m6}r_{o6}r_{o7}\right]$

b. Gain from V_{OCM} to $V_A = \frac{g_{m8}}{2}\left(\frac{1}{g_{m9}}\right) = \frac{g_{m8}}{2g_{m9}}$

CMFB Loop Gain $= \left(\frac{g_{m8}}{2g_{m9}}\right)(-2g_{m7})\left[2g_{m3}\left(\frac{r_{o3}}{2}\right)\left(\frac{r_{o2}}{2}\right) \,||\, 2g_{m4}\left(\frac{r_{o4}}{2}\right)\left(\frac{r_{o5}}{2}\right) \,||\, 2g_{m6}\left(\frac{r_{o6}}{2}\right)\left(\frac{r_{o7}}{2}\right)\right]$

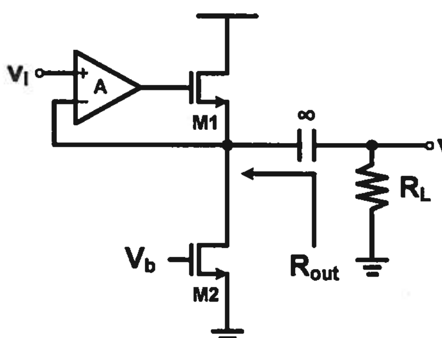
CMFB Loop Gain $= -\frac{g_{m8}g_{m7}}{g_{m9}}\left[\frac{g_{m3}r_{o3}r_{o2}}{2} \,||\, \frac{g_{m4}r_{o4}r_{o5}}{2} \,||\, \frac{g_{m6}r_{o6}r_{o7}}{2}\right]$

c. Poles at $\frac{1}{(g_{m3}r_{o3}r_{o2}||g_{m4}r_{o4}r_{o5}||g_{m6}r_{o6}r_{o7})C_o}$, $\frac{2g_{m8}}{C_T}$, $\frac{g_{m9}}{C_A}$

$\frac{g_{m6}}{C_B}$, $\frac{g_{m4}}{C_D}$, $\frac{g_{m3}}{C_E}$, $\frac{1}{RC_C}$, $\frac{2g_{m1}}{C_F}$

Problem 3 (30 points)
For the circuit shown below, assume that all transistors are operating in the saturation region. This circuit drives a resistive load through an ideal (infinite) AC-coupling capacitor that can be considered as a perfect short in small-signal AC analysis. Give expressions for the following and **do NOT neglect the transistor's output resistance.**

a) Loaded small-signal gain
b) Output resistance. Note, don't include the load resistor, R_L.

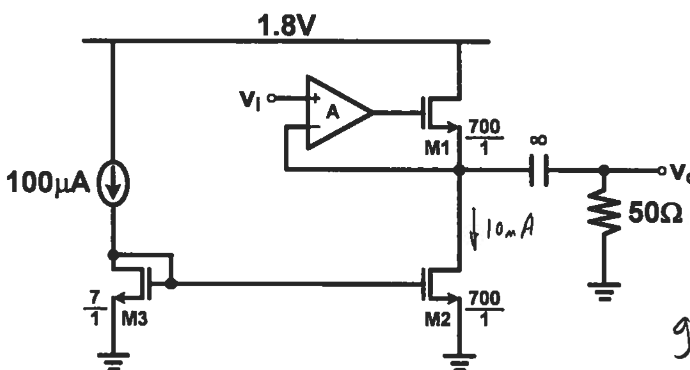


$$A_V = \frac{g_{m1} A}{g_{m1}(1+A) + g_{o1} + g_{o2} + G_L}$$

$$R_{out} = \frac{1}{g_{m1}(1+A) + g_{o1} + g_{o2}}$$

Now a more complete size circuit with the biasing details is shown that drives a 50Ω load resistor. What should the value of *A* be to achieve a loaded gain of 0.9V/V?
Assume the following transistor parameters.

$KP_N=\mu_n C_{ox}=200\mu A/V^2$, $V_{TH,N}=0.4V$, $\lambda_N=0.1V^{-1}$



$$A = \frac{A_V (g_{m1} + g_{o1} + g_{o2} + G_L)}{g_{m1}(1 - A_V)}$$

$$g_{m1} = \sqrt{(200\mu)\left(\tfrac{700}{1}\right)(2)(10mA)} = 52.9\,mA/V$$

$$g_{o1} = g_{o2} = (0.1V^{-1})(10mA) = 1\,mA/V$$

$$G_L = \frac{1}{50\Omega} = 20\,mA/V$$

$$A = \frac{0.9(52.9\,mA/V + 1\,mA/V + 1\,mA/V + 20\,mA/V)}{52.9\,mA/V\,(1-0.9)} = 12.7$$

A for Gain=0.9V/V = 12.7

Scratch Paper