Texas A&M University
Department of Electrical and Computer Engineering

ECEN 474/704 – (Analog) VLSI Circuit Design

Spring 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

UIN:

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. Note that the bottom-most nMOS transistors have a 1:B size ratio. Obtain expressions for the following:

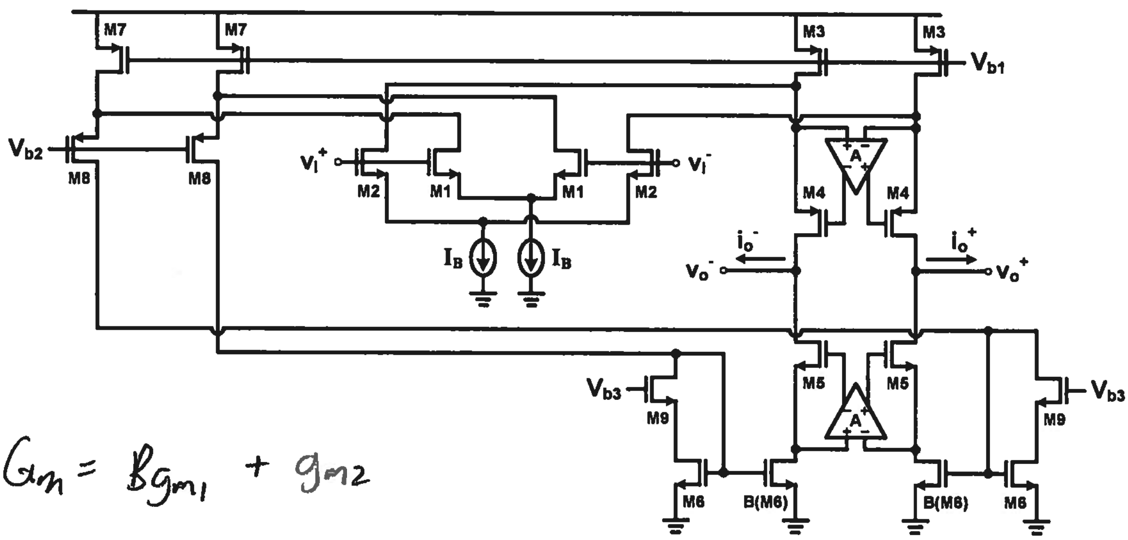
a) Small-signal differential transconductance, $(i_o^+ - i_o^-)/(v_i^+ - v_i^-)$.

b) Output resistance.

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

d) Output referred noise current power spectral density. Consider only thermal noise and include all important noise sources.

e) Input referred noise voltage power spectral density. Consider only thermal noise and include all important noise sources.



a. $G_m = Bg_{m1} + g_{m2}$

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

c. $A_v = G_m R_{out} = \left[Bg_{m1} + g_{m2} \right] \left[r_{o5} g_{m5} (1+A) \frac{r_{o6}}{B} \,||\, r_{o4} g_{m4} (1+A) (r_{o3} || r_{o2}) \right]$

d. $\frac{i_{o,n}^2}{\Delta f} = \left(i_{o1}^2 + i_{o2}^2 + i_{o3}^2 + i_{o6}^2 + i_{oBM6}^2 + i_{o7}^2 \right) 2$

$= \frac{16}{3} kT \left[B^2 g_{m1} + g_{m2} + g_{m3} + B^2 g_{m6} + B g_{m6} + B^2 g_{m7} \right]$

e. $\frac{v_{i,n}^2}{\Delta f} = \frac{i_{o,n}^2}{\Delta f} \left(\frac{1}{G_m} \right)^2$

Problem 2 (35 points)

For the circuit shown below, assume that all transistors are operating in the saturation region **except for M9**. You can assume that the DC operating point for node B is the same as node A.

Calculate the following using these transistor parameters.

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

$KP_P=\mu_p C_{ox}=100\mu A/V^2$, $V_{TH,P}=-0.4V$, $\lambda_P=0.1V^{-1}$

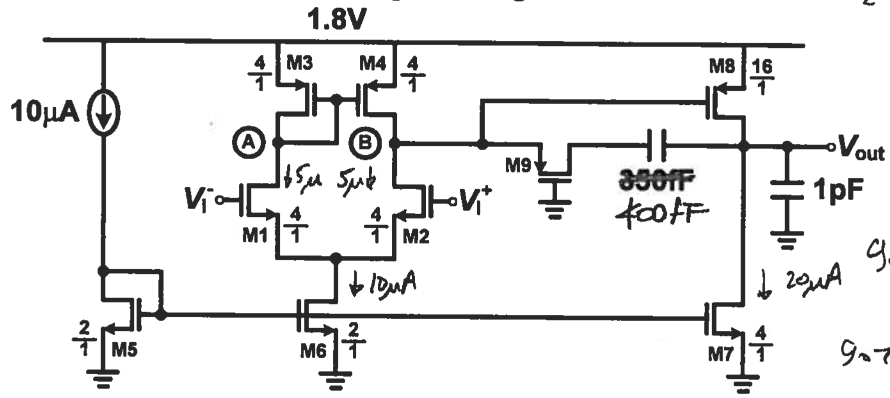
a) Low-frequency gain ($A_{DC}=V_{out}/(V_i^+-V_i^-)$)

b) Dominant pole (ω_{p1})

c) Second pole (ω_{p2})

d) Unity-gain frequency (ω_{GX})

e) Give the M9 aspect ratio 60° phase margin



$$A_{DC}=\left(\frac{-g_{m2}}{g_{o2}+g_{o4}}\right)\left(-\frac{g_{m8}}{g_{o7}+g_{o8}}\right)$$

$$g_{m2}=\sqrt{(200\mu)\left(\tfrac{4}{1}\right)(2)(5\mu)}=89.4\mu A/V$$

$$g_{o2}=g_{o4}=\lambda I_D=(0.1V^{-1})(5\mu A)=0.5\mu A/V$$

$$g_{m8}=\sqrt{(100\mu)\left(\tfrac{16}{1}\right)(2)(20\mu)}=253\mu A/V$$

$$g_{o7}=g_{o8}=\lambda I_D=(0.1V^{-1})(20\mu A)=2\mu A/V$$

$$\text{Node } A = B = 1.8-0.4-\sqrt{\frac{2(5\mu)}{100\mu(4/1)}}=1.24V$$

$$A_{DC}=\left(\frac{89.4\mu}{0.5\mu+0.5\mu}\right)\left(\frac{253\mu}{2\mu+2\mu}\right)=5.65\times10^3\ V/V$$

$$\omega_{P1}=-\frac{(g_{o2}+g_{o4})(g_{o7}+g_{o8})}{g_{m8}C_c}=-\frac{(0.5\mu+0.5\mu)(2\mu+2\mu)}{(253\mu)(400f)}=-39.5\ krad/s=-6.29k$$

$$\omega_{P2}=-\frac{g_{m8}}{C_L}=-\frac{253\mu}{1p}=-253\ Mrad/s=-40.3\ MHz$$

$$\omega_{GX}=A_{DC}\cdot|\omega_{P1}|=(5.65\times10^3)(39.5k)=223\ Mrad/s=35.5\ MHz$$

$$PM=180^\circ-\tan^{-1}\left(\frac{\omega_{GX}}{\omega_{P1}}\right)-\tan^{-1}\left(\frac{\omega_{GX}}{\omega_{P2}}\right)-\tan^{-1}\left(\frac{\omega_{GX}}{\omega_Z}\right)$$

$$60^\circ=180^\circ-\tan^{-1}\left(\frac{223M}{39.5k}\right)-\tan^{-1}\left(\frac{223M}{253M}\right)-\tan^{-1}\left(\frac{223M}{\omega_Z}\right)$$

$$60^\circ=180^\circ-90^\circ-41.4^\circ-\tan^{-1}\left(\frac{223M}{\omega_Z}\right)$$

$$11.4^\circ=-\tan^{-1}\left(\frac{223M}{\omega_Z}\right)$$

$$\omega_Z=-\frac{223M}{\tan(11.4)}=-1.11\ Grad/s$$

$$\omega_Z=\frac{1}{\left(\frac{1}{g_{m8}}-R_Z\right)C_c}\qquad R_Z=\frac{1}{g_{m8}}-\frac{1}{\omega_Z C_c}=6.2k$$

$$\frac{W}{L_9}=\frac{1}{(100\mu)(6.2k)(1.24-0.4)}$$

$A_{DC}=5.65\times10^3\ V/V$

$\omega_{p1}=-39.5\ krad/s$

$\omega_{p2}=-253\ Mrad/s$

$\omega_{GX}=223\ Mrad/s$

$(W/L)_9$ for PM=60° = 1.92

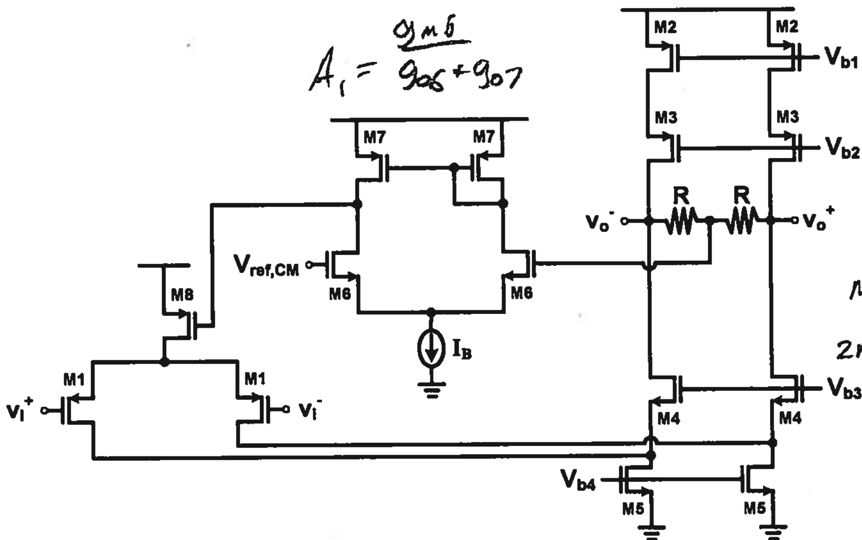
Problem 3 (30 points)

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

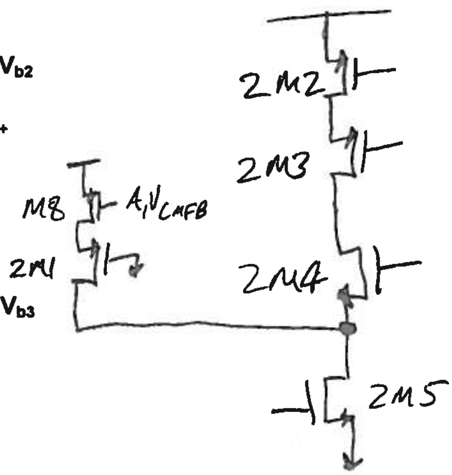
a) Neglecting the CMFB network, give an expression for the fully differential amplifier DC gain, $A_{vd}=(v_o^+ - v_o^-)/(v_i^+ - v_i^-)$.

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

$A_1 = \frac{g_{m6}}{g_{o6}+g_{o7}}$



EQ Amp for CMFB



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

b. $\text{CMFB Loop Gain} = \left(\frac{g_{m6}}{g_{o6}+g_{o7}}\right)(-g_{m8})\left[(2g_{m4})\left(\frac{r_{o4}}{2}\right)\left[\frac{r_{o5}}{2} \,||\, (2g_{m1})\left(\frac{r_{o1}}{2}\right)r_{o8}\right]\right] \,||\, \left[(2g_{m3})\left(\frac{r_{o3}}{2}\right)\left(\frac{r_{o2}}{2}\right)\right]$

$\simeq \left(-\frac{g_{m6}g_{m8}}{g_{o6}+g_{o7}}\right)\left(\frac{g_{m4}r_{o4}r_{o5}}{2} \,||\, \frac{g_{m3}r_{o3}r_{o2}}{2}\right)$

Scratch Paper