Texas A&M University
Department of Electrical and Computer Engineering

ECEN 474/704 – (Analog) VLSI Circuit Design

Fall 2016

Exam #2

Instructor: Sam Palermo

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

Problem	Score	Max Score
1		30
2		30
3		40
Total		**100**

Name: SAM PALERMO

UIN: ____________________

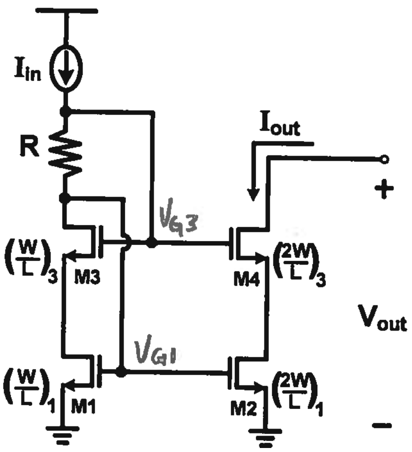
Problem 1 (30 points)

For the following current source obtain the following:

a) Give an expression for the output resistance. You can assume that all transistors are operating in saturation and that you can neglect body effect.

b) Give an expression for the minimum compliance voltage at the output necessary to keep all transistors in saturation.

c) Give an expression for the minimum resistor *R* value required to keep all the transistors in saturation for this minimum compliance voltage. Express this minimum *R* value as a function of I_{in} and the relevant transistor aspect ratio (W/L) values.



a. $r_o = r_{o2} + r_{o4} + g_{m4} r_{o4} r_{o2}$

$\cong g_{m4} r_{o4} r_{o2}$

b. Minimum Compliance Voltage

$$V_{out} \geq V_{DSAT2} + V_{DSAT4}$$

c. ① $V_{G3} - V_{G1} = I_{in} R$

② Minimum $V_{G3} = V_{DSAT1} + V_{GS3} = V_{DSAT1} + V_{DSAT3} + V_T$

Plugging ② into ①

Min $V_{G3} - V_{G1} = V_{DSAT1} + V_{DSAT3} + V_T - (V_{DSAT1} + V_T) = I_{in} R$

$V_{DSAT3} = I_{in} R$

$\sqrt{\frac{2 I_{in}}{\mu C_{ox} \left(\frac{W}{L}\right)_3}} = I_{in} R$

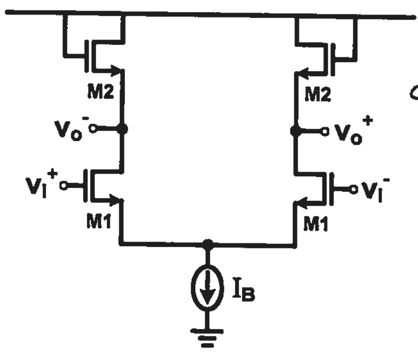
$$R = \sqrt{\frac{2}{I_{in} \mu C_{ox} \left(\frac{W}{L}\right)_3}}$$

Problem 2 (30 points)

For the fully differential amplifier below obtain the following:

a) Give an expression for the differential gain, $A_{vd}=(v_o^+ - v_o^-)/(v_i^+ - v_i^-)$. **Do NOT neglect the transistors' r_o.** Assume all transistors are operating in saturation and that you can neglect body effect.

b) Give an expression for the dominant pole of the amplifier. This expression should include all the appropriate transistor capacitances and include the Miller effect when appropriate.



a. $A_{vd} = \dfrac{g_{m1}}{g_{o1} + g_{o2} + g_{m2}}$

b. $\omega_p = \dfrac{g_{o1} + g_{o2} + g_{m2}}{C_{DB1} + C_{GD1} + C_{SB2} + C_{GS2}}$

Note neglecting Miller in C_{GD1} because $1 - A_{DC} = 1 - \left(-\frac{1}{A_{vd}}\right)$ — this is generally very small

c) Now simplify the differential gain expression by letting the transistors' $r_o=\infty$. Assume that the transistors have the following transistor sizes:

M1 Size = W/L

M2 Size = α*W/L

What should α be to achieve a differential gain of 2?

$$A_{vd} = \frac{g_{m1}}{g_{m2}} = \frac{\sqrt{\mu_n C_{ox} \frac{W}{L} 2(I_B/2)}}{\sqrt{\mu_n C_{ox} \alpha \frac{W}{L} 2(I_B/2)}}$$

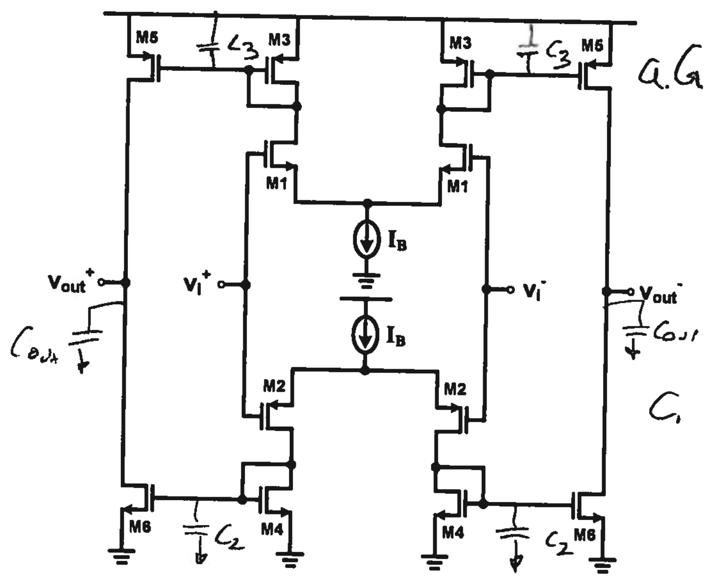
$$A_{vd} = \frac{1}{\sqrt{\alpha}} = 2$$

$$\boxed{\alpha = \frac{1}{4}}$$

Problem 3 (40 points)

For the amplifier below, assume all transistors are operating in saturation and that you can neglect body effect. Obtain expressions for the following:

a) Small-signal transconductance.
b) Output resistance.
c) DC gain.
d) The amplifier's three 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.
e) Output referred noise current power spectral density. Consider only thermal noise and include all important noise sources.
f) Input referred noise voltage power spectral density. Consider only thermal noise and include all important noise sources.



a. $G_m = \frac{g_{m1} g_{m5}}{g_{o1} + g_{o3} + g_{m3}} + \frac{g_{m2} g_{m6}}{g_{o2} + g_{o4} + g_{m4}}$

b. $R_{out} = \frac{1}{g_{o5} + g_{o6}}$

c. $A_v = G_m R_{out} = \frac{\frac{g_{m1} g_{m5}}{g_{o1} + g_{o3} + g_{m3}} + \frac{g_{m2} g_{m6}}{g_{o2} + g_{o4} + g_{m4}}}{g_{o5} + g_{o6}}$

d. $\omega_{p1} = \frac{g_{o5} + g_{o6}}{C_{out}}$, $\omega_{p2} = \frac{g_{m4} + g_{o4} + g_{o2}}{C_2}$, $\omega_{p3} = \frac{g_{m3} + g_{o3} + g_{o1}}{C_3}$

e. $\frac{\overline{i_{o,n}^2}}{\Delta f} = \left(\overline{i_{o1}^2} + \overline{i_{o3}^2} + \overline{i_{o5}^2} + \overline{i_{o2}^2} + \overline{i_{o4}^2} + \overline{i_{o6}^2}\right) 2$

$= \frac{16}{3} kT \left[(g_{m1} + g_{m3}) \left(\frac{1}{g_{o1} + g_{o3} + g_{m3}} \right)^2 g_{m5}^2 + g_{m5} + (g_{m2} + g_{m4}) \left(\frac{1}{g_{o2} + g_{o4} + g_{m4}} \right)^2 g_{m6}^2 + g_{m6} \right]$

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

Scratch Paper