Texas A&M University
Department of Electrical and Computer Engineering

ECEN 474/704 – (Analog) VLSI Circuit Design

Spring 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 one 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

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Problem 1 (30 points)

For the circuit shown below, assume that all transistors are operating in the saturation region. Calculate the following using these transistor parameters.

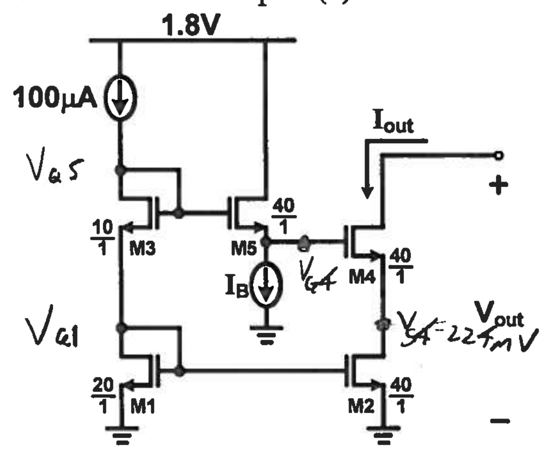
$KP_N = \mu_n C_{ox} = 200\mu A/V^2$, $V_{TH,N} = 0.4V$, $\lambda = 0.1V^{-1}$

a) Output current, $\mathbf{I_{out}}$

b) Minimum output compliance voltage, such than all transistors remain in saturation, $\mathbf{V_{out,min}}$. What is the value of $\mathbf{I_B}$ to achieve this?

c) Output resistance, $\mathbf{R_{out}}$

Note, for parts (a) and (b) you can neglect λ effects in the DC calculations, but you need to include λ effects for part (c).



$$I_{out} = \frac{(W/L)_2}{(W/L)_1} I_{REF} = \frac{(40/1)}{(20/1)} 100\mu A = 200\mu$$

$$V_{out,min} = V_{DSAT2} + V_{DSAT4} = 448mV$$

$$V_{DSAT2} = \sqrt{\frac{2(200\mu)}{(200\mu)(40/1)}} = 224mV = V_{DSAT4}$$

For minimum compliance voltage $\Rightarrow V_{S4} = 224mV$

$$V_{G4} = V_{S4} + V_T + V_{OV4} = 224mV + 0.4V + 0.224mV = 0.848V$$

$$V_{G1} = 0.4V + \sqrt{\frac{2(100\mu)}{200\mu(20/1)}} = 0.624V$$

$$V_{G5} = 0.624 + 0.4 + \sqrt{\frac{2(100\mu)}{200\mu(10/1)}} = 1.34V$$

$$I_B = \frac{\mu C_{ox}}{2}\left(\frac{W}{L_5}\right)(V_{GS} - V_T)^2 = \frac{200\mu}{2}\left(\frac{40}{1}\right)(1.34 - 0.848 - 0.4)^2 = 33.9\mu A$$

$$R_{out} = r_{o2} + r_{o4} + g_{m4} r_{o4} r_{o2}$$

$$r_{o2} = r_{o4} = \frac{1}{\lambda I_D} = \frac{1}{(0.1)(200\mu A)} = 50k\Omega$$

$$g_{m4} = \sqrt{(200\mu)\left(\frac{40}{1}\right)(2)(200\mu)} = 1.79\ mA/V$$

$$R_{out} = 50K + 50K + (1.79m)(50K)^2 = 4.58M\Omega$$

$I_{out} =$ 200μA

$V_{out.min} =$ 0.448 V

$I_B =$ 33.9μA

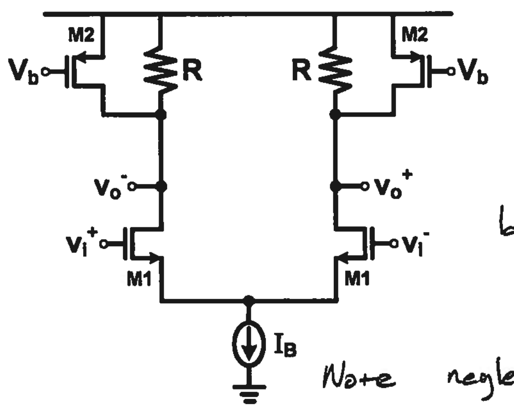
$R_{out} =$ 4.58M

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. $A_{Vd} = \dfrac{g_{m1}}{g_{o1} + g_{o2} + G}$ where $G = \dfrac{1}{R}$

b. $\omega_p = \dfrac{g_{o1} + g_{o2} + G}{C_{DB1} + C_{GD1} + C_{DB2} + C_{GD2}}$

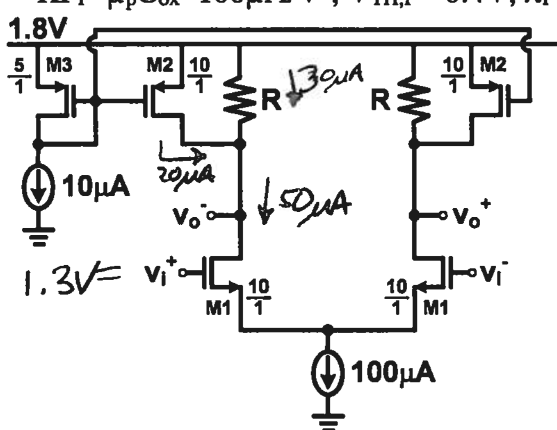
Note neglecting Miller in C_{GD1} because $1 - A_{DG} = 1 - \left(\frac{1}{A_{VD}}\right)$ — this is generally very small

c) Now a more complete schematic is shown with biasing and transistor sizes. Assuming that the input common-mode can be as high as 1.3V, select *R* to achieve the maximum gain, while allowing all transistors to remain in saturation. What is the maximum gain, $A_{v,max}$? Use the following transistor parameters.

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

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

If $V_{ICM} = 1.3V \Rightarrow$ Min $V_o = 0.9V$



Max $R = \dfrac{1.8V - 0.9V}{30\mu A} = 30k\Omega$

$g_{m1} = \sqrt{200\mu\left(\frac{10}{1}\right)(2)(50\mu)} = 447\mu A/V$

$g_{o1} = (0.1)(50\mu) = 5\mu A/V$

$g_{o2} = (0.1)(20\mu) = 2\mu A/V$

$A_{v,max} = \dfrac{447\mu}{5\mu + 2\mu + \frac{1}{30K}} = 11.1$

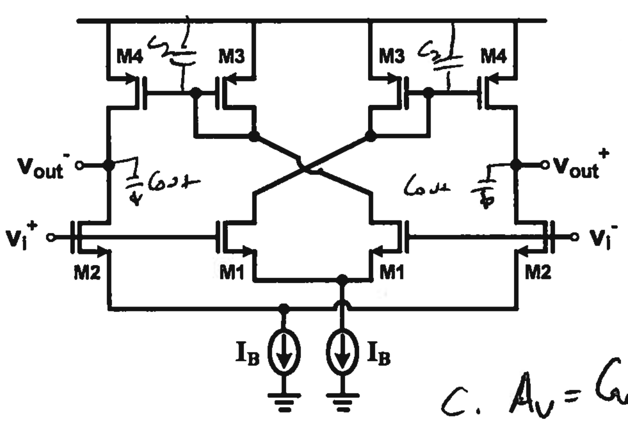
$R_{max} =$ 30kΩ

$A_{v,max} =$ 11.1 V/V

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 two 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. $\frac{g_{m1} g_{m4}}{g_{o1}+g_{o3}+g_{m3}} + g_{m2}$

b. $R_{out} = \frac{1}{g_{o2}+g_{o4}}$

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

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

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

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

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