Texas A&M University
Department of Electrical and Computer Engineering

ECEN 474/704 – (Analog) VLSI Circuit Design

Spring 2018

Exam #3

Instructor: Sam Palermo

- Please write your name in the space provided below
- Please verify that there are **6** 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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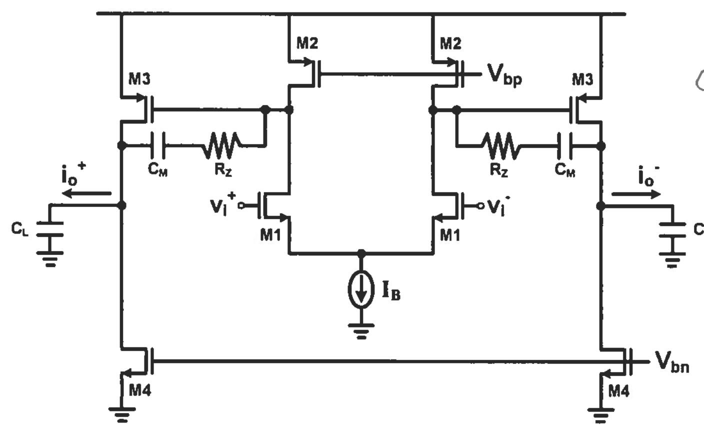
Problem 1 (35 points)

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) Assuming that the dominant pole is at the first stage output, what is the value of R_z that cancels the second pole?



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

$$\boxed{G_m = \frac{g_{m1} g_{m3}}{g_{o1}+g_{o2}}}$$

b. $R_{out} = \frac{1}{g_{o3}+g_{o4}}$ $\Rightarrow$ $\boxed{A_v = G_m R_{out} = \frac{g_{m1} g_{m3}}{(g_{o1}+g_{o2})(g_{o3}+g_{o4})}}$

c. $\omega_{p1} \cong -\frac{(g_{o1}+g_{o2})(g_{o3}+g_{o4})}{C_M g_{m3}}$ $\qquad \omega_{p2} \cong -\frac{g_{m3}}{C_L}$

d. $\omega_{p2} \cong -\frac{g_{m3}}{C_L}$ $\qquad \omega_z = \frac{1}{\left(\frac{1}{g_{m3}} - R_z\right) C_M}$

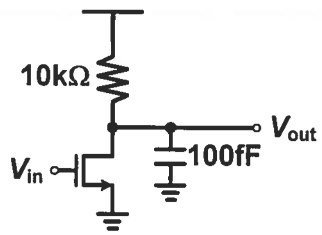
$$\frac{1}{\left(\frac{1}{g_{m3}} - R_z\right) C_M} = -\frac{g_{m3}}{C_L}$$

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

$$\boxed{R_z = \frac{1}{g_{m3}}\left(1 + \frac{C_L}{C_M}\right)}$$

Problem 2 (35 points)

a. Give the transfer function (**w/ numbers**) of the single-stage amplifier shown below. Assume the transistor operates in saturation with $\mathbf{g_m=1mA/V}$ and $\mathbf{\lambda=0}$. Only consider the explicitly drawn capacitors, i.e. no transistor capacitors.

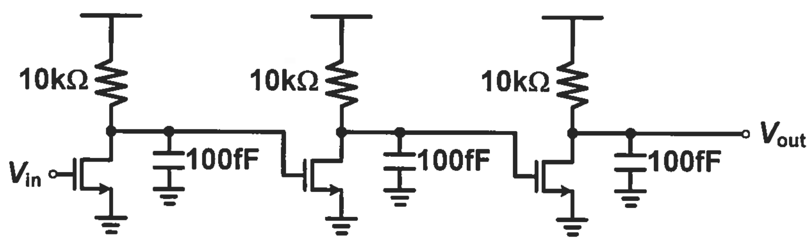


$A_{DC} = -g_m R_D = -(1\,\tfrac{mA}{V})(10k\Omega) = -10\,\tfrac{V}{V}$

$|\omega_p| = \frac{1}{R_D C} = \frac{1}{(10k\Omega)(100fF)} = 1G\ \text{rad/s}$

$$H_1(s) = \frac{V_{out}(s)}{V_{in}(s)} = \frac{-10}{1+\frac{s}{10^9}}$$

b. Now this single-stage amplifier is used in a 3-stage amplifier. Again, assume all transistors operate in saturation with $\mathbf{g_m=1mA/V}$ and $\mathbf{\lambda=0}$ and only consider the explicitly drawn capacitors, i.e no transistor capacitors. Give the 3-stage amplifier transfer function and the frequency at which the amplifier's phase drops from the low-frequency phase value by -180° (ω_{PX}).



$\tan^{-1}\left(\frac{\omega_{px}}{10^9}\right) = 60°$

$H(s) = (H_1(s))^3 = \frac{-10^3}{\left(1+\frac{s}{10^9}\right)^3}$

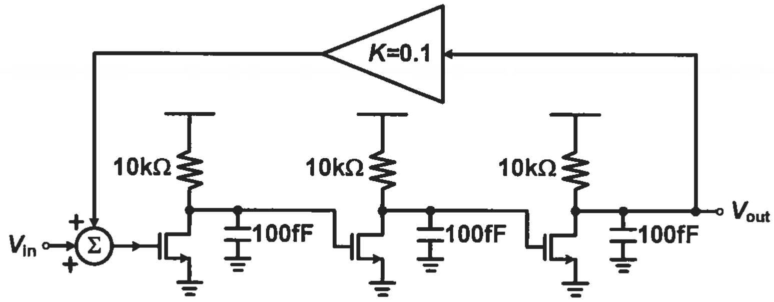
$\omega_{px} = 1.73\ G\ \text{rad/s}$

$\angle H(j\omega) = -3\tan^{-1}\left(\frac{\omega_{px}}{10^9}\right) = -180°$

$$H(s) = \frac{V_{out}(s)}{V_{in}(s)} = \frac{-10^3}{\left(1+\frac{s}{10^9}\right)^3}$$

$\omega_{PX} =$ 1.73 Grad/s

c. Now this 3-stage amplifier is place in feedback with ***K*=0.1**. Give the frequency at which the feedback system $|KH(s)|=1$ (ω_{GX}). Is the system stable?



$$|KH(s)| = 1$$

$$\frac{(0.1)(10^3)}{\left(\sqrt{1+\frac{\omega_{GX}^2}{10^{18}}}\right)^3} = 1$$

$$\left(1+\frac{\omega_{GX}^2}{10^{18}}\right)^{\frac{3}{2}} = 10^2$$

$$1+\frac{\omega_{GX}^2}{10^{18}} = 21.5$$

$$\omega_{GX} = 4.53\ Grad/s$$

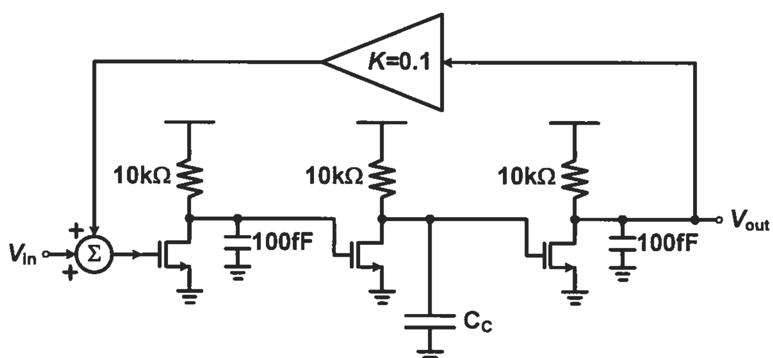
ω_{GX} = 4.53 Grad/s

System Stable? (Yes or No) No ($\omega_{GX} > \omega_{PX}$)

d. Now only the second stage is modified with a large compensation capacitor Cc to establish a single dominant pole system. Assume that this dominant pole contributes -90° at the new ω_{GX}. Considering the other poles in the system, what is the capacitor value necessary for the feedback system (*KH*) to have a phase margin of 45°?

For PM = 45°

$$\angle KH(j\omega_{GXnew}) = -135^\circ$$



w/ one dominant pole $\angle KH(j\omega_{GXnew}) = -90^\circ - 2\tan^{-1}\left(\frac{\omega_{GXnew}}{10^9}\right) = -135^\circ$

$$\tan^{-1}\left(\frac{\omega_{GXnew}}{10^9}\right) = 22.5^\circ$$

$$\omega_{GXnew} = 414\ Mrad/s$$

To place ω_{GXnew} at 414 Mrad/s

$$\omega_{P1}' = \frac{\omega_{GXnew}}{|KH|} = \frac{414\ Mrad/s}{10^2} = 4.14\ Mrad/s$$

$$\omega_{P1}' = \frac{1}{R_o C_c} \Rightarrow C_c = \frac{1}{(10k\Omega)(4.14M\ rad/s)} = 24.1\ pF$$

Cc (PM=45°) = 24.1 pF

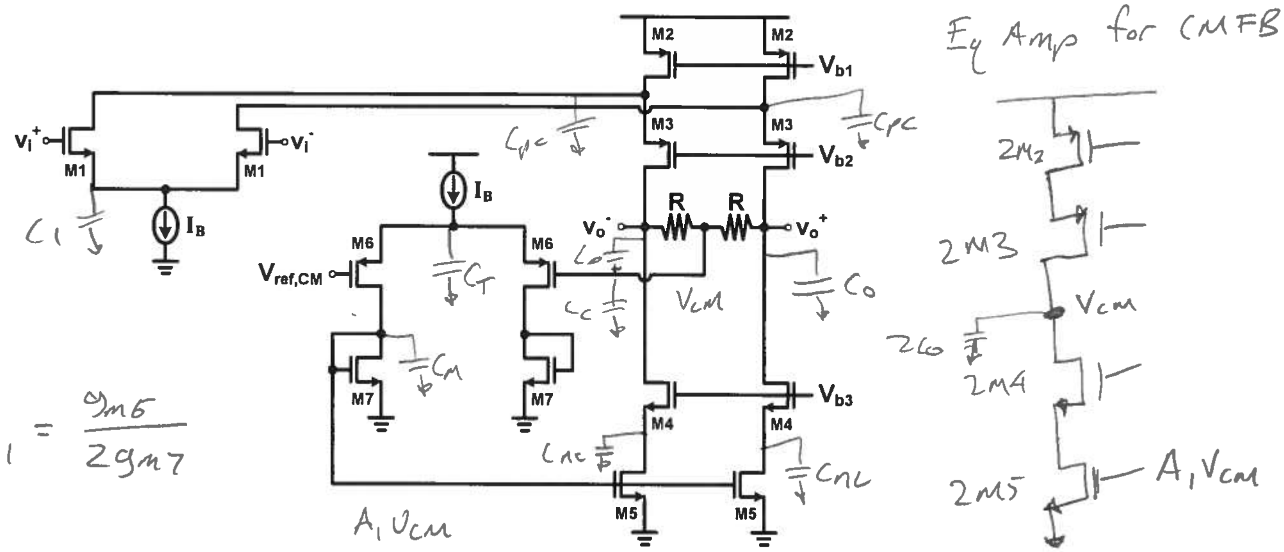
Problem 3 (30 points)

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.

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.



$$A_1 = \frac{g_{m6}}{2g_{m7}}$$

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

b. CMFB Loop Gain $= \left(\frac{g_{m6}}{2g_{m7}}\right)(-2g_{m5})\left[2g_{m3}\frac{r_{o3}}{2}\frac{r_{o2}}{2} \,||\, 2g_{m4}\frac{r_{o4}}{2}\frac{r_{o5}}{2}\right]$

$$= -\frac{g_{m6}g_{m5}}{2g_{m7}}\left[g_{m3}r_{o3}r_{o2} \,||\, g_{m4}r_{o4}r_{o5}\right]$$

c. Poles at $\frac{1}{(g_{m3}r_{o3}r_{o2} \,||\, g_{m4}r_{o4}r_{o5})C_o}$

$$\frac{2}{RC_c},\ \frac{2g_{m6}}{C_T},\ \frac{g_{m7}}{C_M},\ \frac{g_{m4}}{C_{nc}},\ \frac{g_{m3}}{C_{pc}},\ \frac{2g_{m1}}{C_1}$$

Scratch Paper