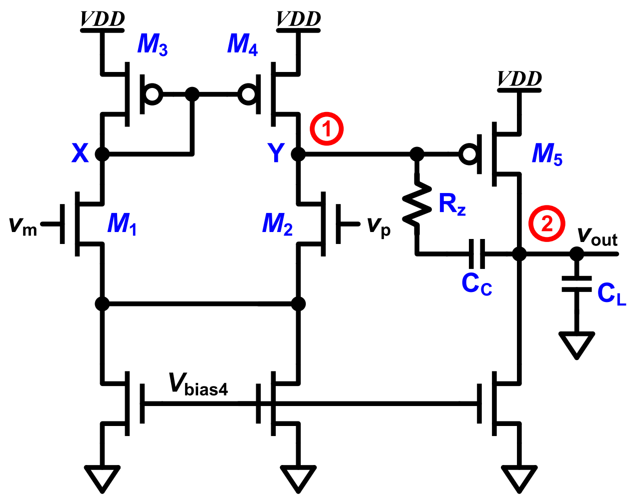
ECE 5411 CMOS Analog Integrated Circuit Design
Sample Final Exam
May 15, 2014 **Name:** ____________________

Closed Book, Closed Notes, Closed Computer. Show your steps clearly to get credit. State clearly any assumptions made. This exam has 5 questions, for a total of 100 points.

1. Consider the following Miller-compensated two-stage amplifier below



The DC gain, and the pole-zero expressions for the above amplifier are given by

$A_v = g_{m1}R_1 g_{m2}R_2$

$\omega_{p_1} \approx \frac{1}{g_{m2}R_2R_1C_c}$

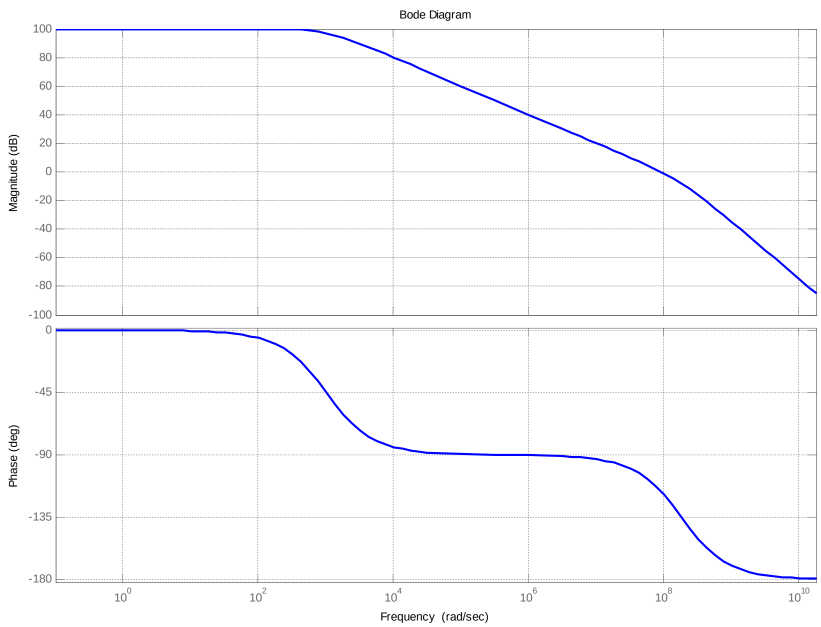
$\omega_{p_2} \approx \frac{g_{m2}C_c}{C_2(C_1+C_C)+C_CC_1} \propto \frac{g_{m2}}{C_2}$

where g_{mk}, R_k and $C_k$denote the transconductance, resistance and capacitances to the ground, at the output of the k^{th} gain stage.

(a) (4 points) For what value of R_z, the RHP zero is pushed to ∞.

(b) (3 points) Argue that the second CS stage (M_5) is biased properly and its g_m is well defined.

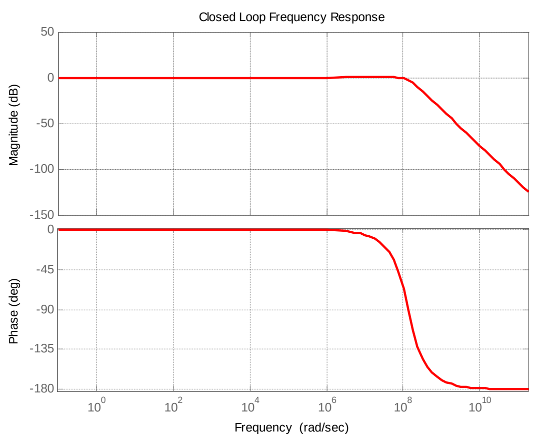
(c) (4 points) The open-loop frequency response for the amplifier is shown below.

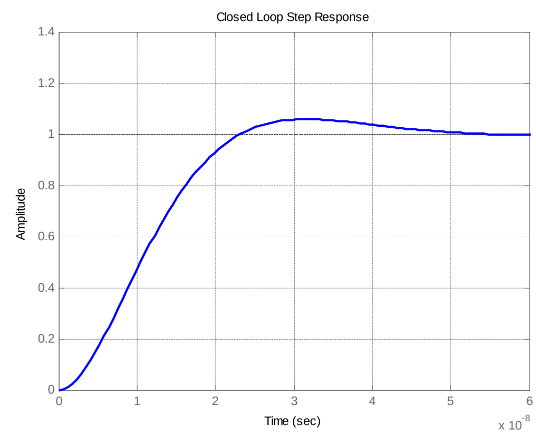


Label the gain and phase crossover points (**GX** and **PX**). Find the phase and gain margins (ϕ_M and **GM**), unity gain frequency (f_{un}) , and the dominant pole of the opamp.

(d) (3 points) Will this opamp be stable in closed loop? Why?

(e) (4 points) The frequency and transient step responses of the opamp in unity-gain feedback are shown below.



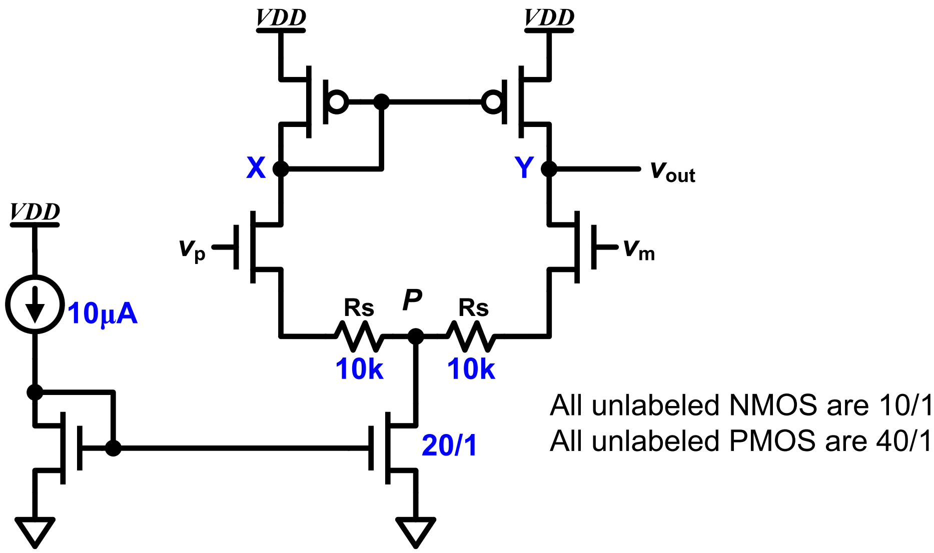


Is the phase margin of this plot of any significance? Why or why not?

(f) (3 points) What are the optimal damping factor (ζ) and phase margin (ϕ_M) for fastest settling of a two-stage opamp?

(g) (4 points) What is the effect of the finite DC gain on the transient settling accuracy of the opamp?

2. For the source-degenerated differential amplifier shown below ($V_{DD} = 5\,V$)



$KP_n = 200\frac{\mu A}{V^2}$, $V_{THN} = 1V$

$KP_p = 50\frac{\mu A}{V^2}$, $V_{THP} = 1V$

$\lambda_n = \lambda_p = 0.1\,V^{-1}$

(a) (4 points) Determine the DC operating currents and voltages at X and Y. Ignore channel length modulation for this part only.

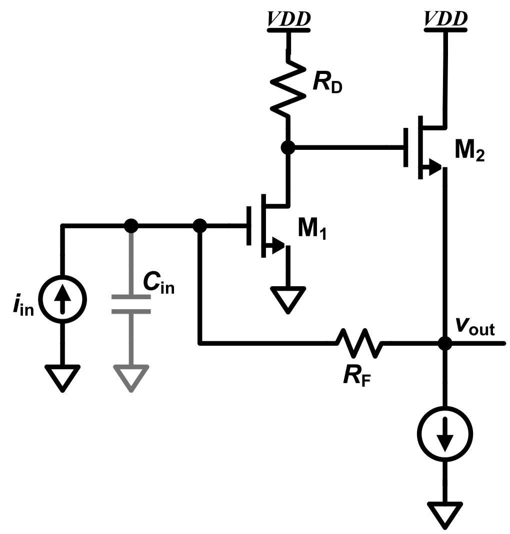
(b) (4 points) Assuming that **P** is an AC ground, draw the half circuits and find the small-signal differential gain ($A_{v,DM} = \frac{v_{out}}{v_{in}}$). Note the PMOS **current mirror** load which also contributes current to the output.

(c) (4 points) Draw the common-mode equivalent circuit and find the common mode gain ($A_{v,CM} = \frac{v_{out}}{v_c}$), where v_c is the common mode small-signal input.

(d) (4 points) What is the common-mode rejection ratio ($CMRR = \frac{A_{v,DM}}{A_{v,CM}}$) for this amplifier?

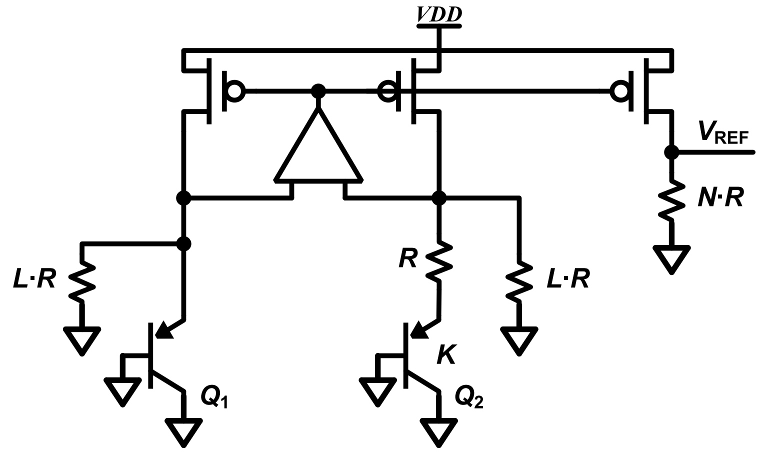
(e) (4 points) How many zeros are present in the AC response of this circuit? Are they on LHP or RHP. Explain why?

3. (15 points) A fiber-optic receiver converts the incident light into a small electrical current (i_{in}) signal using a photodiode. A typical feedback transimpedance amplifier, which converts this current into a large voltage signal (v_{out}). Here a CS amplifier is followed by a source-follower stage, all in a negative feedback loop.



Ignoring channel length modulation and body effect ($\lambda = 0$, $\gamma = 0$), find the low-frequency, small-signal transimpedance (R_T) defined as $R_T = \frac{v_{out}}{i_{in}}$.

4. The following bandgap circuit can operate with low supply voltages. Here, K signifies the number of pnp diodes in parallel.



Given: $\frac{\partial v_{BE}}{\partial T} = -1.5\frac{mV}{K}$, $\frac{\partial v_T}{\partial T} = 0.085\frac{mV}{K}$

$V_{BE_2} = 0.7V$ and $V_{SG} = 0.3V$.

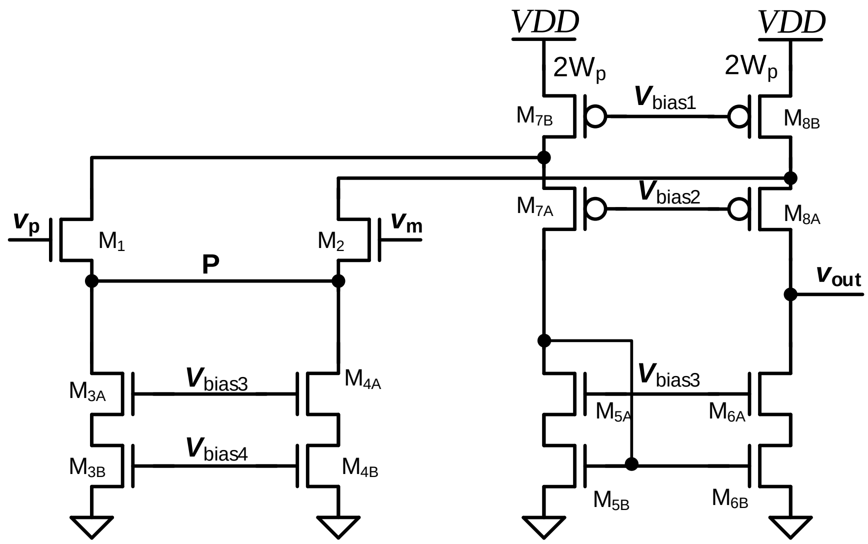
(a) (3 points) Assign positive and negative terminals on the amplifier to ensure negative feedback in the circuit.

(b) (7 points) For $K = 8$, find value of L which for which the output has zero temp coefficient (i.e. $\frac{\partial V_{REF}}{\partial T} = 0$).

(c) (6 points) Find value of N such that $V_{REF} = 0.5V$.

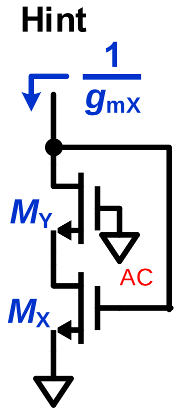
(d) (4 points) What is the minimum supply voltage for which the reference will operate properly?

5. For the folded cascode opamp shown in the figure below,



(a) (4 points) Assuming that **P** is an AC ground, draw the half circuits and find an expression for the small-signal differential gain ($A_{v,DM} = \frac{v_{out}}{v_{in}}$), where $v_{in} = v_p - v_m$. expression. Use variables g_{m1}, r_{o1}, g_{m5}, r_{o5}, etc to show your work.

(b) (4 points) Draw the common-mode equivalent circuit and find the common mode gain ($A_{v,CM} = \frac{v_{out}}{v_c}$), where v_c is the common mode small-signal input. See useful hint below.



(c) (4 points) Find the expression for $CMRR = \frac{A_{v,DM}}{A_{v,CM}}$.

(d) (4 points) Identify **all** the poles in the opamp.

(e) (4 points) Find the input common-mode range for the opamp.