Exam is open-book, open-notes. Clearly mark results with box around. No credit for ambiguous solutions. Show derivations. Return this cover page. Good luck!

UID #: ____________________________

Name: ____________________________

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1. [25] The Miller-compensated two-stage BJT operational amplifier shown below is to be used in a unity-gain feedback buffer (i.e., feedback factor = 1). Consider **ONLY** the capacitors shown in the schematic and assume that all transistors are biased in FAR. Use the following parameters to answer the questions.

\[ V_T = 25mV, \ V_A = 1V, \ \beta = \infty. \]

![Diagram of the Miller-compensated two-stage BJT operational amplifier](image)

1) Calculate the low-frequency gain of the amplifier. [5]
2) Calculate the unity-gain frequency. [5]
3) How many poles are there in the loop-gain? Calculate each pole frequency. [5]
4) How many zeros are there in the loop-gain? Calculate each zero frequency. [5]
5) Assuming an ideal exponential settling behavior, calculate the settling time for 0.01% settling accuracy when the amplifier is used in unity-gain feedback. [5]
2. [25] A simple five-transistor CMOS amplifier is shown in the following diagram. The input signal is fully differential. You may assume that the small-signal parameters of the transistors are known, i.e., $g_m's$, $r_o's$, etc., $C_M$ is the only capacitor in the circuit, and $I_{ss}$ is an ideal current source. Derive the frequency response of the amplifier, and sketch the Bode plot. Calculate any pole or zero frequencies in your Bode plot.
3. [25] Typical bandgap reference (BGR) circuits produce a temperature-independent (TI) output voltage of around 1.2–1.3 V. The fractional BGR shown below can produce a TI output voltage of lower than 1 V. You may assume that devices are well matched and the op-amp is ideal with a very large gain. Also, all MOSFETs are biased in saturation and BJTs in FAR. $V_T = 25mV, V_{BE} = 0.7V$. Transistor sizes are given in the schematic. Ignore base current of BJT and $r_o$ of MOSFET. Answer the following questions.

1) Explain the functionality of the op-amp. Can we swap the positive and negative inputs of the op-amp? Why or why not? [5]
2) Determine the relationship of the collector currents of $Q_1$ and $Q_2$. [5]
3) Give an expression for the output voltage $V_{OUT}$. Explain how the circuit works. [5]
4) Assuming that $23.5V_T + V_{BE}$ gives zero temperature dependence, determine the value of $R_2$ you need to choose to make $V_{OUT}$ TI. [5]
5) If $k = 0.5$, determine the numerical value of $V_{OUT}$. [5]
4. [25] In the active-load CMOS common-source amplifier below, assume all transistors are biased in saturation and consider **ONLY** the capacitors shown in the diagram. Answer the following questions. You may assume the following facts regarding the circuit:

$$g_{m1} = 2g_{m2}, \quad r_{o1} = r_{o2} \approx R, \quad g_{m1}r_{o1} = 20, \quad C_1 \neq C_2.$$ 

![Amplifier Diagram]

1) What is the (very) low-frequency gain of the amplifier? [5]  
2) If $C_1 = 0$, what is the (very) high-frequency gain of the amplifier? [5]  
3) If $C_2 = 0$, what are the pole and zero frequencies of the circuit, if any? Sketch the Bode plot of the frequency response. [5]  
4) If $C_1 = 0$, what are the pole and zero frequencies of the circuit, if any? Sketch the Bode plot of the frequency response. [5]  
5) Sketch the Bode plot of the frequency response with both $C_1$ and $C_2$. What are the pole and zero frequencies of the circuit, if any? [5]