ECEN 5008: Analog IC Design

Midterm Exam #1, Spring 2004

Instructions:

1. **Exam Policy:**
   - Time-limited, 50-minute exam. When the time is called, all work must stop. **Put your initials on the top of each page before the exam ends.**
   - Open book, open notes. No cooperation is allowed.
   - Show all work, partial credit will be given.

2. **Work in the space provided,** or on the back of the sheet, if necessary. Turn in these sheets.

3. The exam has 3 problems. The maximum number of points for each question and part is indicated in the square brackets.

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**NAME:**

Problem 1 [18]:

Problem 2 [50]:

Problem 3 [32]:

**TOTAL [100]:**
1. [18 points] This problem consists of three short, independent questions.

(a) [6] Given the device parameters $\mu_n C_{ox} = 40 \mu A/V^2$, $V_m = 1V$, $\gamma_n \approx 0$, $\lambda_n \approx 0$, solve for $R_b$ such that $I_D = 10 \mu A$ for the circuit shown in Fig.1. State the operating mode for all devices.

![Figure 1](image1)

![Figure 2](image2)

![Figure 3](image3)

(b) [6] Write expressions for the output resistance $R_{out}$ and the gain $v_o/v_i$ in the circuit shown in Fig.2, in terms of device small-signal parameters. The voltage $V_B$ is a DC bias voltage. You can assume both devices are in the active/sat operating mode.

(c) [6] Write expressions for the output resistance $R_{out}$ and the gain $v_o/v_i$ in the circuit shown in Fig.3, in terms of device small-signal parameters. You can assume both devices are in the active/sat operating mode and that $\gamma_n \approx 0$.
2. [50 points] In the CMOS circuit of Figure 4, the device parameters are as follows:

**NMOS:** \( \mu n C_{ox} = 40 \mu A/V^2, V_{th} = 1V, \gamma_n = 0, \lambda_n = 0.01[V^{-1}] \)

**PMOS:** \( \mu p C_{ox} = 20 \mu A/V^2, |V_{tp}| = 1V, \gamma_p = 0, \lambda_p = 0.01[V^{-1}] \)

The device aspect ratios \( W/L \) in \( \mu m/\mu m \) are shown in the figure. The voltage source \( V_B = 3V \) is a DC bias voltage. Complete the following parts and show all work.

![Figure 4](image)

(a) [10] For the DC inputs \( V_{i1} = V_{i2} = 1.5V \), solve for the DC operating points \( I_1 \) through \( I_3 \), \( V_1 \) through \( V_3 \), and the DC output \( V_o \).

(b) [10] For the DC input \( V_{i1} = 1.5V \), solve for the maximum input voltage \( V_{i2} \) such that all devices remain active/sat. Also, state which device will leave the active/sat mode first and which mode it will move into if \( V_{i2} \) were increased further.

(c) [10] For the DC input \( V_{i2} = 1.5V \), solve for the maximum input voltage \( V_{i1} \) such that all devices remain active/sat. Also, state which device will leave the active/sat mode first and which mode it will move into if \( V_{i1} \) were increased further.

(d) [10] At the DC operating point \( V_{i1} = V_{i2} = 1.5V \), solve for the small-signal gain \( V_o/V_{i2} \) (note input #2, assume input #1 is DC only) and solve for the small-signal output resistance \( R_{out} \).

(e) [10] For the DC input \( V_{i1} = 1.5V \), sketch an approximate curve for the output voltage \( V_o \) as a function of the input voltage \( V_{i2} \) over the range \( 0 \leq V_{i2} \leq 10V \). Label the operating modes of devices M0 & M2 in each region, including the voltages where either of these devices changes operating modes.
3. [32 points] In the voltage reference circuit of Figure 5, the device parameters are as follows:

$\mu_n C_{ox} \approx 100 \mu A/V^2, V_{m} \approx 1 V, \gamma \approx 0, \lambda_n \approx 0$

$\mu_p C_{ox} \approx 50 \mu A/V^2, V_{p} \approx 1 V, \gamma \approx 0, \lambda_p \approx 0$

Thermal Voltage: $V_T = 25.9 mV, \frac{\partial V_T}{\partial T} = 86 \mu V/\degree C$

Emitter – base: $V_{eb} \approx 660 mV, \frac{\partial V_{eb}}{\partial T} = -2 mV/\degree C$

Resistors: $TC(R) = \frac{1}{R} \frac{\partial R}{\partial T} = -1200 \text{ ppm}/\degree C = -1.2 \cdot 10^{-3}/\degree C$

The MOS device aspect ratios $W/L$ in $\mu m/\mu m$ and relative scale factors $m$ for the bipolar devices are shown. The op-amp can be assumed to be ideal. Complete the following parts and show all work.

(a) [5] Label the inverting and non-inverting inputs of the op-amp such that the bias circuit will operate properly.

(b) [10] Write an expression for the bias current $I_b$ in terms of the resistance $R$ and process parameters. Solve for the resistance $R$ that gives a bias current: $I_b = 10 \mu A$.

(c) [7] Write an expression for the output voltage $V_o$ in terms of the resistive scale factor $x$ and process parameters.

(d) [10] Solve for the resistive scale factor $x$ such that the temperature coefficient of the output voltage is approximately zero.