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.

4. Homework Policy: Collaboration is allowed. Attach this title page to your homework.

NAME:______________________________

Problem 1 [20]:_____________________

Problem 2 [40]:_____________________

Problem 3 [40]:_____________________

TOTAL [100]:_______________________

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1. **[20 points]** In the CMOS circuit of Figure 1, the device parameters are as follows:

**NMOS:** \( \mu_n C_ox = 100 \mu A/V^2 \), \( V_{tn} = 1V \), \( \gamma_n \approx 0 \), \( \lambda_n \approx 0 \)

The device aspect ratios \( W/L \) in \( \mu m/\mu m \) are shown in the figure. Complete the following parts and show all work.

(a) **[10]** Solve for the DC input \( V_i \) required to force the DC component of the output to \( V_o \approx 0V \) (i.e. zero current in resistor \( R_b \)).

(b) **[10]** Find an analytical expression (no numbers required) for the small-signal voltage gain \( A_v = v_o/v_i \) and output impedance \( R_{out} \) at the DC operating point found in part (a).
2. [40 points] In the CMOS circuit of Figure 2, the device parameters are as follows:

**NMOS:** \( \mu_n C_{ox} = 100 \mu A/V^2, V_m = 1V, \gamma_n \approx 0, \lambda_n = 0.01[V^{-1}] \)

**PMOS:** \( \mu_p C_{ox} = 50 \mu A/V^2, V_p = 1V, \gamma_p \approx 0, \lambda_p = 0.01[V^{-1}] \)

The device aspect ratios \( W/L \) in \( \mu m/\mu m \) are shown in the figure. Complete the following parts and show all work.

(a) [20] Find the minimum DC output voltage \( (V_o)_{\min} \) that maintains the output current \( I_o \approx I_b \). State the operating mode of all devices and the small-signal output resistance \( R_{out} \) (looking into the source of M4) in the range \( (V_o)_{\min} \leq V_o \leq VDD \).

(b) [20] Find the DC output voltage \( V_o \) where the output current is reduced to \( I_o \approx 25\mu A \). State the operating mode of all devices and the output resistance \( R_{out} \) (looking into the source of M4) at this operating point.
3. [40 points] In the CMOS circuit of Figure 3, the device parameters are as follows:

**NMOS:** \( \mu_n C_{ox} = 100 \mu A/V^2, V_m = 1V, \gamma_n \approx 0, \lambda_n = 0.01[V^{-1}] \)

**PMOS:** \( \mu_p C_{ox} = 50 \mu A/V^2, V_p = 1V, \gamma_p \approx 0, \lambda_p = 0.01[V^{-1}] \)

The device aspect ratios \( W/L \) in \( \mu m/\mu m \) are shown in the figure. Complete the following parts and show all work.

![Figure 3](image)

(a) [10] Given the DC input \( V_{i1} = 1.5V \), find the required DC input \( V_{i2} \) to operate all devices in the active/sat mode (hint: Current in M1 should be related by current mirror to current in M2, given by Vsg of M2).

(b) [15] Find analytical expressions (no numbers required) for the voltage gain \( A_{v1} = v_o/v_{i1} \) (note input #1 only) and output resistance \( R_{out} \) at the DC operating point found in part (a).

(c) [15] At the DC operating point \( V_{i1} = 1.5V, V_{i2} = 0V \), state the operating mode of all devices and find analytical expressions (no numbers required) for the voltage gain \( A_{v1} = v_o/v_{i1} \) (note input #1 only) and the output resistance \( R_{out} \) .