General Instructions:

1. Write on one side of the paper. (1 Pt.)

2. Put answers to all questions in the spaces provided on the test. (1 Pt.)

3. Show all work for full credit on questions requiring calculations. No credit will be given for answers alone, without supporting work.

4. Problems and questions are weighted as indicated. The maximum score is 100 points.

5. If you need more paper (provided in class), remove the staple from the exam and, when finished, arrange the test in order. Place the extra pages with supporting work in the test behind the page where the problem appears and indicate accordingly. Staple the entire test together so that there are no loose pages. (1 Pt.)

TEST SCORE: _____________________________ / 100

I certify that I have neither given nor received any assistance while taking this test from anyone.

______________________________ (Signature) (1 Pt.)

☐ Place a check mark in the box if you observed any suspicious actions while taking this test.
Formula Sheet: Equations/Constants that you may, or may not, need are listed below:

\[ K' = 50 \, \mu A/V^2 \] (unless otherwise stated in the problem)
\[ K_n = K'W/L \]
\[ \lambda = 0.01 \, V^{-1} \] (unless otherwise stated in the problem)
\[ V_{TO} = 0.7 \, V \] (unless otherwise stated in the problem)
\[ \gamma = 0.5 \, V^{1/2} \] (unless otherwise stated in the problem)
\[ 2\phi_F = 0.6 \, V \] (unless otherwise stated in the problem)
\[ I_{D-Triode} = \left(\frac{K_n}{2}\right) \left[2(V_{GS} - V_{TN})V_{DS} - V_{DS}^2\right] \]
\[ I_{D-Sat} = \left(\frac{K_n}{2}\right) (V_{GS} - V_{TN})^2 (1 + \lambda V_{DS}) \]
\[ V_{TN} = V_{TO} + \gamma [\sqrt{2\phi_F - V_{BS}} - \sqrt{2\phi_F}] \]
\[ r_o-MOS \approx 1 / (\lambda V_{DS}) \]
\[ g_{m-MOS} = \sqrt{2IDSK_n} \]
\[ V_{ds-sat} = \sqrt{2ID/K_n} \]
\[ g_{ob-MOS} = \eta g_{m-MOS} \]
\[ \eta = \gamma + 2 \sqrt{2(\phi_F - V_{BS})} \]

\[ V_i = kT/q \approx 26 \, mV \] and \[ I_S = 1E-15 \, A \] (unless otherwise stated in the problem)
\[ I_{Diode} = I_S [\exp(V_D/V_t) - 1] \]
\[ C_j = \frac{C_j0}{\left(1 - \frac{V_D}{V_{oj}}\right)^m} \quad \rightarrow 0.33 \leq m \leq 0.5 \]

\[ V_A = 100 \, V \] (unless otherwise stated in the problem)
\[ \beta_F = 50 \] (unless otherwise stated in the problem)
\[ I_{CE} = I_S [\exp(V_{BE}/V_t) - 1] [1 + V_{CE}/V_A] \]
\[ r_o-NPN = V_A / I_{CE} \]
\[ g_{m-NPN} = I_{CE}/V_t \]

\[ CMRR = |A_{dm}| / |A_{cm}| \]

\[ Z_{miller-in} = Z / (1 - k) \]
\[ Z_{miller-out} = Z k / (k - 1) \]
Fabrication – Part A (30 Points)

1. Draw the schematic (label the terminals) and identify the devices of the figures shown below, as they would be used (be specific – base-emitter diode of lateral NPN, accumulation-mode MOS capacitor, etc.). (10 pts)
2. Use the layout shown below to answer the following questions.

(a) Draw the corresponding schematic. (5 pts)
(b) Which terminal(s) (1, 2, 3, 4, or 5) is(are) more than likely connected to the positive power supply?

__________________________

(2 pts)

Why? ________________________________________________________

__________________________

(2 pts)

(c) Which terminal(s) is(are) more than likely connected to the negative power supply?

__________________________

(2 pts)

Why? ________________________________________________________

__________________________

(2 pts)

(d) Which terminal(s) is(are) more than likely the input(s) of the circuit?

__________________________

(2 pts)

(e) What specific capacitor components (e.g., $C_{db\_sidewall}$, $C_{db\_bottom}$, $C_{gs\_overlap}$, $C_{gs\_saturation}$, etc.) do you expect to be present on terminal 5?

__________________________

(5 pts)
Single and Two Transistor Amplifiers – Part B (25 Points)

1. Circle the single transistor amplifiers that produce a non-inverting transfer function. (6 pts)

   CC  CB  CE  CD  CG  CS

2. For the circuit shown and using small signal parameters (e.g., $r_n$, $g_m$, $\beta$, etc.), (a) derive input resistance $r_{in}$ and the transfer function from $V_i$ to $V_{o1}$ (i.e., $V_{o1}/V_i$) – assume $V_A$ is infinite ($r_o$ is infinite).

![Circuit Diagram]

(a) Derive input resistance $r_{in}$ and the transfer function from $V_i$ to $V_{o1}$ (i.e., $V_{o1}/V_i$) – assume $V_A$ is infinite ($r_o$ is infinite). (10 pts)

(b) The gain from $V_i$ to $V_{o2}$ (i.e., $V_{o2}/V_i$) is **greater than** / **less than** / **equal to** $V_{o1}/V_i$. (2 pts)

(c) **True / False**: $V_{o1}$ is in phase with $V_{o2}$. (2 pts)

(d) Derive the resistance looking into the collector of $q_{n1}$ ($r_x$)? (5 pts)
Differential Amplifiers – Part C (41 Points)

1. For the circuit shown and using small signal parameters (e.g., $r_\pi$, $g_m$, etc.) and labels shown (assume $\beta$ and $r_o$ are infinite), (a) derive the differential-mode gain of the circuit ($A_{dm} = V_o/V_{id}$) assuming the gain from $V_1$ to $V_o$ is unity ($V_o/V_1 = 1$), (b) derive the common-mode gain ($A_{cm} = V_o/V_{cm}$) using $r_E'$ for the resistance looking into the drain of $M_{nb1}$, and (c) calculate the common-mode rejection-ratio performance of the circuit. (25 pts)
2. Which devices have been used as current sources or sinks? ____________________________ (6 pts)

3. Of those, which one(s) exhibit(s) the lowest $V_{\text{min}}$? ____________________________ (6 pts)

4. Which one(s) has(ve) the best output resistance performance? _________________________ (4 pts)
**Part A**

1. MOS Capacitor

2. Reverse bias n-substrate junction

3. Isolate p-well from substrate

4. Reverse bias p-substrate junction

5. Polysilicon Resistor

6. n-substrate, p-well Technology
Part B (cont.):

\[ I_{s_1} = \frac{B}{g_m} \quad J_{c} = \frac{B}{g_{c_2}} \]

\[ g_{m_1} = \frac{V_{i}}{I_{c_1}} = \frac{g_{c_2}}{V_{c_2}} \quad R_{o_1} = \frac{V_{o_1}}{I_{c_1}} = \frac{V_{o_2}}{I_{c_2}} = \frac{B}{V_{o_2}} \]

\[ V_x = \left(\frac{g_{m_2}}{B}\right)B \left[ \left( R_{o_2} + (1+\beta)R_e \right) \right] \frac{1}{B \cdot V_{o_2}} \]

Part C:

\[ \frac{V_i}{V_{i_d}} = \frac{(-3m \cdot R_c)}{a} \]

\[ \frac{V_o}{V_{i_d}} = \frac{V_i}{V_{i_d}} \cdot \frac{V_o}{V_i} = g_m \cdot R_c \cdot \left(1\right) = g_m \cdot R_c \cdot a \]

Part D:

\[ V_o = \frac{V_{i_0}}{V_{c_0}} \cdot \frac{V_{i_1}}{V_{c_1}} \cdot \frac{V_{i_2}}{V_{c_2}} \]

\[ V_{o_m} = \left( \frac{g_m \cdot R_c \cdot \left( V_{i_1}^2 \right)}{V_{c_1} + (1+\beta)R_e} \right) \]

\[ = \frac{g_m \cdot R_c}{V_{c_1} + (1+\beta)R_e} \cdot \frac{V_{i_1}}{V_{i_2}} \]

\[ = \frac{g_m \cdot R_c}{1 + (1+\beta)R_e} \cdot V_{i_2} \]
Part c

\[ C_{MPR} = \frac{1}{\frac{A_{cm}}{A_{cm}}} = \left(\frac{\frac{A_{cm}}{A_{cm}}}{\frac{A_{cm}}{A_{cm}}}\right) \left(1 + \frac{1 + \frac{B}{\mu}}{\mu} \right) \left(\frac{V}{\frac{A_{cm}}{A_{cm}}}\right) \]

\[ \gamma \left(1 + \frac{B}{\mu} \right) \approx \gamma m \gamma e' \]

Part c

2. \( m_x \) and \( q_x \)
   \( q_{0x} \)
   \( q_{00} \)

3. \( q_{0x} \)
   \( q_{00} \)

4. \( m_x \) and \( q_x \)