Test Instructions: On your test provide the last four digits of your UT student identification number in the space provided at the top right of each page. Do not include your name on the test, just the last four digits your UT ID#. Carefully read the question before solving the problem. Show all your work in the space provided. Note the following suggestions:

- If necessary, write on the back of the problem page, but indicate where your work is continuing for that problem.
- If you are unable to obtain an intermediate value that is needed for subsequent steps in a problem, make an assumption, state it, and use your assumption for the subsequent steps.
- If you realize that your final answer is wrong, but you run out of time to fix it or are unable to find the mistake, indicate that you believe your answer to be wrong and why.
- Clearly mark your final answer with a box or circle.

Calculators are allowed, but they may not have any communication capability. Additional scratch paper is available on request.

1. (30 points) Consider the NMOS amplifier at right. Assume that the DC operating point is known and that the transistor operates in the forward active region. Use these parameters:

- \( I_D = 2 \text{ mA} \); \( V_{TN} = 1.0 \text{ V} \);
- \( K_N = 1 \text{ mA/V}^2 \)
- \( R_1 = 500 \text{ k}\Omega \); \( R_2 = 500 \text{ k}\Omega \)
- \( R_3 = 2 \text{ k}\Omega \); \( R_s = 1 \text{ k}\Omega \)
- \( R_X = 10 \text{ k}\Omega \); \( R_L = 8 \text{ k}\Omega \)
- \( V_{DD} = 10 \text{ V} \)
- \( C_1, C_2, \) and \( C_3 \) are very large
- Neglect the channel-length modulation unless directed otherwise.

![NMOS amplifier diagram]

a) (4 pts) Find \( g_m \) of the transistor

\[
g_m = \frac{2 \cdot I_D}{V_{in} - V_{TN}} = \sqrt{2 \cdot K_N \cdot I_D} = 2 \text{ mS}
\]

\[
= \frac{2 \cdot 2 \text{ mA}}{3 \text{ V} - 1 \text{ V}} = 2 \text{ mS}
\]

\[
g_m = 2 \text{ mS}
\]
b) (8 pts) Find the input resistance as seen looking into the amplifier from C2

\[ R_{in} = R_{i3} \parallel R_i \]
\[ R_{i3} = \frac{1}{S_m} = 500 \Omega \]
\[ R_i = 500 \Omega \parallel 1k\Omega = 333 \Omega \]

\[ R_{in} = 333 \]

c) (8 pts) Find the terminal voltage gain \( A_{vt} = v_o/v_i \) where \( v_i \) is the small signal voltage at the source of the transistor.

\[ A_{vt} = g_m \left( R_e \parallel R_3 \right) \]
\[ = 2mS \left( 8k\Omega \parallel 1k\Omega \right) \]
\[ = 3.2 \]

\[ A_{vt} = 3.2 \]
d) (5 pts) Find the total voltage gain $A_v = \frac{v_f}{v_x}$

$$A_v = \left( \frac{R_i}{\sqrt{R_2 + R_i}} \right) \left( \frac{R_i \cdot R_2}{R_3} \right)
\begin{align*}
&= \frac{333}{10 + 333} (\approx 3.2) = 3.1 \\
&= 3.1
\end{align*}$$

$$A_v = 3.1$$

e) (5 pts) Suppose that you want to increase the gain by increasing the value of $R_3$. How large could $R_3$ be while ensuring that the transistor's DC operating point remains in the forward active region.

Active region requires

$V_C - V_D \leq V_T I_N$

$V_D \geq V_C - V_T I_N$

$V_{DD} - I_D R_3 \geq 5 - 1$

$$R_3 \leq \frac{V_{DD} - 4V}{2mA} = 3\, k\Omega$$

$$R_{3,max} = 3\, k\Omega$$
2. (15 points) Consider the circuit at right. Using the parameters below, find the Q-point (I_c, V_{CE}) of the PNP transistor shown.

- \( \beta = 150; \) V_{EB} = 0.6 V
- \( R_1 = 56 \text{k}\Omega; \) \( R_2 = 400 \text{k}\Omega \)
- \( R_3 = 67 \text{k}\Omega \)
- \( V_{CC} = V_{EE} = 5 \text{V} \)
- Neglect the Early effect

\[
\frac{I_E}{R} = \frac{I_R}{R_2} = \frac{I_C}{R_3} = \frac{V_{CC} - V_{BE}}{R_3}
\]

\[
I_E = \frac{I_C}{\beta} \quad I_R = \frac{I_C}{\beta}
\]

\[
I_C = \frac{9.4 \text{V}}{126.4 \text{k}\Omega} = 74.3 \text{mA}
\]

\[
V_{CE} = V_{CC} - V_{BE} - I_C R_1 = 10 \text{V} - 74.3 \text{mA} \cdot 123 \text{k}\Omega
\]

\[
I_C = \frac{74.3 \text{mA}}{\beta} = 74.3 \text{mA}
\]

I_c = 74.3 mA  \quad V_{CE} = 0.8 \text{V}
3. (20 points) Consider the PMOS amplifier shown here. Assume the bias point and small-signal parameters are known. Use the parameters below.

- \( g_m = 25 \mu S \); \( I_D = 6.25 \mu A \)
- \( K_P = 50 \mu A/V^2 \)
- \( R_1 = 400 \, k\Omega \); \( R_2 = 100 \, k\Omega \)
- \( R_3 = 480 \, k\Omega \)
- \( V_{DD} = 5 \, V \)
- Neglect channel-length modulation.

a) (12 pts) Assuming \( R_L \) is infinite, find the linear input range, i.e. the maximum input amplitude for which we can assume linear operation.

The general formula for maximum amplitude of a common-drain amp is

\[
v_{i,\max}^{CD} = 0.2V_{OV}(1 + g_m R_S)
\]

We could also get the same expression as follows

\[
v_{gs,\max} = 0.2V_{OV}
\]

\[
v_{gs,\max} = \frac{v_i}{1 + g_m R_S}
\]

\[
v_{i,\max} = 0.2V_{OV}(1 + g_m R_S)
\]

\[
R_S = R_3 || R_L = R_3
\]

\[
V_{OV} = V_{SG} - |V_{TP}|
\]

\[
I_D = \frac{K_P}{2} V_{OV}^2
\]

\[
V_{OV} = \sqrt{\frac{2I_D}{K_P}} = 0.5V
\]

\[
v_{i,\max} = 0.2V_{OV}(1 + g_m R_S)
\]

\[
= 0.2 \cdot 5V(1 + 25 \mu S \cdot 480k\Omega)
\]

\[
v_{i,\max} = 6.5V
\]

Input Range = __________
b) (8 pts) Find the minimum value of $R_L$ such that the amplifier has a linear input range of at least 0.5 V.

\[
\begin{align*}
R_{e, \text{eq}} &= 0.5 \cdot \frac{0.2 \times 0.5}{1 + \frac{1}{g_m (R_3 || R_L)}} \\
R_3 || R_L &= \left[ \frac{0.5}{(0.2 \times 0.5)} - 1 \right] \frac{1}{g_m} = 160 \text{ k}\Omega \\
\frac{480 \text{ k}\Omega - R_L}{480 \text{ k}\Omega + R_L} &= 160 \text{ k}\Omega \\
R_L &= 240 \text{ k}\Omega
\end{align*}
\]
4. (15 points) Find the input resistance of the amplifier shown here. Assume that the DC operating point is known. **Account for the Early effect** (i.e. $r_o \neq 0$). Also note the unusually low value for both the Early voltage. Use these parameters:

- $I_C = 200 \mu A$
- $\beta = 20$, $V_A = 5 \text{ V}$
- $R_E = 30 \text{ k} \Omega$
- $R_{B1} = R_{B2} = 500 \text{ k} \Omega$

\[
\begin{align*}
\gamma_m &= \frac{I_c}{V_T} = 8 \text{ ms} \\
r_{\pi} &= \frac{S}{\gamma_m} = 2.5 \text{ k} \Omega \\
r_o &= \frac{V_A}{I_c} = 25 \text{ k} \Omega
\end{align*}
\]

Note that $r_o$ is in parallel with $R_E$.

**Use Rin equation for standard CC amplifier and replace $i_{CE}$ with $i_{BE}$**

\[
\begin{align*}
R_{ib} &= r_{\pi} + \frac{S}{\gamma_m} \left( \frac{R_E}{r_o} \right) = 2.5 \text{ k} \Omega + 21 \left( \frac{30 \text{ k} \Omega}{25 \text{ k} \Omega} \right) \\
&= 288 \text{ k} \Omega \\
R_{in} &= R_{ib} \parallel R_{bb} \\
&= 133.8 \text{ k} \Omega
\end{align*}
\]

\[R_{in} = 133.8 \text{ k} \Omega \text{ (or } 131 \text{ k} \Omega)\]
5. (20 points) Assume that the DC operating point is known and that the transistor operates in the forward active region. Use these parameters:

- $g_m = 5 \text{ mS}$; $\beta = 100$
- $R_I = 5 \text{ k} \Omega$
- $R_{B1} = R_{B2} = 100 \text{ k} \Omega$
- $R_E = 14 \text{ k} \Omega$
- $R_C = 2 \text{ k} \Omega$
- $R_L = 8 \text{ k} \Omega$
- Neglect the Early effect

a) (10 pts) Find the value of $C_1$ that will ensure operation down to 100 Hz.

$$C_1 = \frac{10}{2\pi (100 \text{ Hz}) (R_I + R_{\text{in}})}$$

$$R_{\text{in}} = \frac{R_{B1} || R_{B2} || [R_m (4 + g_m R_E)]}{50 \text{ k} \Omega || 1.4 \text{ M} \Omega} = 48.3 \text{ k} \Omega$$

$$C_1 = \frac{29.5 \times 10^{-9}}{} \text{ F}$$

$$C_1 = 29.5 \times 10^{-9} \text{ F}$$

b) (10 pts) Find the value of $C_2$ that will ensure operation down to 100 Hz.

$$C_2 = \frac{10}{2\pi (100 \text{ Hz}) (R_L + R_C)}$$

$$C_2 = 1.59 \times 10^{-6} \text{ F}$$