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. (35 points) Consider the PNP amplifier at right. Assume that the DC operating point is known and that the transistor operates in the forward active region. Use these parameters:
   - $I_C = 2 \text{ mA}$; $\beta = 50$
   - $R_B = 50 \Omega$; $R_C = 5 \text{ k}\Omega$
   - $R_B1 = 4 \text{ k}\Omega$; $R_B2 = 80 \text{ k}\Omega$
   - $R_S = 2 \text{ k}\Omega$; $R_L = 100 \text{ k}\Omega$
   - $V_{CC} = V_{BB} = 10 \text{ V}$
   - $C_1$ and $C_2$ are very large
   - Neglect the Early effect unless directed otherwise.

   a) (5 pts) Find $g_m$ and $r_n$ of the transistor

   $$g_m = \frac{I_C}{V_T} = \frac{2 \text{ mA}}{0.75 \text{ mV}} = 80 \text{ mS}$$

   $$r_n = \frac{6}{g_m} = 6.25 \Omega$$

   $$g_m = 80 \text{ mS} \quad r_n = 6.25 \Omega$$
b) (10 pts) Find the input resistance as seen looking into the amplifier from $C_1$

$$R_{in} = \frac{R_{B1}}{1 + \frac{R_{D2}}{r_{\pi} + (\beta + 1)R_C}}$$

$$= \frac{4k}{1 + \frac{30k}{10k}} = \frac{317.5}{1}$$

$$R_{in} = 1.73\, \text{k}\,\Omega$$

c) (10 pts) Find the output resistance looking back into the amplifier from $C_2$.

Neglect Early effect, so $r_s \to \infty$

and

$$R_{out} = \frac{12}{\beta} = 5\, \text{k}\,\Omega$$

$$R_{out} = 5\, \text{k}\,\Omega$$
d) (10 pts) Find the overall small-signal gain $v_o/v_i$. Neglect the Early effect, but be sure to account for the effect of the driving resistance and load resistance ($R_S$ and $R_L$).

\[ A_V = \left( \frac{R_c}{R_c + R_S} \right) \left( 1 + \frac{5m (R_e + R_L)}{1 + \gamma_m R_e} \right) \]

Input

Attenuation

\[ \frac{v_o}{v_i} \]

= 35.3

\[ A_V = -35.3 \]
2. (25 points) Consider the circuit at right. Use the parameters below.
- $K_N = 800 \mu A/V^2; V_{TN} = 0.5 \text{ V}$
- $\lambda = .02 \text{ V}^{-1}$
- $R_D = 15 \text{ k}\Omega, R_S = 5 \text{ k}\Omega$
- $R_G = 1 \text{ M}\Omega$
- $V_{DD} = 3 \text{ V}$

a) (18 pts) Find the Q-point ($I_{DS}, V_{DS}$) of the NMOS transistor shown. Neglect channel-length modulation for this part.

\[ I_c = 0 \rightarrow V(R_N) = 0 \rightarrow V_{GS} = V_{DS} \]
\[ I_D R_D + V_{GS} + I_D R_S = 0 \rightarrow V_{DS} = \frac{2I_D}{K_N} + V_{TN} \]
\[ I_D R_D + \sqrt{\frac{2I_D}{K_N}} + V_{TN} + I_D R_S - V_{DD} = 0 \]

Let $I_D = 100 \text{ mA}$
\[ V_{DS} = V_{DD} - I_D (R_S + R_D) = 3 - 100 \text{ mA} \times 20 \text{ k}\Omega = 0 \text{ V} \]

\[ I_{DS} = 100 \text{ mA} \quad V_{DS} = 1 \text{ V} \]

b) (7 pts) Find the small-signal parameters $g_m$ and $r_o$.
\[ V_o = \frac{1}{\lambda I_D} = 500 \text{ k}\Omega \]
\[ g_m = \frac{2 I_D}{V_{GS} - V_{TN}} = \frac{2 \times 100 \text{ mA}}{0.5 \text{ V}} = 400 \text{ mS} \]
\[ r_o = 500 \text{ k}\Omega \quad g_m = 400 \text{ mS} \]
3. (20 points) Consider the NMOS amplifier below. Assume the small-signal parameters are known. Use the parameters below.

- $g_m = 4 \text{ mS}$
- $R_1 = 1 \text{ k}\Omega$; $R_L = 5 \text{ k}\Omega$
- $R_2 = 500 \text{ k}\Omega$
- $R_3 = 1 \text{ k}\Omega$; $R_4 = 5 \text{ k}\Omega$
- Neglect channel-length modulation.

![NMOS Amplifier Diagram]

(a) (10 pts) Find a value for $C_1$ such that the low-frequency cutoff is well below 100 Hz.

\[ \text{Eqn. 17.5: across } C_1 \]

\[ R_{eq} = R_1 + R_1/R_2 = 2.5 \text{ k}\Omega \]

\[ C_1 = \frac{10}{2\pi(100)(2.5 \text{ k}\Omega)} = 6.3 \text{ nF} \]
b) (10 pts) Find a value for $C_2$ such that the low-frequency cutoff is well below 100 Hz.

\[ R_{c2} = R_c + \frac{i}{f_m} || R_4 \]

\[ = 5 \, \text{k}\Omega + \frac{250 \, \text{Hz}}{15 \, \text{kHz}} \]

\[ = 5.24 \, \text{k}\Omega \]

\[ C_2 = \frac{10}{2 \pi (100) 5.24 \, \text{k}\Omega} \]

\[ C_2 = 3.04 \, \text{mF} \]
4. (20 points) In the amplifier shown below, a small-signal voltage $v_a$ is applied as shown and the resulting voltage at $v_b$ is observed. Find the voltage gain $A_V = v_b / v_a$. This is the "reverse gain" of a common-collector amplifier. Assume that the DC operating point is known and that the transistor operates in the forward active region. Use these parameters:

- $g_m = 5 \text{ mS}$; $\beta = 100$
- $R_1 = 5 \text{ k}\Omega$
- $R_{B1} = R_{B2} = 100 \text{ k}\Omega$
- $R_E = 14 \text{ k}\Omega$
- All capacitors are very large
- Neglect the Early effect

\[ V_{CC} \]

\[ R_{B1} \quad R_{B2} \quad R_E \]

\[ v_a \quad v_b \]

\[ C_1 \quad C_2 \]

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Small-signal model

Let $R_X = \frac{R_{B1}||R_{B2}}{R_E} = 4.5 \quad \Omega$

\[ N_a \]

\[ R_E \quad g_m V_{BE} \quad R_1 \]

\[ R_{B1} \quad R_{B2} \quad R_E \]

\[ v_a \quad v_b \]

\[ N_b = V_b \quad \frac{R_X}{R_{BE} + R_X} \quad R_{BE} = \frac{\beta}{g_m} = 20 \quad \Omega \]

\[ A_V = \frac{N_b}{N_a} = \frac{4.5 \quad \Omega}{4.5 \quad \Omega + 20 \quad \Omega} = 0.185 \]

\[ A_V = 0.185 \]