Name  Joe Solution  

Section  2  

CM 123  

Scores:  
1) 2  
2) 2  
3) 2  
4) 2  

Total 100  

I pledge on my honor that I did not copy any of this exam, and that this work is entirely my own. Furthermore, I did not use PSpice during this exam, except for the lab quiz.  

Signature: [Signature]
Problem 1 (25 Points):

a) Find an equation for the gain $\frac{V_o}{V_in}$. (10 Points)

b) Assuming a bias current of 1 $\mu$A, find numerical values for $V_1$ and $V_0$ due to bias currents. (10 Points)

c) Add resistors (as many as necessary) to the circuit to eliminate the output due to bias currents. Specify numerical values for the resistors and show where you would place them in the circuit diagram. (5 Points)

\[
\frac{V_x}{V_1} = \frac{R_4}{R_4 + R_3} = \frac{2k}{2k + 1k} = 2/3 \quad \text{(2)}
\]

\[
\frac{V_0}{V_x} = 1 + \frac{R_5}{R_6} = 1 + \frac{1k}{2k} = 3/2 \quad \text{(2)}
\]

\[\text{so \ we \ have \ the \ simplified \ circuit} \]

\[
\frac{V_o}{V_1} = \left(\frac{V_x}{V_1}\right) \left(\frac{V_0}{V_x}\right) = \left(\frac{2}{3}\right) \left(\frac{3}{2}\right) = 1 \quad \text{(2)}
\]
We know that \( V_y = V_1 \) and \( V_1 = V_0 \) so solve for:

\[
V_y = \frac{V_0 \cdot R_2}{R_1 + R_2} + \frac{V_{\text{in}} \cdot R_1}{R_1 + R_2} = \frac{V_0}{2} + \frac{V_{\text{in}}}{2}
\]

Since \( V_y = V_1 \) and \( V_1 = V_0 \) \( \Rightarrow \) \( V_y = V_0 \)

so we have

\[
V_0 = \frac{V_0}{2} + \frac{V_{\text{in}}}{2}
\]

Solve for \( V_0 \) \( \Rightarrow \) \( V_0 = V_{\text{in}} \)

a lot of circuit for little function!
For opAmp 2, \( R_P = R_3 || R_4 = 2k \Omega || 1k \Omega \)

\( R_m = R_5 || R_6 = 2k \Omega || 1k \Omega \)

Since \( R_P = R_m \) \( V_0 = 0 \) due to its bias currents. However, since \( V_0 = V_1 \), \( V_0 = -1 \text{mV} \) also.

For opAmp 1 we have

\( R_P = R_1 || R_2 = 2k \Omega || 1k \Omega = 1k \Omega \)

\( R_m = 0 \)

\( V_P = -I_B R_P = (-1 \mu A) 1k \Omega = -1 \text{mV} \)

Since \( V_P = V_m = 0 \) \( V_0 = V_P = -1 \text{mV} \)

\( c) \) See CKT
Problem 2: (25 Points)

Assume that the OPAMP output has limits of \( \pm 15 \text{ V} \).

a) Sketch the transfer curve \( V_o \) versus \( V_{in} \). (5 Points)

b) Find a numerical value for the upper trigger point. (10 Points)

c) Find a numerical value for the lower trigger point. (10 Points)

\[ V_{LT} \]

\[ V_{UT} \]

\[ V_{in} \]

\[ V_o = -15 \text{ V} \]

\[ V_{m} = 0 \]

\[ V_{\phi} \]

\[ V_o = -15 \text{ V} \]
\( V_P = 2V \left[ \frac{R_1 R_3}{R_2 + R_1 R_3} \right] + V_{IN} \left[ \frac{R_2 R_3}{R_1 + R_2 R_3} \right] + (-15V) \left[ \frac{R_1 R_2}{R_3 + R_1 R_2} \right] \)

\[ = 0.909V + V_{IN} (0.455) - 1.364V \]

Set \( V_P = V_{IN} \), solve for \( V_{IN} \)

\( V_{IN} = 1V = V_{TP} \)

For \( LTP \) \( V_0 = +15V \)

\( V_{IN} = 0 \)

\( V_P = 2V \left[ \frac{R_1 R_3}{R_2 + R_1 R_3} \right] + V_{IN} \left[ \frac{R_2 R_3}{R_1 + R_2 R_3} \right] + 15V \left[ \frac{R_1 R_2}{R_3 + R_1 R_2} \right] \)

\[ = 0.909V + V_{IN} (0.455) + 1.364V \]

Set \( V_P = V_{IN} \), solve for \( V_{IN} \)

\( V_{IN} = -5V = LTP \)
Problem 3: (25 Points)

The specifications for the OPAMP in the circuit above are:
- $V_{10} = 1$ mV
- $I_B = 100$ nA
- $A_0 = 1$ MHz (Unity gain bandwidth)
- $V_{CC} = 15$ V
- $V_{EE} = 15$ V

a) Find the gain $V_o/V_{IN}$. (5 points)
b) Find $V_o$ due to offset voltages. (5 Points)
c) Find $V_o$ due to bias currents. (5 Points)
d) Find the upper -3 dB Frequency of the circuit. (5 Points)
e) Add resistor(s) to the circuit to eliminate the output due to bias currents. The added elements should not change the gain. (5 Points)

(d) Pretend the input has two inputs

$$V_o = -\frac{R_8}{R_7} V_{IN} + V_{IN} \left[ \frac{R_{10}}{R_9 + R_{10}} \right] \left[ 1 + \frac{R_8}{R_7} \right]$$

$$= -\frac{5}{9} V_{IN}$$

$$\Rightarrow \frac{V_o}{V_{IN}} = -\frac{5}{9}$$
b) Add $V_{10}$ somewhere easy to do

\[ V_0 = V_{10} \left[ 1 + \frac{R_8}{R_7} \right] \]
\[ = 1 \text{mV} \left( 1 + \frac{1}{3} \right) \]
\[ = \frac{7}{3} \text{mV} \]

\[ \nabla_p = -I_B R_9 || R_{10} \]

\[ \nabla_m = -I_B (R_8 || R_7) + \frac{V_0 R_7}{R_7 + R_8} \]
Set $\nu_p = \nu_m$ solve for $v_0$

$$-I_b(R_{9||R_{10}}) = -I_b(R_{8||R_7}) + \frac{v_0 R_7}{R_7 + R_8}$$

$$v_0 = \left(\frac{R_7 + R_8}{R_7}\right)\left(R_{8||R_7} - R_{9||R_{10}}\right)I_b$$

$$= 244 \mu V$$

d) $\nu_m = v_0 \frac{R_7}{R_7 + R_8} + v_{mN} \frac{R_8}{R_7 + R_8}$

$$F = \frac{R_7}{R_7 + R_8} \Rightarrow F_{3dB} \equiv F_{A_0} = \frac{R_7 A_0}{R_7 + R_8} = \frac{3}{7} \text{ MHz}$$

c) add $R_x$ as shown

$$R_x = (4k||3k) - (1k||2k) = 1048 \Omega$$
Problem 4: (25 Points)

Assume negative feedback. Assume that all resistors are equal. (This is not a Schmitt Trigger.)

a) Find an equation for the load current. (13 Points)

\[ V_o = \frac{V_p}{1 + \frac{R}{R}} = 2 \cdot \frac{V_p}{R} \]

So we have

\[ I_{load} = I_1 + I_2 \]

\[ I_1 = \frac{V_i - V_p}{R} \]

\[ I_2 = \frac{V_o - V_p}{R} \]

Sub in \( V_o = 2V_p \)

\[ I_{load} = \frac{V_i - V_p}{R} + \frac{2V_p - V_p}{R} \]

\[ I_{load} = \frac{V_i}{R} \]
b) Find an equation for the output voltage $V_o$. (12 Points)

Note $V_c = V_p$ and $I_C = I_{load}$ from Part A

$$I_C = C \frac{dV_c}{dt} = I_{load} = \frac{V_p}{R}$$

$$C \frac{dV_c}{dt} = \frac{V_p}{R} \Rightarrow V_c(t) = \frac{1}{RC} \int V_p(t) \, dt + I_c$$

From (6), $V_o = 2V_p = 2V_c$

$$V_o(t) = \frac{2}{RC} \int_{t_0}^{t} V_p(t) \, dt + V_0(t_0)$$

Initial Condition