ECE 476
Exam #2 Spring 2019

Name: __________

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Problem 1.  (20 points)

Consider the circuit shown below. Assume the NPN transistor has a $\beta$ of 250 and an infinite early voltage. Use short-circuit time constant analysis to determine the lower corner frequency, $f_L$, of the amplifier. I solved the DC problem and determined that $I_C$ is 2 mA.

(a) Determine the $r_\pi$ of the transistor.

$$ r_\pi = \frac{r_\pi}{9m} = \frac{B}{1 + \frac{V_T}{U_T}} = \frac{250 \times (25.9 \text{ mV})}{2 \text{ mA}} = \frac{1}{3.2 \text{ k}\Omega} $$

(b) Determine the equivalent time constant associated with capacitor, $C_1$?

$$ T_1 = C_1 \left[ \sum R_5 + \frac{R_1 R_2}{R_1 + R_2} \right] = \frac{1.57 \text{ ms}}{1.57 \text{ ms}} $$

(c) Determine the equivalent time constant associated with capacitor, $C_2$?

$$ T_2 = C_2 \left[ \sum R_4 \left[ \frac{R_4}{\beta + 1} + \frac{R_3 R_1}{R_2 + R_3} \right] \right] $$

$$ T_2 \sim \frac{C_2}{4.7 \mu F} \sim 658 \text{ ms} $$

(d) What is $f_L$?

$$ f_L \sim \frac{1}{2\pi} \left[ \frac{1}{r_\pi} + \frac{1}{C_1} \right] = \frac{1}{3.43 \text{ Hz}} $$
Problem 2. (20 points)
Consider the circuit shown below. Assume the NPN transistor has a $\beta$ of 250 and an infinite Early voltage. Use open-circuit time-constant analysis and Miller’s Theorem to determine the upper corner frequency, $f_H$, of the amplifier. The capacitor $C_2$ is much larger than the transistor parasitic capacitances, $C_\pi$ and $C_m$, and therefore these may be ignored. I solved the DC problem and determined that $I_C$ is 2 mA.

\[ g_m = \frac{\frac{2N}{V_T}}{2S.9mV} = 77 \text{ mV} \]

(a) What is the midband-frequency gain of the amplifier (from base node to collector node)?

\[ K = -g_m R_3 = -77 \text{ mV} \times 2.7 \Omega \approx -208 \]

(b) What is value of the Miller capacitance from the base of the transistor to ground?

\[ C_M \approx (1 - K) C_2 = 209 \times (7 \times 10^{-12} \text{ F}) = 1.4 \times 10^{-10} \text{ F} \]

(c) Compute the relevant time constants.

\[ \tau_1 = C_M \sum \frac{1}{2 \pi} \left( \frac{1}{R_4 \times R_3} \right) = 3.6 \times 10^{-2} \text{ s} \]

\[ \tau_0 = (1 - K) \frac{C_2}{R_3} \approx 4.9 \times 10^{-9} \text{ s} \]

(d) What is $f_H$?

\[ f_H \approx \frac{1}{2 \pi} \left( \frac{1}{\tau_1 + \tau_2} \right) \approx 9.3 \text{ kHz} \]
Problem 3.  (20 points)

Consider the closed-loop amplifier shown below.

(a) What type of negative feedback is being utilized? (series-series, series-shunt, shunt-shunt, shunt-series)?

(b) Draw the feedback network and determine the feedback factor, B.

\[ B = (0.01) \left[ \frac{10K}{20.1K} \right] = 0.00498 \]

(c) What is the closed-loop gain, \( A_f \), approximately?

\[ A_f \approx \frac{1}{B} \approx \frac{1}{0.00498} \approx 200 \]
Problem 4. (20 points)

Consider a negative feedback system. The typical open-loop gain of the op amp used in the design is 35,000 V/V but this open-loop gain is accurate only to 20%. A closed-loop gain of 25 V/V is desired.

(a) What is the minimum value of GBW required by this application so that the closed-loop bandwidth of the amplifier is 10 MHz?

\[ BW \cdot \text{Gain} = GBW = 10 \text{MHz} \times 25 = \sqrt{250 \text{MHz}} \]

(b) What value of B is needed so that the closed-loop gain will be exactly 25 when the typical value of A is used?

\[ A_f = \frac{A}{1 + AB} \Rightarrow \frac{1 + AB}{A} = \frac{A}{A_f} \]

\[ B = (\frac{A}{A_f} - 1) \frac{1}{A} = \left( \frac{35 \times 10^3}{25} - 1 \right) \left( \frac{1}{35 \times 10^3} \right) \]

\[ B \approx 0.006997 \quad \text{Note} \quad \frac{B}{25} \approx 25.1 \]

(c) How much error (approximately) will there be in the closed-loop gain due to the error in the open-loop gain?

\[ \frac{\Delta A_f}{A_f} = \frac{1}{1 + T} \cdot \frac{\Delta A}{A} \]

\[ T = \left( \frac{35 \times 10^3}{0.03997} \right) \]

\[ T \approx 1400 \]

\[ = \frac{1}{1 + (35 \times 10^3) \times 0.03997} \quad (20\%) \]

\[ \approx 0.014 \quad (10\%) \]

(d) If the input impedance of the open-loop system is 5 MΩ, what is the input impedance of the resulting closed-loop system?

\[ \text{Series - Shunt (Voltage Amp)} \]

\[ R_{in} = R_i \cdot (1 + T) \approx \frac{R_i \cdot T}{5 \text{MΩ}} \]

\[ \approx \frac{76}{1400} \approx 54 \Omega \]
**Problem 5. (10 points)**

Answer the questions concerning the classic block diagram which is used to describe negative feedback systems. Assume \( x_s \) is 1 mA, \( x_o \) is 500 mV, and \( x_i \) is 1 \( \mu \)A.

\[ \frac{x_s - x_f}{x_f} = x_i \]
\[ x_f = \frac{x_s - x_i}{1mA - 1mA} \]

(a) What is \( A \)?

\[ A = \frac{500mV}{1mA} = 500 \text{ Ka} \]

(b) What kind of feedback amplifier is this? (voltage, current, transresistance, transconductance)?

\[ I \to V \]

(c) What is the feedback factor, \( B \)?

\[ B = \frac{x_f}{x_o} = \frac{1mA - 1mA}{500mV} = \frac{1mA}{1.998mV} = 500k \]

Note: \( \frac{1}{1.998mV} = 500k \)

(d) What is the loop gain?

\[ T = A \times B = (500k \Omega)(1.998mV) \]

\[ T = 999 \]
Problem 6. (10 points) *** GRADUATE STUDENTS ***

An engineer wants to implement a negative feedback system using a series-shunt feedback topology. The closed-loop gain should be 0.5.

(a) What must the feedback factor, B, be approximately?

\[ B \approx 2 \]

(b) Draw a circuit that can be used to implement the feedback factor i.e. a circuit that can be used to achieve the value of B from part (a). **Hint:** An active rather than a passive circuit is needed.

\[ \text{GAIN} = 1 + \frac{10K}{10K} = 2! \]

(c) Draw the complete negative feedback circuit. **Hint:** You should have two op amps in your circuit!

\[ V_f = \frac{2V_0}{B} \]