Texas A&M University
Department of Electrical and Computer Engineering

ECEN 325 – Electronics

Spring 2017

Exam #1

Instructor: Sam Palermo

- Please write your name in the space provided below
- Please verify that there are 7 pages in your exam
- You may use one double-sided page of notes and equations for the exam
- Good Luck!

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Name: SAM PALERMO

UIN: ____________________________
Problem 1 (30 points)
Plot the magnitude and phase response of the following transfer functions. Label key points and slopes.

\[ F(s) = \frac{(s+10^4)(s+10^6)}{10^5(s+10^5)} \]  
(15 points)

**DC gain** = \(\frac{(10^4)(10^6)}{(10^5)(10^5)} = 1\)

**High Frequency gain** = \(\infty\)

2 **zeros** at \(-10^4, -10^6\)

\(\phi(F(j\omega))\) 1 **pole** at \(-10^5\)

DC gain = \(\infty\)

HF gain = \(10^{-2} = -40 \text{ dB}\)

2 **zeros** at \(-10^4, -10^6\)

2 **poles** at \(\phi \rightarrow \text{DC phase} = -90 - 90 = -180\)
Problem 2 (20 points) 
Assume for problem 2 circuits that all operational amplifiers are ideal.

a) For the following circuit:
   i. Obtain the transfer function, \( \frac{v_o(s)}{v_i(s)} \)
   ii. Set the component values to achieve a 1k\( \Omega \) high frequency input resistance, 20dB high-frequency gain (magnitude), and a pole (3dB) frequency of \( \omega_{3dB} = 10 kHz \).

   \[
   HF \text{ Lin} = R_1 = 1k\Omega \\
   HF \text{ Gain} = \frac{R_3}{R_1} = 10 \Rightarrow R_3 = 10k\Omega \\
   \omega_{3dB} = \frac{1}{R_1C} = 10^4 \text{ rad/s} \\
   C = \frac{1}{(1k\Omega)(10^4 \text{ rad/s})} = 100nF
   \]

   \[
   \frac{v_o}{v_i} = -\frac{Z_{R_3}}{Z_{R_1} + Z_C} = -\frac{R_3}{R_1 + \frac{1}{sC}} \\
   \frac{v_o}{v_i} = -\frac{sCR_3}{1 + sC R_1}
   \]

b) For the following circuit obtain the expression for \( v_o \) as a function of \( v_{i1}, v_{i2}, \) and \( v_{i3} \). Assume ideal opamps. Hint: apply superposition. (20 points)

\[
V_A = -v_{i1} + 2 \frac{Z_C}{Z_R + Z_C} v_{i2}
\]

\[
V_0 = -\frac{Z_C}{Z_R} v_{i3} + \frac{1}{2} \left( 1 + \frac{Z_C}{Z_R} \right) V_A
\]

\[
= -\frac{Z_C}{Z_R} v_{i3} + \frac{1}{2} \left( 1 + \frac{Z_C}{Z_R} \right) \left( -v_{i1} + 2 \frac{Z_C}{Z_R + Z_C} v_{i2} \right)
\]

\[
= -\frac{1}{2} \frac{Z_R + Z_C}{Z_R} v_{i1} + \frac{Z_C}{Z_R} v_{i2} - \frac{Z_C}{Z_R} v_{i3}
\]

\[
V_0 = -\frac{1 + sRC}{c^2RC} v_{i1} + \frac{1}{SRC} v_{i2} - \frac{1}{SRC} v_{i3}
\]
Problem 3 (25 points)
Assume for problem 3 that the operational amplifier is ideal. All the resistors are the same, except for $R_A$.

a) Find the expression for $V_o$ as a function of $V_1$ and $V_2$. (10 points)

b) Find the expression for the differential gain, $A_d$. (5 points)

c) Find the expression for the common-mode gain, $A_{CM}$. (5 points)

d) Find the expression for the common-mode rejection ratio (CMRR). (5 points)

e) Now assume that $R_A = R(1+\Delta)$. Find the maximum absolute value of $\Delta$ to achieve a minimum $|CMRR|$ of 60dB? (5 points)

\[ V_o = -\frac{R}{R_A} V_1 + \frac{1}{2} \left(1 + \frac{R}{R_A}\right) V_2 \]

For differential gain, $V_2 = -V_1 = \frac{V_d}{2}$

\[ V_o = -\frac{R}{R_A} (-\frac{V_d}{2}) + \frac{1}{2} \left(1 + \frac{R}{R_A}\right) \frac{V_d}{2} \]

\[ A_d = \frac{V_o}{V_d} = \frac{1}{4} + \frac{3}{4} \left(\frac{R}{R_A}\right) \]

For common-mode gain, $V_2 = V_1 = V_{cm}$

\[ V_o = -\frac{R}{R_A} V_{cm} + \frac{1}{2} \left(1 + \frac{R}{R_A}\right) V_{cm} \]

\[ A_{CM} = \frac{V_o}{V_{cm}} = \frac{1}{2} - \frac{1}{2} \left(\frac{R}{R_A}\right) \]

\[ CMRR = \frac{1}{4 + \frac{3}{4} \left(\frac{R}{R_A}\right)} \]

\[ \frac{1}{2} - \frac{1}{2} \left(\frac{R}{R_A}\right) \]

\[ \frac{1}{4} \frac{R(1+\Delta)}{R(1+\Delta)} + \frac{\frac{3}{4} R}{\frac{1}{2} R(1+\Delta) - \frac{1}{2} R} = 10^3 \]

\[ 1 + \frac{\Delta}{4} = 10^3 \]

\[ \frac{\Delta}{2} = 10^3 (\frac{\Delta}{2}) - \frac{\Delta}{4} = 1 \]

\[ \Delta = \frac{1}{10^{\frac{1}{2}} - \frac{1}{4}} = 2,000 \times 10^{-1} \]

\[ \Delta \approx 0.2\% \]
Problem 4 (15 points)
The operational amplifier used in the remainder of the problem has the following open-loop transfer function

\[ A(s) = \frac{10^5}{1 + \frac{s}{10}} \]

a) Sketch the open-loop magnitude response of the operational amplifier. Make sure to label the unity-gain frequency.

b) The finite gain-bandwidth operational amplifier from part (a) is used in the following amplifier circuit. Find the expression for the closed-loop transfer function \( v_o/v_i \).

c) What is the closed-loop -3dB frequency (bandwidth) of the total amplifier circuit?

d) Sketch the closed-loop magnitude response of the amplifier circuit. Make sure to label the unity-gain frequency.

\[ V_o \approx \frac{-R_1}{R_2} \frac{5}{1 + \frac{s}{10^6}} \]

where \( \omega_{PI} = \frac{\omega_u}{1 + \frac{R_1}{R_2}} = \frac{10^6}{6} \)

\[ \frac{V_o}{V_i} \approx -\frac{5}{1 + \frac{s(1)}{10^6}} \]

\[ \omega_{PI} = \frac{10^6}{6} \text{ rad/s} \]
Problem 5 (10 points)
Assume that the operational amplifier below is ideal, except that it has a finite slew rate of 1V/μs. What is the maximum input amplitude $V_p$ that produces an output without distortion?

\[ v_i = V_p \sin(10^3 t) \]

\[ v_o = - \frac{1}{SR} \cdot v_i \]

\[ \Rightarrow - \frac{1}{RC} \int v_i(t) \, dt \]

\[ = - \frac{1}{RC} \left( \frac{1}{10^3} \right) V_p \left( - \cos 10^3 t \right) \]

\[ V_o(t) = \frac{V_p}{RC \cdot 10^3} \cos 10^3 t \]

\[ \left| \frac{dV_o(t)}{dt} \right|_{\text{max}} \leq SR \]

\[ \frac{dV_o(t)}{dt} = - \frac{V_p}{RC} \sin 10^3 t \]

\[ \left| \frac{dV_o(t)}{dt} \right|_{\text{max}} = \frac{V_p}{RC} \leq SR \]

\[ V_p \leq SR(\frac{1}{RC}) = \left( \frac{1}{10^3} \right) \left( \frac{1}{100 \mu s} \right) (1 \text{ nF}) \]

\[ V_p \leq 0.1V \]

Max $V_p = 0.1V$
Scratch Paper