ECE 3355: Electronics

Section 26828/19453/18023

Fall 2022

Exam 1

Version A

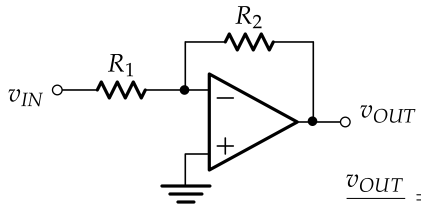
October 8, 2022

Complete the exam on your own, without the help of your notes, prior examples or solutions, your book, or any communication/interaction with others. You must write a complete solution that shows the relevant steps if you want full credit for the problem. You may use a calculator and a crib sheet is provided as part of this exam. **You will have 1 hour 15 minutes to finish the exam.**

Student's Name: ____

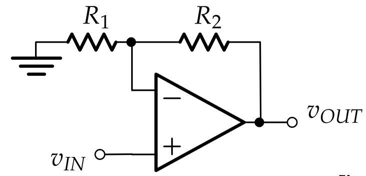
Question	Points	Score
1	15	
2	10	
3	10	
4	20	
5	15	
6	15	
7	15	
Total:	100	

Inverting Amplifier



$$\frac{v_{OUT}}{v_{IN}} = -\frac{R_2}{R_1}$$

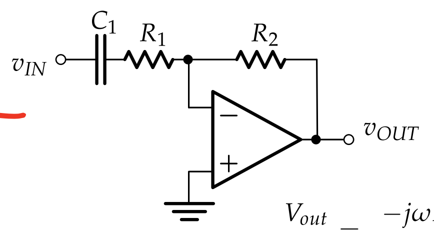
Non-inverting Amplifier

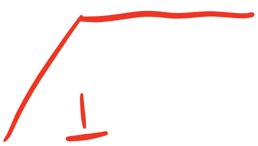


$$\frac{v_{OUT}}{v_{IN}} = 1 + \frac{R_2}{R_1}$$

$\omega \uparrow$ short
$\omega \downarrow$ open

HPF

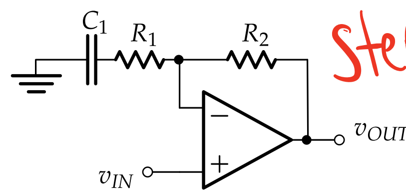


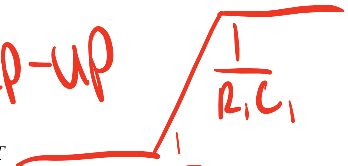


$\frac{1}{R_1C_1}$

$$\frac{V_{out}}{V_{in}} = \frac{-j\omega R_2C_1}{1 + j\omega R_1C_1}$$

Step-up



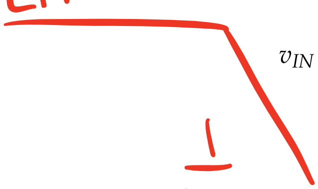


$\frac{1}{R_1C_1}$

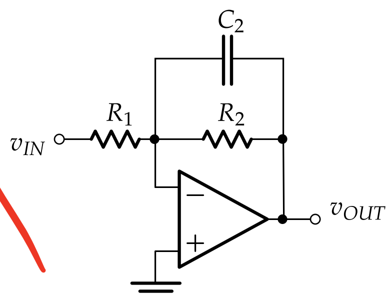
$\frac{1}{(R_1+R_2)C_1}$

$$\frac{V_{out}}{V_{in}} = \frac{1 + j\omega\left(R_1 + R_2\right)C_1}{1 + j\omega R_1C_1}$$

LPF

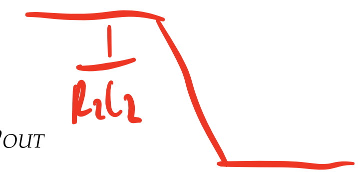


$\frac{1}{R_2C_2}$

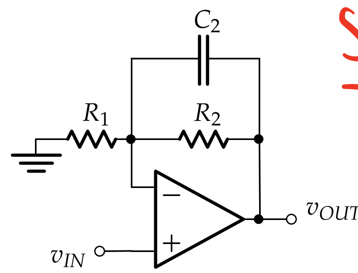


$$\frac{V_{out}}{V_{in}} = \frac{-\frac{R_2}{R_1}}{1 + j\omega R_2C_2}$$

Step-down

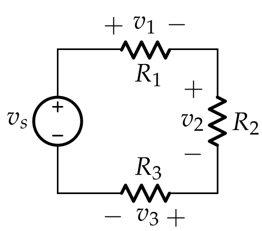


$\frac{1}{R_2C_2}$

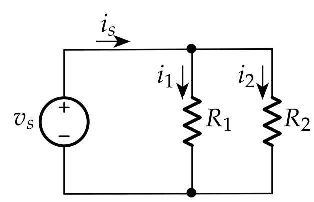


$$\frac{V_{out}}{V_{in}} = \left[1 + \frac{R_2}{R_1}\right]\left[\frac{1 + j\omega\left(R_1||R_2\right)C_2}{1 + j\omega R_2C_2}\right]$$

$\frac{1}{(R_1||R_2)C_2}$



$$v_1 = \frac{R_1}{R_1 + R_2 + R_3}v_s$$
$$v_2 = \frac{R_2}{R_1 + R_2 + R_3}v_s$$
$$v_3 = \frac{R_3}{R_1 + R_2 + R_3}v_s$$

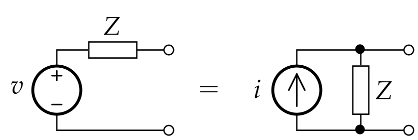


$$i_1 = \frac{R_2}{R_1 + R_2}i_s$$
$$i_2 = \frac{R_1}{R_1 + R_2}i_s$$

$$v_B = \underbrace{V_B}_{\text{DC}} + \underbrace{v_b}_{\text{AC}}$$

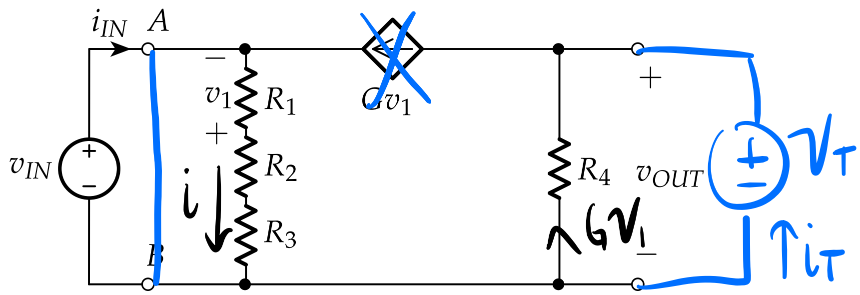
$\overline{V}_b \rightarrow$ Phasor notation

$$CMRR = 20\log_{10}\frac{|A_d|}{|A_{cm}|}$$



$$v = i \cdot Z$$
$$i = \frac{v}{Z}$$

1. (15 points) For the following circuit, find the voltage gain, $\frac{v_{OUT}}{v_{IN}}$, and the input and output resistances.



$$V_{OUT} = -GV_1R_4 = GiR_1R_4$$

$$i = i_{IN} + GV_1 = i_{IN} - GiR_1$$

$$V_1 = -iR_1$$

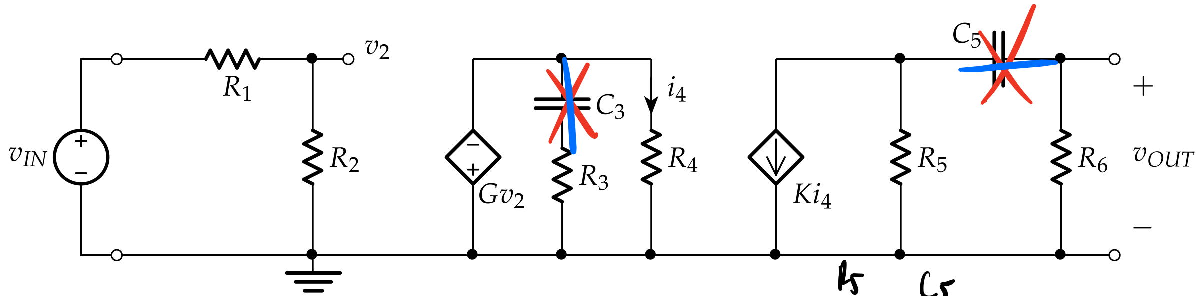
$$V_{IN} = i(R_1 + R_2 + R_3)$$

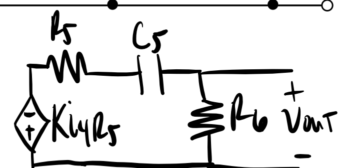
$$\frac{V_{OUT}}{V_{IN}} = \frac{GiR_1R_4}{i(R_1+R_2+R_3)} = \frac{GR_1R_4}{R_1+R_2+R_3}$$

$$R_{IN} = \frac{V_{IN}}{i_{IN}} = \frac{i(R_1+R_2+R_3)}{i(1+GR_1)} = \frac{R_1+R_2+R_3}{1+GR_1}$$

$$R_{OUT} = R_4$$

2. (10 points) For the following circuit,





(a) Write expressions for frequencies of the pole(s) and/or zero(s).

$$\bar V_{OUT} = -K\bar I_4 R_5 \left(\frac{R_6}{R_6+R_5+\frac{1}{j\omega C_5}}\right)$$

$$\frac{\bar V_{OUT}}{\bar I_4} = -KR_5\left(\frac{R_6}{R_6+R_5+\frac{1}{j\omega C_5}}\right) = -KR_5\left(\frac{j\omega R_6 C_5}{1+j\omega(R_5+R_6)C_5}\right)$$

$$-G\bar V_2 = \bar I_4 R_4 \Rightarrow \frac{\bar I_4}{\bar V_2} = -\frac{G}{R_4}$$

$$\bar V_2 = \bar V_{IN}\left(\frac{R_2}{R_2+R_1}\right) \Rightarrow \frac{\bar V_2}{\bar V_{IN}} = \frac{R_2}{R_1+R_2}$$

(b) What is the gain at low frequencies? Open

(b) 0

(c) What is the gain at high frequencies? Short

(c) ________

$$\frac{\bar{V}_{OUT}}{\bar{I}_4} \cdot \frac{\bar{I}_4}{\bar{V}_2} \cdot \frac{\bar{V}_2}{\bar{V}_{IN}} = \frac{\bar{V}_{OUT}}{\bar{V}_{IN}}$$

$$\frac{\bar{V}_{OUT}}{\bar{V}_{IN}} = -KR_5\left(\frac{j\omega R_6 C_5}{1+j\omega(R_5+R_6)C_5}\right)\left(-\frac{G}{R_4}\right)\left(\frac{R_2}{R_1+R_2}\right)$$

$$\frac{\bar{V}_{OUT}}{\bar{V}_{IN}} = KR_5 \cdot \frac{j\omega R_6 C_5}{1+j\omega(R_5+R_6)C_5} \cdot \frac{G}{R_4} \cdot \frac{R_2}{R_1+R_2}$$

$$\omega_p = \frac{1}{(R_5+R_6)C_5}$$

$$\bar{V}_2 = \bar{V}_{IN}\left(\frac{R_2}{R_1+R_2}\right)$$

$$\bar{I}_4 = -\frac{G\bar{V}_2}{R_4}$$

$$\bar{V}_{OUT} = -K\bar{I}_4(R_5 \| R_6)$$

$$\frac{\bar{V}_{OUT}}{\bar{V}_{IN}} = \frac{-K\bar{I}_4(R_5\|R_6)}{\frac{\bar{V}_2}{\left(\frac{R_2}{R_1+R_2}\right)}} = \frac{-K\left(-\frac{G\cancel{\bar{V}_2}}{R_4}\right)(R_5\|R_6)}{\frac{\cancel{\bar{V}_2}}{\left(\frac{R_2}{R_1+R_2}\right)}}$$

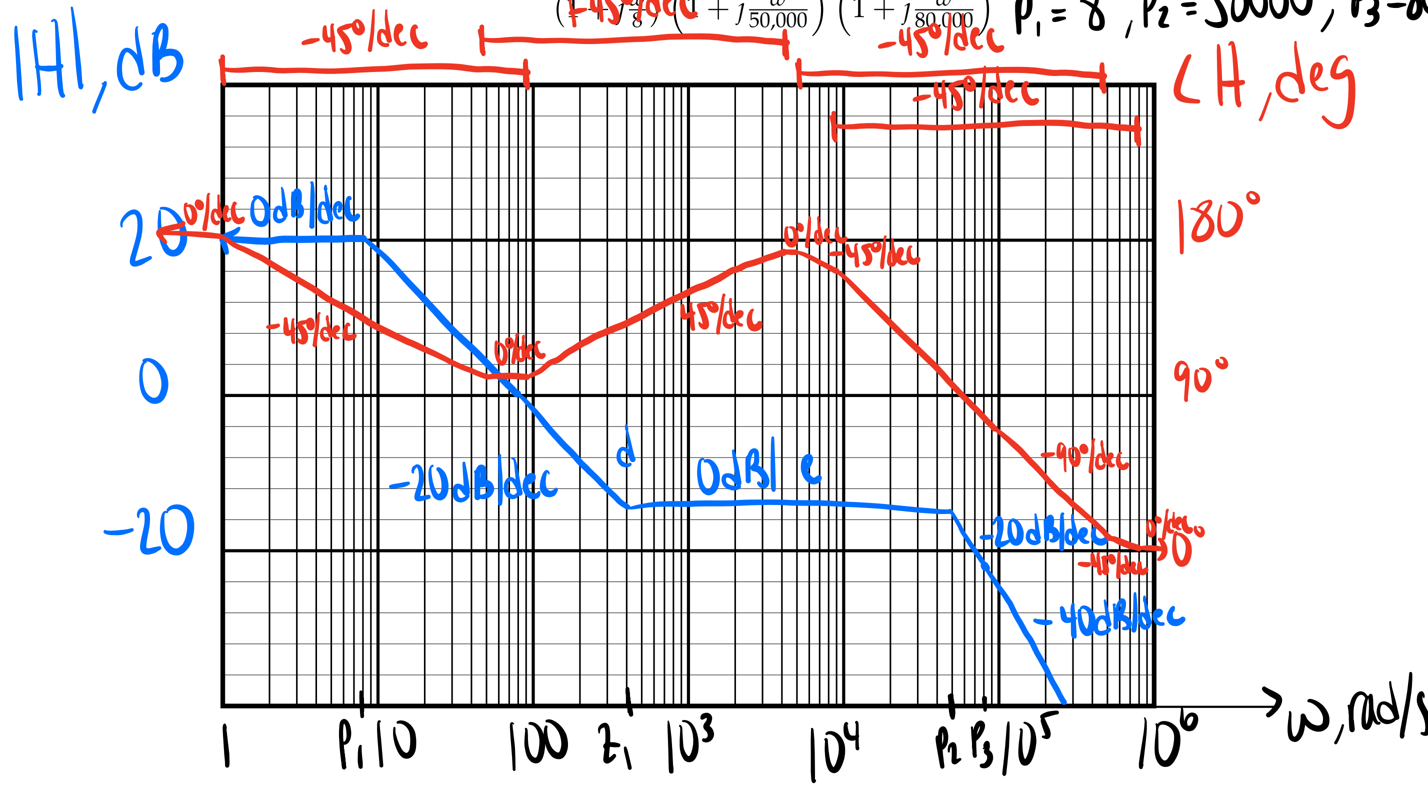
$$\frac{\bar{V}_{OUT}}{\bar{V}_{IN}} = K\frac{G}{R_4}(R_5\|R_6)\left(\frac{R_2}{R_1+R_2}\right)$$

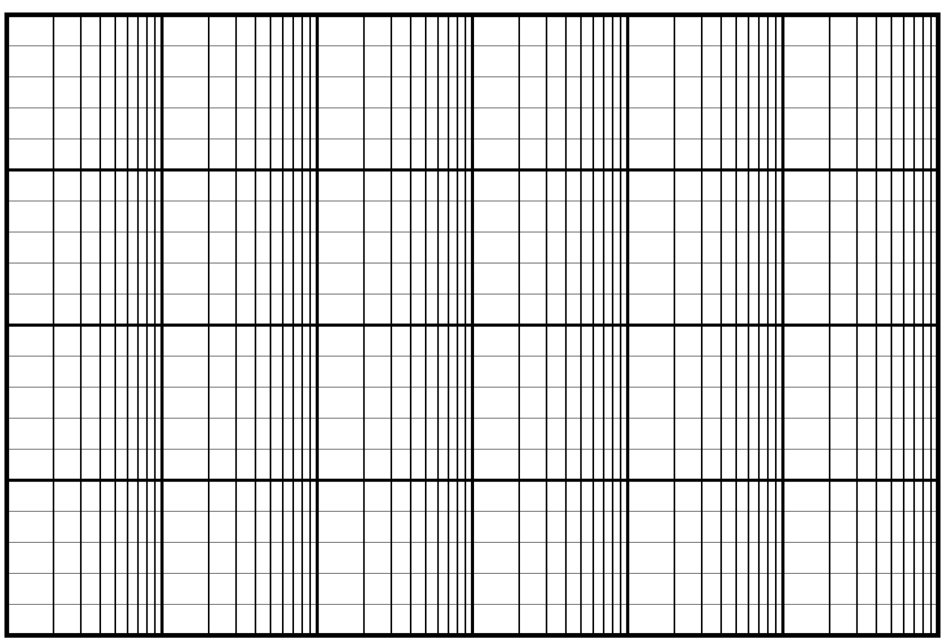
3. (10 points) Plot a straight-line approximation Bode plot on the graph paper provided for both the magnitude and the phase for the following transfer function (the unit for the given values is rad/sec).

$$H(j\omega) = -10\frac{\left(1 + j\frac{\omega}{400}\right)}{\left(1 + j\frac{\omega}{8}\right)\left(1 + j\frac{\omega}{50,000}\right)\left(1 + j\frac{\omega}{80,000}\right)}.$$

$z_1 = 400$

$p_1 = 8$, $p_2 = 50000$, $p_3 = 80000$





$\omega = 0.8 \approx 1$

$H(j0.8) = -10$

$|H(j0.8)| = 10$ or $20\log_{10}(10) = 20\,dB$

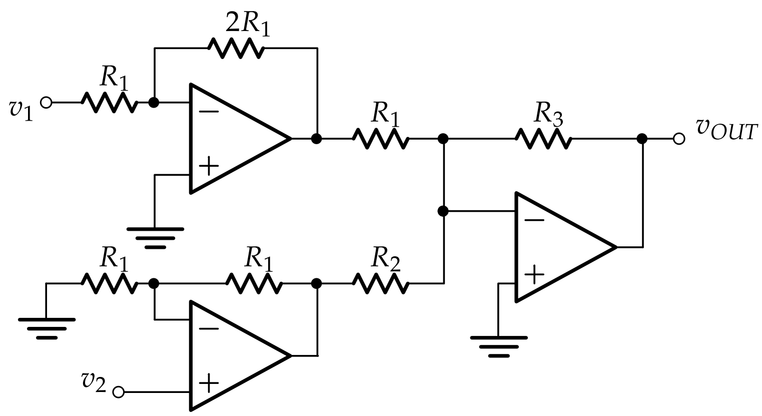
$\angle H(j0.8) = 180° / -180°$

ω large

$$H(\omega) = -\frac{j}{j \cdot j \cdot j} = 1$$

$\angle H(\omega) = 0°$

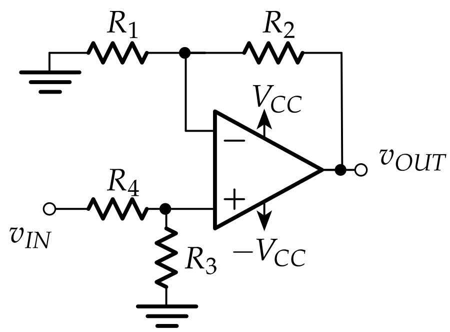
4. (20 points) For the following amplifier,
   (a) Write an expression for v_{OUT} in terms of v_1 and v_2. *Hint:* use superposition or identify the sub-circuits.
   (b) What conditions have to be satisfied for this circuit to be a difference amplifier.
   (c) Using these conditions, what is the difference gain?
   (d) What is the common mode gain?
   (e) What is the input resistance for each of the inputs?



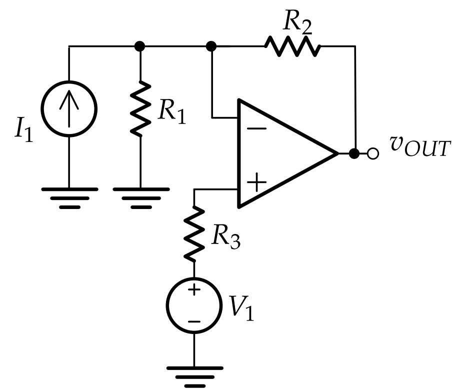
5. (15 points) For the following circuit,

   (a) Using $R_1 = 1\,\mathrm{k\Omega}$, $R_2 = 9\,\mathrm{k\Omega}$, $R_3 = R_4 = 5\,\mathrm{k\Omega}$, $V_{CC} = 10\,\mathrm{V}$ (hence, $-V_{CC} = -10\,\mathrm{V}$), what is the range of v_{IN} that ensures the op-amp does not go into saturation?

   (b) Add a resistor $R_L = 1\,\mathrm{k\Omega}$ across the output (between v_{OUT} and ground). If $v_{IN} = 2\,\mathrm{V}$ and $i_{max} = 10\,\mathrm{mA}$, what is v_{OUT}?



6. (15 points) For the following circuit, find an expression for v_{OUT} in terms of V_1 and I_1.



7. (15 points) You have been asked to design a circuit that has the following straight-line approximation to the Bode plot. Use ideal op-amps, resistors, and capacitors in your design and indicate which order the stages should be placed to ensure the circuit is not very sensitive to changes in the source resistance. Compute the values of the resistors and the capacitors.