ECE 3355: Electronics

Section 13495/27184

Fall 2021

Exam 1

Version A

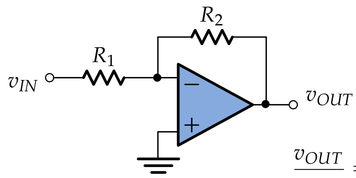
October 9, 2021

Do *not* open the exam until instructed to do so. 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 steps you took to solve the problem to receive full credit. You may use a calculator and a crib sheet is provided as part of this exam. Answer the questions in the spaces provided on the question sheets. If you run out of room for an answer, continue on the back of the page. **You will have 1 hour 15 minutes to finish the exam.**

Student's Name: ______________________________

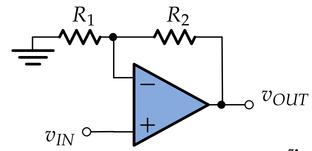
Question	Points	Score
1	15	
2	15	
3	10	
4	15	
5	15	
6	15	
7	15	
Total:	100	

Inverting Amplifier

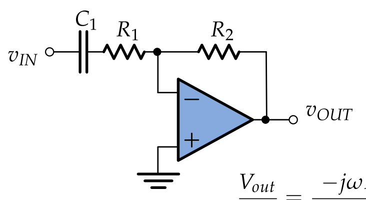


$$\frac{v_{OUT}}{v_{IN}} = -\frac{R_2}{R_1}$$

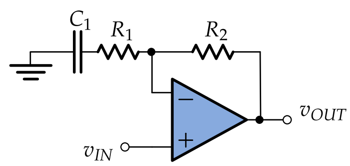
Non-inverting Amplifier



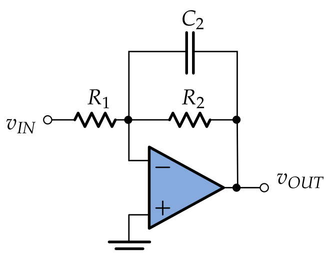
$$\frac{v_{OUT}}{v_{IN}} = 1 + \frac{R_2}{R_1}$$



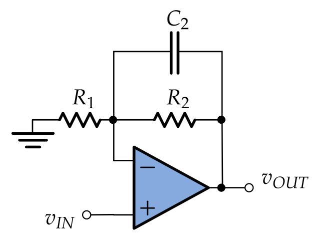
$$\frac{V_{out}}{V_{in}} = \frac{-j\omega R_2 C_1}{1 + j\omega R_1 C_1}$$



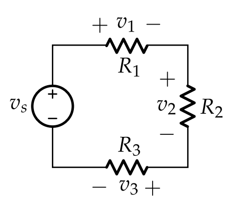
$$\frac{V_{out}}{V_{in}} = \frac{1 + j\omega\,(R_1 + R_2)\,C_1}{1 + j\omega R_1 C_1}$$



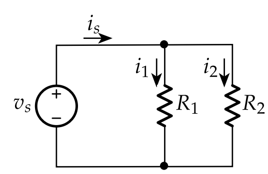
$$\frac{V_{out}}{V_{in}} = \frac{-\frac{R_2}{R_1}}{1 + j\omega R_2 C_2}$$



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



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

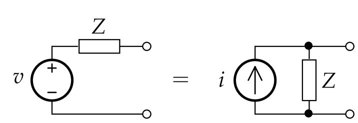


$$i_1 = \frac{R_2}{R_1 + R_2} i_s$$
$$i_2 = \frac{R_1}{R_1 + R_2} i_s$$

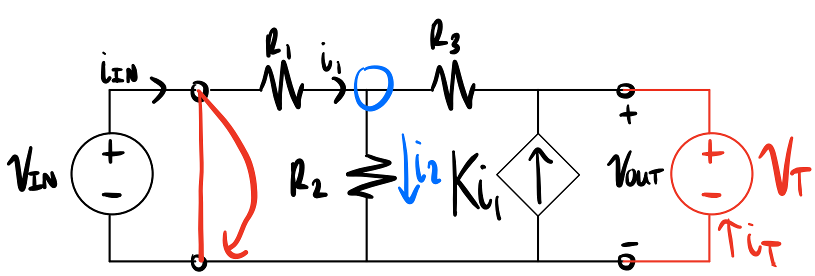
$$v_B = \underbrace{V_B}_{\text{DC}} + \underbrace{v_b}_{\text{AC}}$$

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

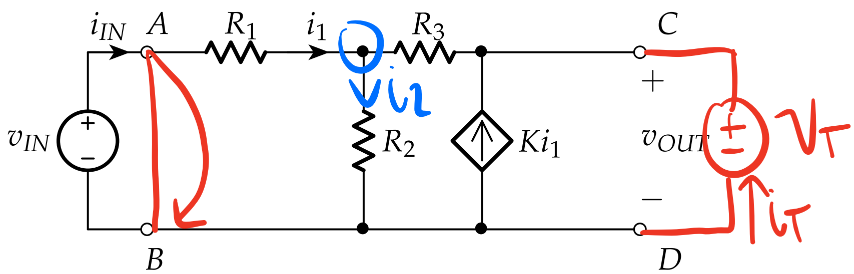
$$CMRR = 20\log_{10}\frac{|A_d|}{|A_{cm}|}$$



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



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



(d)

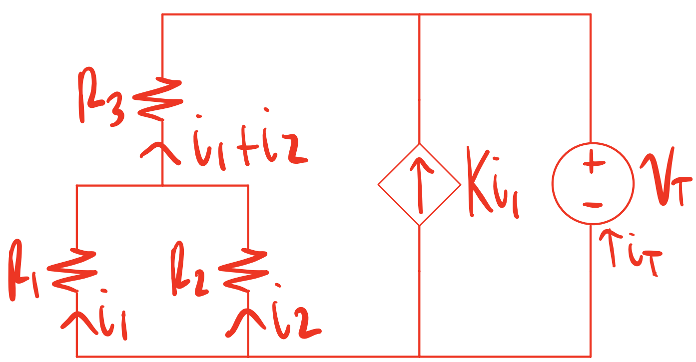
$$i_2 = i_1 + Ki_1$$

$$V_{OUT} = i_2 R_2 + K i_1 R_3 = i_1\left((1+K)R_2 + KR_3\right)$$

$$V_{IN} = i_1 R_1 + i_2 R_2 = i_1\left(R_1 + (1+K)R_2\right)$$

$$\frac{V_{OUT}}{V_{IN}} = \frac{(1+K)R_2 + KR_3}{R_1 + (1+K)R_2}$$

$$R_{IN} = \frac{V_{IN}}{i_{IN}} = \frac{i_1\left(R_1 + (1+K)R_2\right)}{i_1} = R_1 + (1+K)R_2$$



$$R_{OUT} = \frac{V_T}{i_T} = \frac{-i_1 R_1 - (i_1 + i_2)R_3}{-i_1 - i_2 - Ki_1}$$

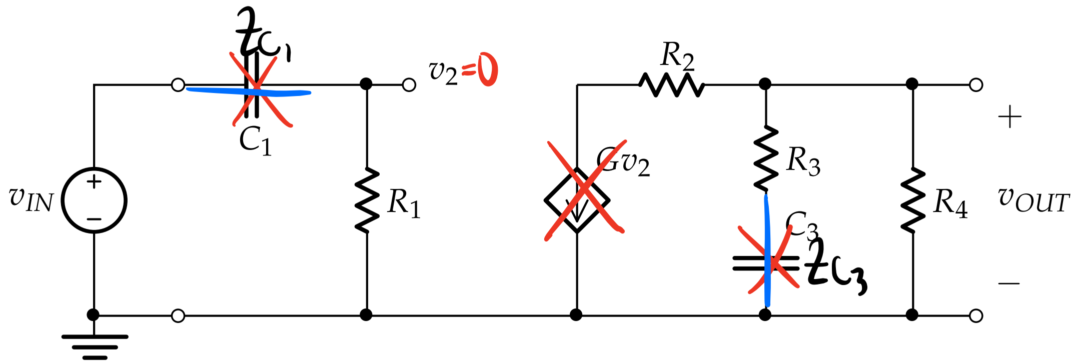
$$i_1 R_1 = i_2 R_2$$

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

$$R_{OUT} = \frac{-i_1 R_1 - (i_1 + i_2) R_3}{-i_1 - i_2 - K i_1} = \frac{-i_1 R_1 - \left(i_1 + i_1 \frac{R_1}{R_2}\right) R_3}{-i_1 - i_1 \frac{R_1}{R_2} - K i_1}$$

$$R_{OUT} = \frac{-i_1 \left(R_1 + R_3 + \frac{R_1 R_3}{R_2} \right)}{-i_1 \left(1 + \frac{R_1}{R_2} + K \right)} = \frac{R_1 R_2 + R_2 R_3 + R_1 R_3}{R_2 + R_1 + K R_2}$$

2. (15 points) For the following circuit, answer the three questions below.



(a) Write an expression for $\frac{\overline{V}_{out}}{\overline{V}_{in}}$ for the following circuit. Write the solution in the form that allows easy identification of the poles and zeros.

$$\overline{V}_{OUT} = -G\overline{V}_2\left((R_3 + Z_{C_3}) \,||\, R_4\right)$$

$$\overline{V}_2 = \overline{V}_{IN}\left(\frac{R_1}{R_1 + Z_{C_1}}\right)$$

$$\overline{V}_{OUT} = -G\overline{V}_{IN}\left(\frac{R_1}{R_1 + Z_{C_1}}\right)\left((R_3 + Z_{C_3}) \,||\, R_4\right)$$

$$\frac{\overline{V}_{OUT}}{\overline{V}_{IN}} = -G\left(\frac{R_1}{R_1 + Z_{C_1}}\right)\left((R_3 + Z_{C_3}) \,||\, R_4\right)$$

(b) What is the gain at low frequencies?

(b) ____________

(c) What is the gain at high frequencies?

(c) ____________

$$\frac{\bar{V}_{OUT}}{\bar{V}_{IN}} = -G\left(\frac{R_1}{R_1+\frac{1}{j\omega C_1}}\right)\left(\frac{\left(R_3+\frac{1}{j\omega C_3}\right)\cdot R_4}{R_3+\frac{1}{j\omega C_3}+R_4}\right)$$

$$\frac{\bar{V}_{OUT}}{\bar{V}_{IN}} = -G\left(\frac{j\omega R_1C_1}{j\omega R_1C_1+1}\right)\left(\frac{(j\omega C_3R_3+1)R_4}{j\omega C_3R_3+1+j\omega C_3R_4}\right)$$

$$\frac{\bar{V}_{OUT}}{\bar{V}_{IN}} = -G\left(\frac{j\omega R_1C_1}{j\omega R_1C_1+1}\right)\left(\frac{(j\omega C_3R_3+1)R_4}{1+j\omega(R_3+R_4)C_3}\right)$$

ω low, capacitor acts as open circuit.

$$\frac{\bar{V}_{OUT}}{\bar{V}_{IN}} = 0$$

ω high, capacitor acts as short circuit

$$\frac{\bar{V}_{OUT}}{\bar{V}_{IN}} = -G(R_3 \| R_4)$$

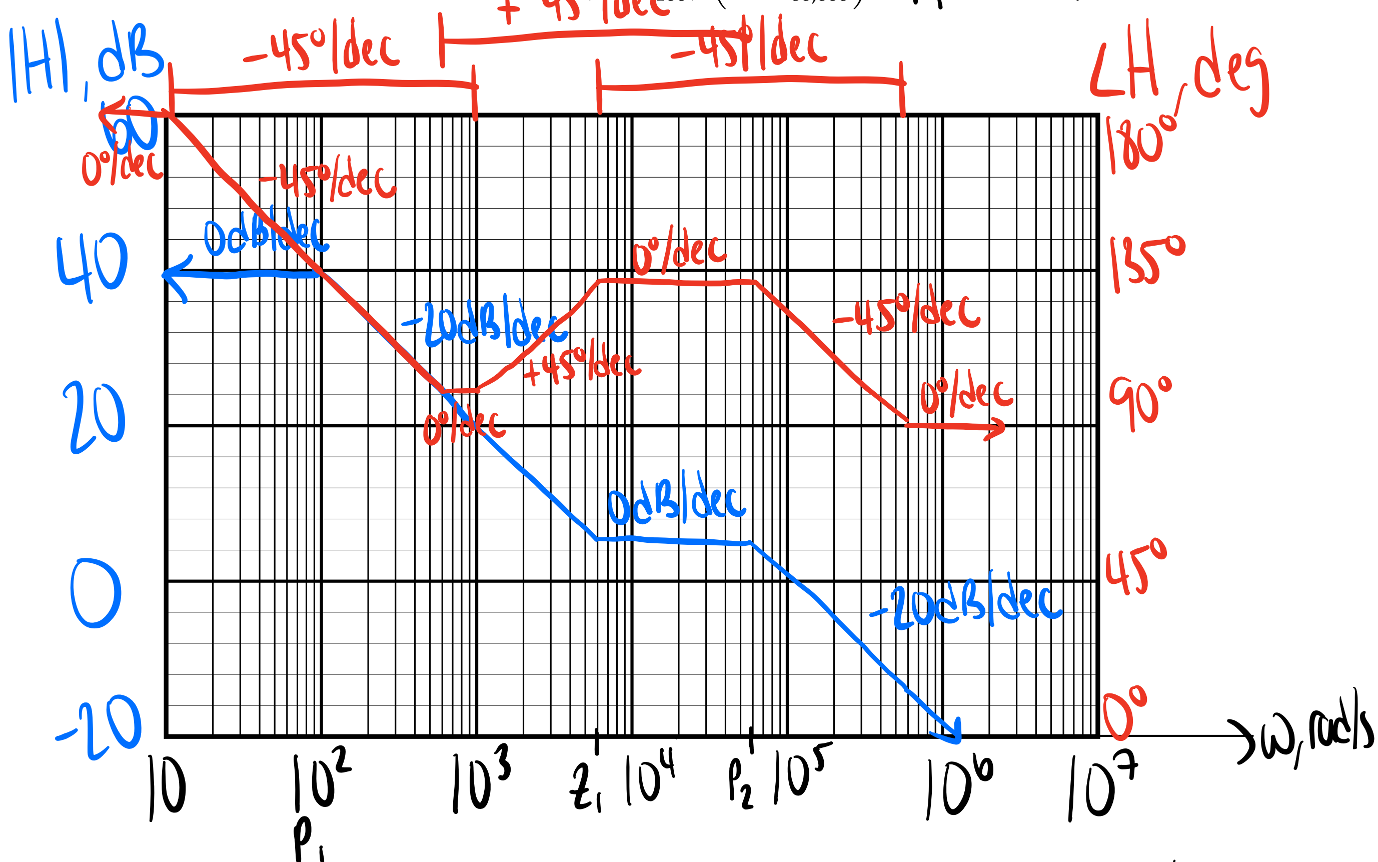
3. (10 points) Bode Plots

(a) Plot a straight-line approximation of the Bode plot on the graph paper provided for the *magnitude only* for the following transfer function (the unit for the values in the denominator of the imaginary terms is rad/sec).

$$H(j\omega) = -100\frac{\left(1 + j\frac{\omega}{6{,}000}\right)}{\left(1 + j\frac{\omega}{100}\right)\left(1 + j\frac{\omega}{60{,}000}\right)}.$$

$z_1 = 6000$

$p_1 = 100, \quad p_2 = 60000$



(b) What is the starting phase (i.e., the phase at low frequencies)?

(b) $180° / -180°$

(c) What is the ending phase (i.e, the phase at high frequencies)?

(c) $90° / -270°$

$\omega = 10$

$H(j10) = -100$

$|H(j10)| = 100$ or $20\log_{10}(100) = 40\,dB$

$\angle H(j10) = 180°$ or $-180°$

$\omega = \infty$

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

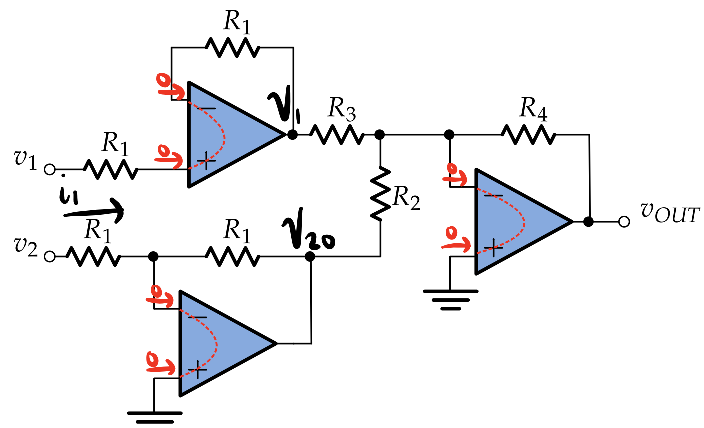
$\angle H(\omega) = 90°$ or $-270°$

4. (15 points) Difference Amplifier

For the following circuit,

(a) use superposition to determine the ratios of the resistors so that the circuit is a difference amplifier.

(b) determine the input resistance seen at the two inputs.



$$V_{20} = -\frac{R_1}{R_1} = -1 = -V_2$$

$$V_{OUT} = -R_4\left(\frac{V_1}{R_3} + \frac{V_{20}}{R_2}\right) = -R_4\left(\frac{V_1}{R_3} - \frac{V_2}{R_2}\right)$$

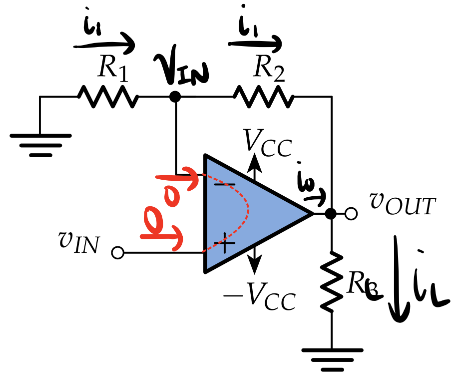
$$V_{OUT} = V_2\underbrace{\left(\frac{R_4}{R_2}\right)}_{A_d} - V_1\underbrace{\left(\frac{R_4}{R_3}\right)}_{A_d}$$

$$\frac{R_4}{R_2} = \frac{R_4}{R_3} \Rightarrow R_2 = R_3$$

$$R_{IN V_1} = \infty$$

$$R_{IN V_2} = \frac{V_2}{i_1} = R_1$$

5. (15 points) For the following circuit, the op-amp is powered by a pair of $\pm V_{CC} = \pm 15$ volt supplies (as shown).



(a) Write an expression for voltage gain, v_{OUT}/v_{IN}.

(b) With $R_1 = 1\,\mathrm{k}\Omega$, $R_2 = 9\,\mathrm{k}\Omega$, $R_L = 1\,\mathrm{k}\Omega$, and $i_{max} = 15\,\mathrm{mA}$, what is the range of v_{IN} that ensures the circuit does not go into saturation?

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

$$\frac{V_{OUT}}{V_{IN}} = 1 + \frac{9[k\Omega]}{1[k\Omega]} = 10$$

$$-15[V] \leq V_{OUT} \leq 15[V]$$

$$-1.5[V] \leq V_{IN} \leq 1.5[V]$$

$$i_o = i_L - i_1 = \frac{V_{OUT}}{R_L} + \frac{V_{OUT}}{R_1 + R_2} = \frac{\pm 15[V]}{1[k\Omega]} + \frac{\pm 15[V]}{1[k\Omega] + 9[k\Omega]}$$

$$= \pm 15[mA] + (\pm 1.5[mA])$$

$$i_o > 15[mA]$$

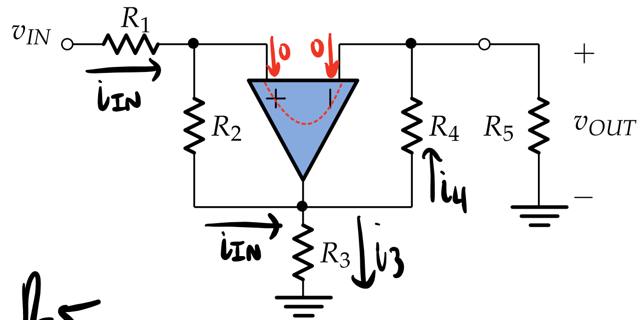
$$\frac{V_{OUT}}{R_L} + \frac{V_{OUT}}{R_1 + R_2} = 15[mA]$$

$$\frac{V_{OUT}}{1[k\Omega]} + \frac{V_{OUT}}{1[k\Omega]+9[k\Omega]} = 15[mA]$$

$$V_{OUT} = \pm 13.64$$

$$-1.364[V] \leq V_{IN} \leq 1.364[V]$$

6. (15 points) For the following circuit, find an expression for the voltage gain, $\frac{v_{OUT}}{v_{IN}}$ in terms of resistor variables.



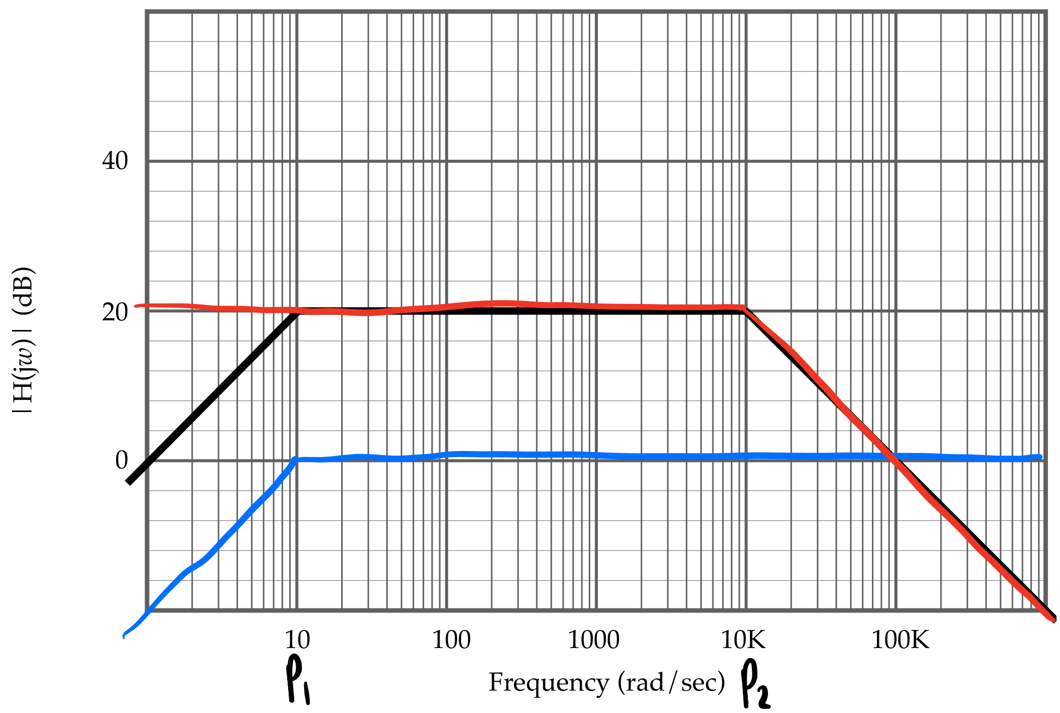
$$V_{IN} = i_{IN} R_1 + i_4 R_5$$

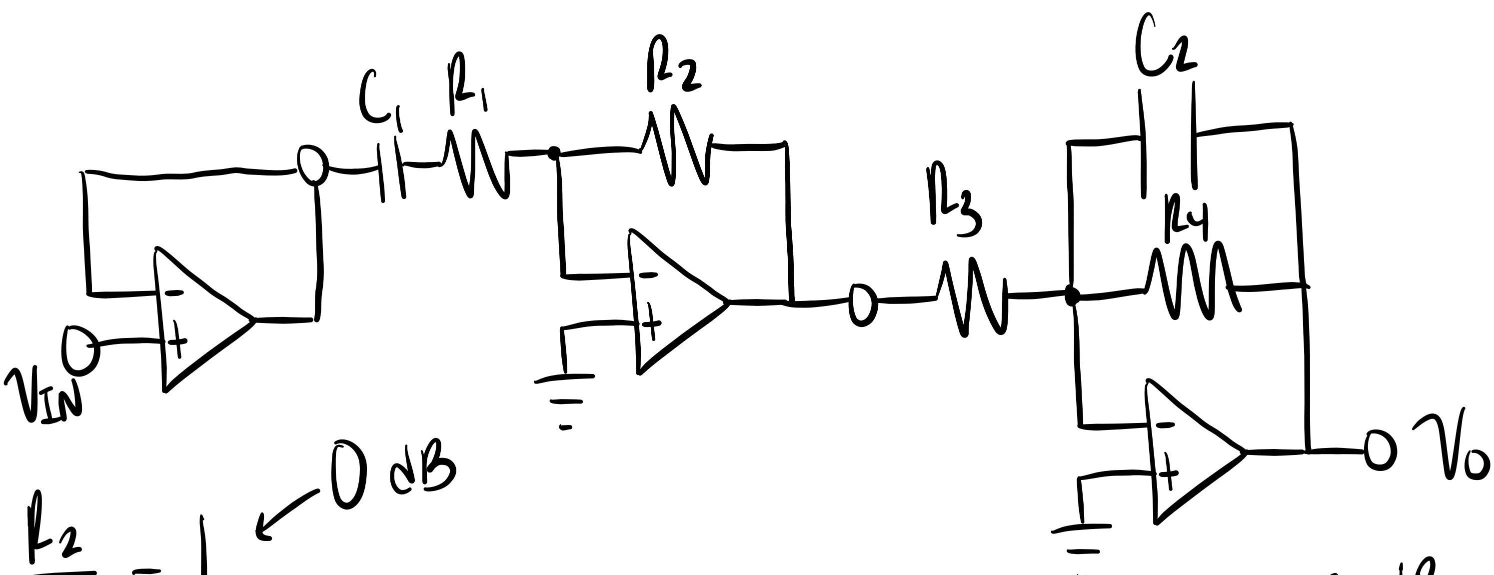
$$V_{OUT} = i_4 R_5$$

$$i_{IN} R_2 = -i_4 R_4 \Rightarrow i_{IN} = -i_4 \frac{R_4}{R_2}$$

$$\frac{V_{OUT}}{V_{IN}} = \frac{i_4 R_5}{i_4\left(-\frac{R_4 R_1}{R_2} + R_5\right)} = \frac{R_2 R_5}{-R_1 R_4 + R_2 R_5}$$

7. (15 points) Using ideal op-amps, design a circuit that has the following straight-line approximation to the Bode plot. Design the circuit so that it is not sensitive to changes in the source resistance.





$\frac{R_2}{R_1} = 1$ ← 0 dB

$R_2 = R_1$

$R_1 = 1[k\Omega]$, $R_2 = 1[k\Omega]$

$\omega_{P_1} = \frac{1}{R_1 C_1} = 10 = \frac{1}{1[k\Omega]C_1}$

$\frac{R_4}{R_3} = 10$ ← 20dB

$R_4 = 10R_3$

$R_4 = 10[k\Omega]$, $R_3 = 1[k\Omega]$

$C_1 = 0.1\,[MF]$

$$\omega_{p_2} = \frac{1}{R_4 C_2} = 10000$$

$$C_2 = \frac{1}{10[k\Omega]\,10000}$$

$C_2 = 10\,[NF]$