ECE 3355: Electronics

Section 19453/18023

Spring 2022

Exam 1

Version A

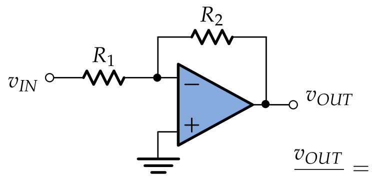
March 5, 2022

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: ____________________

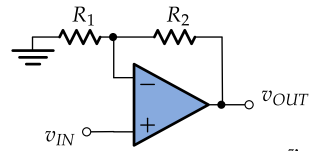
Question	Points	Score
1	15	
2	10	
3	10	
4	20	
5	15	
6	15	
7	15	
Total:	100	

Inverting Amplifier



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

Non-inverting Amplifier



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

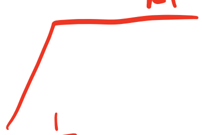
Step-up

$1 + \frac{R_2}{R_1}$

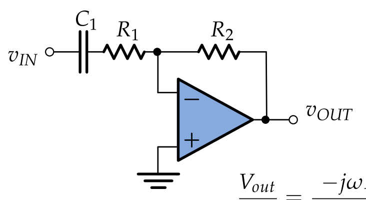
infinite input impedance

HPF

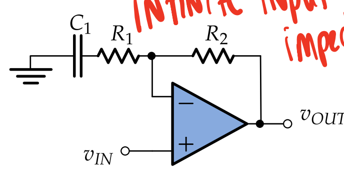
$-\frac{R_2}{R_1}$



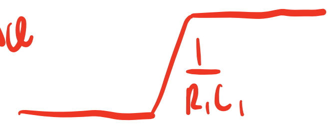
$\frac{1}{R_1C_1}$



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



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



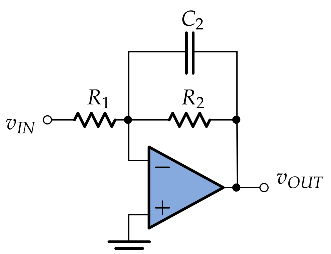
$\frac{1}{R_1C_1}$

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

LPF

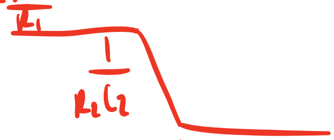
$-\frac{R_2}{R_1}$

$\frac{1}{R_2C_2}$



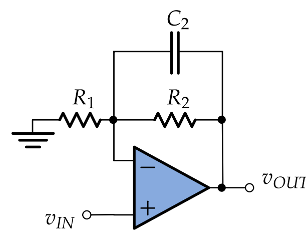
$$\frac{V_{out}}{V_{in}} = \frac{-\frac{R_2}{R_1}}{1 + j\omega R_2 C_2}$$

$1+\frac{R_2}{R_1}$

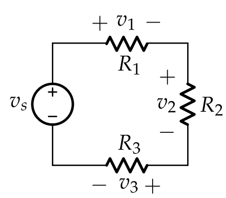


$\frac{1}{R_2C_2}$

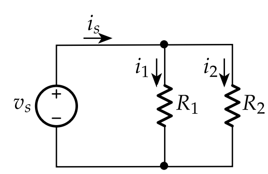
$\frac{1}{(R_1 \| R_2)C_2}$



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



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

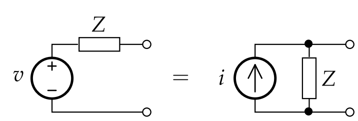


$$i_1 = \frac{R_2}{R_1 + R_2} i_s$$
$$i_2 = \frac{R_1}{R_1 + R_2} i_s$$

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

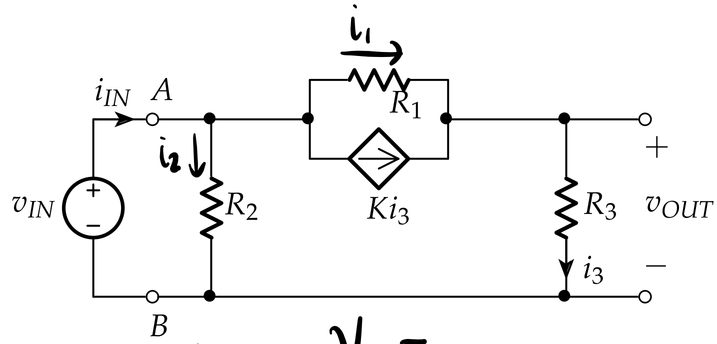
$\overline{V}_b \rightarrow$ Phasor notation

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



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

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



$$V_{OUT} = i_3 R_3 \Rightarrow i_3 = \frac{V_{OUT}}{R_3}$$

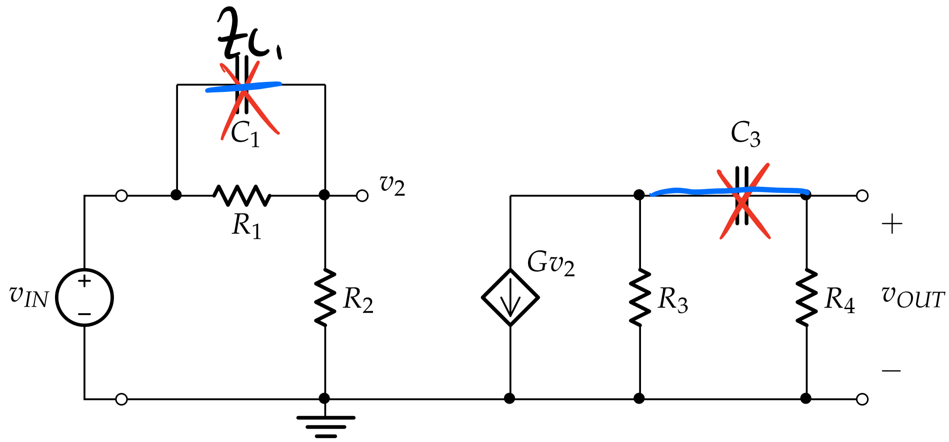
$$V_{IN} = i_2 R_2 = i_1 R_1 + V_{OUT}$$

$$i_3 = i_1 + K i_3 \Rightarrow i_1 = i_3(1-K) = (1-K)\frac{V_{OUT}}{R_3}$$

$$V_{IN} = \left((1-K)\frac{V_{OUT}}{R_3}\right)R_1 + V_{OUT} = V_{OUT}\left((1-K)\frac{R_1}{R_3} + 1\right)$$

$$\frac{V_{OUT}}{V_{IN}} = \frac{1}{(1-K)\frac{R_1}{R_3} + 1}$$

2. (10 points) For the following circuit, answer the three questions below.



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

$$\overline{V}_2 = \frac{R_2}{R_2 + (R_1 \| Z_{C_1})}\overline{V}_{IN} = \left(\frac{R_2}{R_2 + \frac{R_1 \cdot \frac{1}{j\omega C_1}}{R_1 + \frac{1}{j\omega C_1}}}\right)\overline{V}_{IN}$$

$$= \frac{R_2\left(R_1 + \frac{1}{j\omega C_1}\right)}{R_2\left(R_1 + \frac{1}{j\omega C_1}\right) + R_1 \cdot \frac{1}{j\omega C_1}}$$

(b) What is the gain at low frequencies?

(b) 0

(c) What is the gain at high frequencies?

(c) $-G(R_3 \| R_4)$

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

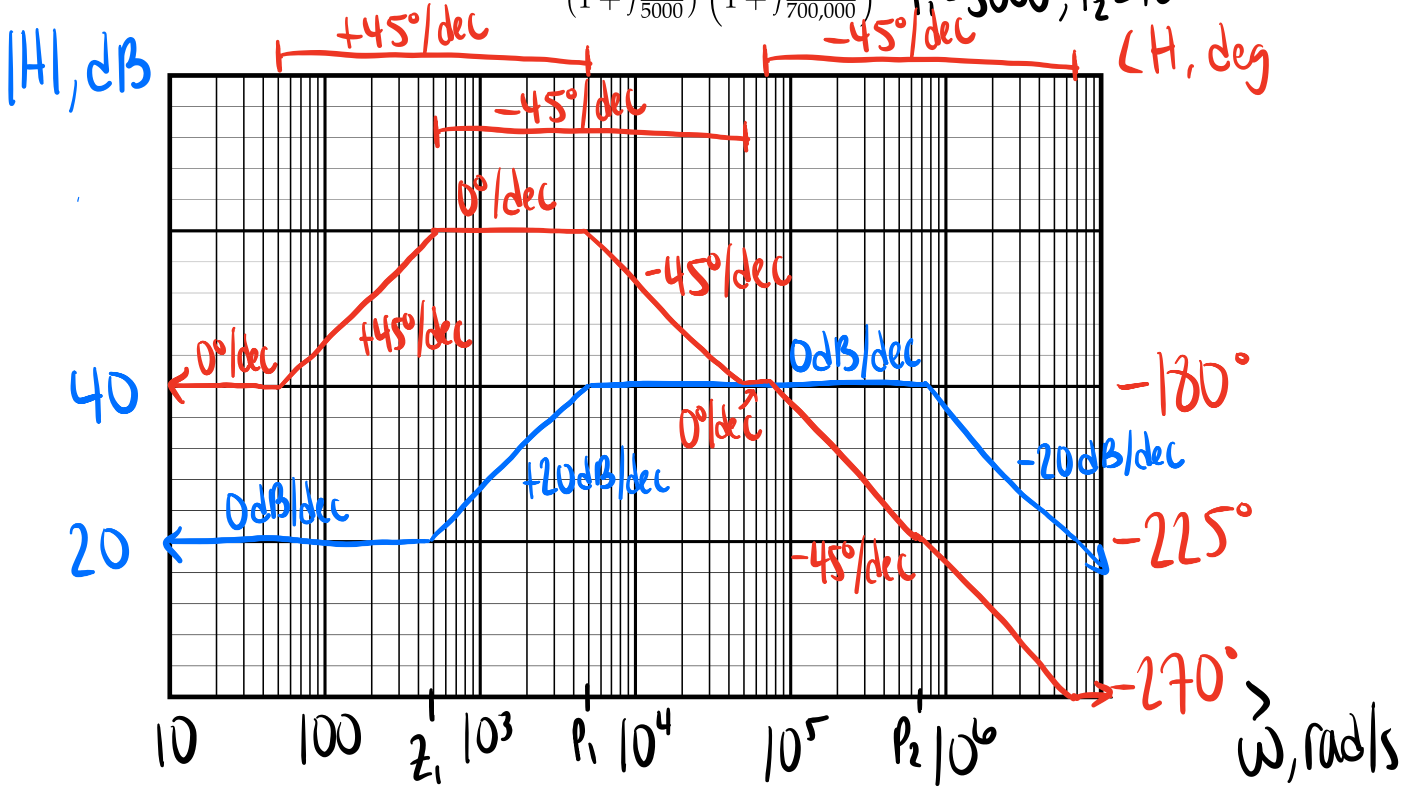
$$= \frac{R_2}{R_2 + R_1} \frac{1 + j\omega C_1 R_1}{1 + j\omega \frac{C_1 R_1 R_2}{R_2 + R_1}}$$

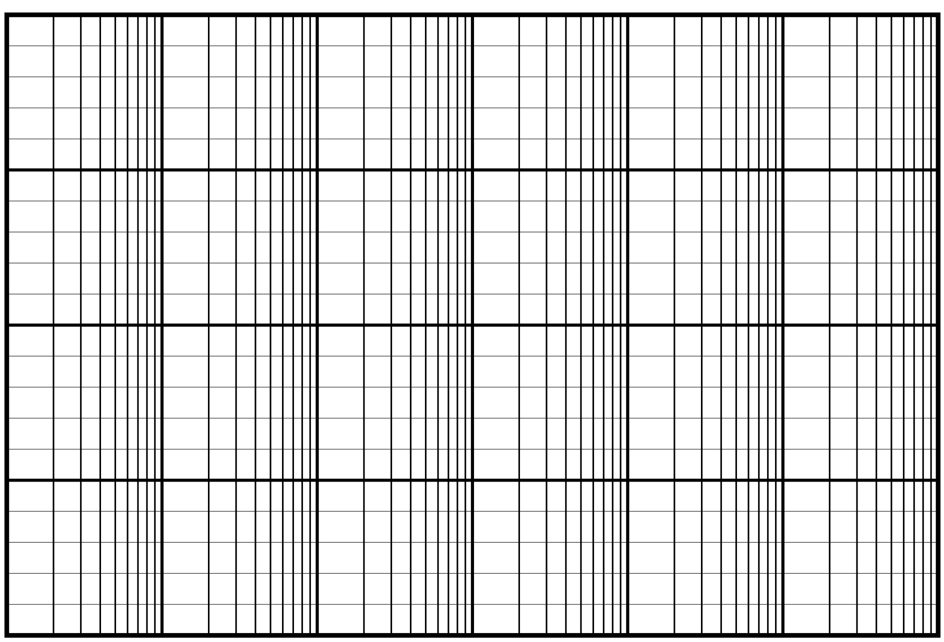
3. (10 points) Plot a straight-line approximation Bode plot on the graph paper provided for both the magnitude and the phase for the following transfer function (the unit for the given values is rad/sec).

$$H(j\omega) = -10\frac{(1+j\frac{\omega}{500})}{(1+j\frac{\omega}{5000})\left(1+j\frac{\omega}{700{,}000}\right)}.$$

$z_1 = 500$

$p_1 = 5000$, $p_2 = 700000$





$\omega = 50$

$H(j50) = -10$

$|H(j50)| = 10$

or $20\log_{10} 10 = 20\,dB$

$\angle H(j50) = -180° / 180°$

ω large

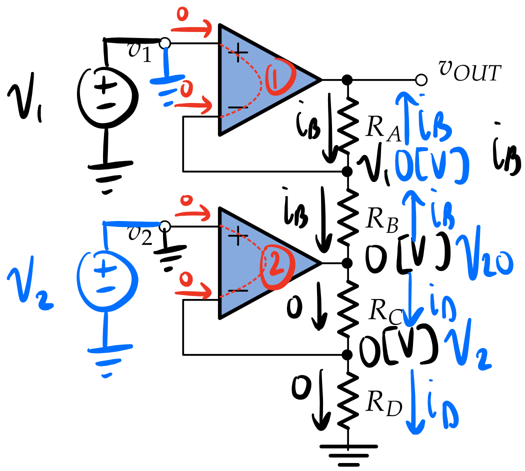
$H(\omega) = -\dfrac{j}{j \cdot j} = j$

$\angle H(\omega) = 90° / -270°$

4. (20 points) For the following amplifier, determine the ratios of R_A, R_B, R_C, and R_D that allow for the circuit to be a difference amplifier **using superposition**.

① $V_2 = 0$

② $V_1 = 0$



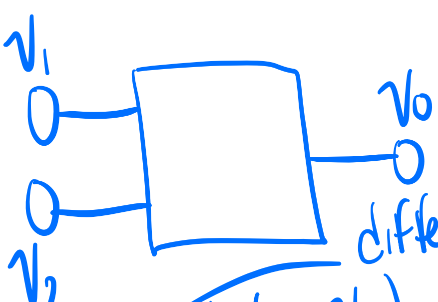
$$i_B = \frac{V_1}{R_B} \Rightarrow V_{01} = V_1 + i_B R_A = V_1 + \frac{V_1}{R_B} R_A$$

$$i_D = \frac{V_2}{R_D}$$

$$V_{20} = V_2 + i_D R_C = V_2 + \frac{V_2}{R_D} R_C$$

$$i_B = \frac{V_{20}}{R_B} = \frac{V_2\left(1+\frac{R_C}{R_D}\right)}{R_B}$$

$$V_{02} = -i_B R_A = -R_A\left(\frac{V_2\left(1+\frac{R_C}{R_D}\right)}{R_B}\right)$$



difference gain

$V_0 = A_d(V_2 - V_1)$

$V_0 = A_d(V_2 - V_1)$

$$V_{OUT} = V_{01} + V_{02}$$

$$= V_1 + \frac{V_1}{R_B} R_A - R_A\left(\frac{V_2\left(1+\frac{R_C}{R_D}\right)}{R_B}\right)$$

$$= V_1 \underbrace{\left(1+\frac{R_A}{R_B}\right)}_{A_d} - V_2 \underbrace{\frac{R_A}{R_B}\left(1+\frac{R_C}{R_D}\right)}_{A_d}$$

$$1 + \frac{R_A}{R_B} = \frac{R_A}{R_B}\left(1+\frac{R_C}{R_D}\right)$$

$$\frac{R_B + R_A}{\cancel{R_B}} = \frac{R_A}{\cancel{R_B}}\left(1 + \frac{R_C}{R_D}\right)$$

$$\frac{R_B + R_A}{R_A} = 1 + \frac{R_C}{R_D}$$

$$1 + \frac{R_B}{R_A} = 1 + \frac{R_C}{R_D}$$

$$\frac{R_B}{R_A} = \frac{R_C}{R_D}$$

what is the common mode gain?

$$V_{OUT} = V_1\left(1 + \frac{R_A}{R_B}\right) - V_2\frac{R_A}{R_B}\left(1 + \frac{R_C}{R_D}\right)$$

$$V_1 = V_2$$

$$V_{OUT_{cm}} = V_1 \underbrace{\left(1 + \frac{R_A}{R_B} - \frac{R_A}{R_B}\left(1 + \frac{R_C}{R_D}\right)\right)}_{A_{cm}}$$

5. (15 points) Consider a difference amplifier, such as the one the previous problem. If $A_d = 10$ and CMRR $= 80\,\text{dB}$, what is the output, v_{OUT}, if

$$v_1 = 1.2[\text{V}]\cos\omega_1 t + 0.25[\text{V}]\sin\omega_2 t$$

and

$$v_2 = 1.3[\text{V}]\cos\omega_1 t$$

$$\text{CMRR} = 20\log\frac{A_d}{A_{cm}} = 80\,\text{dB}$$

$$20\cdot 4 = 80$$

$$\frac{A_d}{A_{cm}} = 10^4 \quad A_d = 10 \Rightarrow A_{cm} = 10^{-3}$$

$$V_2 - V_1 = 0.1[V]\cos\omega_1 t - 0.25[V]\sin\omega_2 t$$

$$V_{o_d} = 10(V_2 - V_1)$$

$$V_{ocm} = 10^{-3}(1.2[V]\cos\omega_1 t)$$

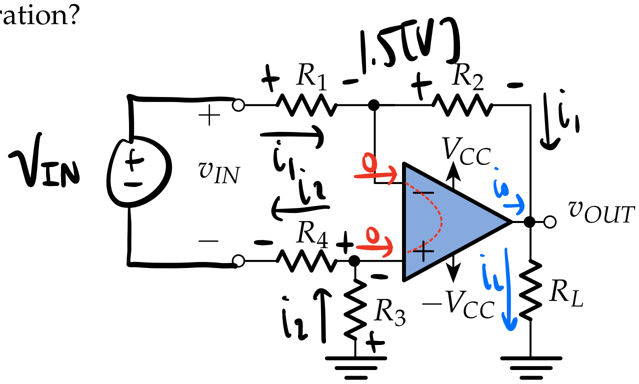
$$V_{OUT} = V_{od} + V_{ocm}$$

$$V_{OUT} = 1[V]\cos\omega_1 t + 2.5[V]\sin\omega_2 t + {}$$
$$+1.2[mV]\cos\omega_1 t$$

6. (15 points) For the following circuit,

(a) Find an expression for the voltage gain, $\frac{v_{OUT}}{v_{IN}}$. *Hint:* draw the test source at the input.

(b) Using $R_1 = R_4 = 2\,\text{k}\Omega$, $R_2 = R_3 = 1\,\text{k}\Omega$, $v_{IN} = -6\,\text{V}$, and $i_{max} = 10\,\text{mA}$, what is the smallest load resistance that you can add to the circuit without having the op-amp go into saturation?



$i_1 = i_2$

$V_{IN} = i_1 R_1 + i_1 R_4$

$\Rightarrow i_1 = \frac{V_{IN}}{R_1 + R_4} = \frac{-6[V]}{2[k\Omega]+2[k\Omega]}$

$i_1 = -1.5[mA]$

$V_+ = 0 - i_1 R_3 = -(-1.5[mA])(1[k\Omega])$

$V_+ = 1.5[V]$

$V_{OUT} = 1.5[V] - i_1 R_2$

$= 1.5[V] - (-1.5[mA])(1[k\Omega])$

$= 3[V]$

$\frac{V_{OUT}}{V_{IN}} = \frac{-i_1(R_3+R_2)}{i_1(R_1+R_4)}$

$\frac{V_{OUT}}{V_{IN}} = \frac{-(R_2+R_3)}{(R_1+R_4)}$

$\frac{V_{OUT}}{V_{IN}} = \frac{3[V]}{-6[V]} = -\frac{1}{2}$

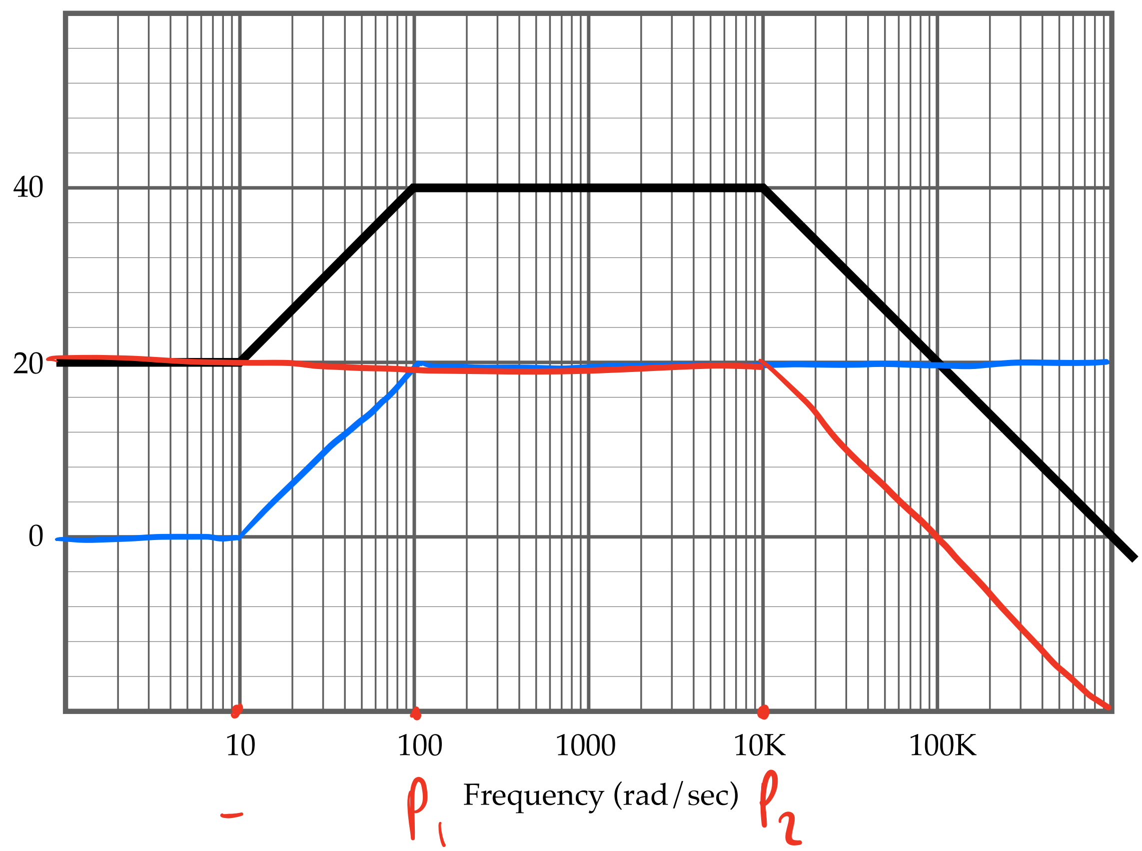
$i_o = 1.5[mA] + i_L < 10[mA]$

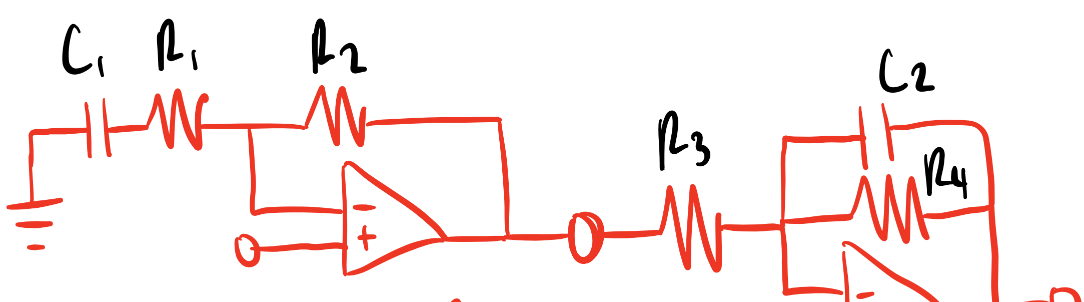
$= 1.5[mA] + \frac{3[V]}{R_L} < 10[mA]$

$\frac{3[V]}{R_L} < 8.5[mA]$

$R_L > \frac{3[V]}{8.5[mA]} = 352.9[\Omega]$

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 to design the circuit and indicate which order the stages should be placed to ensure the circuit is not very sensitive to changes in the source resistance.





$1+\frac{R_2}{R_1} = 10 \leftarrow 20\text{dB}$

$\frac{R_2}{R_1} = 9 \Rightarrow R_2 = 9R_1$

$R_1 = 1[k\Omega]$, $R_2 = 9[k\Omega]$

$\frac{R_4}{R_3} = 10 \Rightarrow R_4 = 10R_3$ ← 20dB

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

$\omega p_1 = \frac{1}{R_1C_1} = 100$

$$\frac{1}{1[k\Omega]C_1} = 100 \Rightarrow C_1 = 10^{-5}[F] = 10[\mu F]$$

$$\omega_{p_2} = \frac{1}{10[k\Omega]C_2} = 10000 \Rightarrow C_2 = 10[nF]$$