ECE 3355: Electronics

Section 12324/17103

Fall 2023

Exam 1

Version A

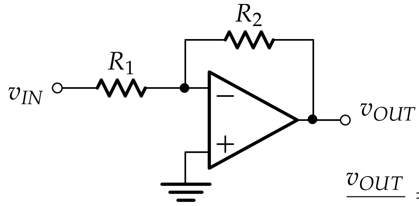
October 7, 2023

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: ______________________________

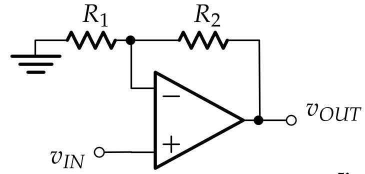
Question	Points	Score
1	15	
2	15	
3	20	
4	20	
5	15	
6	15	
Total:	100	

Inverting Amplifier

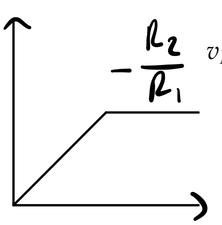


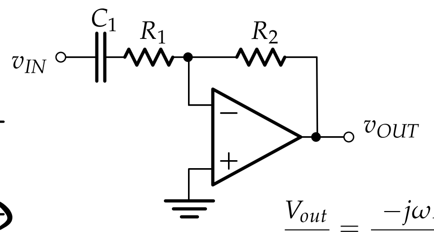
$$\frac{v_{OUT}}{v_{IN}} = -\frac{R_2}{R_1}$$

Non-inverting Amplifier

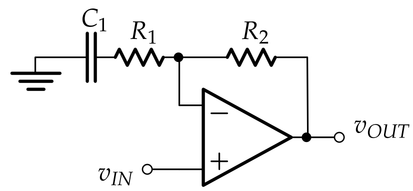


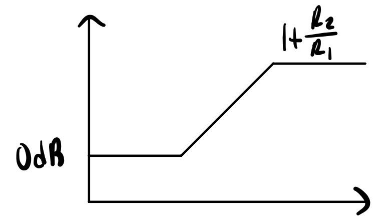
$$\frac{v_{OUT}}{v_{IN}} = 1 + \frac{R_2}{R_1}$$



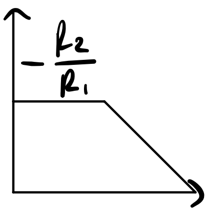


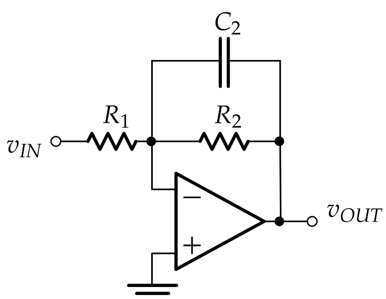
$$\frac{V_{out}}{V_{in}} = \frac{-j\omega R_2 C_1}{1 + j\omega R_1 C_1}$$



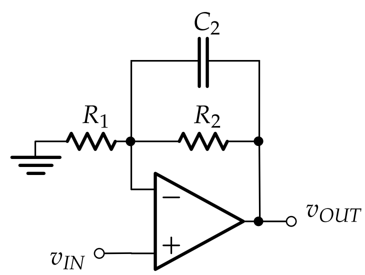


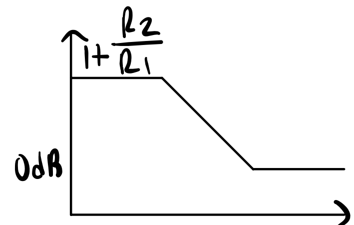
$$\frac{V_{out}}{V_{in}} = \frac{1 + j\omega\left(R_1 + R_2\right)C_1}{1 + j\omega R_1 C_1}$$



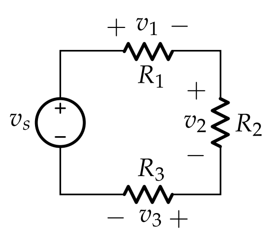


$$\frac{V_{out}}{V_{in}} = \frac{-\frac{R_2}{R_1}}{1 + j\omega R_2 C_2}$$

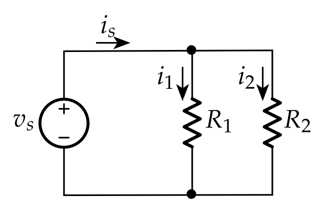




$$\frac{V_{out}}{V_{in}} = \left[1 + \frac{R_2}{R_1}\right]\left[\frac{1 + j\omega\left(R_1 || R_2\right)C_2}{1 + j\omega R_2 C_2}\right]$$



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

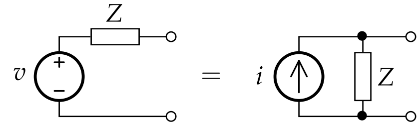


$$i_1 = \frac{R_2}{R_1 + R_2} i_s$$
$$i_2 = \frac{R_1}{R_1 + R_2} i_s$$

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

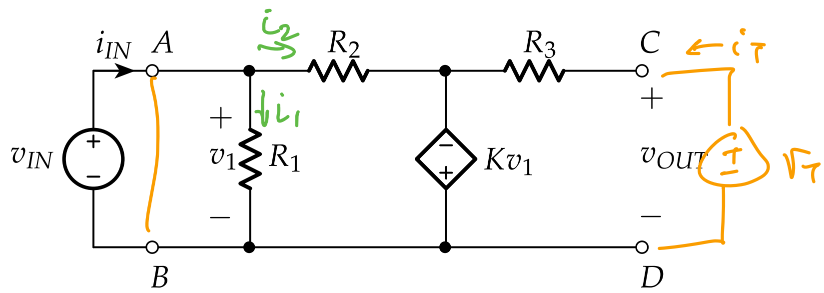
$\overline{V}_b \rightarrow$ Phasor notation

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



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

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



$v_{OUT} = -Kv_1$ and $v_{IN} = v_1$

$$\boxed{\frac{v_{OUT}}{v_{IN}} = -K}$$

$$R_{in} = \frac{v_{IN}}{i_1 + i_2} = \frac{v_1}{\frac{v_1}{R_1} + \frac{v_1 + Kv_1}{R_2}} = \frac{1}{\frac{1}{R_1} + \frac{1}{\frac{R_2}{1+K}}} = R_1 \| \frac{R_2}{1+K}$$

Alternatively, note that $R_{in} = R_1 \| \frac{v_1}{i_2} = R_1 \| \frac{v_1}{\frac{v_1 + Kv_1}{R_2}} = R_1 \| \frac{R_2}{1+K}$

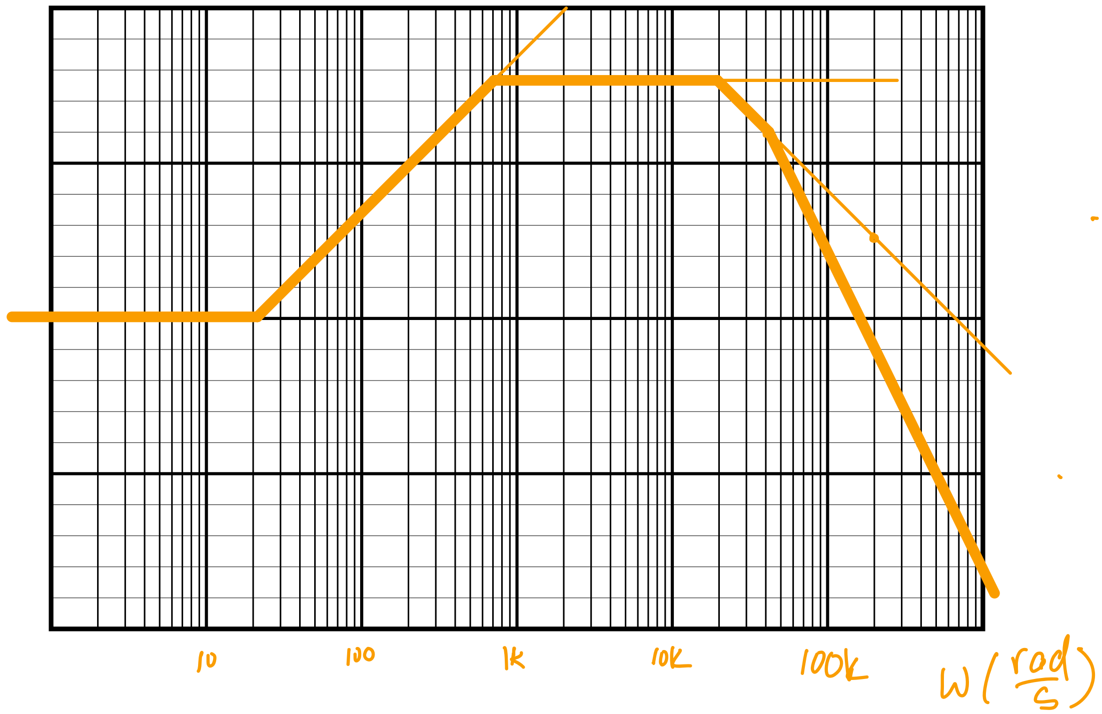
Also: $R_1 \| \frac{R_2}{1+K} = \frac{R_1 \cdot \frac{R_2}{1+K}}{R_1 + \frac{R_2}{1+K}} = \frac{R_1 R_2}{(1+K)R_1 + R_2}$

$R_o = R_3$ since $v_1 = 0$ so $K \cdot v_1 = 0$
and $v_T = i_T R_3$

2. (15 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).

$$H(j\omega) = -100\frac{\left(1+j\frac{\omega}{20}\right)}{\left(1+j\frac{\omega}{700}\right)\left(1+j\frac{\omega}{20{,}000}\right)\left(1+j\frac{\omega}{40{,}000}\right)}.$$



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

(b) 180°

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

(c) 0°

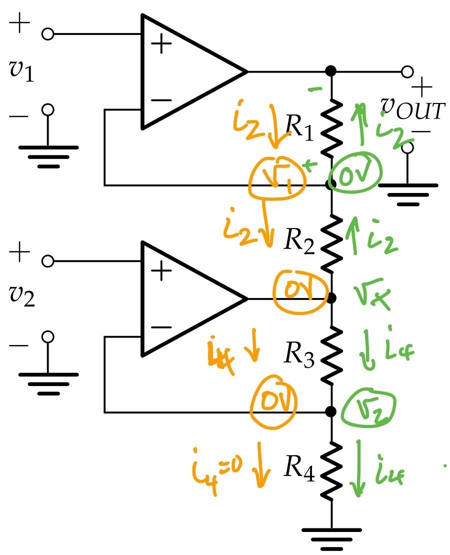
3. (20 points) Difference Amplifier

   (a) Determine the ratios of the resistors (R_1, R_2, R_3, and R_4) that allow for this circuit to be a difference amplifier. (*Hint:* use superposition.)

   (b) What is the difference gain (A_d) when $R_1 = R_4 = 9\,\text{k}\Omega$ and $R_2 = R_3 = 1\,\text{k}\Omega$?

   (c) Using the values above, except for $R_2 = 0.9\,\text{k}\Omega$, what is the CMRR? (*Hint:* you do not need to recalculate the difference gain with the new value of R_2 - just use the value from above.)

   (d) What is the input resistance seen at each of the input terminals (i.e., at v_1 and v_2)?



(a) Using Superposition:

when $v_1 = 0$ $\quad i_4 = \frac{v_2}{R_4}$ and $v_x = v_2 + i_4 \cdot R_3 = v_2 + v_2 \cdot \frac{R_3}{R_4} = \left(1+\frac{R_3}{R_4}\right)v_2$

$i_2 = \frac{v_x}{R_2}$ and $v_o = -i_2 R_1 = -\frac{R_1}{R_2} \cdot v_x = -\frac{R_1}{R_2}\left(1+\frac{R_3}{R_4}\right)v_2$

when $v_2 = 0$ $\quad i_2 = \frac{v_1}{R_2}$ and $v_o = v_1 + i_2 R_1 = v_1 + \frac{R_1}{R_2}v_1 = \left(1+\frac{R_1}{R_2}\right)v_1$

Hence:

$$v_o = \left(1+\frac{R_1}{R_2}\right)v_1 - \frac{R_1}{R_2}\left(1+\frac{R_3}{R_4}\right)v_2$$

To become a difference amplifier,

$$1+\frac{R_1}{R_2} = \frac{R_1}{R_2}\left(1+\frac{R_3}{R_4}\right)$$

$$1+\frac{R_1}{R_2} = \frac{R_1}{R_2} + \frac{R_1}{R_2}\frac{R_3}{R_4}$$

$$1 = \frac{R_1}{R_2}\frac{R_3}{R_4}$$

$$1+\frac{R_2}{R_1} = 1+\frac{R_3}{R_4} \Rightarrow \boxed{\frac{R_2}{R_1} = \frac{R_3}{R_4}}$$

(b) $A_d = 1 + \frac{R_1}{R_2} = \frac{R_1}{R_2}\left(1 + \frac{R_3}{R_4}\right) = 1 + \frac{9k\Omega}{1k\Omega} = \boxed{10}$

(c) To find the common mode gain, set $v_1 = v_2 = v_{cm}$

$$v_o = \left(1 + \frac{R_1}{R_2}\right)v_{cm} - \frac{R_1}{R_2}\left(1 + \frac{R_3}{R_4}\right)v_{cm}$$

$$A_{cm} = \frac{v_o}{v_{cm}} = \left(1 + \frac{R_1}{R_2}\right) - \frac{R_1}{R_2}\left(1 + \frac{R_3}{R_4}\right) = \left(1 + \frac{9}{0.9}\right) - \frac{9}{0.9}\left(1 + \frac{1}{9}\right)$$

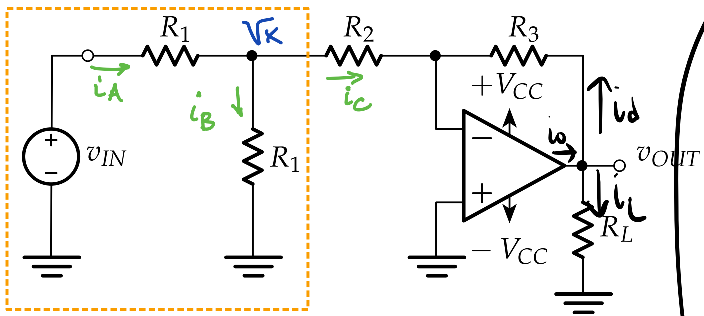
$$= -0.11$$

$$CMRR = 20\log_{10}\frac{|A_d|}{|A_{cm}|} = \frac{10}{0.11} = 39dB$$

(d) Inputs are connected to non-inverting inputs, so

$$R_{in1} = R_{in2} = \infty$$

4. (20 points) For the following circuit, the op-amp is powered by a pair of $\pm V_{CC} = \pm 15$ volt supplies (as shown). Also, $R_1 = 6\,\mathrm{K}\Omega$, $R_2 = 3\,\mathrm{K}\Omega$, $R_3 = 12\,\mathrm{K}\Omega$, $R_L = 600\,\Omega$, and $v_{IN} = -10\,\mathrm{V}$.



Approach 1:

$i_A = i_B + i_C$

$\frac{v_{IN} - v_x}{R_1} = \frac{v_x}{R_1} + \frac{v_x}{R_2}$

$v_{IN} = v_x + v_x + \frac{R_1}{R_2} v_x$

$v_x = \frac{v_{IN}}{2 + \frac{R_1}{R_2}} = \frac{v_{IN}}{4}$

$v_o = -\frac{R_3}{R_2} v_x = -\frac{R_3}{R_2} \cdot \frac{v_{IN}}{4}$

$\boxed{v_o = -v_{IN} = 10\,V}$

Approach 4:

$i_A = \frac{v_{IN}}{R_1 + R_1 \| R_2}$

$v_x = i_A \cdot (R_1 \| R_2)$

$v_x = v_{IN} \cdot \frac{R_1 \| R_2}{R_1 + R_1 \| R_2}$

$= \frac{2}{8} v_{IN} = \frac{1}{4} v_{IN}$

(a) Show whether or not the circuit is in voltage saturation.

(b) Show whether or not the circuit is in current saturation if $i_{max} = 25\,\mathrm{mA}$.

(c) What is v_{OUT}?

Approach 2:

$i_A = \frac{v_{IN}}{R_1 + R_1 \| R_2}$

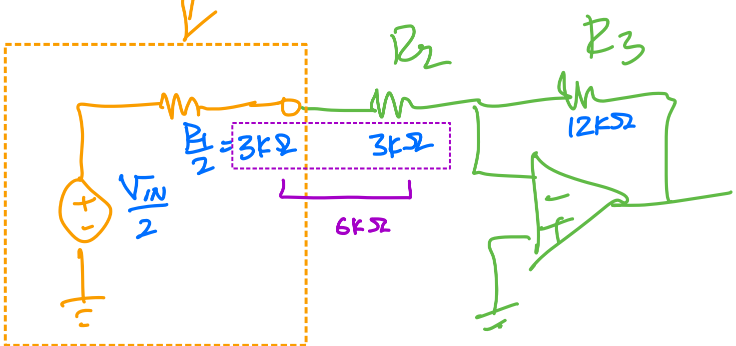
$v_x = v_{IN} - i_A R_1$

$v_x = v_{IN} - \frac{v_{IN} \cdot R_1}{R_1 + R_1 \| R_2}$

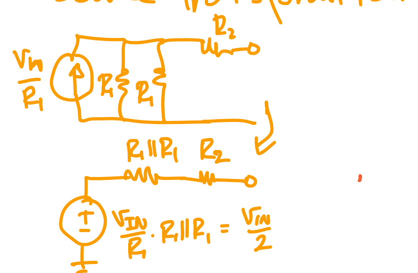
$= v_{IN}\left(1 - \frac{6\,K\Omega}{6\,K\Omega + 6\,K\Omega \| 3\,K\Omega}\right)$

$v_x = \frac{v_{IN}}{4}$

Approach 3: Thevenin Equivalent



Approach 5: Source transformations



Thevenin circuit is just and inverting op-amp with a gain of -2

Hence, $v_{OUT} = -2\left(\frac{1}{2} v_{IN}\right) = -v_{IN} \Rightarrow \boxed{10\,V}$

need to solve for gain correctly to receive credit

(a) not in voltage saturation $10[V] = v_o$, $-15[V] < v_o < 15[V]$

(b) $i_o = \frac{v_{OUT}}{R_L} + \frac{v_{OUT}}{R_3} = \frac{10V}{0.6\,K\Omega} + \frac{10V}{12\,K\Omega} = 17.5\,mA < i_{max}$

hence, not in current saturation

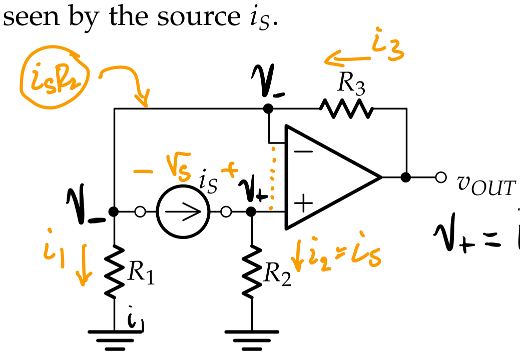
(c) $\boxed{v_{OUT} = 10\,V}$

5. (15 points) For the following circuit,

   (a) find an expression for the transresistance gain, $\dfrac{v_{OUT}}{i_S}$.

   (b) find the resistance seen by the source i_S.

$i_1 = \dfrac{V_-}{R_1}$



$V_+ = i_S R_2 = V_-$

(a) $i_3 = i_1 + i_S = \dfrac{i_S R_2}{R_1} + i_S$

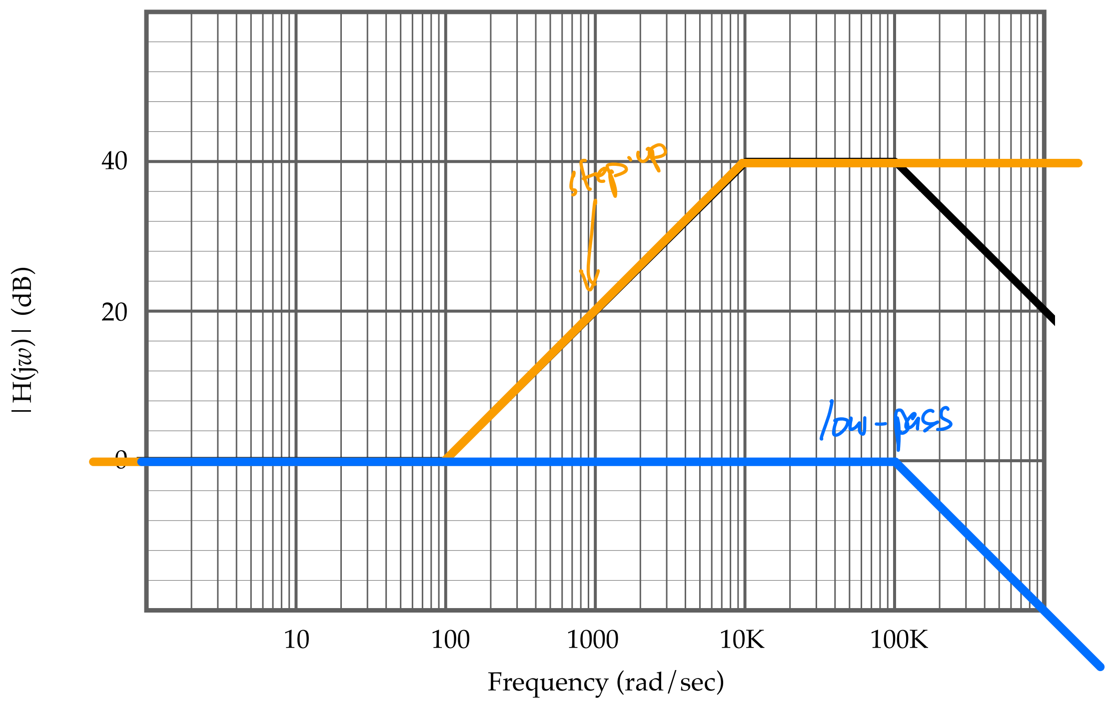
$v_{OUT} = i_S R_2 + i_3 R_3 = i_S R_2 + \left(\dfrac{i_S R_2}{R_1} + i_S\right) R_3$

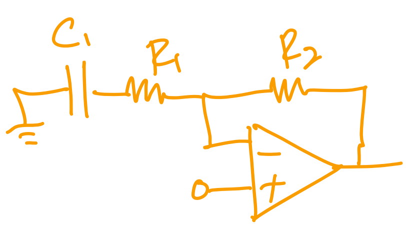
$$\boxed{\frac{v_{OUT}}{i_S} = R_2 + \left(\frac{R_2}{R_1} + 1\right) R_3}$$

(b) since both terminals of i_S are at the same potential, $v_S = 0$

$$\boxed{R_{in} = \frac{v_S}{i_S} = 0\,\Omega}$$

6. (15 points) Design a circuit that has the following straight-line approximation to the Bode plot. Indicate which order the stages should be placed in to ensure that the input resistance does not vary with frequency.





40dB

$1+\frac{R_2}{R_1} = 100$

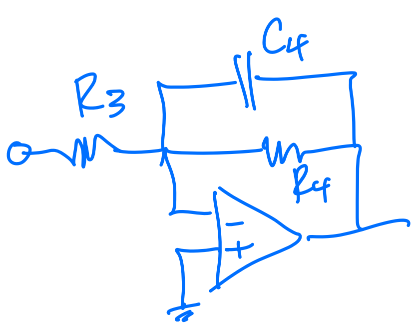
choose $R_2 = 99\,k\Omega$

$R_1 = 1\,k\Omega$

$\frac{1}{R_1 C_1} = 10k\,rad/s$

$C_1 = \frac{1}{10^3 \cdot 10^4} = 10^{-7}\,F$

$= 0.1\,\mu F = 100\,nF$



$\frac{R_4}{R_3} = 1$

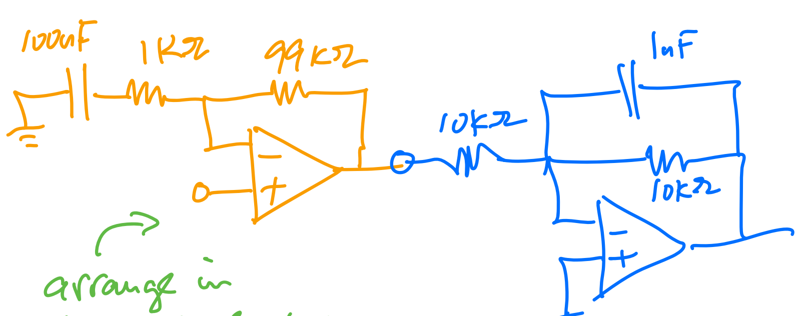
Here: $\frac{R_4}{R_3} = 1$

Choose $R_3 = R_4 = 10k\Omega$

$\frac{1}{R_4 C_4} = 100k\,rad/s$

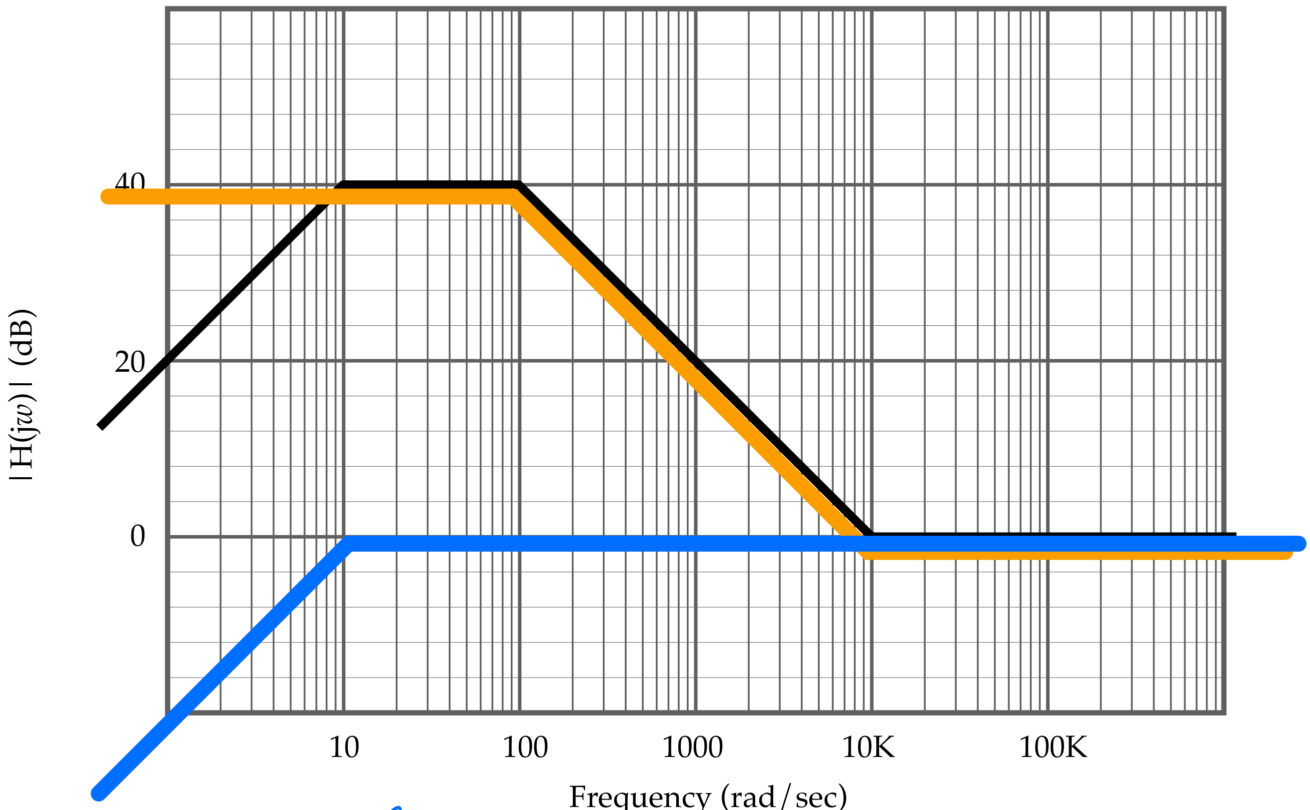
$C_4 = \frac{1}{10^4 \cdot 10^5} = 10^{-9}\,F$

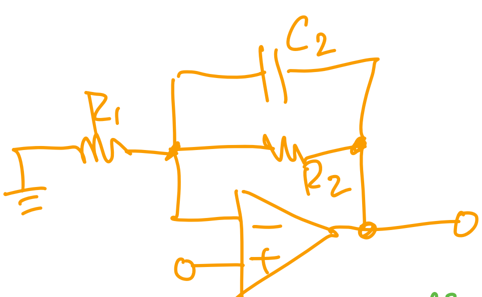
$= 1\,nF$

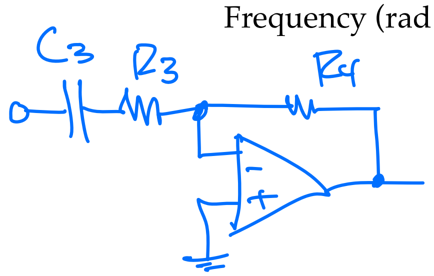


arrange in this order for high input resistance

6. (15 points) Design a circuit that has the following straight-line approximation to the Bode plot. Indicate which order the stages should be placed in to ensure that the input resistance does not vary with frequency.







$1+\frac{R_2}{R_1} = 100$ 40dB

Choose $R_2 = 99\,k\Omega$, $R_1 = 1\,k\Omega$

$\frac{1}{R_2 C_2} = 100\ \frac{rad}{s}$

$C_2 = \frac{1}{10^2 \cdot 9.9\times 10^4} \cong \frac{1}{10^2 \cdot 10^5} \cong 10^{-7} F$

$= 0.1\mu F = 100 nF$

$\frac{R_4}{R_3} = 1$

choose $R_4 = R_3 = 10K\Omega$

$\frac{1}{R_3 C_3} = 10\ \frac{rad}{s}$

$C_3 = \frac{1}{10^1 \cdot 10^4} = 10^{-5} F$

$= 10\mu F$