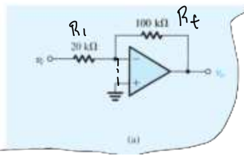
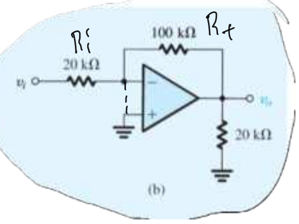
1. Assuming ideal op amps, find the voltage gain v_o/v_i and input resistance Rin of each of the circuits below:



(a)

$$A = -\frac{R_f}{R_i} = \frac{V_o}{V_i}$$

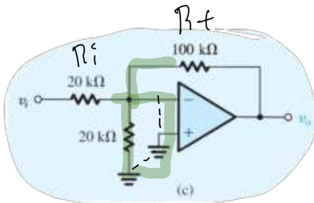
$$A = \frac{-100K}{20K} = -5$$



(b)

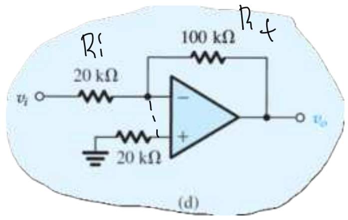
$$A = -\frac{R_f}{R_i}$$

$$A = -5$$



(c)

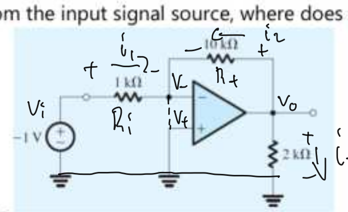
$$A = -\frac{R_f}{R_i} = -5$$



(d)

$$A = -\frac{R_f}{R_i} = -5$$

2. For the circuit below, assuming an ideal op amp, find the currents through all branches and the voltages at all nodes. Since the current supplied by the op amp is greater than the current drawn from the input signal source, where does the additional current come from?



$V_- = V_+ = 0\,[V]$

$$i_2 = \frac{V_o - V_-}{10K} = \frac{10}{10K} = 1\,[mA]$$

$$i_3 = \frac{V_o}{2K} = \frac{10}{2K} = 5\,[mA]$$

$$\frac{V_o}{V_i} = -\frac{R_f}{R_i}$$

$$V_o = -\frac{10K}{1K} V_i$$

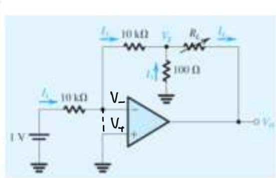
$$V_o = 10\,[V]$$

$$i_1 = \frac{V_i - V_-}{R_i}$$

$$i_1 = \frac{-1}{1K} = -1\,[mA]$$

1mA from source
6mA from op-amp output
"extra" current must come from op-amp power source ($+V_{CC}, -V_{EE}$)

3. The circuit in below utilizes an ideal op amp.
   (a) Find I_1, I_2, I_3, I_L, and V_x.
   (b) If V_O is not to be lower than −13 V, find the maximum
   (c) allowed value for RL.
   (d) If R_L is varied in the range 100 Ω to 1 kΩ, what is the corresponding change in IL and in V_O?



$V_- = V_+ = 0$

KCL @ V_-: $-\frac{1}{10K} + \frac{-V_x}{10K} = 0$

$V_x = -1\,[V]$

a) $I_1 = \frac{1 - V_-}{10K} = \frac{1}{10K} = .1[mA]$

$I_2 = \frac{V_- - V_x}{10K} = -\frac{V_x}{10K} = -\frac{-1}{10K} = 0.1[mA]$

$I_3 = \frac{0 - V_x}{100} = \frac{-(-1)}{100} = 10\,[mA]$

@ V_x: $I_2 + I_3 = I_L$

$.1m + .10m = I_L$

$I_L = 10.1\,[mA]$

b) $I_2 + I_3 = I_L$

$$\frac{V_x - V_o}{R_L} = 10.1m$$

$$\frac{(-1) - (-13)}{10.1m} = R_L$$

$R_L = 1188.\overline{1188} \approx 1.2\,[K\Omega]$

max value to keep $V_o \geq -13[V]$

d) $I_L = I_2 + I_3 = \frac{V_- - V_x}{10K} - \frac{V_x}{100}$

$\therefore$ I_L doesn't depend on R_L

so for $100 \leq R_L \leq 1K\Omega$, $I_L = 10.1\,[mA]$

$\frac{V_x - V_o}{R_L} = 10.1m \Rightarrow V_x - 10.1m R_L = V_o$

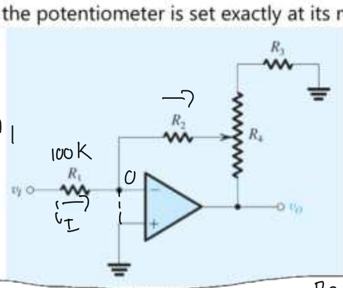
$-1 - 10.1m R_L = V_o$

$R_L = 100\Omega$: $V_o = -2.01\,[V]$

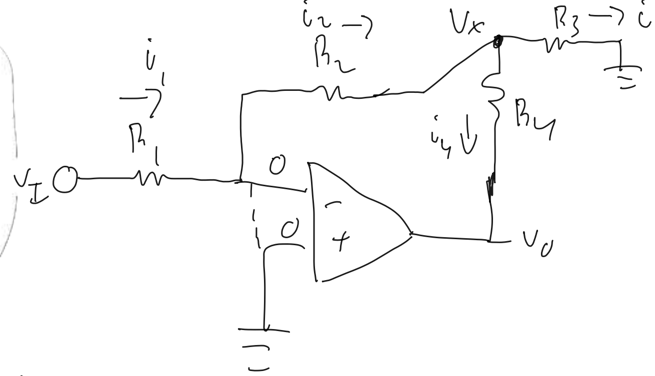
$R_L = 1K\Omega$: $V_o = -11.1\,[V]$

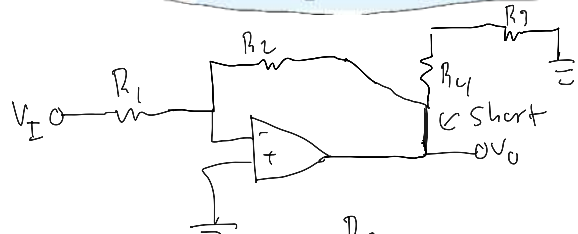
4. Design the circuit shown in Fig. P2.35 to have an input resistance of 100 kΩ and a gain that can be varied from −1 V/V to −100 V/V using the 100-kΩ potentiometer R4. What voltage gain results when the potentiometer is set exactly at its middle value?

$V_I = i_I R_1$

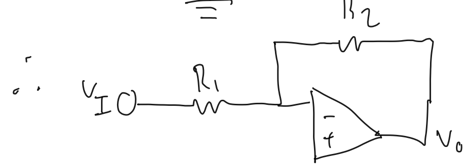


$V_- = V_+ = 0$





$\therefore$



$$\frac{V_o}{V_I} = -\frac{R_2}{R_1} = -1 = A$$

min. gain

$R_2 = R_1$

$R_2 = 100K$

$i_1 = i_2$

$$\frac{V_I}{R_1} = -\frac{V_x}{R_2}$$

$$V_x = -V_I \frac{R_2}{R_1}$$

KCL @ V_x:

$$+\left(\frac{0+V_x}{R_2}\right) + \frac{V_x - V_o}{R_4} + \frac{V_x}{R_3} = 0$$

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

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

$$\frac{V_o}{V_I} = -\left[\frac{R_4}{R_1} + \frac{R_2}{R_1} + \frac{R_4 \cancel{R_2}}{\cancel{R_1} R_3}\right]$$

since $R_2 = R_1$: $\frac{V_o}{V_I} = -\frac{R_4}{R_1} - 1 - \frac{R_4}{R_3}$

$$\frac{V_o}{V_I} = -\frac{\cancel{100k}}{\cancel{100k}} - 1 - \frac{100k}{R_3}$$

max gain

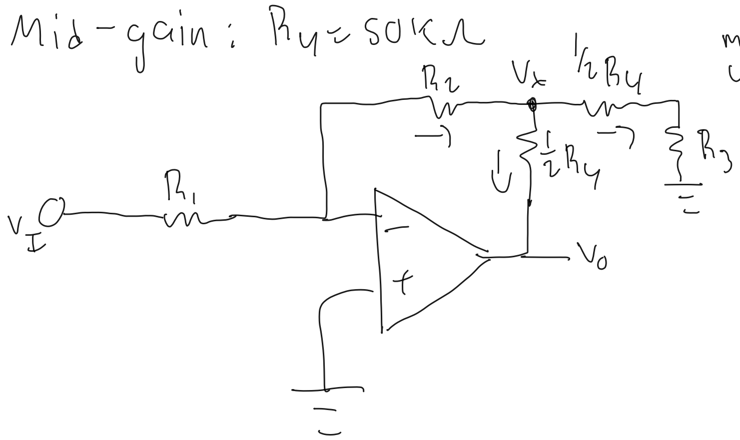
since min already used

$$\frac{V_o}{V_I} = -2 - \frac{100k}{R_3}$$

$$\frac{-100k}{-100+2} = R_3$$

$$R_3 = 1020.41\,[\Omega] \approx 1.02\,[k\Omega]$$

Mid-gain: $R_4 = 50k\Omega$



KCL @ V_x:

$$-\frac{0-V_x}{R_2} + \frac{V_x - V_o}{.5R_4} + \frac{V_x}{.5R_4 + R_3} = 0$$

$$V_x\left(\frac{1}{R_2} + \frac{1}{.5R_4} + \frac{1}{.5R_4 + R_3}\right) = V_o\left(\frac{1}{.5R_4}\right)$$

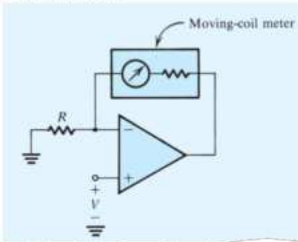
$$-V_I \frac{R_2}{R_1}\left(\frac{1}{R_2} + \frac{1}{.5R_4} + \frac{1}{.5R_4 + R_3}\right) = V_o\left(\frac{1}{.5R_4}\right)$$

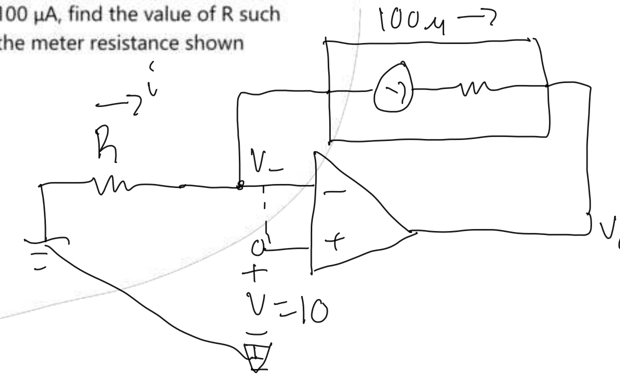
$$\frac{V_o}{V_I} = -\left[\frac{.5R_4}{R_1} + \frac{R_2}{R_1} + \frac{.5R_4 \cancel{R_2}}{\cancel{R_1}(.5R_4 + R_3)}\right]$$

$$\frac{V_o}{V_I} = -\left[\frac{50K}{100K} + 1 + \frac{50K}{50K + 1.02K}\right]$$

$$\frac{V_o}{V_I} = -2.48$$

5. Figure below shows a circuit for an analog voltmeter of very high input resistance that uses an inexpensive moving-coil meter. The voltmeter measures the voltage V applied between the op amp's positive-input terminal and ground. Assuming that the moving coil produces full-scale deflection when the current passing through it is 100 μA, find the value of R such that a full-scale reading is obtained when V is +10 V. Does the meter resistance shown affect the voltmeter calibration?





$V_- = V_+$

Meter resistance should not affect calibration since op-amp will drive current to maintain $V_- = V_+ = V = 10\,[V]$.
Internal resistance only affects required V_o to maintain 100μA of current between $V_- \to V_o$ (across meter).

KCL @ V_-: $-i + 100\mu = 0$

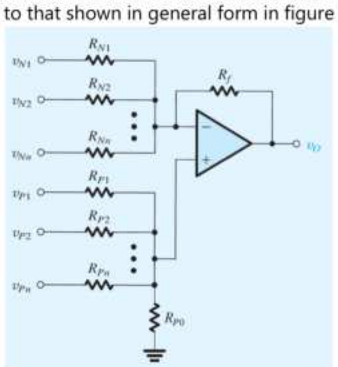
$i = 100\mu$

$-\frac{0 - V_-}{R} = i$

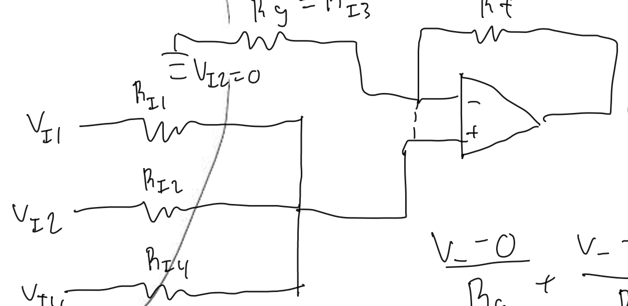
$\frac{V_-}{i} = R$

$R = [100\,K\Omega]$

6. Design a circuit, using one ideal op amp, whose output is $v_O = v_{I1} + 2v_{I2} - 9v_{I3} + 4v_{I4}$. (Hint: Use a structure similar to that shown in general form in figure below)



for non-inverting

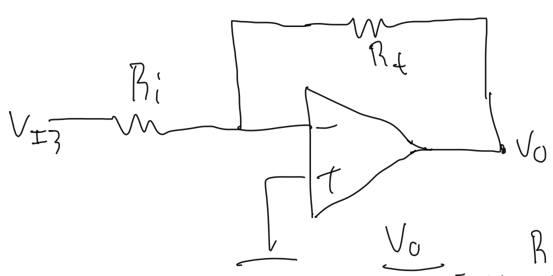


$$\frac{V_- - 0}{R_g} + \frac{V_- - V_o}{R_f} = 0$$

$$V_-\left(\frac{1}{R_g} + \frac{1}{R_f}\right) = V_o \frac{1}{R_f}$$

$$\frac{V_o}{V_+} = \frac{V_o}{V_-} = A_+ = \left(\frac{R_f}{R_g} + 1\right)$$

for inverting: $\frac{V_o}{V_{I3}} = -9 = A_-$



$$\frac{V_o}{V_{I3}} = -\frac{R_f}{R_i} = -9$$

$$\frac{90K}{10K} = 9 \checkmark$$

$R_f = 90K$, $R_{i3} = 10K = R_g$

$$A_+ = 9 + 1 = 10$$

$$V_o = \frac{\frac{V_{I1}}{R_{p1}} + \frac{V_{I2}}{R_{p2}} + \frac{V_{I4}}{R_{p4}}}{\left(\frac{1}{R_{p1}} + \frac{1}{R_{p2}} + \frac{1}{R_{p4}} + \frac{1}{R_{po}}\right)^{-1}}$$

$V_{I1} = \frac{1}{A_+} = .1$

$V_{I2} = .2$

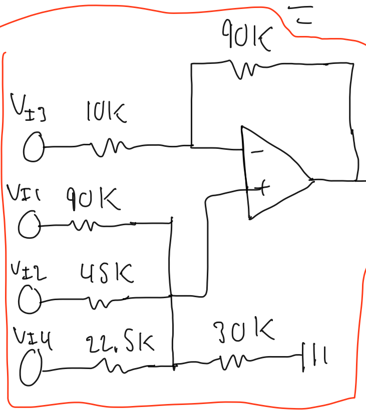
$V_{I4} = .4$

$$\left(\frac{1}{R_{p1}} + \frac{1}{R_{p2}} + \frac{1}{R_{p4}} + \frac{1}{R_{po}}\right)^{-1} = R_f \| R_g = 90K \| 10K = 9K$$

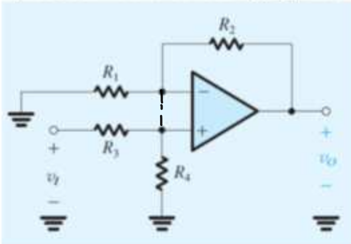
$\frac{1}{R_{p1}} = \frac{.1}{9K}$ $\quad \frac{1}{R_{p2}} = \frac{.2}{9K}$ $\quad \frac{1}{R_{p4}} = \frac{.4}{9K}$

$R_{p1} = 90K$ $\quad R_{p2} = 45K$ $\quad R_{p4} = 22.5K$

$$R_{po} = \left(\frac{1}{R_{p1}} + \frac{1}{R_{p2}} + \frac{1}{R_{p4}}\right)^{-1} = 30K$$



7. Derive an expression for the voltage gain, v_O/v_I, of the circuit below



$V_- = V_+$

KCL @ V_-: $\frac{V_-}{R_1} + \frac{V_- - V_0}{R_2} = 0$

$$V_-\left(\frac{1}{R_1} + \frac{1}{R_2}\right) = V_0\left(\frac{1}{R_2}\right)$$

$$V_-\left(\frac{R_2}{R_1} + 1\right) = V_0$$

$$V_+ = V_I\left(\frac{R_4}{R_3+R_4}\right)$$

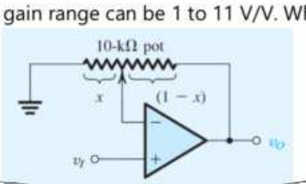
$$V_I\left(\frac{R_4}{R_3+R_4}\right)\left(\frac{R_2}{R_1}+1\right) = V_0$$

$$\frac{V_0}{V_I} = \frac{R_4R_2}{R_1(R_3+R_4)} + \frac{R_4}{R_3+R_4}$$

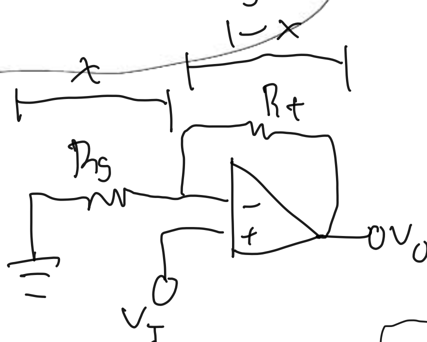
$$\frac{V_0}{V_I} = \frac{R_4R_2 + R_1R_4}{R_1(R_3+R_4)}$$

$$\frac{V_0}{V_I} = \frac{R_4}{R_1}\left(\frac{R_2+R_1}{R_3+R_4}\right)$$

8. The circuit below utilizes a 10-kΩ potentiometer to realize an adjustable-gain amplifier. Derive an expression for the gain as a function of the potentiometer setting x. Assume the op amp to be ideal. What is the range of gains obtained? Show how to add a fixed resistor so that the gain range can be 1 to 11 V/V. What should the resistor value be?



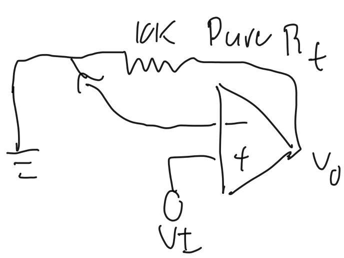
Non-inverting

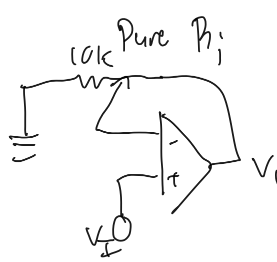


$R_i = x(10K)$

$R_f = (1-x)(10K)$

depending on pot. wiper.





$$A = \frac{V_0}{V_I} = 1 + \frac{R_f}{R_i}$$

$$A = 1 + \frac{(1-x)\,\cancel{10K}}{x\,\cancel{10K}}$$

$$= 1 + \frac{1-x}{x}$$

$$= 1 + \frac{1}{x} - 1$$

$$A = \frac{1}{x}$$

$x=0$; $A = \frac{1}{0} = \infty$

$x=1$; $A = 1$

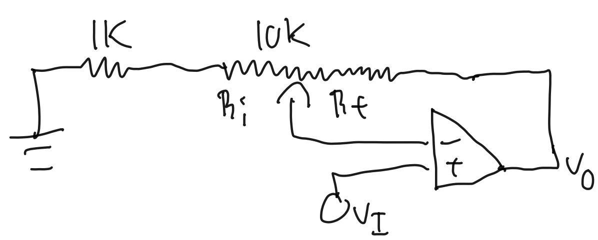
$\therefore$ $1 \le A < \infty$

$$A' = 1 + \frac{(1-x)10K}{x10K + R_g}$$

max @ $x=0$ $\therefore$ $A'_{max} = 1 + \frac{10K}{R_g} = 11$

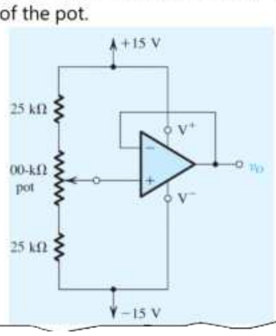
$$= \frac{10K}{R_g} = 10$$

$R_g = 1K$

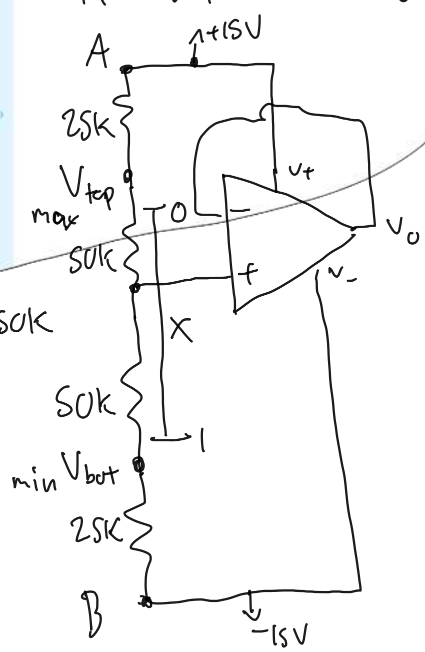


$\therefore$ $1 \le A \le 11$

9. Figure P2.59 shows a circuit that provides an output voltage v_O whose value can be varied by turning the wiper of the 100-kΩ potentiometer. Find the range over which v_O can be varied. If the potentiometer is a "20-turn" device, find the change in v_O corresponding to each turn of the pot.



if wiper at $\frac{1}{2}100k = 50k$



$$\underbrace{25+25+50+50}_{\text{series}} = 150k$$

$V_{AB} = 15 - (-15) = 30V$

$$V_{top} = V_A - V_{AB}\left(\frac{25K}{150K}\right)$$

$$V_{top} = 15 - 30\left(\frac{1}{6}\right)$$

$$V_{top} = 10[V]$$

$$V_{bot} = V_A - V_{AB}\left(\frac{125K}{150K}\right)$$

$$= 15 - 30\left(\frac{5}{6}\right)$$

$$V_{bot} = -10[V]$$

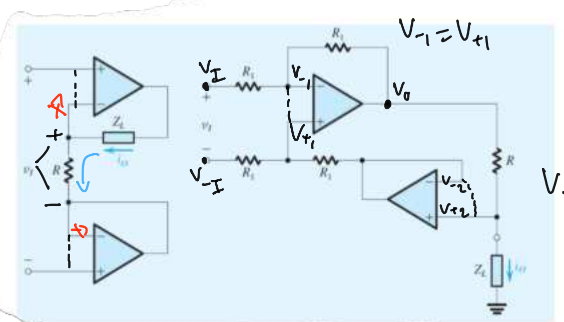
$-10[V] \le V_o \le 10[V]$ since pot. (input) ranges from $-10V$ to $10V$ and $V_- = V_+$

if $x=0$, $V_{top} = V_+ = 10V$

$x=1$, $V_{bot} = V_+ = -10V$

$\Big\}$ $20[V]$ range / 20 turns of pot $= \boxed{\dfrac{1V}{\text{turn}}}$

10. The two circuits below are intended to function as voltage-to-current converters; that is, they supply the load impedance Z_L with a current proportional to v_I and independent of the value of Z_L. Show that this is indeed the case, and find for each circuit i_O as a function of v_I. Comment on the differences between the two circuits.



Left Circuit: $V_I = i_o R$

i_o runs through R since no current enters inputs of op-amp and V_I is voltage across R due to virtual short

Right circuit:

KCL @ V_{-1}: $\dfrac{V_{-1} - V_I}{R_1} + \dfrac{V_{-1} - V_o}{R_1} = 0$

$V_{-1} = V_{+1}$

$$V_{-1}\left(\frac{1}{R_1} + \frac{1}{R_1}\right) = \frac{V_I + V_o}{R_1}$$

$$V_{-1}\left(\frac{2}{R_1}\right) = \frac{V_I + V_o}{R_1}$$

$$V_{-1} = \frac{V_I + V_o}{2}$$

KCL @ V_{+1}: $\dfrac{V_{+1} - V_{-I}}{R_1} + \dfrac{V_{+1} - V_{-2}}{R_1} = 0$

$$2V_{+1} = V_{-I} + V_{-2}$$

$$V_{+1} = \frac{V_{-I} + V_{-2}}{2}$$

$$\frac{V_I + V_o}{2} = \frac{V_{-I} + V_{-2}}{2}$$

$$V_I + V_o = V_{-I} + V_{-2}$$

$$V_{-2} = V_o + V_I - V_{-I} = V_o - V_I$$

KCL V_{+2}: $\dfrac{V_{+2} - V_o}{R} + \dfrac{\overset{i_o}{\overbrace{V_{+2}}}}{Z_L} = 0$

$$i_o = \frac{V_o - V_{+2}}{R}$$

$$V_o - V_{+2} = i_o R$$

$$V_o - (V_o - V_I) = i_o R$$

$$V_I = i_o R$$

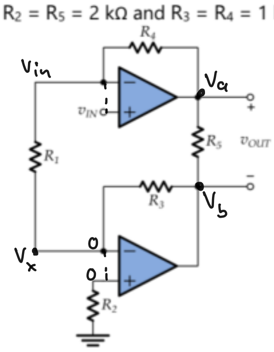
$$\frac{V_I}{R} = i_o$$

In both cases, $i_o = \dfrac{V_I}{R}$

Only depends on input voltage, not load impedance. Left circuit = non-inverting ; right circuit = inverting

11. Find the gain for the following circuits, assuming ideal op-amps.

a. For this circuit, $R_1 = R_2 = R_5 = 2\ k\Omega$ and $R_3 = R_4 = 1\ k\Omega$.



KCL @ Vin: $\frac{V_{in}}{R_1} + \frac{V_{in}-V_a}{R_4} = 0$

$V_{in}\left(\frac{1}{R_1}+\frac{1}{R_4}\right) = V_a\left(\frac{1}{R_4}\right)$

$V_{in}\left(\frac{R_4}{R_1}+1\right) = V_a$

@ Vx: $\frac{V_x - V_{in}}{R_1} + \frac{V_x - V_b}{R_3} = 0$

$-\frac{V_{in}}{R_1} - \frac{V_b}{R_3} = 0$

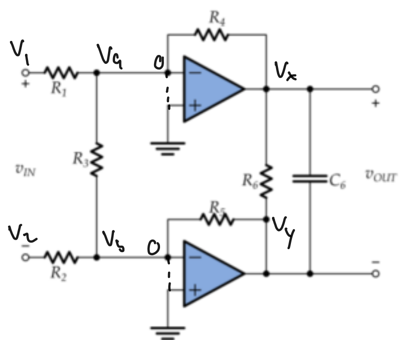
$V_b\left(\frac{1}{R_3}\right) = -\frac{V_{in}}{R_1}$

$V_b = -V_{in}\left(\frac{R_3}{R_1}\right)$

$V_{out} = V_a - V_b = V_{in}\left(\frac{R_4}{R_1}+1\right) - \left(-V_{in}\left(\frac{R_3}{R_1}\right)\right)$

$V_{out} = V_{in}\left(1+\frac{R_4}{R_1}+\frac{R_3}{R_1}\right) \therefore \frac{V_{out}}{V_{in}} = \left(1+\frac{1K}{2K}+\frac{1K}{2K}\right) = 2$

b. For this circuit, $R_1 = 1\ k\Omega$, $R_2 = 5\ k\Omega$, $R_3 = 2\ k\Omega$, $R_4 = 3\ k\Omega$ and $R_5 = 15\ k\Omega$, $R_6 = 6\ k\Omega$, and $C_6 = 1\ \mu F$.



KCL @ Va: $\frac{-V_1}{R_1} - \frac{V_x}{R_4} = 0$

@ Vb: $\frac{-V_2}{R_2} - \frac{V_y}{R_5} = 0$

$V_x = -V_1\left(\frac{R_4}{R_1}\right)$

$V_y = -V_2\left(\frac{R_5}{R_2}\right)$

$V_{out} = V_x - V_y = -V_1\left(\frac{R_4}{R_1}\right) - \left(-V_2\left(\frac{R_5}{R_2}\right)\right)$

$V_{out} = -V_1\left(\frac{R_4}{R_1}\right) + V_2\left(\frac{R_5}{R_2}\right)$

$* V_1 - V_2 = V_{in}$

$-V_1 + V_2 = -V_{in}$

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

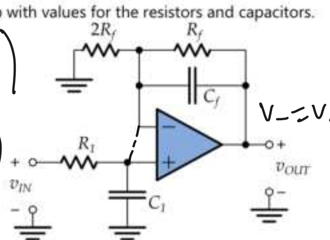
$\frac{V_{out}}{V_{in}} = -\frac{R_4}{R_1} - \frac{R_5}{R_2} = -\frac{3K}{1K} - \frac{15K}{5K}$

$\frac{V_{out}}{V_{in}} = -6$

12. Find the transfer function $H(j\omega) = V_{out}/V_{in}$ for the op amp circuit below, assuming an ideal op amp. Sketch the Bode magnitude and phase plots using straight-line approximations. You will have to come up with values for the resistors and capacitors.

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

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



$V_- = V_+$

KCL @ V_-: $\frac{V_-}{2R_f} + \frac{V_- - V_{out}}{R_f \| C_f} = 0$

$V_-\left(\frac{1}{2R_f} + \frac{1}{\frac{R_f\cdot\frac{1}{j\omega C_f}}{R_f+\frac{1}{j\omega C_f}}}\right) = V_{out}\left(\frac{R_f\cdot\frac{1}{j\omega C_f}}{R_f+\frac{1}{j\omega C_f}}\right)^{-1}$

$V_-\left(\frac{1}{2R_f} + \frac{1+j\omega R_f C_f}{R_f}\right) = V_{out}\left(\frac{1+j\omega R_f C_f}{R_f}\right)$

$V_-\left(\frac{1+2j\omega R_f C_f+2}{2R_f}\right) = V_{out}\left(\frac{1+j\omega R_f C_f}{R_f}\right)$

$V_-\left(\frac{3+2j\omega R_f C_f}{2(1+j\omega R_f C_f)}\right) = V_{out}$

$V_{in}\left(\frac{1}{1+j\omega R_1 C_1}\right)\left(\frac{3+2j\omega R_f C_f}{2(1+j\omega R_f C_f)}\right) = V_{out}$

$\frac{V_{out}}{V_{in}} = \frac{1}{2}\left(\frac{3+2j\omega R_f C_f}{(1+j\omega C_1 R_1)(1+j\omega R_f C_f)}\right) = \frac{3}{2}\frac{\left(1+\frac{2}{3}j\frac{\omega}{\frac{1}{R_f C_f}}\right)}{\left(1+j\frac{\omega}{\frac{1}{C_1 R_1}}\right)\left(1+j\frac{\omega}{\frac{1}{R_f C_f}}\right)} = H(j\omega)$

$R_f = 10K,\ R_1 = 100K$

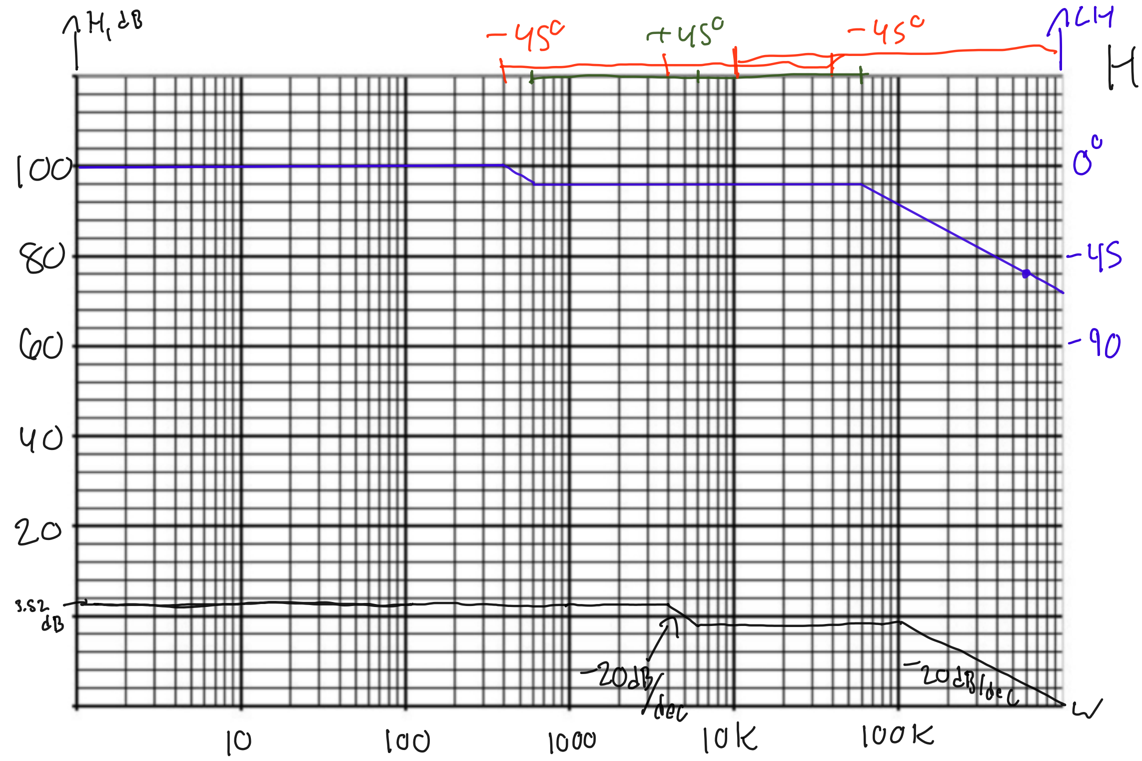
$Z_1 = \frac{1}{R_f C_f \frac{2}{3}} = \frac{3}{2R_f C_f}$

@ $\omega_{z_1} = 6000 = \frac{3}{20K C_f} \therefore C_f = 25\ nF$

$P_2 = \frac{1}{R_f C_f} \therefore \omega_{P_2} = 4000$

$P_1 = \frac{1}{C_1 R_1}$

@ $\omega_{P_1} = 10K = \frac{1}{100K C_1} \therefore C_1 = 1\ nF$



$$H(j\omega) = \frac{3}{2}\frac{\left(1+j\frac{\omega}{6000}\right)}{\left(1+j\frac{\omega}{10k}\right)\left(1+j\frac{\omega}{4000}\right)}$$

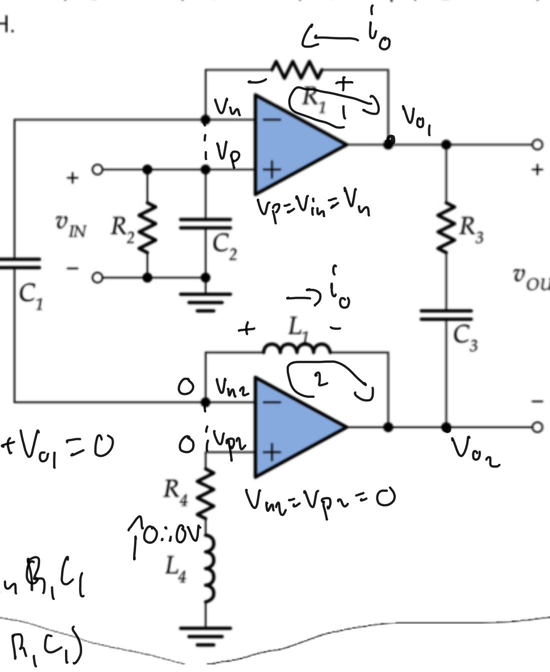
$H(\omega=100) \approx \frac{3}{2} \approx 3.52$

$\angle H \approx 0°$

13. Assuming ideal op-amps,

- Find the transfer function, $H(\omega)=V_{out}/V_{in}$
- Find the number of poles and zeros for this transfer function
- For extra credit, find the values of the poles and zeros for this transfer function

Use R_1=1 kΩ, R_2=2.2 kΩ, R_3=3.3 kΩ, R_4=4.7 kΩ, C_1=2.2 μF, C_2=0.1 mF, C_3=0.01 mF, L_1=3.3 mH, and L_4=39 μH.



$i_o = \dfrac{V_n - V_{n2}}{\frac{1}{j\omega C_1}}$

$i_o = j\omega V_{in} C_1$

KVL1: $-V_n - i_o R_1 + V_{o1} = 0$

$V_{o1} = V_n + i_o R_1$

$V_{o1} = V_{in} + j\omega V_{in} R_1 C_1$

$V_{o1} = V_{in}(1 + j\omega R_1 C_1)$

KVL2: $-V_{n_2} + i_o j\omega L_1 + V_{o2} = 0$

$V_{o2} = -i_o j\omega L_1$

$V_{o2} = -(j\omega V_{in} C_1) j\omega L_1$

$V_{o2} = \omega^2 V_{in} C_1 L_1$

$V_{out} = V_{o1} - V_{o2}$

$= V_{in}(1 + j\omega R_1 C_1) - (V_{in}(\omega^2 C_1 L_1))$

$\dfrac{V_{out}}{V_{in}} = \underset{c}{1} + \underset{b}{j\omega R_1 C_1} - \underset{a}{\omega^2 C_1 L_1} = H(j\omega)$

no denominator ∴ 0 poles

2 zeros: z_1, z_2

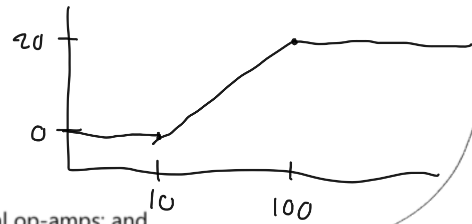
quadratic zeros: $\dfrac{-b \pm \sqrt{b^2 - 4ac}}{2a}$

$$\frac{-(R_1C_1) \pm \sqrt{R_1^2 C_1^2 - 4(C_1L_1)(1)}}{2(C_1L_1)} = -455.2,\ -302.575 \cdot 10^3$$

zeros

14. Design a circuit that meets the following specifications using only parts from the list below (you do not have to use all of the parts).

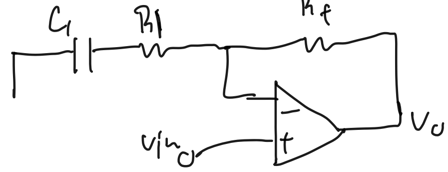
- Gain is 20 dB ±6 dB for $\omega \geq 100$ rad/sec
- Gain is 0 dB ± 6 dB for $\omega < 10$ rad/sec
- $R_{in} > 150\ k\Omega$



Available parts:

- (10) resistors of any value <10 kΩ; • (5) ideal op-amps; and
- any capacitors.

non-inverting high pass shelf



$$H(j\omega) = \frac{1 + j\omega(R_1+R_f)C_1}{1 + j\omega R_1 C_1} = \frac{1 + j\frac{\omega}{\frac{1}{(R_1+R_f)C_1}}}{1 + j\frac{\omega}{\frac{1}{R_1C_1}}}$$

$$P_1 = \frac{1}{R_1C_1} = 100 \therefore C_1 = 10uF$$

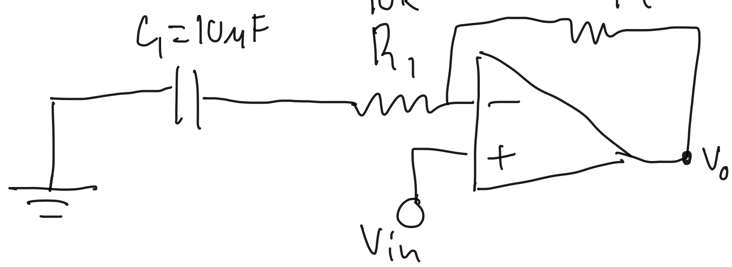
$$Z_1 = \frac{1}{C_1(R_1+R_f)} = 10$$

$\omega \to 0 \quad H \approx 1 \quad 20\log(1) = 0$

$$100 \leq \omega \to \infty \quad H \approx 1 + \frac{R_2}{R_1} \text{ or } 1 + \frac{R_f}{R_1} = 20dB = \underset{\substack{\downarrow \\ |H|}}{20\log(10)}$$

$$1 + \frac{R_f}{R_1} = 10$$

$$\frac{R_f}{R_1} = 9 \therefore \begin{array}{l} R_f = 9k < 10k \checkmark \\ R_1 = 1K < 10K \end{array}$$



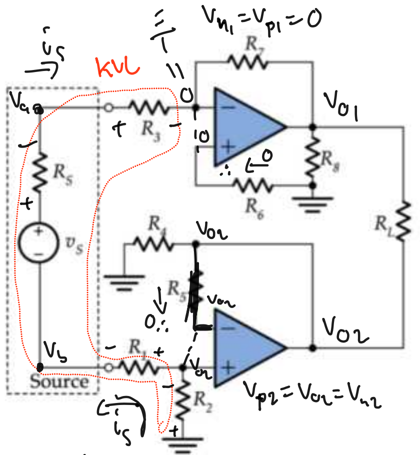
15. Assuming ideal op-amps,

- Find the voltage gain, v_{OUT}/v_S
- Find the input resistance seen by the source

Use R_s=6.9 kΩ, R_1=3.3 kΩ, R_2=4.7 kΩ, R_3=2.2 kΩ, R_4=75 kΩ, R_5=19 kΩ, R_6=27 kΩ, R_7=86 kΩ, R_8=10 kΩ, and R_L=5.6 kΩ.

$V_a - 0 = i_s R_3$

$V_a = \frac{V_s}{17.1K}(R_3)$



KVL: $i_s R_2 + i_s R_1 - V_s + i_s R_s + i_s R_3 = 0$

$V_s = i_s(R_1 + R_2 + R_3 + R_s)$

$i_s = \frac{V_s}{17.1K}$

$0 - V_{o1} = i_s R_7$

$V_{o1} = -i_s R_7 = -\frac{V_s}{17.1K} R_7$

$0 - V_b = i_s(R_2 + R_1)$

$V_b = i_s(R_1 + R_2)$

$= \frac{V_s}{17.1K}(R_1 + R_2)$

$0 - V_{o2} = i_s R_2$

$V_{o2} = -i_s R_2 = -\frac{V_s}{17.1K} R_2$

$V_{out} = -\frac{V_s}{17.1K} R_7 - \left(-\frac{V_s}{17.1K} R_2\right)$

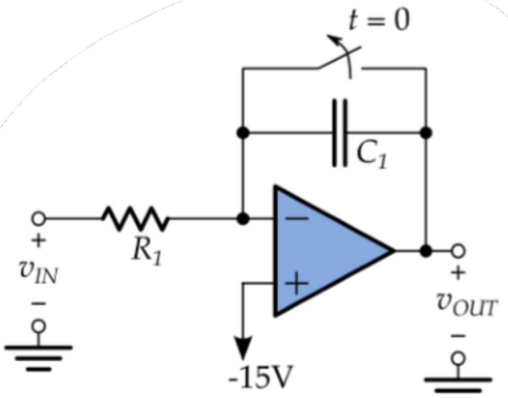
$= V_s\left(-\frac{R_7}{17.1K} + \frac{R_2}{17.1K}\right)$

$\frac{V_{out}}{V_s} = -4.75$

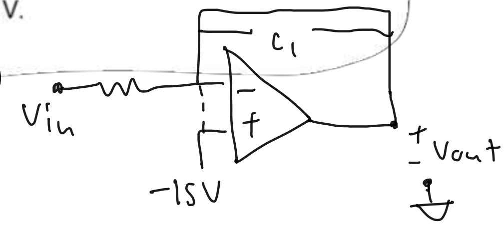
Resistance seen by source: $V_s = i_s R_s$

$R_s = \frac{V_s}{i_s} = 17.1K\Omega$

16. The op-amp in the circuit below is ideal. The switch is closed until $t = 0$, at which time it opens and stays open. Find $v_{OUT}(t)$ for the range $-10\text{ s} < t < 10\text{ s}$. Use $R_1 = 2\text{ k}\Omega$, $C_1 = 3\ \mu\text{F}$, and $v_{IN}(t) = A\sin(\omega_0 t)$, where $\omega_0 = 300$ rad/s and A = 2 V.

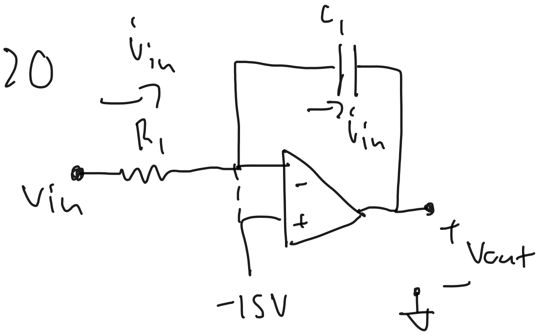


$t<0$



$$V_{out}(0^-) = -15\text{ V} = V_{out}(0^+)$$

$t \geq 0$



$$i_{in} = i_c = C\frac{dV_c}{dt}$$

$$V_c = \frac{1}{C}\int i_c\,dt + V_{out}(0)$$

KCL @ V_-: $\frac{V_{in}-V_-}{R_1} + C_1\frac{d}{dt}(-15 - V_{out}) = 0$

$$\frac{V_{in}+15}{R_1} = -\left[C_1\frac{d}{dt}(-15-V_{out})\right]$$

$$\frac{V_{in}+15}{R_1C_1} = -\frac{d}{dt}(-V_{out})$$

$$\frac{1}{R_1C_1}\left[\int_0^t V_{in}+15\,dt\right] = V_{out}\Big|_0^t$$

$$\frac{1}{.004}\left[\int_0^t 2\sin(300t)+15\,dt\right] = V_{out}(t) - V_{out}(0)$$

$$\frac{1}{.004}\left[-\frac{2}{300}\cos(300t)+15t\Big|_0^t\right] = V_{out}(t)+15$$

$$-\frac{10}{9}\cos(300t) + 2500t - \left[-\frac{10}{9}\overset{1}{\cos(0)}+0\right] = V_{out}(t)+15$$

$$V_{out}(t) = -\frac{10}{9}\cos(300t) + 2500t - \frac{125}{9} \quad 0<t\le 10$$