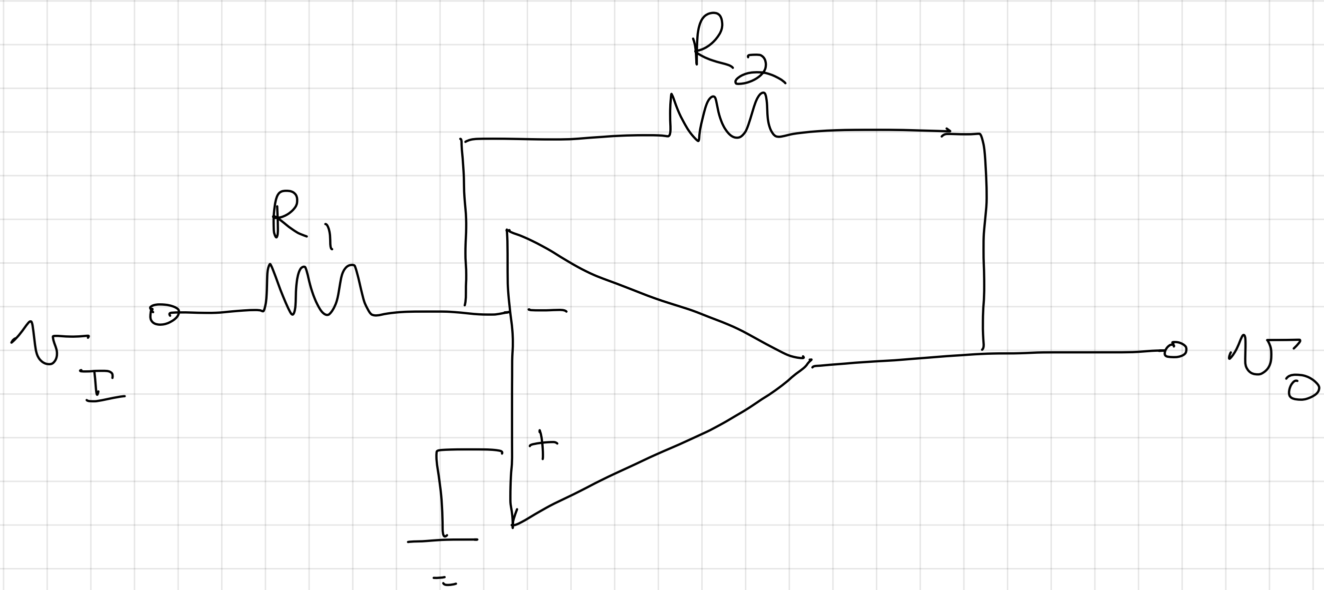
Ex 1

Design an inverting op-amp with a closed loop gain of $-50\ V/V$. Maximum resistor size is $5\,M\Omega$.

Design for the largest input resistance.



$$\frac{v_O}{v_S} = G = -50\frac{V}{V} = -\frac{R_2}{R_1}$$

$R_i = R_1$

$$\frac{R_2}{R_1} = 50$$

$$R_1 = 5\,M\Omega \Rightarrow R_2 = 250\,M\Omega$$

let $R_2 = 5M\Omega$

$$R_1 = \frac{R_2}{50} = 100k\Omega$$

$R_1 = 100k\Omega$

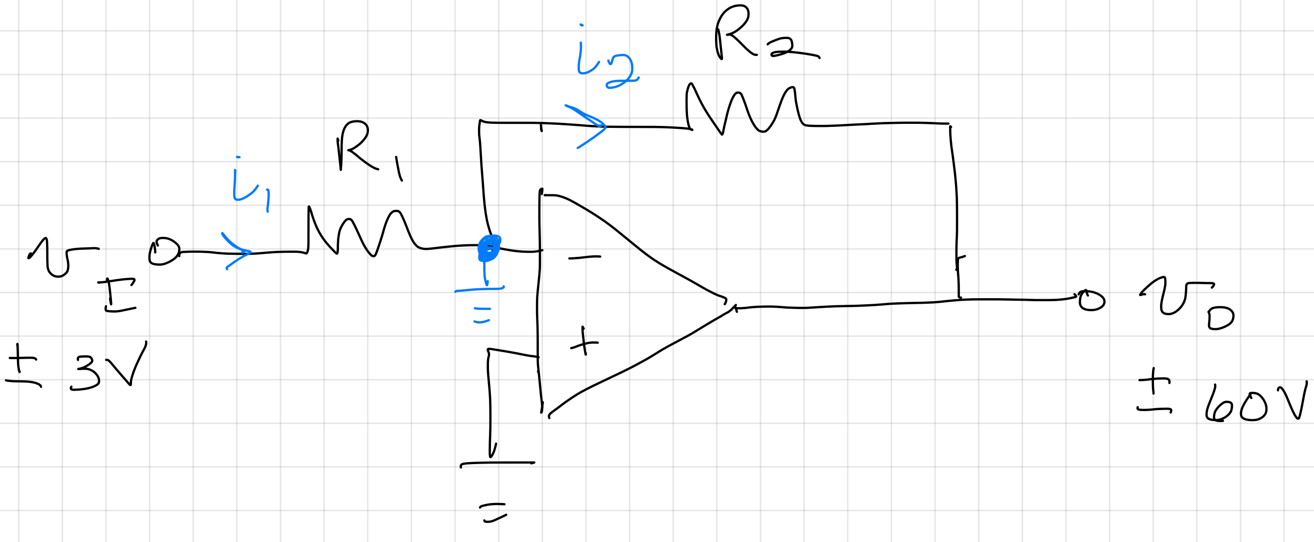
$R_2 = 5M\Omega$

Example 2: Design an inverting amp.

v_I : $\pm 3V$

v_O : $\pm 60V$

$i_{max} = 20\mu A$



$$\frac{v_O}{v_S} = \frac{\pm 60}{\pm 3} = -20\frac{V}{V} = G = -\frac{R_2}{R_1}$$

$$\boxed{\frac{R_2}{R_1} = 60}$$

$$i_2 = \frac{0 - v_o}{R_2} \leq 20\mu A$$

$$i_1 = \frac{v_I - 0}{R_1} \leq 20\mu A$$

$$i_2 = \frac{-v_o}{R_2}$$ for v_o at $60V$

$$i_2 = \boxed{\frac{60}{R_2} \leq 20\mu A}$$

$$R_2 \geq \frac{60}{20\times10^{-6}}$$

$$R_2 \geq 3M\Omega$$

let $R_2 = 3M\Omega$

$$R_1 = \frac{R_2}{20} = 150\,k\Omega$$

$$\frac{v_I}{R_1} \leq 20\mu A$$

$$v_I \leq R_1(20\times10^{-6})$$

$$v_I \leq 3V$$

A possible design

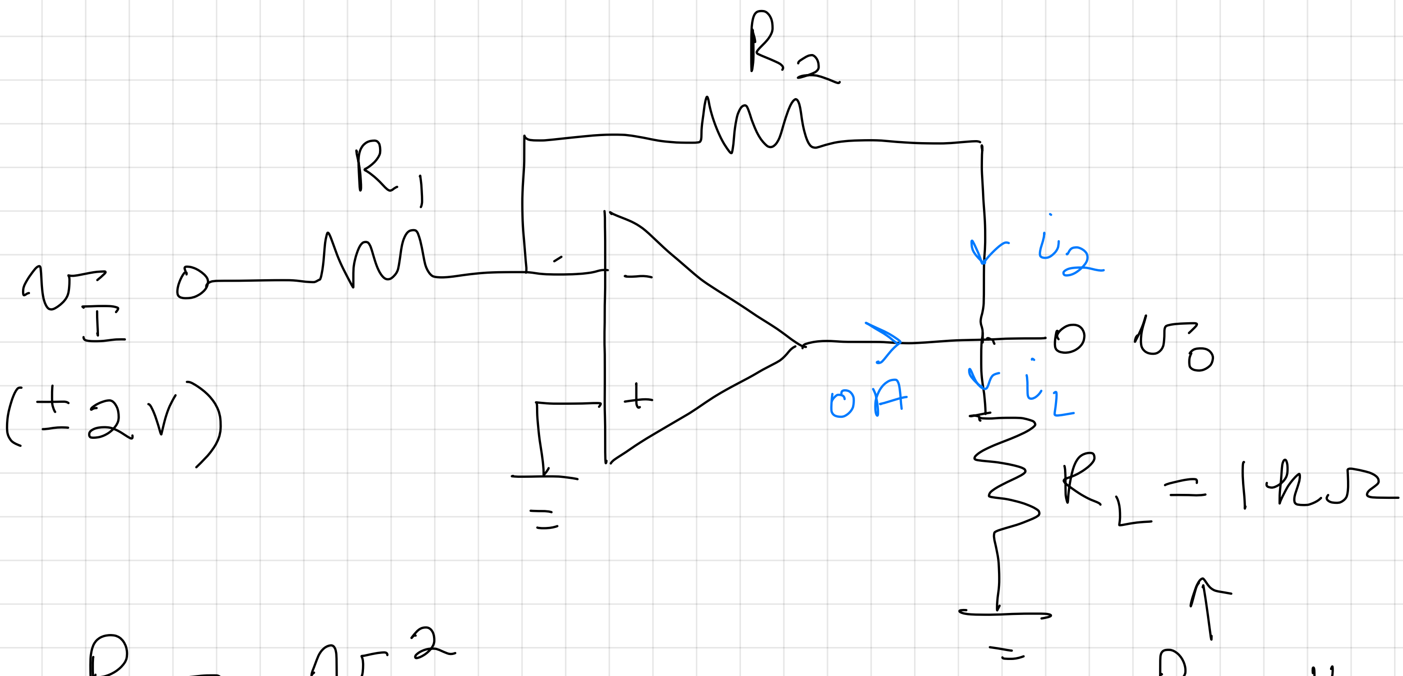
$R_2 = 3M\Omega$

$R_1 = 150k\Omega$

Example 3

inverting op-amp that drives a $1k\Omega$ load. The input voltage varies from $\pm 2V$.
The load must be able to absorb 16mW at peak output

G, R_1, R_2 and the v_O range.



$$P_{L(max)} = \frac{v_{O max}^2}{R_L}$$

$$16 \times 10^{-3} = \frac{v_{O max}^2}{1000}$$

$$\boxed{v_{O max} = \pm 4V}$$

$$G = \frac{v_o}{v_s} = \frac{-4}{2} = -2\,\frac{V}{V}$$

$$-\frac{R_2}{R_1} = -2 \qquad \boxed{R_2 = 2R_1}$$

$R_2 = 2\Omega$

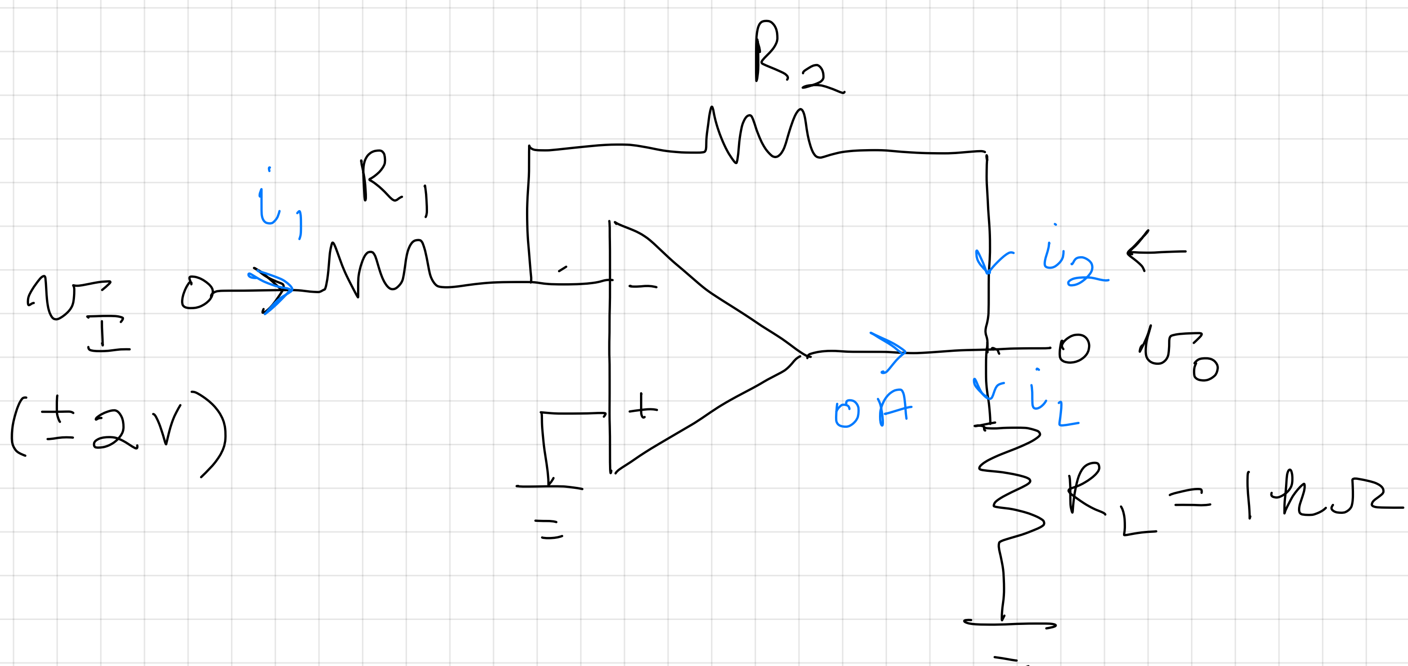
$R_1 = 1\Omega$

$v_o = \pm 4V$

$v_I = \pm 2V$

$G = -2\,\frac{V}{V}$

$P_L = 16mW$



$$i_L = \frac{v_o}{R_L} = \frac{4}{1000} = 4mA$$

$$i_2 = \frac{0 - v_o}{R_2} = 4mA$$

$$R_2 = \frac{\cancel{v_o}^{\,4}}{4mA} = 1k\Omega$$

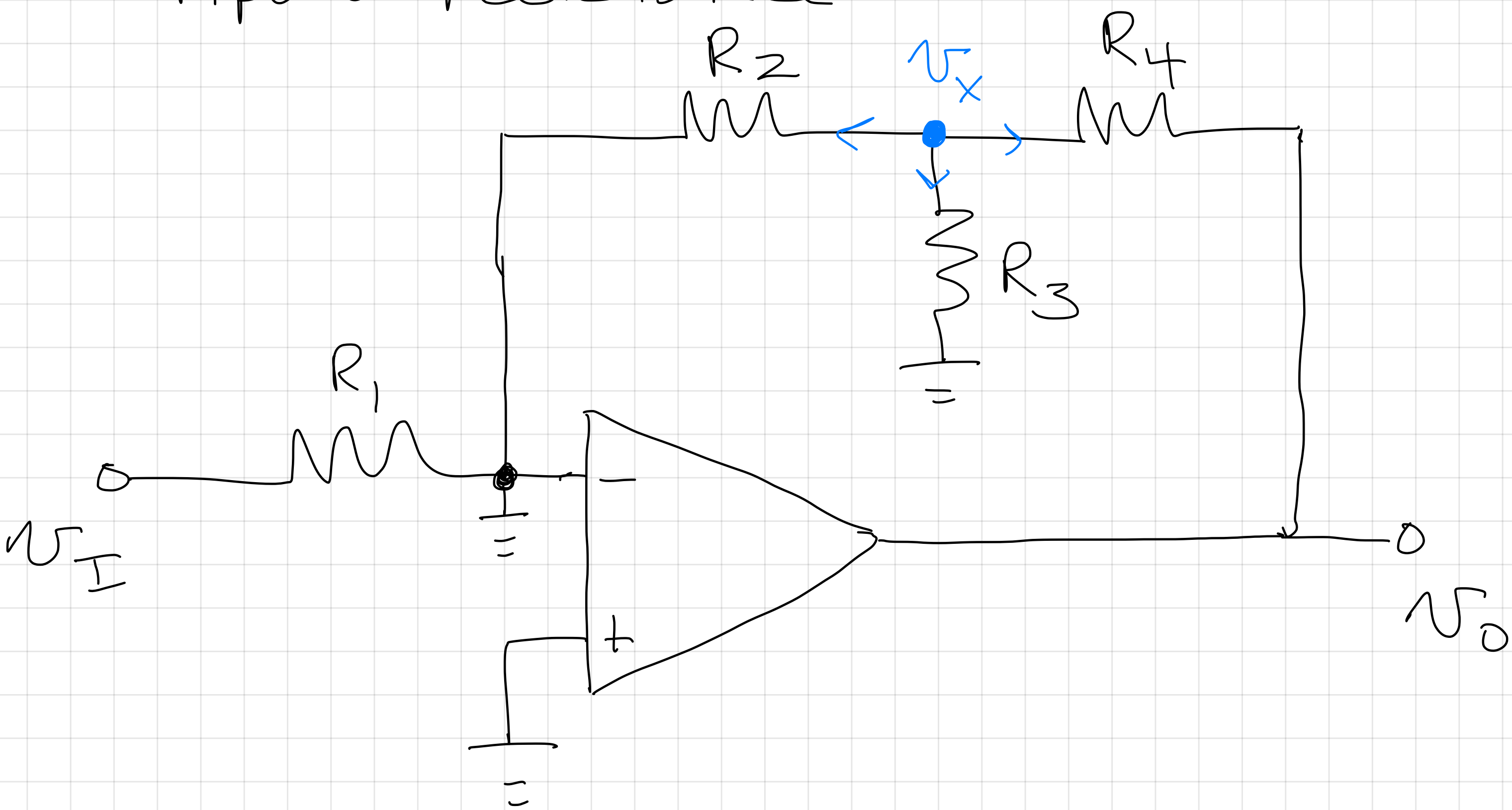
$$R_2 = 1k\Omega$$

$$R_1 = 500\Omega$$

$$i_1 = \frac{v_I}{R_1} = \frac{2}{500}$$

$$i_1 = 4mA$$

add a "T" resistor network in feedback loop to boost input resistance.



by nodal analysis at x node

$$\frac{v_x - 0}{R_2} + \frac{v_x - 0}{R_3} + \frac{v_x - v_o}{R_4} = 0$$

$$\frac{v_o}{R_4} = \frac{v_x}{R_2} + \frac{v_x}{R_3} + \frac{v_x}{R_4}$$

$$\boxed{\frac{v_o}{v_x} = \frac{R_4}{R_2} + \frac{R_4}{R_3} + 1} \qquad \boxed{\frac{v_x}{v_I} = -\frac{R_2}{R_1}}$$

$$\frac{v_O}{v_I} = \left(-\frac{R_2}{R_1}\right)\left(\frac{R_4}{R_2} + \frac{R_4}{R_3} + 1\right) = -100$$

Ex

Want

$R_i = 1m\Omega$

$G = -100 \; V/V$

$R_{max} = 1m\Omega$

let $R_1 = 1m\Omega$

$R_2 = 1m\Omega$

$R_4 = 1m\Omega$

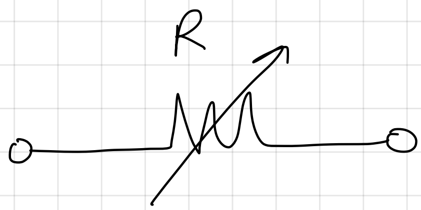
$$\left(-\cancelto{1}{\frac{1m}{1m}}\right)\left(\cancelto{1}{\frac{1m}{1m}} + \frac{1m\Omega}{R_3} + 1\right) = -100$$

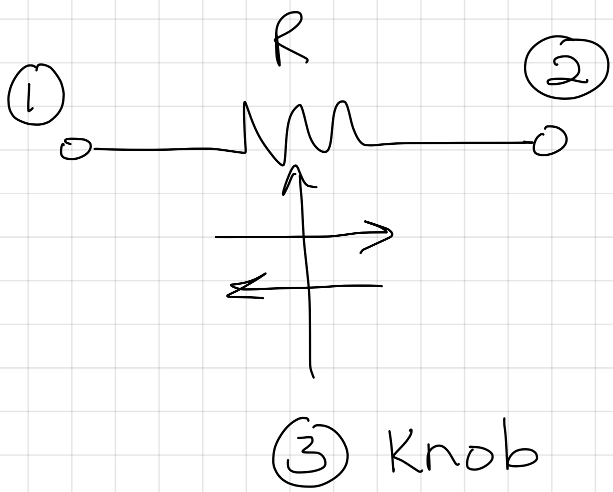
$$\left(2 + \frac{1\times10^6}{R_3}\right) = 100$$

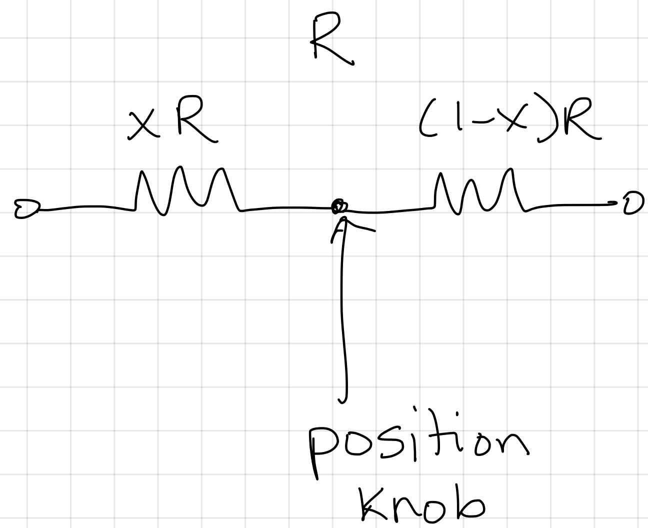
$$\frac{1\times10^6}{R_3} = 98 \qquad R_3 = \frac{1\times10^6}{98}$$

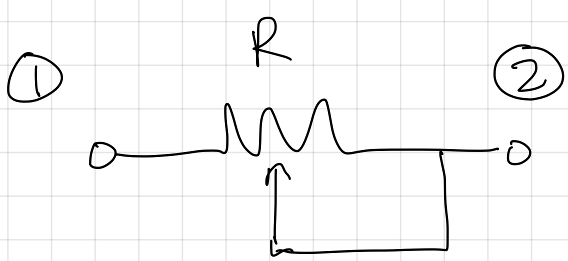
$R_3 = 10.2\ k\Omega$

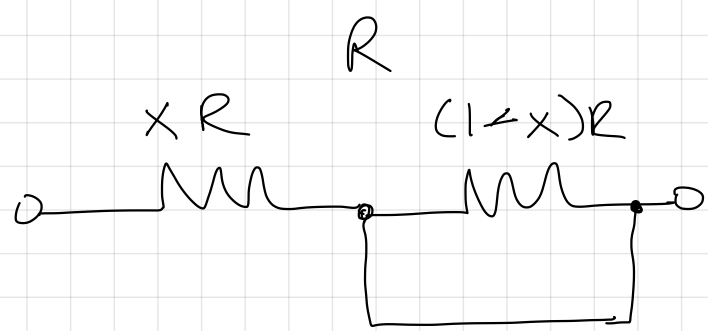
$R \equiv$ range of value



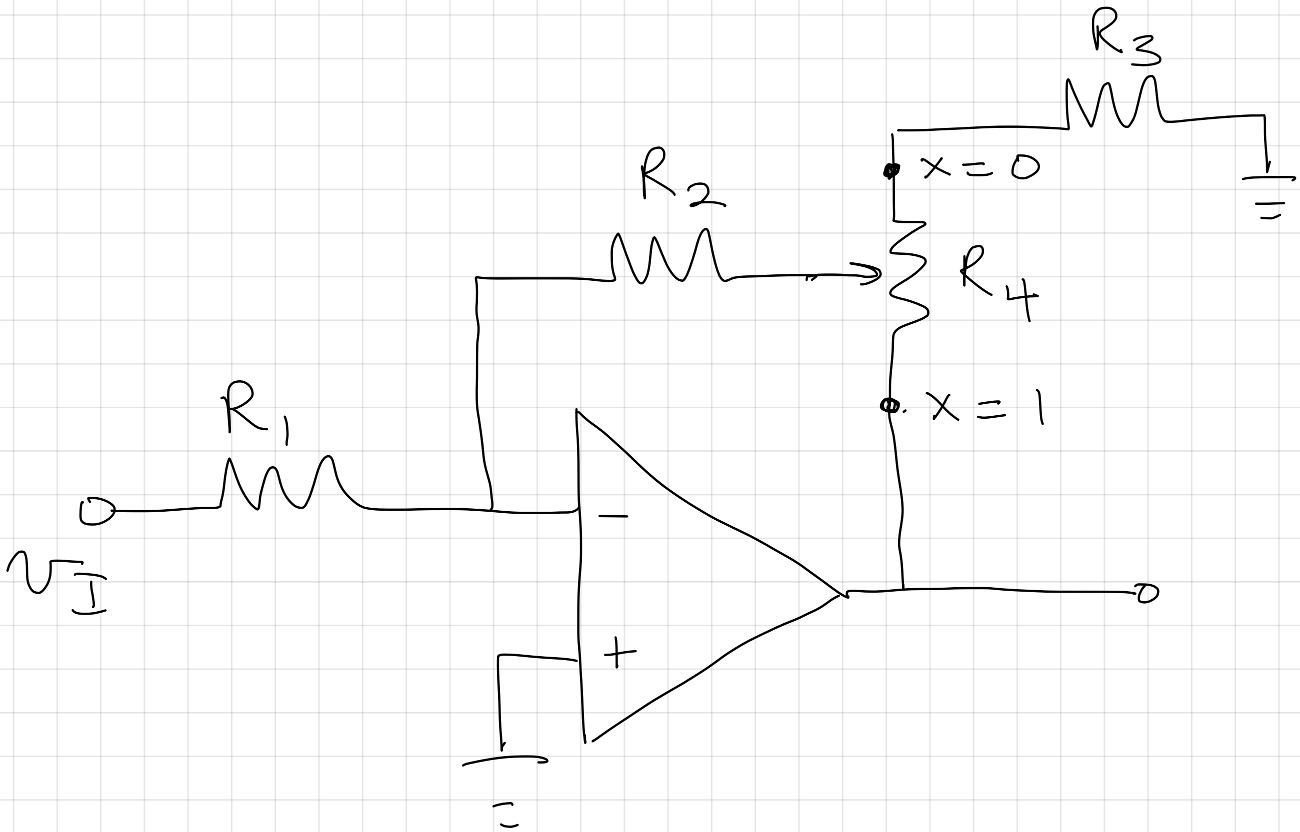








EX of using a pot in the T network.



$R_4 = 100\,k\Omega$ pot

$$\boxed{R_i = 100\,k\Omega}$$

$x=0$ R_4 connects R_2 and R_3 to v_o

$R_4 = 100\,k\Omega$

$x=1$ $R_4 \to 0$

R_2 & R_3 are shorted to output

$R_4 = 0$

$R_3' = R_3 + 100\,k\Omega$

Design R_1, R_2, R_3 such that

$G \Rightarrow -1$ to $-100 \ \frac{V}{V}$

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

① $G = -1 \ \frac{V}{V}$ $\quad R_4 = 0\,\Omega$

$R_3' = R_3 + 100k\Omega$

② $G = -100 \frac{V}{V}$ $\quad R_4 = 100k\Omega$

$R_3' = R_3$

①

$$-\frac{R_2}{R_1}\left(\frac{0}{R_2} + \frac{0}{R_3} + 1\right) = -1$$

$$-\frac{R_2}{R_1} = -1$$

$$R_2 = R_1$$

$$\boxed{\begin{aligned} R_1 &= R_i = 100\,k\Omega \\ R_2 &= 100\,k\Omega \end{aligned}}$$

(2) $$\frac{v_O}{v_I} = -\frac{R_2}{R_1}\left(\frac{R_4}{R_2} + \frac{R_4}{R_3} + 1\right) = -100$$

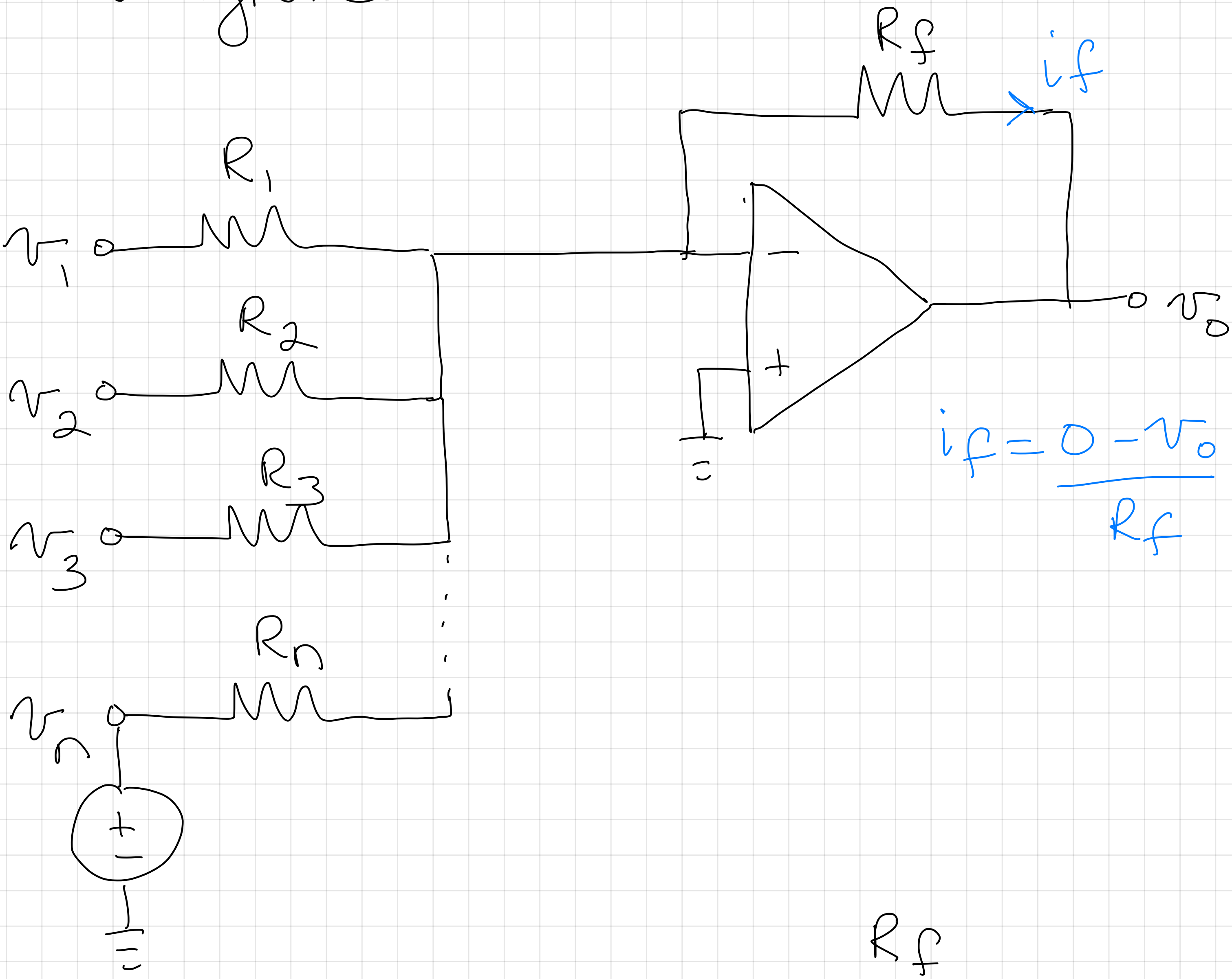
$$-\frac{\cancel{100k}}{\cancel{100k}}\left(\frac{\cancel{100k}}{\cancel{100k}} + \frac{100k}{R_3} + 1\right) = -100$$

$$\left(1 + \frac{100\times10^3}{R_3} + 1\right) = 100$$

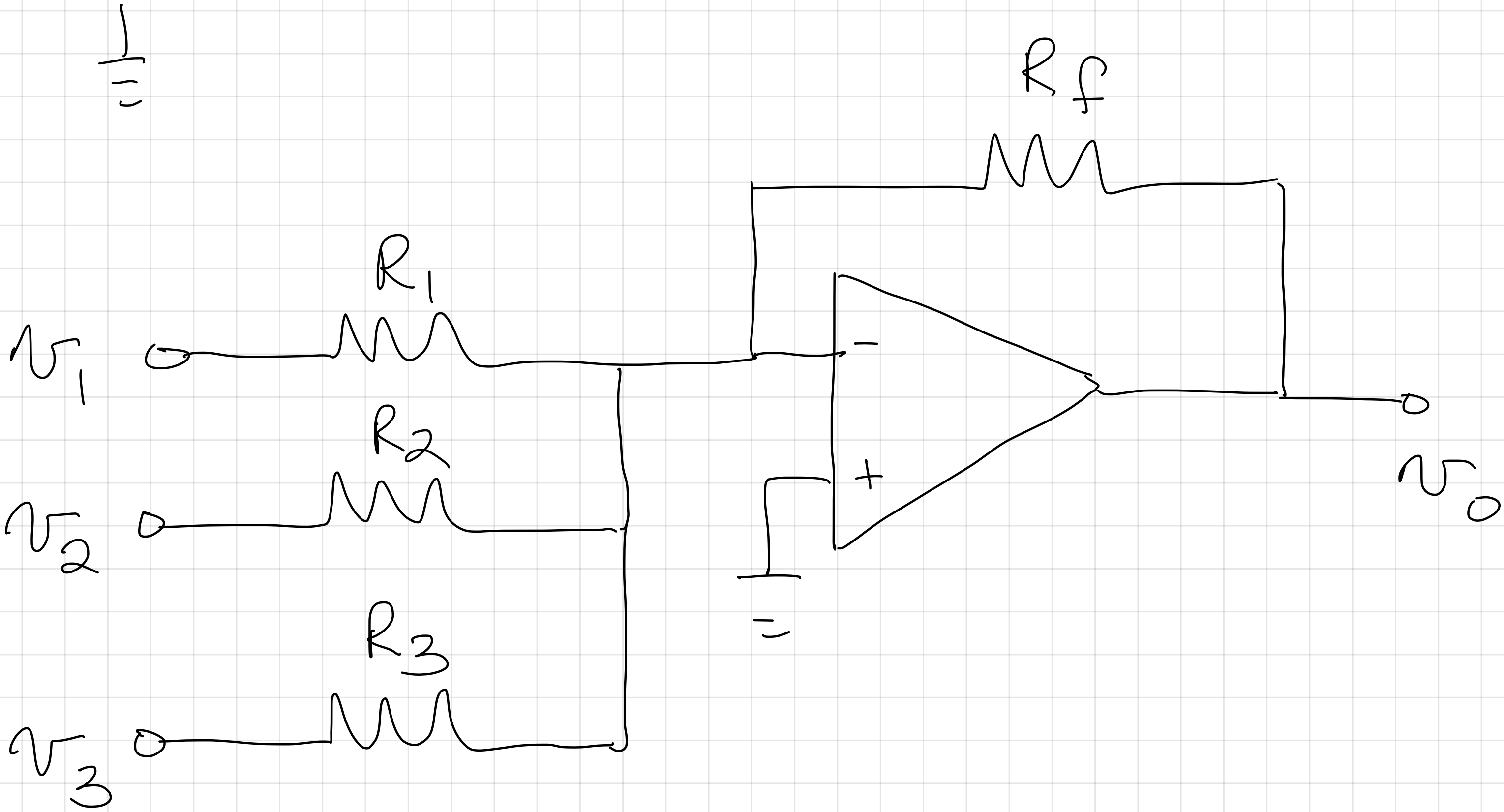
$$\frac{100\times10^3}{R_3} = 98$$

$$\boxed{R_3 = 1.02\,k\Omega}$$

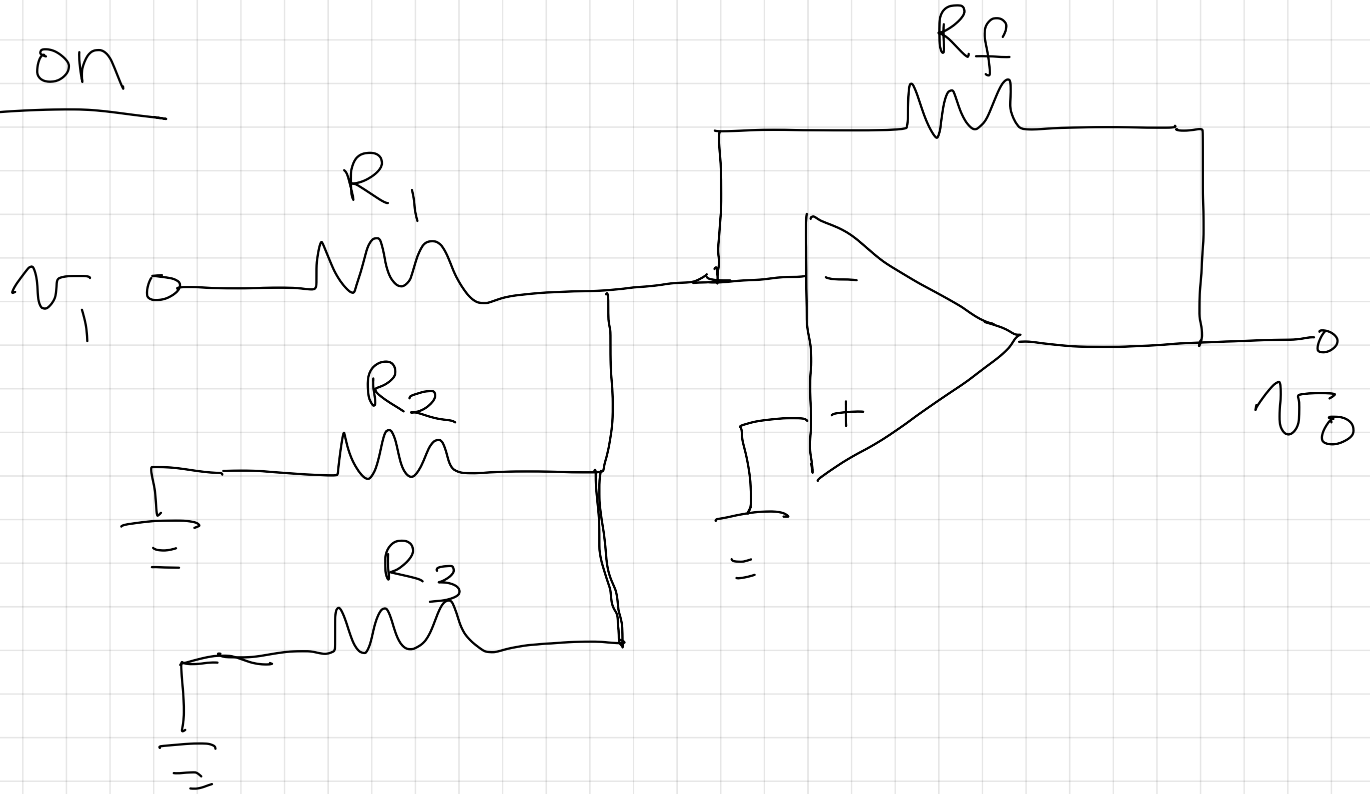
Weighted summer

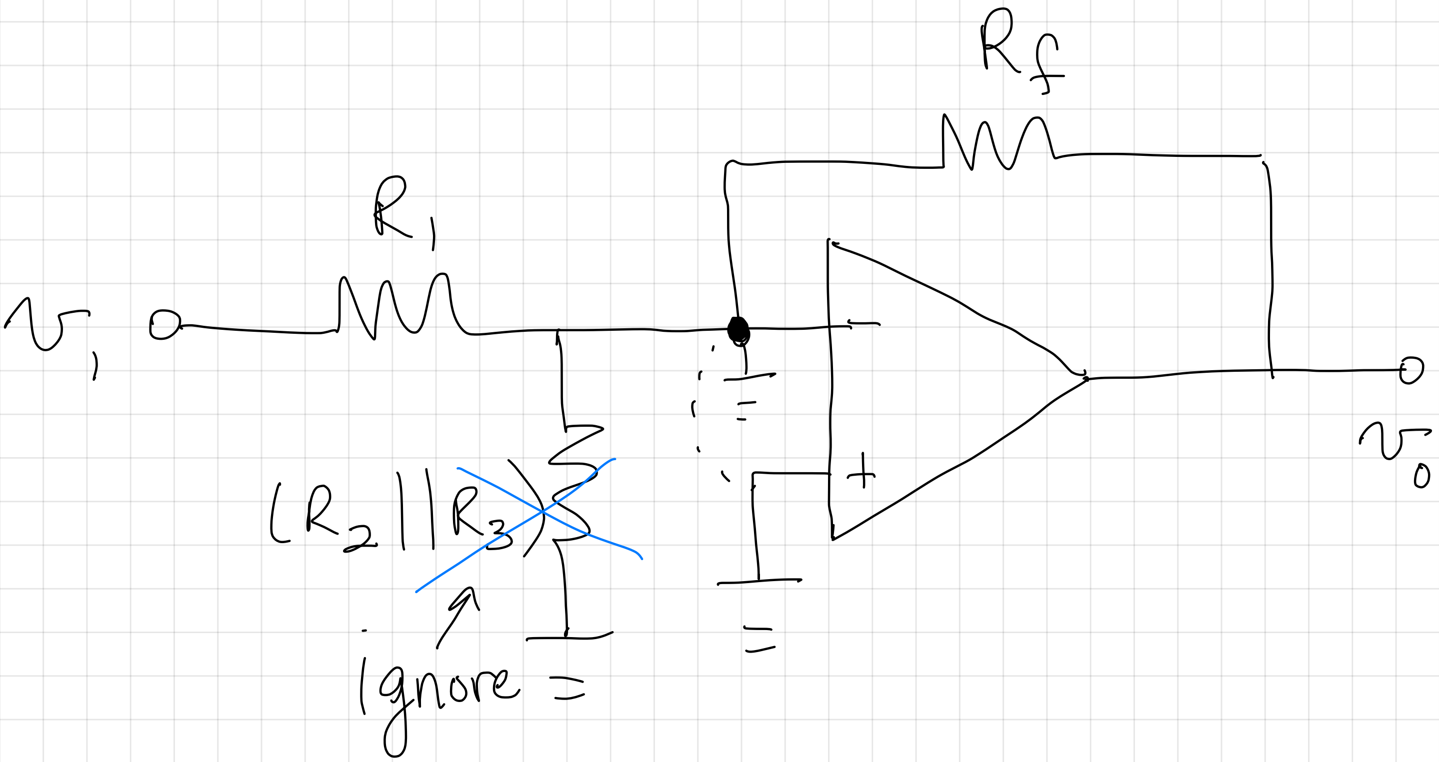


$$i_f = \frac{0 - v_o}{R_f}$$



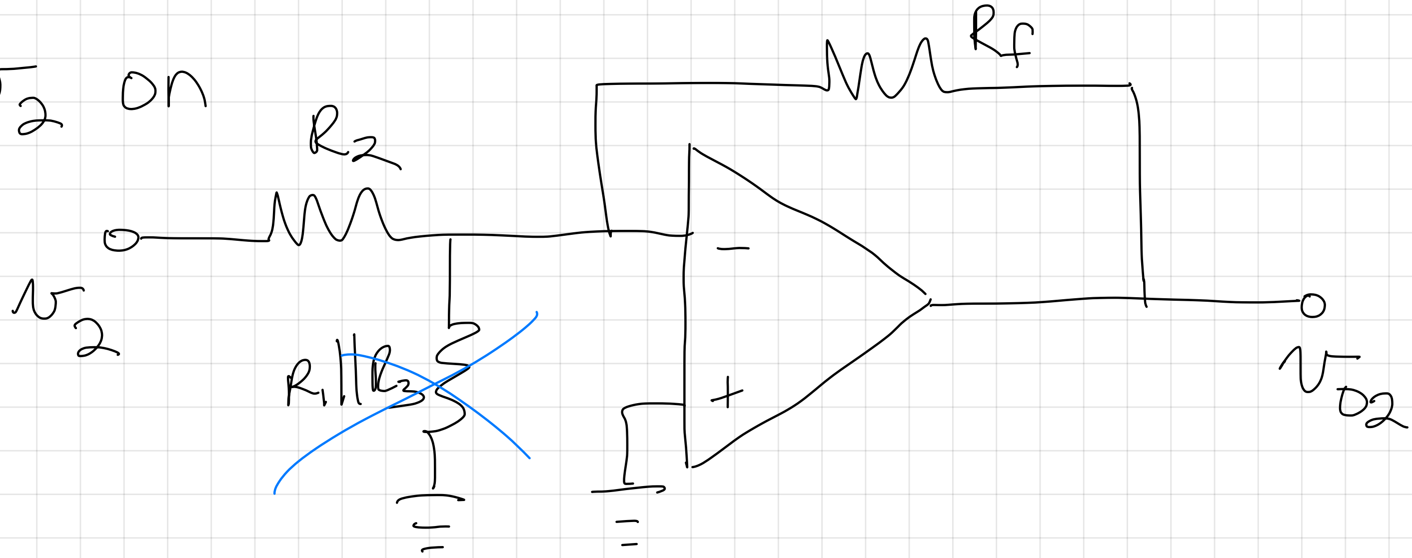
v_1 on





$$v_{o1} = -\frac{R_f}{R_1} v_1$$

v_2 on



$$v_{o2} = -\frac{R_f}{R_2} v_2$$

$$v_{o3} = -\frac{R_f}{R_3} v_3$$

$$v_o = v_{o1} + v_{o2} + v_{o3}$$

$$v_o = -\frac{R_f}{R_1} v_1 - \frac{R_f}{R_2} v_2 - \frac{R_f}{R_3} v_3$$

$\underline{\text{Ex}}$: $v_0 = -5v_1 - 2v_2 - 7v_3$

Design 1)

$$\left.\begin{aligned} -5 &= -\frac{R_f}{R_1} \\ -2 &= -\frac{R_f}{R_2} \\ -7 &= -\frac{R_f}{R_3} \end{aligned}\right\}$$

$R_f = 1M\Omega$

$R_1 = 200k\Omega$

$R_2 = 500k\Omega$

$R_3 = 142.86k\Omega$

$\underline{\text{Design 2}}$

$v_0 = -5v_1 - 2v_2 - 7v_3 \leftarrow$

$$\boxed{\begin{aligned} &i_{max} \text{ in } R_f = 10\mu A \\ &v_{omax} = 5V \end{aligned}}$$

$\frac{R_f}{R_1} = 5$

$\frac{R_f}{R_2} = 2$

$\frac{R_f}{R_3} = 7$

$i_f = \frac{v_{omax}}{R_f}$

$10 \times 10^{-6} \geq \frac{5}{R_f}$

$R_f \geq \frac{5}{10 \times 10^{-6}}$

$$R_f \geq \frac{5}{10 \times 10^{-6}}$$

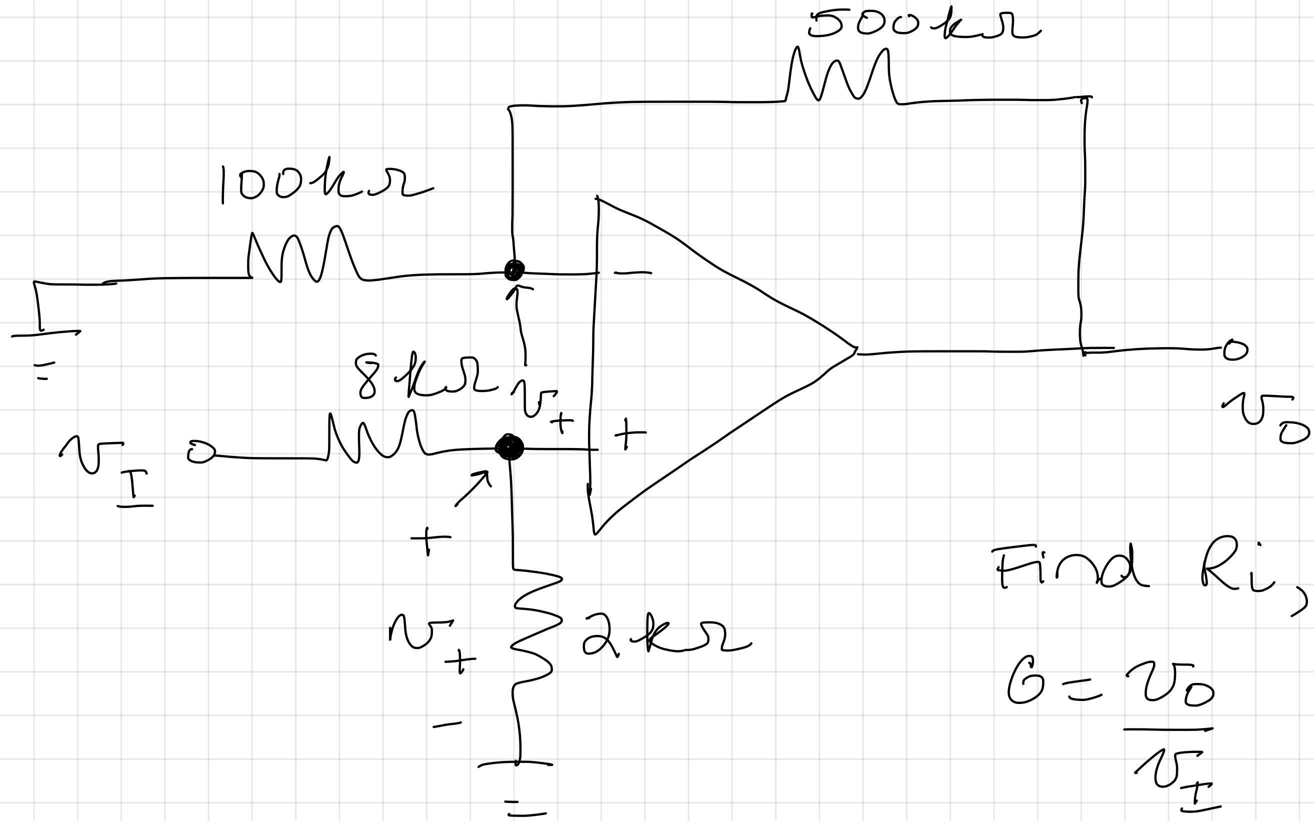
$$R_1 = \frac{R_f}{5}$$

$$R_f \geq 0.5 M\Omega$$

$$R_2 = \frac{R_f}{2}$$

$$R_3 = \frac{R_f}{7}$$

$$\boxed{\begin{aligned} R_f &= 100 k\Omega \\ R_1 &= 20 k\Omega \\ R_2 &= 50 k\Omega \\ R_3 &= 14.29 k\Omega \end{aligned}}$$



Find R_i, G

$$G = \frac{v_O}{v_I}$$

$$R_i = \infty$$

$$v_+ = v_I \left(\frac{2k}{8k + 2k} \right)$$

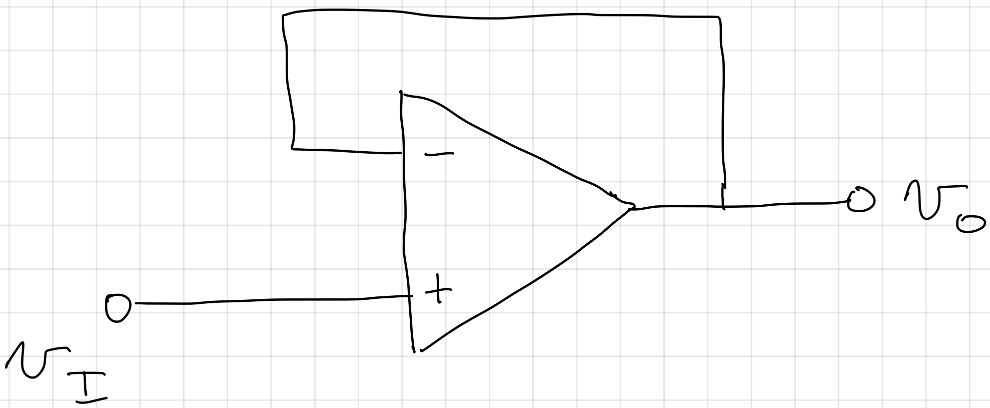
$$\frac{v_O}{v_+} = \left(1 + \frac{500k}{100k} \right)$$

$$\frac{v_O}{v_I} = \left(1 + \frac{500k}{100k} \right) \left(\frac{2k}{8k + 2k} \right)$$

$$= (6)(0.2)$$

$$\boxed{\frac{v_O}{v_I} = 1.2 \ \frac{V}{V}}$$

Voltage Follower (version of non-inverting configuration)



$R_1 = \infty$

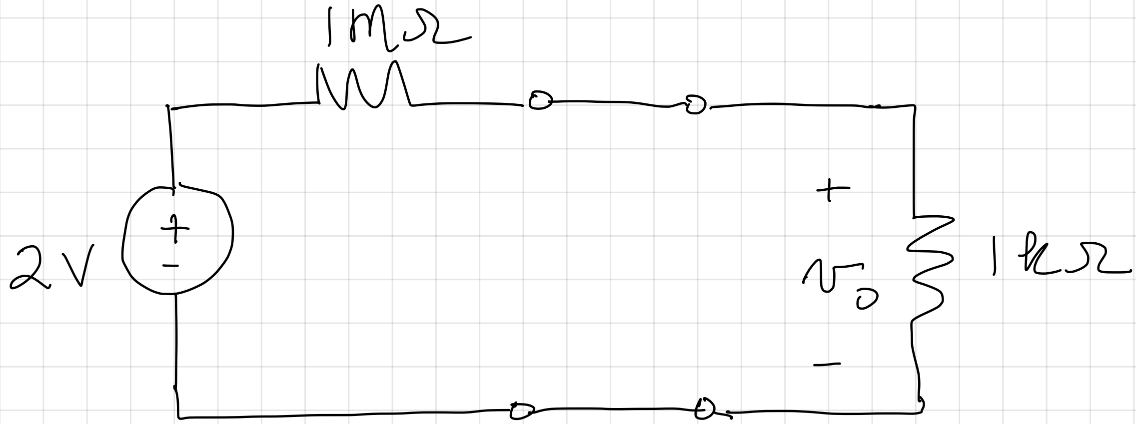
$R_2 = 0$

$$G = \frac{v_O}{v_I} = \left(1 + \frac{\cancel{R_2}^{\,0}}{R_1}\right) = 1$$

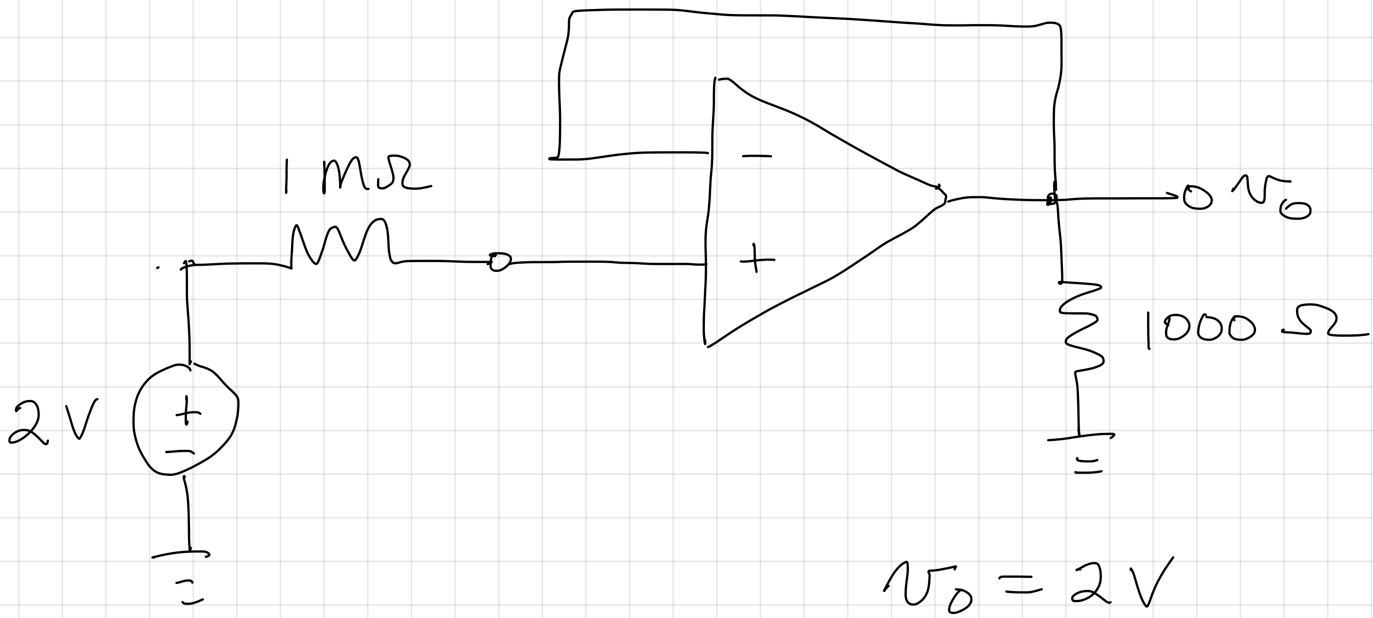
$v_O = v_I \Rightarrow$ voltage follower

EX

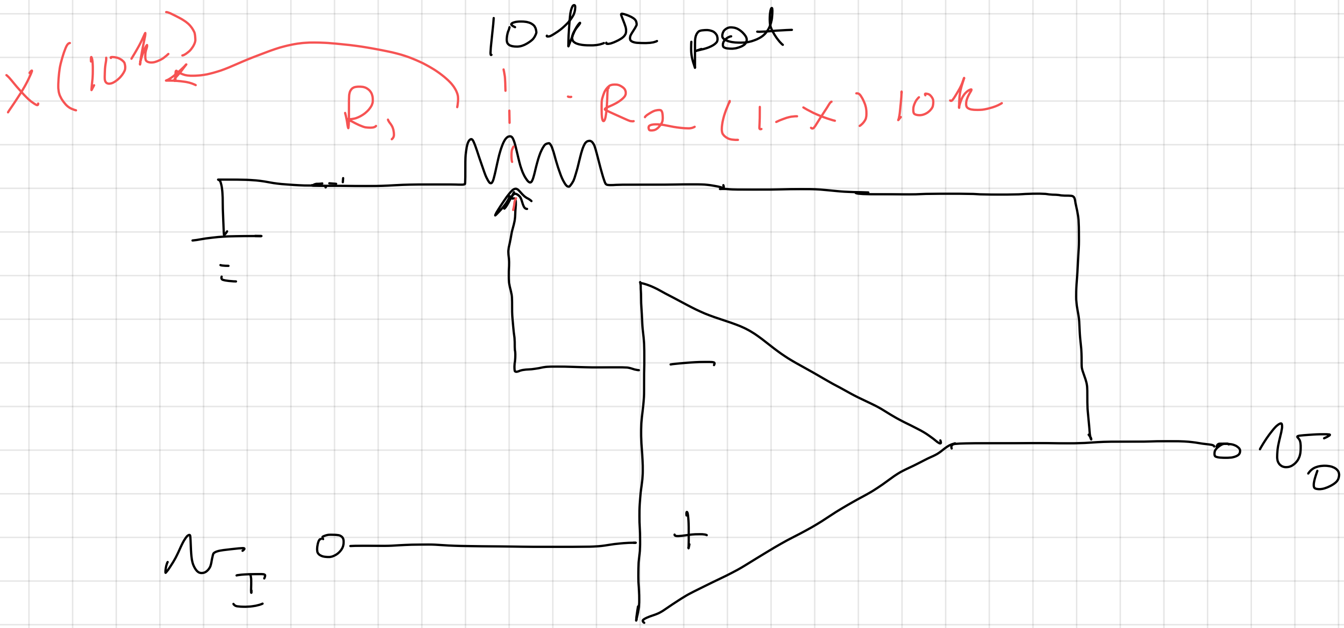
2V source that drives $1k\Omega$ load.
The source resistance is $1M\Omega$



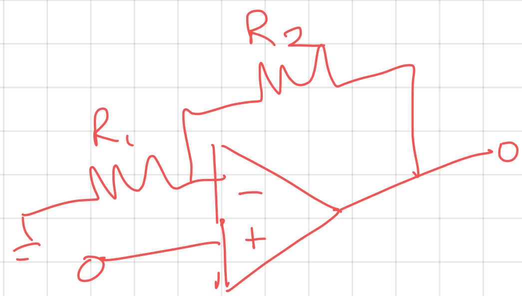
$$v_0 = 2\left(\frac{1000}{1000 + 1\times 10^6}\right) = 0.2\,mV$$



$$v_0 = 2V$$



Find the range of gain



$X = 0$

$R_1 = 0$

$R_2 = 10k\Omega$

$$G = \left(1 + \overbrace{\frac{R_2}{R_1}}^{\infty}\right)$$

$G = \infty$

$X = 1$

$R_2 = 0$

$R_1 = 10k\Omega$

$$G = \left(1 + \overbrace{\frac{R_2}{R_1}}^{0}\right)$$

$G = 1$