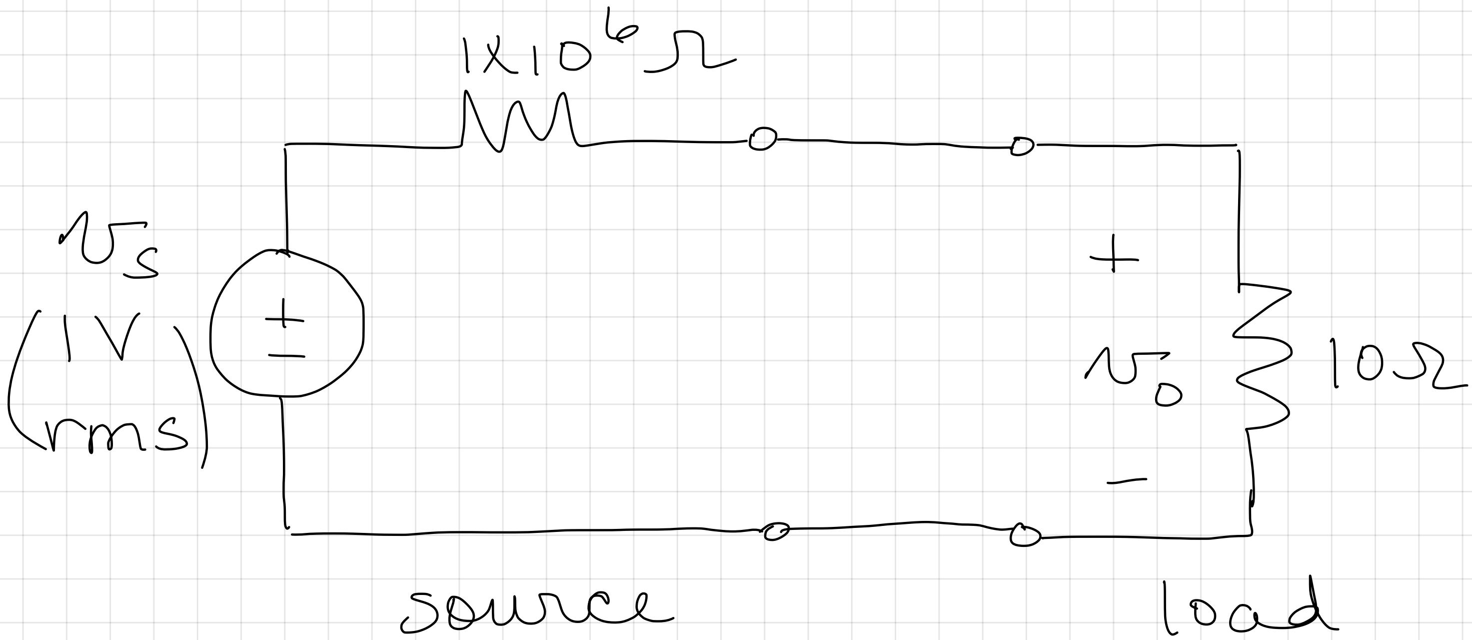
Ex

$v_s = 1\ V_{rms}$, $R_s = 1\,M\Omega$

$R_L = 10\,\Omega$



$$v_o = v_s\left(\frac{10}{10+1\times10^6}\right)$$

$$v_o = v_s\,(.999\times10^{-5})$$

$$\cong \overset{1V}{\cancel{v_s}}\,(10\times10^{-6})$$

$$v_o \cong 10\,\mu V_{rms}$$

$$P_L = \frac{v_o^{\,2}}{10} = \frac{(10\times10^{-6})^2}{10} = 10^{-11}\ W$$

Remember max power transfer?

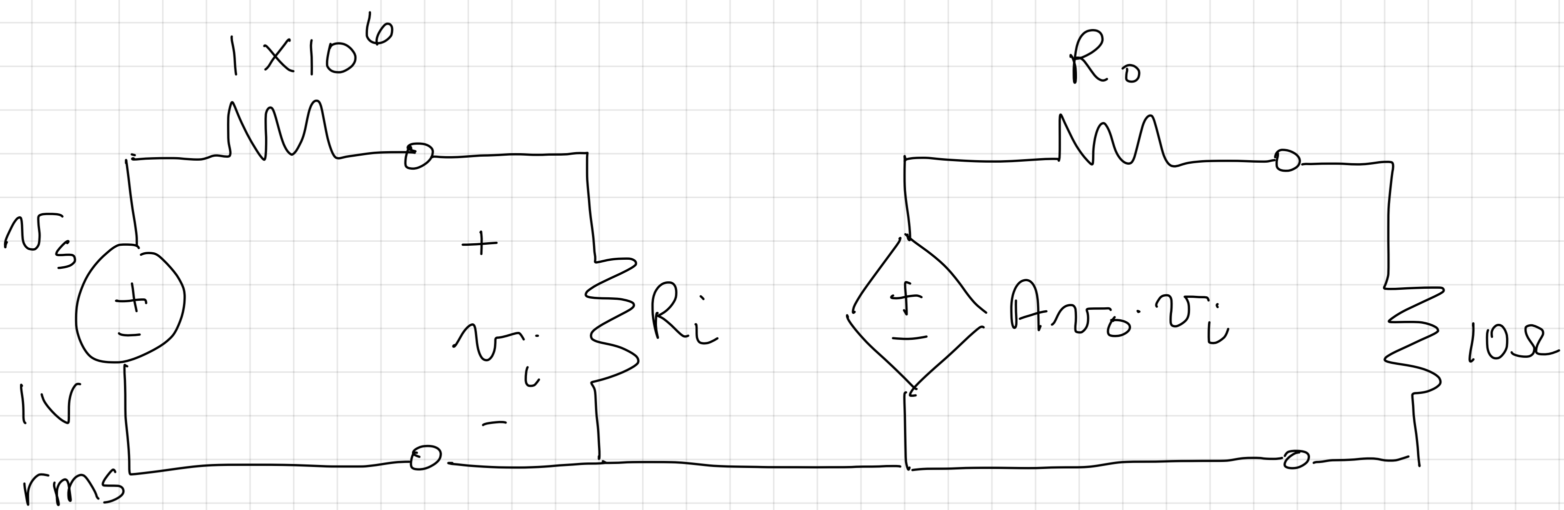
$$R_{TH} = R_L$$

$$1 \times 10^6 >>> 10$$

$$\Downarrow$$

severe mismatch

add amplifier in between source & load.



$A_{vo} = 1\ V/V$ $\quad$ $R_i = 1M\Omega$

$R_o = 10\Omega$

$$\frac{v_o}{v_s} = \cancelto{1}{A_{vo}} \left(\frac{\cancelto{10}{R_L}}{\underset{10}{\cancel{R_L}} + \cancelto{10}{R_o}} \right) \left(\frac{\cancelto{1M\Omega}{R_i}}{\underset{1M\Omega}{\cancel{R_s}} + \underset{1M\Omega}{\cancel{R_i}}} \right)$$

$$\frac{v_o}{v_s} = (1)\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)$$

$$\frac{v_o}{\cancel{v_s} \rightarrow 1V} = 0.25 \ \frac{V}{V}$$

$$v_o = 0.25 \ V rms$$

$$P_L = \frac{{v_o}^2}{10} = \frac{(.25)^2}{10} = 6.25 \, mW$$

$$A_v = \frac{v_o}{v_s} = \frac{0.25}{1} = 0.25 \ \frac{V}{V}$$

$$= -12.04 \ dB$$

$$A_p = \frac{P_o}{P_i} = \frac{6.25 \times 10^{-3}}{(0.5)^2 / 1 \times 10^{-6}}$$

$$A_P = \frac{6.25 \times 10^{-3}}{0.25 \times 10^{-6}} = 25 \times 10^{3} \ \frac{W}{W}$$

$$\text{or} = 43.98 \text{ dB}$$

$v_S \Rightarrow R_S = 100 k\Omega \qquad R_L = 100\Omega$

stage 1 : $R_{i1} = 1 M\Omega$
$R_{o1} = 1 k\Omega$
$A_{vo1} = 10 V/V$

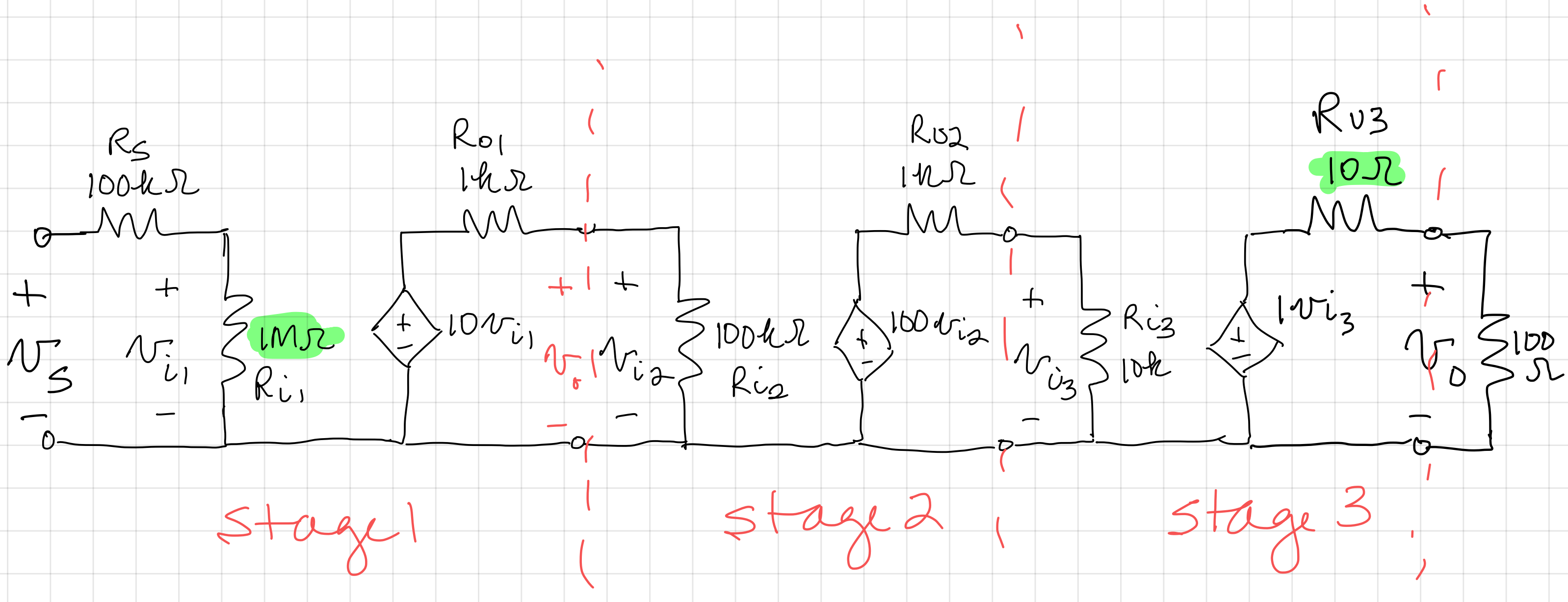
high input resistance

stage 2 : $R_{i2} = 100k$
$R_{o2} = 1 k\Omega$
$A_{vo2} = 100 V/V$

high gain

stage 3 : $R_{i3} = 10 k\Omega$
$R_{o3} = 10\Omega$
$A_{vo3} = 1 V/V$

low output resistance.



$$v_o = 1v_{i3}\left(\frac{100}{100+10}\right) = 0.91\,v_{i3}$$

$$v_{i3} = 100v_{i2}\left(\frac{10\times10^3}{10\times10^3+1\times10^3}\right) = 90.91\,v_{i2}$$

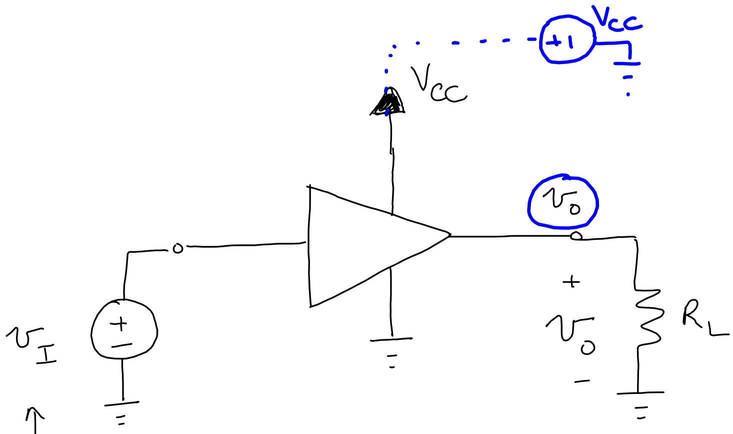
$$v_{i2} = 10\,v_{i1}\left(\frac{100\times10^3}{100\times10^3+1\times10^3}\right) = 9.90\,v_{i1}$$

$$v_{i1} = v_s\left(\frac{1\times10^6}{1\times10^6+100\times10^3}\right) = 0.91\,v_s$$

$$\frac{v_o}{v_s} = \left(\frac{v_o}{v_{i3}}\right)\left(\frac{v_{i3}}{v_{i2}}\right)\left(\frac{v_{i2}}{v_{i1}}\right)\left(\frac{v_{i1}}{v_s}\right)$$

$$= (0.91)(90.91)(9.90)(.91)$$

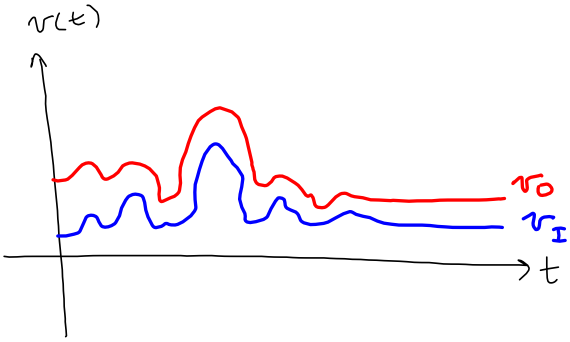
$$\boxed{\frac{v_o}{v_s} = 745.29 \ \frac{V}{V}}$$

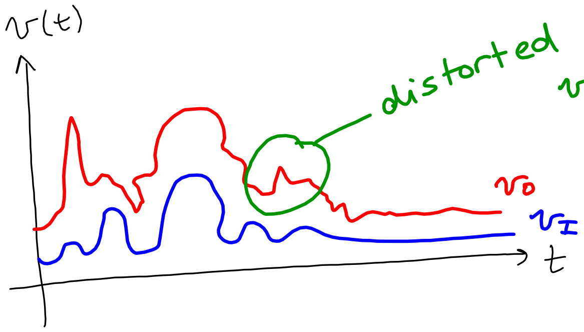


v_I is a weak or small signal (mV to μV)

v_O is the amplified version of v_I (.1 V to 1 V)

Good amplification => Linear $v_O = \underset{\substack{\uparrow \\ \text{constant}}}{A}\, v_I$

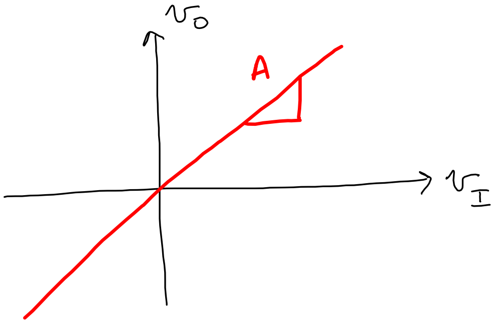




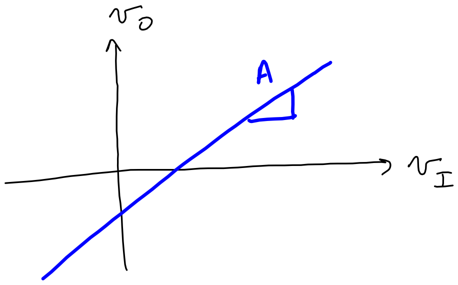
$v_O = A v_I$

$v_O = A v_I + \overbrace{A v_i^2 + A v_i^3 \ldots}^{\text{get rid}}$

voltage transfer characteristic: (VTC)



$v_O = A v_I$



$v_O = A v_I + b$

Amplifier design goals => linear amplification
no distortion

Amplifier Types

voltage amps => $v_O = A_v \cdot v_I$ $A_v \equiv$ voltage gain

current amps => $i_O = A_i \cdot i_I$ $A_i \equiv$ current gain

power amps => $p_O = A_p \cdot p_I$ $A_p \equiv$ power gain

$$A_v = \frac{v_O}{v_I} \left(\frac{V}{V}\right) \qquad A_i = \frac{i_O}{i_I} \left(\frac{A}{A}\right) \qquad A_p = \frac{p_O}{p_I} \left(\frac{W}{W}\right)$$

$$= \frac{v_O \, i_O}{v_I \, i_I} = \left(\frac{VA}{VA}\right)$$

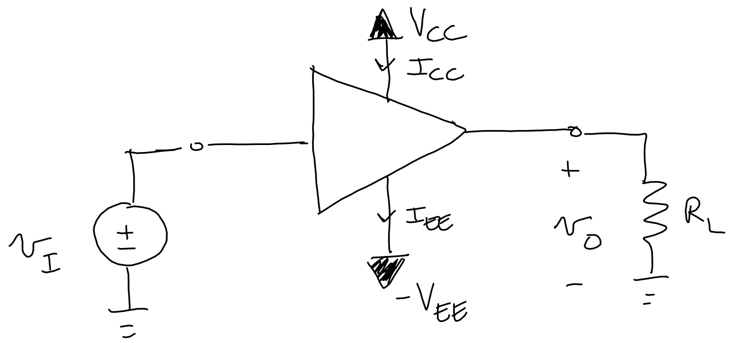
if using log scale => express gain in dB.

$\underline{dB}$

$A_v = 20 \log |A_v|$ $\qquad A_v = -10 \; V/V$

$A_i = 20 \log |A_i|$

$A_p = 10 \log |A_p|$



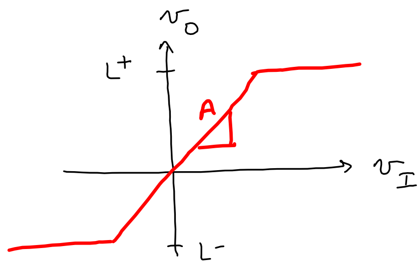
dissipated in amp

$$\underbrace{P_{dc}}_{\text{larger}} + \underbrace{P_I}_{\text{small}} = \underline{P_L} + \underline{P_{Loss}}$$

amplifier efficiency: $\eta = \frac{P_L}{P_{dc}} \times 100$ => percent efficiency

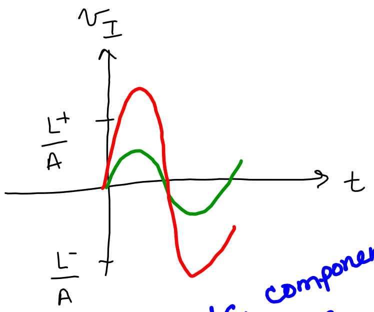
Amplifier saturation

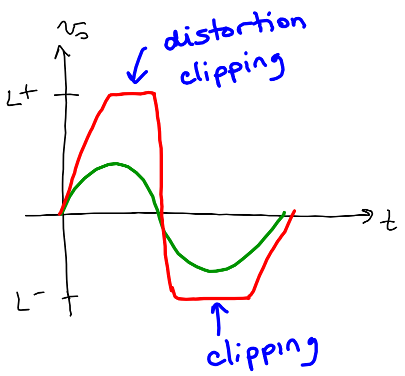
$$v_O = A\, v_I$$



$$\frac{L^-}{A} \le v_I \le \frac{L^+}{A}$$

L^+, L^- are typically 90-99% of the dc supply





dc component
DC bias

$$v_O = V_O + v_o(t)$$
$$i_A = I_A + i_a(t)$$

total signal

AC component
small-signal component

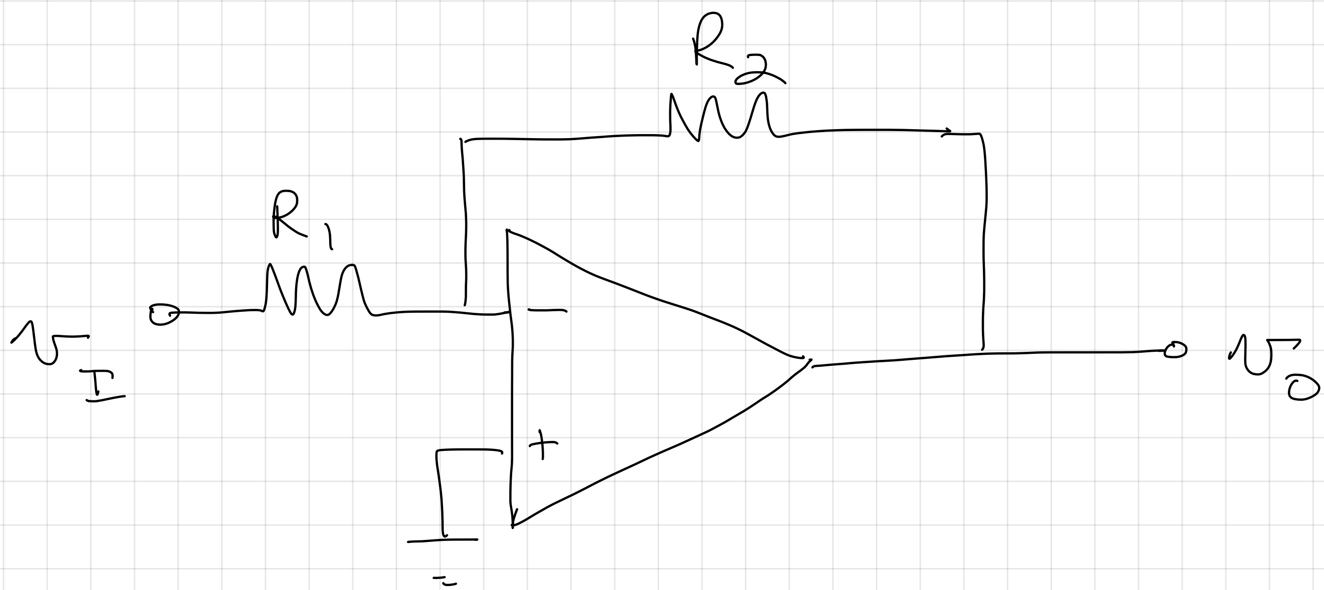
large signal resistance R_i, R_o, R_I, R_O

small signal resistance r_π, r_o, r_i

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 $R_2 = 5M\Omega$

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

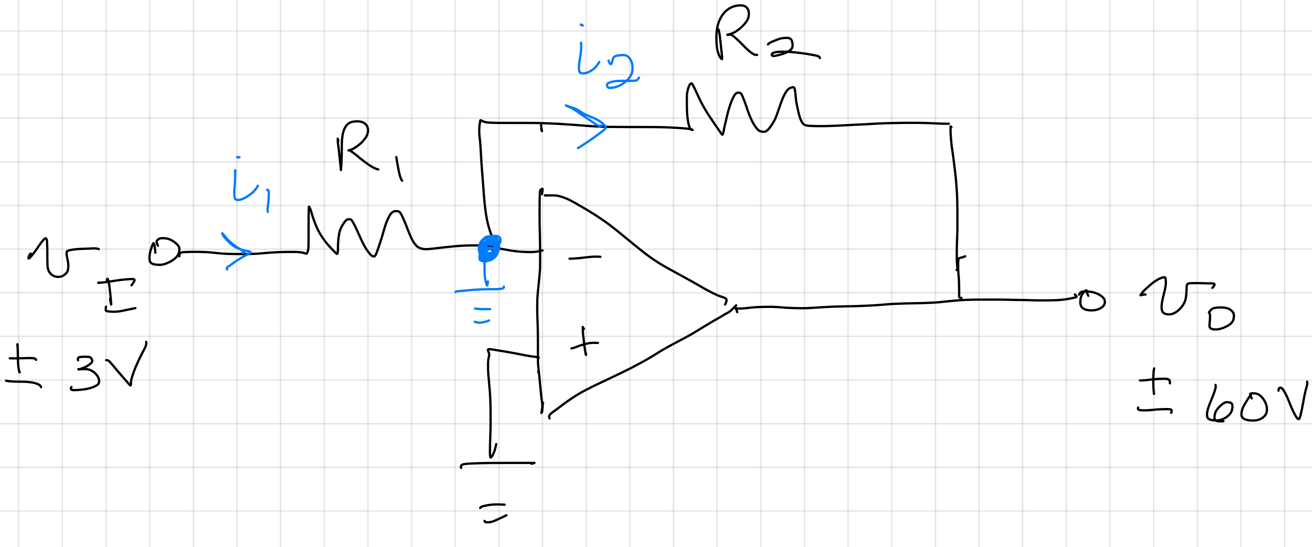
$R_1 = 100k\Omega$
$R_2 = 5M\Omega$

Example 2: Design an inverting amp.

v_I : $\pm 3V$

v_O : $\pm 60V$

$i_{max} = 20\mu A$



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

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

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

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

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

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

$$R_2 \geq \frac{60}{20 \times 10^{-6}}$$

$$R_2 \geq 3\,M\Omega$$

let $R_2 = 3\,M\Omega$

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

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

$$v_I \leq R_1 (20 \times 10^{-6})$$

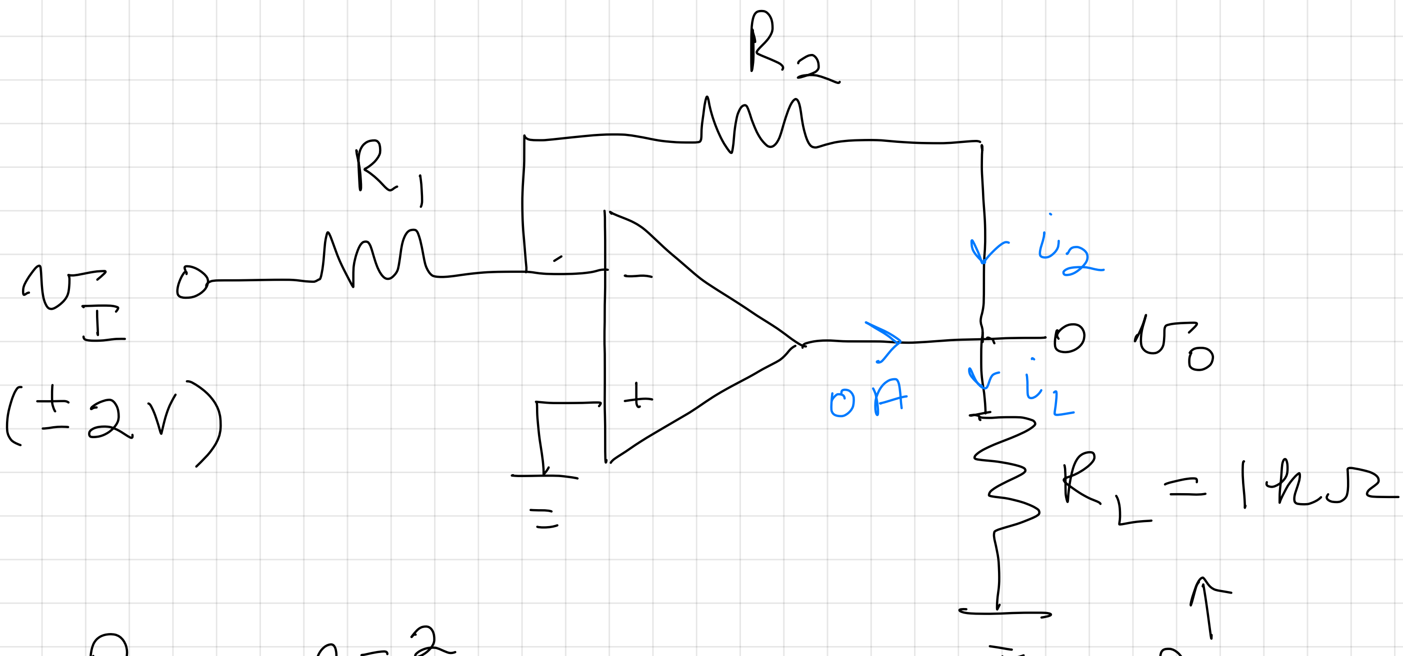
$$v_I \leq 3\,V$$

$$\boxed{\begin{array}{l}\text{A possible design} \\ R_2 = 3\,M\Omega \\ R_1 = 150\,k\Omega\end{array}}$$

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.



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

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

$$\boxed{v_{o\,max} = \pm 4V}$$

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

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

$$\boxed{R_2 = 2R_1}$$

$R_2 = 2\,\Omega$

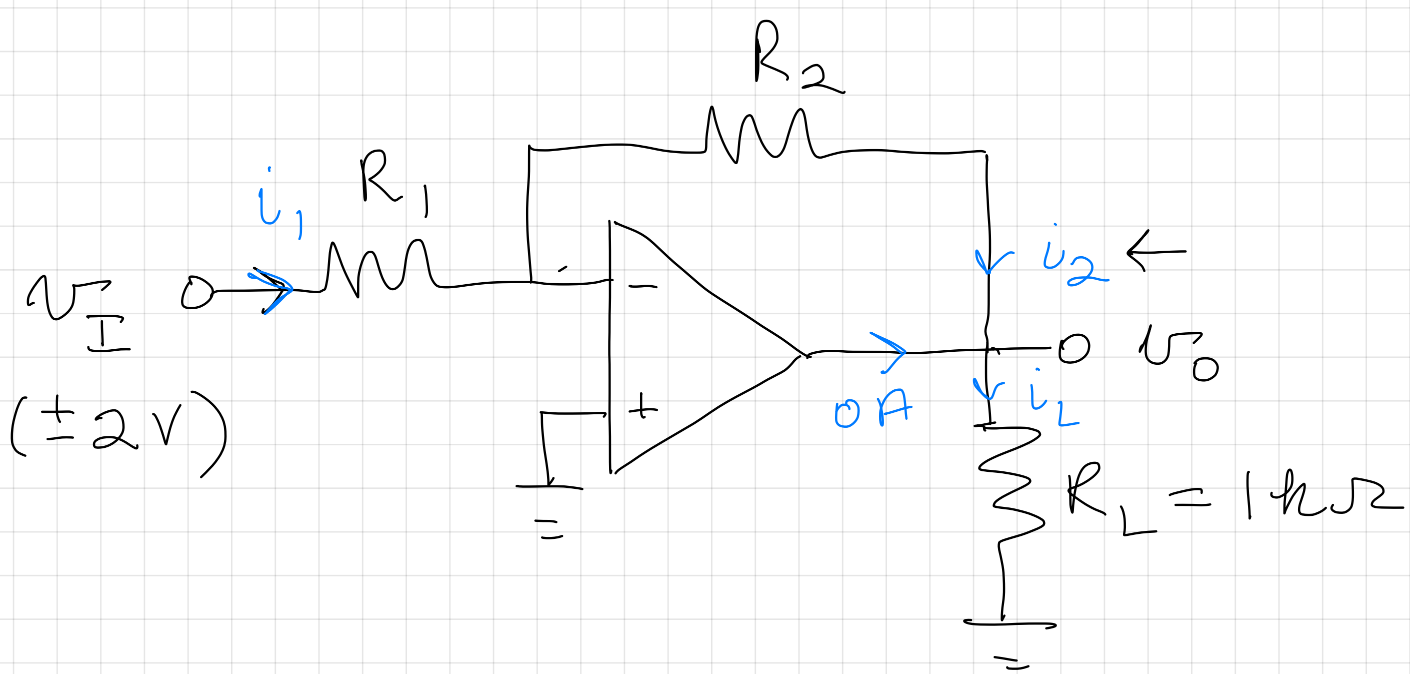
$R_1 = 1\,\Omega$

$v_o = \pm 4V$

$v_I = \pm 2V$

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

$P_L = 16\,mW$



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

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

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

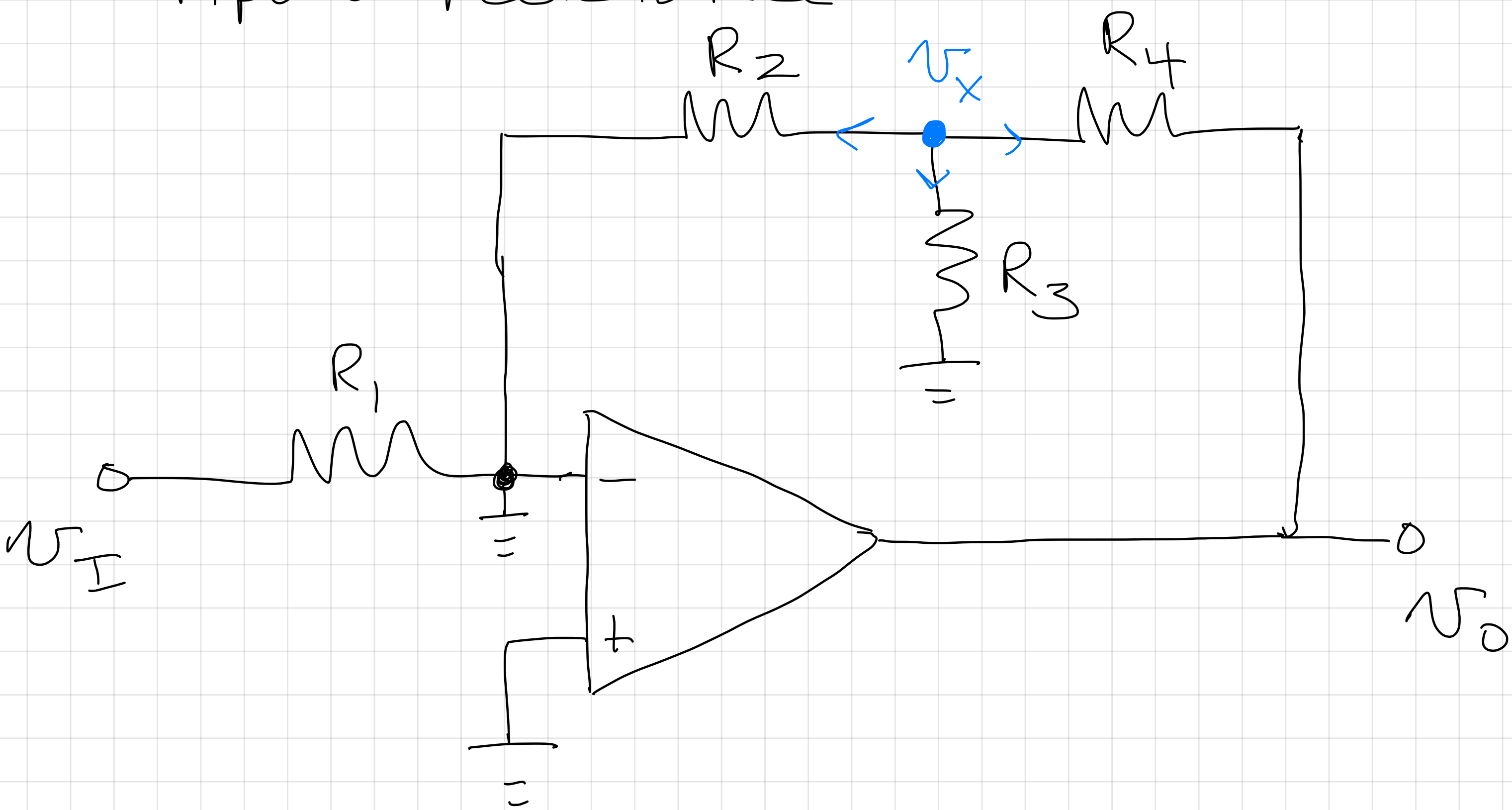
$R_2 = 1k\Omega$

$R_1 = 500\Omega$

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

$$i_1 = 4mA$$

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 $R_1 = 1M\Omega$

$R_2 = 1M\Omega$

$R_4 = 1M\Omega$

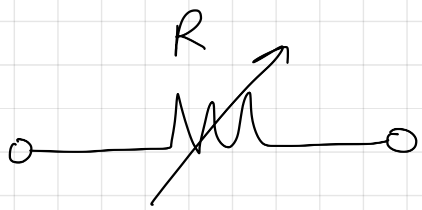
$$\left(-\overset{1}{\cancel{\frac{1M}{1M}}}\right)\left(\overset{1}{\cancel{\frac{1M}{1M}}} + \frac{1M\Omega}{R_3} + 1\right) = -100$$

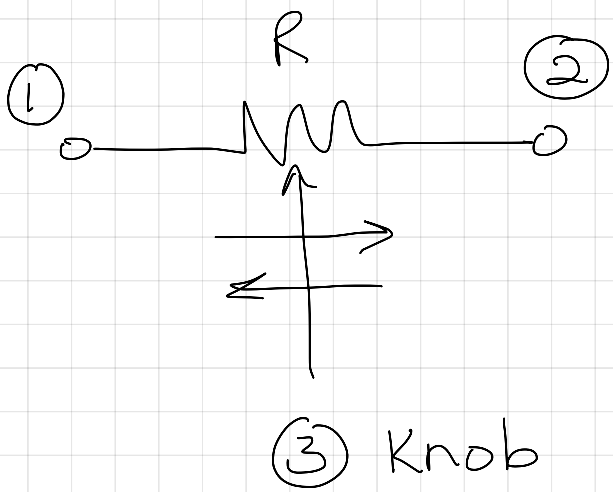
$$\left(2 + \frac{1\times10^6}{R_3}\right) = 100$$

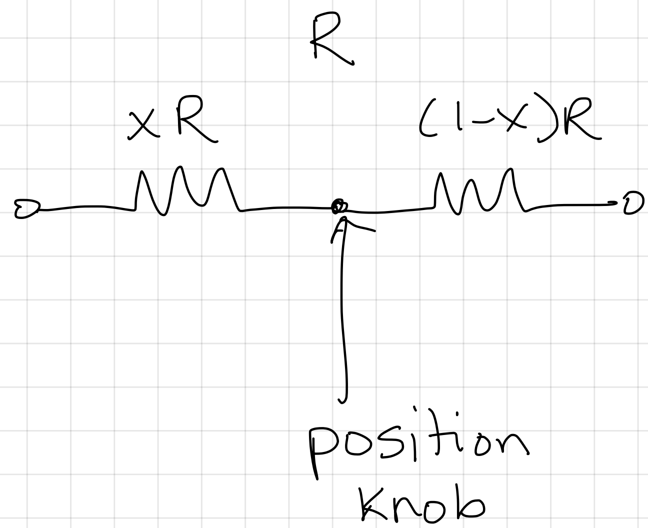
$$\frac{1\times10^6}{R_3} = 98 \qquad R_3 = \frac{1\times10^6}{98}$$

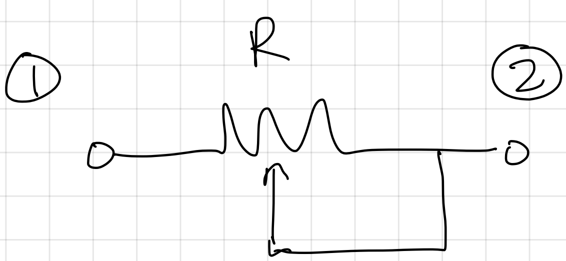
$R_3 = 10.2\ k\Omega$

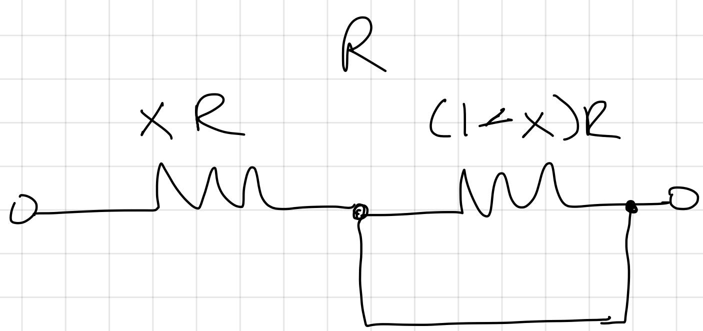
$R \equiv$ range of value



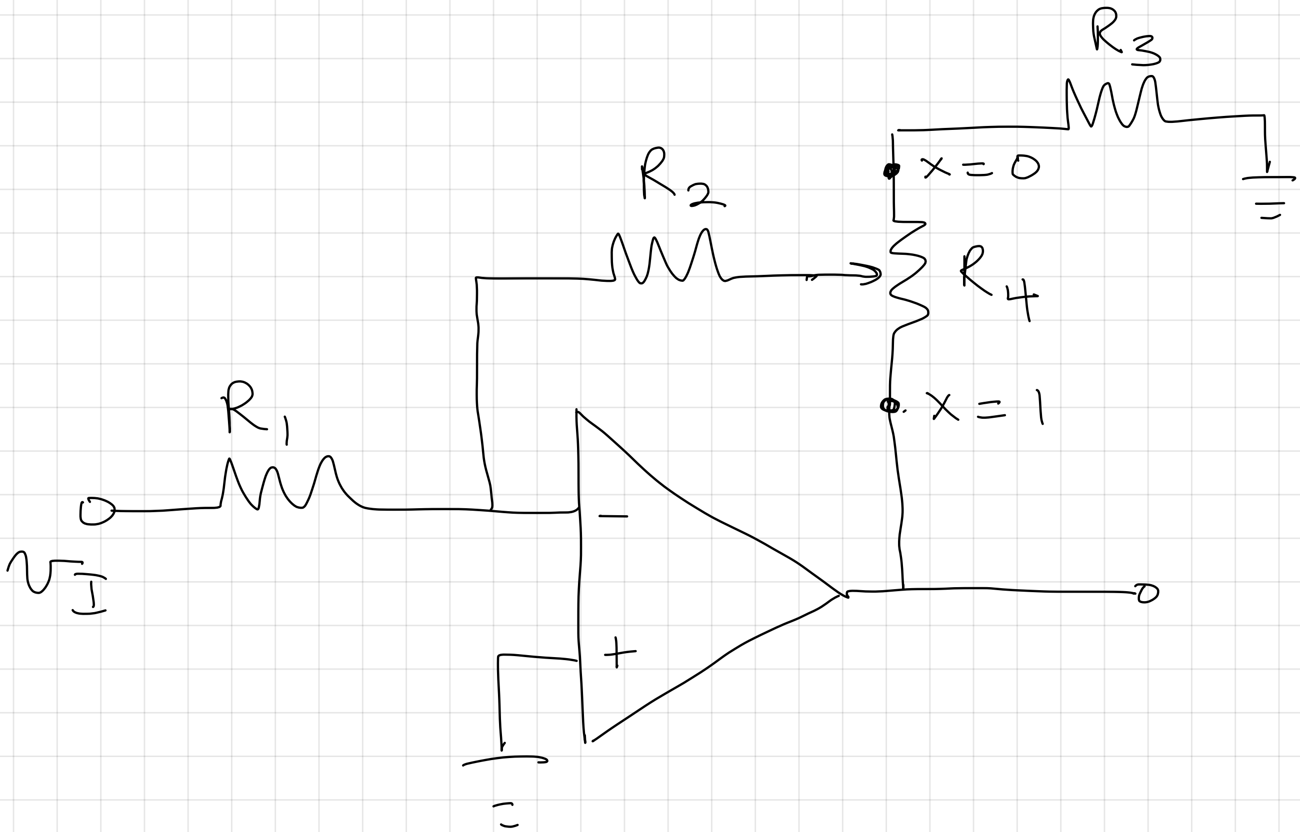








EX of using a pot in the T network.



$R_4 = 100\,k\Omega$ 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

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

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

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

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

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

$\qquad\qquad\qquad R_3' = R_3$

1

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

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

$$R_2 = R_1$$

$$\boxed{\begin{array}{l} R_1 = R_i = 100\,k\Omega \\ R_2 = 100\,k\Omega \end{array}}$$

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

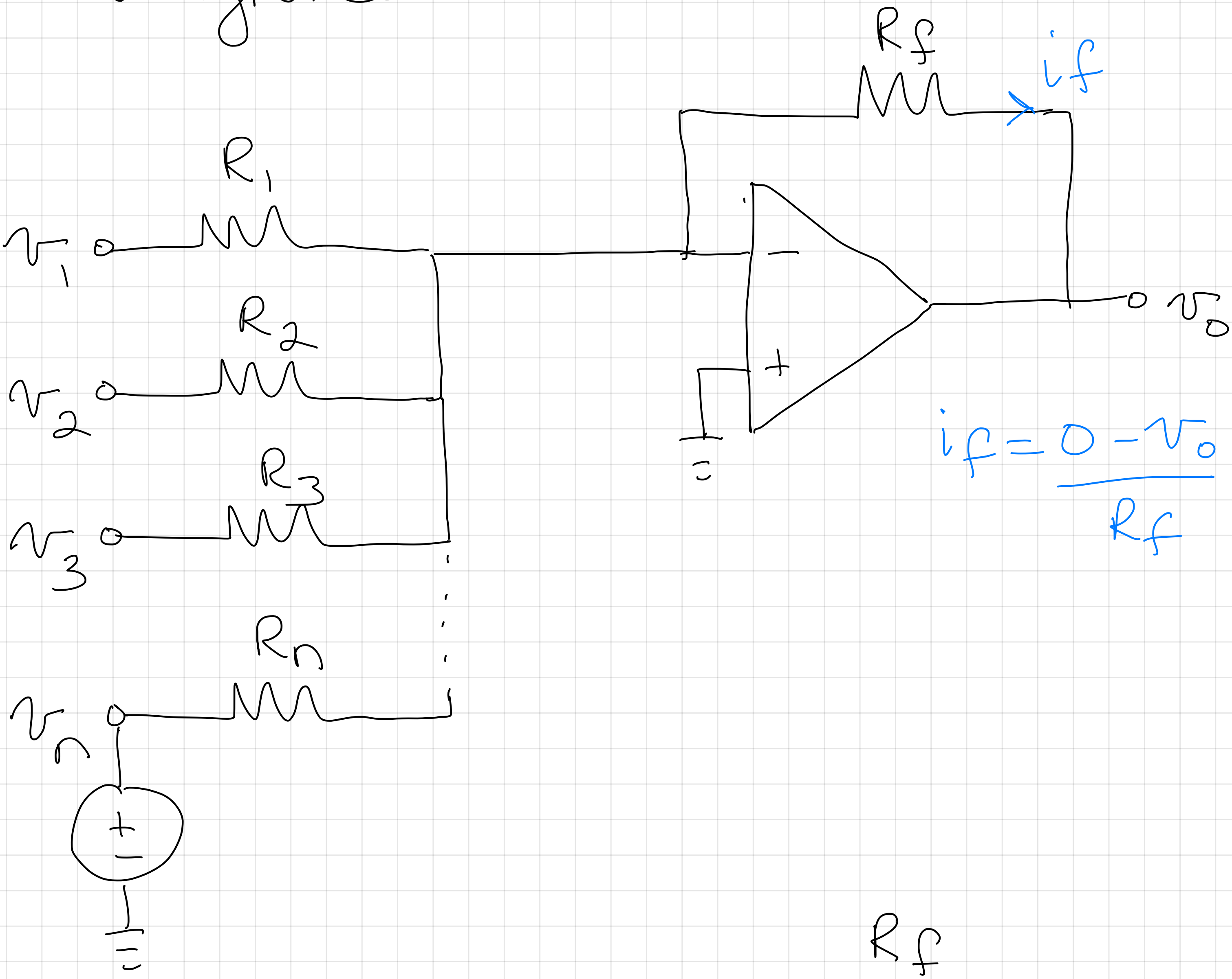
$$-\frac{\cancel{100k}}{\cancel{100k}}\left(\frac{\cancel{100k}}{\cancel{100k}} + \frac{100k}{R_3} + 1\right) = -100$$

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

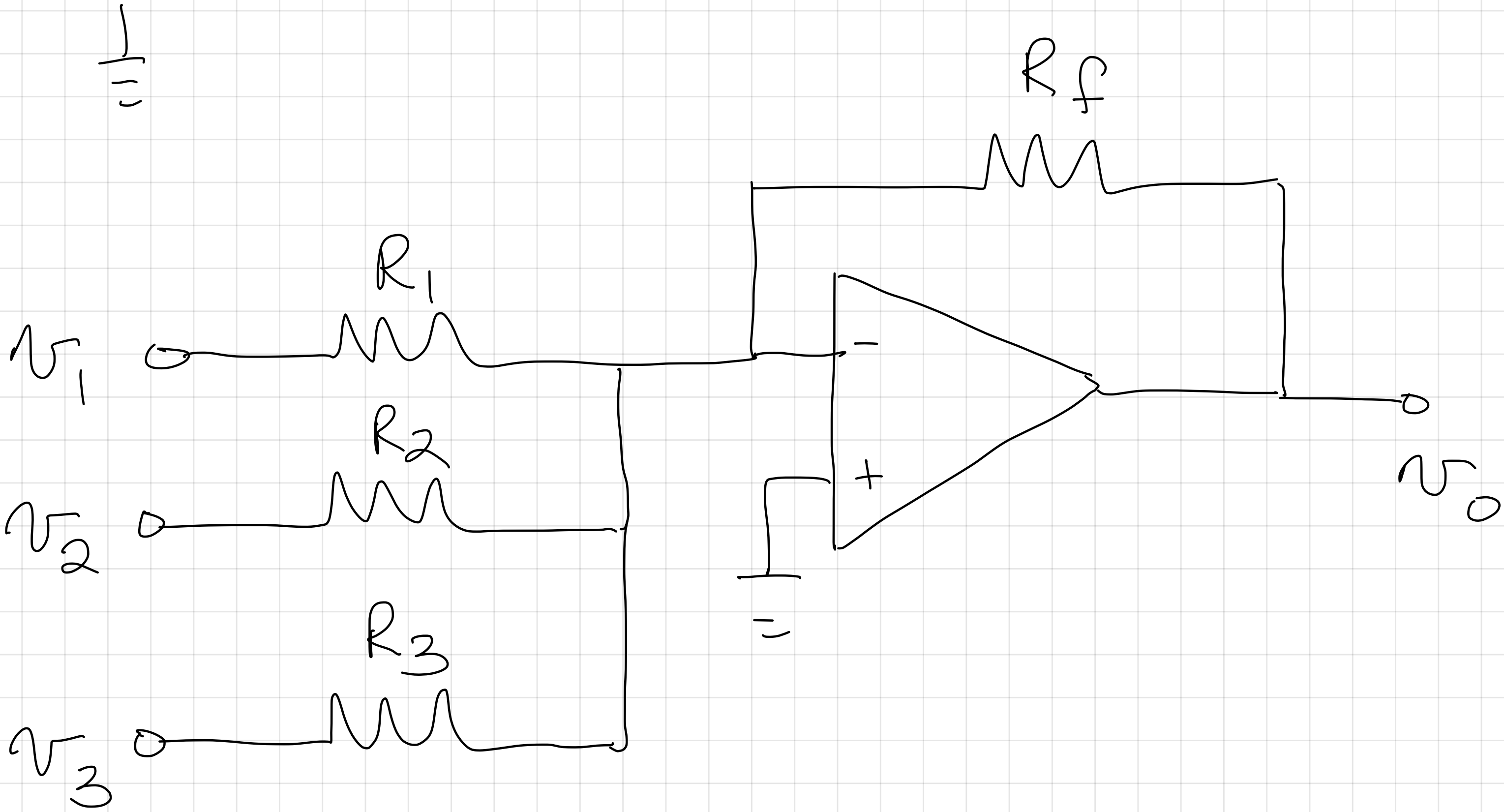
$$\frac{100\times10^3}{R_3} = 98$$

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

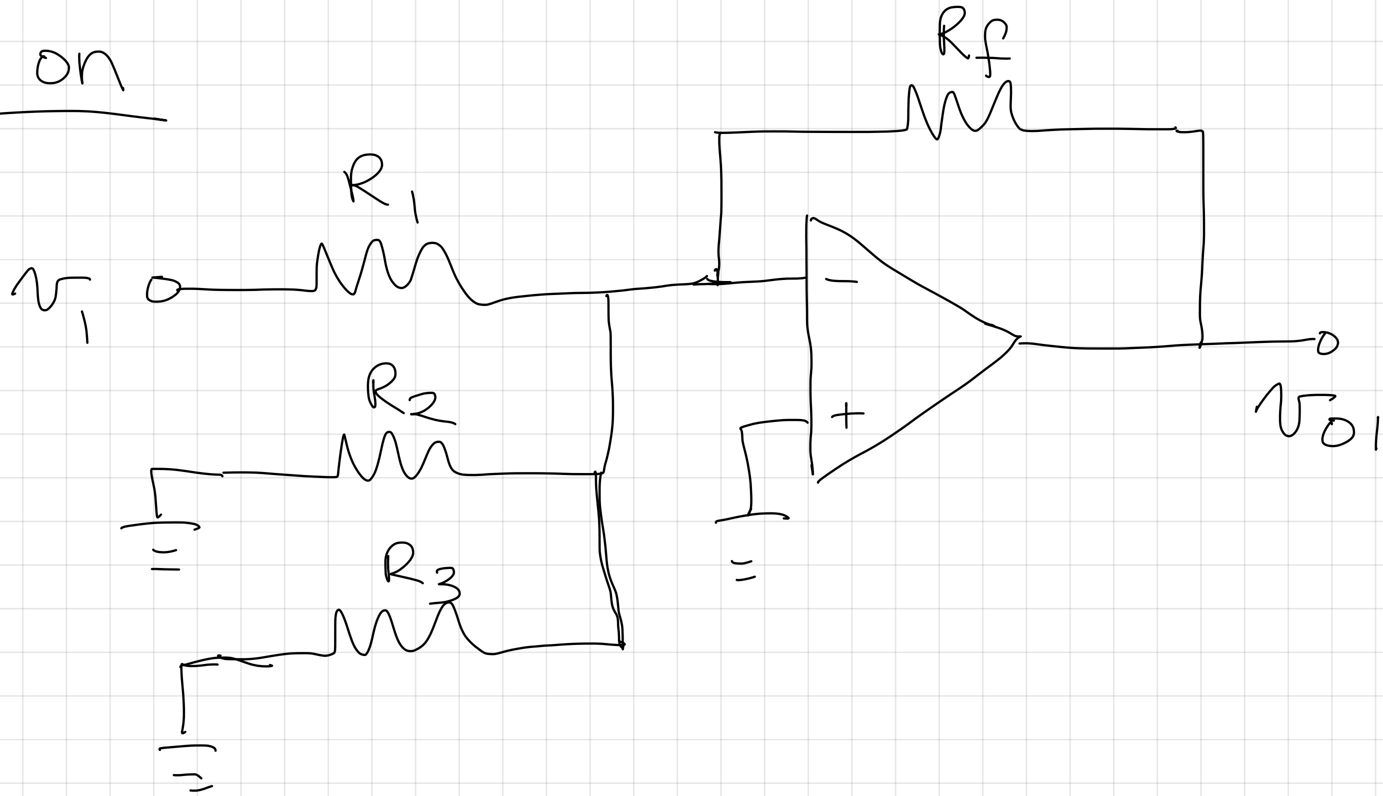
Weighted summer

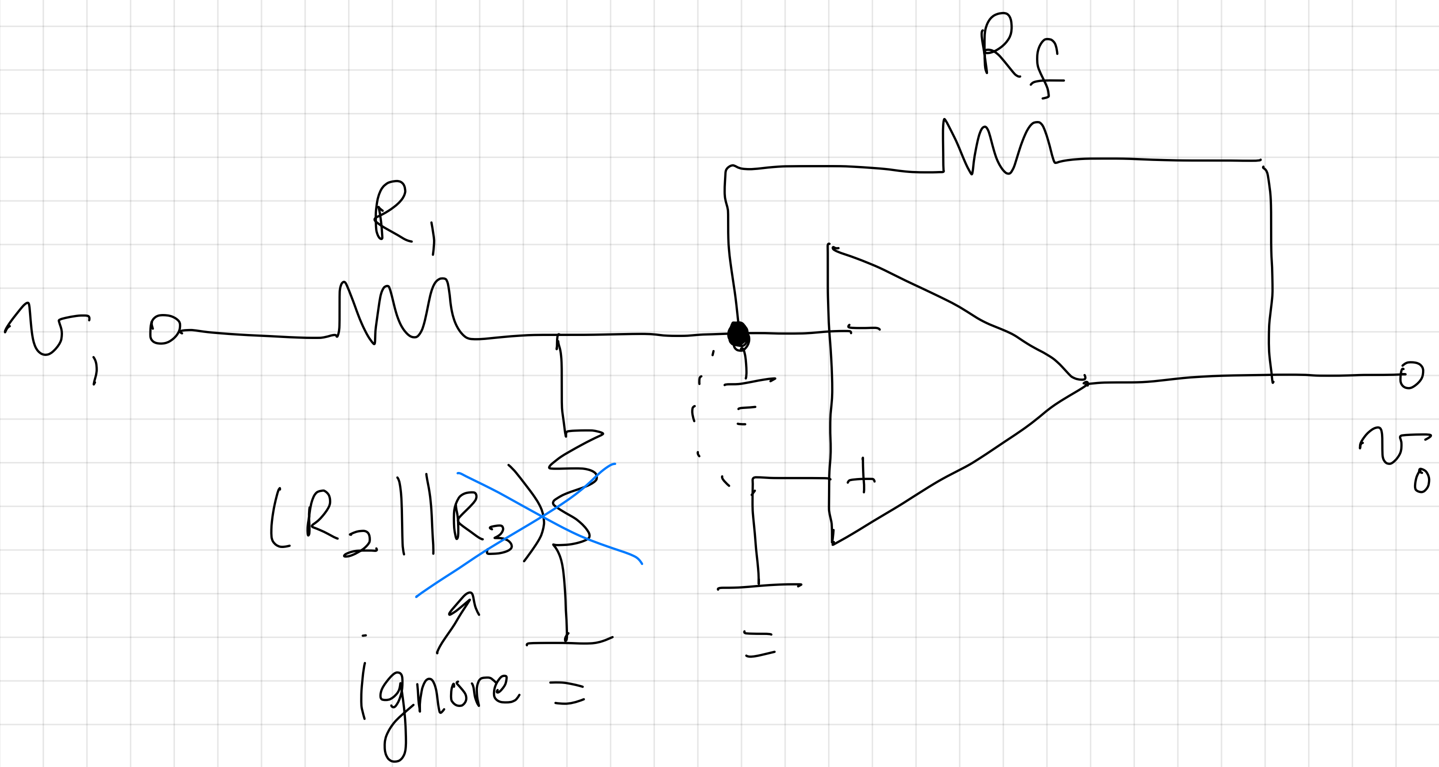


$$i_f = \frac{0 - v_o}{R_f}$$



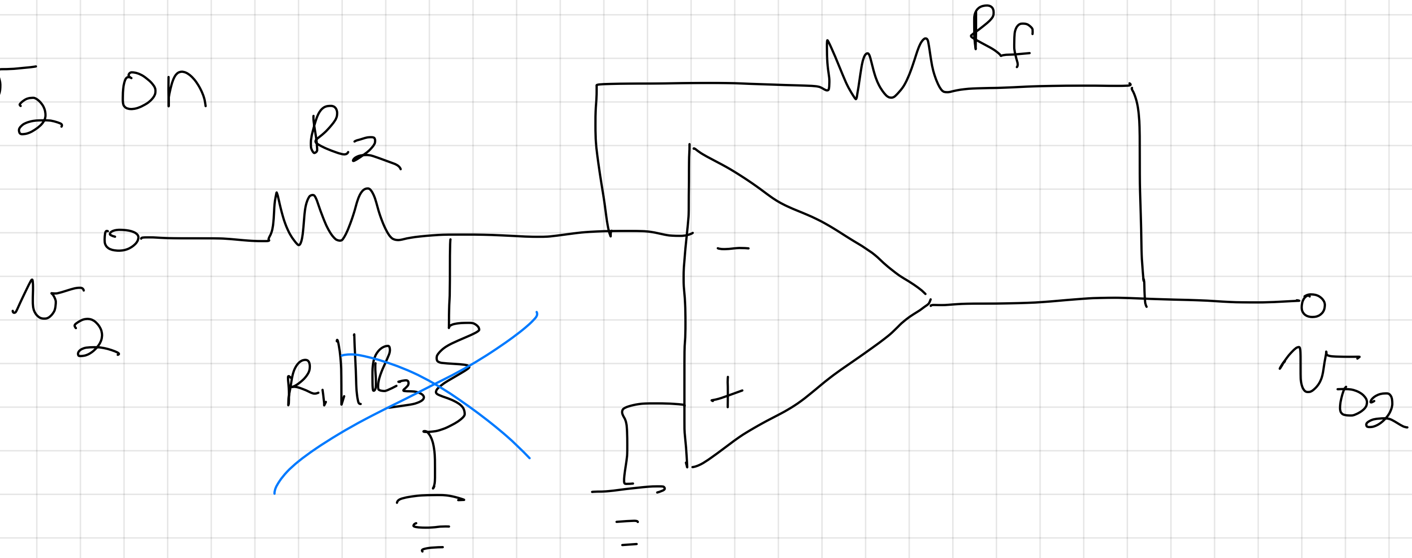
v_1 on





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

v_2 on



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

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

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

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

Ex : $v_0 = -5v_1 - 2v_2 - 7v_3$

Design 1)

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

$R_f = 1M\Omega$

$R_1 = 200k\Omega$

$R_2 = 500k\Omega$

$R_3 = 142.86k\Omega$

Design 2

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

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

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

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

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

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

$10\times10^{-6} \geq \frac{5}{R_f}$

$R_f \geq \frac{5}{10\times10^{-6}}$

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

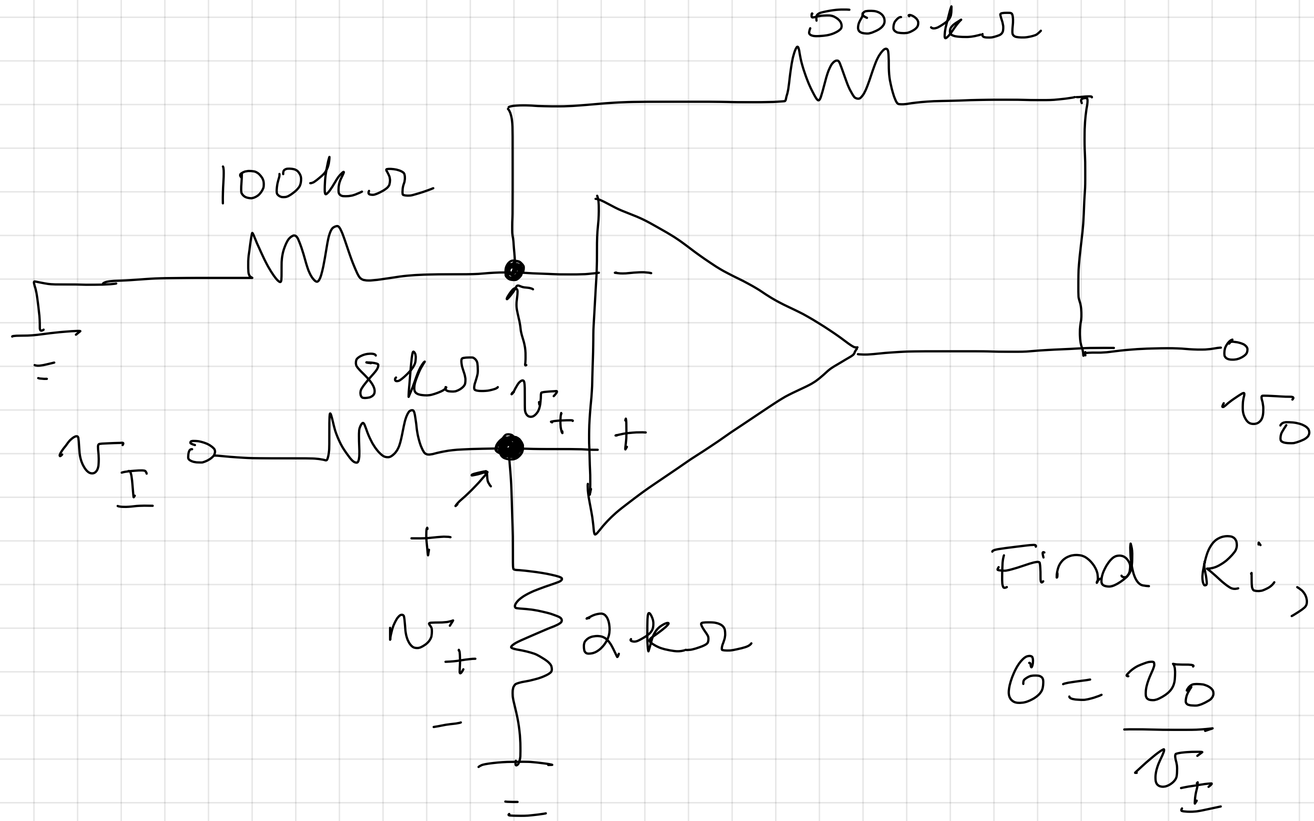
$$R_1 = \frac{R_f}{5}$$

$$R_f \geq 0.5 M\Omega$$

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

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

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



Find R_i, G

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

$R_i = \infty$

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

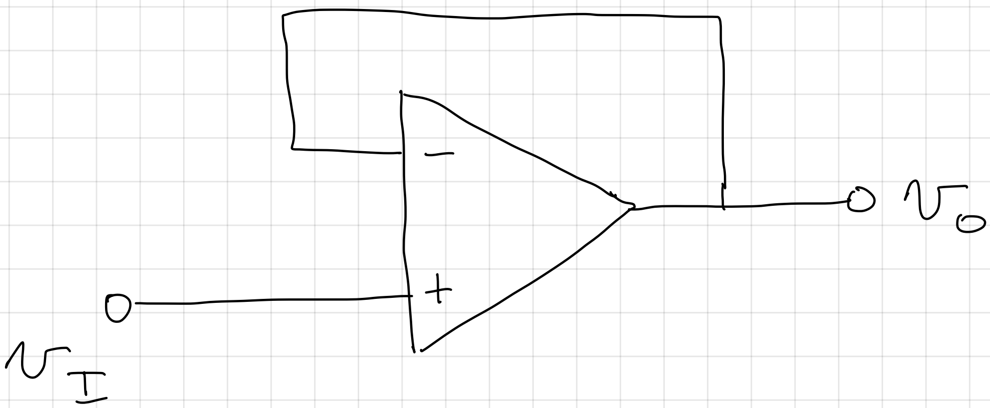
$$\frac{v_O}{v_+} = \left(1 + \frac{500k}{100k} \right)$$

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

$$= (6)(0.2)$$

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

Voltage Follower (version of non-inverting configuration)



$R_1 = \infty$

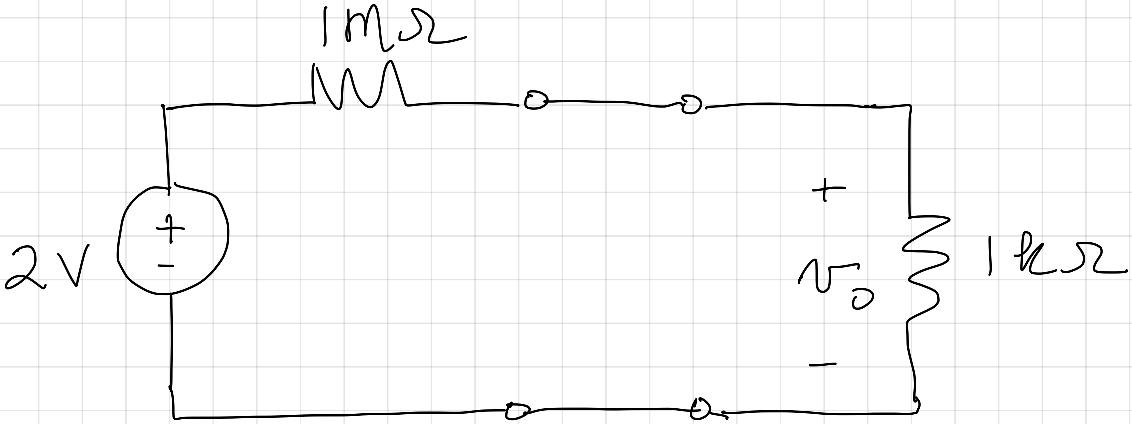
$R_2 = 0$

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

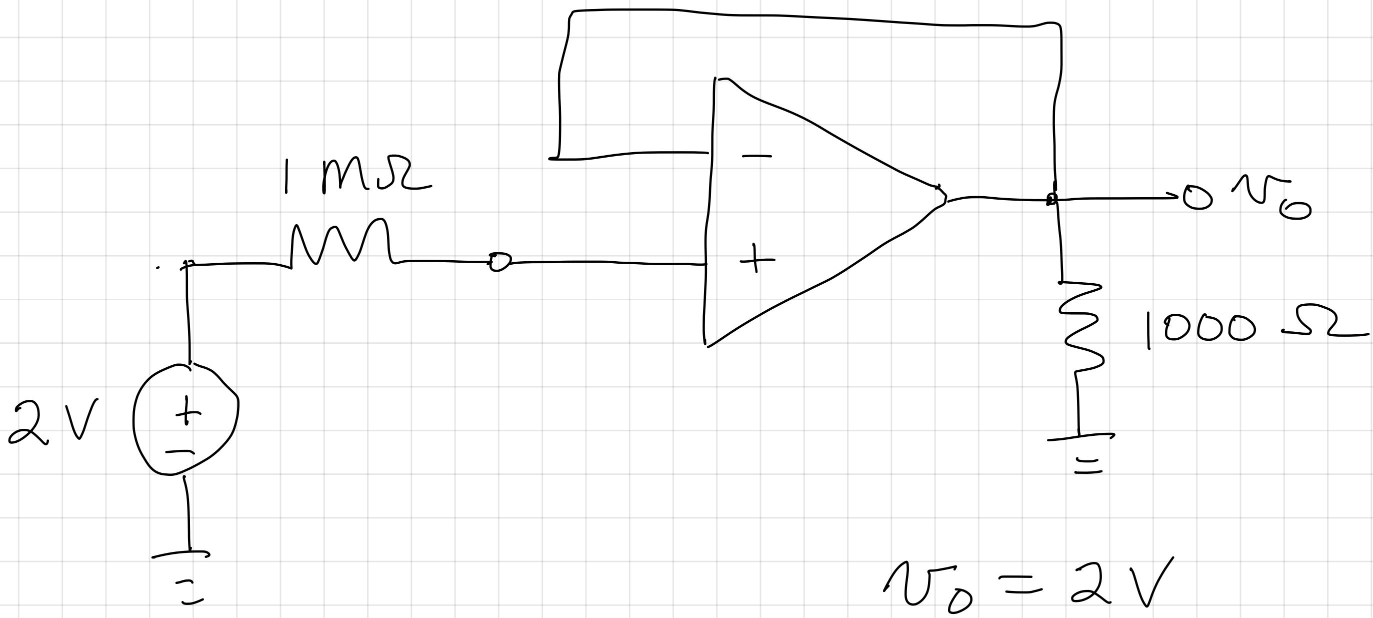
$v_O = v_I \Rightarrow$ voltage follower

EX

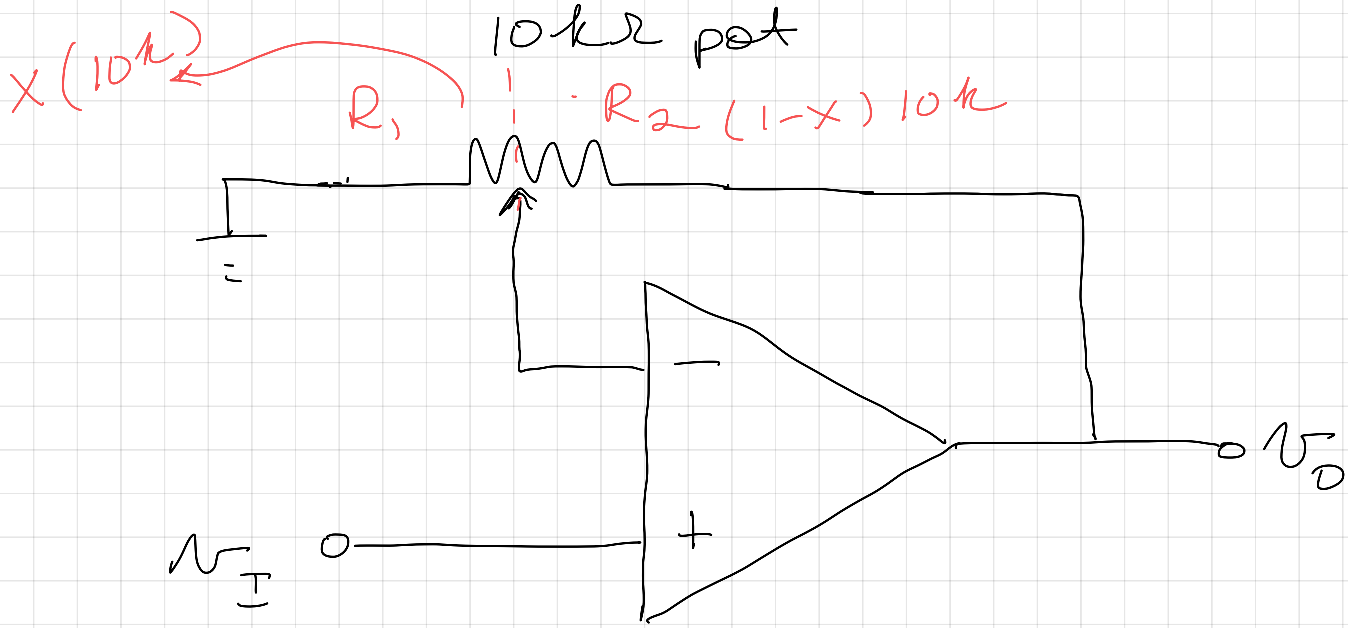
2V source that drives 1kΩ load. The source resistance is 1MΩ



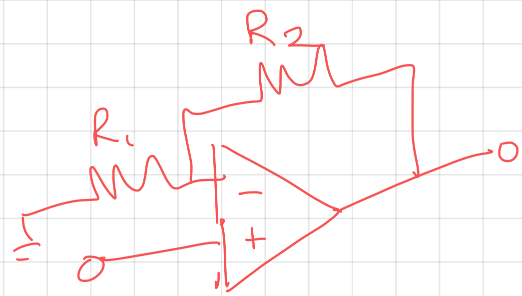
$$v_o = 2\left(\frac{1000}{1000 + 1\times 10^6}\right) = 0.2\,mV$$



$v_o = 2V$



Find the range of gain



$x = 0$

$R_1 = 0$

$R_2 = 10k\Omega$

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

$G = \infty$

$x = 1$

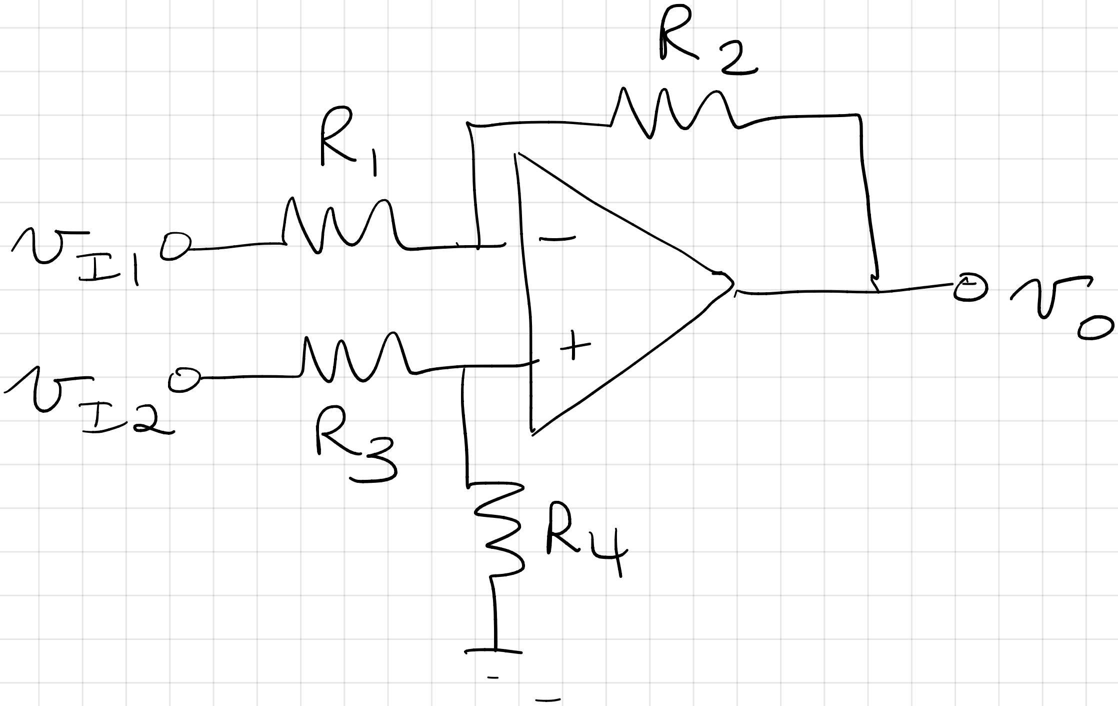
$R_2 = 0$

$R_1 = 10k\Omega$

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

$G = 1$

Difference Amplifiers



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

$R_1 = R_3 = 2\,k\Omega$

$R_2 = R_4 = 200\,k\Omega$

$A_{cm} = 0$
$\uparrow$
perfectly match resistors

$$A_d = \frac{R_2}{R_1} = \frac{200}{2} = 100\,\frac{V}{V} \text{ or } 40\,dB$$

$R_{id} = 2R_1 = 4\,k\Omega$ $\quad$ $R_o = 0$

$CMRR \rightarrow \infty$

$R_1 - R_4$ have 1% tolerance.

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

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

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

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

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

$$= \frac{1}{\frac{R_3}{R_4} + 1}\left[1 - \frac{R_2}{R_1}\frac{R_3}{R_4}\right]$$

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

$$= \frac{\left[\frac{R_4}{R_3} - \frac{R_2}{R_1}\right]}{1 + \frac{R_4}{R_3}}$$

$R_1 = R_3 = 2\ k\Omega$

$R_2 = R_4 = 200\ k\Omega$

$200\,k\Omega \pm 1\%\,(200\,k\Omega)$

$200\,k\Omega\,(1 \pm .01)$

$2\,k\Omega\,(1 \pm .01)$

$$\frac{200(1-.01)}{2(1+.01)} \leq \frac{R_4}{R_3} \leq \frac{200(1+.01)}{2(1-.01)}$$

$$\frac{198}{2.02} \leq \frac{R_4}{R_3} \leq \frac{202}{1.98}$$

$$98.02 \le \frac{R_4}{R_3} \le 102.02$$

$$98.02 \le \frac{R_2}{R_1} \le 102.02$$

$$A_{cm} = \frac{\left[\frac{R_4}{R_3} - \frac{R_2}{R_1}\right] \leftarrow \text{large}}{1 + \frac{R_4}{R_3} \leftarrow \text{small}}$$

want to know the worst case A_{cm}

let $\frac{R_4}{R_3} = 98.02$ $\quad \frac{R_2}{R_1} = 102.02$

$$A_{cm} = \frac{(98.02 - 102.02)}{1 + 98.02} = -0.04 \text{ V/V}$$

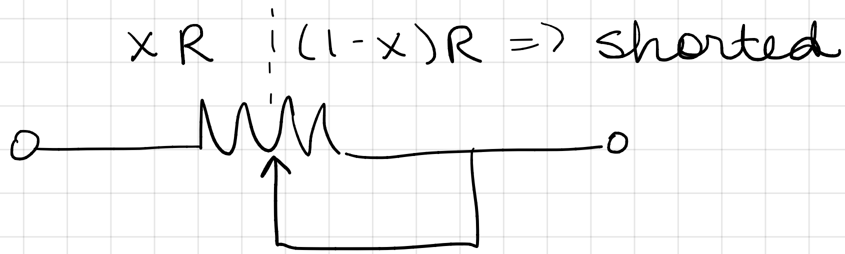
$$|A_{cm}| = 0.04 \ \frac{V}{V} \qquad A_d = \frac{R_2}{R_1} = \frac{102.02\ V}{V}$$

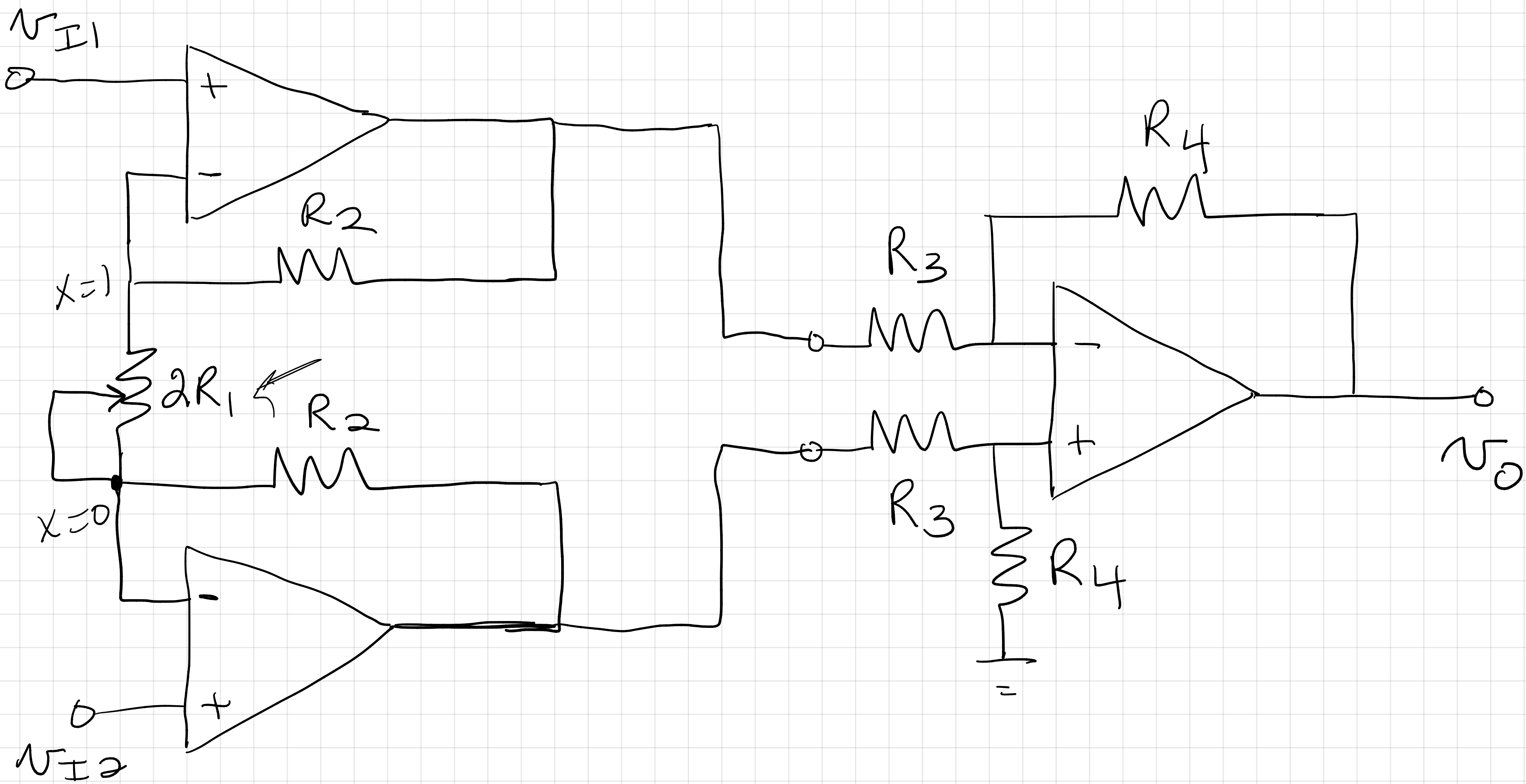
$$CMRR = 20 \log \left| \frac{A_d}{A_{cm}} \right|$$

$$= 20 \log \left| \frac{102.02}{.04} \right|$$

$$= 68.04 \ dB$$

Using a pot to vary gain:





$2R_1 = 100\,k\Omega$ pot.

$$A_d = \left(1 + \frac{2R_2}{2R_1}\right)\left(\frac{R_4}{R_3}\right)$$

$x = 0$ $\quad 2R_1 = 100\,k\Omega$

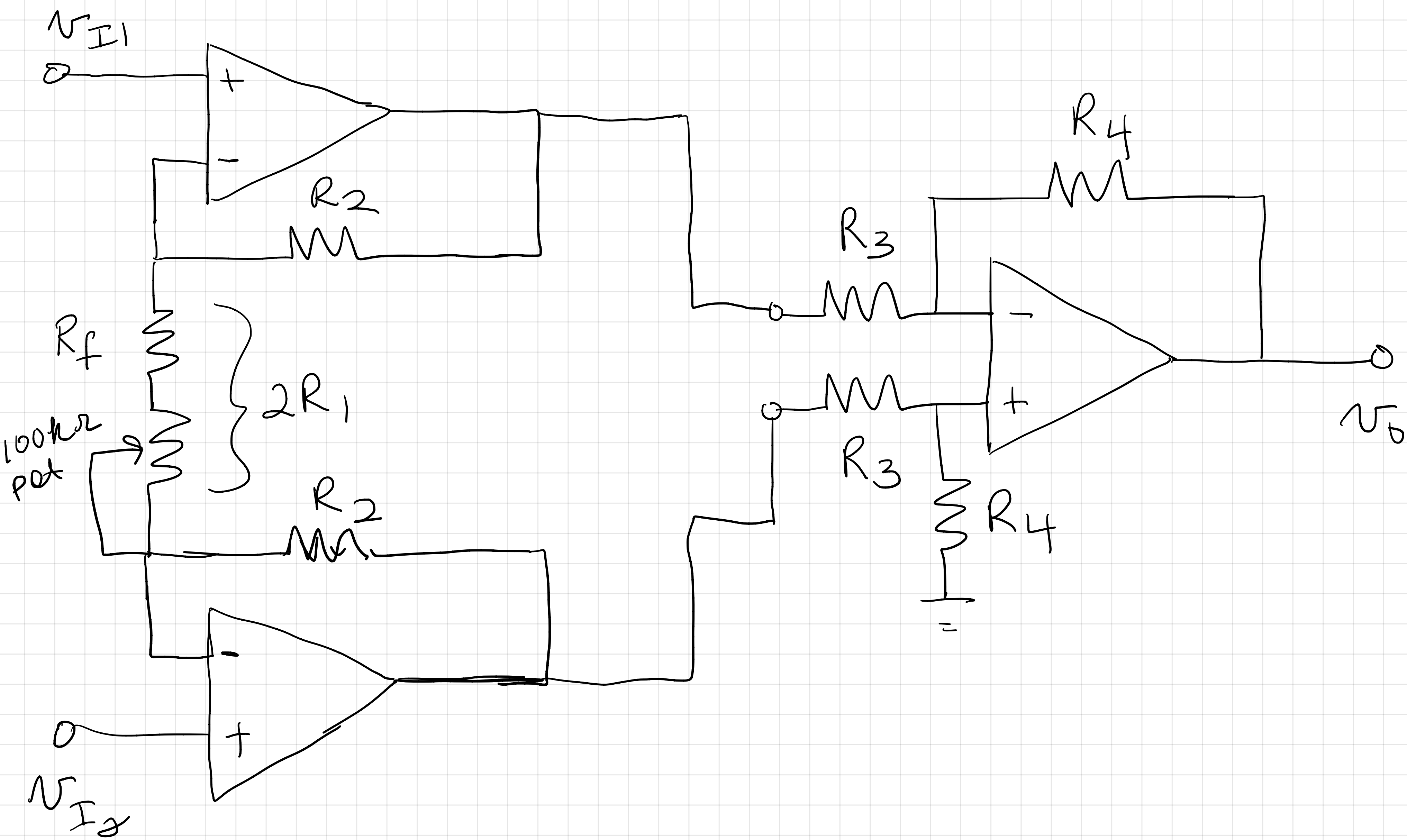
$$A_d = \left(1 + \frac{2R_2}{100k}\right)\left(\frac{R_4}{R_3}\right)$$

$x = 1$ $\quad 2R_1 = 0$

$$A_d = \left(1 + \frac{2R_2}{0}\right)\left(\frac{R_4}{R_3}\right)$$

$x = 0$ $\quad A_d =$ minimum

$x = 1$ $\quad A_d \to \infty$



v_{I1}
R_2
R_4
R_3
R_f
$2R_1$
100kΩ pot
R_2
R_3
R_4
v_o
v_{I2}

Design instrumentation amp

$A_d \rightarrow 2 \frac{V}{V}$ to $1000\ V/V$

$$A_d = \left(1 + \frac{2R_2}{2R_1}\right)\left(\frac{R_4}{R_3}\right)$$

$$2R_1 = R_f + 100\,\cancel{k}\Omega$$

$x = 0 \qquad 2R_1 = R_f + 100\,k\Omega$

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

$$\left(1 + \frac{2R_2}{R_f + 100\times10^3}\right)\left(\frac{R_4}{R_3}\right) = 2$$

let $R_4 = R_3 = 100\,k\Omega$

$$\boxed{\left(1 + \frac{2R_2}{R_f + 100k}\right) = 2}$$

$X=1 \qquad 2R_1 = R_f$

$$\left(1+\frac{2R_2}{2R_1}\right)\left(\cancel{\frac{R_4}{R_3}}^{\,1}\right) = 1000$$

$$\boxed{\left(1+\frac{2R_2}{R_f}\right) = 1000}$$

$$\frac{2R_2}{R_f+100k} = 1 \qquad \frac{2R_2}{R_f} = 999$$

$$\boxed{2R_2 = R_f + 100k} \qquad \boxed{2R_2 = 999R_f}$$

$$R_f + 100k\Omega = 999R_f$$

$$998R_f = 100k\Omega$$

$$R_f = 100.2\Omega$$

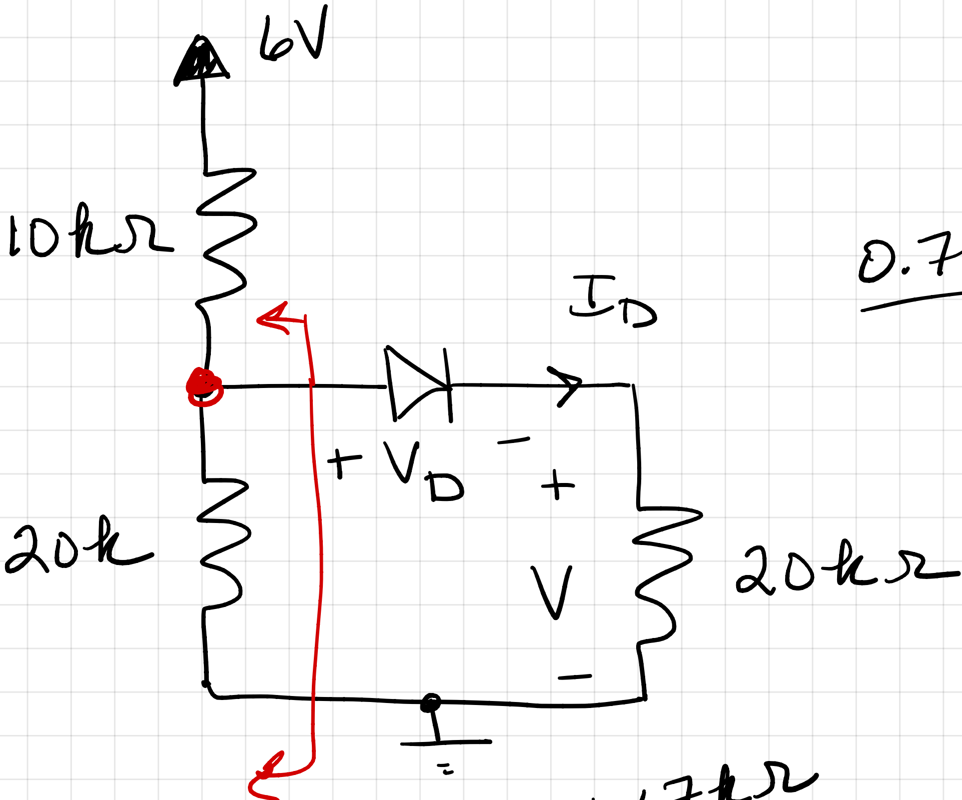
$R_2 = 50.05\ k\Omega$

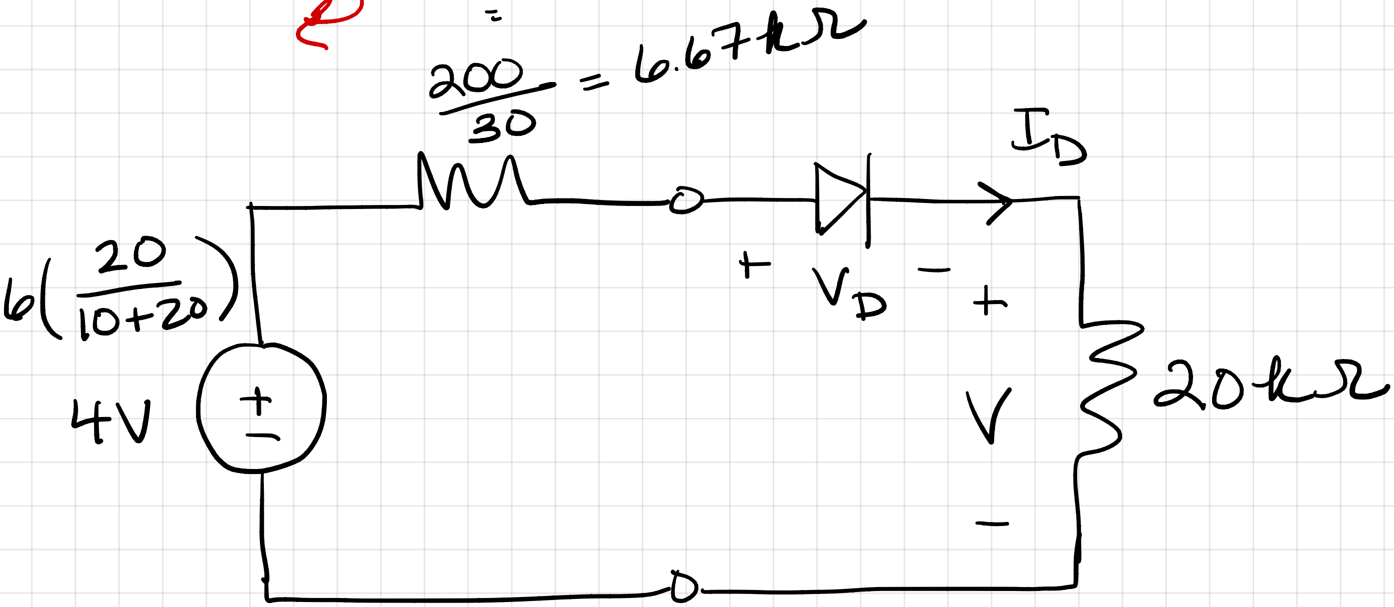
Apply

ideal

$0.7V \leftarrow$ constant drop

exponential model





ideal $V_D = 0$

$$V = 4\left(\frac{20}{20+6.67}\right)$$

$$\boxed{V = 3V}$$

$$I_D = \frac{4}{26.67} = 0.15\,mA$$

constant drop

$V_D = 0.7V$

$$I_D = \frac{4-0.7}{26.67k\Omega}$$

$$I_D = 0.124\,mA$$

$$\boxed{V = (I_D\, 20) = 2.48V}$$

```
clc

Vdd=4;
Rs=6.6667;
Rl=20;

Vd=0.7;
Id=1; %units of mA
x=1;
count=0;

while x >0.000000001
    Idtest=(Vdd-Vd)/(Rs+Rl);
    Vdtest=Vd+0.025*log(Idtest/Id);
    x=abs(Vd-Vdtest);
    Vd=Vdtest;
    Id=Idtest;
    count=count+1;

end

Id
Vd
count
Vl=Id*20
```

for exp

1mA, 0.7V

$I_D = 0.1257\,mA$

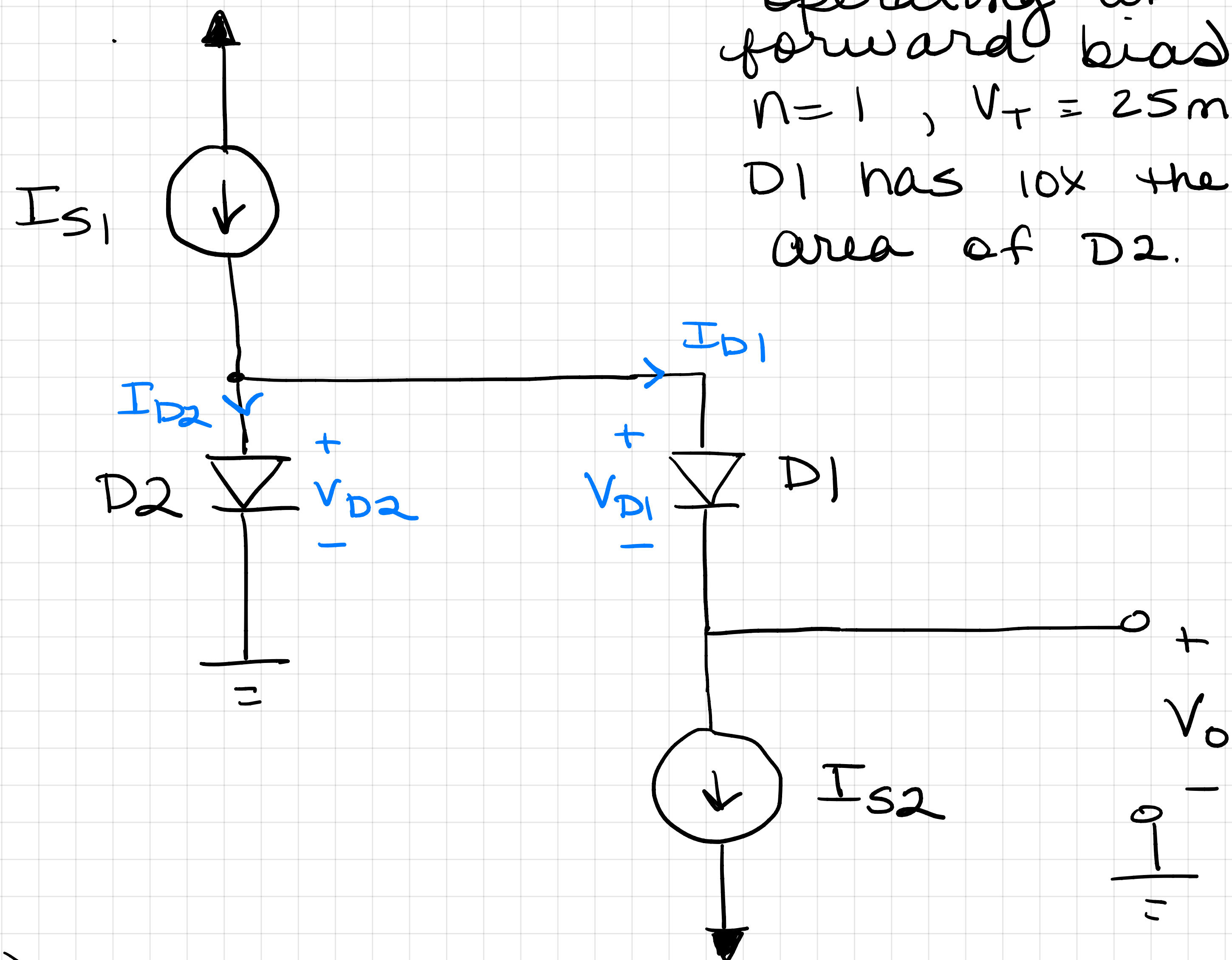
$V_D = 0.6482\,V$

$V = 2.5139\,V$

D1 & D2 are operating in forward bias

$n = 1$, $V_T = 25\,mV$

D1 has 10x the area of D2.



a) $I_{S1} = 10\,mA$

$I_{S2} = 2\,mA$

What is V_o?

$$I = I_s \exp\left(\frac{V}{V_T}\right)$$

$\uparrow$ saturation or scale

$I_{D1} = 2\,mA$

by KCL $I_{D2} = 10 - I_{D1}$

$I_{D2} = 8\,mA$

$D_2 \rightarrow I_s$

$D_1 \rightarrow 10\,I_s$

by KVL: $V_{D2} - V_{D1} - V_o = 0$

$$V_o = V_{D2} - V_{D1}$$

$$I_{D2} = I_s \exp\left(\frac{V_{D2}}{V_T}\right)$$

$$I_{D1} = 10 I_s \exp\left(\frac{V_{D1}}{V_T}\right)$$

$$\frac{\cancel{I_{D1}} \xrightarrow{} 2mA}{\cancel{I_{D2}} \xrightarrow{} 8mA} = \frac{10\cancel{I_s} \exp(V_{D1}/V_T)}{\cancel{I_s} \exp(V_{D2}/V_T)}$$

$$\frac{2}{8} = 10 \exp\left(\frac{V_{D1} - V_{D2}}{V_T}\right)$$

$$\frac{2}{8} = 10 \exp(-V_o/V_T)$$

$$\exp\left(-\frac{V_o}{V_T}\right) = 0.025$$

$$V_o = -\overset{V_T}{(.025)}\ln(.025)$$

$$\boxed{V_o = 92.22\ mV}$$

b) $V_o = 50mV$, what must I_{s2} be changed to?

$$I_{D2} = I_{s1} - I_{s2}$$

$$I_{D1} = I_{s2}$$

$$\frac{I_{D2}}{I_{D1}} = \frac{I_{s1} - I_{s2}}{I_{s2}} = \frac{I_s \exp(V_{D2}/V_T)}{10 I_s \exp(V_{D1}/V_T)}$$

$$\frac{10 - I_{s2}}{I_{s2}} = \frac{1}{10}\exp\left(\frac{V_{D2} - V_{D1}}{V_T}\right)$$

$$V_D = V_{D2} - V_{D1} = 50mV$$

$$\frac{10 - I_{S2}}{I_{S2}} = \frac{1}{10} \exp\left(\frac{50}{25}\right)$$

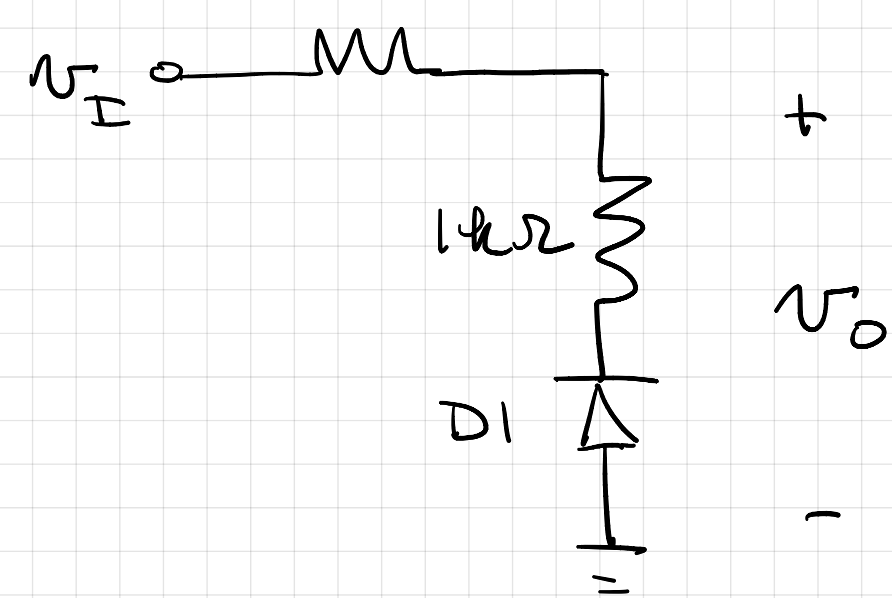
$$\frac{10 - I_{S2}}{I_{S2}} = 0.739$$

$$10 - I_{S2} = 0.739\, I_{S2}$$

$$I_{S2} = 5.75 \text{ mA}$$

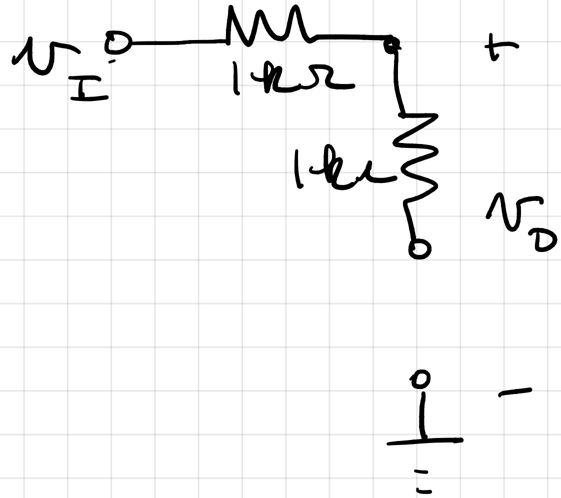
EX 1

Find & plot v_O

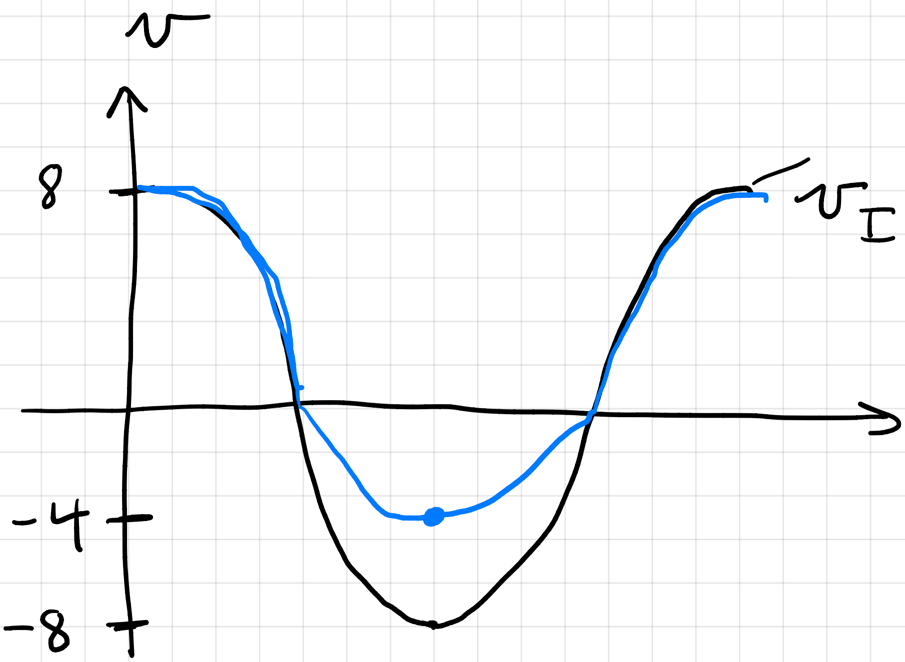


$v_I > 0$

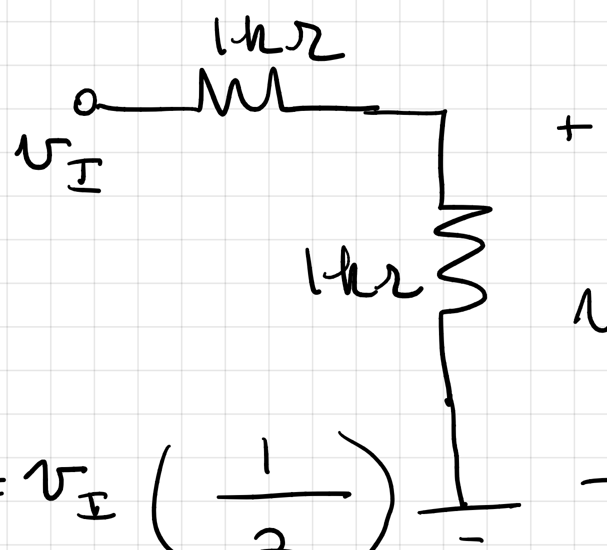
D1 OFF



$v_O = v_I$



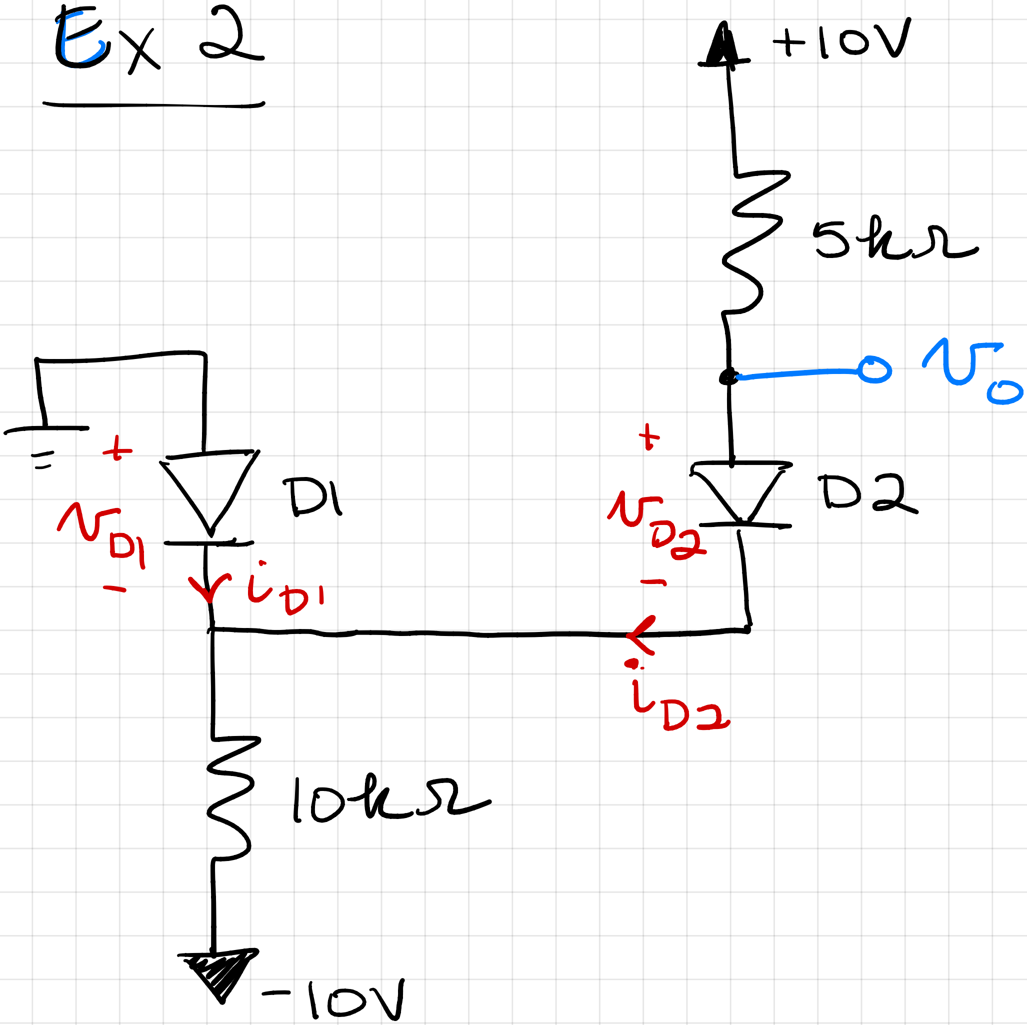
$v_I < 0$



$$v_O = v_I \left(\frac{1}{2} \right)$$

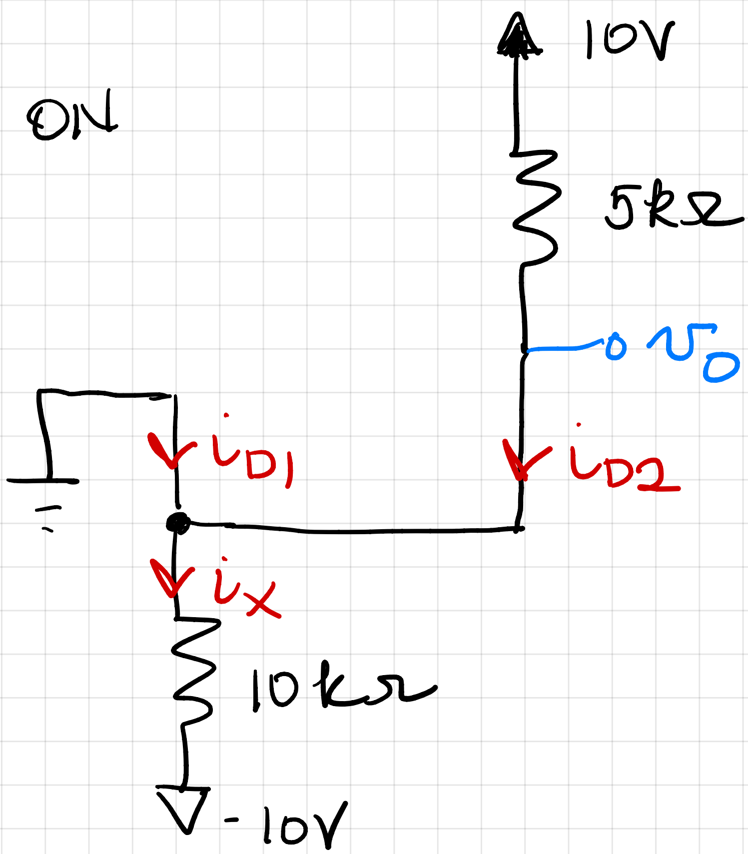
$$v_O = \frac{1}{2} v_I$$

Ex 2



Solve v_o.

Start D_1 & D2 ON



$i_{D1} > 0$, $i_{D2} > 0$

$$i_{D2} = \frac{10 - 0}{5k\Omega}$$

$$\boxed{i_{D2} = 2mA}$$

$$i_x = \frac{0 - (-10)}{10k}$$

$i_x = 1mA$

by KCL

$i_{D1} + i_{D2} = i_x$

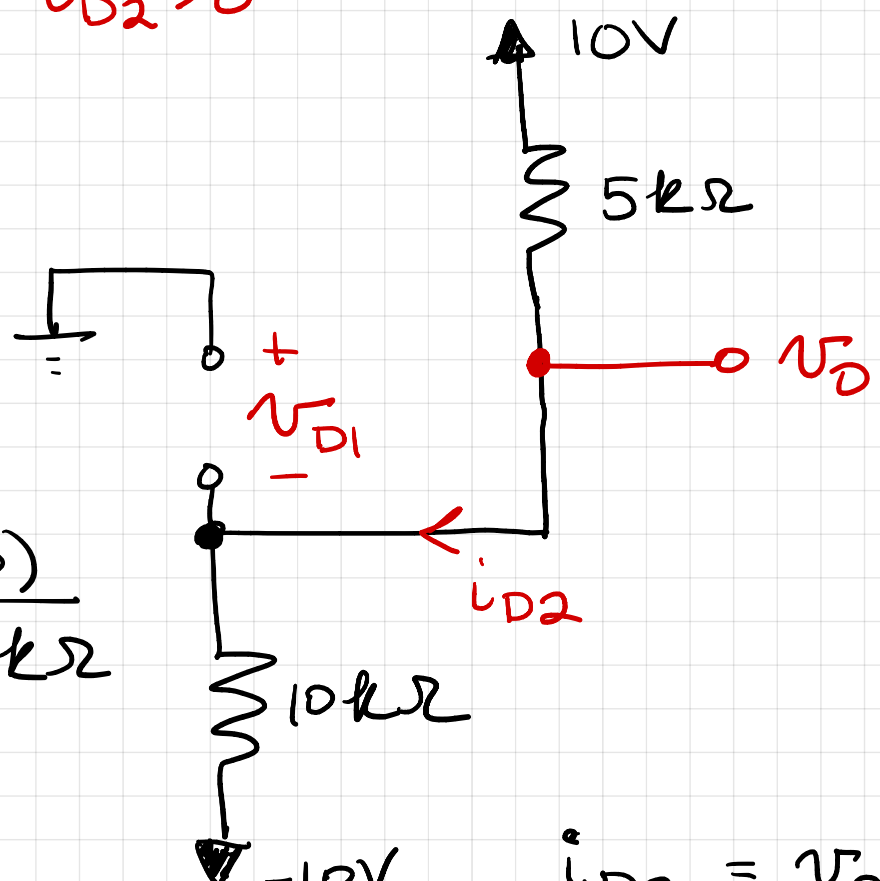
$i_{D1} = i_x - i_{D2}$

$\boxed{i_{D1} = -1mA}$

D1 & D2 are not both on.

D1 OFF & D2 ON

$v_{D1} < 0$ $\quad$ $i_{D2} > 0$



$$i_{D2} = \frac{10-(-10)}{(5+10)k\Omega} = \frac{20}{15\times10^3}$$

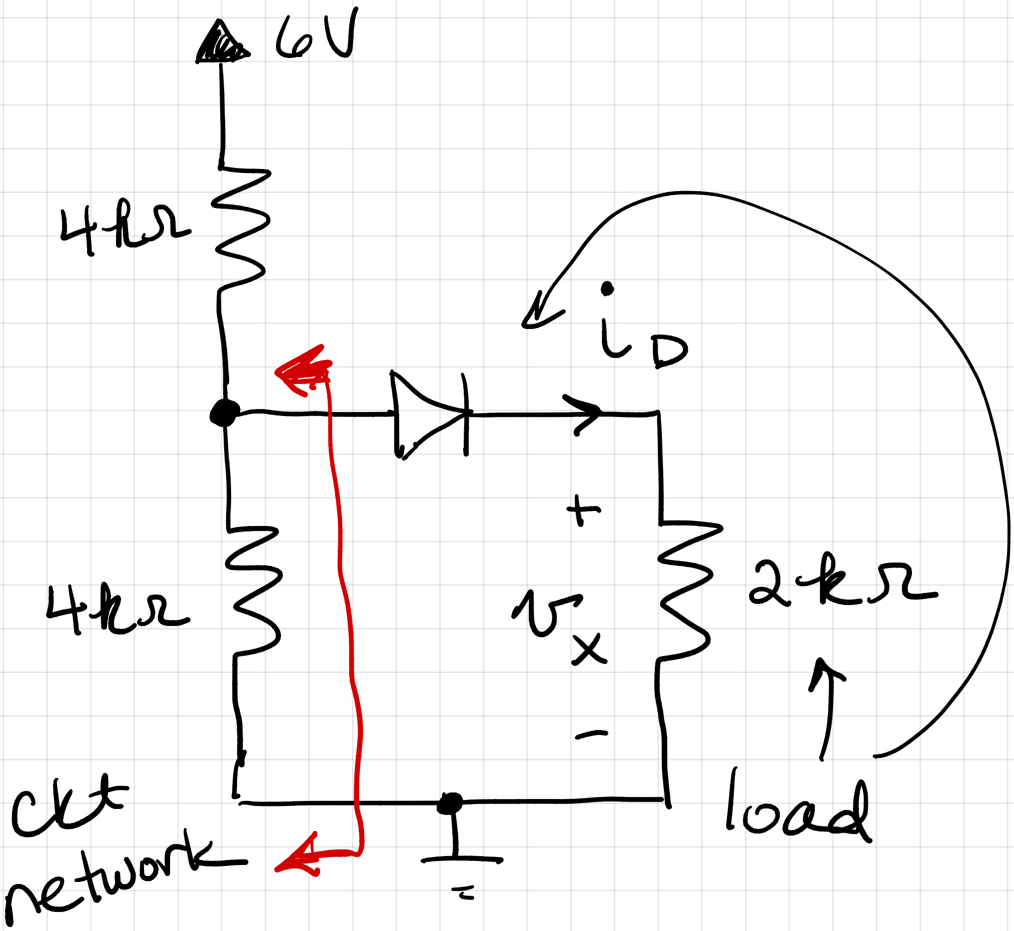
$\boxed{i_{D2} = 1.33mA}$

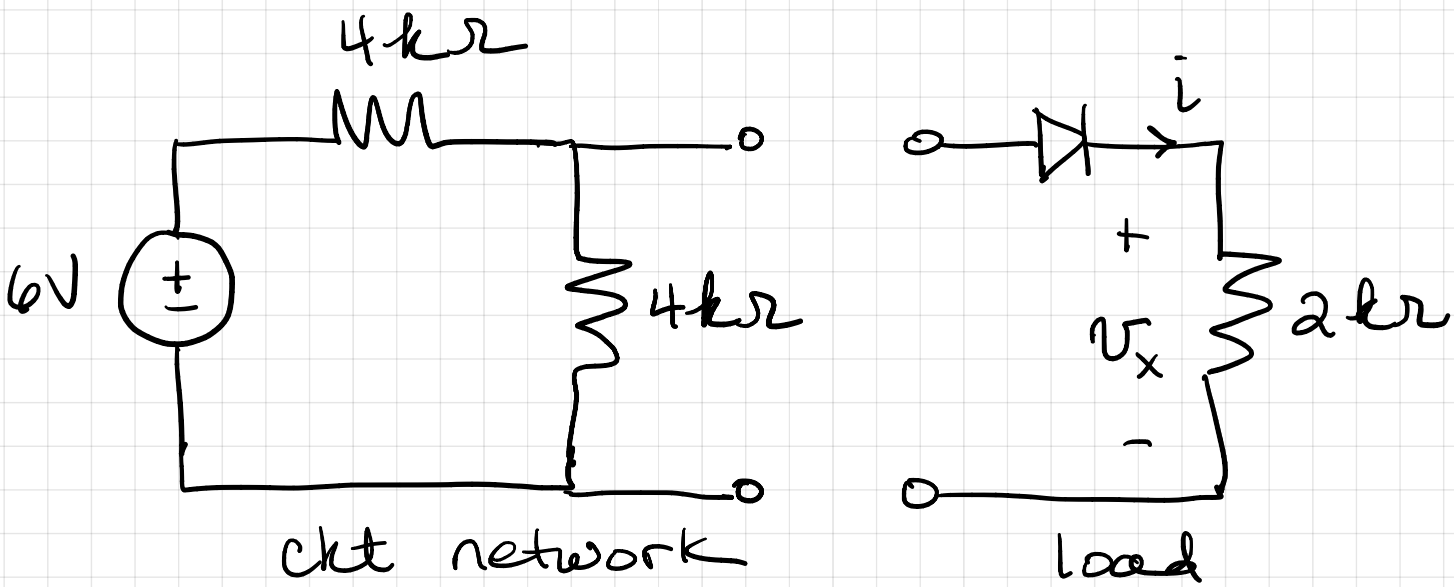
$$i_{D2} = \frac{v_o - (-10)}{10\times10^3} = 1.33mA$$

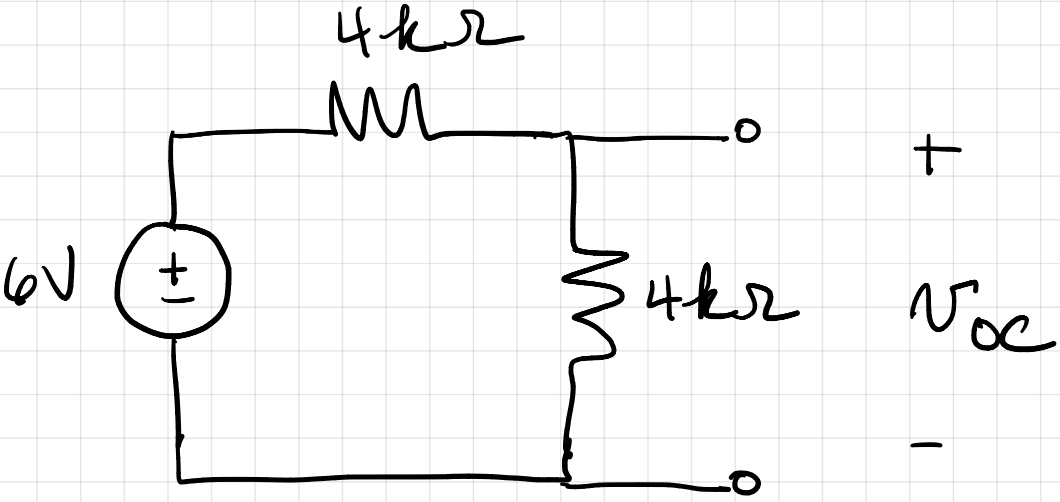
$\boxed{v_o = 3.33V}$

$$v_{D1} = 0 - v_o$$

$$\boxed{v_{D1} = -3.33\text{V}}$$





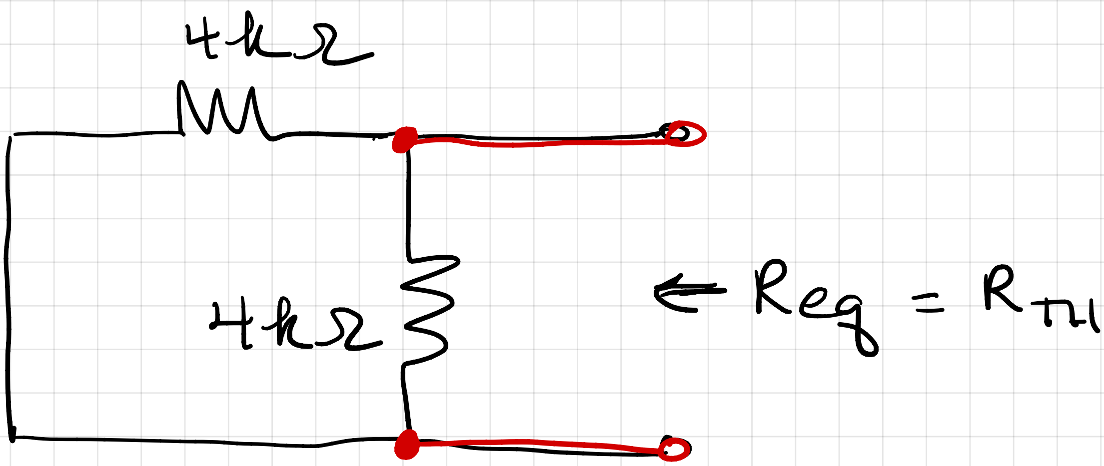


$v_{TH} = v_{oc}$

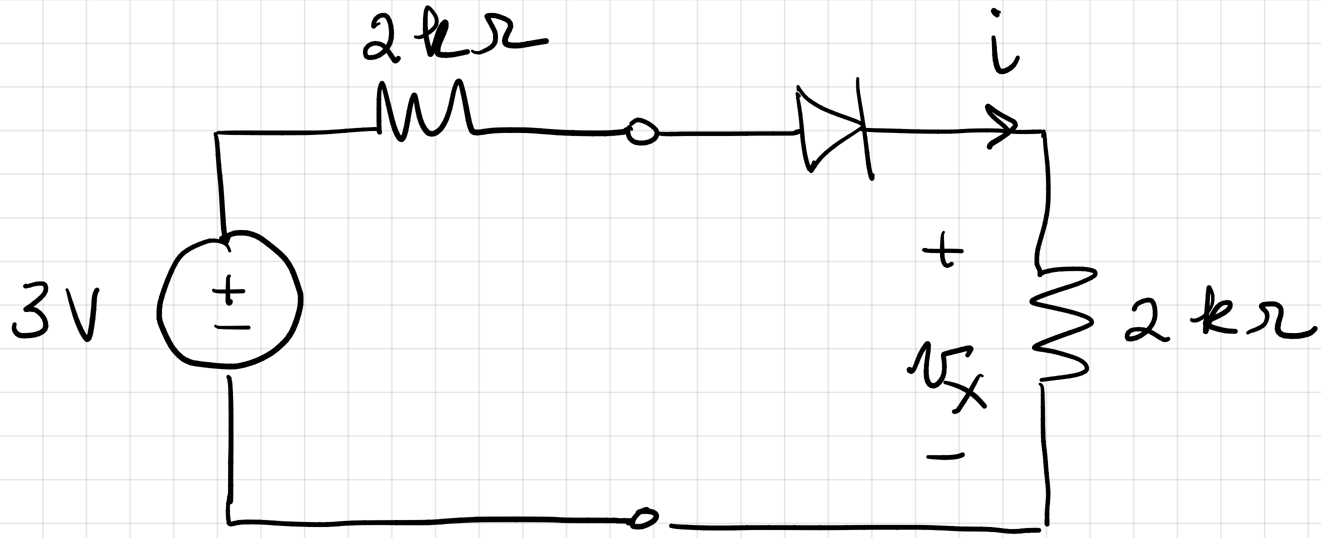
$$v_{oc} = 6\left(\frac{4}{8}\right)$$

$$= 3V$$

$$v_{TH} = 3V$$



$$R_{TH} = (4 \| 4)\,k\Omega = 2\,k\Omega$$



Assume diode is on.

$$v_x = 3\left(\frac{2\times10^3}{4\times10^3}\right)$$

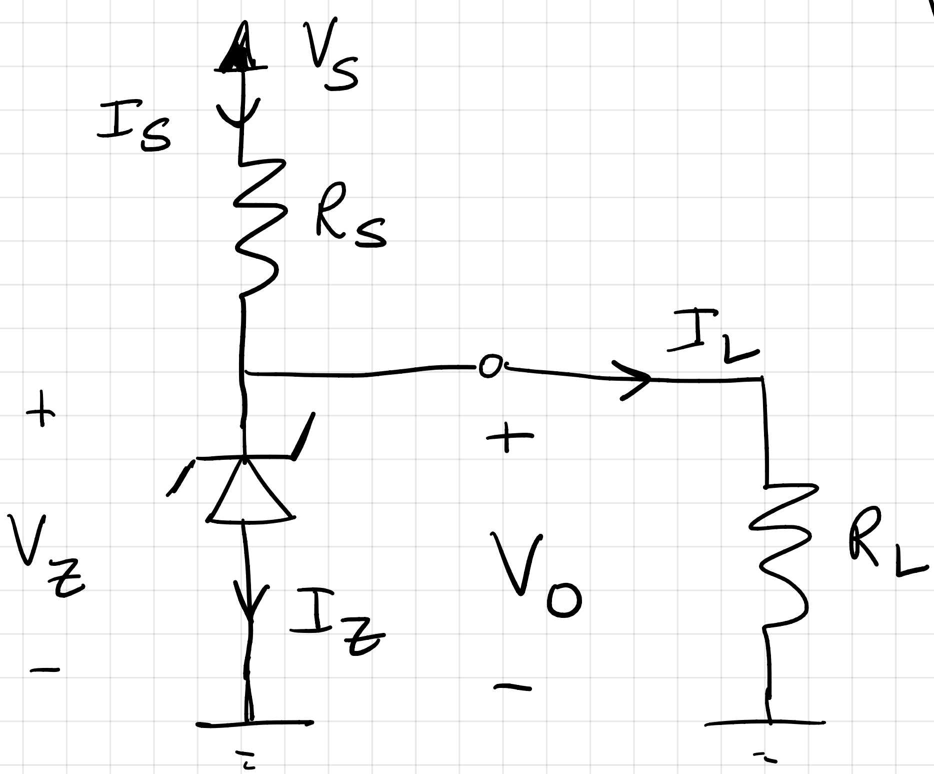
$$\boxed{v_x = 1.5\ \text{V}}$$

$$i_x = \frac{v_x}{2\times10^3}$$

$$i_x = \frac{1.5}{2\times10^3}$$

$$\boxed{i_x = 0.75\ \text{mA}}$$

6.8 V Zener diode Voltage Regulator



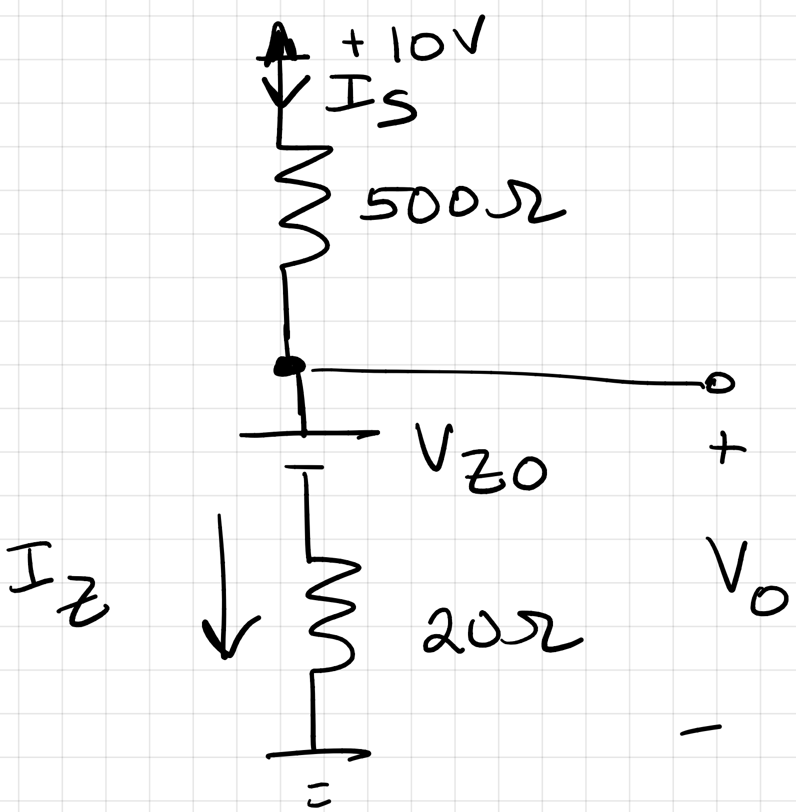
$V_S = 10 \pm 1V$

$R_S = 500\Omega$

$$\boxed{\begin{array}{l} V_Z = 6.8V \\ I_Z = 5mA \end{array}}$$

$r_Z = 20\Omega$

a) Find V_o assume no load $R_L \to \infty$ and V_s is nominal 10V



$V_Z = 6.8V$

$I_Z = 5mA$

$V_{Z0} = V_Z - I_Z r_Z$

$= 6.8 - (5\times10^{-3})(20)$

$V_{Z0} = 6.7V$

$I_Z = \dfrac{10 - V_{Z0}}{500+20}$

$$I_Z = \frac{10 - 6.7}{520} = 6.35\,mA$$

$$V_o = V_{ZO} + 20 I_Z$$
$$= 6.7 + 20(6.35 \times 10^{-3})$$

$$\boxed{V_o = 6.83\,V}$$

b) ΔV_o w/ respect to V_S

$\pm 1V$ change in V_S $\Rightarrow$ ΔV_o

$$\frac{\Delta V_o}{\Delta V_S} = \text{line regulation} \quad \frac{mV}{V}$$

$$I_Z = \frac{V_S - V_{ZO}}{R_S + r_Z}$$

$$V_o = V_{ZO} + I_Z r_Z$$

$$V_o = V_{ZO} + (V_S - V_{ZO})\left(\frac{r_Z}{R + r_Z}\right)$$

ΔV_o as function of ΔV_s

$$\boxed{\Delta V_o = \frac{r_z}{R + r_z}\left(\Delta V_s\right)}$$

$$\frac{\Delta V_o}{\Delta V_s} = \frac{r_z}{R + r_z} = \frac{20}{520} = 38.5 \times 10^{-3}$$

$$= 38.5 \frac{mV}{V}$$ → line regulation

$$\Delta V_o = \left(38.5 \frac{mV}{V}\right)(\pm 1)$$

$$\Delta V_o = \underline{38.5 \, mV}$$ → output voltage change for a given $\pm 1V$

c) Find ΔV_o if we connect a load resistor that draws 1mA away from the zener diode

$I_L = 1mA$

$$\frac{\Delta V_o}{\Delta I_L} = \text{load regulation}$$

$$\frac{\Delta V_O}{\Delta I_L} \Rightarrow \frac{mV}{mA}$$

$$V_O = V_{ZO} + I_Z r_Z$$

$$\Delta V_O = \Delta I_Z (r_Z)$$

$$\boxed{\frac{\Delta V_O}{\Delta I_Z} = r_Z = 20 \frac{mV}{mA}}$$

$$\Delta I_Z = -1mA$$

$$\frac{\Delta V_O}{\Delta I_L} = -20 \frac{mV}{mA}$$

$I_L = 1mA$ $\qquad$ $\Delta V_O = -20mV$

d) ΔV_O for $R_L = 2k\Omega$

$$I_L \cong \frac{6.8}{2000} = 3.4mA$$

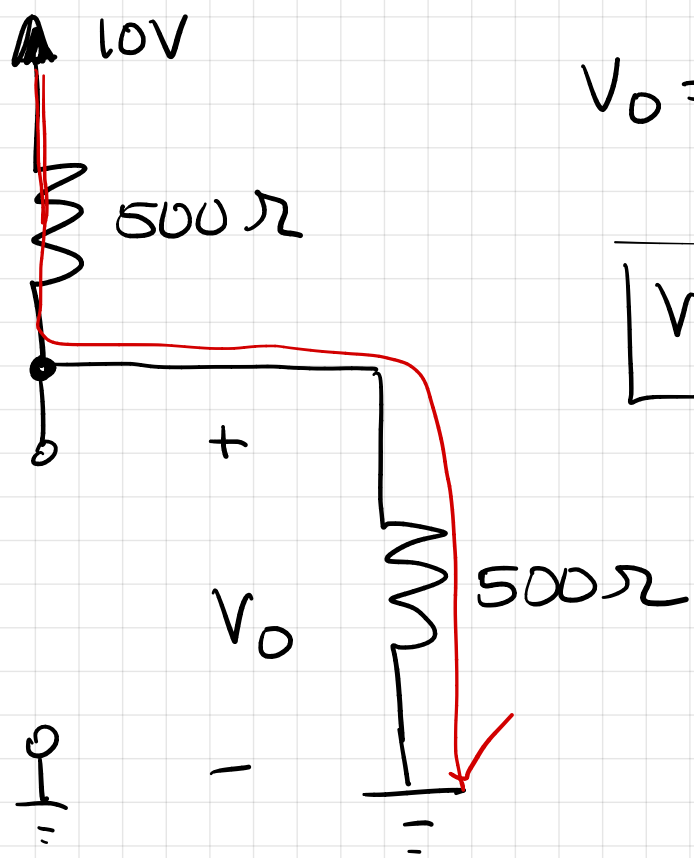
$$\Delta V_O = r_Z \Delta I_Z = -(20)(3.4 \times 10^{-3})$$

$\Delta V_o = -68\,mV$

e) $R_L = 500\,\Omega$

$I_L \cong \frac{6.8}{500} = 13.6\,mA$

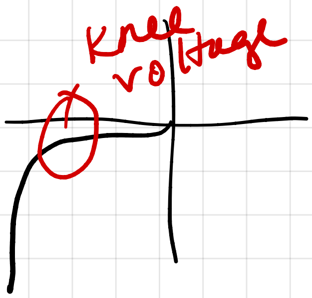
zener diode is no longer in breakdown



$V_o = 10\left(\frac{500}{1000}\right)$

$\boxed{V_o = 5V}$

f) What is the minimum R_L value such that we are on the edge of breakdown.

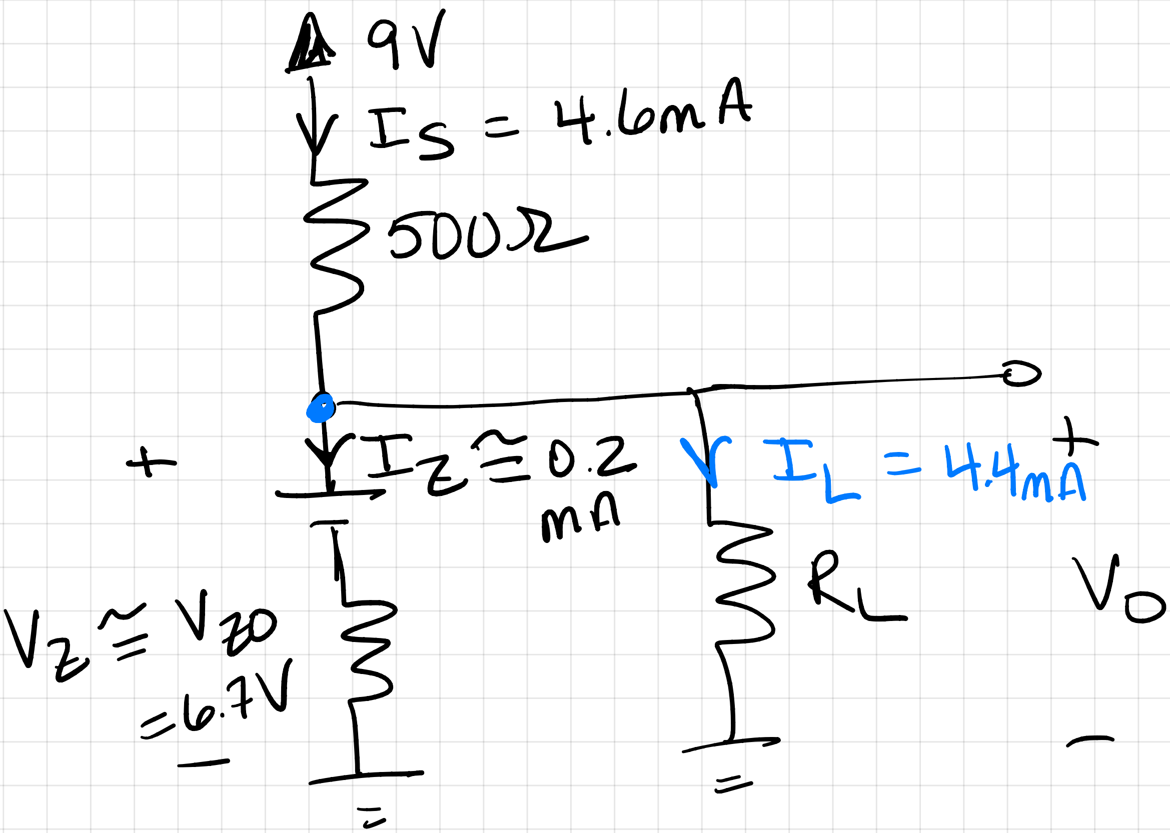


$$I_{ZK} = 0.2mA$$

$$I_Z \cong I_{ZK} = 0.2mA$$

$$V_Z \cong V_{ZO} = 6.7V$$

$$I_S = \frac{9 - 6.7}{500} = 4.6mA$$



$$R_L = \frac{V_Z}{I_L} = \frac{6.7}{4.4 \times 10^{-3}}$$

$$R_L \cong 1.5\ k\Omega$$