(3) Closed-loop gain $= \left(1 + \frac{R_1}{R_2}\right)$

$$= 8$$

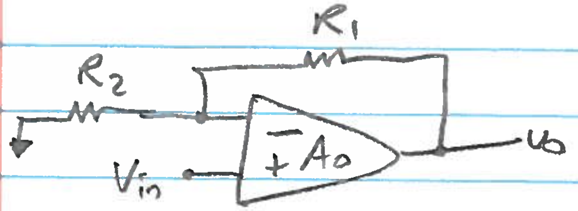
Gain error $= \left(1 + \frac{R_1}{R_2}\right)(A_0)^{-1}$

$$= \frac{8}{2000}$$

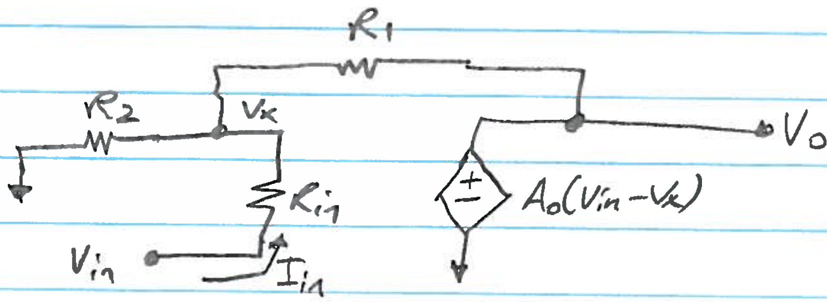
$$= \underline{\underline{0.4\%}}$$

8.7

Non-Inverting Amp



w/ Opamp Model



① KCL @ V_x

$$\frac{V_x}{R_2} + \frac{V_x - V_{in}}{R_{in}} + \frac{V_x - V_o}{R_1} = 0$$

② Use $V_o = A_o(V_{in} - V_x)$

$$V_x = V_{in} - \frac{V_o}{A_o}$$

Plug V_x Eq into ①

$$\frac{V_{in} - \frac{V_o}{A_o}}{R_2} + \frac{V_{in} - \frac{V_o}{A_o} - V_{in}}{R_{in}} + \frac{V_{in} - \frac{V_o}{A_o} - V_o}{R_1} = 0$$

$$V_{in}\left[\frac{1}{R_2} + \frac{1}{R_1}\right] = V_o\left[\frac{1}{A_o R_2} + \frac{1}{A_o R_{in}} + \frac{\frac{1}{A_o}+1}{R_1}\right]$$

$$\frac{V_o}{V_{in}} = \frac{\frac{1}{R_1} + \frac{1}{R_2}}{\frac{1}{A_oR_2} + \frac{1}{A_oR_{in}} + \frac{\frac{1}{A_o} + 1}{R_1}}$$

$$\boxed{\frac{V_o}{V_{in}} = \frac{1 + \frac{R_1}{R_2}}{\frac{R_1}{A_oR_2} + \frac{R_1}{A_oR_{in}} + \frac{1}{A_o} + 1}}$$

As $A_o \to \infty$

$$\frac{V_o}{V_{in}} = 1 + \frac{R_1}{R_2}$$

$$\text{Input Resistance} = \frac{V_{in}}{I_{in}}$$

$$I_{in} = \frac{V_{in} - V_x}{R_{in}} = \frac{V_{in} - \left(V_{in} - \frac{V_o}{A_o}\right)}{R_{in}} = \frac{V_o}{A_o R_{in}}$$

$$\text{Input Resistance} = \frac{V_{in}}{I_{in}} = A_o R_{in} \left(\frac{V_o}{V_{in}}\right)^{-1}$$

where $\frac{V_o}{V_{in}}$ is given above.

as $A_o \to \infty$

$$\text{Input Resistance} = \infty$$

Scanned with CamScanner

(11) if $A_0 = \infty$,

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

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

$\therefore$ closed-loop gain $\dfrac{V_{out}}{V_{in}}$

$$= \frac{(R_2+R_3)\,[R_1 + R_4 // (R_2+R_3)]}{R_2\,[R_4 // (R_2+R_3)]}$$

if $R_1 = 0$,

$$G|_{R_1=0} = 1 + \frac{R_3}{R_2}$$

if $R_3 = 0$,

$$G|_{R_3=0} = \frac{R_2\,[R_1 + R_4 // R_2]}{R_2\,[R_4 // R_2]}$$

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

(12) Gain Error $= \frac{1}{A_o}\left(1 + \frac{R_1}{R_2}\right)$

$= \frac{1}{A_o}(1+8)$

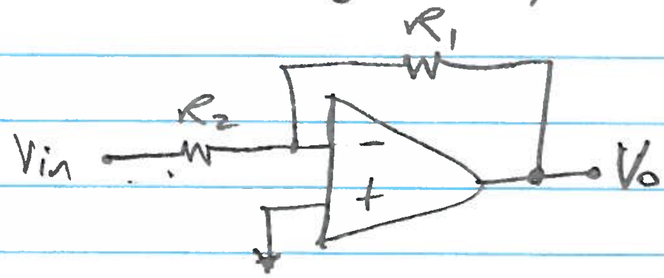
$= 0.2\%$

$\therefore \frac{1}{A_o}(9) = 0.2\%$

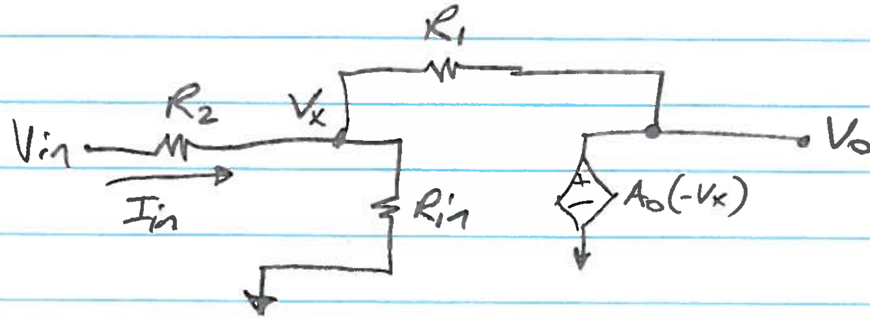
$A_o = 4500$

8.13

Inverting Amp



W/ OpAmp Model



① KCL @ Vx

$$\frac{V_x - V_{in}}{R_2} + \frac{V_x}{R_{in}} + \frac{V_x - V_o}{R_1} = 0$$

② Use $V_o = -A_o V_x$

$$V_x = -\frac{V_o}{A_o}$$

Plug Vx Eq into ①

$$\frac{-\frac{V_o}{A_o} - V_{in}}{R_2} - \frac{\frac{V_o}{A_o}}{R_{in}} + \frac{-\frac{V_o}{A_o} - V_o}{R_1} = 0$$

$$V_{in}\left[\frac{1}{R_2}\right] = -V_o\left[\frac{1}{A_o R_2} + \frac{1}{A_o R_{in}} + \frac{\frac{1}{A_o}+1}{R_1}\right]$$

$$\frac{V_o}{V_{in}} = -\frac{\frac{1}{R_2}}{\frac{1}{A_o R_2} + \frac{1}{A_o R_{in}} + \frac{\frac{1}{A_o}+1}{R_1}}$$

$$\boxed{\frac{V_o}{V_{in}} = \frac{\left(-\frac{R_1}{R_2}\right)}{\frac{R_1}{A_o R_2} + \frac{R_1}{A_o R_{in}} + \frac{1}{A_o} + 1}}$$

$$\text{Input Resistance} = \frac{V_{in}}{I_{in}}$$

$$I_{in} = \frac{V_{in} - V_x}{R_2} = \frac{V_{in} - \left(-\frac{V_o}{A_o}\right)}{R_2} = \frac{V_{in} + \frac{V_o}{A_o}}{R_2}$$

$$\text{Input Resistance} = \frac{V_{in} R_2}{V_{in} + \frac{V_o}{A_o}} = \frac{R_2}{1 + \left(\frac{V_o}{V_{in}}\right)\left(\frac{1}{A_o}\right)}$$

$$\text{Input Resistance} = \frac{R_2}{1 + \left(\frac{V_o}{V_{in}}\right)\left(\frac{1}{A_o}\right)}$$

where $\frac{V_o}{V_{in}}$ is given above.

(31) By KCL,

$$\frac{V_1 - V_x}{R_1} + \frac{V_2 - V_x}{R_2} = -\frac{V_{out} - V_x}{R_F}.$$

$$\because \quad V_{out} = -A_o V_x$$

$$V_x = -\frac{V_{out}}{A_o},$$

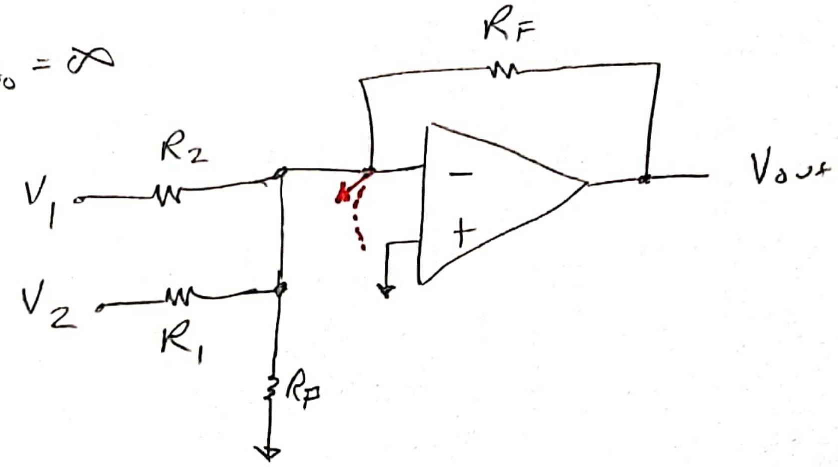
$$\left(\frac{V_1}{R_1} + \frac{V_2}{R_2}\right) + \frac{V_{out}}{A_o}\left(\frac{1}{R_2} + \frac{1}{R_1} + \frac{1}{R_F}\right) = -\frac{V_{out}}{R_F}$$

$$-\left(\frac{V_1}{R_1} + \frac{V_2}{R_2}\right) = V_{out}\left[\frac{1}{R_F} + \frac{1}{A_o}\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_F}\right)\right]$$

$$\therefore \quad V_{out} = -\left(\frac{1}{R_F} + \frac{1}{A_o}\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_F}\right)\right)^{-1} \times \left(\frac{V_1}{R_1} + \frac{V_2}{R_2}\right)$$

8.33

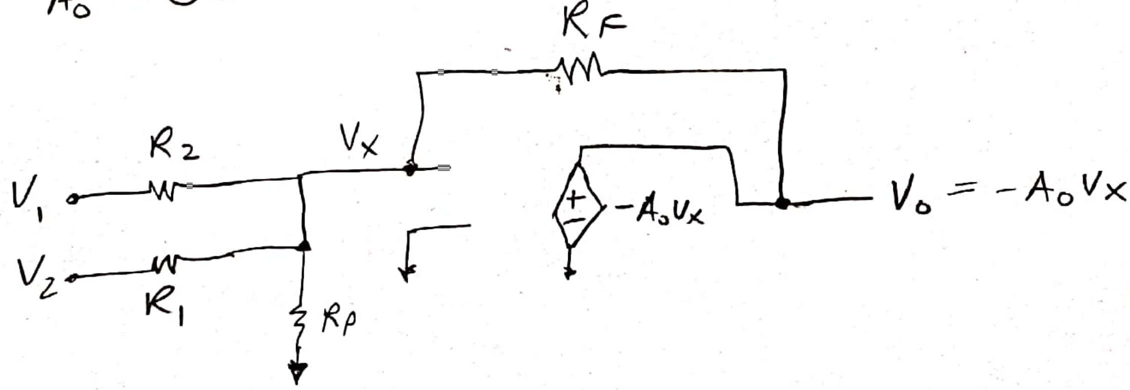
For $A_o = \infty$



Using Superposition

$$V_{out} = -\frac{R_F}{R_2}V_1 - \frac{R_F}{R_1}V_2$$

If $A_o < \infty$



KCL at V_x

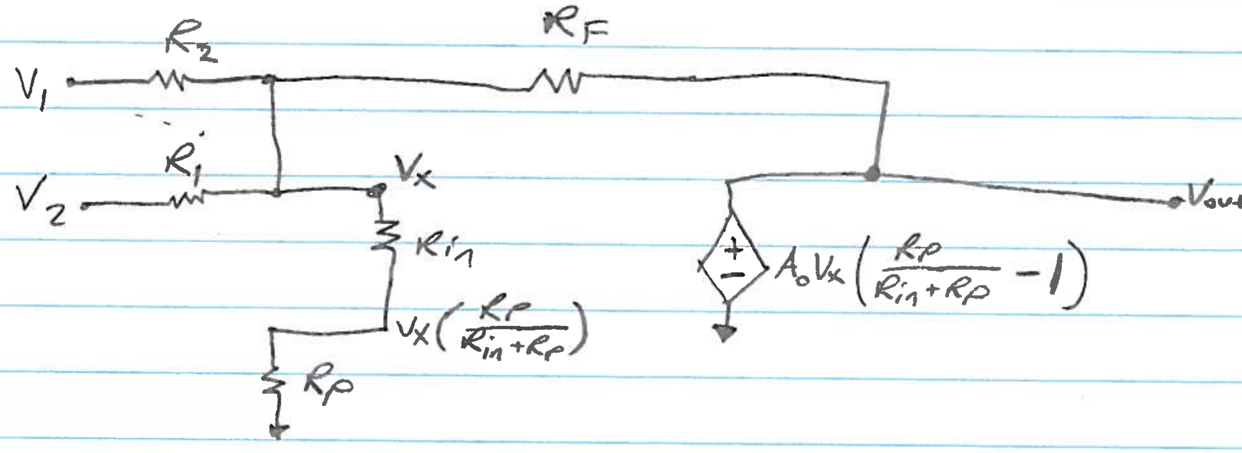
$$\frac{V_x - V_1}{R_2} + \frac{V_x - V_2}{R_1} + \frac{V_x}{R_p} + \frac{V_x(1+A_o)}{R_F} = 0$$

$$V_x\left[\frac{1}{R_2} + \frac{1}{R_1} + \frac{1}{R_p} + \frac{1+A_o}{R_F}\right] = \frac{V_1}{R_2} + \frac{V_2}{R_1}$$

$$V_x = \left[\frac{V_1}{R_2} + \frac{V_2}{R_1}\right]\left[\frac{1}{R_2} + \frac{1}{R_1} + \frac{1}{R_p} + \frac{1+A_o}{R_F}\right]^{-1}$$

$$V_o = -A_oV_x = -A_o\left[\frac{V_1}{R_2} + \frac{V_2}{R_1}\right]\left[\frac{1}{R_2} + \frac{1}{R_1} + \frac{1}{R_p} + \frac{1+A_o}{R_F}\right]^{-1}$$

8.34



Vout Equation

$$V_{out} = A_o V_x\left(\frac{R_p}{R_{in}+R_p}-1\right) = A_o V_x\left(\frac{-R_{in}}{R_{in}+R_p}\right)$$

$$V_x = -\frac{V_{out}}{A_o}\left(\frac{R_{in}+R_p}{R_{in}}\right)$$

KCL @ Vx

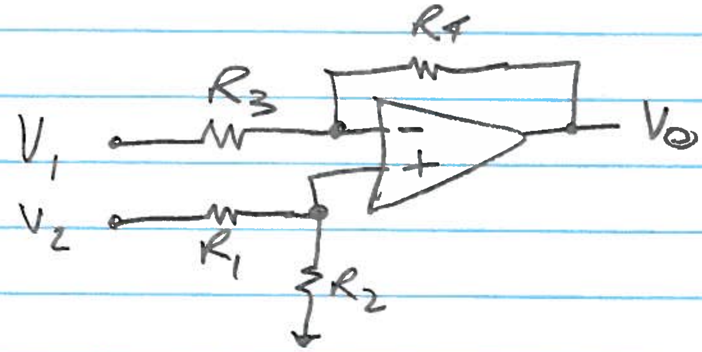
$$\frac{-\frac{V_{out}}{A_o}\left(\frac{R_{in}+R_p}{R_{in}}\right)-V_1}{R_2} + \frac{-\frac{V_{out}}{A_o}\left(\frac{R_{in}+R_p}{R_{in}}\right)-V_2}{R_1}$$

$$+\frac{-\frac{V_{out}}{A_o}\left(\frac{R_{in}+R_p}{R_{in}}\right)-V_{out}}{R_F} + \frac{-\frac{V_{out}}{A_o}\left(\frac{R_{in}+R_p}{R_{in}}\right)}{R_{in}+R_p} = 0$$

$$V_{out}\left[\frac{R_{in}+R_p}{A_o R_{in}}\left[\frac{1}{R_2}+\frac{1}{R_1}+\frac{1}{R_F}+\frac{1}{R_{in}+R_p}\right]+\frac{1}{R_F}\right] = -\frac{V_1}{R_2}-\frac{V_2}{R_1}$$

$$\boxed{V_{out} = \frac{-\frac{V_1}{R_2}-\frac{V_2}{R_1}}{\frac{R_{in}+R_p}{A_o R_{in}}\left[\frac{1}{R_2}+\frac{1}{R_1}+\frac{1}{R_F}+\frac{1}{R_{in}+R_p}\right]+\frac{1}{R_F}}}$$

1. $V_o = -4V_1 + 3V_2$



$$V_o = -\frac{R_4}{R_3}V_1 + \left(1+\frac{R_4}{R_3}\right)\left(\frac{R_2}{R_1+R_2}\right)V_2$$

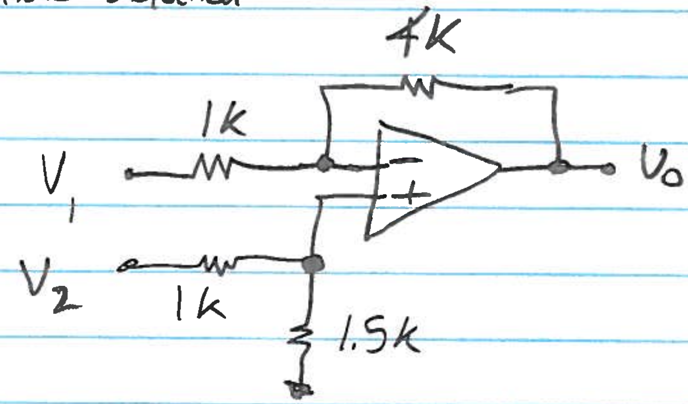
For $-4V_1 \Rightarrow R_4 = 4R_3$

For $3V_2 \Rightarrow \left(1+\frac{4R_3}{R_3}\right)\left(\frac{R_2}{R_1+R_2}\right) = 3$

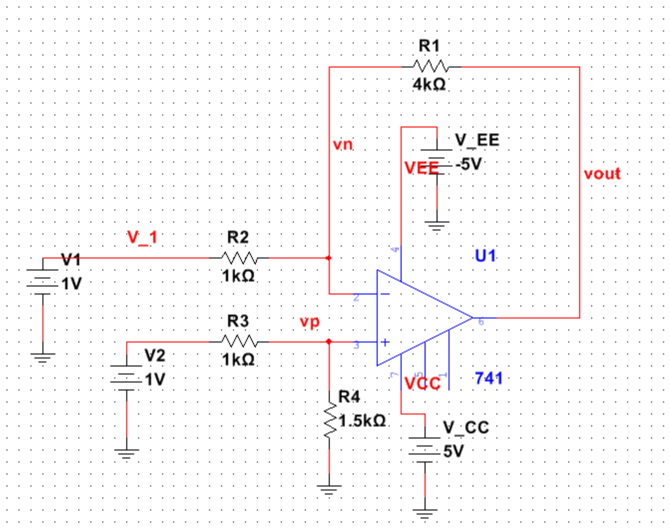
$$\frac{R_2}{R_1+R_2} = \frac{3}{5}$$

$$R_2 = \frac{3}{2}R_1$$

Possible Solution



Multisim Schematic



Set V2=1V and Sweep V1 from -0.5V to 0.5V. Notice that when V1=0, Vout=3V and the curve has a slope of -4V/V over the opamp's linear output range. Also notice that the opamp saturates at 4.1V, which is below the 5V positive power supply.