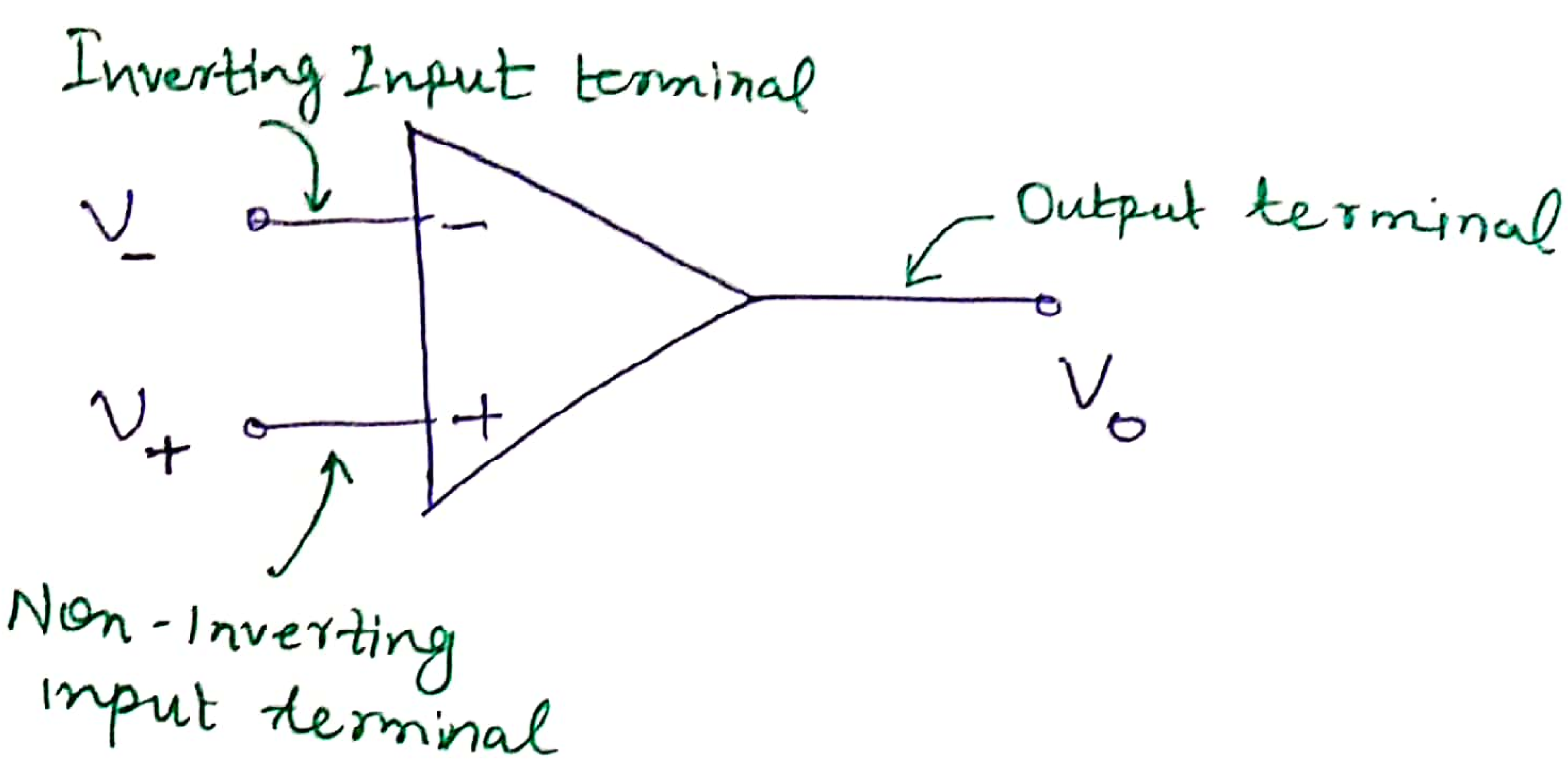
OPERATIONAL AMPLIFIERS (OPAMP):



* Opamp charactoristic Equation;

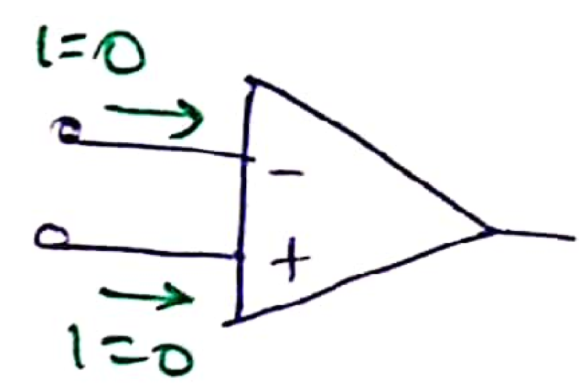
$$V_o = A(V_+ - V_-)$$

where A is known as <u>open loop gain</u> of the opamp.

* The opamp amplify the difference of two input signal therefore it is also known as differential-input, single-ended output amplifier.

* <u>Ideal Opamp Charactoristics</u>:

(1) Infinite input Impedance
  - Signal current into input terminals are zero.



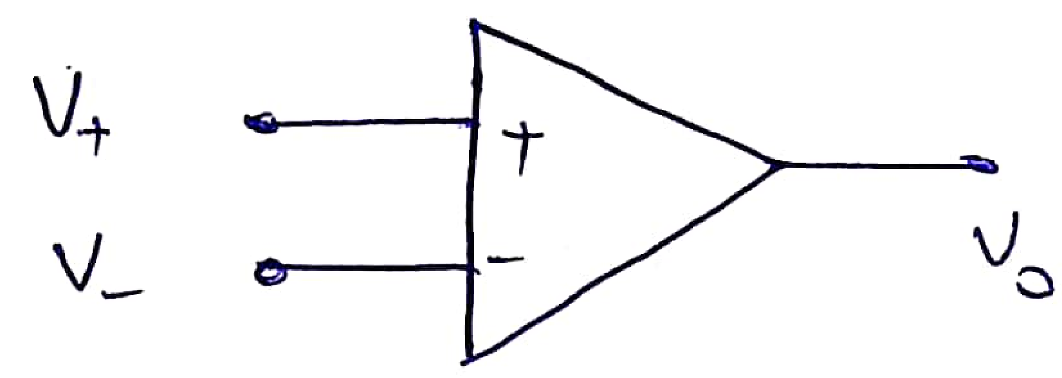
(2) Zero Output Impedance

(3) Common-mode gain is zero
  ie ~~gain is zero or~~ output is zero when same input is applied at both terminals

(4) Open loop gain (A) is infinite

(5) ~~Ban~~: Gain Bandwidth is infinite
  ie Gain remains constant upto infinite frequency

Concept of Virtual Short circuit (VSC) and Virtual Ground (VG)



~~Sin~~ $V_o = A(V_+ - V_-)$

or $V_+ - V_- = \frac{V_o}{A}$

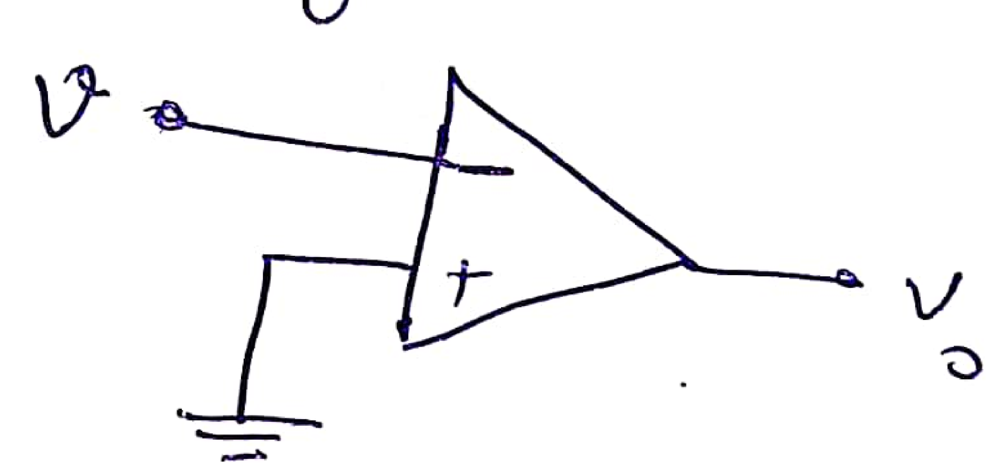
As $A \to \infty$, $\frac{V_o}{A} \to 0$

$V_+ - V_- \cong 0$

$$\boxed{V_+ \cong V_-}$$

ie. Voltage applied at one terminal will appear at another input terminal as if they are shorted. This is known as Virtual Short Circuit (VSC)

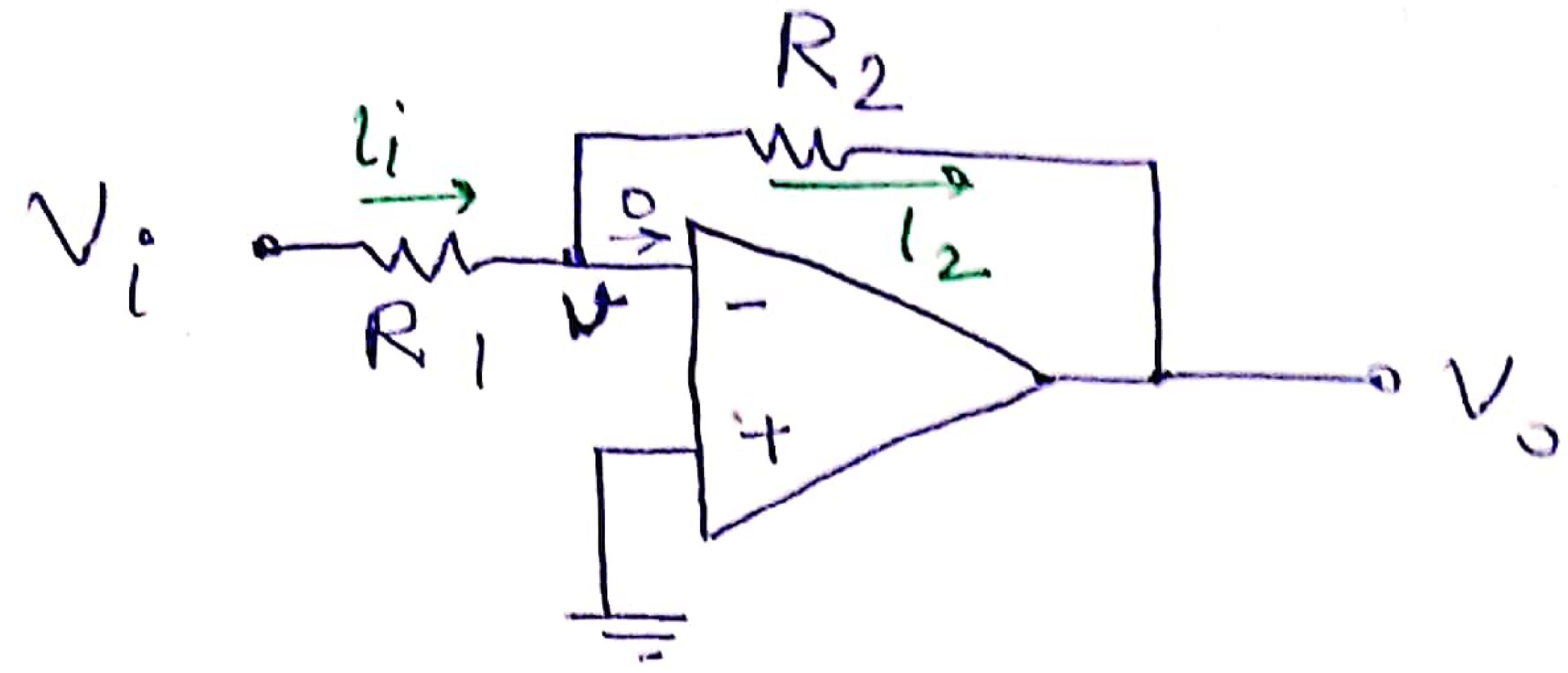
Suppose one of the terminal is grounded



then $\boxed{V = 0}$ 0V will also appear at another terminal

This is known as virtual ground (VG)

Inverting Amplifier Configuration



⇒ Resistor R_2 is connected as a feed back b/w output & enverting enput terminal, this is called as negative feedback.

⇒ The overall gain $\left(G = \frac{V_o}{V_i}\right)$ is known as Close-loop gain,

Due to virtual ground, voltage at inverting enput terminal, $V = 0$

we can write, $i_1 = i_2$

$$\frac{V_i - 0}{R_1} = \frac{0 - V_o}{R_2}$$

$$\boxed{\frac{V_o}{V_i} = -\frac{R_2}{R_1}} \quad \text{——— (1)}$$

⇒ For designing an inverting Amplifier with gain = -10

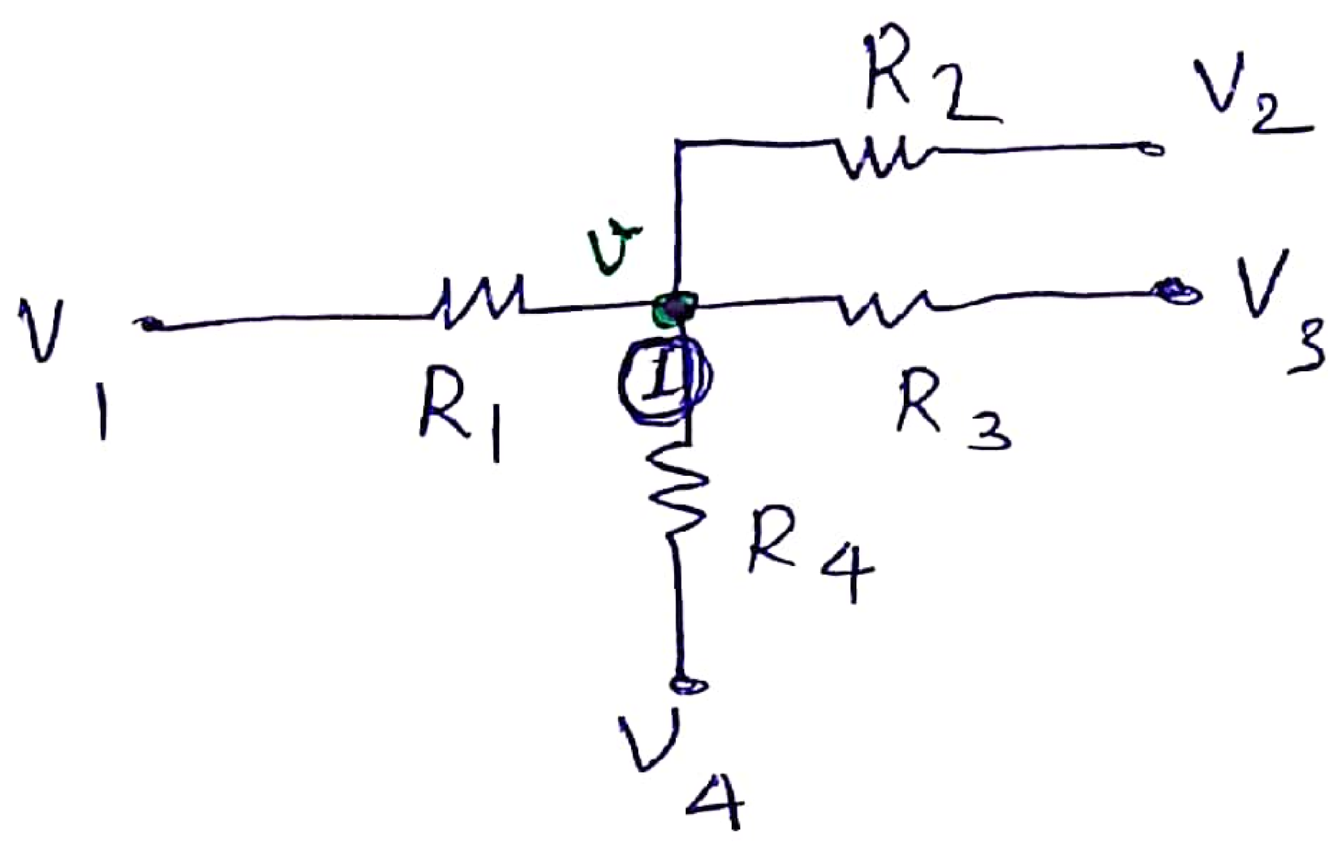
E.g., we select, ~~$R_1 = 1\,M\Omega$~~ $R_1 = 100\,K\Omega$

then $R_2 = 10 R_1 = 1\,M\Omega$

Remark: From (1), R_1 should be small for high gain,
⇒ But we can not take much smaller R_1 as it will make enput impedance low, which should be very high for voltage amplifier.

Opamp circuit Analysis using Nodal equation

- Writing a nodal equation, greatly simplify the opamp circuit analysis, which is a modified version of KCL.



We wish to write nodal equation at node 1, the voltage at which is v.

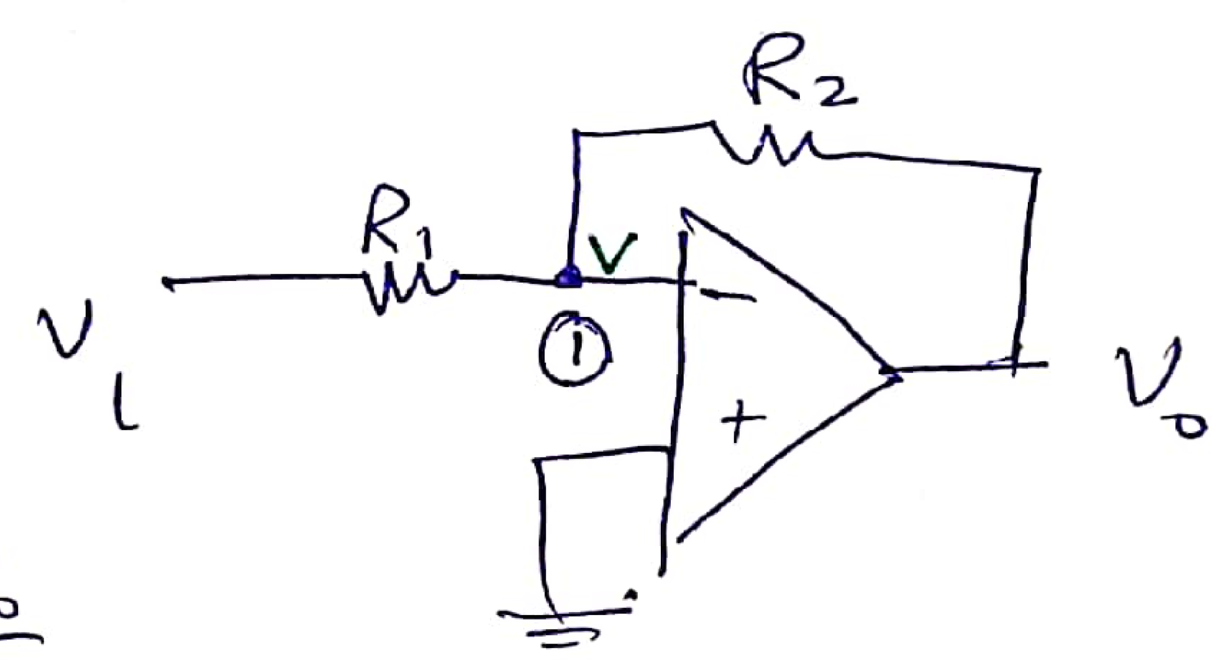
Nodal Eqn.

$$\boxed{\text{Voltage of the node} \times (\text{Sum of all the conductance connected to this node}) = \Sigma(\text{node voltage} \times \text{conductance})}$$

Eg. Nodal eq at 1 [Conductance $= \frac{1}{\text{Resistance}}$]

$$v\left(\frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_3}+\frac{1}{R_4}\right) = \frac{V_1}{R_1}+\frac{V_2}{R_2}+\frac{V_3}{R_3}+\frac{V_4}{R_4}$$

We use nodal equation to analyse inverting amp gain



~~due to~~ writing nodal eqn at 1

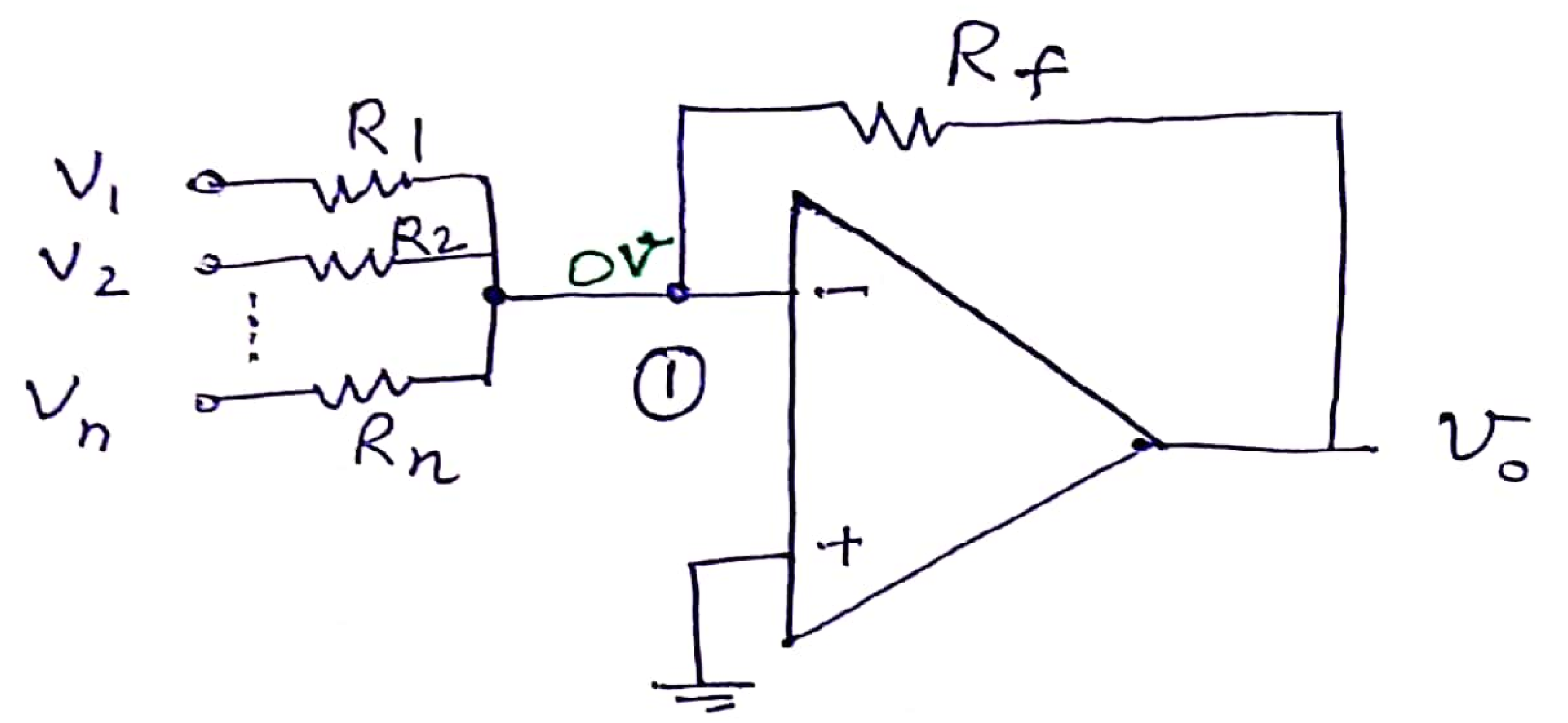
$$v\left(\frac{1}{R_1}+\frac{1}{R_2}\right) = \frac{V_i}{R_1} + \frac{V_o}{R_2}$$

But $v = 0$ due to V.G.

$$\Rightarrow \frac{V_i}{R_1} + \frac{V_o}{R_2} = 0 \Rightarrow \boxed{\frac{V_o}{V_i} = -\frac{R_2}{R_1}}$$

Voltage Summer / Adder

- An important application of inverting configuration



Writing nodal eqn at 1

$$0 \times \left(\frac{1}{R_1} + \frac{1}{R_2} + \dots + \frac{1}{R_n} + \frac{1}{R_f} \right) = \frac{V_1}{R_1} + \frac{V_2}{R_2} + \dots + \frac{V_n}{R_n} + \frac{V_o}{R_f}$$

$$\Rightarrow \quad \frac{-V_o}{R_f} = \frac{V_1}{R_1} + \frac{V_2}{R_2} + \dots + \frac{V_n}{R_n}$$

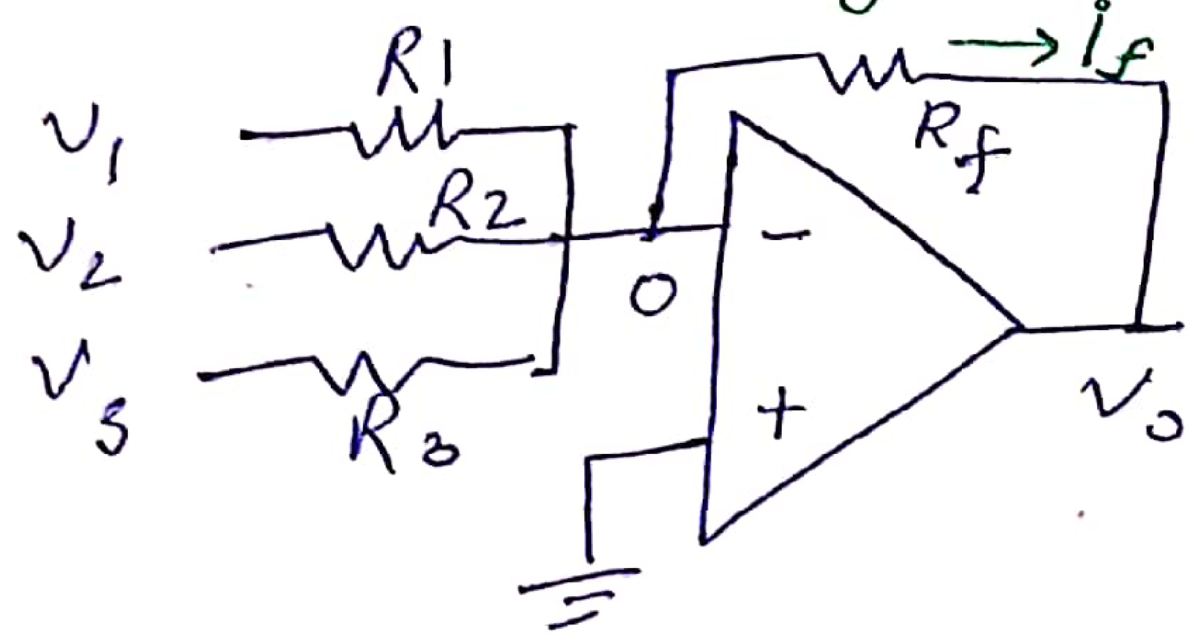
$$V_o = -\left(\frac{R_f}{R_1} V_1 + \frac{R_f}{R_2} V_2 + \dots + \frac{R_f}{R_n} V_n \right)$$

$$\boxed{V_o = -(K_1 V_1 + K_2 V_2 + \dots + K_n V_n)}$$

where $K_1 = \frac{R_f}{R_1}$, $K_2 = \frac{R_f}{R_2}$, ...

The output voltage V_o is a weighted sum of all the input voltages

Ex Design a weighted summer such that $V_o = V_1 + 2V_2 + V_3$



$$V_o = -\left(\frac{R_f}{R_1} V_1 + \frac{R_f}{R_2} V_2 + \frac{R_f}{R_3} V_3 \right)$$

$K_1 = 1 \qquad K_2 = 2 \qquad K_3 = 1$

$\frac{R_f}{R_1} = 1 \qquad \frac{R_f}{R_2} = 2, \qquad \frac{R_f}{R_3} = 1$

R_f is common, ~~let~~ Assume $R_f = 10\,K\Omega$

$\Rightarrow \boxed{R_1 = R_f = 10K}$, $\boxed{R_2 = \frac{R_f}{2} = 5\,K\Omega}$, $\boxed{R_3 = R_f = 1K}$

If we wish to obtain, $v_o = v_1 + 2v_2 - v_3$,
then we can not use this circuit as it can only implement positive k.

Some conditions may be imposed on selecting R_f (otherwise we are free to choose a reasonable value).
eg. In the prev. example ~~that~~ if it is required that the current through R_f should not be exceed 2 mA for a maximum output voltage of 10 V.

Let current through R_f be i_f

then $v_o = i_f R_f$

$\Rightarrow R_{f_{min}} = V_o / i_{f_{max}}$

$R_{f_{min}} = \frac{10v}{2mA} = 5\ K\Omega$

$\boxed{\cancel{10V = 2mA \times R_f} \\ \cancel{R_f = 5\ K\Omega}}$

$\because$ Any lower value of R_f will make i_f higher than 2 mA