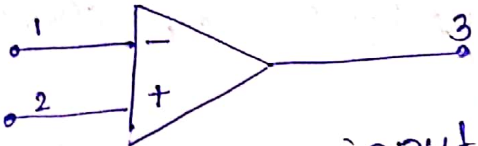
OP-AMP

An OP-AMP (Operational Amplifier) is a circuit element designed to perform mathematical operations like addition, subtraction, multiplication, division, differentiation, integration, etc.

The ability to do such mathematical operation along with amplification of AC as well as dc signal, made it to be known as operational amplifier or OP-Amp.

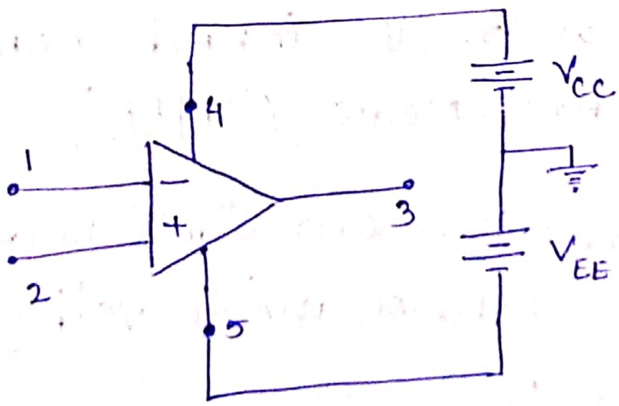
Symbol of Opamp



1 & 2 are input terminals

1 → −ve terminal or inverting input terminal.

2 → +ve terminal or non-inverting input termial.



Most IC OPamps require two dc power supplies. So two terminals 4 & 5 may be there in the IC package which are connected to $+V_{cc}$ & $-V_{EE}$ respectively.

Characteristics of Ideal Op-Amp :-

1. Opamp is designed to amplify the difference between voltage signals applied at its two input terminals $(V_2 - V_1)$

$$V_0 \propto (V_2 - V_1)$$

or $\boxed{V_0 = A(V_2 - V_1)}$ where,

$A \rightarrow$ differential gain or open loop gain

$V_1 \rightarrow$ voltage at terminal 1

$V_2 \rightarrow$ voltage at terminal 2

2. The input impedance of ideal op-amp is infinite.

In other words, ideal opamp doesn't draw any input current.

3. The output impedance of ideal op-amp is zero.

4. Ideal Opamp has infinite common mode rejection ratio (CMRR)

CMRR :- Ratio between differential voltage gain to common mode voltage gain.

$$\boxed{CMRR = \frac{A_d}{A_c}}$$

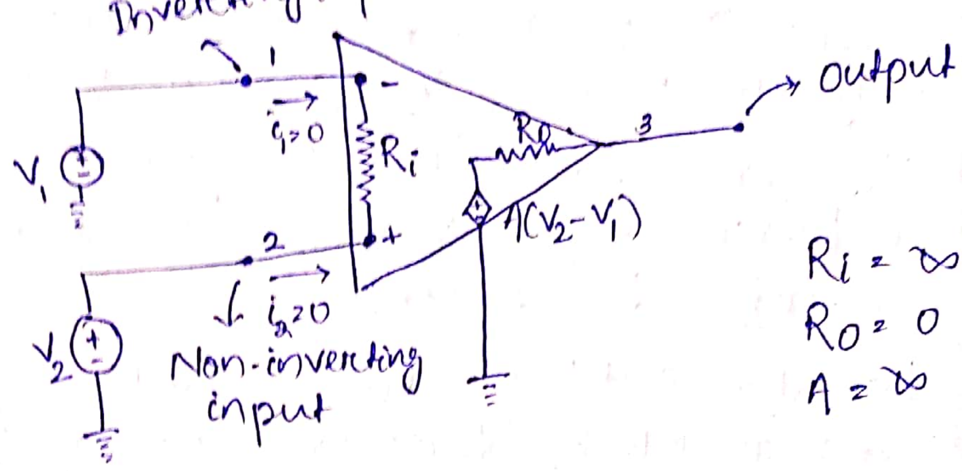
5. Ideal opamp will amplify signals of any frequency with equal gain and thus are said to have infinite bandwidth.

6. Ideal opamp has infinite gain.
7. Ideal opamp has infinite slew rate.

Slew Rate :- The measure of how fast the output voltage can change w.r.t. time.

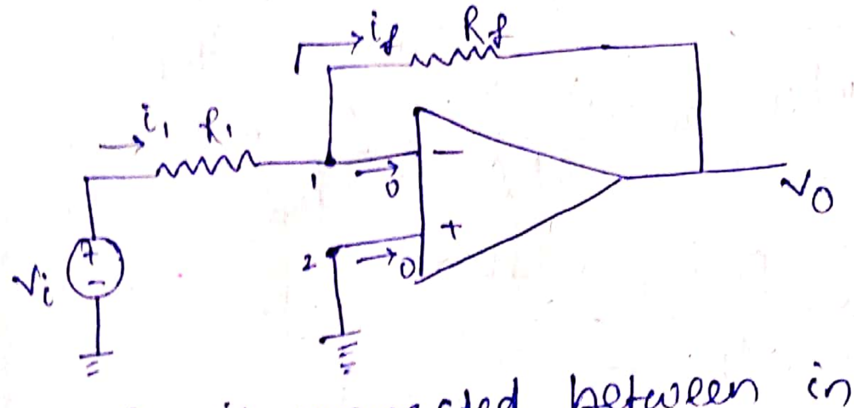
$S.R = \frac{\Delta V_0}{\Delta t}$ unit :- volt/microsecond.

Equivalent Circuit of ideal op-amp



$R_i = \infty$
$R_O = 0$
$A = \infty$

Inverting Op-amp



R_1 is connected between inverting terminal and an input signal source with voltage V_i.

R_f is connected between output terminal of opamp to the inverting terminal.

The closed loop gain $A_V = \frac{V_O}{V_i}$

Output voltage $V_0 = A(V_2 - V_1)$

As ideal opamp has $A = \infty$

$$V_2 - V_1 = \frac{V_0}{A} = 0$$

$$\Rightarrow V_1 = V_2 \ (= 0 \text{ for this case})$$

which means a virtual short circuit exists between the two input terminals. A virtual short circuit means that whatever the voltage is at 2 will automatically appear at terminal 1. But terminal 2 is connected to ground. Thus $V_2 = 0$ and $V_1 = V_2 = 0$.

Therefore, terminal 1 is at <u>virtual ground</u> i.e having zero voltage but not physically connected to ground.

Let the current flowing through R_1 is i_1 and current through R_f is i_f.

By Ohm's law $i_1 = \frac{V_i - V_1}{R_1}$

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

Similarly $i_f = \frac{V_1 - V_0}{R_f} = \frac{0 - V_0}{R_f} = -\frac{V_0}{R_f}$.

Applying KCL at node 1

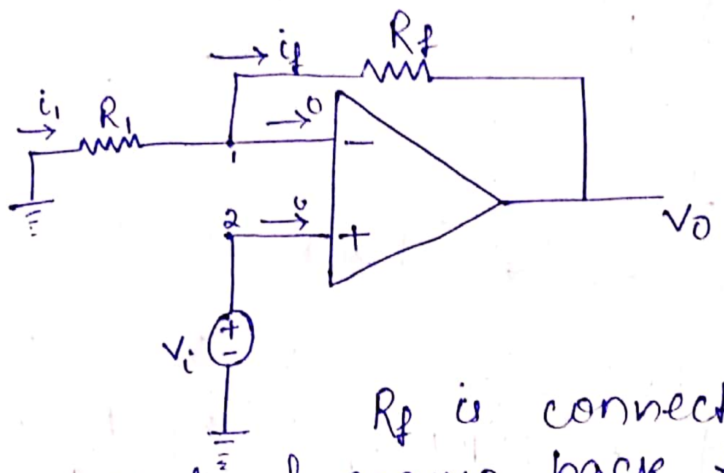
$$i_1 = i_f$$

$$\Rightarrow \frac{V_i}{R_1} = \frac{-V_0}{R_f}$$

$$\boxed{A_V = \frac{V_0}{V_i} = \frac{-R_f}{R_1}}$$

-ve sign provides signal inversion i.e 180° phase shift between input and output signal. Because of this, this configuration is called the inverting configuration.

Non-inverting Op-amp :-



Here, in non-inverting opamp, the input signal V_i is applied to the +ve input terminal of the op-amp.

R_f is connected from output terminal of opamp back to the inverting terminal

R_1 is connected between inverting terminal and ground.

Closed loop gain $A_v = \frac{V_o}{V_i}$

$V_o = A(V_2 - V_1) \Rightarrow V_2 - V_1 = \frac{V_o}{A} = \frac{V_o}{\infty} = 0$

$\Rightarrow V_1 = V_2 = V_i$

Applying KCL at node 1

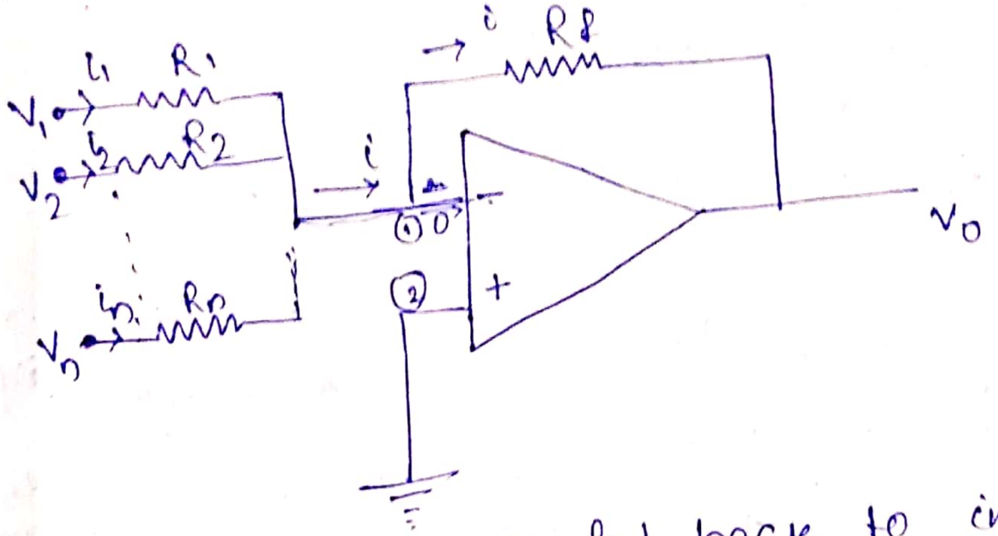
$i_1 = i_f$

$\Rightarrow \frac{0 - V_1}{R_1} = \frac{V_1 - V_o}{R_f}$

$\Rightarrow \frac{-V_i}{R_1} = \frac{V_i - V_o}{R_f}$

$\Rightarrow \boxed{A_v = \frac{V_o}{V_i} = 1 + \frac{R_f}{R_1}}$

Summing Amplifier / Weighted Summer



Here R_f is -ve fed back to input terminal.

A no. of input signals $V_1, V_2, \dots V_n$ each applied to corresponding resistor $R_1 R_2 \dots R_n$ which are connected to the inverting terminal.

The currents are given by

$$i_1 = \frac{V_1}{R_1}, \quad i_2 = \frac{V_2}{R_2} \quad \dots \quad i_n = \frac{V_n}{R_n}.$$

$$i = i_1 + i_2 + \dots + i_n$$

Applying Ohm's law.

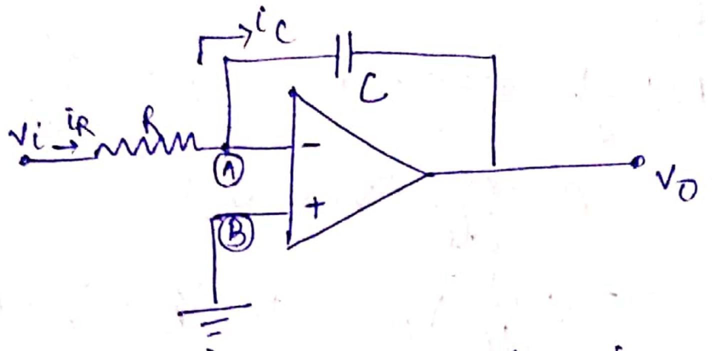
$$i = \frac{0 - V_0}{R_f}$$

$$\Rightarrow \frac{-V_0}{R_f} = i_1 + i_2 + \dots + i_n$$

$$= \frac{V_1}{R_1} + \frac{V_2}{R_2} + \dots + \frac{V_n}{R_n}$$

$$\Rightarrow \boxed{V_0 = -R_f\left(\frac{V_1}{R_1} + \frac{V_2}{R_2} + \dots + \frac{V_n}{R_n}\right)}$$

Integrator :-



The feedback resistor is replaced by a capacitor. The output is integration of given input signal multiplied by time constant.

Applying KCL at node A

$$i_R = i_C$$

$$\Rightarrow \frac{V_i - V_A}{R} = C\frac{dV}{dt}$$

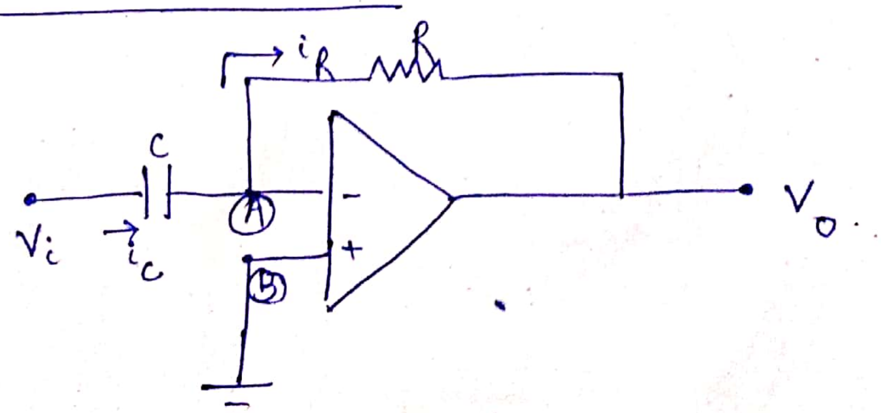
$$\Rightarrow \frac{V_i}{R} = C\frac{d}{dt}(V_A - V_o) \quad \left\{ \text{as } V_A = V_B = 0 \right.$$

$$\Rightarrow \frac{V_i}{R} = -C\frac{dV_o}{dt}$$

$$\Rightarrow \int dV_o = \frac{-1}{RC}\int V_i\,dt$$

$$\Rightarrow \boxed{V_o(t) = \frac{-1}{RC}\int V_i(t)\,dt}$$

Differentiator :-



Applying KCL at node A

$i_c = i_R$

Current through capacitor $i_c = C\frac{dv}{dt}$

$i_c = C\frac{d}{dt}(V_i - V_A)$

$= C\frac{d}{dt}V_i$ $\{$ as $V_A = V_B = 0$

$i_R = \frac{\cancel{V_A}^{0} - V_0}{R}$

$= \frac{-V_0}{R}$

So $C\frac{d}{dt}V_i = \frac{-V_0}{R}$

$\Rightarrow \boxed{V_0(t) = -RC\frac{d}{dt}V_i(t)}$