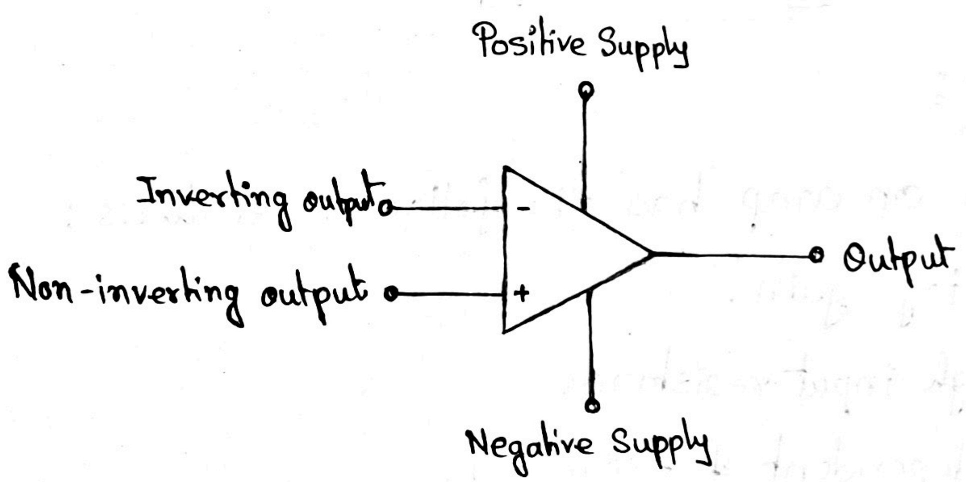
Operational Amplifier (OPAMP):

Operational amplifier are precision, high-gain, differential amplifiers. They were originally designed to perform mathematical operations in computers. Operational amplifiers or OPAMP now adays are widely used in many other applications. An OPAMP can be built from individual transistors and resistors but practically all opamp are manufactured as integrated circuit.

Logical Diagram:

All op amps have at least five terminals,



- **Positive and negative supply:**

Most op amps run on a dual supply or split supply. Typical supply voltages are ±9v, ±15V or ±18V. Certain op amps that are capable of accepting input voltages close to the supply rails can also run on a single supply such as 2v upto 36v.

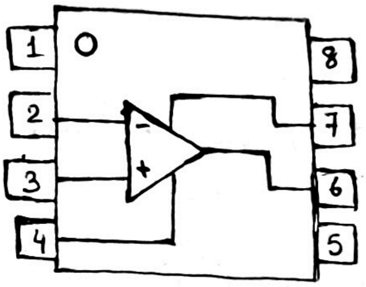
• Inverting and non-inverting inputs:

These are the inputs to the first stage of the amplifier, which is a differential amplifier.

• Output terminal:

Amplifiers may also have two or three other terminals, including the offset null terminals.

Block Diagram:



Ideal OP AMP:

An ideal op amp has the following features:

i) Infinite voltage gain.

ii) Infinitely high input resistance

iii) Gain is independent of frequency.

iv) Zero output resistance.

v) Zero input voltage offset.

vi) Output can swing positive or negative to the same voltages as the supply rails.

- ## Practical OP AMPs:

All op amps fall short of these ideal properties. A more practical op amps has the following properties,

i) Very high voltage gain

ii) Gain falls with frequency. It is constant upto about 10 KHz then falls until it reaches 1 at the transition frequency.

iii) High input resistance. This is usually at leas 2MΩ, often much more.

iv) Low output resistance. Typically 75Ω

v) Input voltage offset is a few millivolts.

vi) The output voltage swings to within a few volts of the supply voltage.

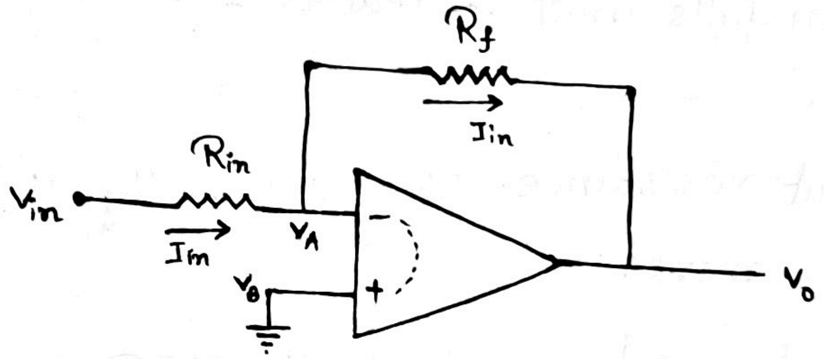
Input - voltage offset:

In practical amplifiers, the output is 0v when the input differs by a small amount known as the input offset voltage. Many op amps have a pair of offset null terminals. These are terminals 1 and 5 in the op amp.

The offset null terminals allow the input offset voltage to be nulled. To do this the same voltage is applied to both inputs, and a variable resistor is adjusted until the output is 0v.

- Inverting Amplifier:

An inverting amplifier takes the input through its inverting terminal through a resistor R_i and produces its amplified version as the output. This amplifier not only amplifies the input but also inverts it.



In the above inverting operational amplifier circuit the input voltage is applied at the inverting input and the non-inverting input is connected to the ground. In this type of amplifier, the output is 180° out of phase to the input, i.e when positive signal is applied to the circuit the output of the circuit will be negative.

By assuming the operational-amplifier is ideal, then the concept of virtual Sort can be applied at the input terminals of the OP-Amp. So that ~~voltad~~ voltage V_A at the inverting terminal is equal to the voltage V_B at the non-inverting terminal (i.e $V_A = V_B$). Here we can see that $V_B = 0$ therefor $V_A = 0$.

Current flowing through register Rin,

$$I_{in} = \frac{V_{in} - V_A}{R_{in}}$$

$$\Rightarrow I_{in} = \frac{V_{in} - 0}{R_{in}} \quad [\because V_A = 0]$$

$$\Rightarrow \boxed{I_{in} = \frac{V_{in}}{R_{in}}} \quad \text{——— (i)}$$

Current flowing through register R_f.

$$I_{in} = \frac{V_A - V_o}{R_f}$$

$$\Rightarrow I_{in} = \frac{0 - V_o}{R_f} \quad [\because V_A = 0]$$

$$\Rightarrow \boxed{I_{in} = -\frac{V_o}{R_f}} \quad \text{——— (ii)}$$

Equating equation (i) and (ii) we have,

$$\frac{V_{in}}{R_{in}} = -\frac{V_o}{R_f}$$

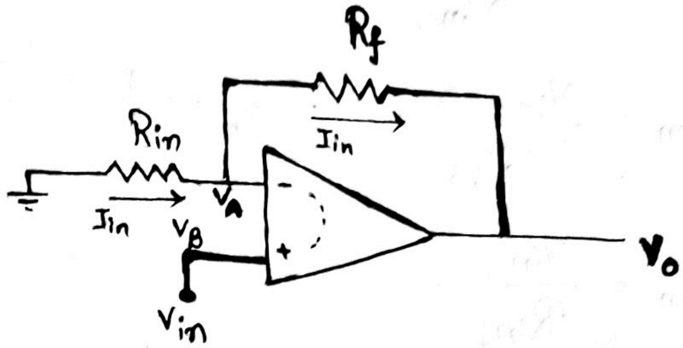
∴ The relation between input voltage and output voltage is

$$\boxed{V_{in} = -\frac{R_{in}}{R_f} V_o}$$

∴ The voltage gain of the circuit is,

$$(A_v) \Rightarrow \boxed{\frac{V_o}{V_{in}} = -\frac{R_f}{R_{in}}}$$

- **Non-Inverting Amplifier:**



In the above non-inverting operational ~~circuit~~ amplifier circuit the input voltage is applied at the non-inverting input terminal, and the inverting terminal is grounded. In this amplifier the output is exactly in phase with the input, i.e. when a positive voltage is applied to the circuit, the output will also be positive.

By assuming the op-Amp is ideal, then concept of virtual ground can be applied, i.e. the voltage at the inverting terminal V_A is equal to the non-inverting terminal V_B. (i.e $V_A = V_B = V_{in}$)

Current flowing through the resistor R_{in},

$$I_{in} = \frac{0 - V_A}{R_{in}}$$

$$\text{"} \quad I_{in} = \frac{-V_A}{R_{in}}$$

$$\boxed{\text{"} \quad I_{in} = -\frac{V_{in}}{R_{in}}} \quad \text{——— (1)}$$

Current flowing through the resistor R_f,

$$I_{in} = \frac{V_A - V_o}{R_f}$$

$$I_{in} = \frac{V_{in} - V_o}{R_f}$$

$$\boxed{I_{in} = \frac{V_{in}}{R_f} - \frac{V_o}{R_f}} \quad \text{——— (ii)}$$

Equating eq^n (i) and (ii) we have,

$$-\frac{V_{in}}{R_{in}} = \frac{V_{in}}{R_f} - \frac{V_o}{R_f}$$

$$\frac{V_o}{R_f} = \frac{V_{in}}{R_{in}} + \frac{V_{in}}{R_f}$$

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

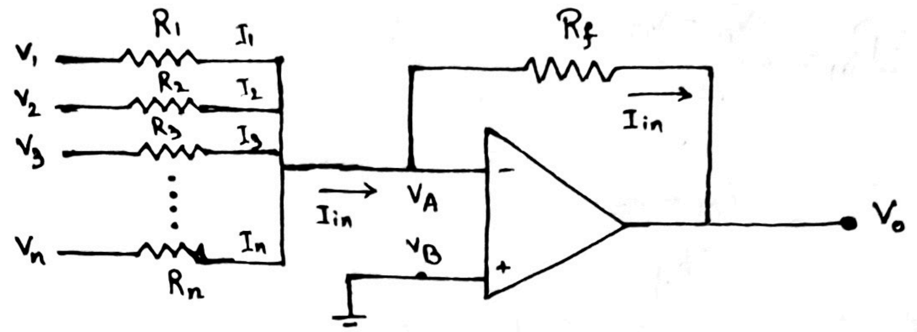
$$\frac{V_o}{\cancel{R_f}} = V_{in}\left[\frac{R_f + R_{in}}{R_{in}\cancel{R_f}}\right]$$

$$\boxed{\therefore V_o = V_{in}\left(1 + \frac{R_f}{R_{in}}\right)}$$ [Relation between input voltage and output voltage]

Therefor the gain of the circuit,

$$\boxed{(A_v) \Rightarrow \frac{V_o}{V_{in}} = \left(1 + \frac{R_f}{R_{in}}\right)}$$

• Summing Amplifier :



An OPAMP (Operational Amplifier) can also perform Summing operation. We can design an opamp circuit to Combine ~~inputs~~ number of input signals and to produce Single output as a weighted sum of input signals.

Summing amplifier is basically an op amp circuit that can combine numbers of input signal to a single output. The Summing amplifier is one variation of inverting amplifier. An inverting amplifier can easily be modified to summing amplifier, if we Connect several input terminals parallel to the inverting input of the OPAMP and the non-inverting input is grounded.

As the non-inverting input terminal is grounded the potential at the point V_B is zero. As the OPAMP is considered as ideal OPAMP the potential at the inverting terminal is also zero.

It is clear from the above circuit that the current Iin is the Sum of the currents in the input terminals.

Therefore,

$$I_{in} = I_1 + I_2 + I_3 + \cdots + I_n$$

$$\text{or } I_{in} = \frac{V_1 - 0}{R_1} + \frac{V_2 - 0}{R_2} + \frac{V_3 - 0}{R_3} + \cdots + \frac{V_n - 0}{R_n}$$

$$\text{or } I_{in} = \frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3} + \cdots + \frac{V_n}{R_n} \quad \text{——— (i)}$$

Now, in case of ideal OPAMP the current at the inverting and non-inverting terminals are zero. So, as per Kirchoff Current Law (KCL) the entire input current passes through the feedback path of resistance R_f.

That means,

$$I_{in} = \frac{0 - V_o}{R_f}$$

$$\text{or } I_{in} = -\frac{V_o}{R_f} \quad \text{——— (ii)}$$

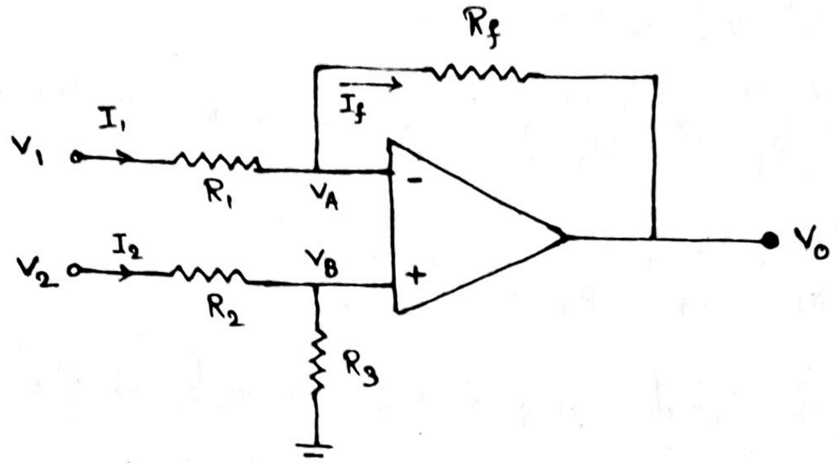
From eq^n (i) and (ii) we get,

$$-\frac{V_o}{R_f} = \frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3} + \cdots + \frac{V_n}{R_n}$$

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

This indicates that the output voltage V_o is the weighted sum of number of input voltage.

• Difference Amplifier:



A difference amplifier is a voltage subtractor circuit which produces an output voltage proportional to the voltage difference of two input signals applied at the inverting terminal and non-inverting terminal of the operational amplifier. Thus a differential is a analog circuit that takes two input signals and outputs the difference between them. In special cases a difference amplifier with a gain of unity (1) is reffered to as a basic voltage subtractor.

The voltage divider rule is used to calculate the voltage at V_B and the noninverting gain equation is used to calculate the noninverting output voltage V_{out+}

$$V_B = V_2 \frac{R_3}{R_2 + R_3} \qquad \text{——— (I)}$$

$$V_{out+} = V_B G_1 = V_2 \frac{R_3}{R_2 + R_3}\left(\frac{R_1 + R_f}{R_1}\right) \qquad \text{——— (II)}$$

The inverting gain equation is used to calculate the inverting output voltage V_{out-}

$$V_{out-} = -V_1 \left(\frac{R_f}{R_1} \right) \qquad \text{——— (iii)}$$

By adding eqn (i) and (ii) we have,

$$V_{out} = V_{out+} + V_{out-}$$

$$\text{a } V_{out} = V_2 \frac{R_3}{R_2 + R_3} \left(\frac{R_1 + R_f}{R_1} \right) - V_1 \left(\frac{R_f}{R_1} \right)$$

For simplicity we consider $R_1 = R_2$ and $R_3 = R_f$ we have,

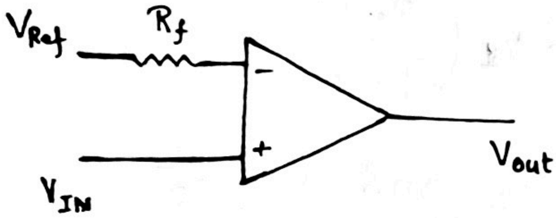
$$V_{out} = V_2 \frac{R_f}{R_1 + R_f} \times \frac{R_1 + R_f}{R_1} - V_1 \times \frac{R_f}{R_1}$$

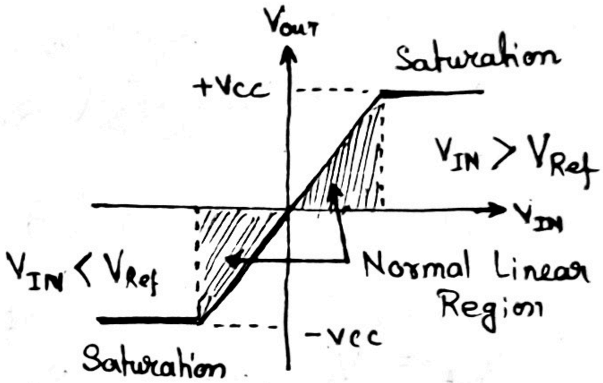
$$\text{a } V_{out} = V_2 \left(\frac{R_f}{R_1} \right) - V_2 \left(\frac{R_f}{R_1} \right)$$

$$\text{a } V_{out} = \frac{R_f}{R_1} \left(V_2 - V_1 \right)$$

Op-Amp Comparator :

The Op-Amp comparator compares one analogue voltage with another analogue voltage level or some preset reference voltage (V_{Ref}) and produces an output signal based on this voltage comparison. Voltage comparators either use positive feedback or no feedback to switch its output between two saturated states.





Let us assume that V_{IN} is less than the DC voltage level at V_{Ref} ($V_{IN} < V_{Ref}$). As the non-inverting input of the comparator is less than the inverting input, the output will be low and at the negative supply voltage −Vcc resulting in the negative saturation of the ~~voltage~~ output voltage.

If we now increase the input voltage V_{IN} so that its value is greater than the reference voltage V_{Ref} ($V_{IN} > V_{Ref}$). As the non-inverting input of the comparator is greater than the inverting input, the output will be high and towards the positive supply voltage +Vcc resulting in the positive saturation of the output voltage.

~~If we now increase the input voltage, V_{IN} so that its value is greater than the reference~~

If we now reduce the input voltage V_{IN} so that it is slightly less than the reference voltage V_{Ref}, the Op Amp's output switches back to its negative saturation voltage acting as a threshold detector. This strategy can also be used as a zero crossover detection using Op Amp.

Therefore a basic Op Amp comparator produces a positive or negative voltage output by comparing its input voltage against some preset DC reference voltage.