OPAMP

It is a - Multistage
- very high gain
- direct coupled
- feedback Amp.

It has - high i/p impedance
- low o/p impedance
- Operated betn 0Hz to 1MHz
- can amplifying both dc & ac.

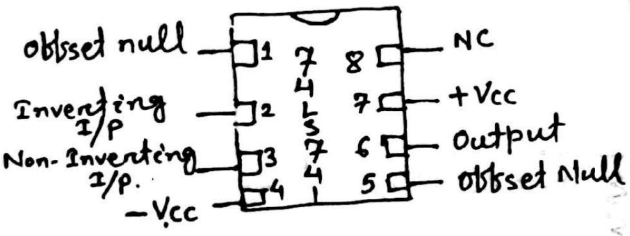
It performs mathematical operations —
Summation, Substraction, Multiplication,
Differentiation, Integration.

Ideal OPAMP characteristics

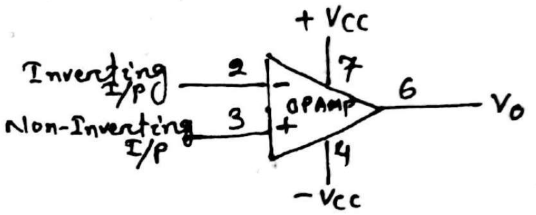
- Input Impedance $= \infty$
- Output Impedance $= 0$
- Voltage Gain $= -\infty$
- Bandwidth $= \infty$
- Slew Rate $= \infty$ (max. o/p changes with unit time)
- CMRR $= \infty$ (free from undesired signal)
- Offset Voltage $= 0$ (O/p is zero when i/p is zero).

OPAMP (Integrated IC)

Typical OPAMP 74LS741

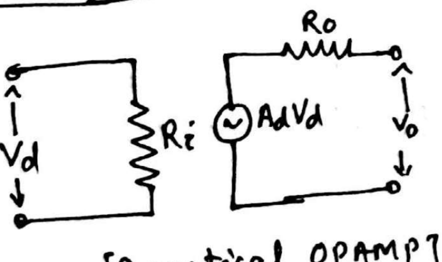


[Pin Diagram]



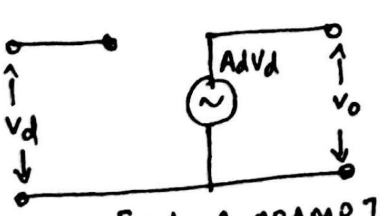
[Symbol with dc supply]

AC Equivalent Circuit of OPAMP



[Practical OPAMP]

- Very high input impedance Ri
- O/p voltage is amplified gain time to the i/p voltage.
- Output Impedance is very low Ro.



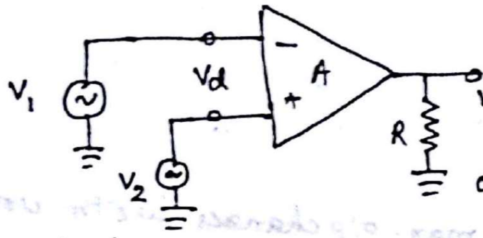
[Ideal OPAMP]

- Input Impedance is ∞ (so open)
- Output Impedance is 0 (so short)
- Voltage gain is ∞.

OP-AMP Configuration ← operates for ac + dc

- Open Loop (No connection betn o/p to i/p)
  - Differential amp
  - Inverting amp
  - Non-inverting amp
- Closed Loop (Connection betn o/p to i/p)
  - Positive feedback
  - Negative feedback

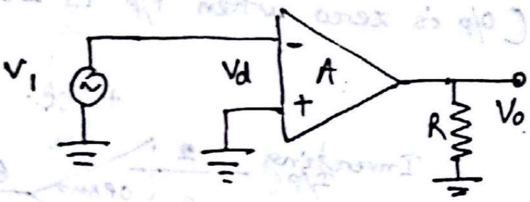
Differential Amp



$V_o = A(V_2 - V_1)$

open loop gain

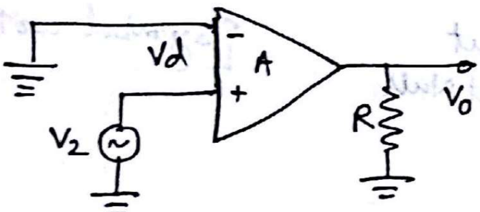
Inverting Amp



$V_o = A(\overset{0}{\cancel{V_2}} - V_1) = -AV_1$

−ve sign in o/p shows 180° out of phase.

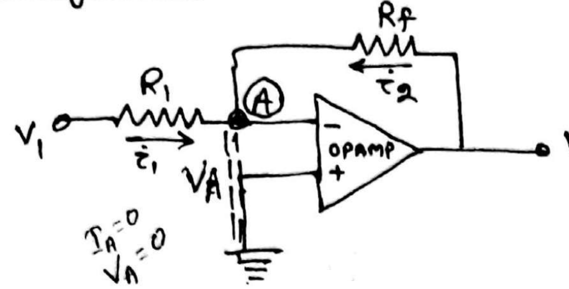
Non-Inverting Amp



$V_o = A(V_2 - \overset{0}{\cancel{V_1}}) = AV_2$

Note
- Due to open loop gain is very high, when the i/p signal is slightly greater then o/p is driven to saturation level.
- which creates distortion in o/p
- So for linear operation the gain should be controlled which can be achieved by feedback or closed loop config.

Inverting Amp



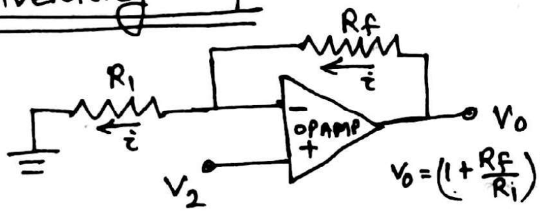
$V_o = -\frac{R_f}{R_1} V_1$

- The feedback Regsistor Rf feeds some portion of o/p to the i/p which employs negative feedback.
- The i/p current and feedback current are algebrically sum at point "A".
- when $i_1 = i_2$ then at point "A" the sum of current is equal to zero.
- So the voltage from point "A" that is "V_A" = 0V, is termed as Virtual Ground (~~not actual ground~~).
- Due to the virtual ground the current goes through R_1 & R_f that is $i_1 = i_2 = i$

$$\text{So} \quad i = \frac{V_1}{R_1} = -\frac{V_o}{R_f}$$

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

Non-Inverting Amp



$V_o = \left(1 + \frac{R_f}{R_1}\right) V_2$

- Due to the virtual short betn two terminals the voltage across R_1 is i/p voltage V_2.
- The V_o applied across the series combination of $R_1 + R_f$.

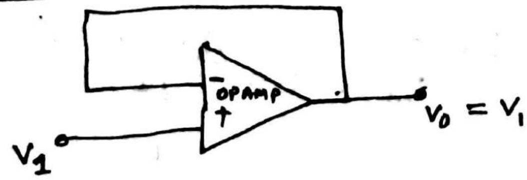
$$\therefore \quad V_2 = i R_1$$

$$V_o = i(R_1 + R_f)$$

$$\text{So } A = \frac{V_o}{V_2} = \frac{i(R_1+R_f)}{i R_1} = \left(1 + \frac{R_f}{R_1}\right)$$

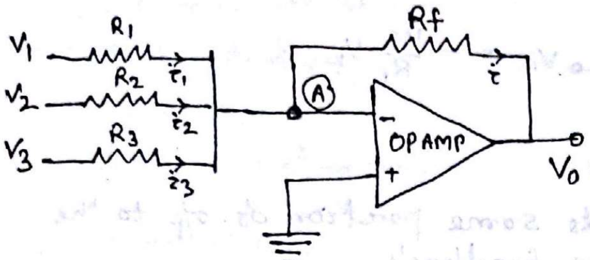
$$\Rightarrow \boxed{A = \left(1 + \frac{R_f}{R_1}\right)}$$

Unit Follower



$V_o = V_1$

Summing Amplifier



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

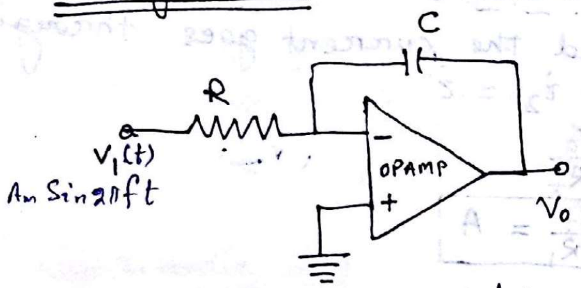
Here $i_1 = \frac{V_1}{R_1}$, $i_2 = \frac{V_2}{R_2}$, $i_3 = \frac{V_3}{R_3}$ & $i = -\frac{V_o}{R_f}$

At point "A"

$$i_1 + i_2 + i_3 - i = 0$$

$$\Rightarrow V_o = -\frac{R_f}{R}(V_1 + V_2 + V_3) \quad \text{if } R_1 = R_2 = R_3 = R$$

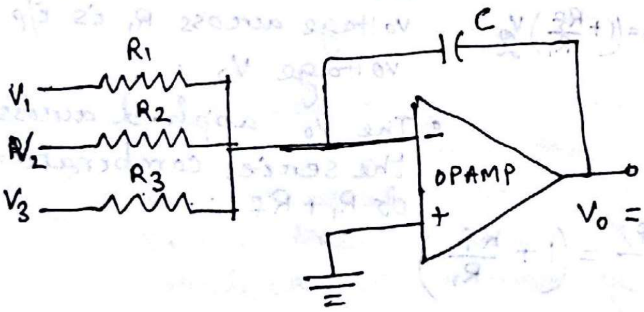
Integrator



$$V_o = -\frac{1}{RC}\int V_1(t)\,dt$$

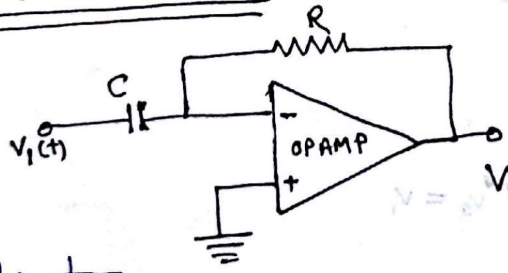
$$\text{slope is } = -\frac{1}{RC}$$

Summing Integrator



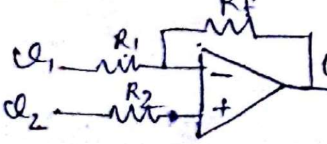
$$V_o = -\left[\frac{1}{R_1C}\int V_1(t)dt + \frac{1}{R_2C}\int V_2(t)dt + \frac{1}{R_3C}\int V_3(t)dt\right]$$

Differentiator

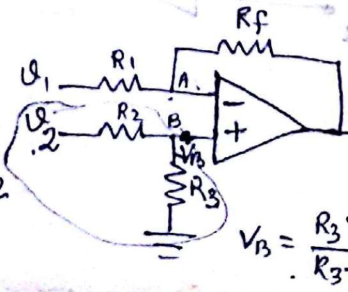


$$V_o = -RC\frac{dV_1(t)}{dt}$$

Substractor



$$v_o = v_{o1} + v_{o2}$$
$$= -\frac{R_f}{R_1}v_1 + \left(1 + \frac{R_f}{R_1}\right)v_2$$



$$v_o = v_{o1} + v_{o2}$$
$$= -\frac{R_f}{R_1}v_1 + \left(1 + \frac{R_f}{R_1}\right)$$

$$V_B = \frac{R_3 V_2}{R_3 + R_2}$$

OP-AMP Parameters

① I/p & O/p OFFSET Voltage -

- In a device when input is zero output should be zero, but in practical OP-AMP there will be some output voltage, called as O/p offset voltage. Which is due to manufacturing defect.
- So a small amount of voltage is applied externally to nullify or to cancel the output offset voltage is known as input offset voltage. Typical range is 1mv to 5mv.

② Slew Rate -

It is the maximum rate of change of output voltage per unit time and expressed in volts per microseconds.

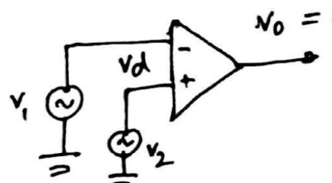
$$SR = \left.\frac{dV_o}{dt}\right|_{max} \quad V/\mu s$$

It indicates the change in output in response to change in input frequency.

③ CMRR (Common Mode Rejection Ratio)

OP-AMP has two type operation

(a) Differential operation



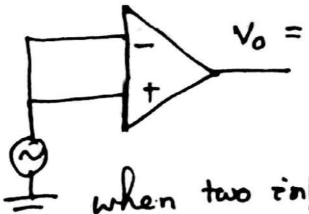
$N_o = Ad\ Vd$

where $V_d = V_2 - V_1$

A_d = Differential gain

So $\boxed{A_d = \frac{V_o}{V_d}}$

(b) Common Mode operation



$V_o = A_c V_C$

when two input are equal the resulting output should be zero. It has no meaning.

So $V_c = \frac{1}{2}(V_{i_1} + V_{i_2})$

A_c = Common mode Gain

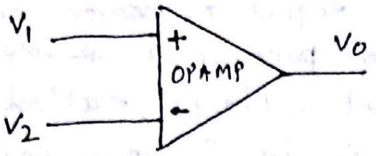
So $\boxed{A_c = \frac{V_o}{V_c}}$

The ratio of differential gain (open loop gain) and the common mode gain is called CMRR.

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

$$\boxed{CMRR_{\text{in dB}} = 20 \log_{10} \frac{A_d}{A_c}}$$

OP-AMP As A Differential Amp



Actually $V_o = A_d (V_1 - V_2)$

where A_d = Gain

- But when $V_1 = V_2$ then $V_o = 0$ has no meaning. So practically the o/p depends on both —
  - (a) difference signal V_d
  - (b) common mode signal V_c

where $V_d = V_1 - V_2$

$V_c = \frac{1}{2}(V_1 + V_2)$

- So output is defined by ⟶

$$\boxed{V_o = A_d V_d + A_c V_c}$$

where A_d = Differential Gain
A_c = Common mode Gain

Measure of Ad

Set $V_1 = -V_2 = 0.5\,V$

So $V_d = 1\,V$ & $V_c = 0$

∴ Measured o/p is the differential gain "Ad".

Measure of Ac

Set $V_1 = V_2 = 1\,V$

So $V_d = 0\,V$, $V_c = 1\,V$

∴ Measured o/p is the common mode gain "Ac".

Note

∴ The ratio of Ad & Ac is called CMRR gives the figure of merit of Amplifier.

$$CMRR = \rho = \left|\frac{A_d}{A_c}\right|$$

Other form

$$V_o = A_d V_d + A_c V_c$$

$$= A_d V_d \left(1 + \frac{A_c V_c}{A_d V_d}\right)$$

$$\Rightarrow \boxed{V_o = A_d V_d \left(1 + \frac{1}{\rho} \frac{V_c}{V_d}\right)}$$