Amplifier

converts weak signals to strong signals

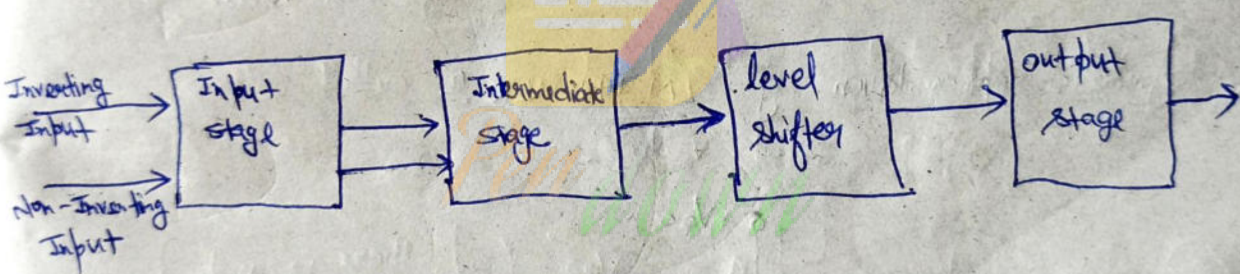
Operational Amplifier

O.A is a directly coupled very high gain amplifier which contains more differential amplifier.

$\boxed{\text{Range of O.A} = 0\,Hz \text{ to } 1\,MHz}$

$\boxed{A = 10^5 \text{ to } 10^6}$

☆ Different stages -



① Stage 1: Dual Input balanced, output is differential amplifier (voltage gain)

② Intermediate stage is used to amplify the signal (voltage gain)

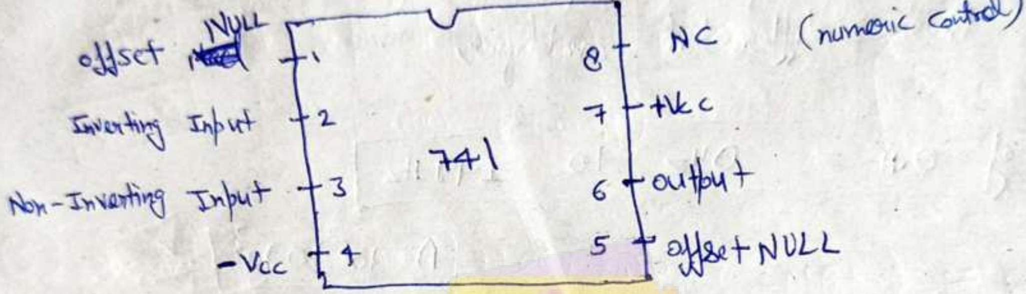
③ In level shifter block, we use the emmiter (CC-Configuration) takes to shift the level of input signal (DC)

Common collector

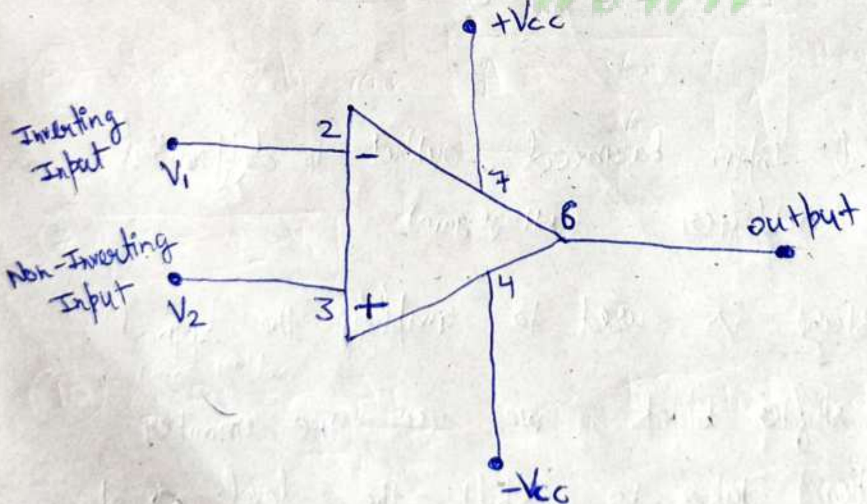
④ output stage proved output (by provide low output impedence)

★ DIP = Dual in line package

LM 741 IC :- (8 pins) (Linear Monolithic)



Symbolic representation of LM 741 IC :-

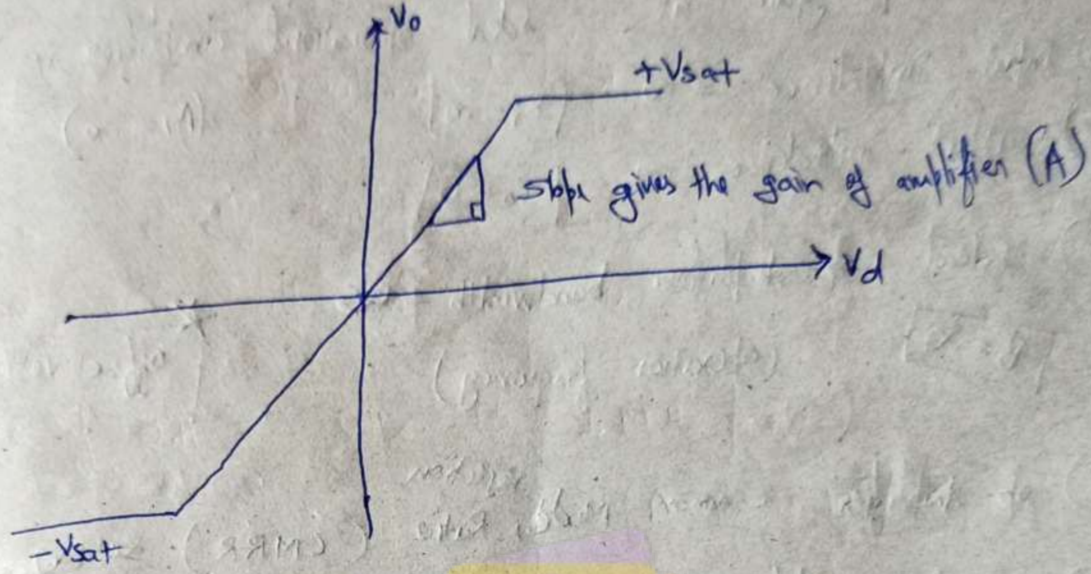


2 inputs
1 output

+ = Non inverting
− = inverting

$$\boxed{V_{id} = V_2 - V_1}$$

voltage-Transfer characterestics of operational Amplifier -

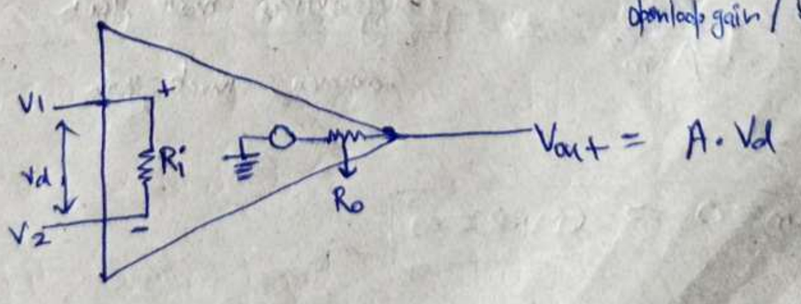


Applications of op-Amp -

1. Active filters
2. Oscillators
3. wave form Converter
4. ADC and DAC
5. Adder, subtractor, multiplier etc
6. Integration
7. Differentiation

op-Amp equivalent circuit -

$R_i = \infty$
$R_o = 0$
openloop gain / B.W $= \infty$
$A = \infty$



★ Ideal Characteristics of Operational Amplifier -

① open loop gain at Ideal operational amplifier is infinite ($A_v = \infty$)

② Input impedence $= \infty$ $\boxed{R_i = \infty}$

③ output impedence $= 0$ $\boxed{R_o = 0}$

④ Ideal op - Amplifier bandwidth $= \infty$

$\boxed{B = \infty}$ (operation frequency)

★ $\boxed{\text{offset voltage} = 0}$

⑤ op - Amplifier common ~~Mode~~ Rejection Ratio (CMRR) $= \infty$

⑥ Ideal Amplifier should have ∞ slew rate. (∞)

⑦ Ideal op - Amplifier should not have a output voltage with zero Input voltage. $\boxed{\text{offset } V = 0}$

⑧ open loop gain $\boxed{A = \dfrac{V_{out}}{V_{in}}}$ { there is not connected closed loop }

⑨ $\boxed{V_{id} = V_2 - V_1}$

⑩ $CMRR = \dfrac{A_{dm}}{A_{cm}} = \dfrac{\text{differential mode gain}}{\text{Common mode gain}}$

$\boxed{\text{if } A_{cm} = 0 \Rightarrow CMRR = \infty}$

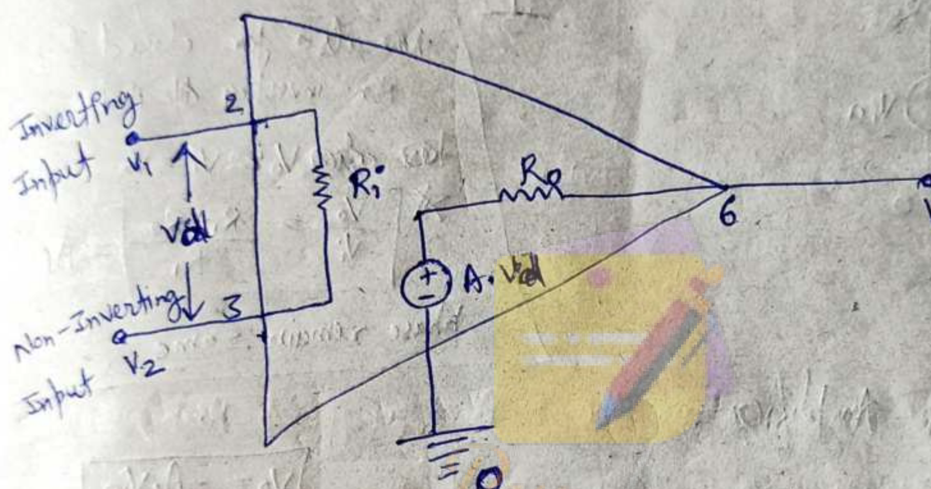
for ideal

⑪ Power supply Rejection Ratio (PSRR) $= 0$

Slew Rate: It is defined as a main rate of change of output ~~wrt input~~ with time $S = \left.\frac{dV_0}{dt}\right|_{max}$

for ideal $\boxed{S = \infty}$

Equivalent ckt of op-Amp -



A_v = open loop gain
$V_d = V_2 - V_1$

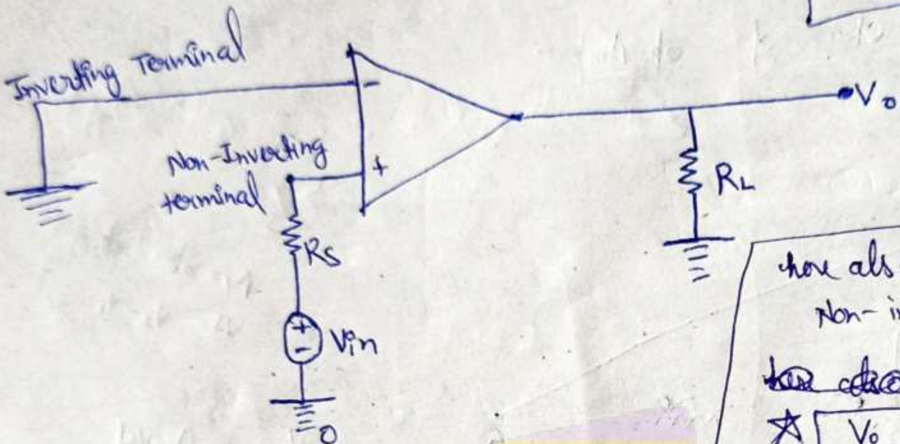
$V_{out} = A_v V_d$

There are 3 types of Amplifier mode -

1. Non-Inverting Amplifier $\boxed{V_0 = \left(1 + \frac{R_f}{R_1}\right) V_{in}}$
2. Inverting Amplifier $\boxed{V_0 = \frac{-R_f}{R_1} V_{in}}$
3. operational Amplifier move → Inverting
   → Non-Inverting
   → differential

① Non-Inverting Amplifier-

$\boxed{V_o = A \cdot V_{in}}$



here also for closed loop Non-inverting Op-Amp

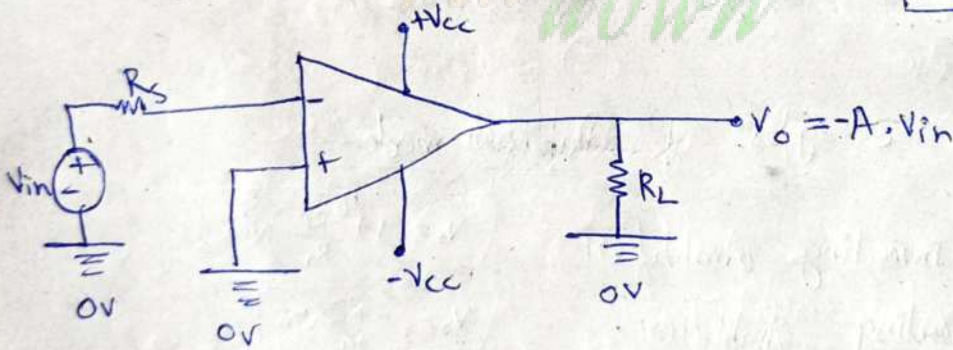
V_o $V_i = V_x$

☆ $\boxed{\frac{V_o}{V_i} = \frac{R_1+R_2}{R_1}} = A_f$

phase remain same

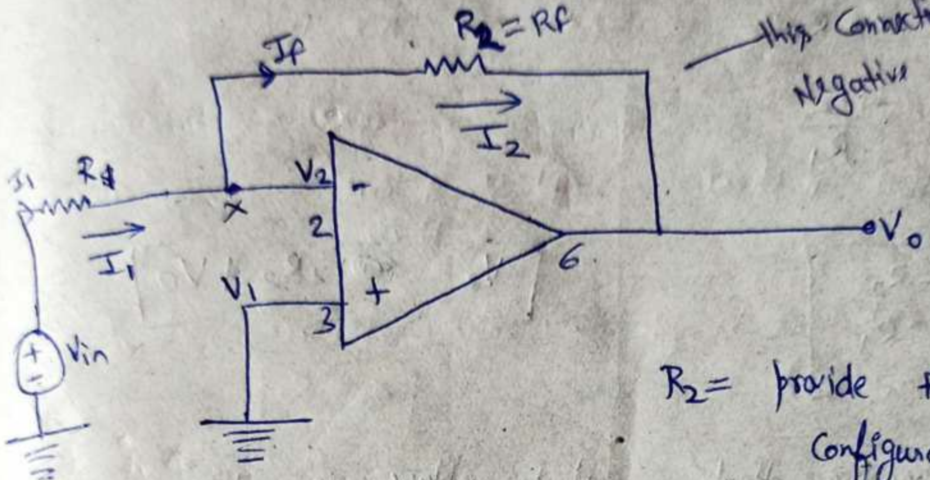
② Inverting Amplifier-

$\boxed{V_o = -A \cdot V_{in}}$



Ⅱ open loop Amplifier

(II) close loop Amplifier: (~~Non~~ Inverting)



this Connection is called Negative feedback

R_2 = provide the close loop Configuration

$$A = \frac{V_o}{V_{id}} = \frac{V_o}{V_1 - V_2}$$

$$I_1 = I_f$$

$$\frac{V_{in} - 0}{R_1} = \frac{0 - V_{out}}{R_2}$$

$$\boxed{\frac{V_{out}}{V_{in}} = A_{CL} = -\frac{R_2}{R_1} = -\frac{R_f}{R_1}}$$

In case of open loop A is ∞ (virtual)

The term Virtual is use to represent that

☆ what is the voltage at non-inverting terminal

Ans) Same voltage at the Inverting terminal (

☆ $I_1 = \frac{V_i}{R_1}$, $I_2 = \frac{V_i}{R_2}$, $V_0 = -R_2 I_2$

here we are assum $I_1 = I_2$, because input as inverting terminals, the output voltage is $-ve$

$$V_o = -R_2 I_2$$

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

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

$$\boxed{A_f = \frac{-R_2}{R_1}}$$

$$\boxed{V_2 = i_2 R_2 + V_o}$$

-ve sign showing that output voltage is 180° out of phase than input voltage.

Hence we can control the A (gain of op-Amp) by varying value of R_2 & R_1

basic of op-Amp

for ideal op-Amp.

Parameter	ideal values	Practical values p-741
(1) Input Impedence (R_i)	∞	2 MΩ (in MΩ)
(2) output Impedence (R_o)	0	75 Ω (in Ω)
(3) open loop gain (A_v)	∞	10^5
(4) offset voltage	0	1 mV
(5) slew rate	∞	0.5 V/μs
(6) CMRR	∞	70–90 db

★ <u>Negative feedback</u>: To operate op-Amp in linear region negative feedback is used in closed loop op-Amp.

★ <u>virtual short</u>: in close loop Amplifier, the $\boxed{V^+ - V^- \simeq 0V}$ that is they seems to be as shorted called as virtual short. (they are virtually shorted)

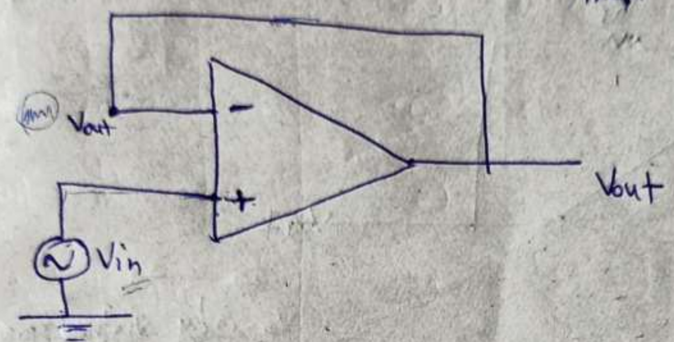
Advantages of Non-Inverting over Inverting op-Amp :-

~~① Vout & Vin are in phase in Non-inverting~~

Non-Inverting	Inverting
① Vin & Vout in phase	① Vin & Vout are 180° apart in phase
② Input Impedence is high $\boxed{Z_1 = (\infty)}$	② Input impedence depend on R_1 $\boxed{Z_1 = R_1}$

Op-Amp as a Buffer–

In Non-Inverting Op-Amp if $R_1 = \infty$
& $R_2 = 0$
then



because of feedback $V^- = V^+$ (virtual short)

$$\boxed{V_{out} = V_{in}}$$

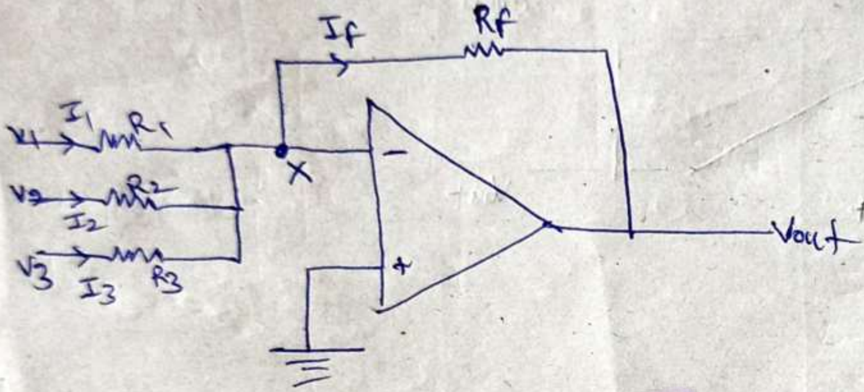
Characteristic:– $\boxed{\begin{aligned} Z_{in} &= \infty \\ V_{out} &= V_{in} \end{aligned}}$

Features:

1. $A_d = 1$
2. High bandwidth
3. High input impedence

op-Amp as Summing Amplifier - (Adder)

① Inverting Summing Amplifier -



by virtual ground
$\boxed{V_x = 0V}$

Applying KCL at X

$$I_1 + I_2 + I_3 = I_f$$

$$\frac{V_1 - 0}{R_1} + \frac{V_2 - 0}{R_2} + \frac{V_3 - 0}{R_3} = \frac{0 - V_{out}}{R_f}$$

$$\boxed{V_{out} = -\left[\frac{R_f}{R_1}V_1 + \frac{R_f}{R_2}V_2 + \frac{R_f}{R_3}V_3\right]}$$

for single R

$$\boxed{V_{out} = \frac{-R}{R_1} V_{in}}$$

for $R_1 = R_2 = R_3 = R$

$$\boxed{V_{out} = -\frac{R_f}{R}\left[V_1 + V_2 + V_3\right]}$$

(a) To use as adder

$$R_F = R$$

$$\boxed{V_{out} = -[V_1+V_2+V_3]}$$

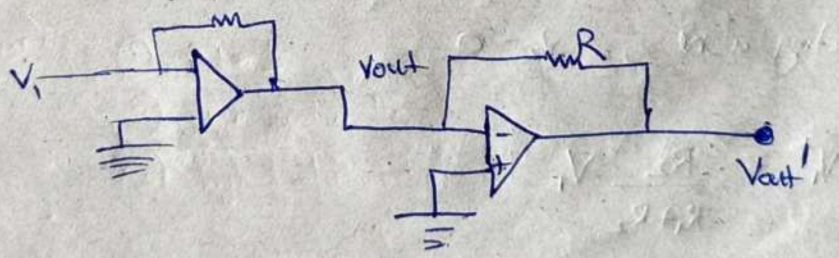
(b) use as averager.

$$R_1 = R_2 = R_3 = R$$

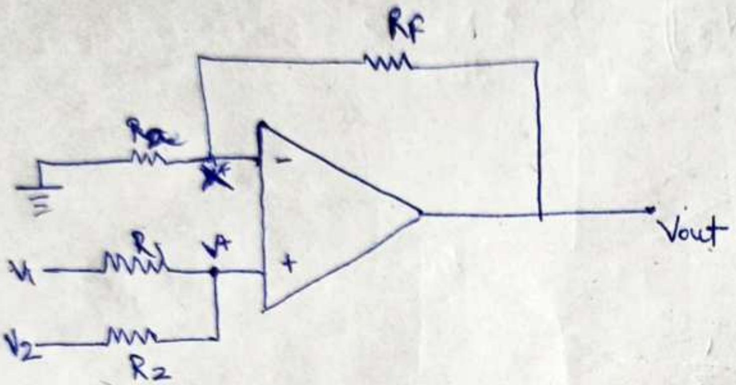
$$\frac{R_F}{R} = \frac{1}{n} = \frac{1}{3}$$

$$V_{out} = -\left[\frac{V_1+V_2+V_3}{3}\right]$$

Note: by using one more inverting op-Amp we can get +ve output.



② Non-Inverting Summing Amplifier -



$\boxed{V_x = V^+}$ by virtual short

$$I_a = I_f$$

$$\frac{V_x - 0}{R_a} = \frac{V_{out} - V_x}{R_f}$$

$$V_{out} = \frac{R_f}{R_a} V_x + V_x$$

$$\boxed{V_{out} = \left[1 + \frac{R_f}{R_a}\right] V^+}$$

Now $V^+ = ?$

by superposition theorem

Let V_1 acting alone, $V_2 = 0$

then $$V_1^+ = \frac{R_2}{R_1 + R_2} V_1$$

$$V_2^+ = \frac{R_1}{R_1 + R_2} V_2$$

$$\boxed{V^+ = V_1^+ + V_2^+ = \frac{R_2 V_1 + R_1 V_2}{R_1 + R_2}}$$

$$\boxed{V_{out} = \left[1+\frac{R_f}{R_a}\right]\left[\frac{R_2V_1+R_1V_2}{R_1+R_2}\right]}$$

Now.

Let $R_1 = R_2 = R$

$$V_{out} = \left[1+\frac{R_f}{R_a}\right]\left[\frac{V_1+V_2}{2}\right]$$

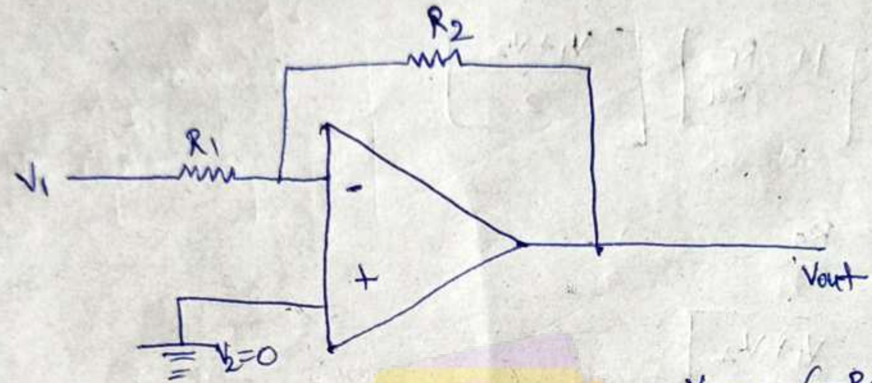
(a) Adder ->

Let $R_f = R_a$

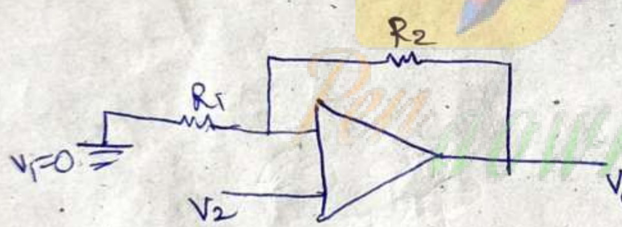
$$\boxed{V_{out} = V_1+V_2}$$

Op-Amp as Differential Amplifier / Subtracter -

① Inverting config -



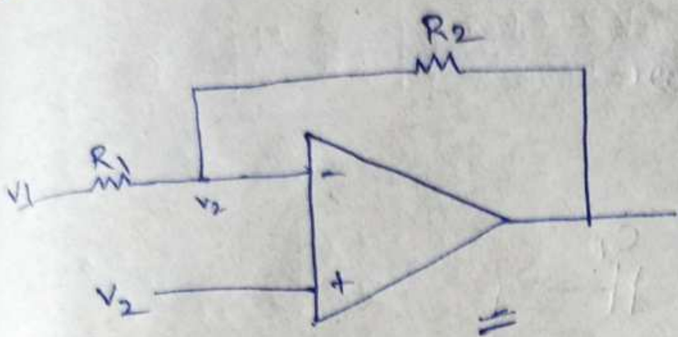
$$V_{o_1} = \left(\frac{-R_2}{R_1}\right)V_1$$



$$V_{o_2} = \left(1+\frac{R_2}{R_1}\right)V_2$$

Now Let V_1 & V_2 acting simultaneously then output voltage

$$V_{out} = V_{o_1} + V_{o_2} = -\frac{R_2}{R_1}V_1 + \left(1+\frac{R_2}{R_1}\right)V_2$$



$V_{out} = K(V_2 - V_1)$

$\boxed{K = \frac{R_2}{R_1}}$

Let

$\frac{V_1 - V_2}{R_1} = \frac{V_2 - V_0}{R_2}$

$V_1R_2 - V_2R_2 = V_2R_1 - V_0R_1$

$V_0 = \frac{(V_1 - V_2)R_2}{R_1}$

Let $V_2^+ = \left(\frac{R_2}{R_1+R_2}\right)V_2$

So

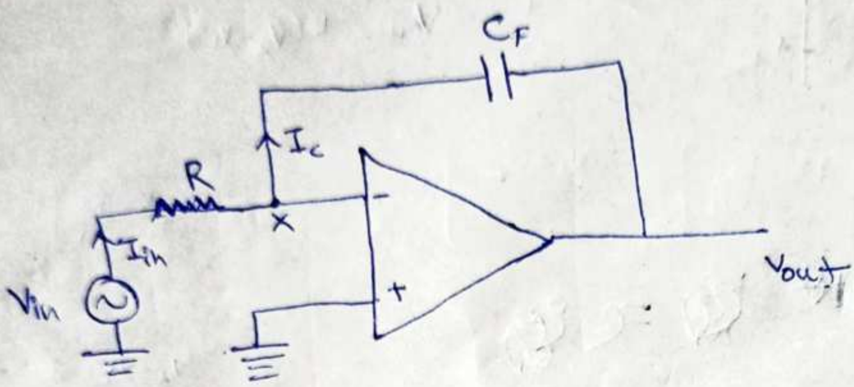
$$V_{out} = -\frac{R_2}{R_1}V_1 + \left(\frac{\cancel{R_1+R_2}}{R_1}\right)\left[\frac{R_2}{\cancel{R_1+R_2}}V_2\right]$$

$$\boxed{V_{out} = \frac{R_2}{R_1}\left[V_2 - V_1\right]}$$

Subtracter

Application of Differential amplifier = in sensors

Op-Amp as Integrator-



x = virtual ground so $I_{in} = I_c$

$$\frac{V_{in} - 0}{R} = I_c$$

Now

$$Q = CV$$

$$\boxed{i_c = C\frac{dV_c}{dt}}$$

$$\frac{V_{in}}{R} = C\frac{dV_c}{dt} = C\frac{d}{dt}\left[0 - V_{out}\right]$$

$$\frac{dV_{out}}{dt} = \frac{-1}{RC} V_{in}$$

$$\boxed{V_{out}(t) = \frac{-1}{RC}\int V_{in}(t)\,dt}$$

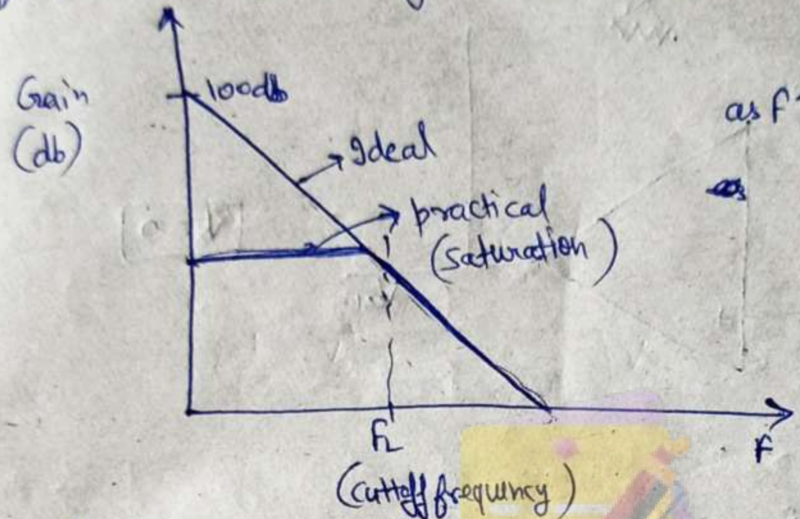
Input → output

straigh line → inclined line

sine wave → cosine wave

square → Triangular

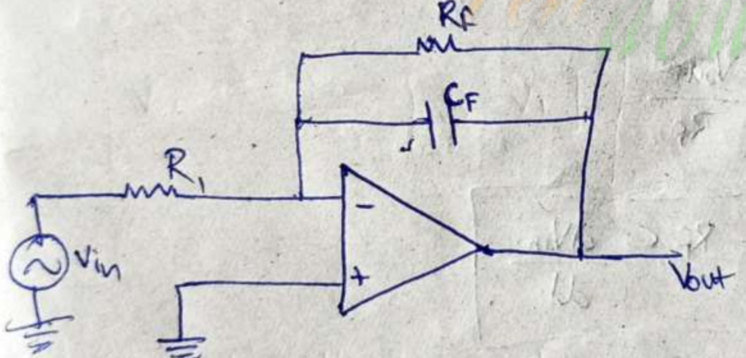
* frequency response of ideal integrator



as f ↑ gain ↓

__Practically :__

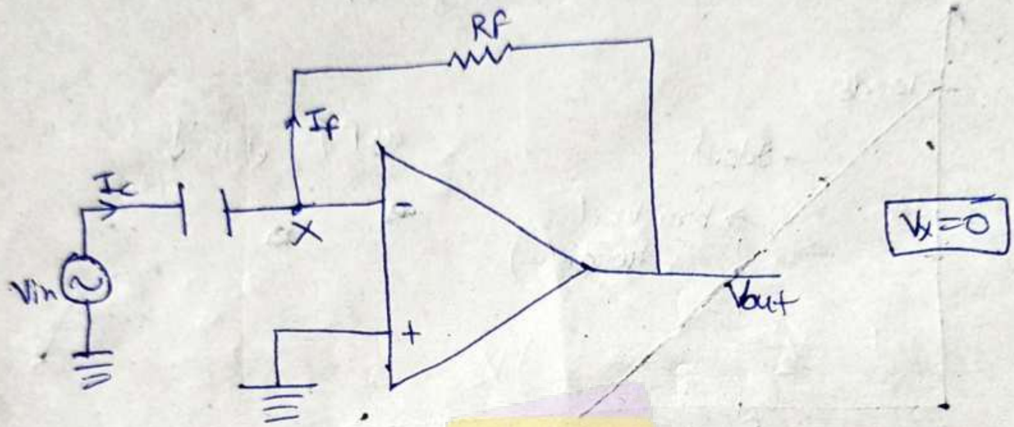
To avoid saturation a R_F is added & ckt is—



$$\boxed{A_v = -\frac{R_F}{R_1}}$$

Op-Amp as Differentiator-

$$\boxed{V_{out} = \frac{dV_{in}}{dt}}$$



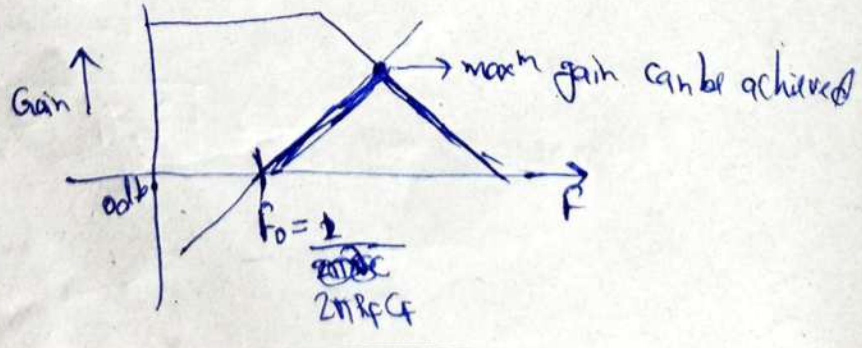
$$I_c = I_f$$

$$C\frac{dV_c}{dt} = \frac{0 - V_{out}}{R_f}$$

$$C\frac{dV_{in}}{dt} = \frac{-V_{out}}{R_f}$$

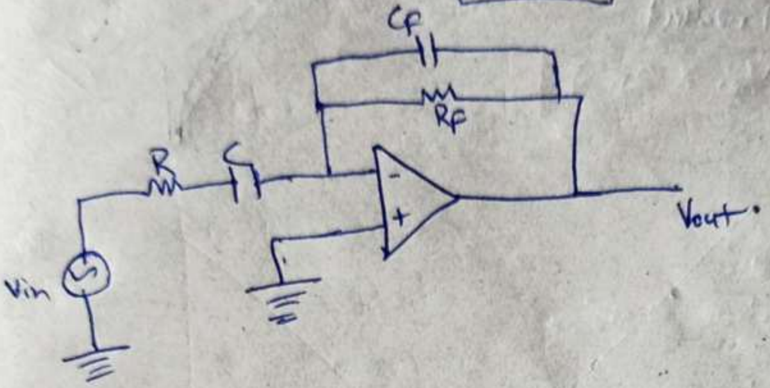
$$\boxed{V_{out} = -R_f C \frac{dV_{in}}{dt}}$$

☆ gain Characteristic



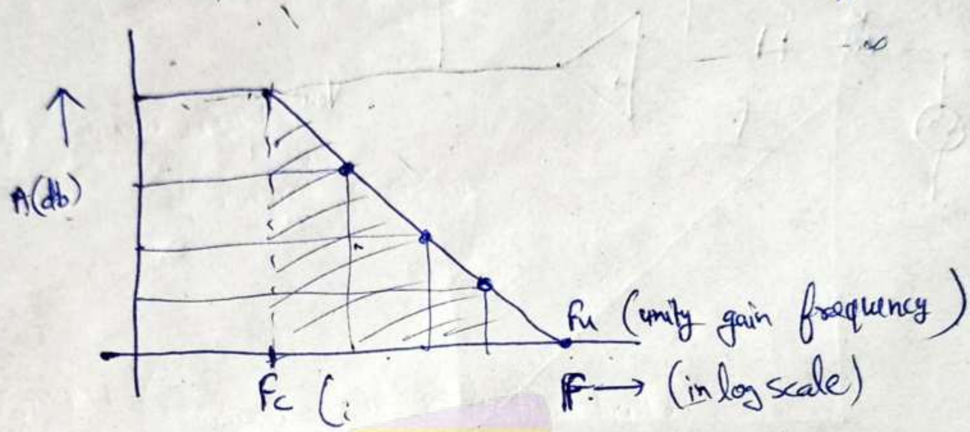
To avoid error - join capacitance ||el to R_f

$\boxed{C_f \parallel R_f}$



definations

① Gain bandwidth Product -



Cuttoff frequency → The frequency at which gain of op-Amp start reducing.

In shaded region the product of gain & freq - remains Constant at every point so called as Gain bandwidth product of op-Amp.

1mhz

fu = 1mhz

★ $\boxed{f_u = 10^6 Hz}$

★ $\boxed{f_c = \frac{f_u}{A_{CL}}}$

★ $\boxed{A_{CL} = A \cdot f}$ (cuttoff bandwidth product)

(a) for Non-Inverting op-Amp -

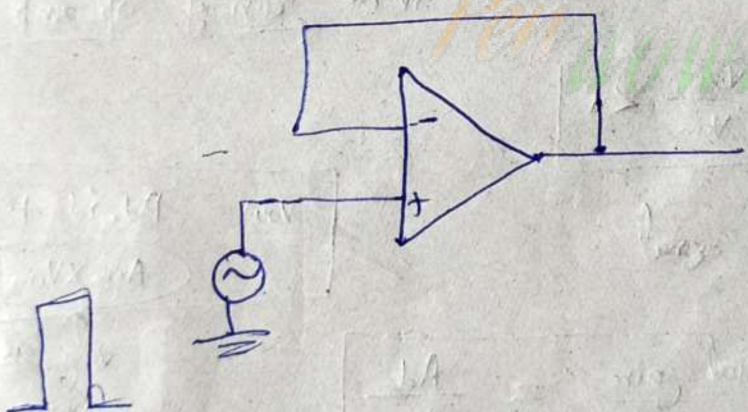
$$\boxed{F_u = A_{CL} \times F_{CL}}$$

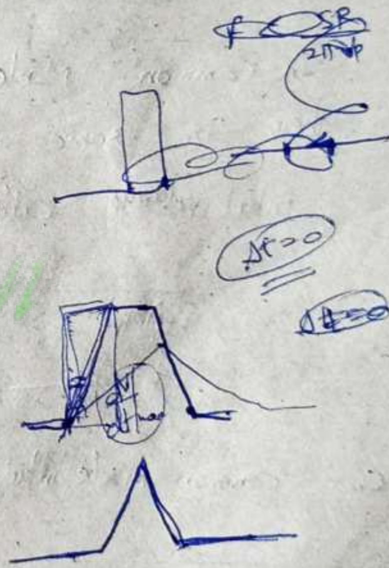
(b) for Inverting -

$$\boxed{F_u = (|A_{CL}| - 1) \times F_{CL}}$$

(2) Slew Rate - The max^m rate at which output of the op-amp can change.

$$\boxed{\text{unit} = V/\mu s}$$





Reason of slew rate - Internal compensation Capacitor

$$i_c = C \frac{dV_c}{dt}$$

$$\boxed{\text{slew rate} = \frac{dV_c}{dt} = \frac{i_c}{C}}$$

ⓐ for sine waves

slew rate

$$\boxed{SR = V_o \times 2\pi\nu}$$

slew rate determines the highest frequency of the op-amp without distortion

ⓑ ~~for square wave~~

~~do normal~~

③ CMMR (Common mode Rejection Ratio) -

In Common Mode configuration, ideally $V_{out} = 0$ but there is some amount of voltage which is less than input voltage called as common mode gain of op-amp

$$\boxed{A_{cm} = \frac{V_{ocm}}{V_{cm}} < 1}$$

$$\boxed{V_{out} = A_d \cdot i_d + A_{cm} \times V_{cm}}$$

very less common mode gain

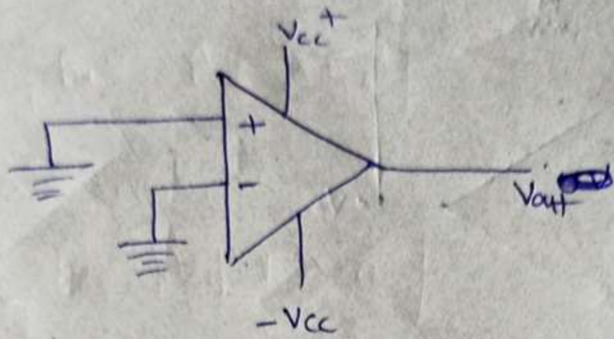
Cm = common mode input signal

$$\boxed{CMMR = \frac{\text{differential gain}}{\text{Common gain}} = \frac{A_d}{A_{cm}}}$$

OR

$$\boxed{CMMR = 20 \log_{10} \left(\frac{A_d}{A_{cM}}\right)}\ db$$

④ Input offset voltage -



When both terminal of op-Amp are at zero volt for ideal op-Amp $\boxed{V_{out} = 0}$ V

but actually we found some finite voltage at output because of slighty mismatch b/wn biasing voltage of each terminal (Vd comes in play)

Called as offset voltage.

☆ Input offset voltage - The amount of voltage applied to input terminals to get output voltage = 0

It gives about 10% error in output voltage

☆ To reduce this error - ☆ we use dc offset NULL