UNIT - II

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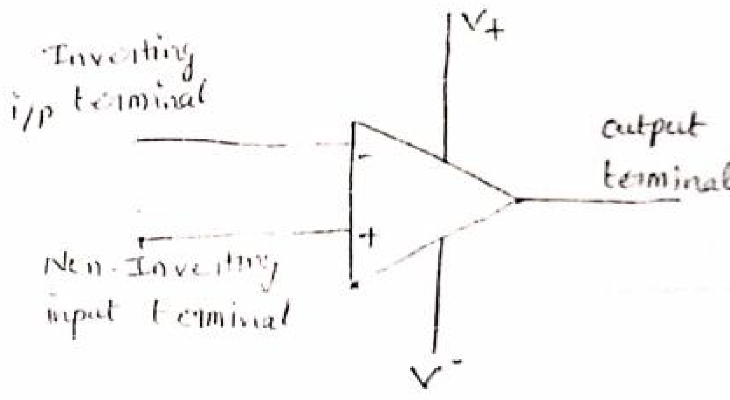
Syllabus :- Introduction to Op-Amp, Differential Amplifier Configurations, CMRR, PSRR, Slew rate. Block diagram, PIN Configuration of 741 Op-Amp. Characteristics of Ideal Op-Amp. Concept of virtual ground. Op-Amp Applications: Inverting, Non-inverting Amplifier, Summing and differential amplifier. Voltage follower, Comparator, Differentiator, Integrator.

The circuit schematic of an Op-Amp is a triangle shape representation. It can be represented with five terminal representation.

Two terminals for Supply, two terminals for input and one for output.



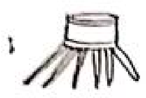
Packages :-

There are three popular packages are available

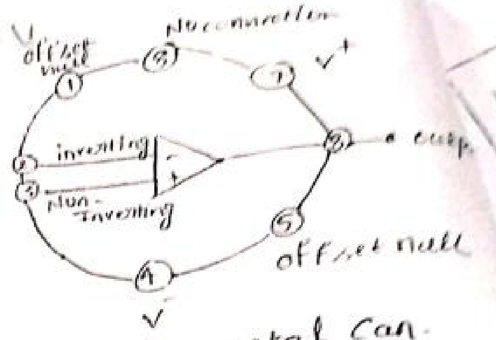
i) Metal Can package.
ii) Dual in line package
iii) Flat type package.

Op-Amp packages may contain single, two (or) four Op-Amps. Typical packages may have 8 terminals, 10 terminals and some times 14 terminals. The widely used Op-Amps are $\mu A741$ and the $\mu A747$ is a dual 741

Metal Can-type

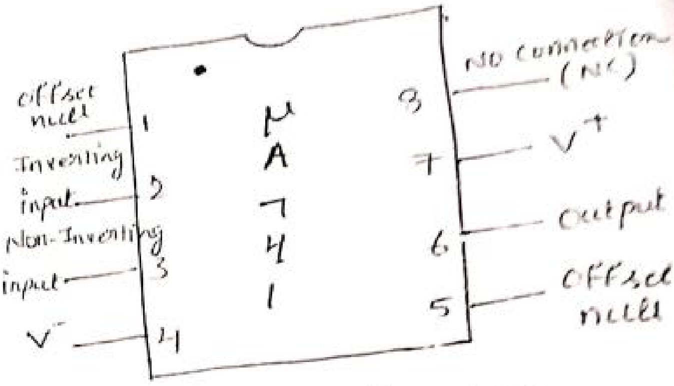


Dual-Inline package



8-pin metal Can.

In these two sections there are 8 pins numbered in Counter clockwise. PIN 1 and PIN 5 represents offset null, PIN 2 is called inverting input terminal and PIN 3 is the Non-inverting input terminal, PIN-6 is called output terminal and PIN 7 & PIN 4 are the power supply terminal



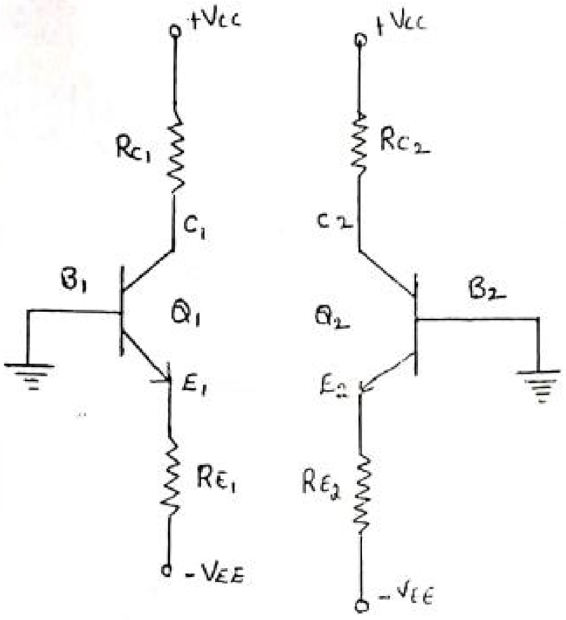
8 pin Dual In line package

labelled as V+ and V- respectively. The PIN 8 is marked as NC indicates "No Connection". The terminal PINs are started at where the dot representation is presented.

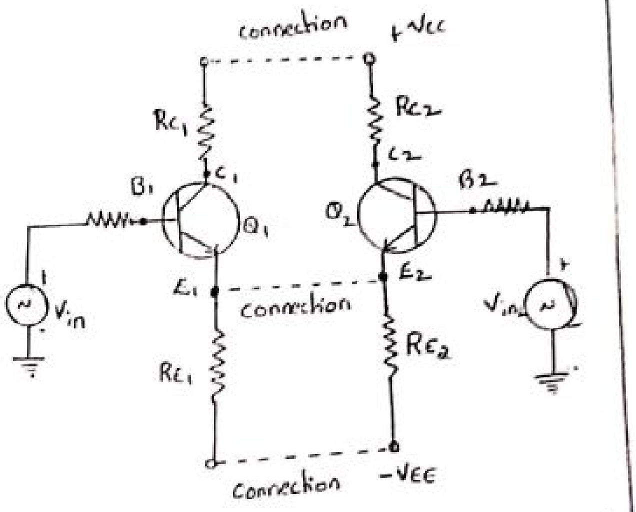
Each Manufacturer uses a specific code ~~and~~ assigns a specific type number to the IC. The Codes used by some of the we known manufacturers of Linear IC's are.

i) Fairchild – μA, μAF
ii) National semi Conductor – LM
iii) Motorola – MC, MFC
iv) RCA – CA, CD
v) Texas instrument – SN
vi) Signetics — N/S, NE/n.

Differential Amplifier

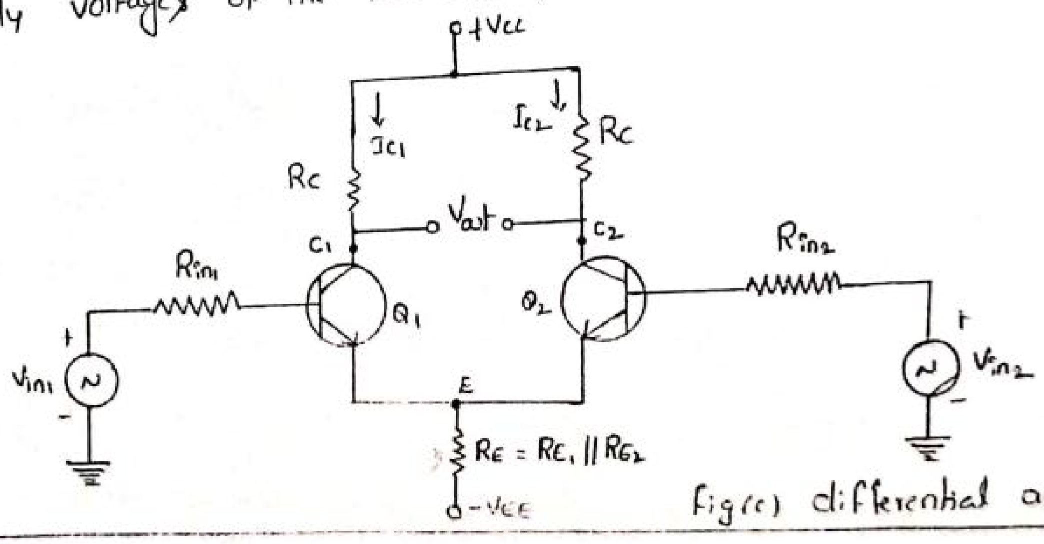


(a) Two identical emitter biased circuits



(b) Connecting the two identical emitter biased circuits together

Let us consider two identical emitter biased circuits using transistors Q_1 and Q_2 as shown in fig(a). The transistors Q_1 and Q_2 are have identical characteristics with R_{E_1} and R_{C_2}, $R_{C_1} = R_{C_2}$ and $|V_{CC}| = |-V_{EE}|$. The basic differential pair can be obtained by combining the two emitter biased circuit of fig(a) together. These two circuits can be combined together as shown in fig(b). we also connect the $+V_{CC}$ supply voltages of the two circuits and connect the $-V_{EE}$ supply voltages



Fig(c) differential amplifier

Let us connect the emitter E_1 of transistor Q_1 to the emitter E_2 of transistor Q_2. Thus, R_{E_1} gets connected in parallel with R_{E_2}. we also apply an input signal V_{in_1} to the base B_1 of transistor Q_1 and V_{in_2} to the base B_2 of transistor Q_2. The output voltage is obtained between the collectors C_1 and C_2

After carrying out all these changes, we obtain the differential amplifier circuit of fig (c). since $R_{C_1} = R_{C_2} = R_C$, since collector resistors are equal and also $R_E = R_{E_1} || R_{E_2}$

fig (c) shows the emitter coupled differential amplifier, This amplifier is dual input balanced output type amplifier, As the input signals are applied to both the input terminals, it is called as dual input and as the output is obtained between the collector of the two transistors, it is called as balanced output, since the output is obtained between two collectors it is known differential output. This amplifier is known as emitter coupled amplifier because the emitters of both the transistors are connected together

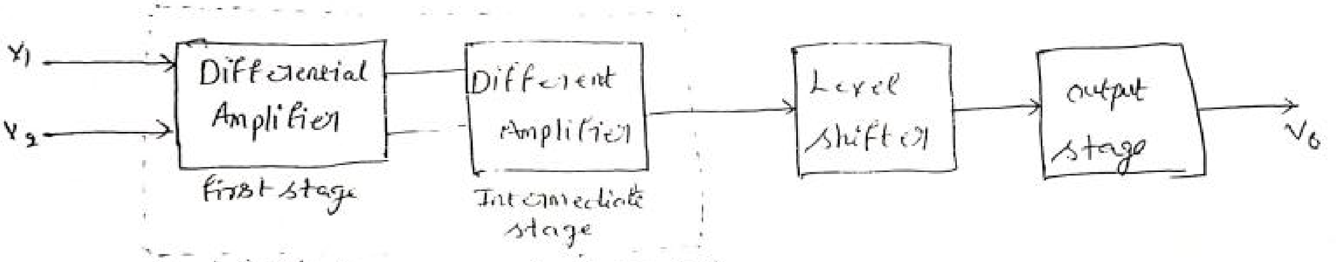
Internal block ... of OP-amp

An OP-amp is a direct coupled multistage amplifier. The different stages of OP-Amp are

1) Input stage — i) First stage
ii) Second stage (Intermediate stage)

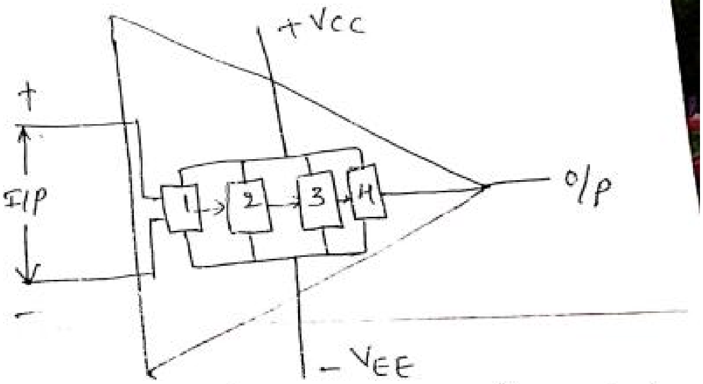
2) Level shifter.

3) Output stage.



1) Input stage

*) In input stage, the first and second stages are cascaded differential amplifiers used to provid high gain.



Block diagram of Op. Amb.

* The differential amplifier amplifies the difference of the input signal.

(i) First stage :-

The first stage is a dual input balanced output differential amplifier. In this configuration two input signals are used and output is balanced because

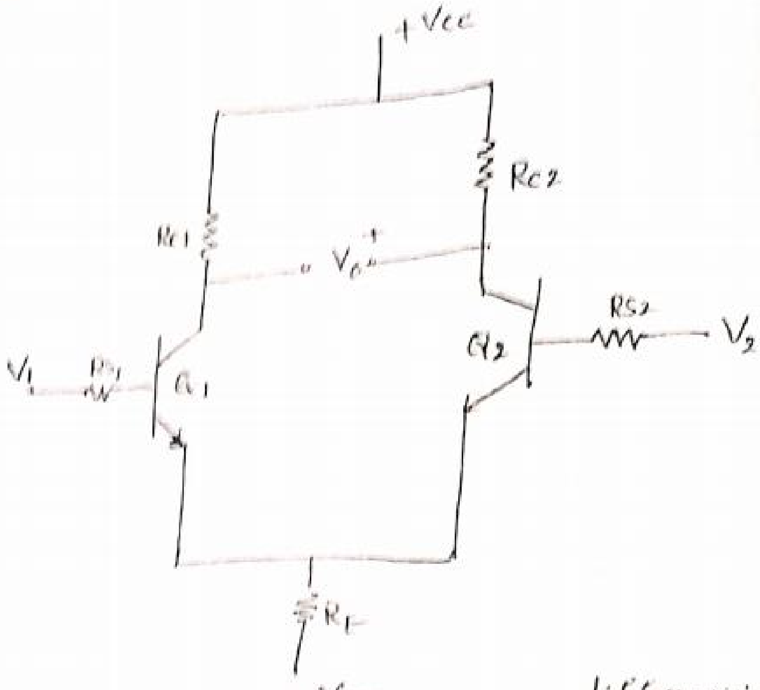
The output is measured between the two collector terminals which are at same DC potential.

*) This stage provides high voltage gain, High CMRR and high input impedance.

*) The CMRR is the ability of cancelling the common signal

*) Requirements of ...

i) High voltage gain
ii) High I/P impedance
iii) Two I/P terminals
iv) Small I/P offset voltage
v) Small I/P offset current
vi) High CMRR
vii) Low bias current



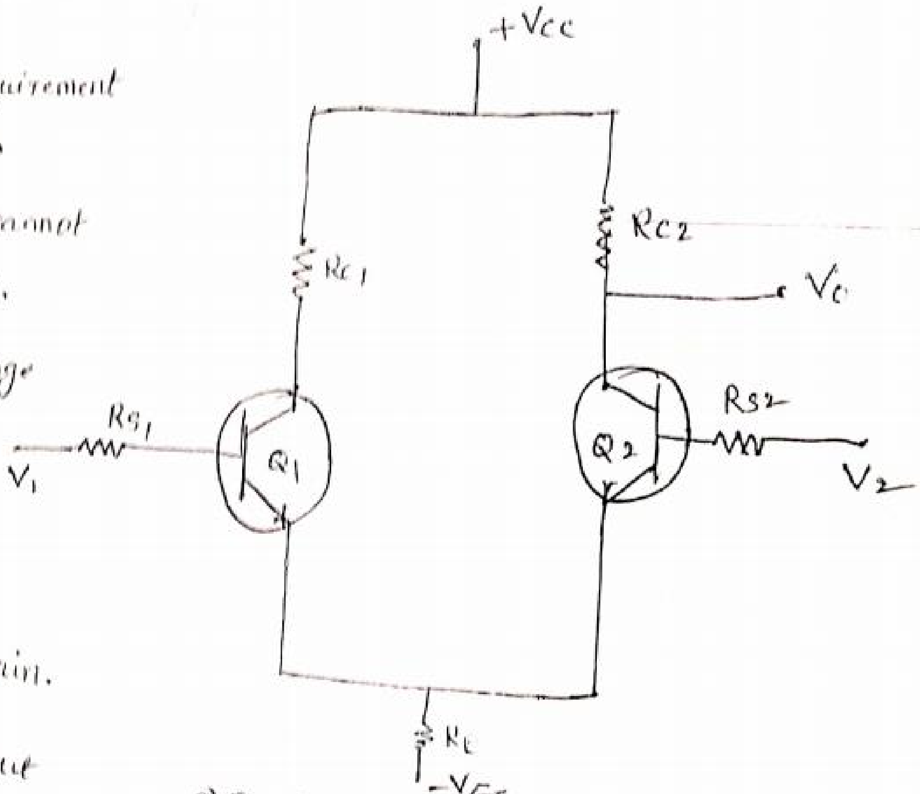
® Dual input balanced output differential amplifier

The overall gain requirement of OP-Amp is very high. Input first stage alone cannot provide such high gain. So, we go for second stage of differential Amplifier.

Second differential ... used with ... be

*) Requirements:

) Very High of Voltage gain.
) Direct coupling without capacitors.



® Dual input unbalanced output differential Amplifier

Second stage of Op Amp is a dual input unbalanced output (4)
differential amplifier. In this configuration two input signals are used and output is measured at one of the collector terminals with respect to ground. It is related to unbalanced output because the collector at which output is measured is at some finite DC potential i.e, there is a DC voltage at the output terminal without any input signal.

*) The second stage provides some additional voltage gain. practically this stage consists of chain of cascaded amplifier called "Multistage amplifier".

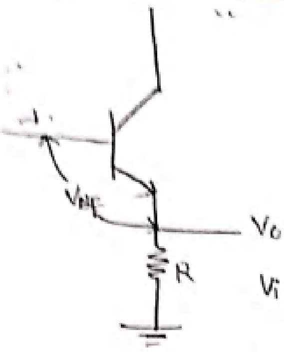
As we are going for direct coupling without capacitors, the dc component is not filtered. Due to that, it is to be also filtered.

There are two reasons for using a level shift in operational amplifier.

(i) Because of direct coupling the amplifier also amplifies the dc signals. as a result the DC level raises from stage to stage. Due to this high voltage levels, the transistors are drives into saturation ~~so that~~ which may cause clipping of the o/p voltage. So that the level shifter is used to shift the DC level to zero with respect to ground, when no o/p signal is applied.

ii) The output should have Quisent voltage level of zero volts for zero input signal for better amplification.

(*) The simplest type of a level shifter is an emitter follower shown in figure.



$V_i = V_{BE} + V_o$
$= 0.7 + V_o$
$V_o = V_i - 0.7$

Fig.(1)

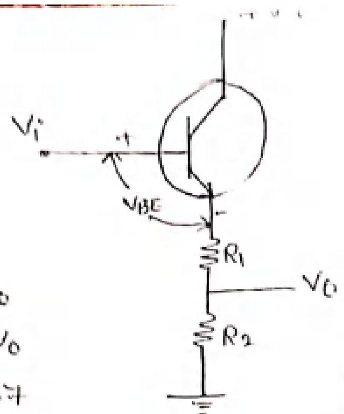
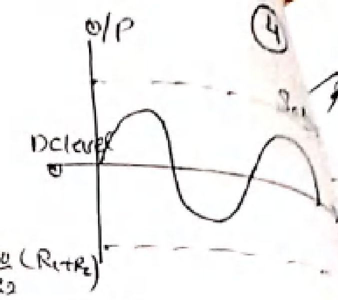


Fig (2)



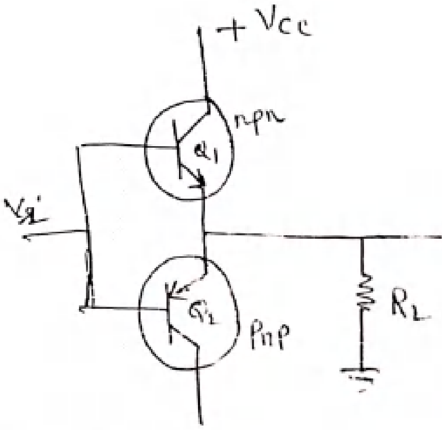
$V_i = V_{BE} + \frac{V_o}{R_2}(R_1+R_2)$

$V_o = \frac{R_2}{R_1+R_2}(V_i - 0.7)$

A Buffer usually used here is an emitter follower with high i/p impedance.

From Fig (i). the amount of shift obtained is $V_o = V_i - 0.7$. This shift is insufficient. So, o/p can be taken at the junction of two resistors R_1 & R_2 as shown in fig(2). Now, shift obtained is $V_o = \frac{R_2}{R_1+R_2}(V_i - 0.7)$

But this arrangement has the disadvantage that the signal voltage also gets attenuated by R_2/R_1+R_2. This disadvantage can be over come by replacing R_2 with current mirror circuit.



The function of the output stage in op-Amp to supply the load current and provide a low o/p impedance.

A simple output stage is an emitter follower with complementary transistors is as shown in the figure.

When Vi is positive, Q_1 is ON and supplies current to the load.
When Vi is negative, Q_1 is off and Q_2 acts as a sink to remove current from R_L.

* The output stage provides :-
  i) Large o/p voltage swing capacity.
  ii) Low o/p resistance.
  iii) Short circuit protection.

independent of R_L. It may
seen that the same current flows through signal source and
d. Therefore, the signal source could be capable of providing
this load current.

Features of 741 op Amp :-

The 741 Op-Amp is originally manufactured by Fairchild and it is sold as μA 741. Where μA represents the manufacturers code.

The 741 Op-Amp is also manufactured by some other manufacturers.

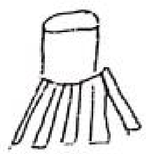
Ex :-

National Semi conductor	LM741
Motorola	MC1741
Texas instruments	SN52741
Signetics	NS741
RCA	CA3741

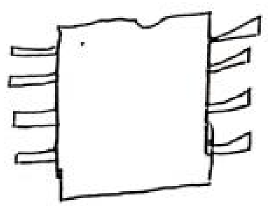
All these op-Amps have same specifications.

→ There are three types of packages.

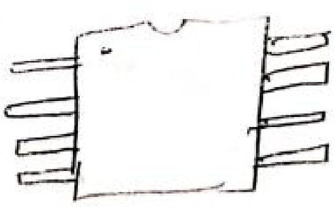
i) The ~~Et~~ Metal Can



(ii) The ~~Metal Can type~~ Dual in line package



(iii) ~~Dual in line package~~ Flat type package



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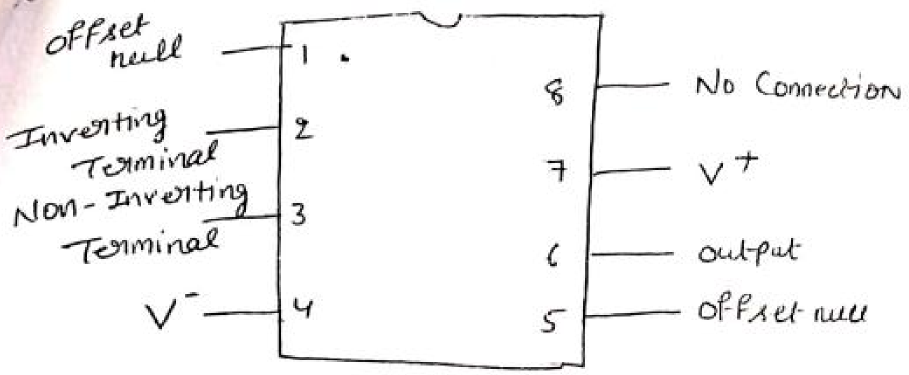


Features :-

i) No Frequency compensation required.

(ii) Short circuit Protection

iii) Offset ~~null~~ voltage null capacity

iv) Lower power Consumption.

v) Large Common mode & differential input voltage range.

Electrical Characteristics of the 741 Op Amp :-

For $V_S = \pm 15V$ at $25°C$

i) Input bias current $I_B = 500nA$ (max)

ii) Input offset current $I_{io} = 200nA$ (max)

iii) Input offset voltage $(V_{io}) = 6mV$ (max)

iv) Input Resistance $(R_i) = 2M\Omega$

v) Output Resistance $(R_o) = 75\Omega$

vi) CMRR = 90 dB

vii) PSRR = $150\mu V/V$

viii) offset voltage drift = $15\mu V/°C$

offset current drift = $200pA/°C$

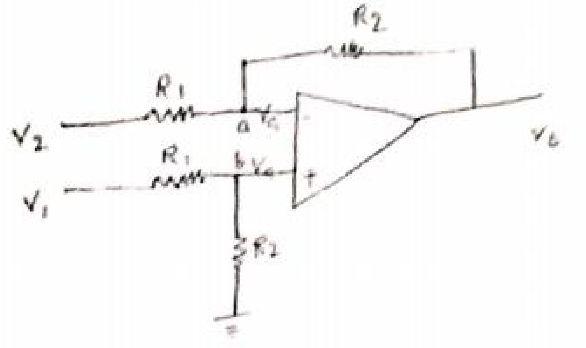
ix) Slew rate = $0.5 V/\mu s$

x) Large signal voltage gain $A_{OL} = 2 \times 10^5$

xi) Power Consumption = 85 mW

Differential Amplifier

The differential Amplifier is an Amplifier which amplifies the difference between the input signals. The differential amplifier circuit is as shown in the figure



Applying KCL at node 'a'

$$\frac{V_a - V_2}{R_1} + \frac{V_a - V_0}{R_2} = 0$$

$$V_a = 0$$

$$-\frac{V_2}{R_1} - \frac{V_0}{R_2} = 0$$

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

$$V_a\left[\frac{1}{R_1} + \frac{1}{R_2}\right] - \frac{V_2}{R_1} - \frac{V_0}{R_2} = 0$$

$$V_a\left[\frac{1}{R_1} + \frac{1}{R_2}\right] = \frac{V_0}{R_2} + \frac{V_2}{R_1} \longrightarrow (1)$$

Apply KCL at node 'b'

~~Applyiying KCL at~~

$$\frac{V_a - V_1}{R_1} + \frac{V_a}{R_2} = 0$$

$$V_a\left[\frac{1}{R_1} + \frac{1}{R_2}\right] - \frac{V_1}{R_1} = 0$$

$$\Rightarrow V_a\left[\frac{1}{R_1} + \frac{1}{R_2}\right] = \frac{V_1}{R_1} \quad \text{--- } (2)$$

From (1) & (2)

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

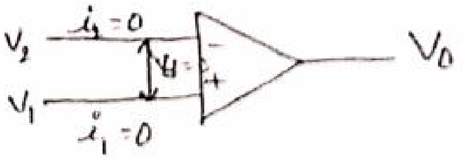
$$\Rightarrow \frac{V_0}{R_2} = \frac{1}{R_1}(V_1 - V_2)$$

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

Therefore, the difference between two input voltage is amplified by $\frac{R_2}{R_1}$ times in the differential Amplifier.

The Ideal Operational Amplifier :

The schematic symbol of an ideal Op-Amp is shown below.



Characteristics :

1) open loop voltage gain $A_{OL} = \infty$
2) Input Impedance $R_i = \infty$
3) Output Impedance $R_o = 0$
4) Band width $BW = \infty$
5) Zero offset i.e, $V_o = 0$ when $V_1 = V_2 = 0$

The above properties can never be realised in practice. There are practical Op Amps that can be made approximate to some of these characteristics.

Feed back

The utility of an OP Amp can be greatly increased by providing negative feedback. There are two feedback connections are used.

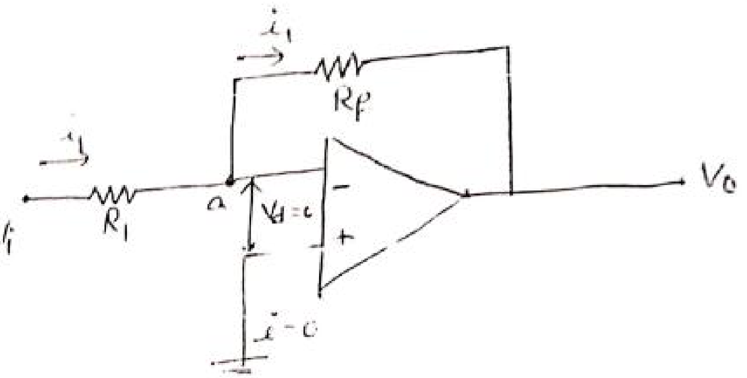
i) Inverting Operational Amplifier.
ii) Non inverting Operational Amplifier.

Concept of Virtual Ground

In electronics, A virtual ground is a node of a circuit that is at a zero potential, without being directly connected to a ground potential.

It is a concept that made for easy explanation and calculation purpose as voltage is approximated to zero in ideal operational Amplifiers.

Inverting operational Amplifier



In this, the output voltage V_o is fed back to the inverting input terminal through the R_f and R_1. Where R_f is the feed back resistor.

Input signal V_i (AC or DC) is applied to the ~~invert~~ input terminal through R_1 and Non-inverting input terminal of Op-Amp is grounded.

Applying KCL at node 'a'.

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

$V_a = 0$ ($\because$ Virtual ground)

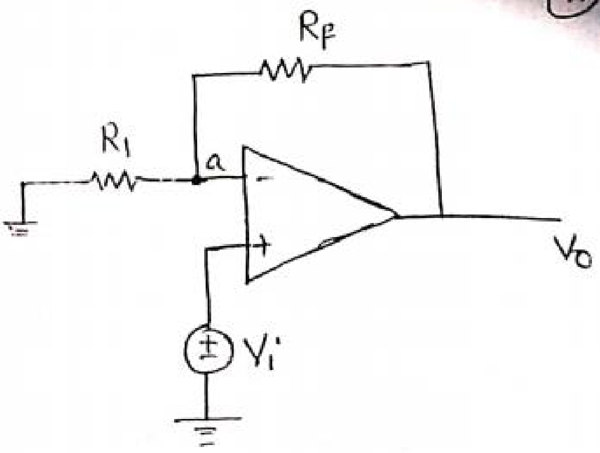
$$\frac{V_i}{R_1} = \frac{-V_o}{R_f}$$

$$\boxed{\therefore A_{CL} = \frac{V_o}{V_i} = -\frac{R_f}{R_1}}$$

- −Ve sign indicates a phase shift of 180° between V_i and V_o.

Inverting Operational Amplifier

The circuit representation of Non-Inverting Amplifier is shown.



Applying KCL at node 'a'

$$\frac{V_i - V_o}{R_F} + \frac{V_i}{R_1} = 0$$

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

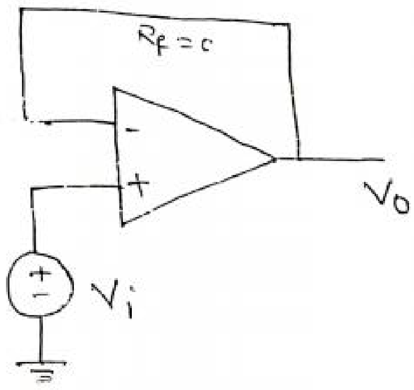
$$\frac{V_o}{R_F} = V_i\left(\frac{R_1 + R_F}{R_1 * R_F}\right)$$

$$\frac{V_o}{V_i} = R_F\left(\frac{R_1 + R_F}{R_1 R_F}\right) \Longrightarrow \frac{V_o}{V_i} = \frac{\cancel{R_1 R_F}}{\cancel{R_1 R_F}} + \frac{R_F * \cancel{R_F}}{R_1 \cancel{R_F}}$$

$$\boxed{\therefore \frac{V_o}{V_i} = 1 + \frac{R_F}{R_1}}$$

$\therefore$ Closed Loop gain for Non-inverting op-Amp is $A_{CL} = 1 + \frac{R_F}{R_1}$

Voltage Follower



For a Non-inverting operational amplifier, if $R_F = 0$ & $R_1 = \infty$ then input voltage follows the output voltage. This circuit is called "Voltage follower."

$R_1 = \infty$

For a Non-inverting op-Amp $A_{CL} = 1 + \frac{R_F}{R_1}$

$$\frac{V_o}{V_i} = 1 + \frac{R_F}{R_1} \quad \text{but } R_F = 0,\ R_1 = \infty, \text{ so}$$

$$\frac{V_o}{V_i} = 1 + \frac{0}{\infty} = 1$$

$$\therefore \frac{V_o}{V_i} = 1$$

$$\boxed{\therefore V_o = V_i}$$

Common mode Rejection Ratio :

The Common mode rejection ratio is the ratio of differential mode gain to the Common mode gain.

$$CMRR\ (\rho) = \left| \frac{A_{DM}}{A_{CM}} \right|$$

Usually it is expressed in decibels.

Ideally A_{DM} must be very large and A_{cm} should be zero.

So, higher the value of CMRR, better is the op-amp.

Power supply rejection ratio :

Power supply rejection ratio is defined as the ratio of the change in input offset voltage due to the change in the supply voltage producing it, keeping other power supply voltage constant.

It is also called as Power supply sensitivity (PSV).

$$PSRR = \frac{\Delta V_{ios}}{\Delta V_{CC}} \Big|_{constant\ V_{EE}}$$

$$PSRR = \frac{\Delta V_{ios}}{\Delta V_{EE}} \Big|_{constant\ V_{CC}}$$

It is also called as Supply Voltage Rejection Ratio.

Characteristics :

Operational Amplifier has two types of characteristics

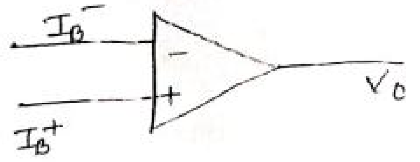
Those are 1) DC characteristics

2) AC characteristics.

DC characteristics :

The DC characteristics are Input bias current, Input offset current, Input offset voltage and thermal drift

In an ideal op amp, we assumed that no current is drawn [from] the input terminals. However, practically, input terminals do conduct [a] small value of dc current to bias the input transistors. The base [cu]rrents entering into the inverting and non-inverting terminals are as shown in I_B^- and I_B^+ respectively. Even though both the transistors are identical, I_B^- and I_B^+ are not exactly equal due to internal imbalences between the two inputs



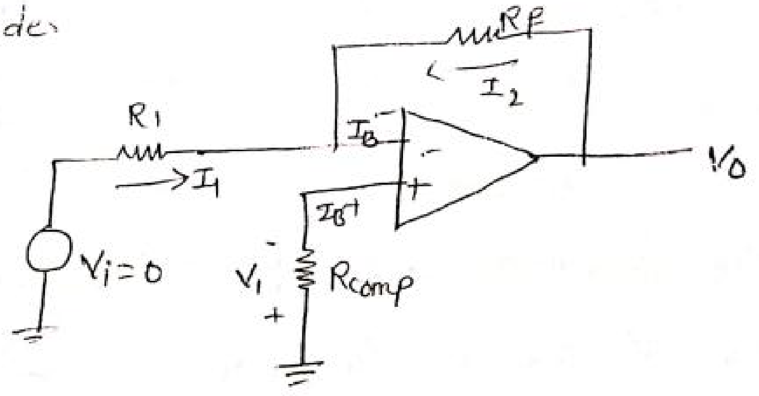
The ~~ne~~ bias current given by the manufacturer can be given as

$$I_B = \frac{I_B^+ + I_B^-}{2}$$

For a 741 op-amp, the bias current is 500 nA (or) less.

Because of this bias current, the voltage at the output terminal is $V_O = (I_B^-) R_F$

To compesate this output voltage because of bias current can be avoided by connecting a compensating resistance at non-inverting terminal side.



$$V_1 = I_B^+ R_{comp}$$

$$I_B^+ = \frac{V_1}{R_{comp}}$$

The node 'a' is at voltage $(-V_1)$, because the voltage at the non-inverting input terminal is $(-V_1)$. So, with $V_i = 0$ we get

$$I_1 = \frac{V_1}{R_1}$$

$$I_2 = \frac{V_2}{R_f}$$

For Compensation, V_0 should zero for $V_i = 0$.

$V_i = V_1 - V_2 = 0$

$V_1 = V_2$

$$\therefore \quad I_2 = \frac{V_1}{R_f}$$

$$I_B^- = I_1 + I_2 = \frac{V_1}{R_f} + \frac{V_1}{R_1} = V_1\left(\frac{1}{R_f} + \frac{1}{R_1}\right) = V_1\left(\frac{R_1 + R_f}{R_1 R_f}\right)$$

Assuming $I_B^+ = I_B^-$

$$\cancel{V_1}\left(\frac{R_1 + R_f}{R_1 R_f}\right) = \frac{\cancel{V_1}}{R_{comp}}$$

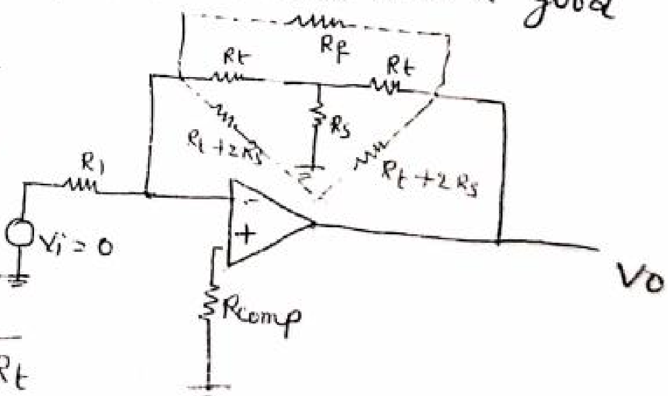
$$\boxed{\therefore R_{comp} = R_1 \,//\, R_f}$$

Bias current compensation will work if both bias currents I_B^+ and I_B^- are equal. Since the input transistors can not be made identical, there will always be some small difference between I_B^+ and I_B^-. This difference is called the offset current I_{os}. and can be written as

$$|I_{os}| = I_B^+ - I_B^-$$

Because of this offset current, the output voltage can be given as $V_0 = R_f I_{os}$.

To Compensate this, the T-feed back network is a good solution. This will allow large feed back resistance while keeping the resistance to ground Low.



By T to π conversion

$$R_f = \frac{R_t^2 + 2R_t R_s}{R_s} \Rightarrow R_s = \frac{R_t^2}{R_f - 2R_t}$$

...t offset voltage:

Input offset voltage is the voltage applied at the input terminals to nulify the output voltage which is due to unavoidable imbalances inside the opamp.

The o/p voltage due to i/p offset voltage is $V_o = \left(1+\frac{R_F}{R_1}\right) V_{ios}$

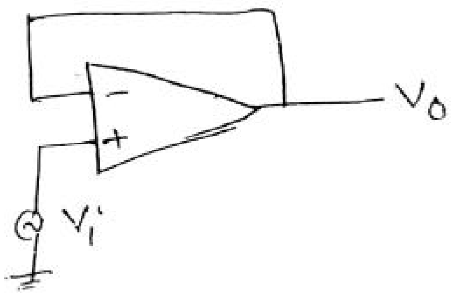
where V_{ios} = input offset voltage

Slew Rate :-

The slew rate is defined as the maximum rate of change of output voltage per unit time and is expressed in Volts/sec. For a 741 OP-Amp, slew rate is 0.5 V/sec.

The slew rate change with i) frequency & Amplitude of i/p signal.
ii) Temperature.
iii) Gain of OP-Amp.

Determination of Slew Rate :-



Let us consider a voltage follower circuit. $V_s = V_m \sin\omega t$

$V_o = V_s = V_m \sin\omega t$

$$\text{Slew rate} = \left.\frac{dV_o}{dt}\right|_{max} = \left.\frac{d}{dt}(V_m \sin\omega t)\right|_{max}$$

$$= \left.\omega V_m \cos\omega t\right|_{max}$$

Cos is maximum at $\omega t = 0$ then $\cos\omega t = \cos 0 = 1$

$\therefore$ Slew rate $= \omega V_m = 2\pi f V_m$ V/μsec

$\therefore$ Slew rate for voltage follower is $2\pi f V_m$ V/μsec

Summing Amplifier :-

Op-Amp may be used to design a circuit whose output is the sum of several input signals. Such a circuit is called a summing Amplifier or 'summer.' The summer is classified as either inverting summer (or) Non-inverting Summer.

Inverting Summer :-

applying KCL

$$\frac{V_a - V_1}{R_1} + \frac{V_a - V_2}{R_2} + \frac{V_a - V_3}{R_3} + \frac{V_a - V_0}{R_f} = 0$$

but for an ideal Op-Amp the potential difference is zero

so $V_a = 0$

$$\frac{0 - V_1}{R_1} + \frac{0 - V_2}{R_2} + \frac{0 - V_3}{R_3} + \frac{0 - V_0}{R_f} = 0$$

$$-\left(\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3}\right) - \frac{V_0}{R_f} = 0$$

$$\frac{V_0}{R_f} = -\left(\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3}\right)$$

$$V_0 = -\left(\frac{V_1 R_f}{R_1} + \frac{V_2 R_f}{R_2} + \frac{V_3}{R_3} R_f\right)$$

if $R_1 = R_2 = R_3 = R_f$

$$V_0 = -(V_1 + V_2 + V_3)$$

Basic applications of OP-Amp :-

The Operational Amplifier has a count less applications. are classified as i) Linear applications

(ii) Non-Linear Applications.

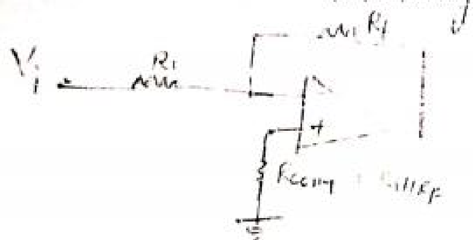
In the Linear Applications the output signal varies with the input signal in a Linear manner. Some Linear Applications are adder, Subtracter, Voltage to Current converter and Current to Voltage Converter, Instrumentation Amplifier ...etc

In Non-Linear Applications the output signal varies with the input signal in a Non-Linear manner. Some Non-Linear Applications are Sample and Hold circuit .. etc

i) Linear Applications :

i) Scale changer / Inverter :

The basic inverting Operational Amplifier is



The gain of the inverting OP-Amp is

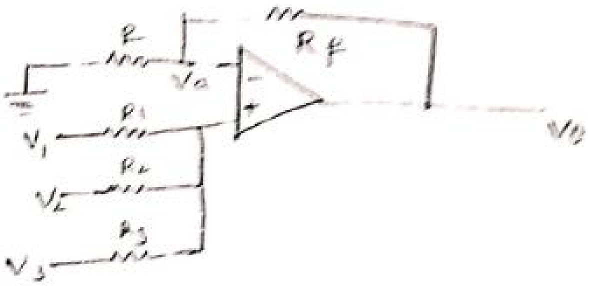
$$A_{CL} = -\frac{R_f}{R_1}$$

if we make $R_1 = R_f$ then $A_{CL} = -1$. then that circuit is called as inverter i.e, the output is 180° out of phase with respect to input through. The magnitudes are same

∴ In this case, the all the input voltages are summed up but inverted.

Non- inverting Summer :-

The circuit diagram representation of Non inverting summer is shown below.



Since voltage at the inverting terminal is Va, and to satisfy the ideal condition i.e, $V_d = 0$, we have to maintain same V_a at '+ve' input terminal

∴ By applying KCL

$$\frac{V_1 - V_a}{R_1} + \frac{V_2 - V_a}{R_2} + \frac{V_3 - V_a}{R_3} = 0$$

$$\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3} - V_a\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right) = 0$$

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

$$\therefore V_a = \frac{\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3}}{\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right)}$$

~~For~~ Non. Let $R_1 = R_2 = R_3 = R$ then

$$\therefore V_a = \frac{\frac{V_1}{R} + \frac{V_2}{R} + \frac{V_3}{R}}{\frac{1}{R} + \frac{1}{R} + \frac{1}{R}} = \frac{\frac{1}{R}(V_1 + V_2 + V_3)}{\frac{3}{R}} = \frac{\frac{1}{R}(V_1 + V_2 + V_3)}{\frac{3}{R}}$$

$$= \frac{V_1 + V_2 + V_3}{3}$$

We know that for Non-inverting Operational Amplifier

Output voltage $V_0 = \left(1 + \frac{R_f}{R}\right) \times V_a$

Let $R_f = 2R$

then $V_0 = \left(1 + \frac{2R}{R}\right) \times V_a$

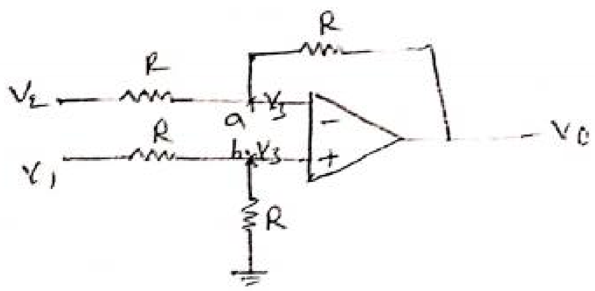
$$= \cancel{3} \times \frac{(V_1 + V_2 + V_3)}{\cancel{3}}$$

$$= V_1 + V_2 + V_3$$

$\therefore$ In the above circuit, if we made $R_1 = R_2 = R_3 = R$, and $R_f = 2R$ then that Non-inverting mode Op-Amp can be used as Adder.

Subtractor :-

The basic differential Amplifier can be used as a Subtractor with all resistors are equal.



Applying KCL at node 'a'

$$\frac{V_3 - V_2}{R} + \frac{V_3 - V_0}{R} = 0$$

$$\frac{V_3}{R} - \frac{V_2}{R} + \frac{V_3}{R} - \frac{V_0}{R} = 0 \Rightarrow \frac{2V_3}{R} - \frac{V_2}{R} - \frac{V_0}{R} = 0 \rightarrow (1)$$

Applying KCL node 'b'

$$\frac{V_3 - V_1}{R} + \frac{V_3}{R} = 0 \Rightarrow \frac{V_3}{R} - \frac{V_1}{R} + \frac{V_3}{R} = 0 \Rightarrow \frac{2V_3}{R} = \frac{V_1}{R} \rightarrow (2)$$

Substituting (2) in (1)

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

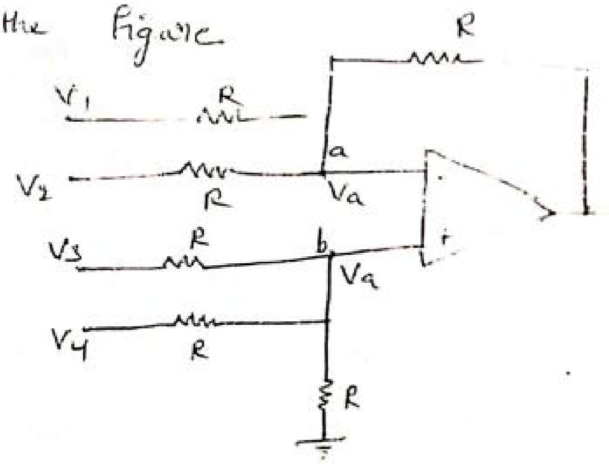
$$\frac{V_1 - V_2}{\cancel{R}} = \frac{V_0}{\cancel{R}}$$

$$\boxed{\therefore V_0 = V_1 - V_2}$$

∴ In this manner, an ~~0~~ differential Amplifier can be working as a Subtractor, if we make all resistors as equal.

Adder - Subtractor :-

The circuit diagram for Adder - Subtractor is as shown in the Figure



$$V_0 = (V_3 + V_4) - (V_1 + V_2)$$

Apply KCL Node 'a'

$$\frac{V_1 - V_a}{R} + \frac{V_2 - V_a}{R} + \frac{V_0 - V_a}{R} = 0$$

$$\frac{1}{R}(V_1 + V_2) + \frac{V_0}{R} - \frac{3V_a}{R} = 0$$

$$\frac{1}{\cancel{R}}(V_1 + V_2 + V_0) = \frac{3V_a}{\cancel{R}}$$

$$\therefore 3V_a = V_1 + V_2 + V_0 \longrightarrow (1)$$

Apply KCL at node 'b'

$$\frac{V_3 - V_a}{R} + \frac{V_4 - V_a}{R} + \frac{0 - V_a}{R} = 0$$

$$\frac{1}{R}(V_3 + V_4) - \frac{3V_a}{R} = 0$$

$$\frac{1}{\cancel{R}}(V_3 + V_4) = \frac{3V_a}{\cancel{R}}$$

$$\therefore 3V_a = V_3 + V_4 \quad \text{---} \quad (2)$$

From (1) & (2)

$$V_1 + V_2 + V_0 = V_3 + V_4$$

$$\boxed{\therefore V_0 = (V_3 + V_4) - (V_1 + V_2)}$$

$\therefore$ The above circuit can be used ~~as~~ ~~for~~ as ~~both~~ for both Adder - subtractor circuit.

Instrumentation Amplifier :-

In a number of industrial and consumer applications, one is required to measure and control physical quantities. Some typical examples are measurement and control of temperature, humidity light intensity, water flow. etc. These physical quantities are usually measured with the help of transducers. The output of transducer has to be amplified that it can drive the indicator (or) display system. This function is performed by an instrumentation amplifier.

The features of instrument amplifier is as shown below

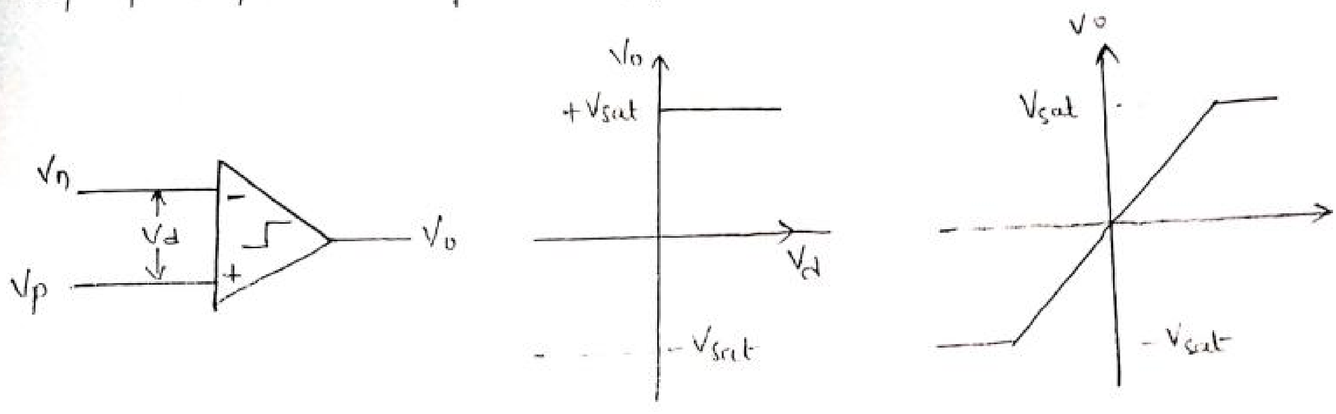
i) High gain Accuracy

ii) High CMRR

iii) Hi...

Comparator

A comparator is a circuit, which compares an input signal with a known reference voltage. It is basically an open loop op-Amp with output $\pm V_{sat}$



Comparator signal | Ideal & practical characteristics | Comparator transistor

The comparator operation can be expressed as

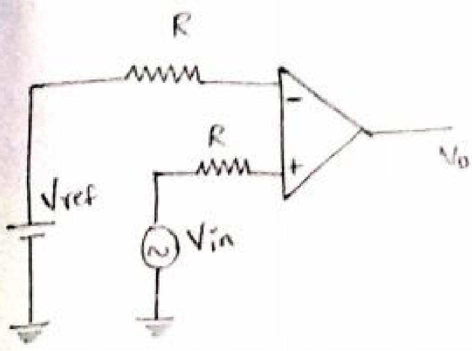
$V_o = +V_{sat}$ for $V_p > V_n$

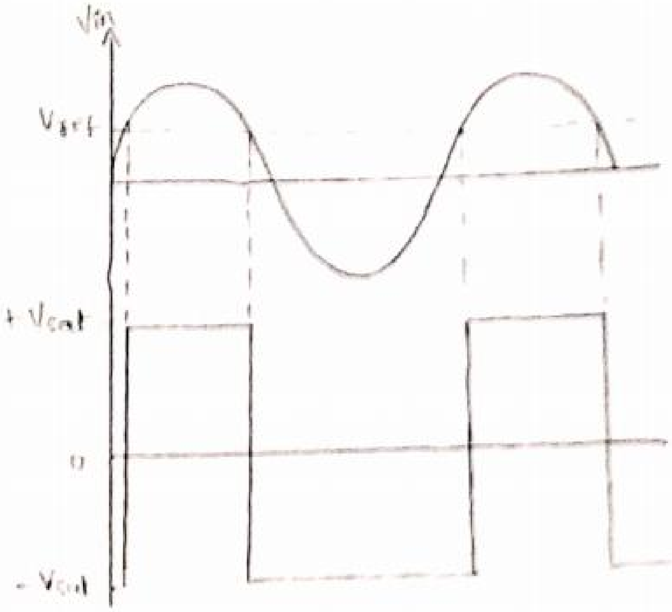
$V_o = -V_{sat}$ for $V_p < V_n$

⇒ For all possible V_p & V_n values, V_o is restricted to only two values $+V_{sat}$ & $-V_{sat}$. Thus the comparator accepts analog signals at the input and produces a binary signal at the output.

⇒ In ideal transfer characteristics of comparator, the vertical line indicates the infinite gain. practical op-Amp gains are typically in the range 10^3 to 10^5

(a) Non-Inverting comparator





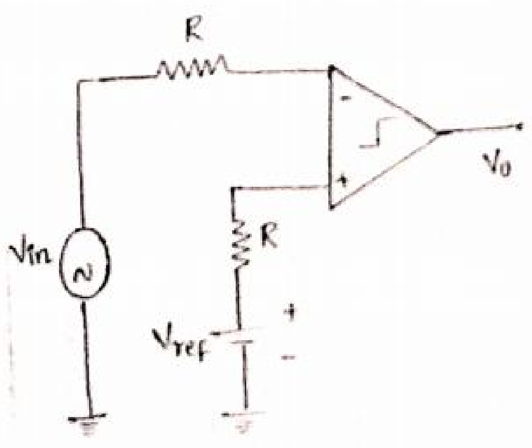
Here input signal is applied to the non inverting terminal and a reference voltage V_{ref} is applied to the inverting terminal.

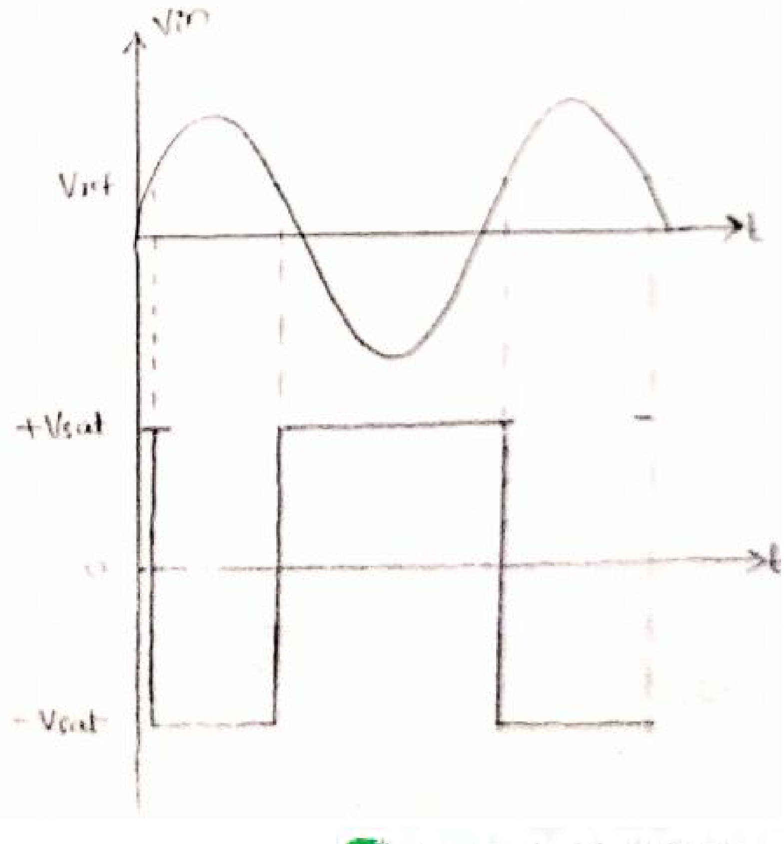
If input voltage is above V_{ref}, then output at high state ($+V_{sat}$)

The output voltage $V_o = +V_{sat}$ for $V_{in} > V_{ref}$

$V_o = -V_{sat}$ for $V_{in} < V_{ref}$

Inverting Comparator :





Here the input signal is applied to inverting termi. and a reference voltage V_{ref} is applied to non inverting termi.

If the input voltage is above the V_{ref} then output is at low state ($-V_{sat}$).

The output voltage $V_o = -V_{sat}$ for $V_{in} > V_{ref}$

$V_o = +V_{sat}$ for $V_{in} < V_{ref}$.

Application of comparator :

(1) Zero crossing detector

(2) Window detector

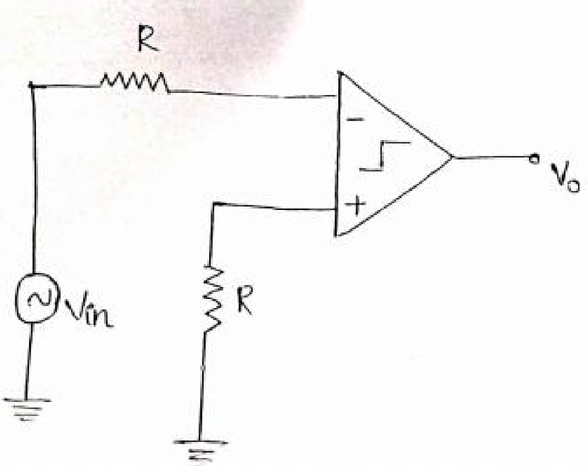
(3) Time maker generator

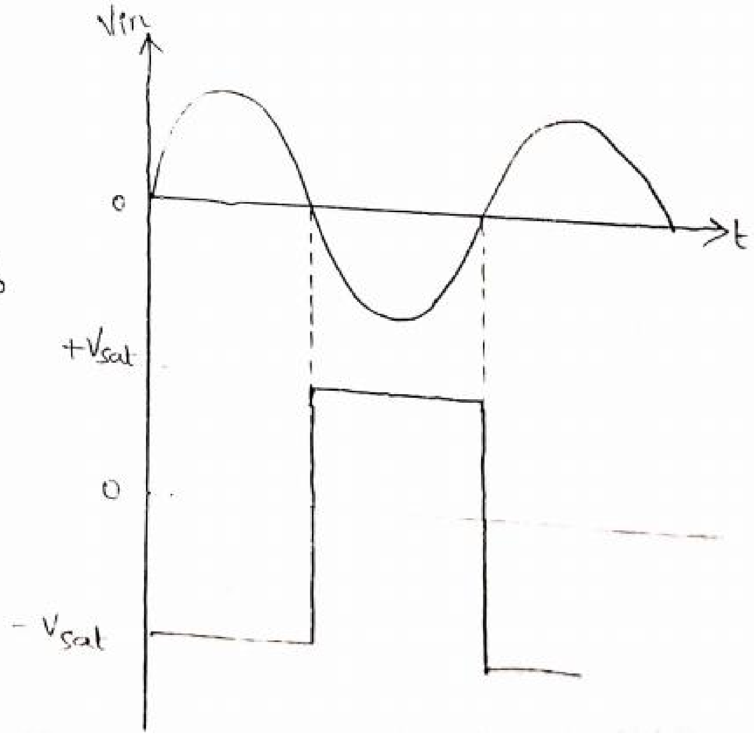
(4) phase detector

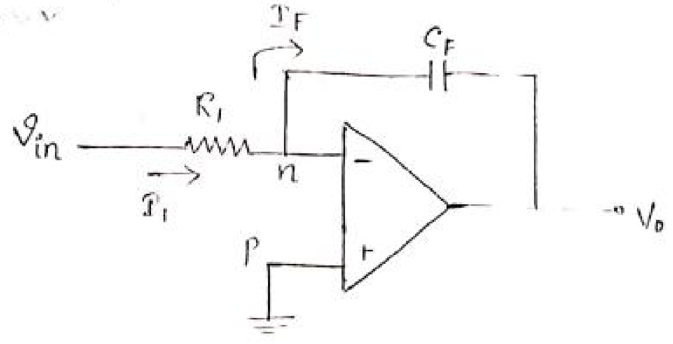
(5) Voltage limiters

(1) Zero crossing detector.

In the basic comparator circuit, if $V_{ref} = 0$ then, the output will change from one state to another state every time when input passes through zero.







Integrator circuit

From figure,

Apply KCL at node 'n'

$$I_1 = I_F$$

$$\frac{v_{in} - v_n}{R_1} = C_F \frac{d}{dt}(v_n - v_0)$$ $\because$ [The current through the capacitor $i = c\frac{dv}{dt}$]

$$\frac{v_{in}}{R} = -C_F \frac{d}{dt} v_0 \quad (\because V_n - V_p = 0)$$

$$\frac{d}{dt}(V_0) = -\frac{1}{R_1 C_F} V_{in}$$

Taking integration on both sides

$$\boxed{v_0 = -\frac{1}{R_1 C_F}\int v_{in}\,dt + V_c(0)} \quad \text{—— (1)}$$

where $V_c(0)$ is the integration constant & the value of V_0 at $t=0$.

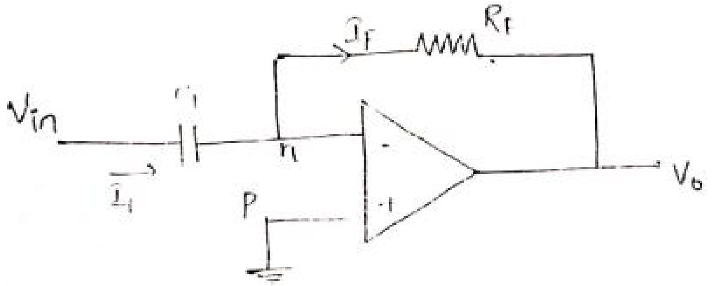
From eq (1), $V_0(t)$ is directly proportional to the negative integral of $V_{in}(t)$

$V_0(t)$ is inversely proportional to the time constant $R_1 C_F$.

Examples

V_{in}	V_0
Sine wave	Cosine wave
Square wave	Triangular wave
step input	Ramp signal

This circuit performs the mathematical operation of differentiation i.e., the output wave is the derivation of input waveform. If R_1 and C_F of the integrator are interchanged as shown in figure we obtain a differentiation for circuit.



Apply KVL at node 'n'

$$I_c = I_F$$

$$C_1 \frac{d}{dt}(V_{in} - V_n) = \frac{V_n - V_o}{R_F}$$

$$C_1 \frac{dV_{in}}{dt} = -\frac{V_o}{R_F}$$

$$V_o = -R_F C_1 \frac{dV_{in}}{dt}$$

Hence the output is the differentiation of input.

Transfer function

Apply Laplace transform to eq(1) on both sides

$$V_o(s) = -R_F C_1 s\, V_{in}(s)$$

Transfer function $\frac{V_o(s)}{V_{in}(s)} = -s R_F C_1$

$$T(jw) = -jw R_F C_1$$

Gain $|T(jw)| = w R_F C_1$

The frequency at which gain $=1$ is $W_0 = \frac{1}{R_F C_1}$