Op-Amps :-

An operational Amplifier or Op-Amps is a voltage amplifying device.

It is basically a multistage direct coupled high gain differential amplifier with high i/p impedance & low o/p impedance.

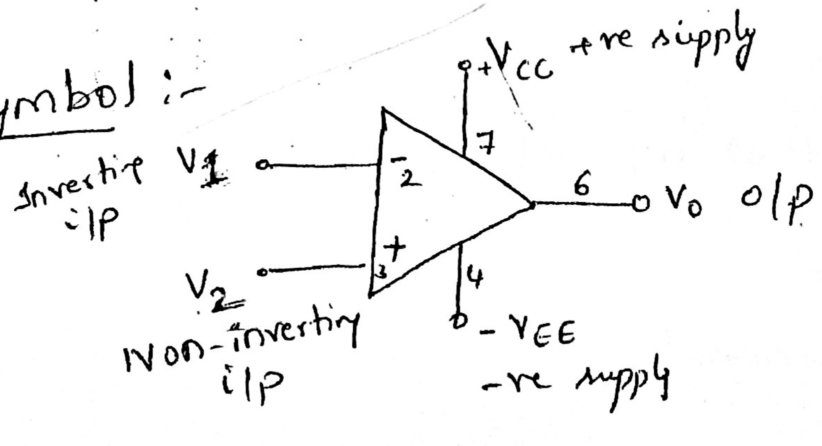
→ It is used to amplify DC and AC signals.

→ It is a device that is used to amplify a signal using an external power source.

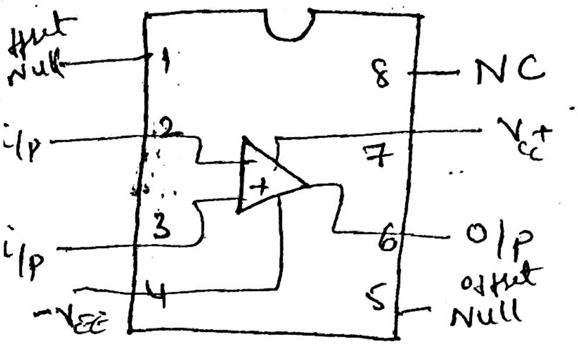
→ It amplifies the difference b/n two i/p signals applied across its i/p. Hence it is also called as difference amplifier.

→ Op-Amps are generally composed of :- Transistors, Resistors, capacitors.

→ Symbol :-



→ Pin details of Op-Amp :- (IC 741)



V_2 :- Non-inverting i/p

V_1 :- Inverting i/p

V_o :- o/p

$+V_{cc}$:- positive power supply

$-V_{EE}$:- -ve —"—

$$V_{out} = gain\,(V_+ - V_-) \quad \text{(open loop)}$$

$$= A_v\,(V_+ - V_-)$$

→ so if V_+ is greater than V_-, the o/p goes +ve

if V_- is greater than V_+, the o/p goes -ve

if $V_2 = V_1$, v_o is zero

→ Typically A_v is very large value around 10,000.

→ variation of o/p voltage :-

if $V_2 = 0$, then $V_o = A(V_2 - V_1)$

$$= -AV_1$$

so that o/p voltage is out of phase with i/p voltage. ∴ it is called as inverting i/p terminal.

if $V_1 = 0$, then

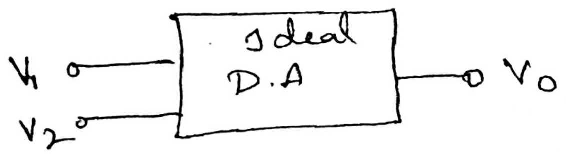
$$V_0 = A_V (V_2 - V_1)$$

$$V_0 = A_V V_2$$

i.e., o/p voltage is in phase with i/p voltage.

$\therefore$ it is called as non-inverting i/p.

* Ideal differential amplifier :-



→ The fig shows the symbolic representation of differential amplifier.

Let V_1, V_2 are the two i/p's, V_0 is the o/p

$\therefore$ for an ideal differential amplifier op-amp the o/p voltage is directly proportional to diff b/w two i/p voltages.

i.e, $V_0 \propto (V_2 - V_1)$

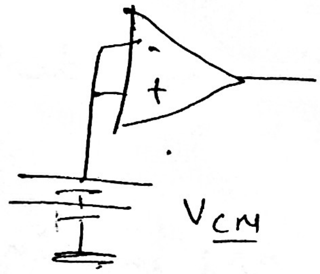
$$\therefore V_0 = A (V_2 - V_1) \quad \text{--- (1)}$$

A → proportionality constant which is equal to gain of the D.A plifier

ie, from Eqn (1)

$V_o = A_c (V_2 - V_1)$

But $V_2 = V_1$



$\therefore V_o = 0$

But the o/p voltage of practical amplifier not only depend on difference b/n two i/p voltages but also depends on the avg common level of the two i/p signals.

Such avg level of the two i/p signals is called as common mode signal (V_c).

$\therefore V_c = \frac{V_1 + V_2}{2}$ —— (4)

$\therefore$ Practically, the D.A produces the o/p voltage proportional to CMS. The gain which it amplifies the CMS to produces the o/p is called CM gain (A_c)

$\therefore V_o = A_c V_c$ —— (5)

$\therefore A_c = \frac{V_o}{V_c}$ —— (6)

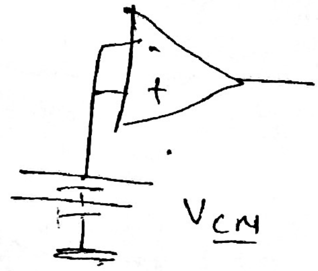
The total o/p voltage of any d.A is expressed as sum of o/p voltage under differential mode & o/p voltage under common mode

(5)

ie, from Eqn (1)

$$V_o = A_c (V_2 - V_1)$$

But $V_2 = V_1$



$$\therefore \underline{V_o = 0}$$

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The total o/p voltage of any d.A is expressed as sum of o/p voltage under differential mode & o/p values under common mode

$$\therefore \quad V_o = A_d V_d + A_c V_c \quad \text{—— (7)}$$

For ideal op-amp, $A_d = \infty$ $\left(\because A_d = \frac{V_o}{V_d}\right.$

V_d is very small compared to V_o).

while $A_c = 0$ $(\because V_1 = V_2)$

→ **Common Mode Rejection Ratio (CMRR):-**

It is the ability of DA to reject the common mode signals.

It is defined as the ratio of differenital mode gain to the common mode gain.

$$\text{i.e.,} \quad CMRR = \rho = \left| \frac{A_d}{A_c} \right|$$

Problems:-

(i) For a d.a with i/p voltages are 600 µV & 480 µV. The d.a gain of the amplifier is 10,000. Find the o/p voltage for the following CMRR (i) CMRR = 200 (ii) CMRR = 10^8

Soln:- $V_1 = 600\,\mu V$; $V_2 = 480\,\mu V$ & $A_d = 10000$

(i) CMRR = 200

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

$$\therefore \quad 200 = \frac{10000}{A_c}$$

$$\underline{A_c = 50}$$

$$V_c = \frac{V_1 + V_2}{2} = \frac{(600 + 480)\,\mu V}{2} = \underline{540\,\mu V}$$

$|||^{ly}$ $V_d = V_1 - V_2 = \underline{120\,\mu V}$

$$\therefore \quad V_o = A_d V_d + A_c V_c$$

$$= (10{,}000 + 120\mu) + (50 \times 540\,\mu V)$$

$$= \underline{1227\,mV} \quad \text{or} \quad 1.227V$$

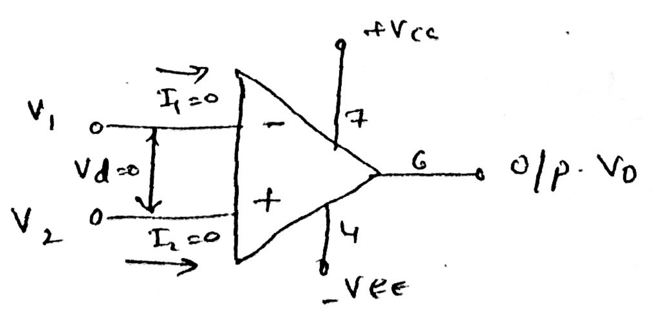
(ii) $CMRR = 10^8$

$A_c = 10^{-4}$

$V_c = 540\,\mu V \quad ; \quad V_d = 120\,\mu V$

$\therefore \; V_o \simeq \underline{1.2V}$

<u>Ideal characteristics of an Op-Amp</u> :-



if we supply two i/p's to the two i/p terminals, ideal op-amp draws no current ie, $I_1 = I_2 = 0$.

$\therefore$ i/p impedance $= \infty$

$V_d = V_2 - V_1 = 0$

It produces finite o/p voltage $\therefore$ gain is ∞.

The o/p V_o is independent of current drawn from the o/p terminal. $\therefore$ o/p impedance is zero & can drive an infinite no of other ckts.

(a) Infinite voltage gain ($A_{OL} = \infty$) :-

$$A_{OL} = \frac{\text{Finite o/p voltage}}{\text{Zero diff voltage}}$$

$$= \frac{V_o}{V_d} = \frac{V_o}{0} = \infty$$

(b) Infinite i/p Impedance ($R_{in} = \infty$)

$I_1 = I_2 = 0$

ie, it indicates V_2 & V_1 are open ckt'd.

$\therefore$ open ckt impedance is high & it is approximately ∞.

(c) Zero o/p impedance ($R_o = 0$) :-

$$R_o = 0$$

(d) Zero Off-set voltage ($V_{os} = 0$) :-

$$V_{os} = 0$$

The presence of small o/p voltage even when both the i/p voltages are at gnd potential. i.e $V_1 - V_2 = 0$

(e) Infinite Bandwidth ($BW = \infty$) :-

$$BW = \infty$$

$f = 0$ to ∞ Hz

$\therefore$ gain is const.

(f) CMRR (ρ) :-

$$\rho = \infty$$

(g) Slew rate :- (S)

It is defined as max rate of change of o/p voltage with time. It is expressed in V/μsec.

$$S = \frac{dv_o}{dt}\Big|_{max}$$

$$= \infty$$

(h) Effect of Temperature :-

The chara of ideal op-amp will not change with temperature.

(i) Power supply rejection ratio (PSRR) :-

It is also called as power supply sensitivity

It is defined as the ratio of the change in i/p offset voltage due to the change in any one supply voltage by keeping other constant.

ie, if V_{EE} is const & due to change in V_{CC}, there is change in i/p offset voltage then PSRR is expressed as,

$$PSRR = \frac{\Delta V_{ios}}{\Delta V_{CC}}$$

or

$$PSRR = \frac{\Delta V_{ios}}{\Delta V_{EE}}$$

It is expressed as mV/V & its ideal value is zero.

ms :

If the base currents for the emitter coupled transistors of DA is 15 μA & 20 μA, determine the i/p bias current (I_b) & I_{ios}.

Soln :- $I_{b1} = 15\mu A$; $I_{b2} = 20\mu A$

$\therefore I_b = \dfrac{|I_{b1}| + |I_{b2}|}{2} = \underline{17.5\mu A}$

$I_{ios} = |I_{b2} - I_{b1}| = \underline{5\mu A}$

(2) For an op-Amp, the I_{ios} is 30nA while $I_b = 60nA$. Calculate two i/p bias current.

soln :- $I_{ios} = |I_{b2} - I_{b1}|$; $I_b = \dfrac{I_{b1} + I_{b2}}{2} = 60nA$

$= \underline{30nA}$ — (1)

$I_b = I_{b1} + I_{b2} = \underline{120nA}$ — (2)

$30nA = I_{b2} - I_{b1}$

$I_{b2} = 30nA + I_{b1}$ — (3)

Substitute (3) in (2)

$120nA = I_{b1} + 30nA + I_{b1}$

$\underline{2I_{b1} = 90nA}$

$\underline{I_{b1} = 45nA}$

$\therefore \underline{I_{b1} + I_{b2} = 120nA}$

$I_{b2} = 120 - I_{b1}$

$= (120 - 45)\,nA$

$= \underline{75nA}$

(j) :- I/p bias current (I_b) :-

$$I_b = \frac{|I_{b1}| + |I_{b2}|}{2}$$

$$I_b = 0$$

(K) I/p offset current (I_{ios}) :-

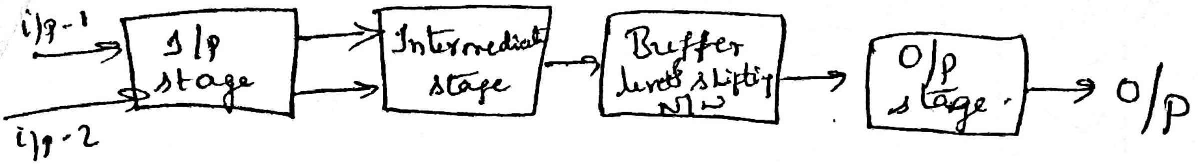
$$I_{ios} = |I_{b2} - I_{b1}|$$

$$I_{ios} = 0$$

* Comparision b/n ideal & practical op-amp (μA741) :-

	Chara	Ideal	practical
1.	A_{OL}	∞	2×10^5
2.	Z_{in} or R_{in}	∞	2 MΩ
3.	Z_{out}	0	75 Ω
4.	V_{ios}	0	2mV
5.	B.W	∞	1MHz
6.	CMRR	∞	90dB
7.	Slew rate	∞	0.5 V/μs
8.	I_b	0	80nA
9.	I_{ios}	0	200nA

ock-diagram of IC-Op-amp :-



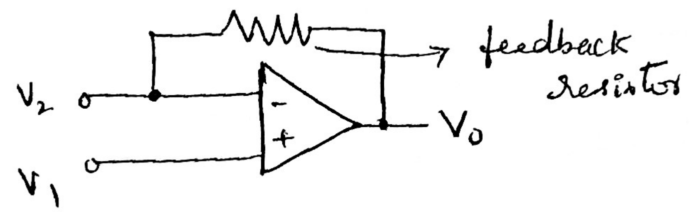
* I/P stage :- The 1st stage is a dual i/p balanced differential amplifier used for providing very high gain of the order 60dB, in order to increase CMRR & i/p impedance of an op-amp.

* Intermediate stage :- This stage is a dual i/p unbalanced diff amplifier which is driven by the o/p of the first stage.
This stage provides the half the gain provided by the first stage & has two i/p terminals, single o/p terminal so this type of amplifier is called as unbalanced amplifier.

level shifting stage :- It is usually an emitter follower CKt used to shift the dc level at the o/p of the intermediate stage of the Op-Amp to zero volts w.r.t gnd.
This stage amplifies both ac aswell as dc signals due to absence of capacitance coupling, hence a small amount of dc component will be present at the o/p of the first stage & this dc component will be amplified by stage & drives the transistor into saturation. This causes the o/p w/f to be distorted & dc shift will be present. In order to reduce distortion & dc shift we use level shifter in the third stage.

O/p stage :- The basic requirements of an o/p stage are low impedance, large AC o/p voltage swing & high current sourcing & sinking capability.
(64) The push-pull complementary amplifier meets all these requirements & hence used as ~~o/p~~ ... the voltage swing symmetrical w.r.t to gnd.

* Closed loop Configuration of Op-Amp:-



* The advantages of -ve f/b are

→ It reduces the gain & makes it controllable.

→ " —— the possibility of distortion

→ It ↑ the B.W

→ It ↑ the R_i

→ It ↓ the R_o

* Concept of Virtual short in an Op-Amp :-

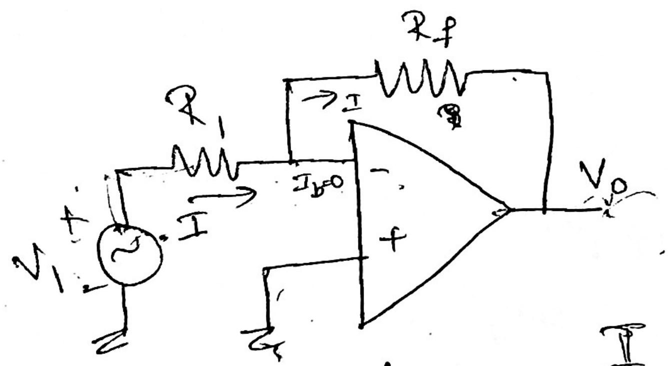
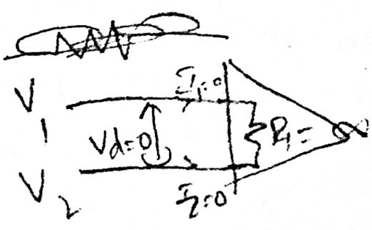


fig (a)



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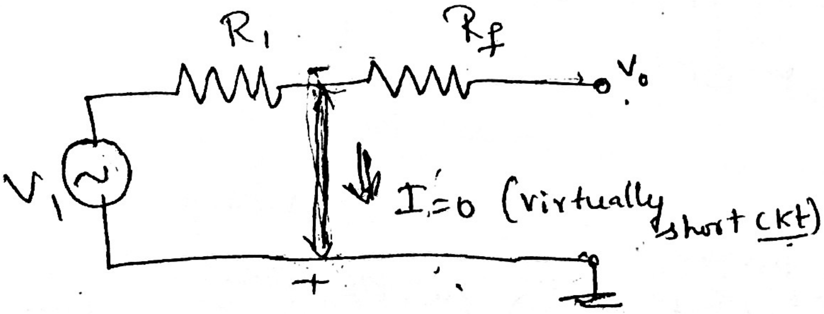
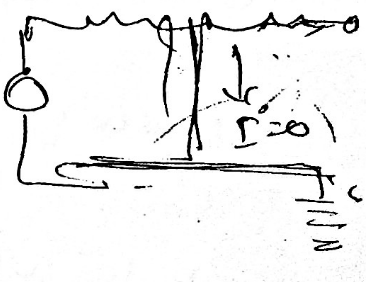


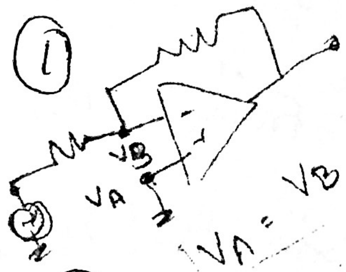
fig (b)



W.K.T differential i/p voltage at i/p terminal of Op-Amp is essentially zero.

Since Open loop gain of Op-Amp is very large & even for a small o/p voltage the Op-Amp difference i/p voltage is approximately zero.

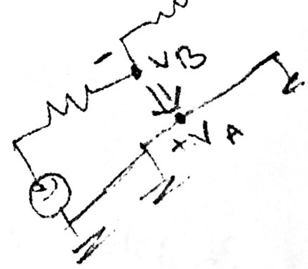
$$\therefore A_{OL} = \frac{V_o}{V_d} \quad \text{--- (1)}$$



$$V_o = A_{OL} V_d \quad \text{--- (2)}$$

or $$V_d = \frac{V_o}{A_{OL}}$$

$V_o = 10V$, $A_{OL} = 10^4$, $V_d = V_o / A_{OL} = 10/10^4 = 1mV$



But $V_d = V_2 - V_1$.

$(V_2 - V_1) = V_1 - V_2$

$$\therefore V_2 - V_1 = \frac{V_o}{A_{OL}}$$

When $A_{OL} \to \infty$, $V_d \Rightarrow 0$

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

$\therefore$ voltage at inverting terminal $V_2 = V_1$ voltage at non-inverting terminal. --- (3)

$\boxed{V_1 = V_2}$

From Eqn (3) the voltage at inverting terminal is always equal to the voltage at the non-inverting terminal.

Hence both the i/p terminals are virtually short as shown in the fig(b), but no current flows throu[gh] the virtually short ckt branch ie, there is no physi[cal] connection b/n inverting & non-inverting i/p terminals which is called virtual gnd concept.

Op-Amp Applications

* From fig(b) the non-inverting terminal is directly connected to gnd ~~too~~ due to virtual gnd concept the voltage at inverting terminal is also equal to zero.

* When open loop gain of the op-amp is very large & the o/p of the op-amp is very low, then we say that the potential at inverting terminal i/p is equal to potential at non-inverting i/p & there exists a short called virtual short.

Real short	virtual short
* Current flows b/n two pts which are really shorted	* Current cannot flow b/n two pts which are ~~really~~ virtually shorted.

Op-Amp Applications :-

Applications are classified as

- → Linear
- → Non-line

* linear Application :- In this type the o/p voltage of an Op-Amp varies linearly with r.t. i/p voltage.
* The -ve f/b is the base of linear applications.

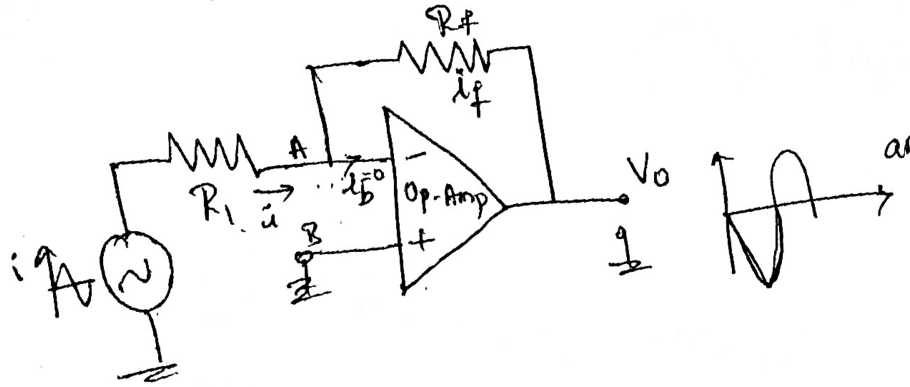
Examples :- voltage follower, diff amplifier, Inverting & non-inverting amplifiers etc

* Non-linear applications :-

A f/b is provided from o/p terminal to either inverting i/p or non-inverting i/p terminal using non-linear elements like diode, transistors etc.

Examples :- Comparators, Clampers, limiters etc.

* Inverting Amplifier :-



* An inverting amplifier is a closed loop amplifier in which the i/p is applied to the inverting terminal i/p.

* The o/p of the amplifier is out of phase by 180° w.r.t the i/p.

Now applying KCL at the node 'A' we get,

$$i = i_b + i_f \quad — (1)$$

here $i_b = 0$ ∵ ideal op-amp has an ∞ R_i & hence current drawn will be zero.

$$\therefore i = i_f \quad — (2)$$

Apply Ohm's law to find currents i & i_f we get

$$\frac{V_i - V_A}{R_1} = \frac{V_A - V_o}{R_f} \quad — (3)$$

But $V_A = V_B = 0$ $\because$ from virtual concept

then Eqn (3) becomes,

$$\frac{V_i}{R_1} = \frac{-V_o}{R_f} \quad \text{--- (4)}$$

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

The factor $\frac{V_o}{V_i}$ is called closed loop gain A_F

$$\therefore A_F = \frac{-R_f}{R_1}$$

- sign means that the closed loop amplifier provides phase shift of 180° from i/p to o/p.

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

If $R_f > R_1$, gain > 1

$R_f < R_1$, gain < 1

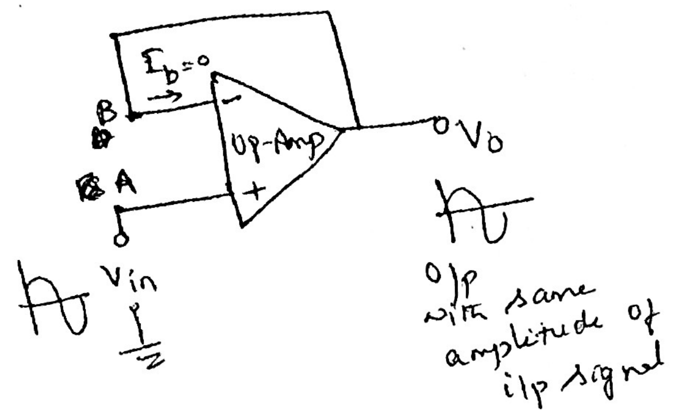
$R_f = R_1$, gain is unity

or $V_o = A_F V_i$

* Here the closed loop gain is the ratio of two resistors R_f & R_1.

This means the gain can be changed by changing the values of R_f & R_1.

* voltage follower :-



This - o/p voltage

* In an amplifier, if the o/p voltage is equal to the i/p voltage it is called voltage follower (or), unity gain amplifier (or) emitter follower.

* From the Ckt, the i/p is applied at non-inverting i/p of the op-amp.

The o/p of the amplifier & the inverting i/p is shorted ∴ from the Ckt the voltage from A'A' is equal to o/p voltage V_0.

$$\therefore V_A = V_0 \quad \text{— (1)}$$

But $i_B = 0$

$$\therefore V_i = V_B \quad \text{— (2)}$$

$$\therefore V_A = V_B \quad \text{— (3)}$$

from (1) & (2)

$$V_0 = V_i$$

(##)

This ckt is called as voltage follower because the o/p voltage is equal to & inphase with i/p voltage.

∴ The voltage gain is given by,

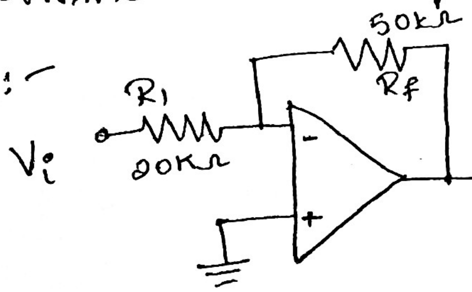
$$A_v = \frac{V_o}{V_i} = \frac{A}{A+1} \quad \text{where } A >> 1$$

neglecting unity in the Eqns

$$A_v = \frac{V_o}{V_i} = \frac{A}{A} = 1$$

Problems:-

(1) Determine the voltage gain of the Op-Amp ckt shown below:-



soln:-

$$A_v = \frac{V_o}{V_i} = \frac{-R_f}{R_1} = \frac{-50K}{20K} = -2.5$$

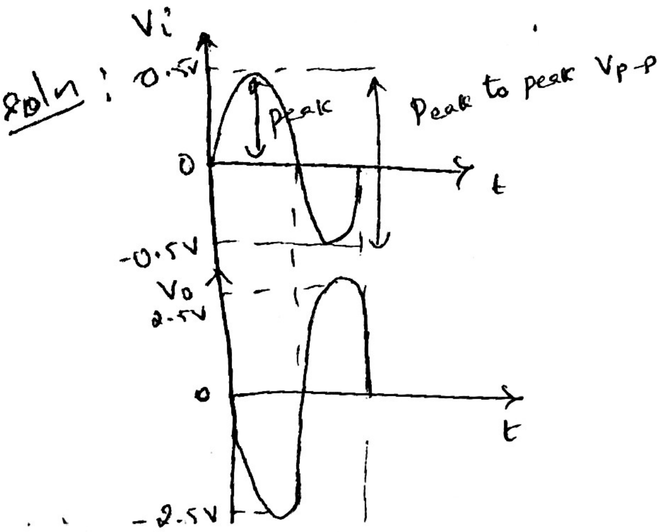
Gain in dB = A_v (dB)

$= 20 \log (A_v)$

$= 20 \log (2.5) = 7.95 \text{dB}$

2) A sine wave of 0.5 peak voltage is applied to inverting amplifier using $R_1 = 10K\Omega$ & $R_f = 50K\Omega$. If the supply voltage of $\pm 12V$. Determine the o/p voltage & sketch the w/f. If now the amplitude of i/p sine wave is ↑ to 5V what will be the o/p? Is it practically possible? Sketch the waveform.

Soln:



$$A_v(dB) = \frac{-R_f}{R_1} = \frac{-50K}{10K} = -5$$

when $V_i = 0.5V$ (peak)

$$\therefore \frac{V_o}{0.5} = -5$$

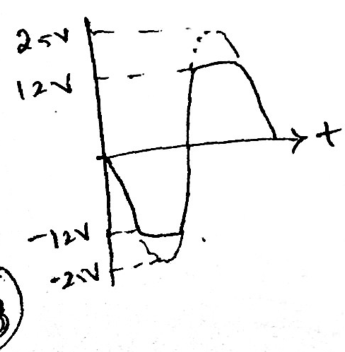
$$\therefore V_o = -0.5 \times 5 = -2.5 \text{ (peak)}$$

when $V_i = 5V$, then

$$A_v = \frac{V_o}{V_i} = -5$$

$$\frac{V_o}{5} = -5$$

$$\therefore V_o = -5 \times 5 = -25V \text{ (peak)}$$



$V_o = A_d(V_2 - V_1)$
↓
∞

so o/p doesn't vary for [illegible]
it is limited by the power supply

(10.0) 90)

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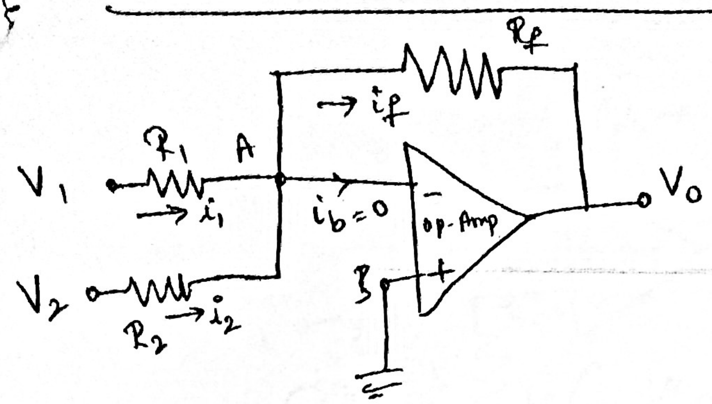
Inverting Summer or Adder:-



* If two or more i/p signals are applied to inverting terminal of Op-Amp, the O/P is sum of these i/p's this is called inverting Summer.

* Let V_1 & V_2 be the i/p voltages applied to inverting i/p of an Op-amp through R_1 & R_2.

* The f/b resistor R_f Connected b/n o/p to inverting i/p of Op-Amp & non-inverting i/p terminal is gnd.

Now applying KCL at node 'A' we get,

$$i_1 + i_2 = i_f + i_b \quad —— (1)$$

But $i_b = 0$

$$\therefore \quad i_1 + i_2 = i_f \quad —— (2)$$

Now applying Ohm's law to find Currents

$$\frac{V_1 - V_A}{R_1} + \frac{V_2 - V_A}{R_2} = \frac{V_A - V_o}{R_f} \quad —— (3)$$

According to virtual gnd Concept $V_A = V_B = 0$.

$\therefore$ Eqn (3) becomes

$$\frac{V_1}{R_1} + \frac{V_2}{R_2} = \frac{-V_o}{R_f}$$

$$V_o = -R_f\left(\frac{V_1}{R_1} + \frac{V_2}{R_2}\right) \quad \text{--- (4)}$$

Let us substitute $R_1 = R_2 = R_f = R$ in Eqn (4)

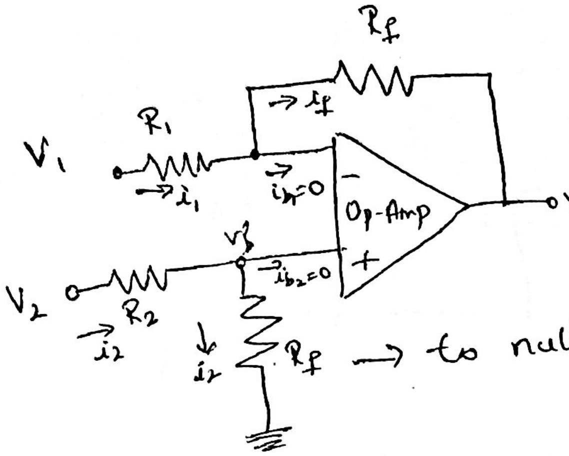
$$\therefore V_o = -\frac{R}{R}(V_1 + V_2)$$

$$V_o = -(V_1 + V_2)$$

* Therefore the o/p of Op-amp is equal to sum of two i/p voltages.

* The -ve sign indicates that o/p voltage is 180° out of phase w.r.t. to the i/p voltage.

Subtractor or Difference Amplifier :-

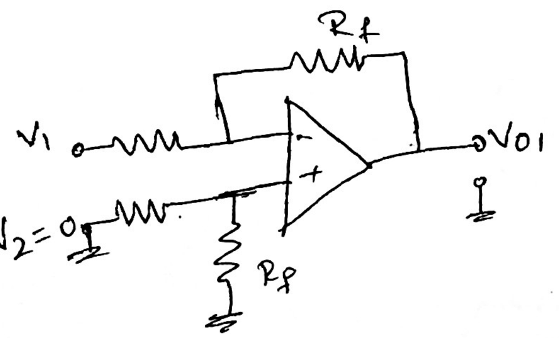


$R_f \rightarrow$ to nullify the offset voltage

* The subtractor ckt consists of two i/p signal & is given to inverting & non-inverting terminal of the op-Amp.

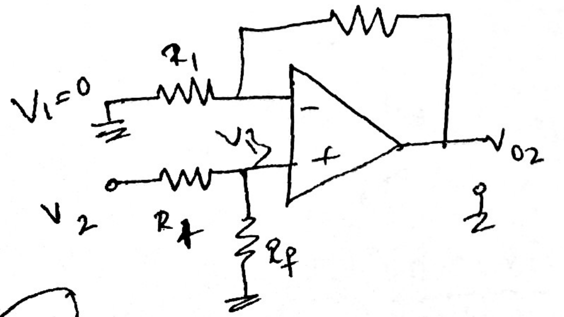
Let us obtain the V_o using superposition principle by applying the following steps :-

step 1 :- Reduce V_2 to zero & find the o/p vtg due to V_1 :-



$$V_{o1} = -\left(\frac{R_f}{R_1}\right) V_1 \quad \text{—— (1)}$$

step 2 :- Reduce V_1 to zero & find the o/p Vtg due to V_2 :-



$$V_{o2} = \left(1 + \frac{R_f}{R_1}\right) V_B \quad \text{—— (2)}$$

where 'V_B'' is the vtg drop across R_f.

$$\therefore V_B' = V_{o2}\left(\frac{R_f}{R_1+R_f}\right)$$

$$= V_2\left[\frac{R_f}{R_1\left(1+\frac{R_f}{R_1}\right)}\right] \quad \text{--- (3)}$$

Substituting Eqn (3) into (2) we get

$$V_{o2} = V_2\left(\frac{R_f}{R_1}\right) \quad \text{--- (4)}$$

Step 3:- Resulting o/p vtg is given by principle of superposition

$$\therefore V_o = V_{o1} + V_{o2}$$

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

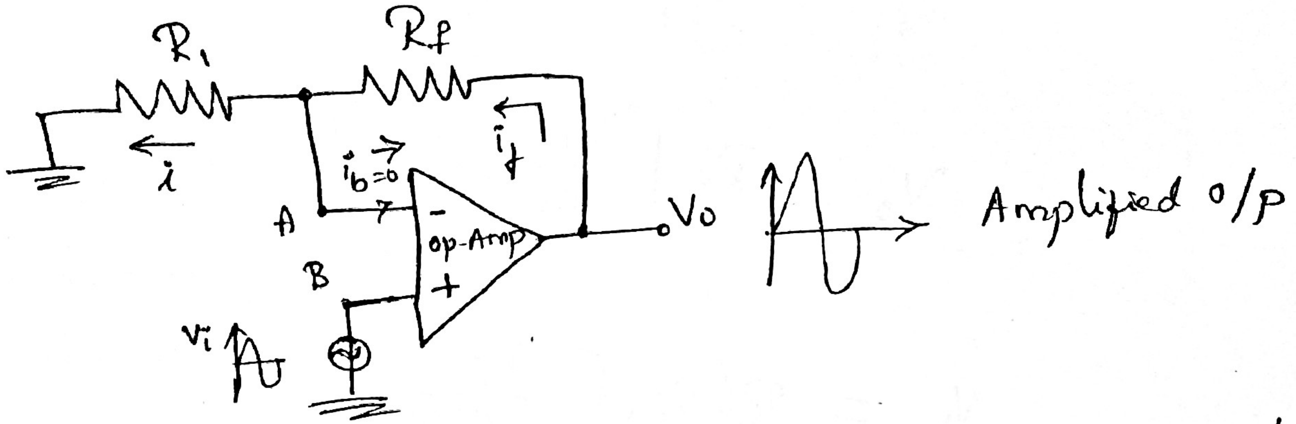
$$V_o = \frac{R_f}{R_1}\left(V_2 - V_1\right) \quad \text{--- (5)}$$

If we choose $R_f = R_1$, then

$$V_o = V_2 - V_1 \quad \text{--- (6)}$$

Hence the given ckt works as subtractor.

Non-Inverting amplifier :-



* In this amplifier ckt, the i/p signal is amplified without producing any phase shift b/n i/p & o/p signals. Hence it is called as non-inverting amplifier

Now apply KCL at the node 'A' we get,

$$i_f = i_b + i \quad \text{--- (1)}$$

$i_b = 0$ Since ideal Op-Amp draws zero current

$$\therefore i_f = i \quad \text{--- (2)}$$

Apply Ohm's law to find current i_f & i

we get,

$$\frac{V_o - V_A}{R_f} = \frac{V_A - 0}{R_1} \quad \text{--- (3)}$$

Since $V_A = V_B = V_{in}$

$\therefore$ Eqn (3) is modified as

$$\frac{V_o - V_{in}}{R_f} = \frac{V_{in}}{R_1} \quad \text{--- (4)}$$

$$\therefore \frac{V_o}{R_f} = \frac{V_{in}}{R_1} + \frac{V_{in}}{R_f}$$

$$V_o = R_f\left[\frac{V_{in}}{R_1} + \frac{V_{in}}{R_f}\right].$$

$$V_o = \cancel{R_f} V_{in}\left[\frac{R_f + R_1}{R_1 \cancel{R_f}}\right]$$

$$\frac{V_o}{V_{in}} = \frac{R_f + R_1}{R_1}$$

$$\frac{V_o}{V_{in}} = 1 + \frac{R_f}{R_1}$$

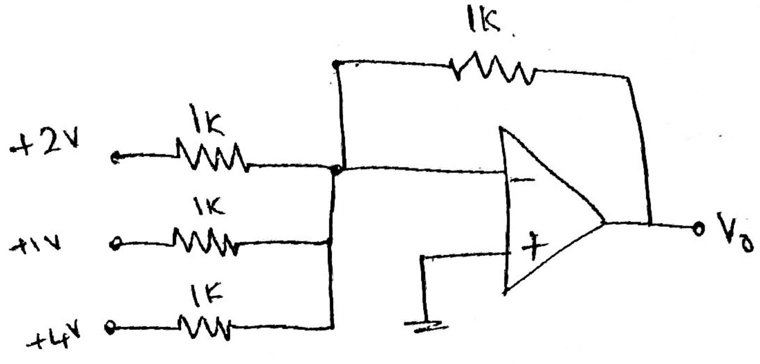
$$\therefore \underline{\underline{V_o = V_{in}}}\left(1 + \frac{R_f}{R_1}\right)$$

$$\underline{\underline{A_f = \left(1 + \frac{R_f}{R_1}\right)}}$$

$$\therefore V_o = \underline{\underline{V_{in} A_F}}$$

Determine

① Determine the o/p voltage for the Op-Amp adder ckt shown



soln :-

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

$$= -\left[V_1 + V_2 + V_3\right]$$

$$V_o = -7V$$

② Design a scaling adder ckt using op-Amp to give the o/p $V_o = -(8V_1 + 6V_2 + 5V_3)$

soln :-

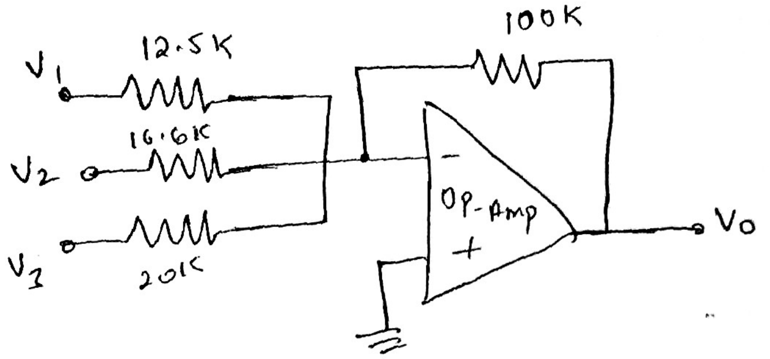
$$V_o = -\left[\frac{R_f}{R_1}V_1 + \frac{R_f}{R_2}V_2 + \frac{R_f}{R_3}V_3\right]$$

let $R_f = 100K\Omega$

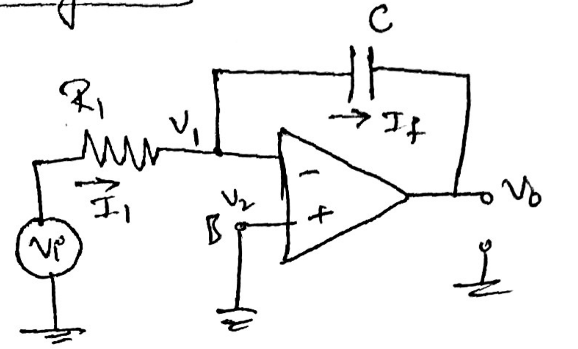
Given :- $\frac{R_f}{R_1} = 8$, $R_1 = \frac{R_f}{8} = \frac{100}{8} = 12.5K\Omega$

$\frac{R_f}{R_2} = 6$, $R_2 = 16.66K\Omega$

$\frac{R_f}{R_3} = 5$, $R_3 = 20K\Omega$



* Integrator :-



The o/p voltage is proportional to the i/p voltage integrated over time

* An integrator ckt can be designed using only passive elements (R, L, C) such an integrator is called passive integrator.

* It has a capacitor in the f/b loop.

* Since non-inverting i/p terminal is grounded $\therefore V_2 = 0$

Due to virtual gnd $V_1 = V_2 = 0$

* Due to high i/p impedance of op-amp the flow of current into its inverting terminal is zero. $\therefore$ Same current flows through R & C

$$\therefore \quad I_1 = I_f \quad \text{--- (1)}$$

But $I_1 = \frac{V_i - V_1}{R} = \frac{V_i}{R}$ — (2)

& $I_f = C \frac{d}{dt}[V_1 - V_0]$

$I_f = -\frac{C dV_0}{dt}$ — (3)

Substituting (2) & (3) into (1) we get

$$\frac{V_i}{R} = -C\frac{dV_0}{dt}$$

$$\frac{dV_0}{dt} = -\frac{1}{RC} V_i$$

Integrating both sides w.r.t 't' we have

$$V_0 = -\frac{1}{RC}\int_0^t V_i\,dt + V_0(0) \quad \text{— (4)}$$

where $V_0(0)$ is the initial voltage on the capacitor at $t=0$

* From eqn (4) we find that the o/p vtg V_0 is proportional to the integral of the i/p vtg V_i.

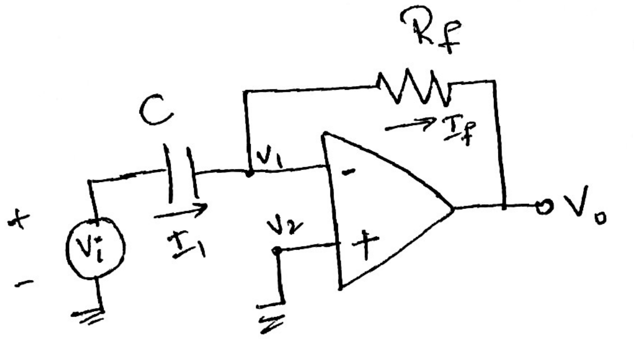
If the initial vtg on the capacitor at $t=0$ is zero then $V_0(0) = 0$

$$\therefore V_0 = -\frac{1}{RC}\int_0^t V_i\,dt$$

* The o/p of integrator is a Cosine w/f if an i/p Bu[illegible]
sinusoidal.

* If the i/p is step type, o/p is ramp type
* — " — Square type o/p is triangular wave.

* **Differentiator :-**



The O/P of the ckt is approximately directly proportional to the rate of the change of the i/p.

* The ckt of op-Amp differentiator can be obtained from op-Amp integrator ckt by simply interchanging the position of R & C.

* Since $V_2 = 0$ due to virtual ground concept.

$$\therefore V_1 = V_2 = 0.$$

* Due to high impedance of op-amp current flow through R & C is

$$I_1 = I_f \quad — (1)$$

But $I_1 = C\frac{d}{dt}(V_i - V_1)$

$$= C\frac{dV_i}{dt} \quad \text{--- (2)}$$

& $I_f = \frac{V_1 - V_0}{R}$

$$= \frac{-V_0}{R} \quad \text{--- (3)}$$

Using these Eqns in (1) we get

$$C\frac{dV_i}{dt} = -\frac{V_0}{R}$$

$$\therefore V_0 = -RC\frac{dV_i}{dt}$$

* If i/p is step type o/p is spike

* If i/p is sine type o/p is cosine w/f.

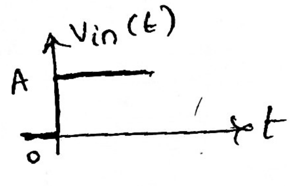
* Signal conversion using Op-Amp :-

(1) Integrator :-

Consider time constant $RC = 1$ & initial o/p voltage

$V_o(0) = 0V$

→ step i/p :-



A step i/p signal with a magnitude of 'A' volts applied at the i/p & it is expressed as,

$$V_{in}(t) = A \quad \text{for } t \geq 0$$

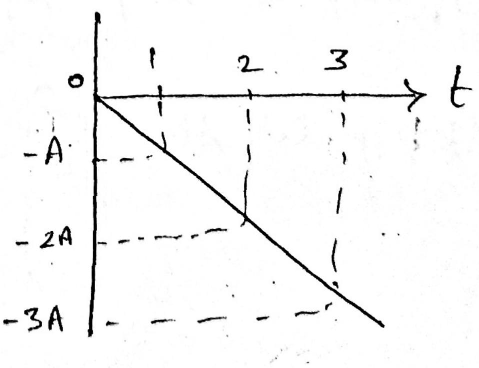
$$V_{in}(t) = 0 \quad \text{for } t < 0$$

$$\therefore V_o(t) = -\int_0^t V_{in}(t)\,dt$$

$$= -\int_0^t A \cdot dt$$

$$= -A\int_0^t dt$$

$$\boxed{V_o(t) = -A[t]_0^t}$$



* The o/p voltage ↓ to -ve max as 't' ↑