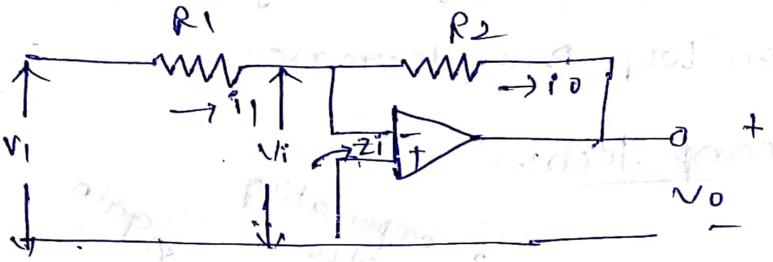
Unit-III

Applications of op-Amp

inverting diff op-amp:-

→ let a voltage V_1 be apply to the inverting i/p terminal of op. to a resistor R_1 with the non inverting terminal is



grounded. i.e. -ve F.B. will be provided through resistor R_2. let V_i and V_o denotes the i/p and o/p voltages. There will be 180° phase shift b/w V_o and V_i.

→ The overall gain of the amp is given as V_o/V_1 with Z_i is the i/p impedence, due to the virtual ground there is no current flows into the amp. ∴ current through resistor R1 should be equals to current through resistor i.e., $i_1 = i_0$.

$$\frac{V_1 - V_i}{R_1} = \frac{V_i - V_o}{R_2}$$

$$\frac{V_1}{R_1} - \frac{V_i}{R_1} = \frac{V_i}{R_2} - \frac{V_o}{R_2}$$

$$\frac{V_o}{R_2} = \frac{V_i}{R_1} + \frac{V_i}{R_2} - \frac{V_1}{R_1} \quad — (1)$$

we have the o/p voltage $V_0 = -A\,V_i$

where A is open loop gain. sub V_i in the above eq.

$$\therefore \frac{V_0}{R_2} = V_i\left(\frac{1}{R_1} + \frac{1}{R_2}\right) - \frac{V_1}{R_1}$$

$$\frac{V_0}{R_2} = -\frac{V_0}{A}\left(\frac{R_1 + R_2}{R_1 R_2}\right) - \frac{V_1}{R_1}$$

$$\frac{V_0}{R_2} + \frac{V_0}{A}\left[\frac{R_1 + R_2}{R_1 R_2}\right] = \frac{-V_1}{R_1}$$

$$V_0\left[\frac{1}{R_2} + \frac{R_1 + R_2}{A R_1 R_2}\right] = \frac{-V_1}{R_1}$$

$$V_0\left[\frac{A R_1 R_2 + R_1 R_2 + R_2^2}{A R_1 R_2^2}\right] = \frac{-V_1}{R_1}$$

$$\frac{V_0}{V_1} = \frac{-A R_1 R_2^2}{R_1\left[A R_1 R_2 + R_1 R_2 + R_2^2\right]} \Rightarrow = \frac{-A R_2^2}{R_2\left[A R_1 + R_1 + R_2\right]}$$

$$\boxed{\frac{V_0}{V_1} = \frac{-A R_2}{\left[A R_1 + R_1 + R_2\right]}} \quad \text{--- (2)}$$

→ In practice, the typical values of V_0, A, R_1, R_2 the 1st term of eq (2) becomes negligibly small as compared to the 2nd term hence it can be ignore.

$\therefore$ The closed loop gain $\frac{V_0}{V_1} = -\frac{R_2}{R_1}$

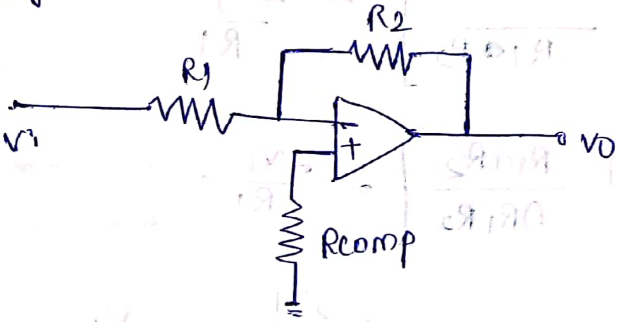
if $R_1 = R_2$ the closed loop gain equal to -1

→ It implies that the o/p has same magnitude as the i/p signal but it is out of phase by $180°$.

∴ This op-amp is called "inverter."

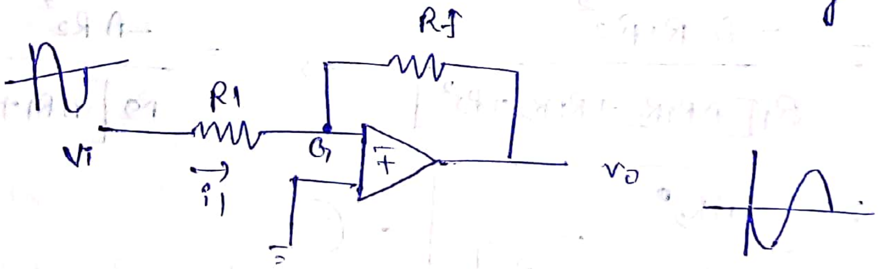
→ If the ratio $R_2/R_1 > 1$ The ckt is termed as "scale changer."

→ In order to provide for i/p bias current compensation it is usually to incorporate resistor $R_{comp} = R_1 || R_2$ b/w the noninverting i/p terminal and the ground as shown in fig.



op-amp acts as inverting amp:-

→ An inverting amp as shown in fig



→ A weak signal vi is apply is the inverting. i/p terminal and vo is the o/p voltage with phase inversion which is it is essential that non inverting terminal is grounded.

→ Due to the virtual ground the current does not enter into the op-amp for all practical applications current through R_1 is equal to the current through f.B resistive R_f.

∴ $I_1 = I_0$.

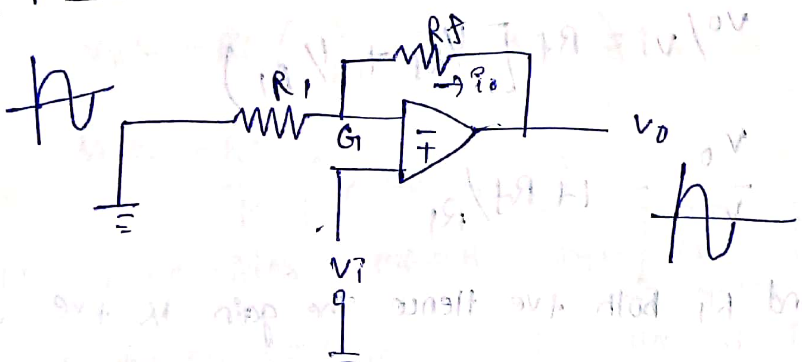
$$\frac{V_i}{R_1} = \frac{0 - V_O}{R_f} = \frac{-V_O}{R_f}$$

$$\boxed{\frac{V_i}{R_1} = \frac{-V_O}{R_f}} \Rightarrow \boxed{\frac{V_O}{V_i} = \frac{-R_f}{R_1}}$$

Here R_1 and R_f are external resistance for this type of amp the closed loop gain depends only on the F.B resistor R_1 and R_f. By properly choosing R_1 & R_f any desired gain can be obtained.

→ It is seen that there is phase inversion b/w the i/p & o/p voltages. Hence the name is inverting amp.

op-amp acts as noninverting amp:-



→ In this type of op-amp the i/p signal v_i to be applied without phase inversion to the noninverting i/p terminal and inverting i/p terminal grounded through resistor R_1 as shown in fig.

→ R_f is the F.B resistance due to the virtual no current flows into op-amp at G no current ~~towards~~ to the op amp the potential due to G may be assumed to v_i.

∴ The current through R_1 = current through R_f.

→ R_f is the F.B resistance due to the virtual no current flows into the op-amp at G towards to the op-amp the potential due to G may be assumed to v_i.

The current flows through R_1 = current flows through R_f
$i_1 = i_0$

$$\boxed{\frac{0 - V_i}{R_1} = \frac{V_1 - V_0}{R_f}}$$

$$\frac{-V_i}{R_1} = \frac{V_i}{R_f} - \frac{V_0}{R_f}$$

$$-\frac{V_i}{R_1} - \frac{V_i}{R_f} = -\frac{V_0}{R_f}$$

$$V_0/R_f = V_i\left[1/R_f + 1/R_1\right]$$

$$V_0/V_i = R_f\left[1/R_f + 1/R_1\right]$$

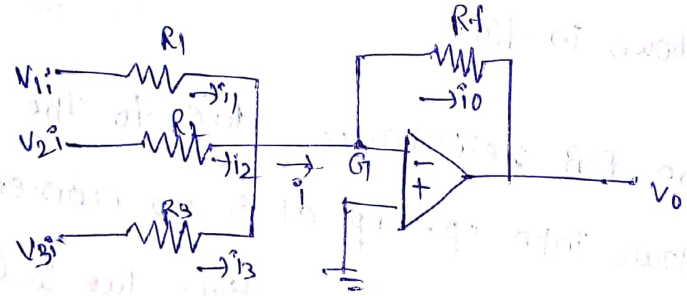
$$\frac{V_0}{V_i} = 1 + R_f/R_1$$

→ Here R_f and R_1 both +ve Hence the gain is +ve.

• There is no phase inversion b/w i/p and o/p voltages

→ The voltage gain always greater than unity.

op-amp acts as a inverting adder (or) summing adder



→ A summing amp the o/p voltage is the sum of all the i/p voltages with the -ve sign. it also termed as inverting adder

→ several i/p voltages V_1, V_2, V_3 are apply to the inverting i/p of the op-amp through resistors R_1, R_2 & R_3, as shown in fig.

keeping the non inverting terminal is grounded.

→ If I denotes the i/p current we have $I = I_1 + I_2 + I_3$

Because the virtual ground at G, The current through F.B resistor Rf. should be equals to current through the op-amp.

i.e $I = I_0$.

$$i_1 + i_2 + i_3 = i_0$$

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

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

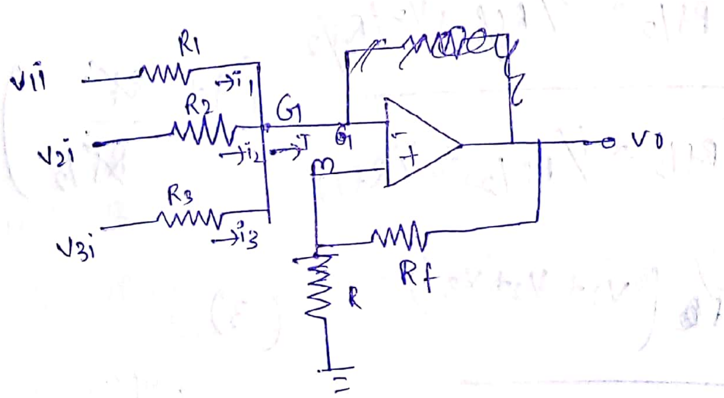
$$V_0 = \frac{-R_f}{R} (V_1 + V_2 + V_3)$$

→ If we consider $R_f = R$ then $\boxed{V_0 = -(V_1 + V_2 + V_3)}$

Hence the o/p voltage is the sum of i/p voltages with -ve sign. Hence the name is inverting adder.

Non-Inverting summing amplifier:-

⇒ A non inverting amp as shown fig.



→ let the voltage at the inverting i/p terminal will be Vm. because of the virtual ground at the i/p terminals the voltage at G also Vm. applying KCL to the node G.

we have $\frac{V_1 - V_m}{R_1} + \frac{V_2 - V_m}{R_2} + \frac{V_3 - V_m}{R_3} = 0$

$$\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3} = V_m\left[\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right]$$

$$V_m = \frac{V_1/R_1 + V_2/R_2 + V_3/R_3}{1/R_1 + 1/R_2 + 1/R_3}$$

→ The op-amp along with the resistors R and Rf act as non inverting amp.

∴ closed loop gain $V_o/V_m = 1 + \frac{R_f}{R}$

substituting for V_m in the above expression we get

$$V_o = V_m\left(1 + \frac{R_f}{R}\right)$$

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

let $R_1 = R_2 = R_3 = R = R_f/2$.

$$\therefore V_o = \frac{V_1/R_f/2 + V_2/R_f/2 + V_3/R_f/2}{1/R_f/2 + 1/R_f/2 + 1/R_f/2}\left(1 + \frac{R_f}{R_f/2}\right)$$

$$= \frac{\frac{2}{R_f}\left(V_1 + V_2 + V_3\right)}{\frac{2}{R_f}(1+1+1)} (3)$$

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

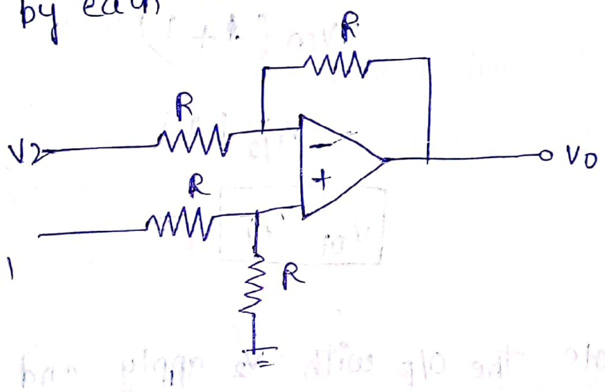
$$\boxed{V_o = V_1 + V_2 + V_3.}$$

→ The o/p is the sum of i/p voltages without change of time Hence the name is non inverting summing amp.

op-amp act as subtractor:-

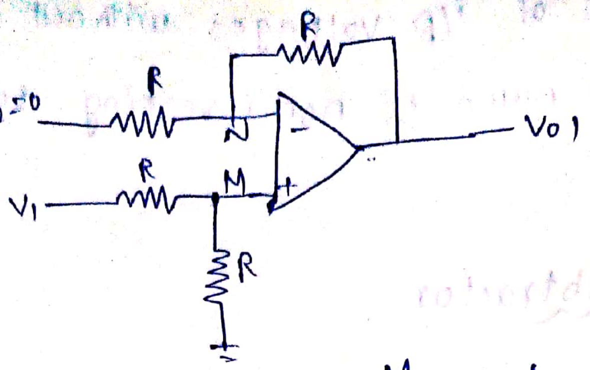
→ The op-amp function has a subtractor giving an o/p voltage with the diff of i/p voltages. The ckt is mainly a basic diff amp in which all resistors are all are equal magnitude is the o/p of the amp can be calculated on the basis of superposition principle.

principle:- The current through (or) voltage across as element in a linear bilateral n/w equals to the algebric sum of currents (or) voltages produce indepen-dently by each source.



→ V_1, V_2 are the i/p voltages at the noninverting and inverting terminals respectively. From the ckt o/p voltage $\boxed{V_0 = V_1 - V_2}$.

case i:- let V_{01} denote the o/p with V_1 apply and V_2 said equal to zero. The ckt modifies as shown.



→ let the potential of node ~~V/n~~ M will be V_m.

$\therefore V_m = V_1\left(R/R+R\right)$

By using potential devided principle

$V_m =$ ~~$V_{m}(1+$~~ $V_1/2$

→ The ckt is non inverting amp with an i/p $V_1/2$ at the non inverting terminal and the inverting i/p terminal is grounded through resistor R.

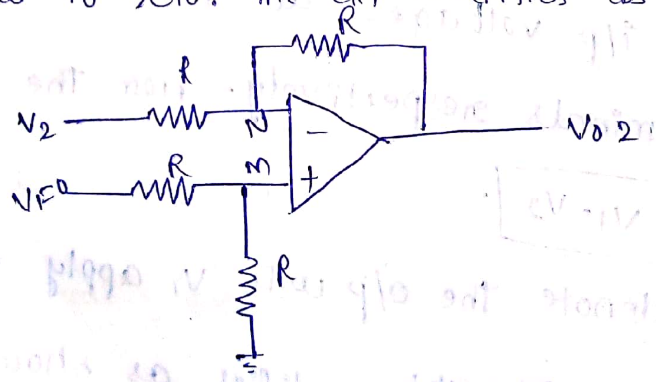
$\therefore$ The o/p voltage $V_{01} = V_m\left(1+R/R\right)$

$= V_m(1+1)$

$= V_1/2\,(2)$

$\boxed{V_{01} = V_1}$

caseii:- let V_{02} denote the o/p with V_2 apply and V_1 is said equal to zero. The ckt modifies as shown in fig



→ The ckt is basically an inverting amp whose o/p is V_{02}.

$V_{02} = -R_f/R\ V_2 = -R/R\,V_2$

$\boxed{V_{02} = -V_2}$

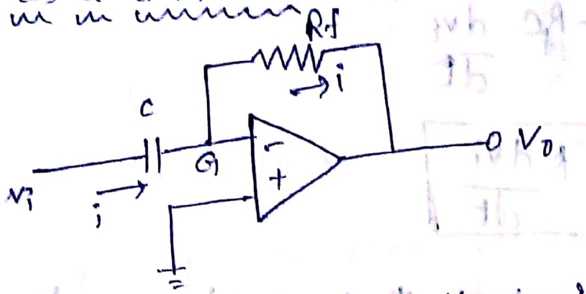
→ when both i/p's V_1 and V_2 are applied we have by the principle of superposition

$$V_0 = V_{01} + V_{02}$$

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

Hence the op-amp acts as a subtractor.

op amp acts as a differentiator :-



→ In this type of op amp the o/p voltage is proportional to the 1st derivative of the i/p voltage.

The 1st derivative The i/p voltage V_i is apply to the inverting i/p

→ From The ckt The i/p voltage V_i is apply to the inverting i/p terminal of the op-amp ~~through~~ a capacitor C with noninverting i/p terminal is grounded.

→ let V_0 denotes the o/p voltage. The o/p is connected back through the i/p at G. Through the F.B resistor R_f. The voltage V_i is apply to the capacitor it can charge if Q is the charge on the capacitor.

$\therefore C = q/V_i \qquad V_i = q/C$

→ Differentiating V_i w.r.to time we get $\frac{dV_i}{dt} = \frac{d}{dt}\left(\frac{q}{C}\right)$

$$\boxed{\frac{dV_i}{dt} = \frac{1}{C}\frac{dq}{dt}}$$

→ let i denotes the charging current because of the virtual ground at G. The current passing through F.B resistor should be equal to current passing through capacitor

$\therefore i = \frac{dq}{dt}$ also $i = \frac{-V_0}{R_f}$

$$\frac{-v_o}{R_f} = \frac{dq}{dt}$$

The value of the $\frac{dq}{dt}$ sub in the above eqn

$$\frac{dv_i}{dt} = 1/c \cdot \frac{-v_o}{R_f}$$

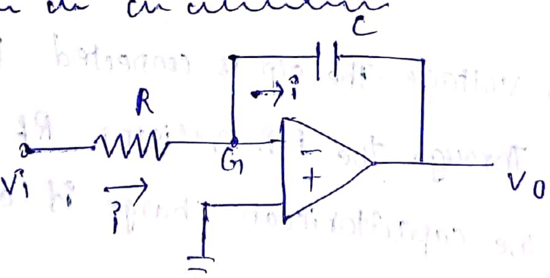
$$v_o = -R_f C \frac{dv_i}{dt}$$

$$\boxed{v_o = k\frac{dv_i}{dt}}$$

→ where k is constant that can be equals to $-R_f C$

∴ The o/p voltage is proportional to the 1st derivative of the i/p voltage Hence the name is differentiator.

op amp can acts as a integrator:-



→ The op-amp may also be used an integrator the op-amp The o/p voltage is proportional to the integral of the i/p voltage.

→ The i/p voltage v_i is apply through a resistor R to the inverting i/p terminal of op-amp. keeping the non inverting i/p terminal is grounded. The o/p is connected back to the i/p through a capacitor C. Because of the virtual ground at G no current flows into the op-amp

→ ∴ The voltage across the capacitor whenever gets charge is equal to $-v_o$. The charge on the capacitor

$$\boxed{q = -CV_0}$$

at the end of time 't' $\quad -CV_0 = \int_0^t i\,dt$

But $\quad i = \dfrac{V_i}{R}$

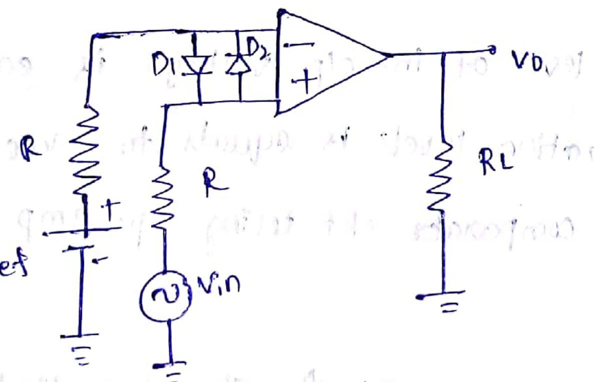
$$\therefore \; -CV_0 = \int_0^t \frac{V_i}{R}\,dt$$

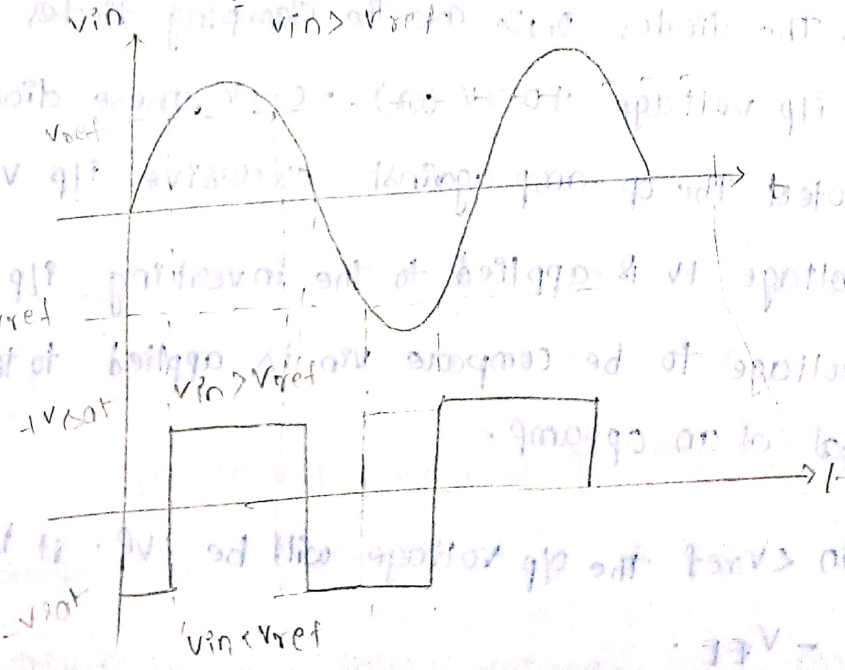
$$\boxed{V_0 = -\frac{1}{RC}\int_0^t V_i\,dt} \Rightarrow \boxed{V_0 = K\int_0^t V_i\,dt}$$

V_0 where RC is constant

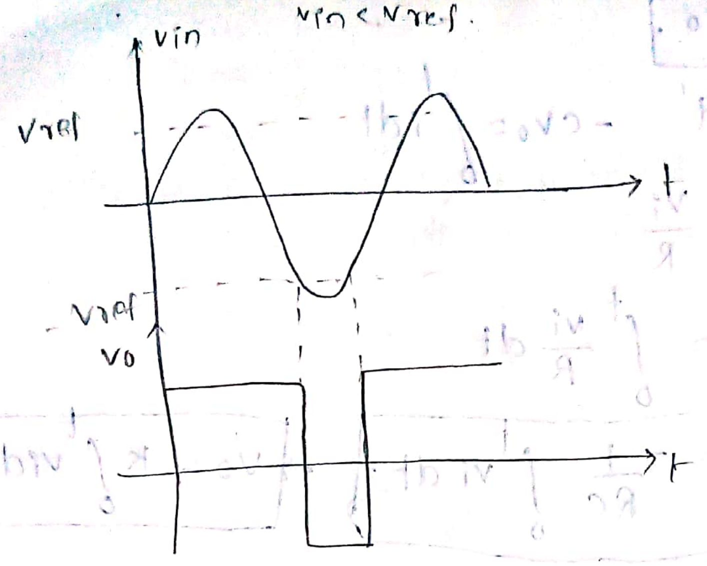
→ From this eqn we can seen that the o/p voltage is integral of the i/p voltage Hence the name is integrator.

Op-amp can acts as a comparator:-





a) when Vref is +Ve



b) when vref is -ve

→ A comparator is a device which compares a signal voltage with a ref voltage. ref voltage is applied to the inverting i/p terminal this signal

→ The ref volta is to be compared is applied to the other i/p terminal ie non inverting i/p terminal.

→ Depending upon the which of the two voltages is grater The o/p is either +ve (or) -ve saturation voltage

→ The +ve saturation level of the o/p voltage is equals to +vcc. The -ve saturation level is equals to -vcc.

→ A basic non inverting comparator ckt using op-amp as shown in fig

→ From the fig. The diodes D_1, D_2 are the clamping diodes and they clamp ref i/p voltage +0.7V (or) -0.7V. These diodes are used to protect the op-amp against excessive i/p voltages

→ A ref voltage 1V is applied to the inverting i/p terminal and the voltage to be compare vin is applied to the non inverting i/p terminal of an op-amp.

→ ∴ Vin < Vref the o/p voltage will be -ve. It is approximate equals to $-V_{EE}$.

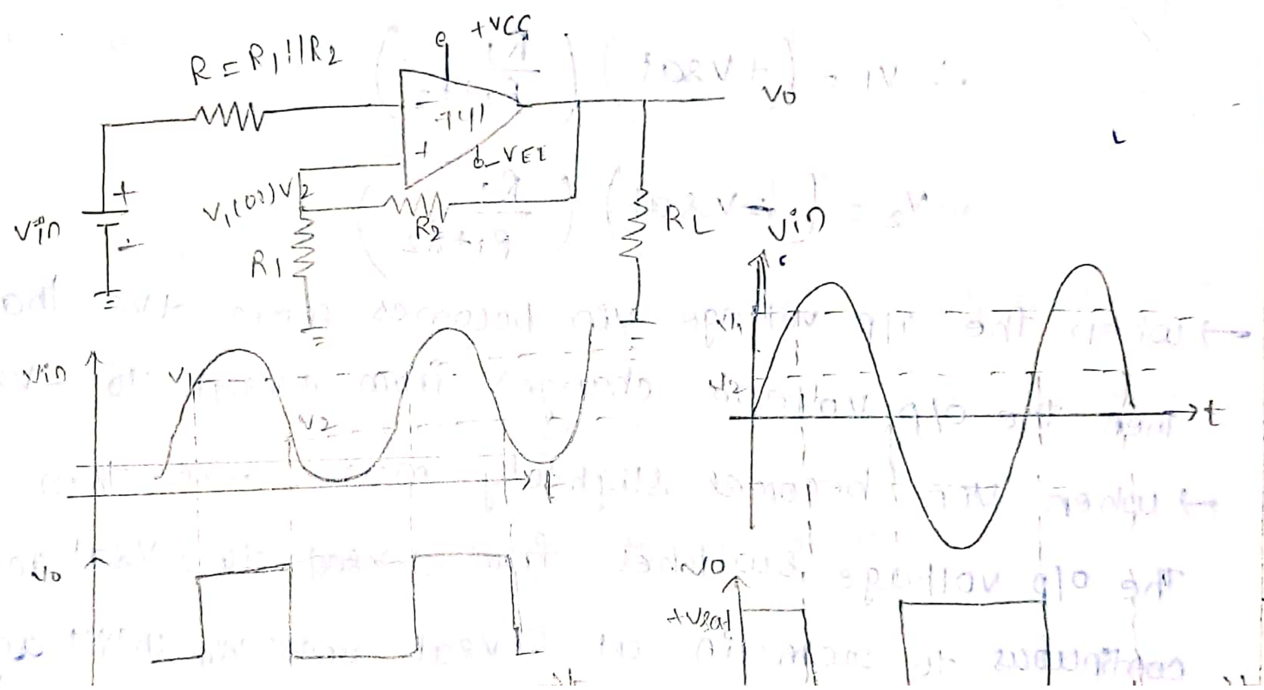
→ If $V_{in} > V_{ref}$ the o/p voltage would be ~~+ve~~ +ve, it being approximately equals to $+V_{CC}$.

→ When even V_{in} becomes equals to V_{ref}. The o/p voltage V_o changes instantaneously from one saturation level to another level. i.e from $+V_{CC}$ to $-V_{EE}$ or from $-V_{EE}$ to $+V_{CC}$

→ The i/p & o/p waveforms are shown in fig.

→ The comparator sometimes called as "voltage level detector."

Schmitt trigger using op-amp:-



(or) lower trip point (or) lower threshold point.

→ The state of the o/p changes in this process the o/p voltage takes the shape of square wave. This is graphically shown above.

→ let V_1 = UTP, V_2 = LTP

→ whenever the i/p is sine wave the device would be termed sinewave to square wave converter.

→ An op-amp provides with +ve feed back we can function as schmitt trigger the ckt is shown above.

→ when $V_o = +V_{sat}$ the voltage across R_1 is V_1. when $V_o = -V_{sat}$ the voltage across R_1 is V_2

$$\therefore V_1 = (+V_{sat})\left(\frac{R_1}{R_1+R_2}\right)$$

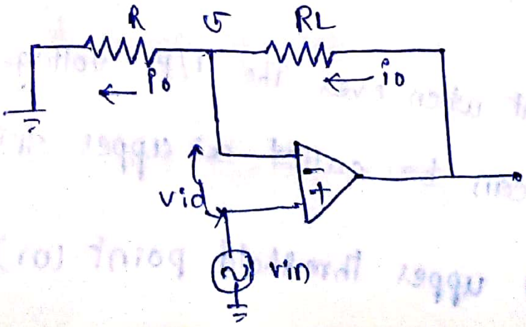
$$V_2 = (-V_{sat})\left(\frac{R_1}{R_1+R_2}\right)$$

→ when the i/p voltage Vin becomes more +ve than V_1. Then the o/p voltage changes from $+V_{sat}$ to $-V_{sat}$.

→ when Vin becomes slightely more -ve than V_2. The o/p voltage switches from $-V_{sat}$ to $+V_{sat}$ and it continuous to remain at $+V_{sat}$ untill vin again reaches the value V_1

→ The i/p and o/p w/fs are shown in the fig.

op-amp acts as a voltage to current converter:-



→ An op-amp can be used with an advantage of voltage to current converter. In this type of ckt an i/p voltage gets converted into an o/p current The ckt as shown in fig.

→ From the ckt 'vid' is the differential i/p voltage and Io is the o/p current and R_L is the load resistance.

→ The i/p voltage vin is apply to the non inverting i/p terminal of an op-amp. Because of virtual ground as a i/p terminals practically no current flows into the op-amp. and we have the current through R F.B. element equal to voltage

→ ∴ F.B voltage element $V_f = i_o \cdot R$.

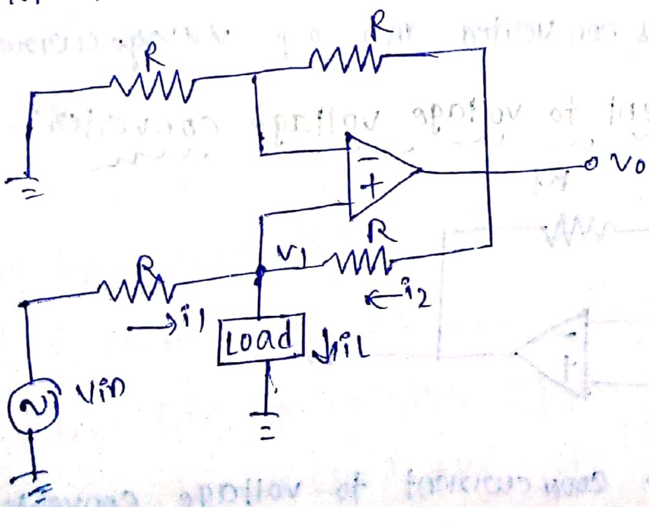
By applying KVL at node G $V_{in} = V_f$.

$\therefore V_{in} = i_o R$.

$\therefore i_o = V_{in}/R$ Here R is a fixed value. Hence the i/p voltage vin gets converted into an o/p current Io.

∴ The op-amp ckt is called voltage to current converter.

→ The another method of voltage to current is shown in fig This ckt load is grounded.



→ let V_1 denotes the voltage of the non inverting terminal and I_L is the load current.

→ By applying KCL we have $I_L = I_1 + I_2$,

$$= \frac{V_{in} - V_1}{R} + \frac{V_0 - V_1}{R}$$

$$i_L = \frac{V_{in} + V_0 - 2V_1}{R}$$

$$V_{in} + V_0 - 2V_1 = i_L R \Rightarrow V_{in} + V_0 - i_L R = 2V_1$$

$$\boxed{V_1 = \frac{V_{in} + V_0 - i_L R}{2}}$$

→ w.k.T. The closed loop gain of the non inverting op-amp is given as $\left(1 + R_f/R_1\right)$.

→ Here all resistors are of equal value.

$$\therefore \left(1 + R/R\right) = 2$$

→ ∴ o/p voltage $V_0 = 2V_1$

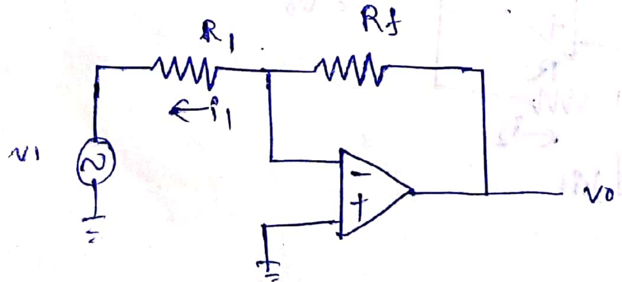
$$V_0 = 2\left(\frac{V_{in} + V_0 - i_L R}{2}\right)$$

$$\boxed{\cancel{V_0} = V_{in} + \cancel{V_0} - i_L R}$$

→ sub/ value $V_{in} = i_L R \Rightarrow \boxed{i_L = \frac{V_{in}}{R}}$

→ The i/p voltage gets converted into o/p voltage current.

Op-amp acts as current to voltage voltage converter:-



→ op-amp can acts as current to voltage converter. The basic ckt is the same for an op amp can acts as a inverting amp.

→ From this ckt the overall gain of the op-amp is given as

$$\frac{V_0}{V_1} = -R_f/R_1$$

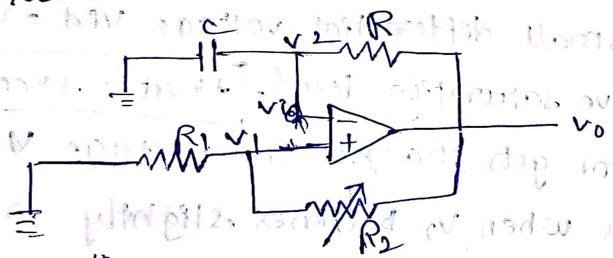
$$V_0 = -\left(V_1/R_1\right) R_f$$

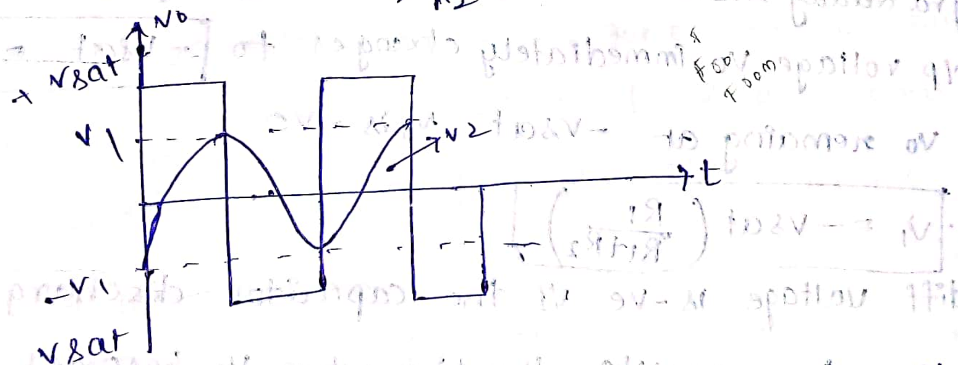
$$\boxed{V_0 = -i_1 \cdot R_f}$$

Here $i_1 = \frac{V_1}{R_1}$

→ Hence the i/p current is converted into an o/p voltage.

Square wave Generator:-





→ The op amp can function as square wave generator as shown in the figure.

→ From the fig it is seen that the voltage at the noninverting i/p terminal is V_1. The voltage across R_1. The voltage at the inverting i/p terminal is V_2. at the voltage across the capacitor

→ In practice $+V_{sat} = +V_{CC}$ and $-V_{sat} = -V_{EE}$ depending on wheather the diff i/p voltage V_{id} is +ve (or) -ve the o/p voltage V_0 is -ve (or) +ve saturation level

Let it be assumed that the capacitor is not ... when the DC supply voltages +VCC and -VEE are applied.

∴ voltage across capacitor is $V_2 = 0$.

~~Square wave generator~~:-

but V_1 is not equal to zero but it has finite value because of offset voltage. The actual value of V_1 depends not only on the o/p offset voltage but also the resistors R_1 and R_2. Let it be assumed that V_1 is +ve ∴ we have diff voltage

$$V_{id} = V_1 - 0 = V_1$$

→ even though the small differential voltage $V_{id} = V_i$ can drive the op-amp into +ve saturation level. $\boxed{+V_{sat} = +V_{CC}}$ with this voltage the capacitor gets charged. The voltage V_2 ~~gradually~~ gradually rises. When V_2 becomes slightly more +ve than V_1, the o/p voltage V_o immediately changes to $\boxed{-V_{sat} = -V_{EE}}$

→ with V_o remaing at $-V_{sat}$, V_1 is -ve

$$\therefore \boxed{V_1 = -V_{sat}\left(\frac{R_1}{R_1+R_2}\right)}$$

→ The diff voltage is -ve V_1. The capacitor discharges again charges in the opposite direction. When V_2 becomes slightly more -ve than $-V_1$, then op-amp o/p switches to $+V_{sat}$ again.

→ This will complete one cycle of the o/p wave

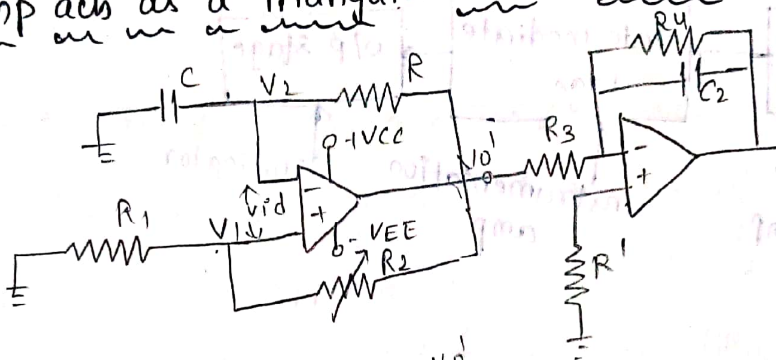
we have $\boxed{V_1 = +V_{sat}\left(\frac{R_1}{R_1+R_2}\right)}$

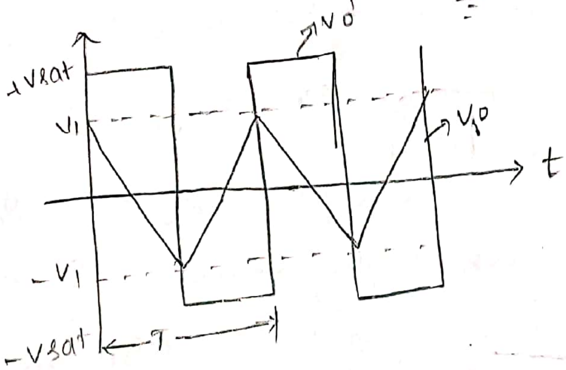
→ ∴ The o/p w/f of V_o to be a square wave. The op-amp can function as a square wave generator which is also referred as astable multivibrator (or) free running oscillator

→ The time period of astable multivibrator is

$$\boxed{T = 2RC \log_e\left(\frac{2R_1 + R_2}{R_2}\right)}$$

op-amp acts as a triangular wave Generator:-





→ The basic ckt of triangular wave generator as shown in fig. in a it is a series combination of square wave generator ckt and integrator generator ckt.

→ The o/p of the integrator ckt.

$$\boxed{V_o = \frac{-1}{R_3 C_2} \int V_o' \, dt}$$

i-e, o/p voltage V_o is proportional to time integral of V_o'.

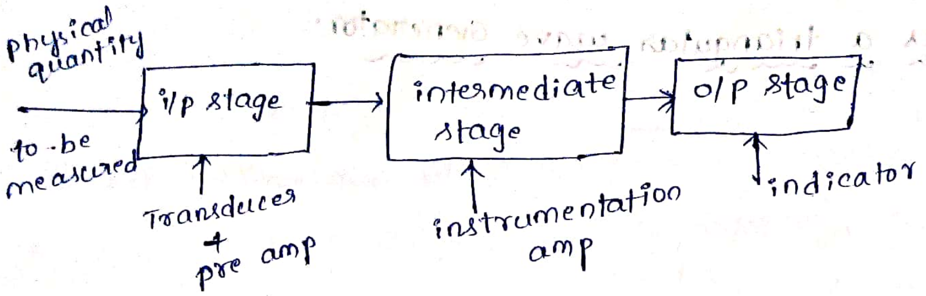
→ The i/p is square wave and o/p wave is triangular.

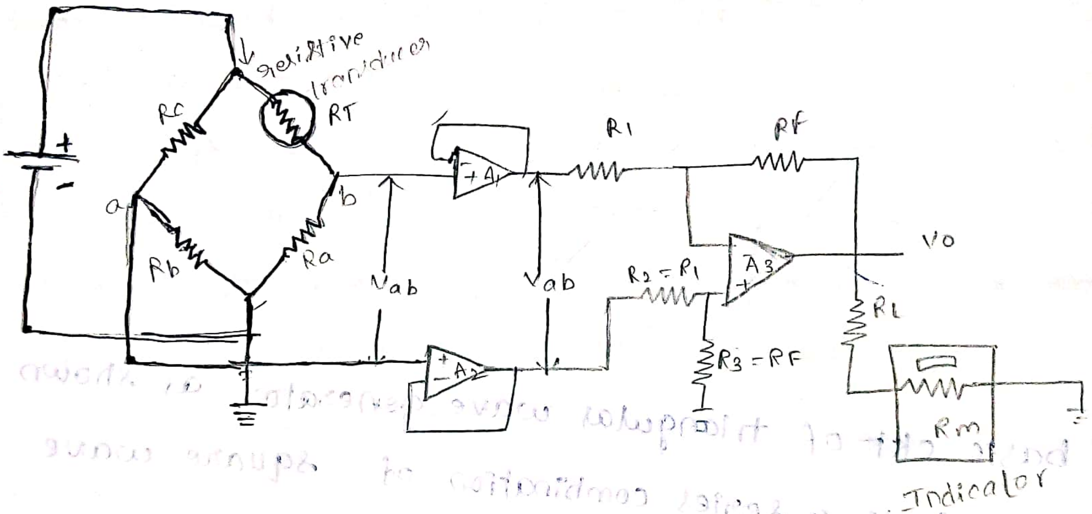
→ The o/p voltage wave is triangular one

→ In order to get the o/p voltage wave is triangular one general rule will be satisfied is 5 times $R_3 C_2 > T/2$. where T is timeperiod of i/p square wave and also it is neccessary to shunt the capacitor C_2 by a resistor $R_4 = 10R_3$.

→ In order to obtain stable triangular wave

** Instrumentation amplifier using op-amp:-





→ The instrumentation amp mainly used in industrial applications. The amp is usually prevent by the o/p of a transducer. a transducer converts one form of energy into another form of energy for example physical energy into electrical energy

→ The In industrial applications it is neccessary to measure the physical quantities like temperature, humidity in such condition an instrumentation amp place a major role

→ The block diagram repolesentation of Kumi instrumentation system as shown in fig.

→ The instrumentation amp forms an the intermediate stage of the stage system the main function is amplify the weak o/p signal of the i/p stage. so that the strengthen signal can operate an indicator, The indicator is suitably calibrated. It can measure directly the physical quantity.

→ An instrumentation amp which uses a transducer bridge is shown in figure.

→ From the Fig A_1, A_2, A_3 are the op-amps. R_a, R_b, R_c, R_T are the ratio arms. where R_f is the Feed back resistance. The transducer used is a resistive transducer of a resistor R_T and it forms one of the ratio arms of the wheatstone bridge.

→ It can be energised by a suitable source in practice the bridge is balanced under desired set conditions said by the designer depending on practical requirement.

→ At balancing condition $V_a = V_b$.

$$\boxed{\frac{R_c}{R_b} = \frac{R_T}{R_a}}$$

→ when the physical quantity to be measured the changes The resistance of the transducer changes as a result the bridge becomes unbalanced. let ΔR represents the change in resistance of the transducer.

∴ The new value of resistance equals to $R_T + \Delta R$.

→ let Vab represents voltage across the terminals of the bridge we have $\boxed{V_{ab} = V_a - V_b}$.

$$\text{But } V_a = V_{dc}\left(\frac{R_a}{R_a + R_T + \Delta R}\right)$$

$$V_b = V_{dc}\left(\frac{R_b}{R_b + R_c}\right)$$

$$V_{ab} = V_{dc}\left(\frac{R_a}{R_a + R_T + \Delta R}\right) - V_{dc}\left(\frac{R_b}{R_b + R_c}\right)$$

$$= V_d$$

let $R_a = R_b = R_c = R_T = R$

$$V_{ab} = V_{dc}\left(\frac{R}{R+R+\Delta R}\right) - V_{dc}\left(\frac{R}{R+R}\right)$$

$$= V_{dc}\left(\frac{R}{2R+\Delta R}\right) - V_{dc}\left(\frac{R}{2R}\right)$$

$$= V_{dc}\left[\frac{R}{2R+\Delta R} - \frac{R}{2R}\right]$$

$$= V_{dc}\left[\frac{R}{2R+\Delta R} - \frac{1}{2}\right]$$

$$= V_{dc}\left[\frac{2R - (2R+\Delta R)}{2(2R+\Delta R)}\right] = V_{dc}\left[\frac{-\Delta R}{2(2R+\Delta R)}\right]$$

$$\boxed{V_{ab} = V_{dc}\,\frac{-\Delta R}{2(2R+\Delta R)}}$$

→ This voltage V_{ab} is applied to the instrumentation amp is the combination of 3 operational amp's.

→ Where A_1 & A_2 are the voltage followers. Their main function is to eliminate the loading effect the bridge n/w. But we have the gain of the amp A_3 is $\frac{-R_f}{R_1}$.

∴ The V_0 o/p voltage $\boxed{V_0 = V_{ab}\,\frac{-R_f}{R_1}}$

sub V_{ab}

$$V_0 = V_{dc}\,\frac{-\Delta R}{2(2R+\Delta R)} \cdot \frac{-R_f}{R_1}$$

But in general ΔR is quite small

$\therefore 2R+\Delta R \simeq 2R$

$$V_o = V_{dc} \frac{\Delta R}{2(2R)} \frac{R_f}{R_1}$$

$$\boxed{V_o = V_{dc} \frac{\Delta R}{4R} \frac{R_f}{R_1}}$$

→ In this expression the DC source V_{dc}, R_1, R and R_f having fixed magnitude.

$\therefore$ o/p voltage $\boxed{V_o \propto \Delta R}$

→ The o/p voltage is directly proportional. the change in resistance of the transducer and this change in resistance is a measure of the physical quantity involve.

→ The o/p voltage Vo can operate an indicating meter which can be calibrated directly interms of the physical quantity being measure.

<u>Ac amplifier</u>:-

→ The applications discussed so far are dealing with both Ac and DC signals. now we can interact with only AC signals the Ac amplifiers is used when it is required to get the Ac frequency of an op-amp.

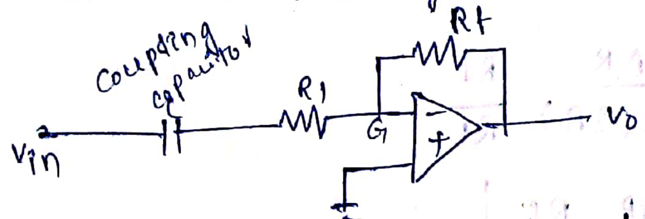
→ It is neccessary to eliminate the DC components this can be achieve by using an Ac amp with a coupling capacitor.

→ Ac amplifiers are two types

1. inverting Ac amp
2. Non inverting Ac amplifier

Inverting AC amplifier:-

→ The ckt of the inverting AC amp is shown in fig.



→ The coupling capacitor besides blocking the DC component of the i/p and also sets the lower 3dB frequency of the amp with the help of resistor R_1.

→ consider the virtual ground at G. The o/p voltage V_o is given by $\boxed{V_o = -I R_f}$

$$V_o = \frac{-V_{in}}{R_1 + 1/SC}$$

$$\frac{V_o}{V_{in}} = \frac{-R_f}{R_1 + 1/SC} \Rightarrow \frac{-R_f SC}{R_1 SC + 1}$$

$$= \frac{\cancel{C} R_f S}{\cancel{C}(R_1 S + 1/C)}$$

$$\frac{V_o}{V_{in}} = \frac{-R_f S}{R_1[S + 1/R_1 C]}$$

From this eqn the lower cutoff frequency f_L is given by

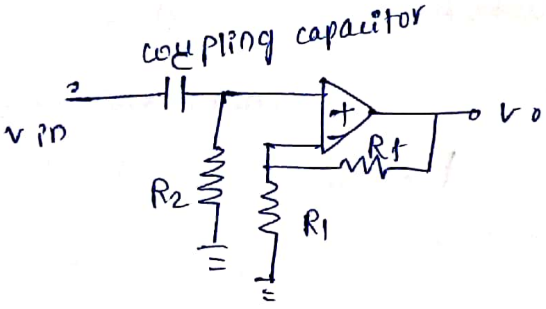
$$f_L = \frac{1}{2\pi R_1 C}$$

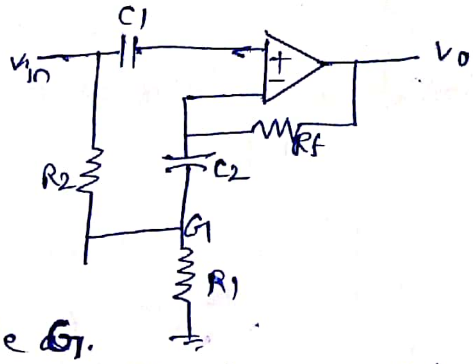
→ The capacitor behaves as a ckt usually in the mid band range of frequencies.

∴ The gain becomes $-R_f/R_1$

nonInverting Ac amp :-

→ The ckt of noninverting Ac amp is shown in fig





→ If R2 is not connected to node G. but connect to the ground then it will be provide a DC component to the ground because of this the overall i/p impedence of the amp reduces.

→ This prblm is rectified by connecting the capacitor C1 as shown in fig. The capacitor C1 this act as short ckt to ac signals.

→ The Resistance R2 carries no current when node G and noninverting terminal Rf same potential this can improves the i/p impedence of the ckt.

log amplifier:-

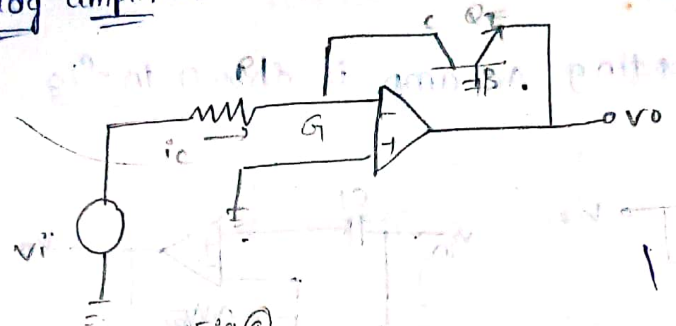


Fig ⓐ

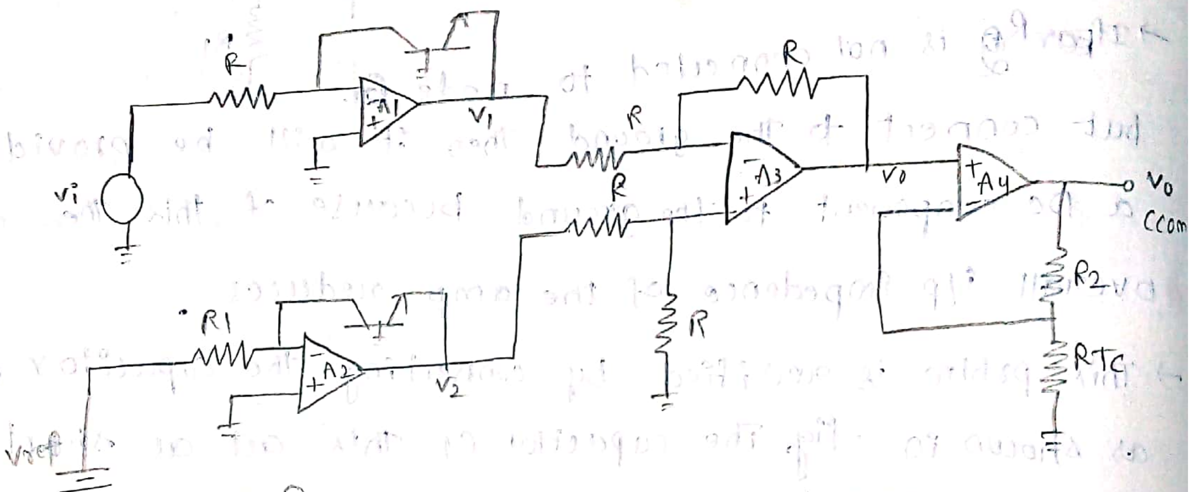


Fig ⓑ

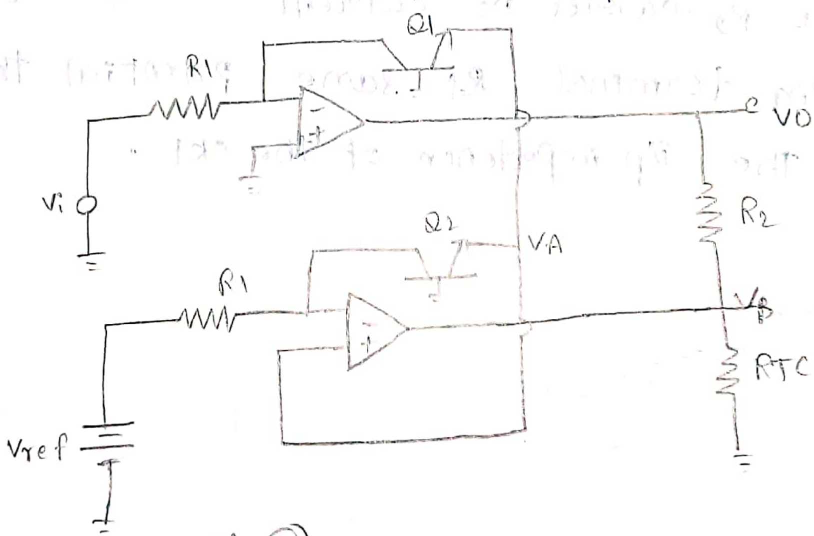


Fig ⓒ

→ log amp and antilog amp are used in many application in practice The o/p voltage of log amp is proportional to the logarithmic of the i/p voltage. The diode current eqn forms the basic principle of operation of a log amp

→ The diode current eqn may be expressed

$$I_D = I_S(e^{qV/KT} - 1)$$

where I_D = current through the diode

I_s is reverse saturation current

Q is charge on electron i.e, 1.6×10^{-19} coloumbs

V is the voltage applied across the diode

k is boltzman constant i.e, 1.38×10^{-23} Joules/kelvin

T is obsolute temperature

→ consider the basic log amp. ckt as shown in fig@

→ The ckt uses a grounded base transistor Q in the F.B path

The collector terminal is connected to the inverting i/p of the op-amp. since the non inverting i/p terminal is grounded because of the virtual groundat 'G' the potential at collector terminal becomes '0'.

→ since both base and collector terminals are grounded

∴ The transistor can be visualise as a diode

∴ The diode current eqn is applicable.

→ ∴ From the ckt

$$I_E = I_s\left(e^{qV_E/kT} - 1\right)$$

But $I_E = I_C$ when base is grounded

$$I_C = I_s\left(e^{qV_E/kT} - 1\right)$$

$$I_C/I_s = e^{qV_E/kT} - 1$$

$$\frac{I_C}{I_s} + 1 = e^{qV_E/kT}$$

→ Since $I_C \gg I_s$

$$\frac{I_C}{I_s} = e^{qV_E/kT}$$

$$\frac{qV_E}{kT} = \log_e\left(\frac{I_C}{I_s}\right)$$

$$V_E = \frac{kT}{q} \cdot \log_e\left(\frac{I_C}{I_s}\right)$$

→ From the ckt diagram we have $I_C = \frac{V_i}{R_1}$ sub the value of I_C in the above expression

$$V_E = \frac{KT}{q} \log_e \left(\frac{V_i}{R_1 I_s}\right)$$

→ From the ckt the o/p voltage $V_0 = -V_E$

let $R_1 I_s = V_{ref}$

$$\boxed{V_0 = \frac{-KT}{q} \log_e \left(\frac{V_i}{V_{ref}}\right)}$$

→ In the above expression for V_0 the value of k, T and q are fix and also Vref can be kept constant.

$$\boxed{\therefore V_0 \propto \log(V_i)}$$

→ From this expression the o/p voltage is proportional to logarithm of the i/p voltage. For this reason this ckt is called "log amp".

→ This expression may also be written as

$$V_0 = \frac{-KT}{0.4343\, q} \log_{10}\left(\frac{V_i}{V_{ref}}\right)$$

→ In order to the above relationship holds good it is essential that Vref is constant we have $V_{ref} = R_1 I_s$.

→ hence the reverse saturation current I_s should remain constant but I_s is found to vary from transistor to another transistor also I_s is temperature dependent Thus it may not be possible in practice it can be obt a stable ref voltage.

→ In order to obey this difficult to the ckt is modi to the modified ckt are shown in fig(b) and (c)

→ from the fig (b) the ckt uses four op-amps. The i/p signal V_i is applied to the op-amp A1 and the ref voltage. V_{ref} is applied to the op-amp A2 both op-amps A1 and A2 are integrated in a close ckt on the same silicon va. wafer. so that the reverse saturation current match at all temperatures.

→ ∴ $I_{S1} = I_{S2} = I_S$.

→ For op amp A1 the o/p voltage $V_1 = \frac{-KT}{q} \log\left(\frac{V_i}{R_1 I_S}\right)$.

$$V_2 = -\frac{KT}{q} \log\left(\frac{V_{ref}}{R_1 I_S}\right)$$

→ These 2 o/p forms i/ps to op-amp A3 to the o/p V_o is diff of the i/p's.

$$V_o = V_2 - V_1$$

$$= -\frac{KT}{q} \log\left(\frac{V_{ref}}{R_1 I_S}\right) + \frac{KT}{q} \log\left(\frac{V_i}{R_1 I_S}\right)$$

$$= \frac{KT}{q} \log\left(\frac{V_i}{V_{ref}}\right)$$

→ since V_{ref} is not dependent and temperature and it is fixed value in magnitude from the above expression.

→ The o/p voltage V_o is still dependent on T.

∴ This dependent of V_o is applied to the non inverting terminal of A4 which provides a non inverting gain of $\left(1 + \frac{R_2}{R_{TC}}\right)$

where R_{TC} = a temperature sensitive resistance with +ve coefficient it is also called "sensistor".

→ ∴ The o/p of op-amp A4 = $V_{o(comp)} = \left(1+\frac{R_2}{R_{TC}}\right)\frac{KT}{q}\log\left(\frac{V_i}{V_{ref}}\right)$

→ From this expression RTC helps to maintain the slope of the eqn of V_o (comp) constant at all temperatures.

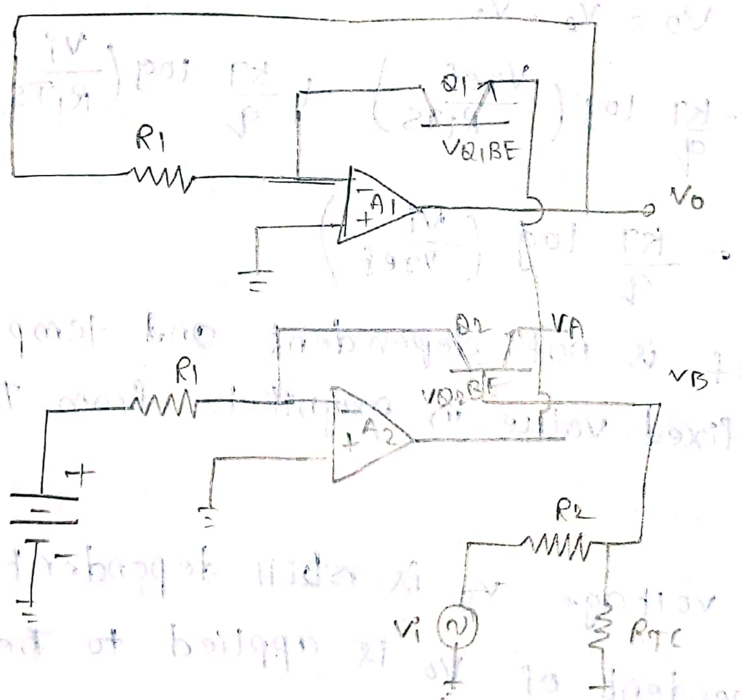
→ ∴ V_o compensation ∝ log (V_i)

→ Another modified ckt which uses only two op-amps as shown in fig c.

→ from this modified ckt the o/p voltage is given by the same expression but there is a phase inversion.

→ $$V_{o(comp)} = -\left(1+\frac{R_2}{R_{TC}}\right)\frac{KT}{q}\log\left(\frac{V_i}{V_{ref}}\right)\left(1+\frac{R_2}{R_{TC}}\right)$$

Antilog amp:-



→ The i/p voltage V_i is applied to the base of the transistor Q_2 via the potential devider arrangement of R_2, RTC. The o/p voltage V_o of the antilog amp is fed back to the inverting i/p terminal of op-amp A1 we have $V_{Q1BE} = \frac{KT}{q}\log_e\left(\frac{V_o}{R_1 I_S}\right)$

$\left(1+\frac{R_2}{R_{TC}}\right)$ $V_{Q_2BE} = \frac{kT}{q} \log_e\left(\frac{V_{ref}}{R_1 I_S}\right)$

also $V_i = -V_{Q_1BE}$ since the base of the transistor Q_1 is grounded.

$$\therefore V_i = -\frac{kT}{q} \log_e\left(\frac{V_o}{R_1 I_S}\right)$$

→ The potential at $V_B = V_i\left(\frac{R_{TC}}{R_2+R_{TC}}\right)$

By using potential divider rule. But V_B is the voltage at the base of the transistor Q_2.

∴ The emitter voltage of the transistor Q_2 is equal to

$$V_A = V_B - V_{Q_2BE}$$

$$-\frac{kT}{q} \log\left(\frac{V_o}{R_1 I_S}\right) = V_i\left(\frac{R_{TC}}{R_2+R_{TC}}\right) - \frac{kT}{q} \log_e\left(\frac{V_{ref}}{R_1 I_S}\right)$$

$$V_i \frac{R_{TC}}{R_2+R_{TC}} = -\frac{kT}{q} \log\left(\frac{V_o}{R_1 I_S}\right) + \frac{kT}{q} \log_e\left(\frac{V_{ref}}{R_1 I_S}\right)$$

$$V_i \frac{R_{TC}}{R_2+R_{TC}} = -\frac{kT}{q}\left[\log_e\left(\frac{V_o}{R_1 I_S}\right) - \log_e\left(\frac{V_{ref}}{R_1 I_S}\right)\right]$$

$$-\frac{kT}{q} \log_e\left(\frac{V_o}{V_{ref}}\right) = V_i \frac{R_{TC}}{R_2+R_{TC}}$$

$$\log_e\left(\frac{V_o}{V_{ref}}\right) = -\frac{q}{kT} V_i\left(\frac{R_{TC}}{R_2+R_{TC}}\right)$$

0.4343 is multiplied on both sides of the expression

$$0.4343 \log_e\left(\frac{V_o}{V_{ref}}\right) = -0.4343 \frac{q}{kT} V_i \frac{R_{TC}}{R_2+R_{TC}}$$

where $0.4343 \log_e\left(\frac{V_o}{V_{ref}}\right) = \log_{10}\left(\frac{V_o}{V_{ref}}\right)$

$0.4343 \log_e\left(\frac{V_o}{V_{ref}}\right) =$

$$\log_{10}\left(\frac{V_o}{V_{ref}}\right) = -kV_i$$

$$\left[\log_e x = \frac{\log_{10} x}{\log_{10} e}\right.$$

$$\log_e x = \frac{\log_{10} x}{0.4343}$$

$$\left. 0.4343 \log_e x = \log_{10} x \right]$$

where $k = 0.4343 \frac{q}{kT} \frac{R_{TC}}{R_2 + R_{TC}}$

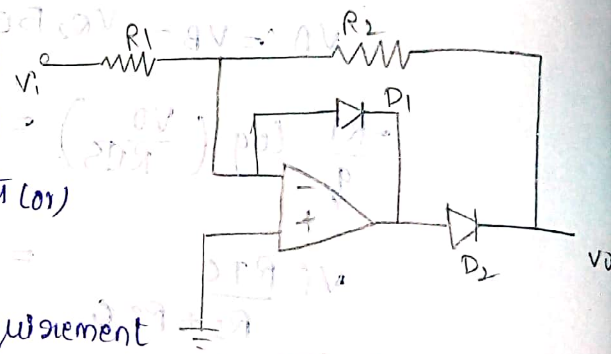
$$\frac{V_o}{V_{ref}} = 10^{-kV_i}$$

$$\therefore \boxed{V_o = V_{ref}\, 10^{-kV_i}}$$

→ Since Vref is of constant magnitude from this relationship it is concluded that an increase of i/p voltage by 1 volts as a result decrease of 10V in the o/p voltage. Then the ∴ ckt can function as antilog amp.

Precision Rectifiers:-

→ precision rectifiers are required if the voltages less than threshold voltage for example few millivolts (or) micro volts.

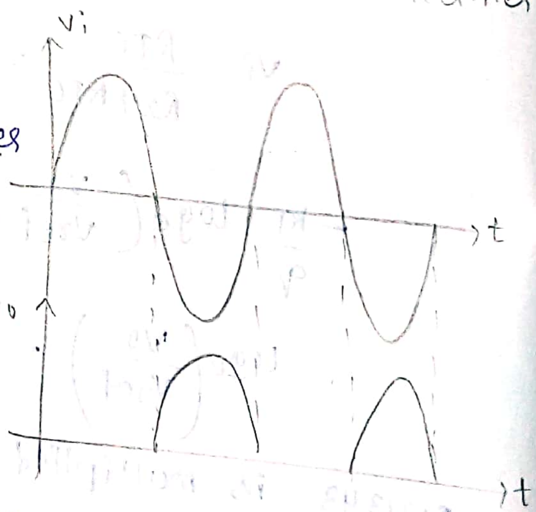


a. Half wave rectifier

→ An op amp ideally fulfills the requirement

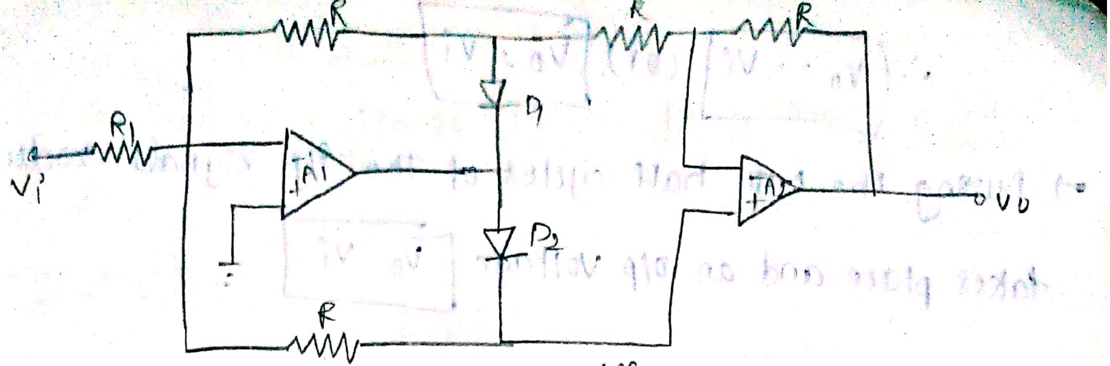
precision halfwave rectifier:-

→ The ckt of precision halfwave rectifies using op-amp is shown in fig.

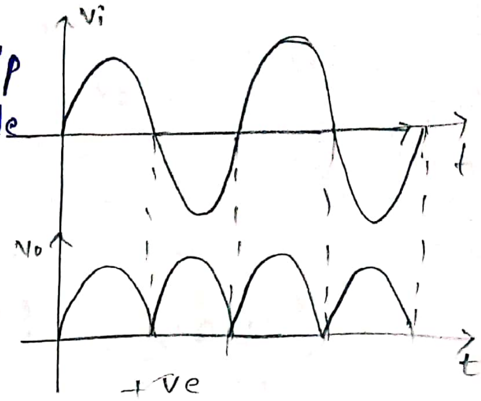


→ The ckt uses two diodes D_1 and D_2. The resistor R_2 to the F.B path the resistor R_1 in the i/p ckt. Since the noninverting i/p terminal is grounded

→ During the +ve half cycle of the i/p voltage V_i we can see that the diode D_1 gets F.B. The diode D_2 gets R.B. Hence only diode D_1 can conduct and there is no current through resistor R_2 then this result the o/p voltage $V_o = 0$.



b. full wave rectifier.



→ During the -ve half cycle of the i/p voltage V_i. It is seen that the diode D_1 gets R.B. and Diode D_2 F.B.

Hence D_1 is OFF and D_2 is ON. The ckt behaves like an inverting amp.

→ ∴ The o/p voltage is given by $V_0 = -R_2/R_1 V_i$.

→ Let R_2 and R_1 the resistors of equal magnitude i.e, $R_1 = R_2$

$$\boxed{\therefore V_0 = -V_i.}$$

→ But During The -ve half cycle V_i itself -ve

$$\boxed{\therefore V_0 = V_i.}$$

→ The i/p and o/p waveforms on shown in figure.

precision fullwave rectifiers:

→ precision fullwave rectifier is shown in fig.

→ The ckt uses two identical diodes D_1 and D_2 and several resistors in conjuction with two op-amps as shown in fig

→ During the +ve half cycle of the i/p voltage V_i. The diode D_1 gets F.B. and D_2 gets R.B.

→ ∴ The o/p voltage $\boxed{V_0 = V_i.}$

→ Illy During The -ve half cycle of the i/p Voltage V_i the diode D_1 gets R.B. and D_2 gets F.B.

$\therefore \boxed{V_0 = -V_i}$ (or) $\boxed{V_0 = V_i}$

→ During the both half cycles of the i/p signals conduction takes place and an o/p voltage $\boxed{V_0 = V_i}$