B Sc II year Semister-III Paper-VII (ELE-301) Sub-Electronics

Linear Integrated Circuits

1. Operational Amplifier

1 The Operational Amplifier (OP-AMP):

An operational amplifier is a direct-coupled high-gain amplifier. It is a versatile device that can be used to amplify dc as well as ac input signals and was originally designed for computing such mathematical functions as addition, subtraction, multiplication, and integration. Thus the name operational amplifier stems from its original use for these mathematical operations and is abbreviated to OP-Amp. With the addition of suitable external feedback components, the modern day op-amp can be used for a variety of applications, such as ac and dc signal amplification, active filters, oscillators, comparators, regulators, and others.

Fig.1. shows the most widely used of such symbols for a circuit with two inputs and one output. For simplicity, power supply and other pin connections are omitted. Since the input differential amplifier stage of the op-amp is designed to be operated in the differential mode, the differential inputs are designated by the (+) and (-) notations. The (+) input is the noninverting input. An ac signal (or dc voltage) applied to this input produces an in phase (or same polarity) signal at the output. On the other hand, the (-) input is the inverting input because an ac signal (or dc voltage) applied to this input produces an 180^0 out-of-phase (or opposite polarity) signal at the output.

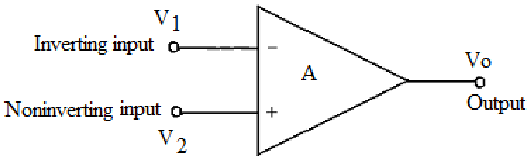

Fig. 1. Schematic symbol of OP-Amp

V_1 = voltage at the inverting input (volts),
V_2 = voltage at the noninverting input (volts),
V_o = output voltage (volts).

All these voltages are measured with respect to ground.

A = large-signal voltage gain, which is specified on the data sheet for an op-amp

2 The Ideal Op-Amp:

An ideal op-amp would exhibit the following electrical characteristics:

1. Infinite voltage gain A.
2. Infinite input resistance R_i so that almost any signal source can drive it and there is no loading of the preceding stage.
3. Zero output resistance Ro so that output can drive an infinite number of other devices.
4. Zero output voltage when input voltage is zero.
5. Infinite bandwidth so that any frequency signal from 0 to ∞ Hz can be amplified without attenuation.
6. Infinite common-mode rejection ratio so that the output common-mode noise voltage is zero.
7. Infinite slew rate so that output voltage changes occur simultaneously with input voltage changes.

There are practical op-amps that can be made to approximate some of these characteristics using a negative feedback arrangement. In particular, the input resistance, output resistance, and bandwidth can be brought close to ideal values.

3 Operational Amplifier Parameters:

i) Input bias current:- Note that the stage of the OP-Amp is a differential amplifier consisting two transistors. These transistors are properly biased. Hence there will be some base current for the input transistors even in the absence of any input signal, i.e. when the input is zero. Thus the input current at the two inputs in this case is the base current of the two transistors in the first differential amplifier stage. The input bias current is one half of the sum of separate currents flowing into the input terminals of the amplifier when the output is equal to zero volts.

Hence input bias current, $I(B) = [I(B_1)+I(B_2)]/2$

Smaller the input bias current, larger would be the input impedance of the amplifier.

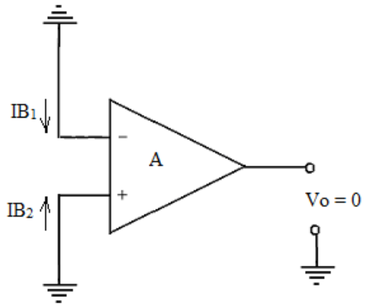

Fig. 1.

ii) Input offset current:- The difference between the separate input currents flowing into the input terminals when the output is zero is called as input offset current. Hence, input offset current I(io) is given by

$$I(io) = \left| IB_1 - IB_2 \right|$$

Smaller the input offset current better would be the OP-Amp. The input transistors are usually matched to great extent such that both the bias currents are almost equal.

iii) Input offset voltage:- A mismatch in the base to emitter voltage of the input differential amplifier transistors is the cause of the non zero output. Such non zero output can be made zero by applying input of proper magnitude and polarity. The input voltage that must be applied between the two input terminals to get output zero is called as the input offset voltage. Lesser is the input offset voltage, better would be the amplifier.

iv) Open loop gain:- Open loop gain, is the ratio of output voltage to the voltage applied between the two inputs of the operational amplifier. Fig. 2 shows three different ways in which the input could be applied.

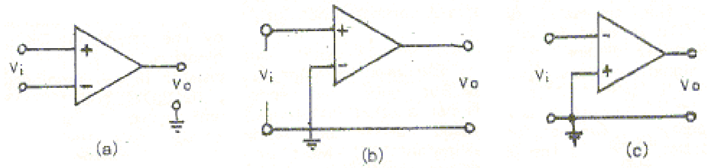

Fig. 2.

Note that in all the three cases, the ratio Vo/Vi is same and is the open loop voltage gain of the amplifier.

v) Differentia/Input Resistance:- Differential input resistance Ri (often referred to as input resistance) is the equivalent resistance that can be measured at either the inverting or noninverting input terminal with the other terminal connected to ground. For ideal operational amplifier it is infinite.

vi) Output Resistance:- Output resistance Ro is the equivalent resistance that can be measured between the output terminal of the operational amplifier and the ground. For ideal OP-Amp it should be close to zero.

vii) Common mode rejection ratio:- Generally, it can be defined as the ratio of the differential voltage gain A_d to the common-mode voltage gain A_{cm}; that is,

$$CMRR = \frac{A_d}{A_{cm}}$$

The differential voltage gain Ad is the same as the large-signal voltage gain A, however, the common-mode voltage gain can be determined from the circuit of fig. 3 using the equation

$$A_{cm} = \frac{V_{ocm}}{V_{cm}}$$

where V_{ocm} = output common-mode voltage,
V_{cm} = input common-mode voltage, and
A_{cm} = common-mode voltage gain.

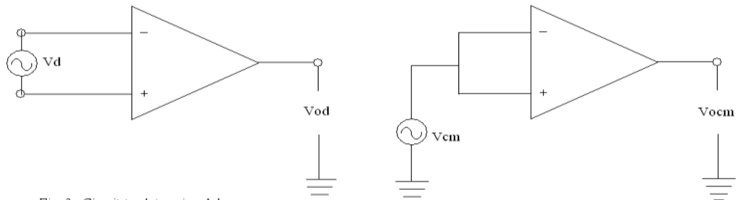

Fig. 3a. Circuit to determine Ad.
Fig. 3b. Circuit to determine Acm.

Generally the A_{cm} is very small and $A_d = A$ is very large; therefore, the CMRR is very large. The higher the value of CMRR, the better is the matching between two input terminals and the smaller is the output common-mode voltage.

viii) Slew Rate:- Normally an operational amplifier is operated under closed loop conditions i.e. with a negative feedback. An operational amplifier consists of a large number of active and passive components. It is therefore natural that signal would require some minimum time (which depends on a particular circuit arrangement) to pass through the devices. Hence if a sharply rising signal or a high frequency signal is applied at the input, then the output gets delayed, giving rise to a delayed feedback, due to which the gain of the amplifier will be too large. Hence the operational amplifier will go into saturation resulting into a distorted output. Because of this fact, there is a limit on the rate of increase of input voltage, which depends on the delay in action introduced by the device.

The slew rate is the time rate of change of the closed loop amplifier voltage under large signal conditions.

Finite value of slew rate limits the maximum frequency and amplitude to which an amplifier can respond. Let the output of an OP-AMP be expressed as;

$$v = V \sin \omega t$$

Then, the rate of rise of output voltage will be

$$dv/dt = \omega V \cos\omega t$$

Hence maximum slew rate would ωV, when $\cos\omega t = 1$.

Thus slew rate, $S = \omega V = = 2\pi f V$

From the above equation for a given slew rate of a device, note that, the product (f.V) is constant. Hence if the frequency f is larger, then the amplitude V has to be smaller and vice versa.

4 Use of Op Amp as an Inverting Amplifier:

The circuit diagram of inverting amplifier using OP-Amp is shown in fig.1. In this case, a negative feedback is used, so that the gain of the amplifier gets reduced. As seen from the Fig.1 the non-inverting input terminal (+) is grounded and an input signal is applied to the inverting input (-) through the resistor R_1. Output will then be out of phase with the input. Resistor R_2 is the feedback resistor. The resistors, R_1, R_2 and the internal resistance of the source (not shown in the figure) form a voltage divider across the output terminals (i.e. between the output and common ground). Thus some portion of the output, which will get dropped across resistor, R_1 will constitute the feedback voltage. But this being out of phase with the input, the feedback is a negative feedback.

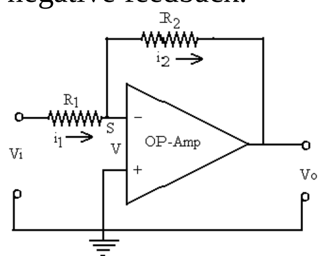

Fig.1.

Let V be the potential at the point S called as the summing point. If, i_1 is the current flowing through the resistor R_1, then;

$$i_1 = \frac{V_i - V}{R_1} \qquad (1)$$

Similarly the current 1_2 flowing through R_2 will be

$$i_2 = \frac{V - V_o}{R_2} \qquad (2)$$

Now as the current 1_1 enters the summing point S, it can flow to the ground along two paths, (1) through the internal resistance of OP AMP to ground and (2) through R_2 and the output resistance of the amplifier to the ground. But as the ideal OP AMP is supposed to have infinite input resistance, no current should enter at the input of the device.

Hence, $i_1 = i_2$ (3)

Because the open loop gain of the amplifier is the ratio of output to the differential input, and as the output is out of phase with the input we can write;

Open loop gain

$$A = \frac{-V_o}{V} \qquad (4)$$

Using eqns. 1,2, 3 and 4 we have,

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

Rearranging it we get,

$$\frac{R_2}{R_1} V_i = -V_o\left(1 + \frac{1}{A} + \frac{R_2}{R_1}\frac{1}{A}\right) \qquad (5)$$

But in ideal case the open loop gain is infinite i.e. $A = \infty$, and hence, the gain with feedback,

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

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

or $$A(f) = -\frac{R_2}{R_1} \qquad (6)$$

The negative sign in the expression indicates that the output is out of phase with input. Hence this mode of operation is called as the inverting mode of the amplifier. The feed back used in this case, is called as the operational feedback. A(f), the gain with feedback, is called as the closed loop gain of the amplifier.

5 Noninverting Amplifier:

In this configuration, a signa1 is applied to the noninverting input and as in the case of an inverting amplifier, a negative feedback is incorporated. Fig.1(a) shows a circuit of a noninverting amplifier. While the same, circuit is redrawn for convenience and is shown in fig.1(b).

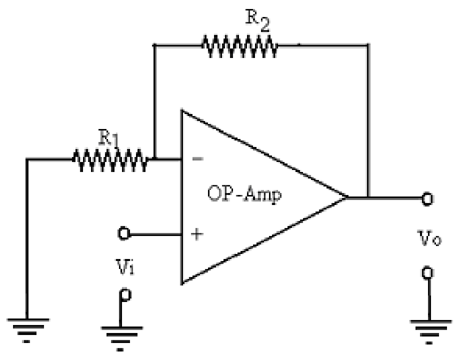

Fig. 1(a).

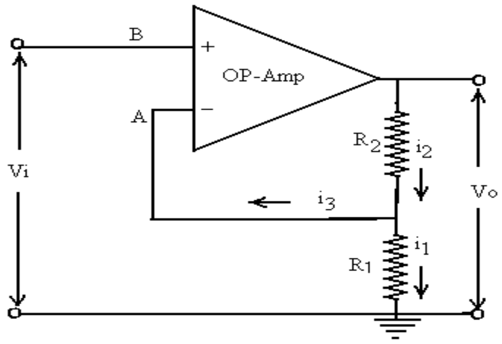

Fig. 1(b).

Let i_2 be the current flowing through the resistor R_2. Current i_2 will branch into two parts i_3. and i_1 as shown in fig.1 (b). Because the input impedance of an ideal OP-AMP is infinite, current i_3 would be zero,

Thus $i_1 = i_2$ (1)

Because same current now flows through resistors R_1 and R_2, the combination of the two resistors acts as a voltage divider.

From Fig.1 (b), the voltage V(A) at A would be

$$V(A) = \frac{V_o R_1}{R_1 + R_2}$$

If V is the potential difference between B and A i.e. potential difference between the noninverting and inverting input, then

$V = Vo/A$ (2)

Thus the potential at B with respect to the ground would be

$$V(B) = V(A) + V = V_o\left(\frac{1}{A} + \frac{R_1}{R_1 + R_2}\right)$$

But V(B) = Vi. Hence,

$$V_i = V_o\left(\frac{1}{A} + \frac{R_1}{R_1 + R_2}\right) \qquad (3)$$

Because the open loop gain of an ideal OP AMP is infinite, eqn. 3 can be written as;

$$V_i = V_o\left(\frac{R_1}{R_1 + R_2}\right)$$

Hence the gain

$$A(f) = \frac{V_o}{V_i} = \frac{R_1 + R_2}{R_1} = 1 + \frac{R_2}{R_1}$$

$$A(f) = 1 + \frac{R_2}{R_1} \qquad (4)$$

Where the quantity A(f), is the closed loop gain of the noninverting amplifier.

Note that the closed loop gain A(f) depends only on R1 and R2 and not on the open loop gain A. Thus the gain A(f) is independent of replacement, temperature changes, supply voltage changes and ageing. The closed loop gain is positive, which shows that the output is in phase with the input. The gain is the same at zero frequency (DC) as well as at higher frequencies.

6 Unity gain voltage follower or buffer:

Fig.1 shows a circuit of a unity gain buffer. In this circuit, because all the output voltage is fed back to the input, maximum negative feedback is employed. Note that this circuit is similar to the usual noninverting amplifier where $R_1 = \infty$ and R2 = 0. The closed loop gain would then be

$$A(f) = 1 + \frac{R_2}{R_1} = 1$$

Thus this circuit will produce output exactly identical to the input. The advantages associated with this circuit would be appreciated only after understanding the effective input and output impedances. The resultant input impedance is
very high and can be expressed as;

$Z_i(f) = Z_i\,A$

Effective output impedance gets reduced and is expressed as

$Z_0(f) = Z_0/A$

Thus the circuit possesses very large, input impedance and extremely low output impedance. In addition to unity gain, the circuit does not introduce any phase change. Hence the unity gain amplifier is very much useful in isolating any circuit from a load, or it can act as a buffer amplifier.

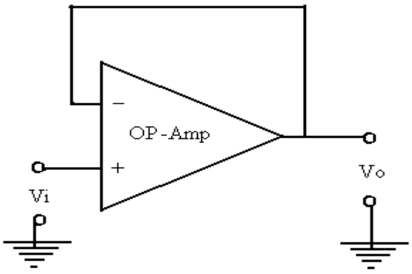

Fig. 1

7 Adder or Summing Amplifier:

Fig.1 shows the operational amplifier as an adder. The circuit is basically an inverting amplifier with a modification on the input side. Let the voltages V1, V2 and V3 be applied at A, B, and C respectively and the common ground as shown in Fig.1.

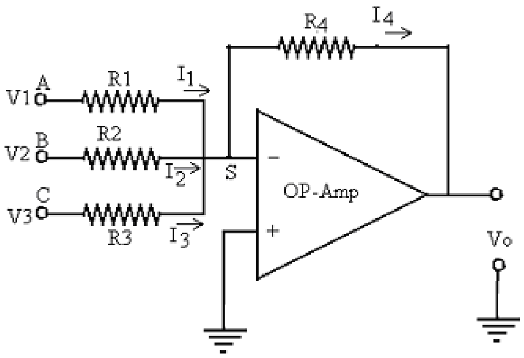

Fig. 1.

Let I_1, I_2 and I_3 be the currents flowing through the resistors R1, R2 and R3. These currents meet at the summing point S and the total current can branch in two ways, viz. some portion flowing through R4 and the remaining part flowing into the intput terminal of the amplifier. But the input impedance of an ideal operational amplifier being infinite, the net current flows through R4 only.

Hence

$$I_1 + I_2 + I_3 = I_4 \qquad (1)$$

Because summing point is at virtual ground;

Current

$$I_1 = \frac{V_1 - 0}{R_1} = \frac{V_1}{R_1} \qquad (2a)$$

$$I_2 = \frac{V_2 - 0}{R_2} = \frac{V_2}{R_2} \qquad (2b)$$

$$I_3 = \frac{V_3 - 0}{R_3} = \frac{V_3}{R_3} \qquad (2c)$$

$$I_4 = \frac{0 - V_o}{R_4} = -\frac{V_o}{R_4} \qquad (2d)$$

Note that the direction of current I_4 indicates that the potential at S is higher than the potential at the output terminal, and hence the potential difference across R_4 is [0 -Vo].

From eqns. (1) and (2)

$$\frac{V_1}{R_1}+\frac{V_2}{R_2}+\frac{V_3}{R_3}=-\frac{V_o}{R_4}$$

or $$Vo=\frac{R_4}{R_1}V_1+\frac{R_4}{R_2}V_2+\frac{R_4}{R_3}V_3 \qquad (3)$$

Thus individual voltages can be added, but with an added multiplying factor or weighting factor, (i.e. R4/R1, R4/R2, etc.).

If R1=R2=R3=R4, then

$$Vo = -(V1 + V2 + V3) \qquad (4)$$

This shows that the output voltage is the sum of the input voltages but with a change of the sign.. The additional negative sign only indicates the phase relation between input and output voltages. The negative sign in the expression can be removed by using a unity gain inverting amplifier or a sign changer.

8 Op-Amp as Subtractor:

Suppose the subtraction to be performed is V2 - V1 = V. This can be achieved by two methods.

(1) Feed V1 to a unity gain inverting amplifier and then feed the output of the sign changer, along with V2 to an adder. The result will be Vi = V2 + (-V1) = V2- V1. But in this case, an additional OP-AMP would be required for inversion.

(2) The subtraction can also be done by using a single OP-AMP as shown in fig.1. As usual, because of the high input impedance of the OP AMP, we have

$$I_1 = I_2 \text{ and } I_3 = I_4 \qquad (1)$$

Because of very large open loop gain, differential mode input = output/gain= zero.

Hence, potential V(A) = potential V(B)

Let V(A) = V(B) = V (say), then

$$I_1=\frac{V_1-V}{R_1} \qquad (2a)$$

and $$I_2=\frac{V-V_o}{R_2} \qquad (2b)$$

Similarly,

$$I_3=\frac{V_2-V}{R_1} \qquad (3a)$$

and $$I_4=\frac{V-0}{R_2}=\frac{V}{R_2} \qquad (3b)$$

Thus from eqns. 1, 2 and 3 we get,

$$\frac{V_1}{R_1}=V\left(\frac{1}{R_1}+\frac{1}{R_2}\right)-\frac{V_o}{R_2} \qquad (4)$$

$$\frac{V_2}{R_1}=V\left(\frac{1}{R_1}+\frac{1}{R_2}\right) \qquad (5)$$

Subtracting equation (5) from equation (4), we get

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

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

Now if $R_1 = R_2$ then

$$Vo = V_2 - V_1$$

Thus the output would be the, difference between the two input voltages. Note that because the OP-AMP responds equally well to dc as well as ac signals, the above subtraction is possible for all dc (or zero frequency) voltages, all ac voltages irrespective of their form and even for dc and ac voltages together.

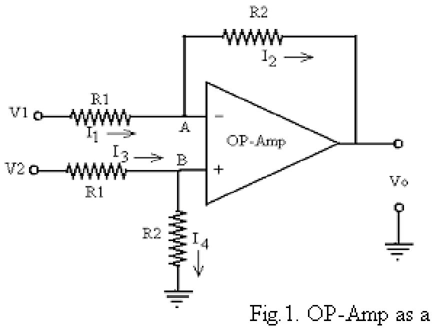

Fig. 1. OP-Amp as a subtractor.

9 Operational Amplifier as Integrator:

Passive components like R and C can be used to function as an integrating circuit. For the passive integrator circuit shown in Fig.1, v_i = the instantaneous magnitude of the voltage applied to the circuit, and v_o = the corresponding instantaneous value of the output voltage. If i = instantaneous current in the circuit, and q = instantaneous charge on the
capacitor, then, $v_o = q/C$.
But $i = dq/dt$ or $dq = idt$, or $q = \int idt$.
Hence

$$v_0 = \frac{q}{C} = \int \frac{idt}{C} \quad (1)$$

$$v_0 = \frac{1}{RC} \int \frac{iRdt}{C} \quad (2)$$

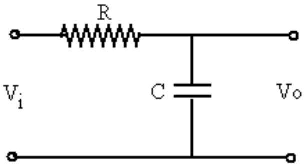

Fig. 1.

Now by Kirchoff's law,

$$v_i = iR + q/C \quad (3)$$

But if RC, the time constant of the circuit is very large as compared to the periodic time of the applied voltage, then RC>>1/f or R>>1/fC.

Thus $R >> \frac{1}{2\pi fC}$

This shows that the reactance of the condenser is much smaller than the resistance R. Hence voltage drop (q/C) across the capacitor is negligible compared to the voltage drop (iR) across the resistor R. Thus eqn. 3 reduces to
$v_i = iR$.
Hence from eqn 2, we get,

$$v_0 = \frac{1}{RC} \int v_i dt \quad (4)$$

Thus the output is proportional to the time integral of the input voltage. The main drawbacks in this integrator circuit are as follows.
(i) There is a limit on the frequency of the input voltage.
As RC>> T, i.e. f >> 1/RC. In other words, the circuit can function as an integrating circuit only when the frequency of the input voltage is much larger than 1/RC.
(ii) Under the above mentioned condition, reactance of the capacitor will be very much smaller than the resistor and hence the output will be always very small, or the circuit will attenuate the input voltage in the process of integration.

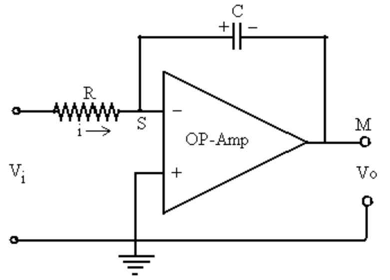

Fig. 2.

An operational amplifier can be used as an integrator with much better performance. This can be achieved by replacing the feedback resistor in the inverting amplifier circuit by a capacitor as shown in fig 2. Note that this circuit is essentially the inverting amplifier, where the feedback is provided through the capacitor C, and the point S is as usual, at the virtual ground. Now instantaneous voltage across the capacitor is,

$$v_c = q/C \qquad (5)$$

But $q = \int i dt$, hence

$$v_c = \int \frac{idt}{C} \qquad (6)$$

The capacitor is connected between the output terminal and S, which is at ground potential. For a positive going input voltage v_i, the current i will be directed towards the point S. In such a case the polarity of the voltage drop produced across the capacitor will be as shown in fig.2. As v_o is the potential of M with respect to ground, i.e. with respect to S, hence

$$v_o = -\int \frac{idt}{C}$$

Similarly as S is at virtual ground, hence,

$$i = v_i/R$$

Substituting for i we get,

$$v_o = -\int \frac{v_i dt}{RC} = -\frac{1}{RC}\int v_i dt \qquad (7)$$

Thus output is proportional to the time integral of the input voltage.

The variation of the output voltage of an ordinary integrator circuit (using passive network) and the one with an operational amplifier is shown in fig. 3(a) and fig. 3(b).

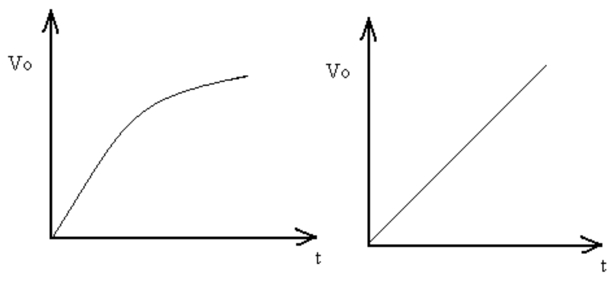

Fig. 3(a). Passive integration. Fig. 3(b). OP-AMP integration.

It could be seen that; the output of the OP-AMP integrator increases at constant rate while with RC circuit, it rises exponentially. A linearly rising voltage, ca1led as a ‘ramp’ is very useful in various electronic circuits such in analogue to digital converters, digital voltmeters, DVM etc.

If the input to the integrator is a square wave, then this is equivalent to feeding positive and negative dc voltages alternately to the integrator. Then the output of the integrator will ramp up and down alternately. In other words the output will be a triangular wave as shown in Fig. 4.

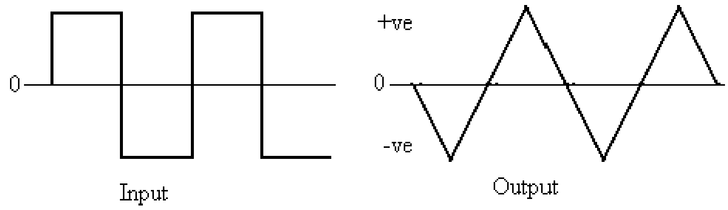

Fig. 4.

10 Operational amplifier as a differentiator:

A simple network shown in fig.1 using passive components can be used as a differentiator circuit. Applying Kirchhoff's law to the circuit, we get,

$$v(i) = iR + q/C \tag{1}$$

Where $v(i)$ = instantaneous input voltage

i = instantaneous input current

and q = instantaneous charge on the capacitor.

Now if the RC time constant is small as compared to the period of the input signal, i.e. CE << T or RC << 1/f or R << 1/2πfC, then the reactance of the capacitor would be much larger as compared to the resistance in the circuit. Thus all the applied voltage will appear across the capacitor.

Hence $v(i) = q/C$ (2)

or $$v(i) = \int \frac{i\,dt}{C}$$

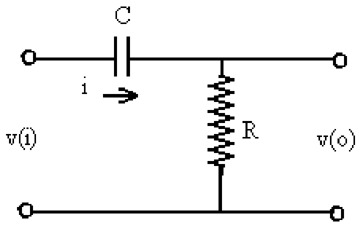

Fig. 1.

Differentiating we get

$$\frac{dv(i)}{dt} = \frac{i}{C}$$

or $$i = C\frac{dv(i)}{dt}$$

Then the instantaneous output voltage v(o) would be,

$$v(o) = iR = RC\frac{dv(i)}{dt} \tag{3}$$

Thus the output is proportional to the differential of the input voltage. But note that this is only true if RC time constant is small compared to the period of the input signal. Hence circuit functions as a differentiator only for definite frequencies and in addition the output voltage is much smaller than the input. This is because the reactance of the capacitor is much larger than the series resistor. An operational amplifier as shown in fig.2 can be used as a differentiator, wherein the above-mentioned drawbacks are minimized.

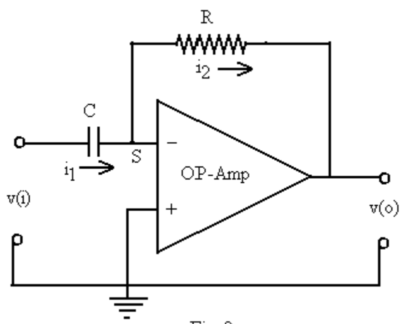

Fig. 2.

As usual are summing point s will be at virtual ground. Thus all the applied input voltage would appear across the capacitor. Thus if v(i) = instantaneous voltage the capactor, then v(i) = q/C.
Hence q = Cv(i).
Thus instantaneous current i_1 in the capacitor would be

$$i_1 = \frac{dq}{dt} = C\frac{dv(i)}{dt} \qquad (4)$$

Now because the input impedance of the OP AMP is very large, the current i_1 through the capacitor would be equal to the current i_2 flowing through the resistor.

But 1 $$i_2 = \frac{0 - v(o)}{R} = -\frac{v(o)}{R} \qquad (5)$$

Hence we have i1 = i2, or

$$C\frac{dv(i)}{dt} = -\frac{v(o)}{R}$$

or $$v(o) = -RC\frac{dv(i)}{dt} \qquad (6)$$

Thus the output is proportional to the differential of the input voltage. Note that,
1. No assumptions have been made regarding the time constant RC, and hence the above equation is true for any frequency.
2. The negative sign indicates that the amplifier introduces a phase change of 180.
3. The constant (RC) can be reduced to unity, with proper values of R and C.
4. If a sinusoidal voltage v(i) = Vsin(ωt) is applied a input to the differentiator, then

$$v(o) = -RC\frac{dv(i)}{dt} = -RC\omega V\cos(\omega t)$$

Thus the amplitude (RCωV) of the output is directly proportional to the frequency. In other words, a high frequency input signal will appear at the output with larger amplitude.

11 Regenerative comparator (Schmitt trigger):

A schmitt trigger is a binary circuit i.e. the circuit possesses two stable states. The state of thrs circuit can be changed by input voltage of proper magnitude. This circuit incorporates a positive feedback and hence due to the regenerative action the state of the circuit changes almost instantaneously.

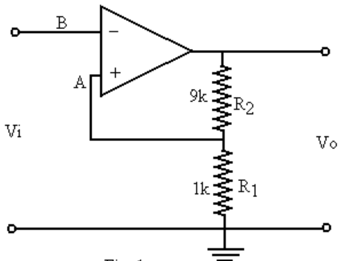

Fig. 1.

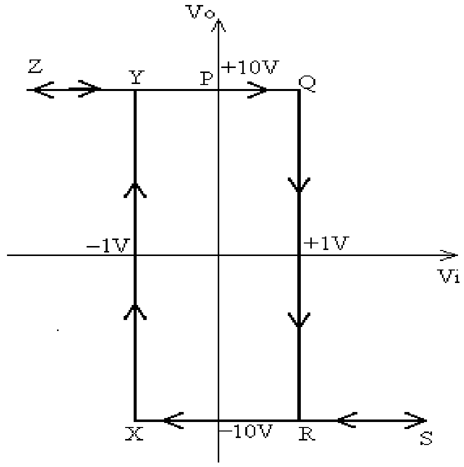

Fig. 2.

Fig. 1 shows a simple regenerative comparator circuit. Two resistors (1K, 9K) form a feedback network. Some fraction of the output is fed at the noninverting input of the OP AMP. Thus the feedback becomes a positive feedback. Initially let the input v(i) to the comparator be zero, and then let the supply of the OP-AMP be put on. The output would be very small and let it be positive.

A fraction; $\frac{R1}{R1+R2}Vo = \beta Vo$ will be fed back to the input. Because inverting input is grounded i.e. input v(i) is equal to zero, the only source at the input will be βVo. This when applied to the noninverting input will be amplified, producing larger positive voltage at the output. Again, a fraction of this will be fed back in the input and thus producing still larger positive voltage. This is the regenerative action and is due to the positive feedback. Hence due to the regenerative action, output will become positive and maximum within a very short time. Thus circuit can have two stable states. Let the positive maximum voltage obtained with the circuit be + 10 volt and the negative maximum voltage be equal to -10 volt. Thus in this case V+ = +10V and V- = -10 volt. Let the output of the OP AMP be +10 volt. Then the potential at A would be +1 volt. Thus the circuit here is very similar to a usual comparator, with a reference voltage of +1 volt, being supplied to the noninverting input and a variable voltage Vi (to be compared) applied to the inverting input.

As long as Vi is less than +1 volt, the output of OP AMP will remain at +10 volt. But as soon as Vi just exceed + 1 volt, the output will start decreasing from +10 volt. The effect of this decrease is that the voltage at A also decreases, which makes Vi much larger than V(A). This larger Vi will still decrease the output and also the voltage V(A). Hence due to this regenerative action, the output of the OP AMP will change almost instantaneously to -10 volt. The minimum input voltage required to change the state of the output is called as the threshold or triggering voltage. As the output has ultimately changed to -10 volt, the voltage at A should also change to -1 volt. At this stage, because Vi is still larger than V(A) the output will remain -10 volt. If Vi is further increased beyond +1 volt the output will remain constant at -10 volt. This variation of output with input is shown by PQRS in Fig.2.

Now if the input is decreased from some higher voltage up to +1 volt or even below +1 volt, the output of the comparator will not change. The reason is that the reference voltage to the comparator is -1 volt instead of +1 volt. The output of the comparator can suddenly change to +10 volt, as soon as Vi just goes below -1 volt. If the input voltage is further decreased, the output will remain the same at + 10 volt. This variation of output with input is shown by the portion SRXYZ in fig.2. The output can only be changed if the input voltage is increased beyond +1 volt afterwards.

Note that the two threshold (triggering) levels of the comparator are not the same. These are +1 volt and -1 volt respectively. The difference between these two threshold voltages is called as the Hystersis V(H). Thus V(H) = +1 volt -(-1volt) = 2 volt, for the above circuit. By proper selection of the resistors, different values of the threshold levels can be obtained.

12 Astable Multivibrator using Op-Amp:

An astable multivibrator does not have a stable state. The circuit alternately goes from one state to the other and back to the first, for which no external signal is required. The astable multivibrator circuit using OP-Amp, shown in Fig.1, possesses following two feedback networks.

1. A positive feedback network consisting of the resistors R_1 and R_2.
2. A negative feedback network comprising of the resistor R and the capacitor C.

The voltage fed back by R and C combination is the voltage that appears across the capacitor C. This feedback action will be delayed, because of the finite time required for charging a capacitor through a resistor. This feedback is a 'slow' one, whereas the positive feedback is a regenerative one, and its action is 'fast'. Hence due to the effect of the positive feedback the circuit is forced to go into saturation and thus the output can be either V+ or, V-. Let the output be positive maximum i.e. V+ and let the capacitor have no charge initially. Thus V(B) is equal to zero, while V(A) is βV+, where $\beta = R_1/(R_1 + R_2)$. In this case, because V(A)>>V(B) and is positive, hence the output remains at V+. But as the capacitor starts getting charged, V(B) starts increasing and the OP-AMP starts comparing the variable voltage V(B) with the reference voltage V(A). The moment V(B) crosses βV + the comparator suddenly changes its output to V-. Because the output voltage has become negative maximum V-, the reference voltage changes to βV-. At the same time, as the output voltage changes to V-, the capacitor starts discharging and then recharging in the opposite direction. As expected, the OP-AMP again compares the variable voltage V(B) with the reference voltage βV-. The output of the comparator suddenly changes to V+, the moment V(B) crosses βV-. Thus state of the multivibrator goes on changing alternately with time and the multivibrator never remains stable in any state. Hence the multivibrator is called as an astable or free running multivibrator.

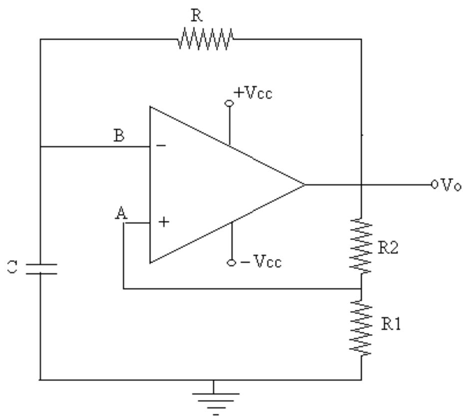

Fig.1.

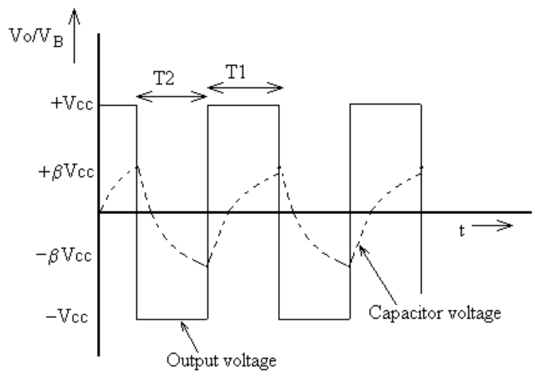

Fig. 2. Waveforms of the astable multivibrator.

The time diagram, showing the output voltage and the voltage across the capacitor is as shown in Fig.2. As seen from the Fig.2, the capacitor discharges from βV+ to βV- in time T_2 and it charges from βV- to βV+ in the time T_1.

A capacitor charges from V_1 to V_2 by a source V(f) in time t is given by;

$$V_2 = V(f) - \left(V(f) - V_1\right)e^{-\frac{t}{RC}}$$

{Final voltage = Source voltage – (Source voltage – Initial voltage) $e^{-\frac{t}{RC}}$ }

$$V(f) - V_2 = \left(V(f) - V_1\right)e^{-\frac{t}{RC}}$$

$$\left(V(f)-V_2\right)e^{\frac{t}{RC}}=\left(V(f)-V_1\right)$$

$$e^{\frac{t}{RC}}=\frac{V(f)-V_1}{V(f)-V_2}$$

Taking Log of both sides, we get

$$\frac{t}{RC}=\mathrm{Log}\,\frac{V(f)-V_1}{V(f)-V_2}$$

$$t=RC\mathrm{Log}\,\frac{V(f)-V_1}{V(f)-V_2}$$

Or the capacitor charges from $V_1 = \beta V-$ to $V_2 = \beta V+$ by a source V(f) = V+ in time t_1 is given by;

$$t_1=RC\mathrm{Log}\,\frac{(V+)-(\beta V-)}{(V+)-(\beta V+)}$$

But V+ = +Vcc and V- = -Vcc and substituting these, we get

$$t_1=RC\mathrm{Log}\,\frac{(Vcc)-(-\beta Vcc)}{(Vcc)-(\beta Vcc)}$$

$$t_1=RC\mathrm{Log}\,\frac{1+\beta}{1-\beta} \qquad (1)$$

Similarly we can obtain,

$$t_2=RC\mathrm{Log}\,\frac{1+\beta}{1-\beta} \qquad (2)$$

Therefore, the time period, T is given by

$$T = t_1 + t_2 = 2RC\mathrm{Log}\,\frac{1+\beta}{1-\beta} \qquad (3)$$

Substituting the value of β as

$$\beta = R_1/(R_1+R_2) \qquad (5)$$

We get

$$T=2RC\mathrm{Log}\left(1+\frac{2R_1}{R_2}\right) \qquad (6)$$

The above derivation is based on the assumption that the output of the OP-AMP possesses equal magnitudes of the maximum positive and negative voltage.

13 Monostable Multivibrator using Op-Amp:

A monostable multivibrator has one stable state and another one as a quasistable state. The circuit can be forced, to go into a quasistable state with a triggering pulse. But the circuit goes back to its stable state after a definite duration T. The circuit of a monostable multivibrator using Op-Amp, shown in Fig.1., is similar to that of an astable multivibrator, with one important change viz. a diode D2 is connected across the capacitor C.

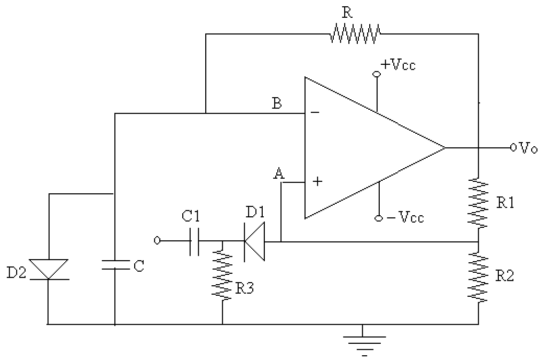

Fig. 1.

When the circuit is put on, then because of the positive feedback the circuit will be forced to go into one of the saturated state. The state can change as the capacitor C charges through the series resistor R. But the diode D2 across the capacitor C does not allow the voltage across the capacitor to cross the ‘cut in’ voltage, (when the output is positive maximum i.e. V+). If the cut in voltage is less than (βv+), the capacitor voltage can never exceed βV+, and the multivibrator cannot change state. In other words, in the stable state of the multivibrator, the output voltage would be V+.

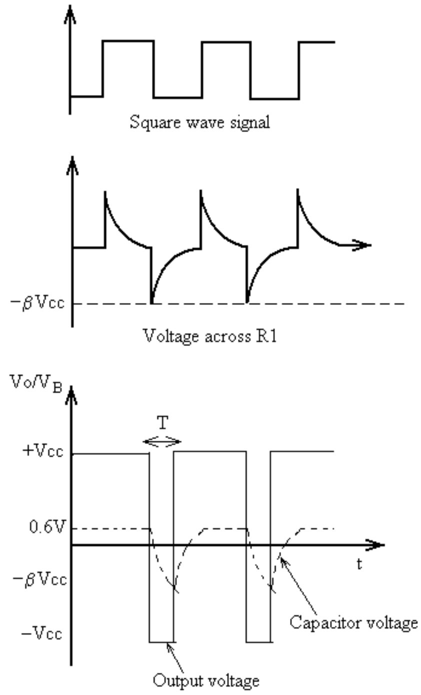

Fig. 2. Waveforms of the Monostable multivibrator.

A simple method, to change the state of the multivibrator is to short the resistor R1. When R1 is shorted (momentarily), the reference voltage V(A) to the comparator becomes zero, while voltage V(B) across capacitor is 0.6 V only. Thus as V(B) is greater than V(A), the comparator output changes to V- immediately. If the short is removed, the output voltage would remain negative maximum i.e. V-. Because the polarity of output voltage has reversed, capacitor discharges and the polarity of the voltage across it reverse. The diode gets reverse biased and hence is out of picture.

When the voltage across the capacitor crosses (βV-) the output will immediately change to V+. The capacitor discharges and recharges in opposite sense. But the moment the voltage across the capacitor reaches 'cut in', the diode starts conducting and thus stops any further rise in the voltage. Thus there is no possibility of change in the state, i.e. the multi vibrator goes back to its stable state.

Though shorting of the resistor R1 is simple method to change the state of the multi vibrator, it is most impracticable. Instead, if a negative going pulse is applied at A, so that for a short duration, V(A) becomes less than V(B), then the multi vibrator will change the state.

A square wave signal applied the R3 C1 combination can change the state of the multivibrator. Because the R3 C1 combination differentiates the square wave input, producing both positive and negative going spikes the positive going spikes are blocked by the diode D1, while the negative going pulses reach the point A. Thus the multivibrator can be forced to change the state. Time diagram showing voltages at various points is as shown in Fig. 2. The multivibrator remains in the quasistable state for the time T as shown in the figure.

Time required for a capacitor to charge from V_1 to V_2 through a source V(f) is;

$$t = RCLog\frac{V(f) - V_1}{V(f) - V_2} \qquad (1)$$

Hence the time required to charge the capacitor from V_1 = 0.6 (volt) to V_2 = βV- = -βVcc by the source V(f) = V- = -Vcc is given by;

$$T = RCLog\frac{(-Vcc)-(0.6)}{(-Vcc)-(-\beta Vcc)} = RCLog\frac{(-Vcc)}{(-Vcc)(1-\beta)}$$

$$= RCLog\frac{1}{(1-\beta)}$$

Since 0.6 volt is very small in comparison with Vcc.
Substituting the value of $\beta = R_1/(R_1+R_2)$, we get,

$$T = RCLog\left(1+\frac{R1}{R2}\right) \qquad (2)$$

The period of the multivibrator is not related to the period of the triggering square wave signal. Hence this multivibrator is very useful in generating pulses of definite duration.

14 Wien bridge oscillator using Op-Amp:

Because of its simplicity and stability, one of the most commonly used audio-frequency oscillators is the Wien Bridge. Figure 1 shows the Wien bridge oscillator in which the Wien bridge circuit is connected between the amplifier input terminals and the output terminal. The bridge has a series RC network in one arm and a parallel RC network in the adjoining arm. In the remaining two arms of the bridge, resistors R1 and RF are connected. The phase angle criterion for oscillation is that the total phase shift around the circuit must be 0°. This condition occurs only when the bridge is balanced, that is, at resonance.

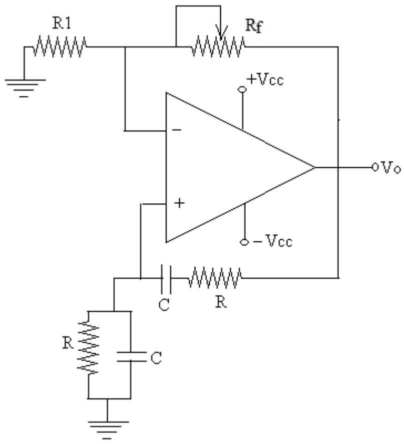

Fig. 1. Circuit diagram of Op-Amp as Wien bridge oscillator.

The frequency of oscillation f_0 is exactly the resonant frequency of the balanced Wien bridge and is given by

$$f0 = \frac{1}{2\pi RC} = \frac{0.159}{RC} \qquad (1)$$

assuming that the resistors are equal in value, and capacitors are equal in value in the reactive leg of the Wien bridge.

At this frequency the gain required for sustained oscillation is given by

$$Av = 1/\beta = 3 \qquad (3)$$

But the feedback factor β is given by

$$\beta = \frac{R_F}{R_1 + R_F} \qquad (4)$$

Thus equating these two equations, we get

$$\frac{R_1 + R_F}{R_F} = 1 + \frac{R_1}{R_F} = 3$$

or $\quad R_F = 2\ R_1 \qquad (5)$

Usually the resistance R_F is used as a potentiometer, which can be adjusted exactly to obtain the condition.