Nowadays Electronics become the important part of our day to day life. Most of the gadgets and control circuits are designed using basic electronic devices. People are taking interest in this subject either as hobby or a career. This book will explain the basic construction and working of basic devices used in electronics. The text in this book is also useful to students preparing for B.Sc., diploma, degree and other engineering examinations.
The simple language and the lecture style used by the author makes the reader to understand the subject very easily. The author has given focus on concepts rather than mathematical derivations. These features will help the reader to understand the theoretical and practical use of electronic devices.



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Pradip Kamble
Rahul Patil

# Understanding of Basic Electronics Devices

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**DEDICATED TO OUR PARENTS**

## Preface to the First Edition

Nowadays Electronics become the important part of our day to day life. Most of the gadgets and control circuits are designed using basic electronic devices. People are taking interest in this subject either as hobby or a career. This book will explain the basic construction and working of basic devices used in electronics. The text in this book is also useful to students preparing for B.Sc., diploma, degree and other engineering examinations.

The simple language and the lecture style used by the author makes the reader to understand the subject very easily. The author has given focus on concepts rather than mathematical derivations. These features will help the reader to understand the theoretical and practical use of electronic devices.

Author has no claim to the original research in preparing the book. Liberal use of the material available in the works of eminent authors has been made. Author has tried to explain the concepts in more simple and lucid manner. The authors are thankful to these eminent authors for their valuable work.



The authors are thankful to the colleagues and friends who have given valuable suggestions regarding the scope of the book. Author is indebted to Lap Lambert Publications, Germany for publishing the book in short period of time.

Errors might have crept in despite utmost care to avoid them and author shall be grateful if these are pointed out along with valuable suggestions for the improvement of the quality of the book.

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**Authors**

## Understanding of Basic Electronic Devices

## CONTENTS

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## Topic 1: Transistor Amplifier

**Transistor Amplifier:** Single stage transistor CE amplifier, D.C. and A.C. equivalent circuits, load line analysis- d.c. load line, a.c. load line and Q point, Frequency Response Curve of an Amplifier

### 1.0 Single Stage Common Emitter Transistor Amplifier:

Amplifier is an electronic circuit which amplifies weak input signal given to it. Usually this weak signal is given to the base of transistor. This produces the variation in base current of transistor and results in corresponding variation in collector current which is much more than Ib. Fig. 1.1shows single stage common emitter amplifier. In this circuit resistor R1 and R2 provides the biasing of transistor and provides zero signal base current. In this amplifier voltage divider biasing method is used since it provides good stabilization of the operating point. Capacitors $C_1$, and $C_0$ are called coupling capacitors. These capacitors pass *ac* signal from one side to the other, and block *dc* signals. Hence these capacitors are also called the blocking capacitors. Capacitor $C_e$ acts as a bypass capacitor. It bypasses *ac* currents from the emitter to the ground. If the capacitor $C_e$ is not present, the *ac* voltage developed across Re will affect the input *ac* voltage. Such feedback of ac signal is reduced by putting the capacitor $C_e$. Rc is collector load resistance. Output signal is coupled through $C_0$ to any device having resistance $R_0$. In a common emitter amplifier during positive half cycle of input voltage, the base current increases. As forward bias increases, there is increase in emitter current Ie and collector current Ic. Therefore, voltage drop across Rc increases. As a result Vce = Vcc- IcRc decreases thus for a positive half-cycle at the input, negative half cycle is obtained at the output. So in a CE amplifier there is a phase difference of $180^0$ between input and output. The voltage gain of the amplifier is given by $Av = \frac{output\ voltage}{input\ volatge} = \frac{Vo}{Vi}$

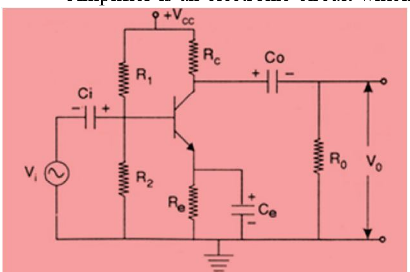


**Fig.1.1 Single stage CE amplifier**



### 1.1: D.C. and A.C. Equivalent Circuits:

In transistor amplifier, d.c currents are due to dc. supply voltage given to the circuit. The a.c. input signal produces fluctuations in the transistor currents and voltages. One can study the working of transistor amplifier by performing d.c. and a.c. analysis. By adding *d.c.*and a. *c.* currents and voltages, we get the total currents and voltages in the circuit.

#### *1.1.1 D.C. equivalent circuit:.*

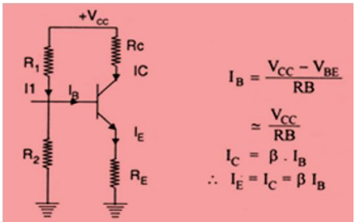


Fig.1.2 D.C. equivalent circuit

In a *d.c.* equivalent circuit, only *d.c.* conditions is considered. As direct current cannot flow through a capacitor, therefore all the capacitors look like open circuits in the *d.c.* equivalent circuit. To draw the ***d.c.*** equivalent circuit

(i) Reduce all a. *c.* sources to zero( remove a.c. sources).

(ii) Open all the capacitors (remove all capacitors).

Applying these steps to Fig. 1.1, we get the D.C. equivalent circuit in Fig.1.2. From this figure, it is possible to calculate *d.c.*currents and voltages.

***(ii) A. C. Equivalent Circuit:***

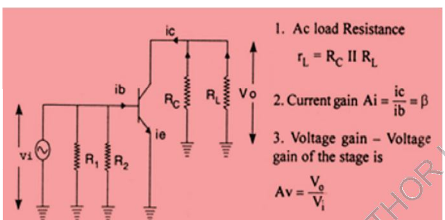


Fig.1.3 A.C. equivalent circuit

In a. *c.* equivalent circuit of a transistor, consider only a. *c.* conditions. Here *d.c.* voltage may be considered as zero. The capacitors are generally used to bypass the *a.c.* signal hence they appear as short circuits to the *a.c.* signal. To draw *a.c.* equivalent circuit use following steps.

(i) Reduce all *d.c.* sources to zero (Vcc = 0)

(ii) Short all the capacitors.



Applying these two steps to Fig. 1.1, we get the *ac.* equivalent circuit shown in F**ig. 1.3.**From this figure, we can calculate the ***ac.*** currents and voltages. It is clear that total current in any branch is the sum of *d.c.* and ***a.c.*** currents through that branch. Similarly, the total voltage across any branch is the sum of ***d.c.*** and ***a.c.*** voltages across that branch.

***1.2: Load Line Analysis:***

The output characteristics are the graphs plotted between Collector current Ic versus Vce for given value of base current Ib. The output characteristics are determined experimentally. It indicates the relation between Vce and Ic. The relationship between Vce and Ic is linear which can be represented by a straight line on the output characteristics known as a load line. The points lying on the load line give the possible values of Vce and Ic in the output circuit. There are two types of load line as i) *d.c.* load line and ii) a.c. load line.

**1.2.1:d.c. load line:**

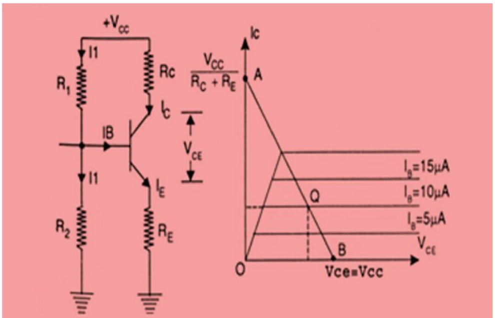



**Fig.1.4 (i) D.C. equivalent circuit (ii) d.C. load line**

It is the line on the output characteristics of a transistor circuit which gives the values of Ic and Vce corresponding to zero signal or *d.c.* conditions. Consider *d.c.* equivalent circuit for Ce amplifier as shown in Fig.1.4 (i) in the absence of a.c. signal. Applying Kirchhoff's voltage law to collector circuit we write

Vcc=IcRc+Vce+IeRe

Vcc=Vce+Ic(Rc+Re)

$$Ic(Rc + \mathrm{Re}) = -Vce + Vcc$$

$$Ic = -\frac{1}{Rc + \mathrm{Re}} + \frac{Vcc}{Rc + \mathrm{Re}} - - - -(1)$$



This eq.1 is of the type y = mx + c. Hence it represents a straight line on output characteristics as shown in **Fig.1.4**(ii) This straight line has the slope $-\frac{1}{Rc + \mathrm{Re}}$ and intercept the current axis at $\frac{Vcc}{Rc + \mathrm{Re}}$ i.e. at point A. as the slope of the straight line depends on Rc (re constant) hence it is called load line.

The end points are found as follows for point A, Vce=0 therefore $Ic = \frac{Vcc}{Rc + \mathrm{Re}}$ and for point B, Ic =o therefore from eq.1 Vce = Vcc. If we connect these two pints by straight line on output characteristics we get a d.c. load line.

**1.2.2: A.C. Load Line:**

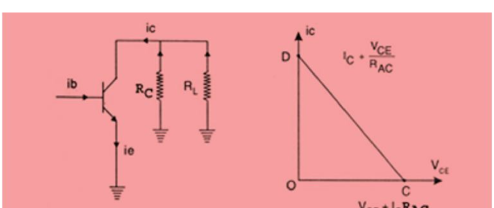



**Fig.1.5 i) A.C. equivalent circuit (ii) A.C. load line**

This is the line on output characteristics of a transistor circuit, which gives the values of Ic and Vce when a.c. signal is applied. Consider ***ac.*** equivalent circuit shown in Fig. 1.5 (i). To add ***a.c.*** load line to the output characteristics, we require two end points.

***i.e.*** (i) Maximum Collector-emitter voltage point C .This is given by

$Vce=(Vce)_Q+(Ic)_Q.R_{AC}$

(ii) Maximum Collector current point D given by,

$Ic=(Ic)_Q+Vce/R_{AC}$

Where $R_{AC}$ is a.c. equivalent resistance of amplifier which is given by,

$R_{AC} = \frac{Rc.R_L}{Rc + R_l}$. If we join points C and D then the a.c. load line will be constructed as shown in Fig.1.5(ii).

**1.3Frequency Response Curve of an Amplifier:**

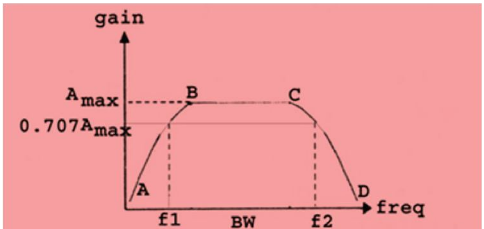



**Fig.1.6 Frequency response curve of an amplifier**

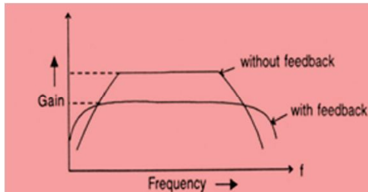



**Fig.1.7 Effect of negative feedback on gain response curve of an amplifier**



It is seen that the gain of the amplifier varies with the frequency of the input signal. It is because the reactance of the capacitor in the circuit changes with the frequency of the input signal. Hence, it affects the output voltage. The curve plotted between voltage gain and signal frequency of an amplifier is known as frequency response curve. Fig. 1.6 shows the frequency response of a typical amplifier. From this curve it is clear that gain of the amplifier increases as the frequency increases .during portion AB of the curve known as low freq. range. Then the gain remains constant for portion BC of the curve known as mid freq. range. The gain decreases with frequency for the portion CD of the curve known as high frequency range. When amplifier is to be designed, ensure that gain is uniform over some specified frequency range. For instance, in case of audio amplifier, it is necessary that all the frequencies in the sound spectrum ***(i.e.*** 20 Hz to 20 kHz) should be uniformly amplified; otherwise speaker will give a distorted sound output

**Band width:** The range of frequency for which the gain of amplifier drops from its maximum value to 0.707 times the maximum gain. The frequencies $f_1$ and $f_2$ as known as lower and upper cut off frequencies. And the difference f2-f1 is represents the band width.

- ***Effect of Negative feedback on the gain Response Curve :***

When negative feedback is applied, voltage, gain of the amplifier decreases, but bandwidth increases as shown in Fig.1.7.When negative voltage feedback is employed, the voltage actually applied to the amplifier is extremely small. The gain with feedback is called closed-loop gain. The gain without feedback is called open-loop gain.

**EXERCISE**

**1. Select most correct alternative for the following**

1. To draw d.c. equivalent circuit, reduce all------------ fo zero.

(A) ac sources (B) d.c. sources

(C)current sources (D)voltage source

2. -------- circuit increases the amplitude of weak input signal given to it.

**(A)amplifier** (B)scillator

(C) rectifier (D) transmitter

3 -------------- equivalent circuit, all capacitors are shorted.

(A) volatge (B) d.c

(C) current **(D) a.c.**

4. The relation between Vce and Ic represented by a straight line on output characteristic curve is known as a -------------

(A) frequency response (B) frequency curve

**(C) load-line** (D) amplifier line

5. The purpose of d.c. conditions in a transistor is to ---------

(A) Reverse bias the emitter (B) Forward bias the collector

**(C) Set up operating point** (D) start its working

6. A CE amplifier is also called --------circuit.

**(A) grounded emitter** (B) grounded bias

(C) grounded collector (D) open collector

7. --------- equivalent circuit all capacitors are open circuited.

(A)a.c. **(B) d.c.**

(C) voltage (D) current

8. The phase difference between output and input signal in CE amplifier is ---------- degree.

(A) 0 (B) 60

(C) 90 **(D)180**

9. --------source produces fluctuations in the transistor current and voltage .

(A) volatge source (B) d.c. source

(C)current source **(D) a .c. source**

10. ----------- on the output characteristics of a transistor circuit gives the values of Ic and Vce corresponding to zero signal.

(A)Straight line (B)a.c.load line

(C) d.c.load line (D)both (b) & (c)

11.In single stage CE amplifier------ transistor is used.

(A)four (B) three

(C)two (D) one

12. The point of intersection of d.c. and a.c. load line is called ----------

(A)Intersection point (B) Quiescent operating point

(C) dc point (D) a.c. point

13. The curve between voltage gain and signal frequency of an amplifier is known as — curve.

(A)band width (B)frequency response

(C) gain response (D)output

14. In a transistor

(A) $I_e=I_c+I_b$ (B) $I_e=I_c-I_b$ (C) $I_c=I_e+I_b$ (D) $I_b=I_c+I_e$

15. The most commonly used transistor arrangement is ----------

(A) Common emitter (B) Common base

(C) Common collector (D) common source

16. The voltage gain of an amplifier is expressed in ----------

(A)Volts (B) ampere

(C) decibel(dB) (D)bell



**2. General Questions.**

1. Explain the operation of a common emitter transistor amplifier with neat diagram.
2. Explain d.c. and a.c. equivalent circuit for CE amplifier.
3. Explain how will you draw d.c. load line on the output characteristics of a transistor.
4. Explain the frequency response curve of an amplifier .What is the effect of negative feedback on gain response curve?

## Topic 2: Transistor Oscillators

Feedback in amplifiers and its types, theory of feedback oscillator, Barkhausen's criterion for sustained oscillations, Oscillatory circuit (tank circuit),essentials of transistor oscillator, sinusoidal oscillators-phase shift oscillator, Colpitt's oscillator, Hartley oscillator, Crystal oscillator using transistors.

**2.0Introduction:**

Oscillator is an electronic circuit which converts ***dc*** energy into an ac energy at a very high frequency. Oscillator is an electronic source of alternating current or voltage having sine, square or saw tooth shapes. It is a circuit which generates an ***ac*** signal without requiring any externally applied input signal. Oscillator is used radio and TV transmitters and receivers, dielectric and induction heating etc.

**2.1 Feedback in amplifiers:**

The process of injecting a fraction of output energy of some device back to the input is known as ***feedback.*** Feedback is useful to reduce the noise in amplifier. It also makes amplifier operation stable. Depending upon whether the feedback energy adds or opposes the input signal, there are two basic types of feedback *viz,* positive feedback and negative feedback.



**2.1.1Positive Feedback:**

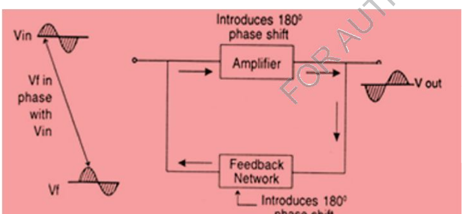



**Fig.2.1(i) Positive feedback**

When the feedback energy (voltage or current)as shown in Fig.2.1(i) is in phase with the input signal and thus aids it, it is called positive feedback. Both amplifier and feedback network introduce a phase shift of $180_0$. it causes a 360° phase shift around the loop which causes the feedback voltage $V_f$ to be in phase with the input signal V. The positive feedback increases the gain of the amplifier. But positive feedback increases distortion and instability. Therefore, positive feedback is rarely employed in amplifiers. Important use of positive feedback is in oscillators.

**2.1.2Negative Feedback:**

When the feedback energy (current or voltage) is out of phase with the input signal and thus opposes it, it is called negative feedback. Introduces $180^0$ phase shift Fig. 2.1(ii) shows that the amplifier introduces a phase shift of 180° into the circuit. Here feedback network is designed in such a way that it introduces no phase shift (0° phase shift). So the feedback voltage $V_f$ is $180^o$ out of phase with the input signal Vm.

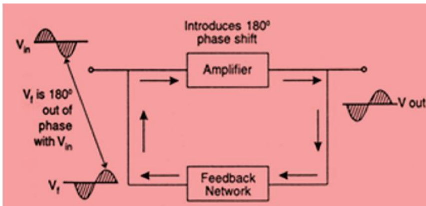



Fig. 2 *Negative Feedback*

**Fig.2.1 (ii) Negative feedback**

***Advantages of Negative Feedback:***

(i) Reduction in distortion

(ii) Stability in gain

(iii) Increased Bandwidth

(iv) Improved input and output impedances.

Because of these advantages, the negative feedback is frequently employed in amplifiers.

**2.2 Difference between Amplifier and Oscillator:**

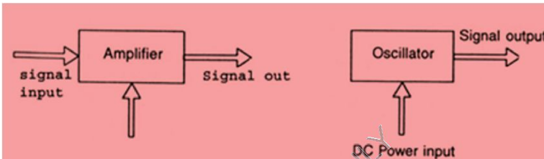



**Fig.2.2 (i) Amolifier** **(ii) Oscillator**



**(a)Amplifier:** An amplifier produces an output signal hose waveform, frequency and amplitude of output signal depends on the waveform, frequency and amplitude of input signal. For amplifier additional power is supplied by external dc source. Fig. 2.2 (i)shows the block diagram for amplifier.

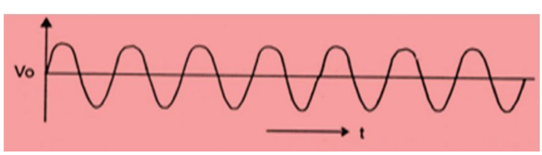
**(b)Oscillator:** In case of oscillator, the waveform, frequency and amplitude of output signal depends on the circuit itself. Oscillator does not require an external signal to start or maintain energy conversion process. Fig. 2.2(ii)shows the block diagram of oscillator .It keeps producing an output signal, so long as dc power source is connected.

**2.3Types of Waveforms**

The basic oscillator can produce the following types of waveforms

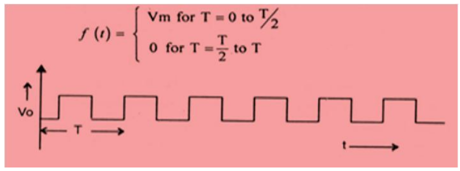
**a) Sine wave:**

These oscillations produce sine wave at output when they are turned ON. The fundamental function for this oscillations is given byf (t)=Vm Sin(ωt), where Vm is amplitude of the output voltage.

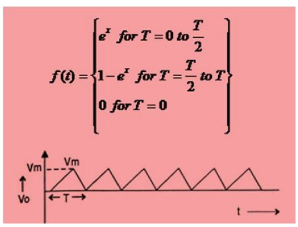


b) **Square wave:**

These oscillators produce triangular wave at the output. The fundamental function for these oscillations is



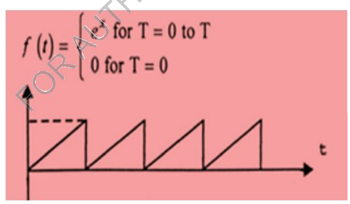

c) **Triangular wave:**




These oscillators produce triangular wave at the output. The fundamental function for these oscillations is

d) **Saw tooth wave**:

These oscillators produce saw-tooth wave at the output. The fundamental function for these oscillations is






e) **Staircase waveform**


**2.4Oscillatory Circuit or tank circuit:**

A circuit which produces electrical oscillations of any desired frequency is known as an **oscillatory circuit** or **tank circuit.** A simple oscillatory circuit consists of a capacitor ***(C)*** and inductance coil ***(L)*** in parallel as shown in **Fig.2.3.**This electrical system can produce electrical oscillations of frequency determined by the values of *L* and *C*.

- **Oscillations in tank circuit:**

Suppose the capacitor is charged from a d.c. source with a polarity as shown **in Fig.2.3 *(i) so*** *that* the upper plate of capacitor has deficit of electrons and the lower plate has excess of electrons. Therefore, there is a voltage across the capacitor and the capacitor has electro-static energy.

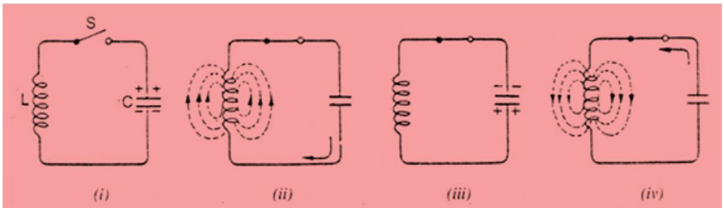



**Fig. 2.3 Oscillations in tank circuit**

*(ii)* When switch S is closed as shown in Fig. 2.3*(ii),* the capacitor will discharge through inductance and the electron flow will be in the direction indicated by the arrow. This current flow sets up magnetic field around the Coil. Due to the inductive effect, the current builds up slowly towards a maximum value. The circuit current will be maximum when the capacitor is fully discharged. At this instant, electro-static energy is zero but because maximum current, the magnetic field energy around the coil is maximum. This is shown in **Fig. 2.3*(ii).***Obviously, the electro-static energy across the capacitor is completely converted into magnetic field energy around the coil.

*(iii)* Once the capacitor is discharged, the magnetic field will begin to collapse and produce a counter e.m.f. According to Lenz's law, the counter e.m.f. will keeps the current flowing in the same direction. The result is that the capacitor is now charged with opposite polarity, making upper plate of capacitor negative and lower plate positive as shown in Fig. 2.3*(iii).*

*(iv)* After the collapsing field has recharged the capacitor, the capacitor now begins to discharge; current now flowing in the opposite direction. Fig. 2.3*( iv)* shows capacitor fully charged and maximum current is flowing. The sequence of charge and discharge results in alternating motion of electrons or an oscillating current. The energy is alternately stored in the electric field of the capacitor *(C)* and the magnetic field of the inductance coil *(L).* This interchange of energy between *L* and *C* is repeated over arid again resulting in the production of electrical oscillations.

**Wave form :**

If there were no losses in the tank circuit the interchange of energy between *L* and C would continue indefinitely .In a practical tank circuit, there are resistive and radiation losses in the coil and dielectric losses in the capacitor. During each cycle, a small part of the originally imparted energy is used up to overcome these losses. The result is that the amplitude of

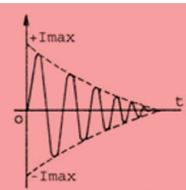


**Fig. 2.4 Damped oscillations in tank circuit**

oscillating current decreases gradually and eventually it becomes zero when all the energy is consumed as losses. Therefore, the tank circuit by itself will produce *damped oscillations* as shown in Fig. 2.4. The frequency of oscillations in the tank circuit is determined by the *L* and *C*. The actual frequency of oscillations is the resonant frequency (or natural frequency) of the tank circuit given by

$$f = \frac{1}{2\pi\sqrt{LC}}$$

### 1.5 Basic Requirements for Transistor Oscillator:

Fig. 2.5Shows the block diagram of an oscillator. It basically requires:

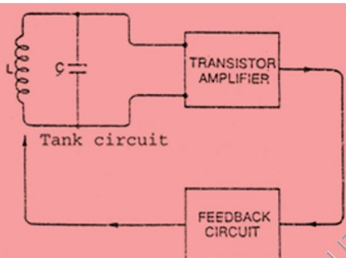


**Fig.2.5 basic requirement of Oscillator circuit**

***(i) Tank circuit**:* It consists of inductance coil *(L)* connected in parallel with capacitor *(C).* The frequency of oscillations in the circuit depends upon the values of inductance of the coil and capacitance of the capacitor.

***(ii) Transistor amplifier**:* The transistor amplifier receives d.c. power from the battery and changes it into a.c. power for supplying to the tank circuit. The oscillations occurring in the tank circuit are applied to the input of the transistor amplifier. Because of the amplifying properties of the transistor, we get increased output of these oscillations. This amplified output of oscillations is due to the d.c. power supplied by the battery. The output of the transistor can be supplied to the tank circuit to meet the losses.

***(iii)Feedback circuit**:* The feedback circuit supplies a part of collector energy o the tank circuit in correct phase to aid the oscillations *i.e.* it provides positive feedback.



### 1.6 Feedback oscillator and Barkhausen criterion:

Block diagram for feedback oscillator is shown in Fig.2.6. Here fraction of the output energy is fed back to the input. In feedback oscillator feedback is positive so that feedback voltage is in phase with the input voltage.

Let Vf be the feedback voltage. If A is the gain of an amplifier without feedback and β is the feedback factor then $V_f = \beta Vo$. Input voltage in presence of feedback will be,

Vi=Vs+Vf------- (1)

Gain of amplifier without feedback is given by

$$A = \frac{Vo}{Vi}$$
$$\therefore Vo = AVi = A(Vs + Vf) \quad usnig(1)$$
$$\therefore Vo = AVs + AVf = AVs + A\beta Vo \quad as\ Vf = \beta Vo$$
$$\therefore Vo - A\beta Vo = AVs$$
$$\therefore Vo(1 - A\beta) = AVs$$
$$\therefore \frac{Vo}{Vs} = A_f = \frac{A}{1 - A\beta} ------(2)$$

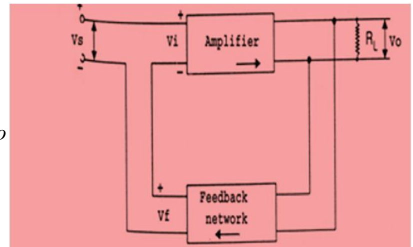


**Fig.2.6 Block diagram of feedback oscillator**

Here $A_f$ = gain of amplifier with feedback, A- gain of amplifier without feedback, β-feedback factor, Aβ- loop gain.

**Case I:** If β is positive then from this equation we see that feedback gain $A_f$ is greater than the gain A of the amplifier without feedback.. This type of feedback is called positive feedback.

**Case II: Case I:** If β is negative then from eq.1 we see that feedback gain $A_f$ is less than the gain A of the amplifier without feedback. This type of feedback is called negative feedback.

**Case III: Barkhausen criterion of oscillation**

For feedback amplifier feedback gain is given by

$$A_f = \frac{A}{1 - A\beta}$$

- If feedback factor β is positive and loop gain Aβ=1 the from above equation we see that feedback gain $Af = \infty$. This means that there is output voltage when Vi=0 i.e. there is an output in absence of input voltage and the amplifier works as an oscillator.
- The condition Aβ=1 is called Barkhausen criterion.
- If Aβ<1 the amplifier will not produce continuous oscillations. so in practical circuits loop gain Aβ is kept greater than 1.



**2.7 Different Types of Transistor Oscillators:**

A transistor can work as an oscillator to produce continuous undamped oscillations of any desired frequency if tank and feedback circuits are properly connected to it. All oscillators under different names have similar function *i.e.* they produce continuous undamped output. However, the major difference between these oscillators lies in the method by which energy is supplied to the tank circuit to meet the losses. The following are the transistor oscillators commonly used at various applications in electronic circuits.

*(i)* Tuned collector oscillator

*(ii)* Hartley oscillator

*(iii)* Collpitt's oscillator

*(iv)* Phase shift oscillator

*(v)* Wien Bridge oscillator

*(vi)* Crystal oscillator

**1) Hartley oscillator:**

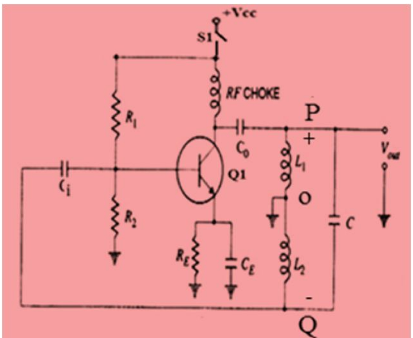



**Fig.2.7 Hartley oscilator circuit**

Hartley oscillator is very popular and is used as local oscillator in radio receivers. Fig.2.7 shows the circuit of Hartley oscillator. A tapped inductance $L_1$ and $L_2$ are placed across a common capacitor C and the center of the two inductors is tapped (grounded) as shown in Fig. 1. The tank circuit is made up of C, $L_1$ and $L_2$.The resister $R_1$,$R_2$ and $R_E$ provide self-biasing with a voltage divider. $C_E$ acts as bypass capacitor. RF Choke provides d.c. bias while blocks ac signal to reach the dc power supply. The coupling capacitor Cc has negligible impedance at the circuit operating frequency but it blocks any d.c. voltage between collector and base. The frequency of oscillations is determined. by the values of $L_1$, $L_2$ and C and is given by,



$$f_o = \frac{1}{2\pi\sqrt{LC}} ----(1)$$

Where $L=L_1+L_2+2M$

**Circuit operation:** When switch S is closed collector current starts rising and charges the capacitor 'C'. When this capacitor is fully charged it discharges through coils $L_1$ and $L_2$ setting up oscillations of frequency determined by equation (1).The oscillations i.e. voltage across $L_2$ across applied to the base of transistor and appearing the amplified form in the collector circuit. In this way energy is continuously supplied to the tank circuit to overcome the losses occurring in it so that continuous undamped oscillations are obtained. It is seen that energy supplied to the tank circuit is of correct please. The ends P and Q of the inductance L1 and L2 are $180^o$ out of phase and phase shift of $180^o$ degrees is produced by transistor. In this way energy feedback to the tank circuit is in phase with the generated oscillations by tank circuit.

***Advantages:***

i. Used in radio and TV receivers as local oscillator.

ii. In radio receivers. It has two main advantages that is adaptability to wide range of frequencies and is easy to tune.

***Disadvantage:***

i. It uses inductance

.

**Example:** *Find the operating frequency of a transistor Hartley oscillator if* $L_1$= 100µH, $L_2$= 1mH, Mutual inductance between the coils M=20µH *and C= 20pF.*

*Given:*

$L_1$= 100µH, $L_2$= 1mH=1000µH, M=20µH *and* $C= 20pF=20X10^{-12}F$.

*Solution:*

*1) Hartley Equivalent Inductance* $L=L_1+L_2+2M$

$$= 100+1000+2X20 = 1140\ \mu H$$

$$L = 1140X10^{-6}\ H$$

$$2)\textit{Frequency of oscillation} = f_o = \frac{1}{2\pi\sqrt{LC}}$$

$$= \frac{1}{2X3.14\sqrt{1140X10^{-6}X20X10^{-12}}} = 1052X10^3\ Hz = 1052KHZ$$



**2) Colpitt's Oscillator:**

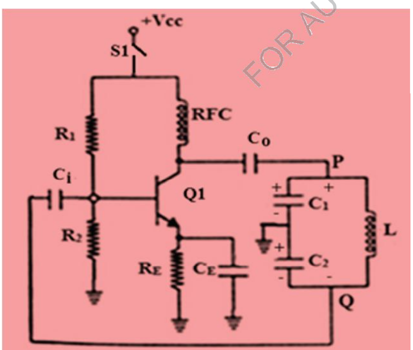


Fig.2.8 Colpitts oscillator circuit

The circuit diagram for Collpitt's oscillator is shown in Fig.2.8. It is similar to Hartley oscillator with minor modifications. Instead of using a tapped inductance, two capacitors $C_1$and $C_2$are placed across a common inductance *L* and the center of the two capacitors is tapped(grounded) as shown in Fig. 1. The tank circuit is made up of$C_1$, $C_2$and *L*. The frequency of oscillations is determined. by the values of $C_1$, $C_2$and *L* and is given

$$f_o = \frac{1}{2\pi\sqrt{LC}} \quad \text{where} \quad C = \frac{C_1.C_2}{C_1 + C_2}$$

**Circuit operation:** When switch S is closed, the capacitors $C_1$ and $C_2$are charged. These capacitors discharge through coil *L,* setting up oscillations of frequency determined by exp.(1). The oscillations across $C_2$ are applied to the base-emitter junction and appear in the amplified form in the collector circuit and supply losses to the tank circuit. The amount of feedback depends upon the relative capacitance values of $C_1$and $C_2$. The smaller the capacitance $C_1$, the greater the feedback. It is easy to ascertain that energy feedback to tank circuit is of correct phase. The capacitors $C_1$ and $C_2$ act as a simple alternating voltage divider. Therefore, points *P* and Q are$180^0$ Out of phase. A further phase shift of 180° is produced by the transistor. In this way, feedback is properly phased (positive feedback) to produce continuous undamped oscillations.

***Advantages:***

iii. Used in commercial signal generators to produce high frequencies above 1MHz.

iv. Used in radio and TV receivers as local oscillator.

v.Used in high frequency heating applications.

***Disadvantage:***

i.It uses inductance.

**Example :**Find the operating frequency of a transistor Colpitt's oscillator if $C_1$= 0.001μF, $C_2$= 0.O1 μF and L = l5 μH.

Given:

$C_1$= 0.001μF, $C_2$= 0.O1 μF and L = l5 μH, f = ?

Solution:

1) Colpitt's Equivalent capacitor is given by

$$C = \frac{C_1 . C_2}{C_1 + C_2}$$

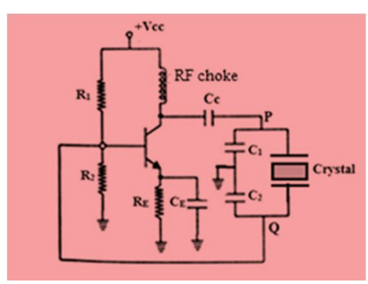
$$= \frac{0.001 X 0.01}{0.001 + 0.01} = \frac{1.0 X 10^{-5}}{0.011} \mu F = 9.09 X 10^{-4} \mu F = 9.09 X 10^{-10} F$$

$$2) Frequency\ \ of\ oscillation = f_o = \frac{1}{2\pi\sqrt{LC}}$$

$$= \frac{1}{2X3.14\sqrt{15X10^{-6} X9.09X10^{-10}}} = 1361X10^3\ Hz = 1361KHZ$$

**3.Crystal oscillator:**

Crystal oscillators are used in stable and accurate oscillations of very high frequency. Fig.2.9shows the circuit diagram of crystal oscillator. Here Quartz crystals are used in crystal oscillations because its strength and natural frequency of oscillation is high.



A slab of quartz crystal is mounted between two metal plates. The quartz crystal has very high value of Q-factor as compared to LC tank circuit. The high value of Q-factor of crystal produces oscillations with stable frequency. A variety of crystal oscillator circuits are possible.

**Working of crystal oscillator:**

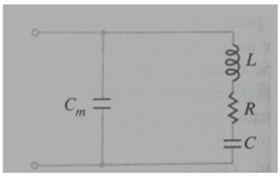



**Fig.2.10 A.C. equivalent circuit of Quartz crystal**

In this circuit quartz crystal is connected as a series element in the feedback path from collector to the base of transistor. The resister $R_1$, R2 and $R_E$ provide self-biasing with a voltage divider. $C_E$ acts as bypass capacitor. RF Choke provides d.c. bias while blocks ac signal to reach the dc power supply. The coupling capacitor Cc has negligible impedance at the circuit operating frequency but it blocks any d.c. Voltage between collector and base.ac equivalent circuit for quartz crystal is shown in Fig.2.10. The crystal acts as inductor that resonates with $C_1$ and $C_2$. The oscillations across $C_2$are applied to the base-emitter junction and appear in the amplified form in the collector circuit and supply losses to the tank circuit. The amount of feedback depends upon the relative capacitance values of $C_1$ and $C_2$. The smaller the capacitance $C_1$, the greater the feedback. It is easy to ascertain that energy feedback to tank circuit is **of** correct phase. The capacitors $C_1$ and $C_2$ act as a simple alternating voltage divider. Therefore, points *P* and Qare$180^0$ Out of phase. A further phase shift of 180° is produced by the transistor. Thus the total phase shift around the loop is $360^O$ thus the requirement of positive feedback is satisfied.

The frequency of oscillator is decided by series resonant frequency of the crystal and it is given by $f_o = \frac{1}{2\pi\sqrt{LC}}$ where $C = \frac{C1.C2}{C1+C2}$

It is to be noted that in case of crystal oscillator change in supply voltage or transistor parameters does not change the frequency of oscillator.

**Advantages:**

(i) It is does not requires any inductor.
(ii) Various ranges of frequencies are possible by replacing the crystal.
**(iii)** High frequencies in the range of MHz can be produced.

**Applications of crystal oscillator:**

i. It is used as basic timing device in electronic wrist watch.
ii. Crystal oscillators are useful in frequency and time standards.
iii. High frequencies up to 10MHz can be produced.
iv. It is used in microprocessor and computers to produce accurate clock signals.

**Example:** A crystal has the following parameters: L=0.33H,C=0.065pF,R=5.5Kohm.Find the series resonant frequency of the crystal. Ans: 1.09MHz

**4. Phase shift oscillator:**

Good frequency stability and waveform can be obtained from oscillators employing resistive and capacitive elements. Such amplifiers are called *R.-C or phase shift oscillators* and have the additional advantage that they can be used for very low frequencies.

**Theory:** In a phase shift oscillator, a phase shift of $180^0$ is obtained using phase shift circuit. A further phase shift of $180^0$ is produced by the transistor. Thus, energy supplied back to the tank circuit is assured of correct phase.

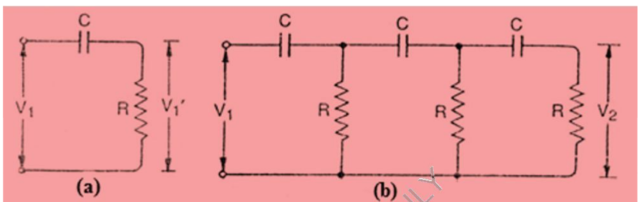



**Fig. 2.11 (a) single RC section (b) Three RC sections**



**Phase shift circuit:**

A phase-shift circuit essentially consists of an *R-C* network.Fig.2.11 (a) shows a single section of *RC* network. From the elementary theory of electrical engineering it can be shown that alternating voltage $V_1'$ across *R* leads the applied voltage $V_1$ by θ .The value of θ depend upon the values of R and *C and given by* $\tan\theta = \frac{1}{\omega RC} = \frac{1}{2\pi fRC}$. If resistance *R* is varied so that the value of θ lead $V_1$ by 90° i.e. θ=90° , adjusting *R* to zero would be impracticable because it would lead to no voltage across *R*. Therefore in practice *R* is varied to such a value to make V'1to lead *Vi* by 60°. Fig. 2.11(b) shows the three sections of RC network. Each section produces a phase shift of $60^0$, consequently, a total phase shift of 180° is produced *i.e.* voltage $V_2$ leads the voltage $V_1$ by 180°.

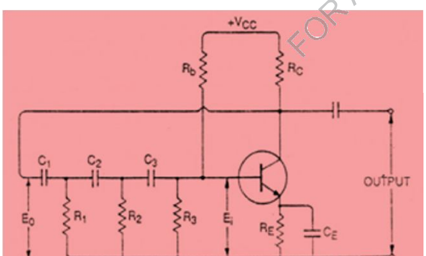



**Fig.2.12 Phase shift oscillator circuit**

**Phase shift oscillator circuit:**

Fig.2.12 shows the circuit of a phase shift oscillator. It consists of a single stage transistor amplifier and *RC* phase shift network. The phase shift network consists of three sections $R_1C_1$, $R_2C_2$ and $R3C_3$.

At some particular freq1ency *f*, the phase shift in each *RC section* is $60^0$. So that the total phase shift produced by the *RC* network is $180^0$. The frequency of oscillations is given by

$$f_o = \frac{1}{2\pi RC\sqrt{6}} \text{-------} \qquad (1)$$

**Circuit operation**: The phase shift oscillator circuit is shown in Fig.2.12 . When the circuit is switched on, it produces oscillations of frequency determined by exp. 1. The output $E_0$ of the amplifier is fed back to *RC* feedback network. Feedback network produces a phase shift of 180° and a voltage $E_1$appears at its output which is applied to the transistor amplifier. Obviously, the feedback fraction $m = Ei/E_0$. The feedback phase is correct. A phase shift of 180° is' produced by the transistor amplifier. A further phase shift 180° is produced by the *RC* network. As a result, the phase shift around the entire loop is 360° and thus results in positive feedback.

***Advantages:***

*(i)* It does not require transformers or inductors.

*(ii)* It can be used to produce very low frequencies.

*(iii)* The circuit provides good frequency stability.

***Disadvantages:***

*(i)* It is difficult for the circuit to start oscillations as the feedback is generally small.

*(ii)* This circuit gives small output.



**Example:** In the phase shift oscillator $R_1 = R_2 = R_3 = 1M\Omega$ and $C_1 = C_2 = C_3 = 68pF$: At what frequency does the circuit oscillate?

Given: $R_1 = R_2 = R_3 = 1M\Omega = 1X10^6$ Ohms

$C_1 = C_2 = C_3 = 68pF = 68x10^{-12}F$

$f = ?$

Solution: Frequency of phase shift oscillator is given by

$$f_o = \frac{1}{2\pi RC\sqrt{6}}$$

$$= \frac{1}{2X3.14X1X10^6 X68X10^{-12}\sqrt{6}} = \frac{1}{427.04X10^{-6}X2.45} = \frac{1}{1046.248X10^{-6}} = 955.7Hz$$

## EXERCISES

**1. Select the correct alternative.**

1.--------- is an electronic circuit which converts d.c. energy info a.c. energy.

(A) Amplifier (B) **Oscillator**

(C) Op-amp (D) Flip-Flop

2. A circuit which produces electrical oscillations of any desired frequency is known as --------

(A) **Oscillatory circuit** (B) Amplifier circuit

(C) frequency generator (D) Invertor

3) Tank circuit produces ---------- oscillations.

(A)undamped (B) **damped**

(C) sinusoidal (D) any shape

4. For Barkhausen criteria for sustained oscillation A□□value must be ----------

(A) 0 (b) 2

**(C) less than 1** **(D)**1

5. In phase-shift oscillator, the phase shift in each RC network is -------------

(A) $90^0$ (B)$120^0$

**(C) $60^0$** (D) $45^0$

6. In phase-shift oscillator, the feedback factor beta is ---------

(A) 1/20 (B) **1/29** (C)1/25 (D) 1/30

7. In --------- oscillator, two capacitors are placed across a common inductor.

(A)Phase-shift (B) **Collpit's**

(C) Wein-bridge (D) Hartley

8 Tank circuit provides phase shift of ----------

(A) $45^0$ (B) $60^0$

(C) $360^0$ **(D) $180^0$**

9. Oscillator is an electronic circuit which converts ----- energy into a.c. energy.

(A) a.c . (B) **d.c.**

(C) solar (D) wind

10. An oscillator circuit uses -------- feedback.

(A ) **positive** (B) negative

(C) current (D) positive and negative

11. In phase-shift oscillator, the frequency determining elements are --------

(A) R (B) C

(C) **R and C** (D) L and C

12. In the Colpitt's oscillator, the frequency determining elements are --------

(A) R (B) C

(C) R and C (D) **L and C**

13. Expression for frequency of phase shift oscillator is -------------

$(A) f_o = \frac{1}{2\pi RC}$ **B. $f_o = \frac{1}{2\pi R\sqrt{6}}$**

$(C) f_o = \frac{1}{2\pi\sqrt{RC}}$ $(D) f_o = \frac{1}{2\pi\sqrt{LC}}$

14. Expression for frequency of Colpitt's oscillator is -----------

$a) f_o = \frac{1}{2\pi RC\sqrt{6}}$ $b) f_o = \frac{1}{2\pi RC}$ $c) f_o = \frac{1}{2\pi\sqrt{LC}}$ $d) f_o = 2\pi\sqrt{LC}$

15. In Hartley oscillator, frequency of the oscillations fo is -----

$a) f_o = \frac{1}{2\pi RC\sqrt{6}}$ $b) f_o = \frac{1}{2\pi RC}$ $c) f_o = \frac{1}{2\pi\sqrt{LC}}$ $d) f_o = 2\pi\sqrt{LC}$

15. The equivalent capacitor in Colpitt's or crystal oscillator is given by -------

$(A) C = \frac{C1.C2}{C1+C2}$ $(B) C = \frac{C1.C2}{C1-C2}$

$(C) C = \frac{C1-C2}{C1+C2}$ $(D) C = \frac{C1+C2}{C1-C2}$

16. The crystal oscillator is used to produce --------- frequencies.

(A) moderate (B) low

(C) **High** (D)very low

17. Oscillator circuits are useful in ---------

(A) amplifier (B) **transmitter**

(C) receiver (D) logic gates

18. The condition Aβ=1 is known as ----------criterion.

(A) Collpitt's (B) Hartley

(C) Newton's (D) **Barkhausen**



**2. General Questions.**

1) What is an oscillator? Explain the difference between amplifier and oscillator. (5M)
2) Explain positive and negative feedback in amplifier and state its advantages. (5M).
3) Explain different types of waveforms in oscillator. (5M).
4) With suitable diagram, explain the nature of oscillations for tank circuit and expression for frequency. (5M).
5) Explain theory of feedback oscillator. Discuss different cases.(10M)
6) With a neat diagram explain the action/working of Hartley oscillator. (5M).
7) With a neat diagram explain the action of Colpitt's oscillator (5M).
8) With a neat diagram explain the circuit operation of phase-shift oscillator (5M).

9) With a neat diagram explain the circuit operation of crystal oscillator (5M).

10) For the Colpitt's oscillator $C_1$ = 750 pF, $C_2$ = 2500 pF, L = 40 μH. Determine The operating frequency Ans. *: 1052 kHz (5M)*

11) For the Phase shift oscillator $R_1=R_2=R_3=4.7K\Omega$ and $C_1=C_2=C_3=0.01\mu F$. Determine the operating frequency.(5M)

## Topic 3: Operational Amplifier

Differential amplifier and its type, Op-Amp, Block diagram of an Op-Amp. Op-Amp parameters, Characteristics of an ideal and practical Op-Amp(IC741),Applications of Op-Amps: Inverting amplifier and Non-inverting amplifier, Adder, Subtractor, Differentiator, Integrator.

### 3.0 Introduction:

We have studied RC coupled amplifier in previous chapter. Main drawbacks of this amplifier i) The gain of a single stage amplifier is generally insufficient for practical use ii) The frequency response of these amplifiers is fairly wide. But the gain of RC coupled amplifiers falls at lower as well as higher frequencies. iii) d.c. Voltages cannot be amplified as capacitor is used as coupling element. iv) Input impedance is small and output impedance is large v) the output changes with the change in supply voltage and temperature.

These drawbacks of cascaded amplifiers are removed by using two identical stages of direct coupled amplifiers to form a differential amplifier. The d.c. voltages can be amplified by using differential amplifier .Differential amplifier is the direct coupled amplifier using two balanced stages of amplifiers to amplify the difference between two-voltage signals and reject the voltage common to both stages.



### 3.1 Advantages of differential Amplifier:

i) The differential amplifier amplifies the difference between two input signals and rejects the common mode signal.

ii) Differential amplifier can be used as basic building block for Operational amplifier.

iii) It can be used to amplify ***ac*** as well as ***dc*** signals.

iv) Differential amplifier is a direct coupled amplifier consisting of two identical transistors. So its frequency response is independent of frequency and drift in output is minimized.

v) In some applications, very low signals are to be amplified. The noise present in such instruments is larger than the signal to be amplified. Therefore it is desirable to amplify the difference between these signals and reject the common mode signal.

### 3.2 Differential Amplifier:

Differential amplifier is a direct coupled amplifier which uses two stages of amplifiers. Fig.3.1 shows a differential amplifier. It consists of two identical transistors and use identical collector resistors $Rc_1 = Rc_2$. $R_E$ is common emitter resistance of high value. It provides high impedance at point C. $R_E$ acts as a constant current source. Because of direct coupling, the input ***ac*** signals at very high frequencies can be applied as input signal. Because there are no coupling or bypass capacitors, there is no lower cut off frequency.

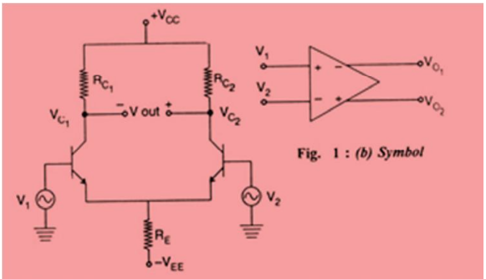


Fig.3.1 (a) Differential Amplifie (b) Symbol

The output voltage is zero, when two input voltages are equal. When V1 is greater than V2 an output voltage with the polarity of V1. When V2 is greater than V1, the output voltage is inverted and has the opposite polarity.

The diff. amplifier has two separate inputs. Input V1 is called the non- inverting input because $V_{out}$ is in phase with V1. V2 is called inverting input because $V_{out}$ is $180^0$ out of phase with V2. Output voltage is given by

$$Vo = A\,(V1 — V2)$$

where V0 — Voltage between collectors, A — gain of the amplifier and V1 — non-inverting input voltage and V2 — inverting input voltage. When both the non-inverting and inverting input voltages are present the total input is called a differential input because the output voltage equals the voltage gain times the difference of the two input voltage.



**3.2.1 Types or Mode of Operation of differential amplifier:**

There are four types or modes of operation of differential amplifier as

1 .Double ended input and output
2. Single-ended input and double-ended output.
3. Double-ended input and single-ended output.
4. Single-ended input and output.

***1. Double-ended input and output mode:***

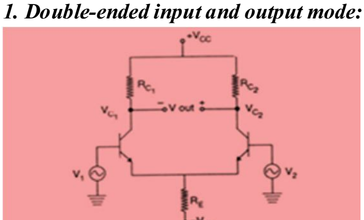


Fig.3.2(a) Double-ended input and output mode

In this mode of operation, the input is double-ended *i.e.* inputs V1 and V2 are applied to the bases of two transistors at the same time as shown in Fig.3.2(a).The output is also double-ended, *i.e.* Vo is taken between the collectors of two transistors.

$$Vo=A(V1-V2)$$

***2. Single-ended input and double-ended output mode:***

In this type, the input is single-ended *i.e.* only one input is applied and other is grounded as shown in Fig. 3.2(b).The output is double-ended *i.e.* between two collectors. A double-ended output requires a floating load. Therefore, double-ended output is inconvenient

The output voltage Vo is given by Vo=A(V1-V2)

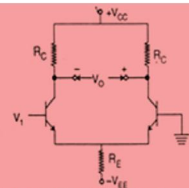



**Fig.3.2(b) Single ended input and double ended output mode**

**3. *Double ended input and single-ended output:***

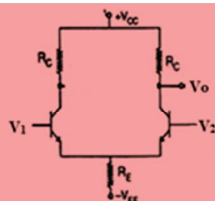



**Fig.3.2(c)Double ended input and single-ended output**

In this mode of Operation, both inputs $V_1$ and $V_2$ are applied simultaneously. Therefore, input is double ended but the output is single-ended *i.e.* Vo is taken between the collector of a transistor and a ground. Fig. 3.2 (c) shows double-ended input and single ended output mode.

The output voltage Vo is given by Vo=A(V1-V2)

Where A- gain, V1-noninverting input, V2-inverting input.

The voltage gain 'A' in this type is half of that obtained in double-ended input. This mode of operation is widely used, because it can drive single ended loads like CE amplifiers, emitter follower or input stage of an op-amp.



***4. Single-ended input and output mode:***

In this mode, input is applied to the base of any one transistor only and the other input is grounded as shown in Fig.3.2 (d). The output is taken at a collector and ground. Therefore, output is also single ended. Therefore input and output are is single-ended.

Since V2= 0: Output voltage Vo= AV1

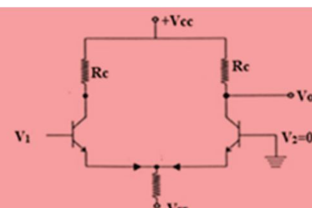



**Fig.3.2(d) Single-ended input and output mode**

**3.3 Comparison between normal amplifier and Differential Amplifier:**

| Normal amplifier: | Differential amplifier |
|---|---|
| (i) Normal amplifier uses only one input voltage | (i) Differential amplifier uses two input voltages |
| (ii) Single +Vcc power supply is used | (ii) Two power supply +Vcc is used. |