RAJIV GANDHI PROUDYOGIKI VISHWAVIDYALAYA, BHOPAL

New Scheme Based On AICTE Flexible Curricula

B.Tech. First Year

Branch- Common to All Disciplines

BT104	**Basic Electrical & Electronics Engineering**	**2L-0T-2P**	**3Credits**

Course Contents:

Unit- I :

D.C. Circuits: Voltage and current sources, dependent and independent sources, Units and dimensions, Source Conversion, Ohm's Law, Kirchhoff's Law, Superposition theorem, Thevenin's theorem and their application for analysis of series and parallel resistive circuits excited by independent voltage sources, Power & Energy in such circuits. Mesh & nodal analysis, Star Delta transformation & circuits.

Unit – II :

1- phase AC Circuits: Generation of sinusoidal AC voltage, definition of average value, R.M.S. value, form factor and peak factor of AC quantity , Concept of phasor, Concept of Power factor, Concept of impedance and admittance, Active, reactive and apparent power, analysis of R-L, R-C, R-L-C series & parallel circuit

3-phase AC Circuits: Necessity and advantages of three phase systems, Meaning of Phase sequence, balanced and unbalanced supply and loads. Relationship between line and phase values for balanced star and delta connections. Power in balanced & unbalanced three-phase system and their measurements

Unit – III : Magnetic Circuits: Basic definitions, magnetization characteristics of Ferro magnetic materials, self inductance and mutual inductance, energy in linear magnetic systems, coils connected in series, AC excitation in magnetic circuits, magnetic field produced by current carrying conductor, Force on a current carrying conductor. Induced voltage, laws of electromagnetic Induction, direction of induced E.M.F.

Single phase transformer- General construction, working principle, e.m.f. equation, equivalent circuits, phasor diagram, voltage regulation, losses and efficiency, open circuit and short circuit test

Unit IV:

Electrical Machines: Construction, Classification & Working Principle of DC machine, induction machine and synchronous machine. Working principle of 3-Phase induction motor, Concept of slip in 3- Phase induction motor, Explanation of Torque-slip characteristics of 3-Phase induction motor. Types of losses occurring in electrical machines. Applications of DC machine, induction machine and synchronous machine.

Unit V :

Basic Electronics: Number systems & Their conversion used in digital electronics, De morgan's theorem, Logic Gates, half and full adder circuits, R-S flip flop, J-K flip flop. Introduction to Semiconductors, Diodes, V-I characteristics, Bipolar junction transistors (BJT) and their working, introduction to CC, CB & CE transistor configurations, different configurations and modes of operation of BJT

Course outcomes:

The final outcome of the subject will result into an enhancement in understanding the basic concepts of Core Electrical Engineering subjects. The topics covered under this subject will help to enhance the basic understanding of Electrical machines and power systems and basic electronics.

Evaluation: Evaluation will be continuous and integral part of the class followed by final examination.

List of experiments/demonstrations:

- Basic safety precautions. Introduction and use of measuring instruments – voltmeter, ammeter, multi-meter, oscilloscope. Real-life resistors, capacitors and inductors.
- Measuring the steady-state and transient time-response of R-L, R-C, and R-L-C circuits to a step change in voltage (transient may be observed on a storage oscilloscope). Sinusoidal steady state response of R-L, and R-C circuits – impedance calculation and verification. Observation of phase differences between current and voltage. Resonance in R-L-C circuits.
- Transformers: Observation of the no-load current waveform on an oscilloscope (non- sinusoidal wave-shape due to B-H curve nonlinearity should be shown along with a discussion about harmonics). Loading of a transformer: measurement of primary and secondary voltages and currents, and power.
- Determination of equivalent circuit parameters of a single phase transformer by O.C. and S.C. tests and estimation of voltage regulation and efficiency at various loading conditions and

verification by load test.

- Demonstration of cut-out sections of machines: dc machine (commutator-brush arrangement), induction machine (squirrel cage rotor), synchronous machine (field winging - slip ring arrangement) and single-phase induction machine.
- Torque Speed Characteristic of separately excited dc motor.
- Synchronous speed of two and four-pole, three-phase induction motors. Direction reversal by change of phase-sequence of connections. Torque-Slip Characteristic of an induction motor. Generator operation of an induction machine driven at super- synchronous speed.
- Synchronous Machine operating as a generator: stand-alone operation with a load. Control of voltage through field excitation.
- Study of V-I Characteristics of Diodes.
- Applications of Diodes and their verification.
- Transistor applications as amplifier and switch.
- Verification of truth table for various gates, Flip-Flops.
- Realizations of Various gates, Flip-Flops etc.
- Verification of De morgan's theorems.

References

1. D.P. Kothari & I.J. Nagrath, Basic Electrical Engineering, Tata McGraw Hill, latest edition.
2. S.N. Singh , Basic Electrical Engineering, P.H.I.,2013
3. Rajendra Prasad, Fundamentals of Electrical Engineering, Prentice Hall,2014
4. M.S. Sukhija, T. K. Nagsarkar, Basic Electrical and electronics engineering, Oxford University press,2012
5. C.L. Wadhwa, Basic Electrical Engineering. New Age International.
6. B.L. Theraja & A.K Theraja Textbook of Electrical Technology - Vol. 1, S. Chand Publication
7. E. Hughes & I.M. Smith Hughes Electrical Technology Pearson
8. Vincent Del Toro Electrical Engineering Fundamentals

UNITS AND DIMENSIONS :

The quantitative description of any object or material involves measurement and comparison of physical quantities. Any physical quantity can be measured using a standard unit of that quantity. The unit of a physical quantity is the reference standard used to measure it.

Dimension is a measurable physical quantity, while unit is a way to assign a number or measurement to that dimension. There is difference between dimension and unit. For example, length is a dimension, but it is measured in units of feet or meter. A particular quantity can be reported in many different kinds of units, but it will always have the same dimensions. Dimensions are represented using symbols by: length [L], mass [M] and time [T]. In order to maintain uniformity in the field of science and engineering the S.I. unit is used ("ysteme International d'Unites). The seven fundamental units in "I are - Meter, Kilogram, Second, Ampere, Kelvin, Mole and Candela.

IMPORTANT LAWS :

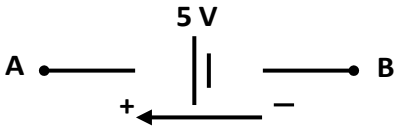
a. **Ohm's law :** The current through a conductor between two points is directly proportional to the potential difference across it, provided the temperature of conductor and all other factors remain constant. The relations for ohms law are $I = \frac{V}{R}$; $V = IR$; $R = \frac{V}{I}$

b. **Kirchhoff's current law :** The algebraic sum of the currents at a junction is equal to zero.

c. **Kirchhoff's voltage law :** The algebraic sum of the voltage sources in any closed circuit is always equal to the sum of the voltage drops as well as voltage rises in that closed circuit.

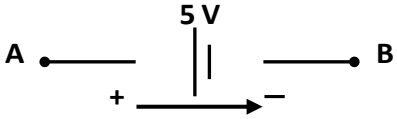
d. **Assumption of polarity (sign) while applying Kirchhoff's voltage law (KVL) to electrical networks :**

i) Voltage sources :



Rise in Potential
+ 5 V

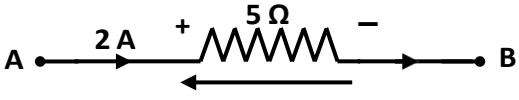
Assumed direction of movement along network



Fall in Potential
– 5 V

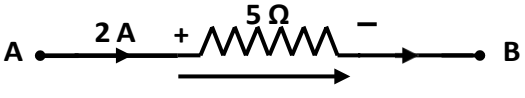
Assumed direction of movement along network

ii) Passive elements:



Rise in Potential
+10 V

Assumed direction of movement along network

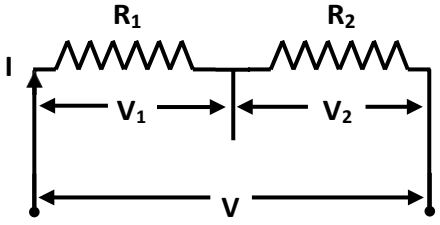


Fall in Potential
– 10 V

Assumed direction of movement along network

The analysis of DC circuits can be carried out if the below mentioned relations are known :

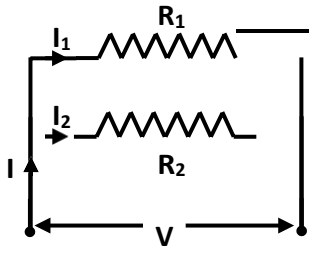
a. Resistors in series : $R_{eq} = R_1 + R_2$



b. Resistors in parallel : $R_{eq} = \frac{R_1 R_2}{R_1 + R_2}$

c. The voltage division for the circuit shown is :

$V_1 = V \frac{R_1}{R_1 + R_2}$ and $V_2 = V \frac{R_2 R_1}{R_1 + R_2}$



d. The division of current for the circuit shown is :

$I_1 = I \frac{R_2}{R_1 + R_2}$ and $I_2 = I \frac{R_1}{R_1 + R_2}$

In DC circuit analysis usually the circuits are reduced in steps to get their equivalent resistance and then obtain the required solution.

RELATIONS FOR POWER AND ENERGY:

We have electrical power, **P= VI**

An electrical power of 1 watt is consumed in a circuit if a potential difference of 1 volt when applied across it, causes a current of 1 ampere to flow through it. Other relations for power are, **$P=I^2R$ and $P = V^2/R$.**

Unit for power is watts or **kW.**

We have electrical energy, **E = Power x Time.**

An electrical energy of 1 watt-sec is consumed in a circuit when a power of 1 watt is utilized for one second

OR An electrical energy of 1 kWh is consumed in a circuit when a power of 1 kW is utilized for one hour.

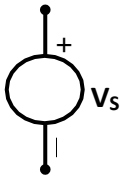
Other relations for energy are, **$E=I^2Rt$ and $E = VIt$** ; Unit for energy is **Watt-sec or Watt-hr or kWh.**

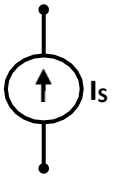
VOLTAGE AND CURRENT SOURCES :

- Any device that produces electrical energy can be called a source.
- A source is usually expected to deliver power to a network and not to absorb it.
- A voltage source maintains the required difference in potential across the circuit it is connected.
- A current source supplies the required quantity of current to the circuit it is connected.
- An ideal constant voltage source is one whose output voltage remains absolutely constant irrespective of the change in load current. These voltage sources must possess zero internal resistance, so that the internal voltage drop in the source is zero. It is not practically possible to have an ideal constant voltage source.
- An ideal constant current source is one whose output current remains absolutely constant. These current sources have infinite internal resistance. Practically these sources possess a very high resistance when compared to its external load resistance.

DEPENDENT AND INDEPENDENT SOURCES :

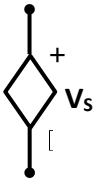
- The sources in which the voltage or current depends upon a current or voltage elsewhere in the circuit are known as Dependent sources or Controlled sources.
- The sources in which the voltage is completely independent of the current or the current is completely independent of the voltage are known as Independent sources.
- An ideal independent voltage source is one that maintains a specified voltage between its source terminals regardless of the current drawn from it. *It is symbolised as shown :*
  The positive and negative signs indicate the conventional direction of electric field when the source is applied to a load.





- An ideal independent current source is one that maintains a specified current through its terminals regardless of the voltage across the terminals. *It is symbolised as shown :*
  The arrow indicates the conventional direction of current when the source is connected to a load.

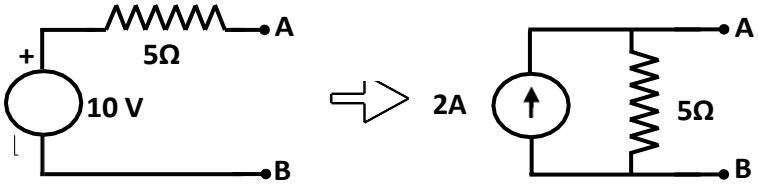
- A dependent voltage source is one that produces a voltage as a function of voltages elsewhere in a given circuit. *It is symbolised as shown :*



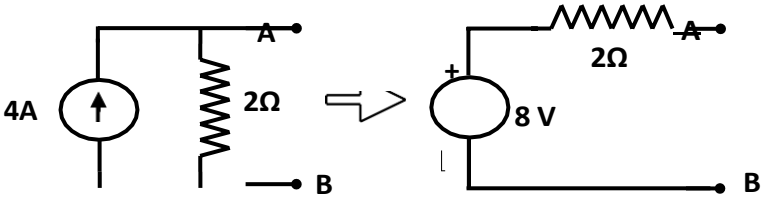
- A dependent current source is one that produces a current as a function of currents elsewhere in a given circuit. *It is symbolised as shown :*

SOURCE CONVERSION :

- A voltage source with a series resistor can be converted into an equivalent current source with a resistor in parallel to it.
- A current source with a parallel resistor can be converted into an equivalent voltage source with a resistor in series with it.
- The conversions are possible only when their respective open circuit voltages are equal or their respective short circuit currents are equal.
- *Example for voltage source to current source conversion :*



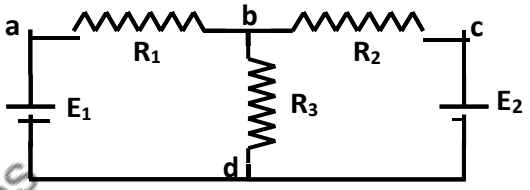
- *Example for current source to voltage source conversion :*



- Conversion of sources helps in simplifying the analysis of circuits.

NETWORK TERMINOLOGIES :

- A network or circuit is an arrangement of active and passive elements that form closed paths.
- Consider the circuit shown :
- It has two active elements E_1 and E_2.
- It has three passive elements R_1, R_2 and R_3.
- A node of a network is an equi-potential surface at which two or more circuit elements are joined.
- In the circuit shown above *a, b, c* and *d* are nodes.
- A junction is that point in a network where three or more circuit elements are joined.
- In the circuit there are two junctions *b* and *d*.
- A branch is that part of a network which lies between junction points.
- There are three branches *dab, dcb* and *db*.
- The branch *dab* has two elements $E_1$and R_1.
- The branch *dcb* has two elements E_2 and R_2.
- The third branch *db* has only one element R_3.



- A loop is any closed path of a network.
- The loops in the circuit are *abda, dbcd* and *abcda*.
- A mesh is the most elementary form of a loop.
- The meshes in the circuit are *abda* and *dbcd*.
- A mesh is also a loop that cannot have another loop within it.
- A mesh current is that current which flows around the perimeter of the mesh.
- The mesh currents are always assumed to flow in the clockwise direction.
- Branch currents have physical identity but mesh currents are fictitious quantities introduced so that they allow us to solve problems with minimum number of unknowns**.**

MESH AND LOOP ANALYSIS :

- When the number of branches in a network increase, the earlier methods used will lead to complications. In order to simplify the solution of such networks one of the methods is the Loop analysis or the Mesh analysis.
- The step by step procedure adopted to use the method of mesh analysis is :
  - **a.** Observe the circuit for finding the possible number of meshes, if there are any current sources, convert them into their equivalent voltage sources.
  - **b.** Assign mesh currents to each mesh assuming the current to flow in clockwise direction.
  - **c.** Apply KVL to each mesh and write the equations.
  - **d.** The number of equations will be equal to the number of unknown mesh currents.

e. The equations are solved to determine the mesh currents.

f. The required branch currents are determined from the mesh currents determined.

g. In case the branch current determined is negative, then the branch current is flowing opposite to the assumed direction.

h. In case the branch current determined is positive, then the branch current is flowing in the assumed direction.

NODE VOLTAGE ANALYSIS :

- A node is a point in a network that is common to two or more circuit elements. If three or more elements are joined at a point, that point can be called a junction. It is also called as an independent node or principle node.
- Usually the negative terminal of an active element is selected as the reference node or datum node and its potential is assumed to be zero.
- The node voltage is the voltage of a given node with respect to the reference node or datum node.
- The node analysis method helps us to find the voltages at all the principle nodes with respect to the reference node.
- Usually all the branch currents are assumed to be positive when the direction of the currents are not known or not given in the circuit.
- At all the principle nodes, the currents flowing towards the node are considered negative and the currents flowing away from the node are considered positive.
- The step by step procedure adopted to use the method of nodal analysis is:

a. Observe the circuit to find the number of principle nodes and identify the reference node.

b. Number the principle nodes serially and assume the node voltages.

c. Assume the currents to flow outward from the nodes in each branch.

d. Apply KCL to all the nodes and write the equations in terms of voltages and resistances.

e. The number of equations will be equal to the number of principle nodes.

f. The equations are solved to find the values of the assumed node voltages.

g. With the determined values of the node voltages all the branch currents are calculated.

SUPERPOSITION THEOREM :

This theorem is very useful as it extends the use of Ohm's law to circuits that have more than one source. It is possible to calculate the effect of each source at a time and then superimpose results of all the other sources.

Statement : "In a network with two or more sources, the current or voltage for any component is the algebraic sum of the effects produced by each source acting separately".

Step by step procedure to analyse a network using superposition theorem :

Let us consider the circuit shown in figure-A, I_1, I_2 and I_3 are the currents flowing in the circuit due to the two voltage sources of 8V and 12V.

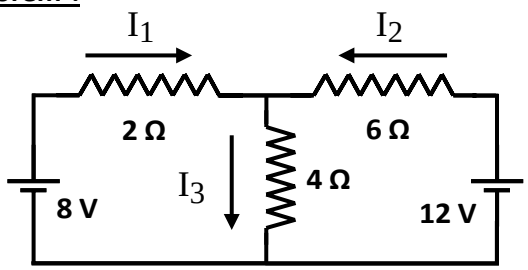


FIGURE - A

To solve the circuit by using superposition theorem, only one voltage source has to be considered to be acting at a time in the circuit.

So the 8V source is retained and the 12V source is removed, as it has no internal resistance the circuit is drawn as shown in figure-B.

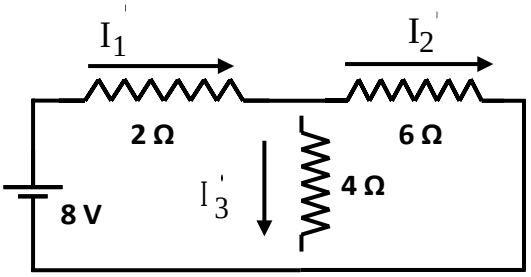


FIGURE - B

I_1', I_2' and I_3' are the currents flowing in the circuit as shown due to the 8V source only. The equivalent resistance of the circuit is calculated, the total current and the branch currents are found using Ohm's law.

Next considering the 12V source only in the circuit the 8V source is removed, as it has no internal resistance the circuit is drawn as shown in figure-C.

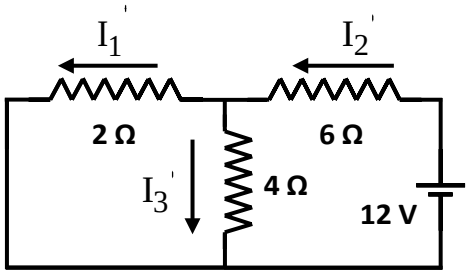


FIGURE - C

I_1', I_2' and I_3' are the currents flowing in the circuit as shown due to the 12 V source only. The total current and branch currents are calculated.

The currents I_1, I_2 and I_3 flowing in the circuit shown in figure-A, can be obtained by combining the values of the currents flowing in figure-B and figure-C.

So the branch currents of figure-A are $I_1 = I_1' - I_1''$; $I_2 = I_2' - I_2''$ and $I_3 = I_3' - I_3''$

THEVENIN'S THEOREM :

This theorem is quite useful in analyzing complicated networks comprising of a number of voltage or current sources. It helps in simplifying the process of solving for the unknown values of voltage and current in a network.

By Thevenin's theorem, many sources and components, no matter how they are interconnected, can be represented by an equivalent series circuit with respect to any pair of terminals in the network.

In fig. - 1 below the block at the left contains a network connected to terminals A and B, which can be replaced by a single source of emf, V_{TH} in series with a single resistance R_{TH}.

Where V_{TH} is the open circuit voltage across terminals A and B and R_{TH} is the open circuit resistance across terminals A and B

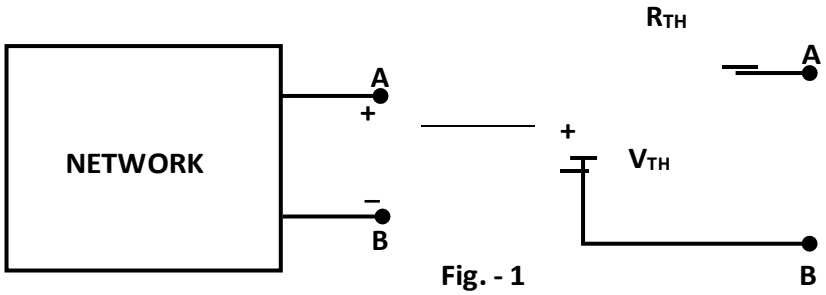


Fig. - 1

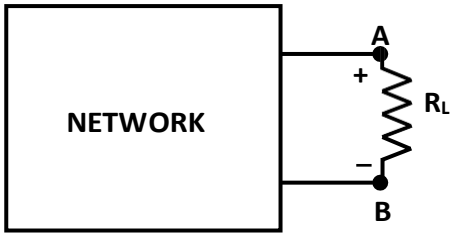


Fig. - 2

STATEMENT : "Thevenin theorem states that the entire network connected to A and B can be replaced by a single voltage source V_{TH} in series with a single resistance R_{TH}, connected to the same two terminals".

STEP BY STEP PROCEDURE IN THEVENIZING A CIRCUIT :

The step by step procedure adopted to solve any network by Thevenin's theorem is given below :

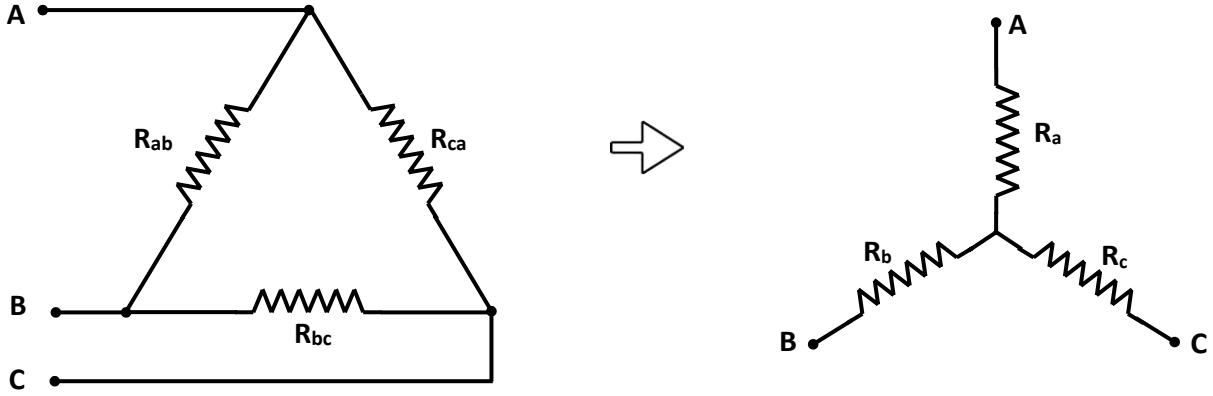
a. The load resistor R_L of the network through which the current flowing has to be determined is identified.
b. The load resistor R_L is temporarily disconnected from the network.
c. Let the points be named A and B.
d. The open circuit voltage which appears across the points A and B is determined. This is called Thevenin voltage V_{TH}.
e. In order to determine the Thevenin resistance of the network behind the points A and B.
f. The voltage sources in the network are replaced by their internal resistances and the current sources are replaced by an open circuit.
g. The equivalent resistance across the terminals A and B is determined which is called Thevenin resistance R_{TH}.
h. Replace the entire network by the Thevenin source, whose voltage is V_{TH} and whose internal resistance is the Thevenin resistance R_{TH}.
i. Connect the load resistor R_L back across the points A and B, from where it was removed earlier.
j. Calculate the current flowing through the load resistor using the relation :

$$I = \frac{V_{TH}}{R_{TH} + R_L}$$

STAR-DELTA RELATIONS :

- When a three terminal circuit is encountered in any network the star delta relations can be used to simplify the circuit.
- By initially converting the three terminal network from one form to another and by applying other simplifying techniques the network can be solved.

DELTA TO STAR CONVERSION :



Let us consider aDelta circuit shown above. Let us find the resistance between the terminals A and C with terminal B open.It is observed that the resistors R_{ab} and R_{bc} will be in serieswith each other and this series combination will be in parallel with R_{ca}. Hence, the equivalent resistance between the terminalsA and C can be written as, $R_{ca} \cdot \frac{R_{ca} \cdot R_{ab} \cdot R_{bc}}{R_{ab} \cdot R_{bc} \cdot R_{ca}}$

Similarly, resistance between terminals A and B, $R_{ab} \cdot \frac{R_{ab} \cdot R_{ca} \cdot R_{bc}}{R_{ab} \cdot R_{bc} \cdot R_{ca}}$

the resistance between terminals B and C, $R_{bc} \cdot \frac{R_{bc} \cdot R_{ab} \cdot R_{ca}}{R_{ab} \cdot R_{bc} \cdot R_{ca}}$

Considering the Star circuit shown above, the resistance between the terminals A and C = $R_a \cdot R_c$

Between A and B = $R_a \cdot R_b$ and between B and C = $R_b \cdot R_c$

Equating resistance between similar terminals in the two circuits, we get,

$R_a \cdot R_c \cdot \frac{R_{ca} \cdot R_{ab} \cdot R_{bc}}{R_{ab} \cdot R_{bc} \cdot R_{ca}}$ ……(1)

$R_a \cdot R_b \cdot \frac{R_{ab} \cdot R_{ca} \cdot R_{bc}}{R_{ab} \cdot R_{bc} \cdot R_{ca}}$ ……(2)

$R_b \cdot R_c \cdot \frac{R_{bc} \cdot R_{ab} \cdot R_{ca}}{R_{ab} \cdot R_{bc} \cdot R_{ca}}$ …… (3)

Subtracting equation (3) from equation (1), we get, $R_a \cdot R_b \cdot \frac{R_{ab} \cdot R_{ca} \cdot R_{ab} \cdot R_{bc}}{R_{ab} \cdot R_{bc} \cdot R_{ca}}$ ……(4)

Adding equation (2) to equation (4) and dividing by 2, we get, $R_a \cdot \frac{R_{ab} \cdot R_{ca}}{R_{ab} \cdot R_{bc} \cdot R_{ca}}$ ……(5)

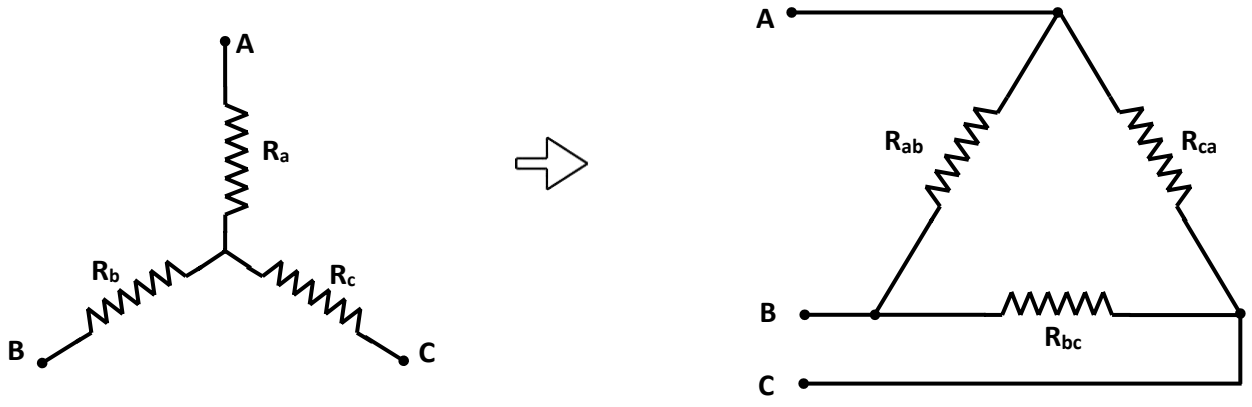
Similarly, $R_b \cdot \frac{R_{bc} \cdot R_{ab}}{R_{ab} \cdot R_{bc} \cdot R_{ca}}$ ……(6) and $R_c \cdot \frac{R_{ca} \cdot R_{bc}}{R_{ab} \cdot R_{bc} \cdot R_{ca}}$ ……(7)

Hence the Star values of resistors in terms of the Delta resistors are expressed as:

$$R_a = \frac{R_{ab} R_{ca}}{R_{ab} + R_{bc} + R_{ca}} \; ; \quad R_b = \frac{R_{bc} R_{ab}}{R_{ab} + R_{bc} + R_{ca}} \; ; \quad R_c = \frac{R_{ca} R_{bc}}{R_{ab} + R_{bc} + R_{ca}}$$

STAR TO DELTA CONVERSION :

Let us consider a Star connected circuit shown above. The resistance between the terminals A and C is found to be = $R_a + R_c$. The resistance between B and C = $R_b + R_c$ and that between A and B = $R_a + R_b$.



Let us consider the Delta connected circuit shown above, the resistance between the terminals A and C with terminal B open can be written as, $R_{ac} = \frac{R_{ca}(R_{ab} + R_{bc})}{R_{ab} + R_{bc} + R_{ca}}$

Similarly, resistance between terminals A and B, $R_{ab} = \frac{R_{ab}(R_{ca} + R_{bc})}{R_{ab} + R_{bc} + R_{ca}}$

and the resistance between terminals B and C, $R_{bc} = \frac{R_{bc}(R_{ab} + R_{ca})}{R_{ab} + R_{bc} + R_{ca}}$

Equating resistance between similar terminals in the two circuits, we get,

$$R_a + R_c = \frac{R_{ca}(R_{ab} + R_{bc})}{R_{ab} + R_{bc} + R_{ca}} \quad \text{.....} \quad (1)$$

$$R_a + R_b = \frac{R_{ab}(R_{ca} + R_{bc})}{R_{ab} + R_{bc} + R_{ca}} \quad \text{.....} \quad (2)$$

$$R_b + R_c = \frac{R_{bc}(R_{ab} + R_{ca})}{R_{ab} + R_{bc} + R_{ca}} \quad \text{.....} \quad (3)$$

Subtracting equation (3) from equation (1), we get, $R_a + R_b = \frac{R_{ab} R_{ca} + R_{ab} R_{bc}}{R_{ab} + R_{bc} + R_{ca}}$ .....(4)

Adding equation (2) to equation (4) and dividing by 2, we get, $R_a = \frac{R_{ab} R_{ca}}{R_{ab} + R_{bc} + R_{ca}}$ .....(5)

Similarly, $R_b = \frac{R_{bc} R_{ab}}{R_{ab} + R_{bc} + R_{ca}}$ (6) $R_c = \frac{R_{ca} R_{bc}}{R_{ab} + R_{bc} + R_{ca}}$ (7)

From equations (5), (6) and (7), we get,

$$R_a R_b + R_b R_c + R_c R_a = \frac{R_{ab}^2 R_{bc} R_{ca} + R_{bc}^2 R_{ab} R_{ca} + R_{ca}^2 R_{ab} R_{bc}}{(R_{ab} + R_{bc} + R_{ca})^2}$$

$$R_a R_b + R_b R_c + R_c R_a = \frac{R_{ab} R_{bc} R_{ca} (R_{ab} + R_{bc} + R_{ca})}{(R_{ab} + R_{bc} + R_{ca})^2}$$

$$R_a R_b + R_b R_c + R_c R_a = \frac{R_{ab} R_{bc} R_{ca}}{R_{ab} + R_{bc} + R_{ca}} \quad \text{.....(8)}$$

Dividing Equation (8) by equation (7), we get,

$$R_{ab} = \frac{R_a R_b + R_b R_c + R_c R_a}{R_c}$$

Dividing Equation (8) by equation (5), we get,

$$R_{bc} = \frac{R_a R_b + R_b R_c + R_c R_a}{R_a}$$

Dividing Equation (8) by equation (6), we get,

$$R_{ca} = \frac{R_a R_b + R_b R_c + R_c R_a}{R_b}$$

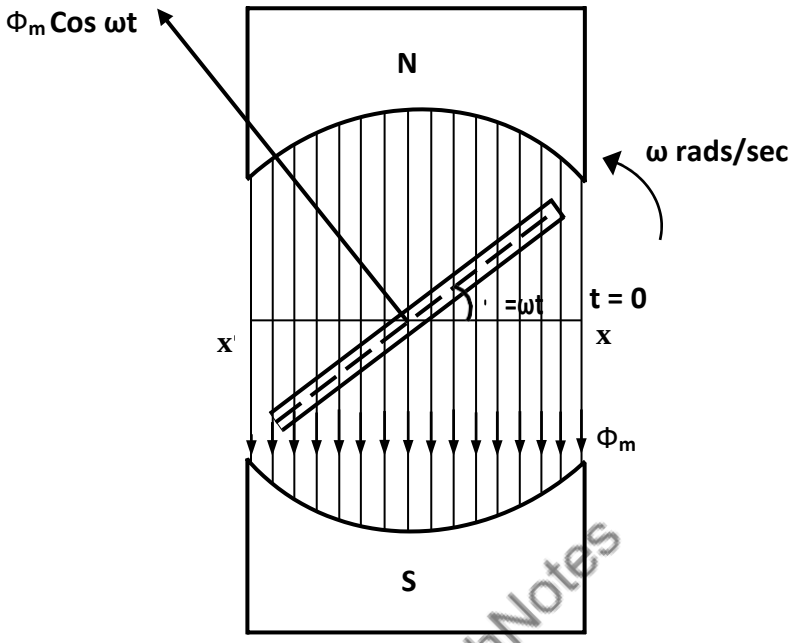
Hence the Delta values of resistors in terms of the Star resistors are expressed as:

$$R_{ab} = \frac{R_a R_b + R_b R_c + R_c R_a}{R_c}; R_{bc} = \frac{R_a R_b + R_b R_c + R_c R_a}{R_a}; R_{ca} = \frac{R_a R_b + R_b R_c + R_c R_a}{R_b}$$

Generation of sinusoidal AC voltage, definition of average value, R.M.S. value, form factor and peak factor of AC quantity, Concept of Phasor, Concept of Power factor, Concept of impedance and admittance, Active, reactive and apparent power, analysis of R-L, R-C, R-L-C series and parallel circuit.

Single Phase AC Circuits

Generation of single phase voltages:



Let us consider a coil with N turns, rotating in a uniform magnetic field with an angular velocity ω rads/sec as shown in figure. Let the time be measured from the x-axis. When the plane of the coil coincides with the x-axis maximum flux Φ_m links the coil. After time t the coil moves through an angle θ = ωt

In this position the component of the flux which is perpendicular to the plane of the coil is $\Phi = \Phi_m Cos\omega t$

We have flux linkages = $N\Phi = N\Phi_m Cos\omega t$; Induced emf at this instant is, $e = -\frac{d}{dt}(N\Phi)$

$$= -N\frac{d}{dt}(\Phi_m s\omega t) = -mN\Phi_m(-Sn\omega t) = mN\Phi_m Sn\omega t$$

When the coil makes an angle θ = 90°, Sin θ = 1, Hence, the emf induced in the coil is maximum, ie. E_m

$\therefore E_m = mN\Phi_m$ **or** $e = E_m Sn\omega t$ **or** $e = E_m Sn$

The induced emf varies as sine function of the time angle ωt and when emf is plotted against time a sine curve is traced.

Terms and Definitions:

Cycle: One complete set of positive and negative values of an alternating quantity is known as a cycle.

Frequency: The number of cycles/sec is called the frequency of the alternating quantity.

Time period: The time taken by an alternating quantity to complete one cycle is called its time period.

Amplitude: The maximum value either positive or negative of an alternating quantity is known as its amplitude.

Phase: It is the fraction of the time period of that alternating quantity which has elapsed since the current last passed through the zero position of reference.

Phase difference: It is the difference in phase angle between any two alternating quantities.

Instantaneous value: It is the value of any alternating quantity at a particular instant of time.

Average value: It is that value of steady current, which transfers across any circuit the same charge as is transferred by that alternating current during the same time. Average value, $I_{av} = 0.637\ I_m$

Root mean square value: It is given by that steady current which when flowing through a given circuit for a given time produces the same heat as produced by the alternating current when flowing through the same circuit for the same time. Root mean square value, $I_{rms} = 0.707\ I_m$

Form factor: It is defined as the ratio of its rms value and average value

Form factor = rms value / average value = $0.707\ I_m / 0.637\ I_m = 1.11$ for sine wave.

Peak factor or Crest factor: It is defined as the ratio of its maximum value and rms value.

Peak factor = Maximum value / rms value = $I_m / 0.707\ I_m = 1.414$ for sine wave.

Resistance: Its property is to oppose the flow of current through it. Resistance is a measurable quantity and its unit is Ohm.

Inductance: Its property is to induce emf in itself whenever a changing current flows through it, its unit is Henry.

Inductive reactance: It causes opposition to the flow of current through it. Reactance is a non-measurable quantity which can only be calculated its unit is Ohm.

Capacitance: It is the capacity of any capacitor to store charge and its unit is Farad.

Capacitive reactance: It causes opposition to the flow of current through it. Reactance is a non-measurable quantity which can only be calculated its unit is Ohm.

Impedance: It is the total opposition due to the resistance as well as the reactance of the circuit to the flow of current. It is a non-measurable quantity which can only be calculated its unit is Ohm.

Admittance: Admittance is a measure of how much current is admitted in a circuit. Admittance (Y) is the inverse of impedance (Z). Admittance has its most obvious utility in dealing with parallel AC circuits. The unit of admittance is Siemens.

Active power: It is also called Average power or True power or Real power. It is the actual power which is dissipated in the resistance of the circuit $P = VI \cos \Phi$ or $P = I^2R$, the unit is watts or KW.

Reactive power: It is the power developed in the inductive reactance of the circuit. It is also called wattless power Reactive power = $VI \sin \Phi$, its unit is Reactive Voltamperes or Kilovoltamperes reactive

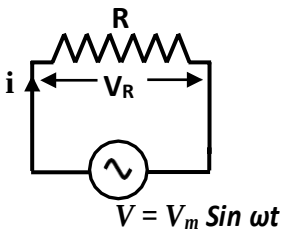
Apparent power: It is the product of the rms values of voltage and current.

Apparent power =VI, its unit is Voltampere or Kilovoltamperes

Power factor: It is the cosine of the phase angle Φ existing between the voltage and current in any AC circuit. It has no unit. It can have values varying between zero and unity. It can also be either lagging or leading in nature.

Phasor: A phasor is a complex number representing a sinusoidal function whose amplitude, angular velocity and initial phase are time invariant.

AC circuit with Resistance only:



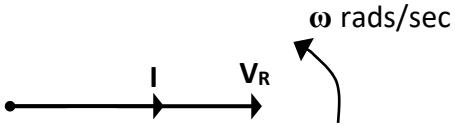
CIRCUIT DIAGRAM

Let the alternating voltage be $v = V_m Snmt$

the current $= \frac{V_m}{R}$ or $= \frac{V_m Snmt}{R}$

The value of *i* will be maximum when $Snmt = 1$

$\therefore I_m = \frac{V_m}{R}$ or $= I_m \ Snmt$



PHASOR DIAGRAM

The voltage across the resistor and the current through the resistor are in phase with each other.

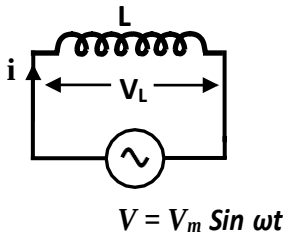
The instantaneous power, $p = v = V_m Snmt I_m Snmt$

$= V_m I_m Sn^2 mt = V_m I_m [\frac{1 - Cos2mt}{2}] = \frac{V_m I_m}{2} - \frac{V_m I_m}{2} Cos2mt$

The average value of $\frac{V_m I_m}{2} Cos2mt$ over a complete cycle is zero

$\therefore P = \frac{V_m I_m}{2}$ or $= \frac{V_m}{\sqrt{2}} \frac{I_m}{\sqrt{2}}$ $\therefore Power = VI$ Hence, a pure resistive circuit consumes power.

AC circuit with Inductance only:



CIRCUIT DIAGRAM

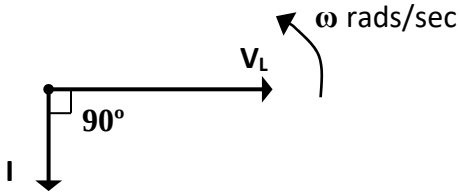
Let the alternating voltage be $v = V_m Snmt$

the self induced emf, $e_L = L \frac{d}{dt}$

$\therefore V_m Snmt = L \frac{d}{dt}$ or $d = \frac{V_m}{L} Snmtdt$

Integrating both sides, we have

$= \frac{V_m}{L} \int Snmtdt = \frac{V_m}{mL} [-Cosmt]$ or $= \frac{V_m}{mL} Sn [mt - \frac{\pi}{2}]$



PHASOR DIAGRAM

We have *i* to be maximum when $Sn [mt - \frac{\pi}{2}]$ is unity

$\therefore I_m = \frac{V_m}{mL}$ or $= I_m \ Sn [mt - \frac{\pi}{2}]$

It is observed that the current lags the voltage by 90°

The quantity mL is called inductive reactance and also represented as $_L = 2\pi fL$

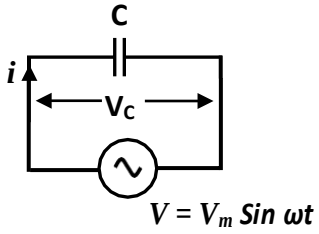
The instantaneous power, $p = v = V_m Snmt I_m Sn [mt - \frac{\pi}{2}] = = - V_m Snmt I_m Cosmt$

$= -V_m I_m Snmt Cosmt = -\frac{V_m I_m}{2} Sn2mt$

Power for the complete cycle, $P = -\frac{V_m I_m}{2} \int_0^{2\pi} Sn2mtdt = 0$

A pure inductive circuit does not consume any power

AC circuit with Capacitance only:



Let the alternating voltage be $v = V_m Snmt$

Let charge on the plates be $= q$

But charge, $q = Cv = CV_m Snmt$

Current, $= \frac{dq}{dt} = \frac{d}{dt}[CV_m Snmt] = mCV_m Cosmt$

or $= \frac{V_m}{1/mC} Cosmt$ **or** $= \frac{V_m}{1/mC} Sn[mt + \frac{\pi}{2}]$

The current *i* will be maximum when $Sn[mt + \frac{\pi}{2}]$ **is unity**

$\therefore I_m = \frac{V_m}{1/mC} = \frac{V_m}{C}$ **Where** C **is the capacitive reactance**

$\therefore = I_m Sn[mt + \frac{\pi}{2}]$ **It is observed that the current leads the voltage by 90°**

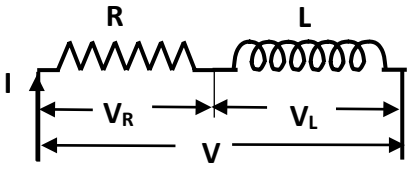
The instantaneous power, $p = v$ = $V_m Snmt I_m Sn[mt + \frac{\pi}{2}]$ = $Snmt I_m Cosmt$

$= V_m I_m SnmtCosmt = \frac{V_m I_m}{2} Sn2mt$

Power for the complete cycle, $P = \frac{V_m I_m}{2} \int_0^{2\pi} Sn2mtdt = 0$

A pure capacitive circuit does not consume any power

R - L series circuit:



CIRCUIT DIAGRAM

Let us consider a resistor and inductor in series.

If V is the rms value of the applied voltage then I

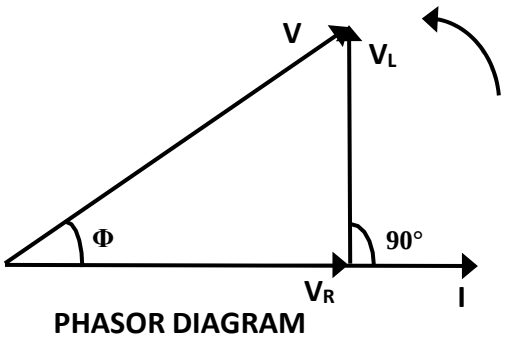
will be the rms value of the current drawn by the circuit.

The voltage across R = V_R = IR, where V_R is in phase with I.

The voltage across L = V_L= IX_L, where V_L leads I by 90°

The applied voltage V is the phasor sum of the two

voltage drops V_R and V_L

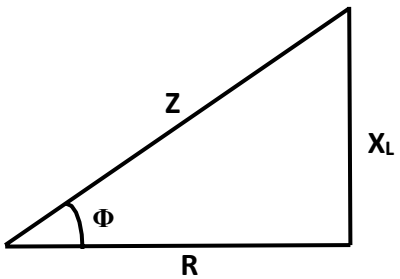


PHASOR DIAGRAM

From the phasor diagram, we have

$V = \sqrt{V_R^2 + V_L^2} = \sqrt{IR^2 + I_L^2} = I\sqrt{R^2 + L^2}$

$I = \frac{V}{\sqrt{R^2 + L^2}}$ **or** $I = \frac{V}{Z}$



IMPEDANCE TRIANGLE

Where Z is the impedance of the circuit = $\sqrt{R^2 + L^2}$

From the phasor diagram, $tan = \frac{V_L}{V_R} = \frac{I_L}{IR} = \frac{L}{R}$

or $= tan^{-1}\frac{L}{R}$ **Also** $Cos = \frac{V_R}{V} = \frac{R}{IZ} = \frac{R}{Z} \therefore Cos = \frac{R}{Z}$

From the phasor diagram, we can draw the Impedance triangle as shown in figure.

We have Power, $P = VICos = [IZ]I[\frac{R}{Z}] = I^2R$

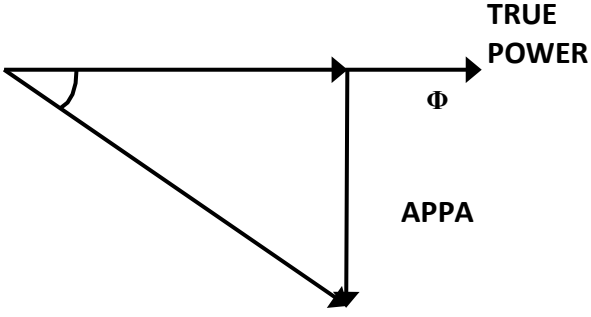
$\therefore Power = I^2R$

From the power triangle, we have

True power = $P = VICos$ **Reactive**

power = $P = VISn$ **Apparent**

power = $P = VI$



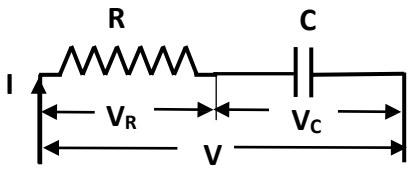
RENTPOWER

V

REACTIVE POWER

R - C series circuit:

Let us consider a resistor and capacitor in series. If V is the rms value of the applied voltage then I will be the rms value of the current drawn by the circuit.



CIRCUIT DIAGRAM

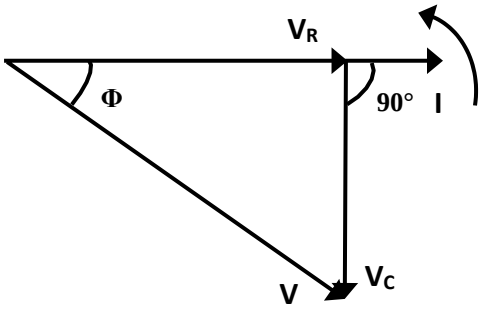
The voltage across R = V_R = IR, where V_R is in phase with I

The voltage across C = V_C = IX_C, where V_C lags I by 90°

The applied voltage V is the phasor sum of the two voltage drops V_R and V_C . From the phasor diagram, we have

$$V = \sqrt{V_R^2 + V_C^2} = \sqrt{IR^2 + I_C^2} = I\sqrt{R^2 + C^2}$$

$$I = \frac{V}{\sqrt{R^2 + C^2}} \quad \text{or} \quad I = \frac{V}{Z} \quad ; \quad \text{where } Z = \sqrt{R^2 + C^2}$$

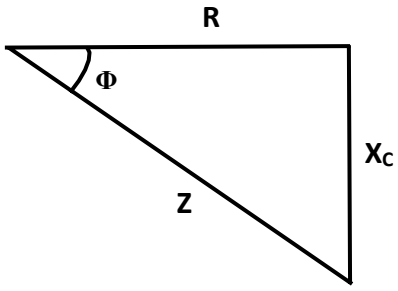


PHASOR DIAGRAM

From the phasor diagram, $tan = \frac{VC}{V_R} = \frac{I_C}{IR} = \frac{C}{R}$

or $= tan^{-1}\frac{C}{R}$

From the phasor diagram, we can draw the Impedance triangle as shown in figure.



IMPEDANCE TRIANGLE

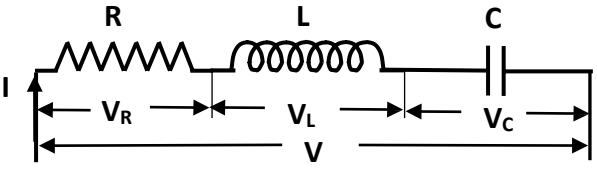
From the impedance triangle $Cos = \frac{R}{Z}$

We have $P = VICos$ or $P = I^2R$

R - L - C Series circuit:

Let us consider a resistor, inductor and capacitor in series.

If V is the rms value of the applied voltage then I will be the rms value of the current drawn by the circuit.



CIRCUIT DIAGRAM

The voltage across R = V_R = IR, where V_R is in phase with I

The voltage across L = V_L = IX_L, where V_L leads I by 90°

The voltage across C = V_C = IX_C, where V_C lags I by 90°

In the phasor diagram the voltages V_L and V_C are 180°out of phase with each other. V_L is greater in magnitude than V_C so the resultant voltage will be $(V_L - V_C)$.

The applied voltage V will be the phasor sum of the voltages V_R and $(V_L - V_C)$.

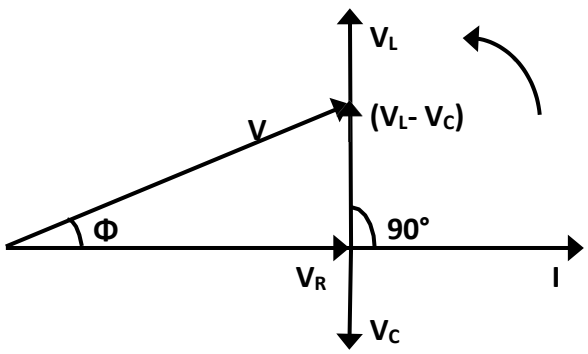
We have $V = \sqrt{V_R^2 + (V_L - V_C)^2} = \sqrt{IR^2 + (I_L - I_C)^2}$

$= I\sqrt{R^2 + (L - C)^2}$ or $I = \frac{V}{\sqrt{R^2 + (L - C)^2}}$

Or $I = \frac{V}{Z}$ where $Z = \sqrt{R^2 + (L - C)^2}$

From the phasor diagram, $tan = \frac{(V_L - V_C)}{V_R}$

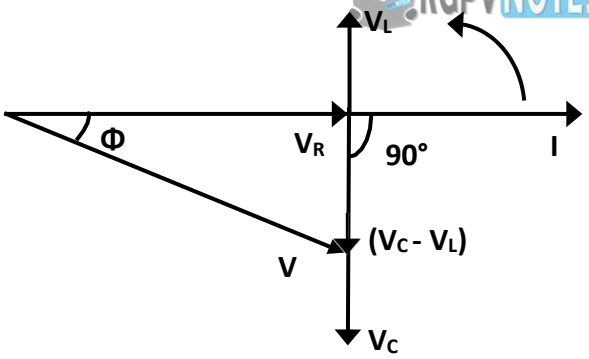
$= \frac{(I_L - I_C)}{IR} = \frac{(L - C)}{R}$ or $= tan^{-1}\frac{(L - C)}{R}$



PHASOR DIAGRAM FOR $X_L > X_C$

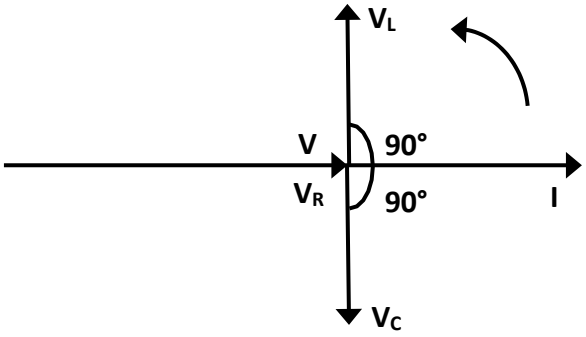
We have $Cos = \frac{R}{Z}$ **and** $P = VICos$ **or** $P = I^2R$

a) For the condition $X_L > X_C$ from the phasor diagram we find that the current lags the applied voltage by an angle Φ, which is greater than zero but less than 90°. So a series RLC circuit with $X_L > X_C$ behaves as a R-L series circuit.



PHASOR DIAGRAM FOR $X_C > X_L$

b) For the condition $X_C > X_L$ from the phasor diagram we find that the current leads the applied voltage by an angle Φ which is greater than zero but less than 90°. So a series RLC circuit with $X_C > X_L$ behaves as a R-C series circuit.



PHASOR DIAGRAM FOR $X_L = X_C$

c) For the condition $X_L = X_C$ from the phasor diagram we find that the current is in phase with the applied voltage, the phase angle between the current and applied voltage is zero. So the series RLC circuit with $X_L = X_C$ behaves as a pure R circuit. Hence a series R-L-C circuit can behave in three different ways depending upon the values of the Inductive and Capacitive reactances.

Necessity and advantages of three phase systems, Meaning of Phase sequence, balanced and unbalanced supply and loads. Relationship between line and phase values for balanced star and delta connections. Power in balanced and unbalanced three-phase systems and their measurement.Expression for power factor

THREE PHASE CIRCUITS

Necessity of three phase systems:

Three phase power is usually generated, transmitted and distributed as it has a large number of advantages. Three phase systems are widely used by electrical grids all over the world to transfer power. They are also used to power large motors and other heavy loads. Three phase systems are always adopted because they are very economical.

Advantages of three phase systems:

The advantages of three phase systems over single phase systems are:-

- **Three phase apparatus are smaller in size and lighter in weight than a single phase apparatus with same power output, which makes them cheaper.**
- **Three phase systems require only 75% of the weight of conducting material of that required by single phase systems to transmit the same amount of power.**
- **Parallel operation of three phase generators is simple when compared to that of single phase generators**
- **Output of a three phase machine is 1.5 times the output of a single phase machine of the same size.**
- **Three phase motors are self-starting but single phase motors are not self starting**
- **Three phase motors have better power factor and efficiency compared to single phase motors.**
- **In a single phase circuit, the power delivered is pulsating, whereas, in a three phase system, constant power is delivered when the loads are balanced.**
- **In a single phase system, the instantaneous power is not constant and is sinusoidal, which results in vibrations, but in a three phase system, the instantaneous power is always the same.**
- **Single phase supply can be managed from a three phase supply, but it is not possible to get a three phase supply from a single phase supply.**
- **Three phase supply can be rectified into dc supply with lesser ripple factor.**

Phase sequence: It is the order in which the voltages in the three coils reach their positive maximum values one after the other.

Balanced systems:

In a three phase circuit if all the impedances are equal then the circuit is called a balanced system. To a balanced circuit if balanced three phase voltage is applied the currents flowing shall also be balanced. The three phase voltages are equal in magnitude but 120° out of phase from each other and so are the three currents. The sum of all the phase currents or the phase voltages will be equal to zero.

Unbalanced systems:

The three phase systems can be unbalanced. The unbalance may be due to the unbalance in the supply or unbalance in the load. Sometimes both the supply and the load may be unbalanced.

In the analysis of unbalanced systems each phase has to be treated separately and the resultant can be obtained by their phasor representation. Let us consider a balanced supply system where the three phase voltages are : $V \angle 0°$, $V \angle 120°$, $V \angle 240°$**. Let the unbalanced impedances be :** $Z_1 \angle \theta_1°$, $Z_2 \angle \theta_2°$, $Z_3 \angle \theta_3°$ **respectively in the three phases.**

The current in each phase will be:

$$I_1 = \frac{V}{Z_1} \angle -_1 °; \quad I_2 = \frac{V}{Z_2} \angle 120-_2 °; \quad I_3 = \frac{V}{Z_3} \angle 240-_3°$$

<u>Star connection</u>: If similar ends of the three phase windings are joined together at a common point N, a star connection is obtained.

<u>Delta connection</u>: If dissimilar ends of the three phase windings are joined to form a closed loop, a delta connection is obtained.

<u>Relations in star connection</u>:

From the figure - 1, it is observed that, the current flowing in the phase winding of each phase = The current flowing in that respective line. Hence, Phase current = Line current or $I_{PH} = I_L$

Consider the lines R and Y, line voltage V_{RY} is the phasor difference of E_{RN} and E_{YN}. To subtract E_{YN} from E_{RN}, the phasor E_{YN} is reversed and the phasor sum with E_{RN} is obtained. The two phasors E_{RN} and $-E_{YN}$ are equal in magnitude and equal to $E_{PH}$and are 60° apart as observed in the phasor diagram shown in figure - 2.

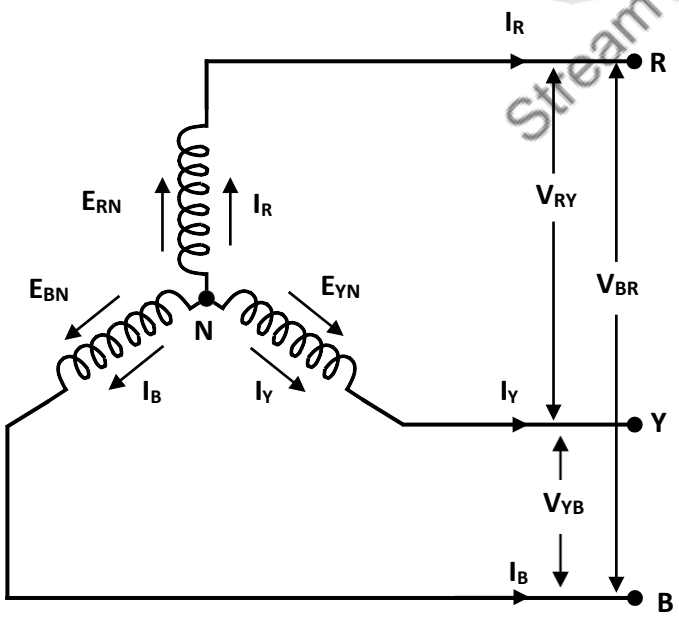


Fig. - 1

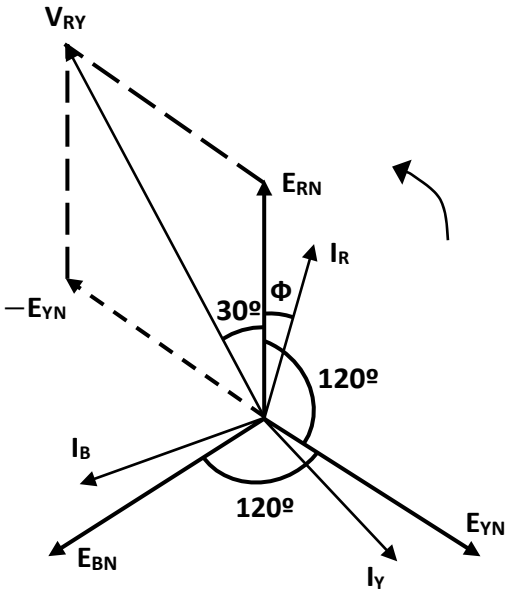


Fig. - 2

From the phasor diagram shown in figure - 2, we have

$$V_{RY} = 2E_{PH} Cos\left(\frac{0}{2}\right) = 2E_{PH}\, Cos30^{\circ} = \sqrt{3}E_{PH}$$

Similarly $V_{YB} = E_{YN} - E_{BN} = \sqrt{3}E_{PH} and V_{BR} = E_{BN} - E_{RN} = \sqrt{3}E_{PH}$

$\therefore V_L = \sqrt{3}V_{PH} and I_L = I_{PH}$

From figure - 2, it is observed that: The line voltages are 120º apart

The line voltages are 30º ahead of their respective phase voltages

The angle between the line currents and corresponding line voltages is (30 + Φ)

Power per phase = $V_{PH}I_{PH}Cos\Phi$ **; Total power =** $3V_{PH}I_{PH}Cos\Phi$

With line values, Total power = $\sqrt{3}V_LI_LCos\Phi$ **where Φ is the phase angle between** $V_{PH}andI_{PH}$

Relations in delta connection:

From the figure - 3, it is observed that one phase winding is included between any pair of lines.

Hence, the Line voltage = Phase voltage i.e. $V_L = V_{PH}$

The current in any line is equal to the phasor difference of the currents in the two phases attached to that line. Hence, the current in line R is the phasor difference of I_R and I_B. To subtract I_B from I_R, the phasor I_B is reversed and its phasor sum with I_R is obtained. The two phasors I_R and – I_B are equal in magnitude and equal to I_{PH} **and are 60° apart as observed in the phasor diagram shown in figure - 4.**

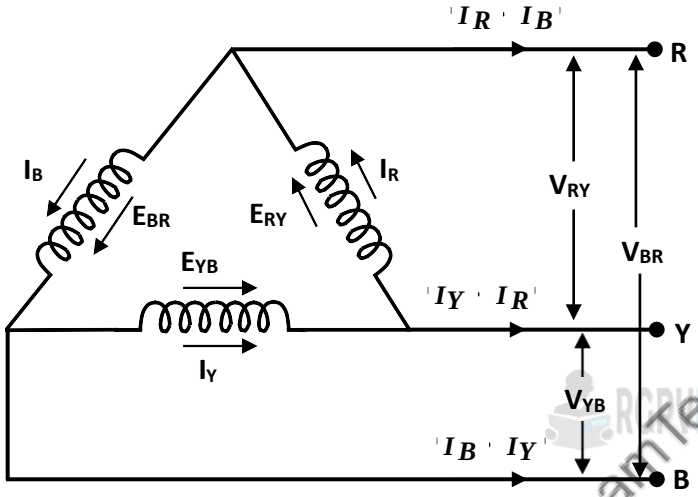


Fig. - 3

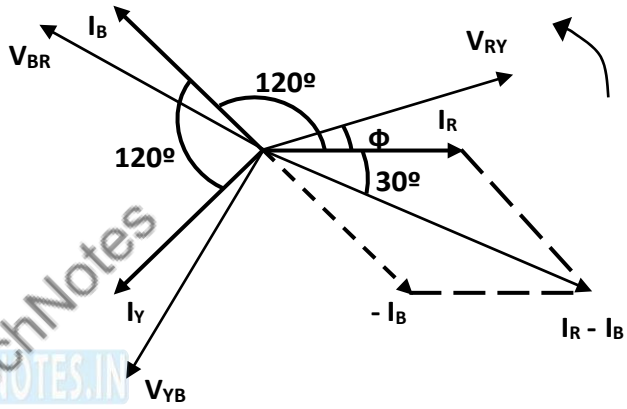


Fig. - 4

From the phasor diagram shown in figure - 4, we have

$$(I_R - I_B) = 2I_{PH}Cos\left(\frac{0}{2}\right) = 2I_{PH}Cos30^\circ = \sqrt{3}I_{PH}$$

Similarly $(I_Y - I_R) = \sqrt{3}I_{PH}and(I_B - I_Y) = \sqrt{3}I_{PH}$

$\therefore I_L = \sqrt{3}I_{PH}andV_L = V_{PH}$

From figure - 4, it is observed that: The line currents are 120º apart

The line currents are 30ºbehind their respective phase currents

The angle between the line currents and corresponding line voltages is (30 + Φ)

Power per phase = $V_{PH}I_{PH}Cos\Phi$ **; Total power =** $3V_{PH}I_{PH}Cos\Phi$

With line values, Total power = $\sqrt{3}V_LI_LCos\Phi$ **where Φ is the phase angle between** $V_{PH}andI_{PH}$

Measurement of three phase power using two wattmeter for Star connected load:

Let us consider the loads to be connected in star as shown in figure - 5. The current coils of the two wattmeters are connected in line R and line B. The potential coils of the wattmeters are connected across lines R and Y as well as lines B and Y.

Let the instantaneous values of potential difference across the loads be v_r , v_y , v_b and the corresponding values of instantaneous line currents be $_r$, $_y$, $_b$

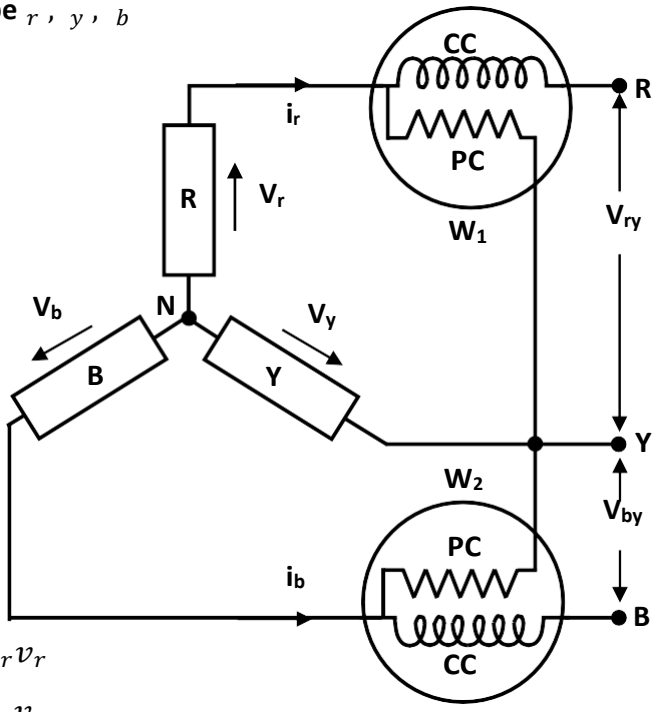


Fig. - 5

The instantaneous power in load R = $_r v_r$

The instantaneous power in load Y = $_y v_y$

The instantaneous power in load B = $_b v_b$

Total instantaneous power = $_r v_r + _y v_y + _b v_b$

From the figure - 5, it is observed that the instantaneous current through current coil of W_1 = $_r$ and the instantaneous potential difference across its potential coil = $(v_r - v_y)$

Instantaneous power measured by W_1 = $_r(v_r - v_y)$

Similarly the instantaneous current thro current coil of W_2 = $_b$ and the instantaneous potential difference across its potential coil = $(v_b - v_y)$

Instantaneous power measured by W_2 = $_b(v_b - v_y)$

$W_1 + W_2$ = $_r(v_r - v_y) + _b(v_b - v_y)$

or $W_1 + W_2$ = $_r v_r + _b v_b - v_y(_r + _b)$ ----------(1)

Applying KCL to the junction N shown in figure - 5, we get

$_r + _y + _b = 0$ or $(_r + _b) = -_y$ ---------- (2)

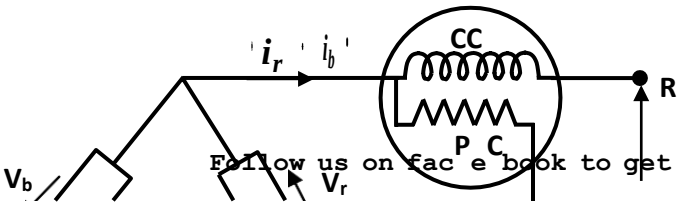
Introducing equation (2) in equation (1) we get,

$W_1 + W_2$ = $_r v_r + _y v_y + _b v_b$ which is equal to total instantaneous power consumed by a three phase star connected load.

<u>Measurement of three phase power using two wattmeter for Delta connected load</u>:

Let us consider the loads to be connected in delta as shown in figure - 6.

Let the instantaneous values of potential difference across the loads be v_r, v_y, v_b and the corresponding values of instantaneous phase currents be $_r$, $_y$, $_b$



The instantaneous power in load R = $_r v_r$

The instantaneous power in load Y = $_y v_y$

The instantaneous power in load B = $_b v_b$

Total instantaneous power = $_r v_r + \ _y v_y + \ _b v_b$

From the figure - 6, it is observed that the instantaneous current through current coil of W_1 = $(_r - _b)$ **and the instantaneous potential difference across its potential coil =** v_r

Instantaneous power measured by W_1 = $(_r - _b) v_r$

Similarly the instantaneous current through current coil of W_2 = $(_b - _y)$ **and the instantaneous potential difference across its potential coil =** $(-v_y)$

Instantaneous power measured by W_2 = $(_b - _y)(-v_y)$

$W_1 + W_2$ = $(_r - _b) v_r +$ **+** $(_b - _y)(-v_y)$

or $W_1 + W_2 = \ _r v_r + \ _y v_y - \ _b (v_r + v_y)$ **--- (1)**

Applying KVL to closed loop ABC in figure - 6, we get

$v_r + v_y + v_b = 0$ **or** $(v_r + v_y) = -v_b$ **--- (2)**

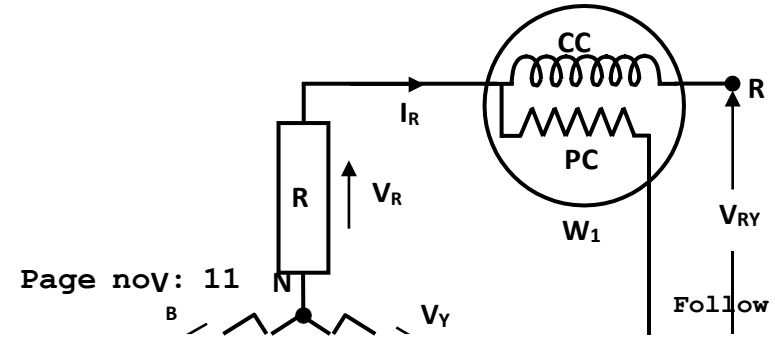
Introducing equation (2) in equation (1), we get

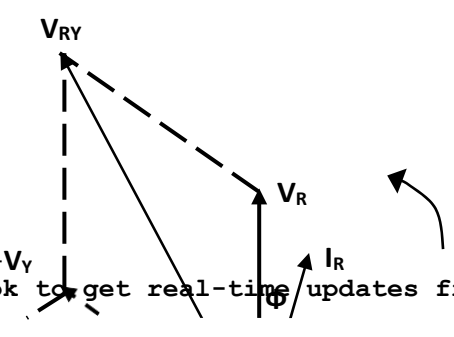
$W_1 + W_2$ = $_r v_r + \ _y v_y - \ _b (-v_b)$

$W_1 + W_2$ = $_r v_r + \ _y v_y + \ _b v_b$ **which is equal to total instantaneous power consumed by a three phase delta connected load.**

Expression for power factor in terms of wattmeter readings:

Let us consider a three phase balanced star connected load with a lagging phase angle Φ. Let V_R, V_Y and V_B be the rms values of phase voltages across the star connected load and I_R, I_Y and I_B be the phase currents.





Since the load has a lagging power factor, the phase currents lag their respective phase voltages by an angle Φ as shown in the phasor diagram. The power is measured using two wattmeters. The current through current coil of $W_1 = I_R$ and the potential difference across its potential coil = V_{RY}.

From the phasor diagram the phase angle between V_{RY} and $I_R = (30 + \Phi)$

- Reading of $W_1 = I_R V_{RY} \cos (30 + \Phi)$

The current through current coil of $W_2 = I_B$ and the potential difference across its potential coil = V_{BY}.

From the phasor diagram the phase angle between V_{BY} and $I_B = (30 - \Phi)$.

- Reading of $W_2 = I_B V_{BY} \cos (30 - \Phi)$

Since the load is balanced $I_R = I_Y = I_B = I_L$ and $V_{RY} = V_{BY} = V_{BR} = V_L$

- $W_1 = V_L I_L \cos (30 + \Phi)$ and $W_2 = V_L I_L \cos (30 - \Phi)$

$W_2 + W_1 = V_L I_L [\cos 30 \cos \Phi + \sin 30 \sin \Phi + \cos 30 \cos \Phi - \sin 30 \sin \Phi]$

$W_2 + W_1 = V_L I_L (2 \cos 30 \cos \Phi) = V_L I_L \left(2 \frac{\sqrt{3}}{2} \cos \Phi\right) = \sqrt{3} V_L I_L \cos \Phi$

- $W_2 + W_1$ = Total Three phase power. $W_2 + W_1 = \sqrt{3} V_L I_L \cos \Phi$ ---- (1)

$W_2 - W_1 = V_L I_L \cos (30 - \Phi) - V_L I_L \cos (30 + \Phi)$

$= V_L I_L [\cos 30 \cos \Phi + \sin 30 \sin \Phi - \cos 30 \cos \Phi + \sin 30 \sin \Phi]$

$= V_L I_L [2 \sin 30 \sin \Phi] = V_L I_L \left[2 \frac{1}{2} \sin \Phi\right] = V_L I_L \sin \Phi$ ------(2)

Dividing equation (2) by equation (1) we get

$$\frac{(W_2 - W_1)}{(W_2 + W_1)} = \frac{(V_L I_L \sin \phi)}{(\sqrt{3} V_L I_L \cos \phi)} = \frac{\tan \phi}{\sqrt{3}} \quad \text{or} \quad \tan \phi = \left(\sqrt{3} \frac{(W_2 - W_1)}{(W_2 + W_1)}\right)$$

$$\text{or} \quad \phi = \tan^{-1}\left(\sqrt{3} \frac{(W_2 - W_1)}{(W_2 + W_1)}\right) \qquad \cos \phi = \cos\left(\tan^{-1}\sqrt{3} \frac{(W_2 - W_1)}{(W_2 + W_1)}\right)$$

<u>Variation in wattmeter readings for lagging power factors:</u>

The wattmeter readings for lagging power factors will be -

$W_1 = V_L I_L \cos (30 + \Phi)$ and $W_2 = V_L I_L \cos (30 - \Phi)$

The phase angle Φ can be assumed to possess different values and the variation of the wattmeter readings can be observed.

Phase angle Φ	0°	60°	90°
Wattmeter reading W_1	+ ve	0	- ve
Wattmeter reading W_2	+ ve	+ ve	+ ve
	$W_1 = W_2$ for resistive loads		$W_1 = W_2$

Unit - III Magnetic Circuits - Syllabus

Basic definitions, Magnetization characteristics of Ferro magnetic materials, Magnetic field produced by current carrying conductor, Force on a current carrying conductor, AC excitation in magnetic circuits. Laws of electromagnetic Induction, induced voltage, direction of induced E.M.F, selfinductance and mutual inductance, energy in linear magnetic systems, Coils connected in series.

MAGNETIC CIRCUITS

Magnetic flux: The total number of flux lines coming out of the N-pole of a magnet is called the Magnetic flux. It is represented by Φand the unit is weber

Magnetic flux density: It is the number of flux lines passing through an unit area of cross section held perpendicular to the lines of flux. It is given by the expression $B = \Phi/A$ its unit is Wb/m^2

Magnetic field strength or Magnetic intensity or Magnetizing force: The magnetic field strength at any point within a magnetic field is given by the force experienced by a unit N-pole of one weber placed at that point. It is represented by H and the unit is Newton/weber

Absolute permeability: A magnetic material when placed in a magnetic field acquires magnetization due to induction. A measure of the degree to which the lines of force of the magnetizing field can penetrate the medium is called the absolute permeability of the medium.

It is also defined as the ratio of flux density in that material to the magnetizing force producing that flux density. It is given by $\mu = B/H$ and the unit is Henry/metre

It is also given by $\mu = \mu_o\mu_r$ where $\mu_o = 4\pi \times 10^{-7}$ Henry/metre

Relative permeability: It is given by the ratio of the flux density produced in that material to the flux density produced in vacuum by the same magnetizing force. It is given by $\mu_r = B/B_o$

Magneto motive force: It drives or tends to drive flux through a magnetic circuit orIt is also equal to the work done in joules in carrying a unit magnetic pole once through the entire magnetic circuit. Its unit is Ampere turns.

Reluctance: It is defined as the property of a material that opposes the creation of magnetic flux in it. It is a measure of the opposition offered to the passage of magnetic flux through a material. It is given by $S = l/\mu_o\mu_r A$or $S = mmf/\Phi$its unit is AT/Wb.

Permeance - It is the reciprocal of reluctance. It is defined as the property of a material that initiates the development of magnetic flux. It is given by, $Permeance = \Phi/mmf$ its unit is Wb/AT or Henry.

Relations in magnetic circuits:

$$We have, H = \frac{NI}{l} \ or \ NI = Hl \ ; \quad B = \mu_o\mu_r H \ or \ H = \frac{B}{\mu_o\mu_r} \ ; \quad B = \frac{\Phi}{A} \ ; \quad NI = \frac{B}{\mu_o\mu_r} \times l$$

$$Amp.turns \ for \ any \ material, AT_M = \frac{B}{\mu_o\mu_r} \times l_M \ ; \ Amp.turns \ for \ airgap, AT_G = \frac{B}{\mu_o} \times l_G$$

Leakage flux: Whenever a magnetic material is magnetized flux lines are produced in the material. The flux lines existing in the material and the air gap is called Useful fluxΦ_U. The flux lines not existing in the

material and existing around the coil wound on the magnetic material is called leakage flux Φ_L. Leakage flux is the flux that follows a path not intended for it. The total flux produced by the solenoid $\Phi = \Phi_U + \Phi_L$. The ratio of total flux produced by the solenoid to the useful flux set up in the material and air gap is known as leakage co: efficient. It is given by $\lambda = \Phi/\Phi_U$ and its value is more than 1.

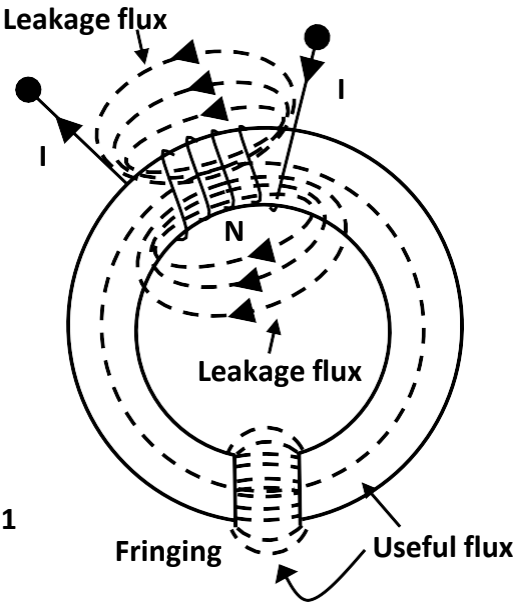


Fig. - 1

Fringing is the bulging of the magnetic flux lines in the air gap of a magnetic material. This increases the effective area in the air gap and decreases the flux density. Every magnetic material with air gaps suffer from the problem of fringing. Fringing is directly proportional to the length of the air gap. Fig.-1 shows a magnetic circuit with mmf (NI), Total flux, Useful flux and Leakage flux. The effect of Fringing is also shown in the air gap of the magnetic material.

<u>Series magnetic circuit</u>:

A magnetic circuit that is made up of a number of magnetic materials of different cross sectional areas, of different lengths, of different relative permeability along with an air gap carrying the same value of flux represents a series magnetic circuit. This magnetic circuit will have only one path for the magnetic flux.

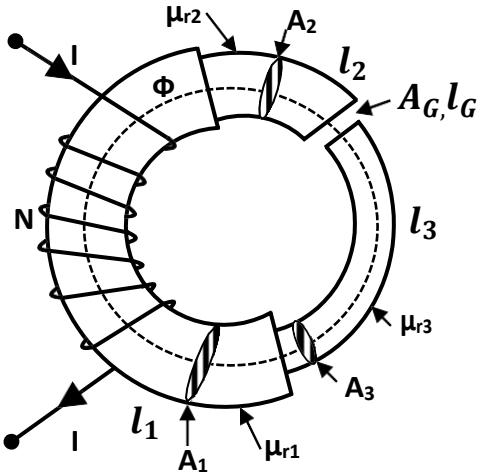


Fig. - 2

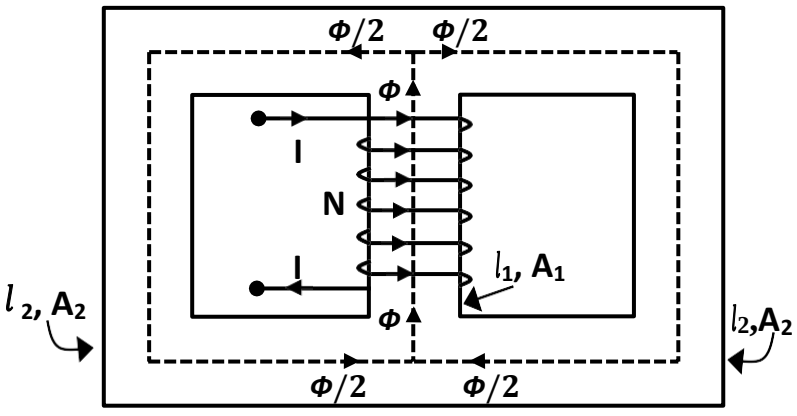


Fig. - 3

A series magnetic circuit made of three parts is as shown in fig. -2. The total ampere turns required for the magnetic circuit will be equal to the sum of all the ampere turns required for each of the magnetic material as well as the air gap. Total AT = $AT_1 + AT_2 + AT_3 + AT_G$

Parallel magnetic circuit:

A magnetic circuit that has two or more than two paths for the magnetic flux is called a parallel magnetic circuit. In these circuits the value of flux will not be the same in all the parts of the magnetic circuit. A parallel magnetic circuit can also have an air gap in the central limb or in the side limbs or in all the limbs. A simple parallel magnetic circuit is as shown in fig. - 3. The total ampere turns required for the magnetic circuit will be equal to the sum of the ampere turns required for the central limb and the ampere turns required for one of the side limbs. It indicates that the ampere turns required for one side limb is capable of driving flux in both the side limbs.

Total AT = Ampere turns required for central limb + Ampere turns required for any one side limb.

Total AT = $AT_C + AT_S$

Magnetization characteristics of Ferromagnetic materials:

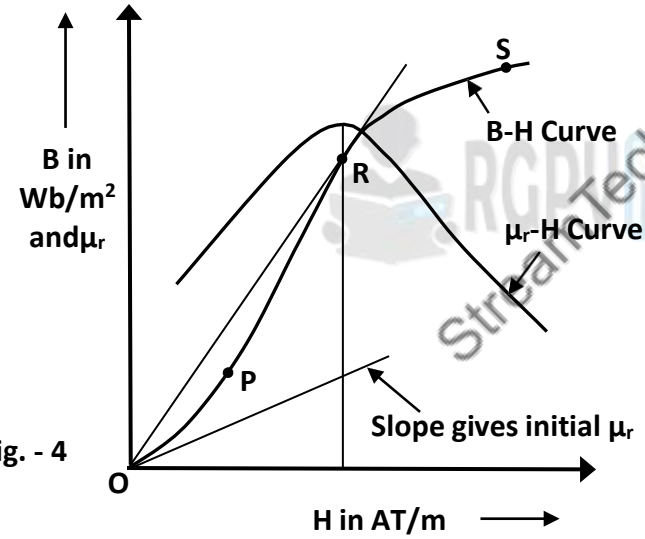


Fig. - 4

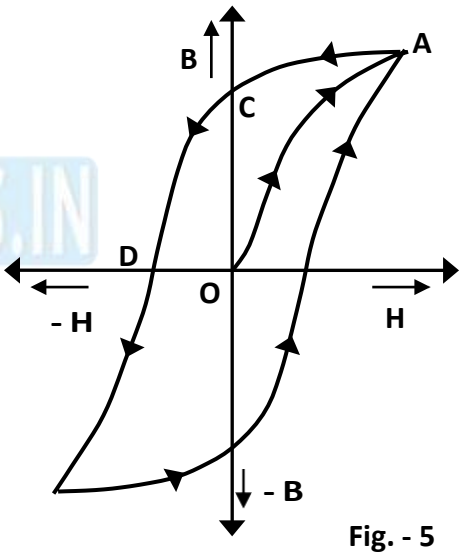


Fig. - 5

When an iron specimen is subjected to an increasing value of magnetizing force, H and the corresponding values of flux density B plotted against H helps in realizing the B-H curve shown in fig.-4. Using the relation $\mu_r = B/\mu_o H$the curve of relative permeability μ_r against H may be obtained from the plotted magnetisation characteristics. From the $\mu_r - H$ curve it is observed that the value of μ_r varies considerably with the value of H that helps in ascertaining the value of operating flux density. The B-H curve obtained can be divided into three regions - initial region OP, middle region PR and the region beyond R. The curve near the origin is nearly a straight line through the origin and the slope yields the value of initial permeability. The value of H at which the curve begins to bend varies over a wide range from material to material. In the middle region, increase in a small value of H will have a very large increase in the value of B. The slope is the greatest and the maximum value of permeability is within this region. At point R the tangent to the curve passes through the origin, where μ_r has its maximum value. In the region beyond R,

any further increase in the value of H will have a small change in the value of B. The curve indicates the extent of magnetization due to the increase in value of H. The curve beyond point S shows that any further increase in the value of H will not have any variation in the value of B indicating the magnetic saturation of the material.

Hysteresis: Whenever an iron bar is taken through one cycle of magnetization a Hysteresis loop shown in fig. - 5 is traced. The area of the loop represents the total energy spent in taking the iron bar through one cycle of magnetization. The Hysteresis loop is a plot of B and H, it is also defined as the lagging of flux density B behind the magnetizing force H. When H is increased initially the curve OA is traced and the iron bar gets magnetically saturated. As and when H is decreased B also decreases. But when H is zero the value of B is not zero. The distance OC on the Y-axis represents the Residual flux density B_r . The value of flux density B_r measures the retentivity of the material. To demagnetize the iron bar, we have to apply the magnetising force in the reverse direction. When H is reversed the value of B is reduced to zero at point D. The distance OD on the X-axis represents the Coercive force H_C . The value of H required to eliminate the residual magnetism is known as Coercive force and is a measure of the Coercivity of the material. Fig.-5 shows a Hysteresis loop traced for an iron bar taken through one cycle of magnetization.

Magnetic field produced by a current carrying conductor:

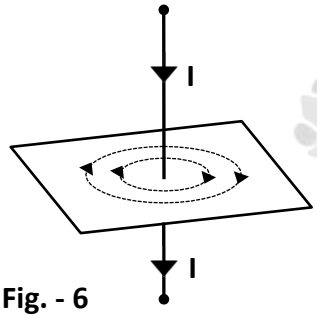


Fig. - 6

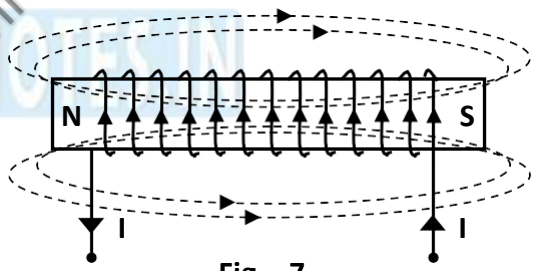


Fig. - 7

Let us consider a conductor passing through a card board as shown in fig.- 6, let a current I flow through it from top to the bottom. A magnetic compass when placed close to the wire has its needle pointing in a specific direction. The points of the needle are marked by moving the magnetic compass around the current carrying conductor. All the points when joined together appear in the form of a circle showing the existence of flux lines around the current carrying conductor. This simple experiment shows that a current carrying conductor will always have a magnetic field created around it. The Right hand thumb rule helps us to find out the direction of flux lines created around the current carrying conductor. If the current carrying conductor is grasped by the right hand such that the thumb held perpendicular to all the fingers points to the direction of current flow, then the fingers curled around the conductor points to the direction of magnetic flux around it.

Right hand thumb rule can also be applied to a coil wound around a magnetic material and carrying current as shown in fig.-7. If the coil is grasped by the right hand such that the four fingers curl around the coil

pointing to the direction of current flow, the thumb held perpendicular to the four fingers points to the N-pole of the magnetic material.

Force on a current carrying conductor placed in a magnetic field:

Let us consider a current carrying conductor placed in a magnetic field of a permanent magnet. The flux lines produced by the magnet come out of the N pole and end up at the S pole. The flux lines of the magnetic field created by the current carrying conductor are in a circular form, aiding certain flux lines and opposing certain flux lines of the magnetic field of the magnet as shown in fig. - 8. The side on which the flux is aided becomes stronger and the side on which the flux gets opposed becomes weaker. The current carrying conductor is pushed from the side which has a stronger flux towards the side which has a weaker flux. Hence, due to the interaction between the two fluxes, a mechanical force is experienced by the current carrying conductor as shown in fig. - 9. The direction of the mechanical force experienced by the current carrying conductor placed in a magnetic field can be determined by Fleming's left hand rule.

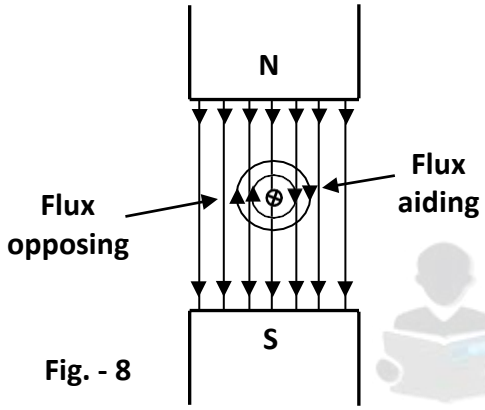


Fig. - 8

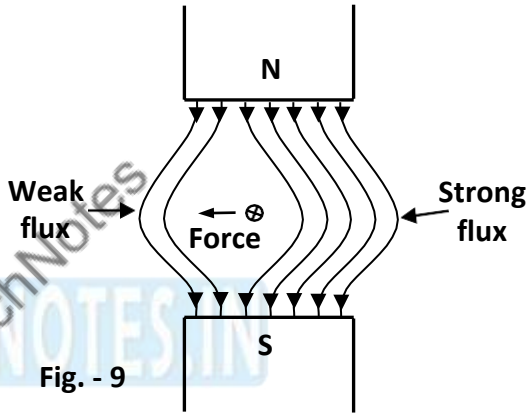


Fig. - 9

AC excitation of Magnetic circuit: A magnetic circuit with input given from an AC supply is called an AC magnetic circuit. Fig. - 10 shows a circular iron core wound with a coil of N turns. An alternating current, $i = I_m Sin mt$ flowing through the coil, creates an alternating flux Φ. As the current through the coil is sinusoidal in nature the flux created is also sinusoidal in nature varying with time.

The flux produced is given by $\Phi = \Phi_m Sin mt$

When the changing flux Φ links with N number of turns of the coil, emf is induced in the coil given by,

$e = -N\frac{d\Phi}{dt} = -N\frac{d}{dt}(\Phi_m Sin mt)$

$= -Nm\Phi_m Cos mt = Nm\Phi_m(Sin mt - 90°)$

Maximum value of induced emf, $E_m = Nm\Phi_m$

$\therefore e = E_m(Sin mt - 90°)$

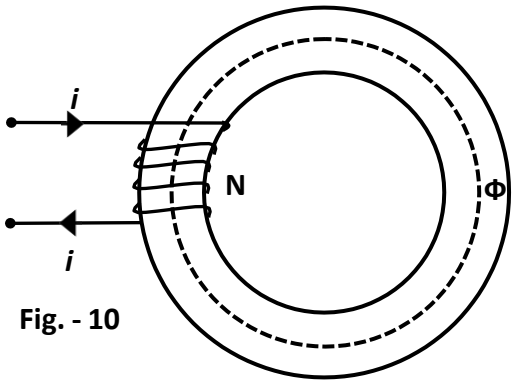


Fig. - 10

Electromagnetism: The phenomenon whereby an emf and hence current is induced in any conductor which is cut across or is cut by a magnetic flux is known as Electromagnetic induction.

Faraday's laws of electromagnetic induction - First law: Whenever the flux linked with a circuit changes, an emf is always induced in it or whenever a conductor cuts across magnetic field lines, an emf is induced in that conductor.

Second law: The magnitude of the induced emf is equal to the rate of change of flux linkages.

$$e = -N\frac{d\Phi}{dt} volts$$

The first law explains the phenomenon of Electromagnetic induction and the second law helps us to ascertain its magnitude.

Lenz's law: The direction of induced emf is always such that it tends to set up a current opposing the motion or the change of flux responsible for inducing that emf or The direction of induced emf is such as to oppose the very cause producing it.

Lenz's law helps us to ascertain the direction of the induced emf (statically)

Fleming's right hand rule: If the first finger of the right hand be pointed in the direction of the magnetic flux and if the thumb be pointed in the direction of motion of the conductor relative to the magnetic field, then the second finger held at right angles to both the thumb and the first finger, represents the direction of induced emf.

Fleming's right hand rule helps us to ascertain the direction of the dynamically induced emf

Fleming's left hand rule: If the first finger of the left hand be pointed in the direction of the magnetic flux and the second finger points in the direction of the current, then the thumb held at right angles to the first finger and second finger, would point in the direction of the mechanical force produced on the current carrying conductor.

Fleming's left hand rule helps us to find out the direction of the force experienced by a current carrying conductor when placed in a magnetic field.

Induced emf's: Electro magnetically induced emf's are of two types - Statically induced emf and Dynamically induced emf

Dynamically induced emf: Whenever a moving conductor cuts across magnetic flux lines, an emf is induced in the conductor called as dynamically induced emf or when a stationary conductor is cut by a rotating magnetic field, an emf is induced in the conductor.

This is observed in D.C and A.C. Generators.

If the conductor cuts the flux at right angles then the dynamically induced emf, $e = Blv$ volts and If the conductor moves at an angle θ with the direction of the lines of flux, then the dynamically induced emf, $e = BlvSin\theta$ volts

Statically induced emf: Whenever a changing flux links with a stationary coil, an emf is induced in the coil called as statically induced emf. This is observed in Transformers.

$$Statically\ induced\ emf, \quad e = -N\frac{d\Phi}{dt} volts$$

Statically induced emf's are of two types - Self induced emf and Mutually induced emf

Self induced emf: This is the emf induced in a coil due to the change of its own flux linked with it.

$$We\ have\ self\ induced\ emf, \quad e_L = L\frac{dI}{dt}\text{volts}$$

Mutually induced emf: This is the emf induced in one coil by the influence of another coil.

$$We\ have\ mutually\ induced\ emf, \quad e_M = M\frac{dI_1}{dt}volts$$

Self inductance: The property of a coil by virtue of which an emf is induced in it, whenever a changing current flows through it is called as self Inductance or The property of a coil due to which it opposes any change of current through it is known as self inductance. Its unit is Henry

$$We\ have\ self\ inductance, \quad L = \frac{N\Phi}{I} \ \ or \ \ L = \frac{\mu_o\mu_r AN^2}{l} \ \ or \ \ e_L = L\frac{dI}{dt}$$

Mutual inductance: It is the ability of one coil to produce an emf in a nearby coil by induction when the current in the first coil changes. This action is reciprocal. Its unit is Henry.

$$We\ have\ mutual\ inductance, \quad M = \frac{N_2\Phi_1}{I_1} \ \ or \ \ M = \frac{\mu_o\mu_r AN_1N_2}{l} \ \ or \ \ e_M = M\frac{dI_1}{dt}$$

Energy stored in a Magnetic field: The energy stored in a magnetic field is given by the expression,

$$E = \frac{1}{2}LI^2\ Joules\ ;\ \ wehave,\ L = \frac{N\Phi}{I} \ \ \therefore E = \frac{1}{2}N\Phi I \ \ Also,\ NI = H \times l \ and \ \ \Phi = B \times A$$

$$\therefore E = \frac{1}{2}(H \times l)(B \times A) \ = \ \frac{1}{2}BHV \ \ Joules \ \ where\ V\ is\ the\ volume\ of\ magnetic\ material$$

Coils connected in Series:

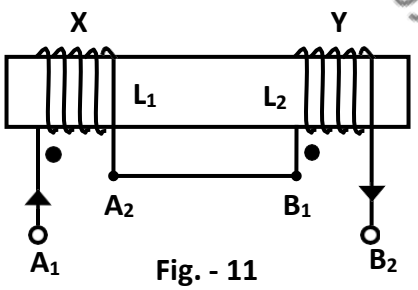


Fig. - 11

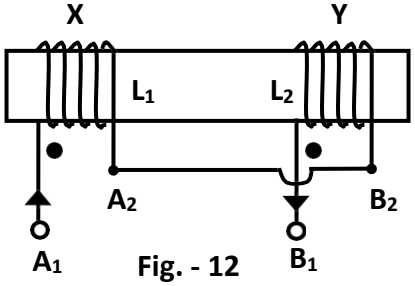


Fig. - 12

Let us consider two coils X and Y wound coaxially on an insulating cylinder with self inductances L_1 and L_2 Henry respectively and mutual inductance M Henry. Let the terminals A_2 and B_1 be joined together as shown in fig.-11. As per the dot convention as the currents are entering the dot, the fluxes produced in the coils are in the same direction and the coils are said to be cumulatively coupled. Hence, the equivalent self inductance L_A is given by $L_A = L_1 + L_2 + 2M$

Next, let the terminals A_2 and B_2 be joined together as shown in fig.-12. As per the dot convention, the fluxes produced in the coils are in opposition and the coils are said to be differentially coupled. Hence, the equivalent self inductance L_B is given by $L_B = L_1 + L_2 - 2M$

From the equations obtained for L_A and L_B, the value of Mutual inductance, $M = L_A - L_B/4$

Single phase transformer - Syllabus

General construction, working principle, emf equation, phasor diagram, equivalent circuits, voltage regulation, losses and efficiency, open circuit and short circuit test.

Transformer

A transformer is a stationary electrical apparatus that transfers power from one circuit to another by induction. It is the only A.C. machine that possesses the highest possible efficiency.

Construction: A transformer mainly consists of two windings and a laminated core with insulation. The winding connected to the supply is called primary winding and the winding connected to the load is called secondary winding. The winding made on the laminated core has a specific number of turns of copper conductors insulated from each other and from the core. The copper conductor can be of different cross sections. The core is made up of silicon steel laminations that are normally 0.3 to 0.6 mm thick. The laminations are insulated from each other by a thick coat of varnish. A bunch of laminations put together forms the core that are held together by bolts and nuts or riveted. High silicon content steel has a high relative permeability and low coefficient of Hysteresis. The use of high silicon content steel reduces hysteresis loss and by laminating the core the eddy current loss is minimized. The cores may be of different shapes. Depending on the shape of the core, we have core type transformers and shell type transformers. The figures show the magnetic cores used for shell type and core type transformers.

Core type: This type of core has a single window as shown in fig.-1 and the windingssurround a considerable part of the core. The coils are of cylindrical type and are wound in helical layers. Each layer is insulated from theother by insulating paper. The windings are always interleaved toreduce leakage flux i.e.half the primary and half the secondary on one limb and the other halves on the other limb. The LV winding is always placed close to the core and the HV winding is made above LV winding. The individual laminations of the core may be a single piece or it may be made up of two pieces.

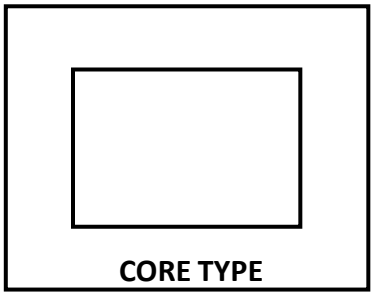


Fig. - 1

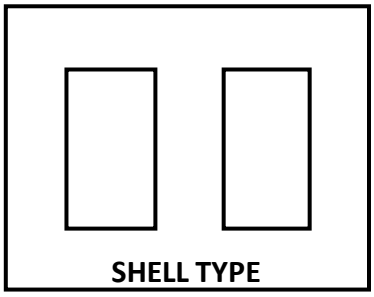


Fig. - 2

Shell type: This type of core has two windows as shown in fig. -2 and the core surrounds a considerable part of the winding. The individual laminations are usually made up of two pieces. The windings are always placed only on the central limb. Usually the HV winding is placed at the center and the LV winding is distributed equally on either sides of the HV winding. This type of winding is called Sandwich winding.

Principle of operation: The basic principle of operation of transformers is based on Faraday's laws of electromagnetic induction. The transformer has two windings wound on a laminated steel core. When AC supply is given to the primary winding, current flows through the primary winding producing a magnetic

flux that is alternating in nature. As the magnetic field lines always form a closed loop the flux produced exists in the steel core. The flux that exists in the core links the primary as well as secondary winding. Therefore according to Faraday's law both the windings get emf induced in them.

Emf equation: Let an AC voltage V_1 of supply frequency f be applied to the primary winding.

The sinusoidal flux produced by the primary will be $\Phi = \Phi_m Sin mt$

$$The\ instantaneous\ value\ of\ emf\ induced\ in\ primary, e_1 = -N_1 \frac{d\Phi}{dt} = -N_1 \frac{d}{dt}(\Phi_m Sin mt)$$

$$e_1 = -mN_1\Phi_m Cos mt \quad = -2\pi f N_1 \Phi_m Cos mt \quad \therefore e_1 = 2\pi f N_1 \Phi_m Sin(mt - 90°)$$

From the above equation, the maximum value of induced emf in primary is $E_{m1} = 2\pi f N_1 \Phi_m$

The rms value of the primary emf $= E_1 = 0.707 E_{m1} \quad \therefore E_1 = 0.707 \times 2\pi f N_1 \Phi_m \quad = 4.44 f N_1 \Phi_m$

$E_1 = 4.44 f N_1 \Phi_m$ and $E_2 = 4.44 f N_2 \Phi_m$

Transformation ratios: Considering an ideal transformer, we have $V_1 = V_2$ and $E_1 = E_2$

The ratio of secondary voltage to primary voltage is called voltage transformation ratio.

It is represented by K and is also called as the turns ratio $V_2 = KV_1$

$$The\ voltage\ transformation\ ratio, \quad K = \frac{V_2}{V_1} = \frac{E_2}{E_1} = \frac{N_2}{N_1}$$

In an ideal transformer, we also have, Output = Input or $V_2 I_2 = V_1 I_1$

$$\therefore \frac{I_2}{I_1} = \frac{V_1}{V_2} = \frac{E_1}{E_2} = \frac{N_1}{N_2} = \frac{1}{K} \quad or \quad I_2 = \frac{I_1}{K}$$

Hence,the currents are in the inverse ratio of the voltage transformation ratio.

Transformer on no-load: If the primary winding is applied with an AC supply voltage V_1 and the secondary winding is kept open, then the transformer is considered to be on no-load. Due to the applied voltage V_1, an alternating current I_O flows in the primary that creates an alternating flux ϕ.

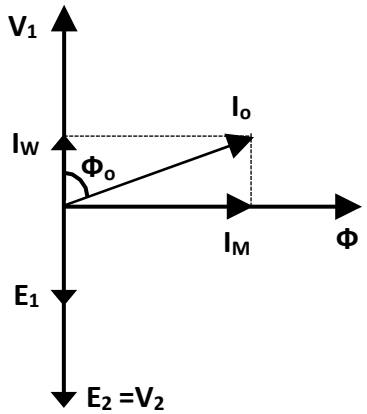


Fig. - 3

The applied voltage to the primary leads the flux by 90°. This flux that exists in the magnetic core links with the primary and secondary windings to induce emf's E_1 and E_2 that lag the flux by 90°.As there is no voltage drop in the secondary winding, $E_2 = V_2$. The no-load current I_O,also called as exciting current of the transformer lags the applied voltage V_1 by an angle ϕ_o. It is observed in fig. - 3, that the no-load current I_O has two components - I_M is the magnetising component that produces the desired flux in the core and is in

phase with the flux ϕ. The other component I_W is called the working component or iron loss component that overcomes the hysteresis and eddy current losses occurring in the core. This component of the current is in phase with the applied voltage.

We have the magnetising component of the no-load current, $I_M = I_O \sin\phi_o$

and the working component of the no-load current, $I_W = I_O \cos\phi_o$

The no-load current, $I_O = \sqrt{I_M^2 + I_W^2}$; The input power on no-load, $W_O = V_1 I_O \cos\phi_o$

The no-load power factor, $\cos\phi_o = \dfrac{W_O}{V_1 I_O}$

Transformer on load : Whenever some variety of load is connected across the secondary winding of the transformer, the transformer is said to be on load. The load may be resistive, R-L or R-C. As the primary and secondary windings are made on the magnetic core using copper wires, let us assume that they possess a resistance of R_1 and R_2 respectively. The leakage flux in the primary winding varies linearly with the primary current and that in the secondary winding varies linearly with the secondary current. These leakage fluxes may be simulated by assigning primary and secondary leakage inductances along with the respective winding resistances. Let the reactance corresponding to the leakage inductance of primary and secondary be represented by X_1 and X_2. Fig. - 4, represents the circuit of a transformer with its winding resistance and leakage reactance.

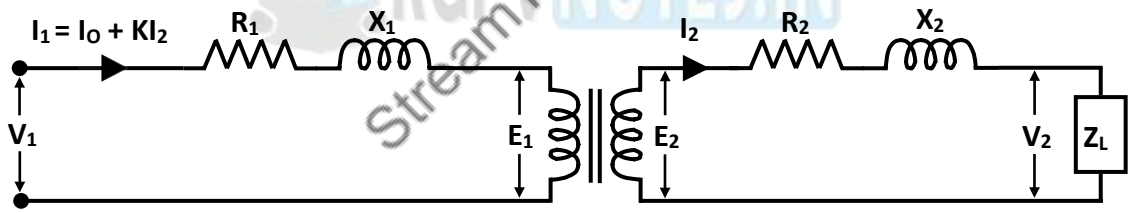


Fig. - 4

The value of R_1 and X_1 cause a voltage drop so that E_1 will be less than V_1. Similarly, V_2 is less than E_2 due to R_2 and X_2. Considering an R-L load, the current I_2 lags V_2 by an angle ϕ_2. The primary current I_1 has two components, the no-load current I_O and the current I_1^1 that neutralizes the demagnetizing effect of the secondary current I_2. The additional mmf's due to the load currents in the secondary and primary windings create fluxes which cancel each other, leaving the original flux ϕ.

The magnitude of I_1^1 will be such that $N_1 I_1^1 = N_2 I_2$

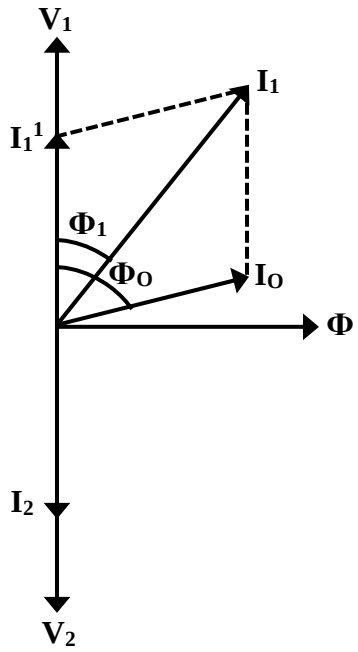
or $I_1^1 = \dfrac{N_2}{N_1} I_2 = KI_2$

The primary current on load, $I_1 = I_O + I_1^1$

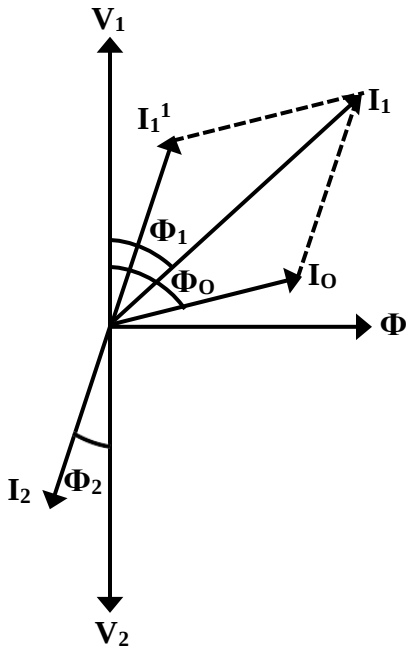
$\therefore \quad V_1 = -E_1 + I_1 Z_1$

and $V_2 = E_2 - I_2 Z_2$

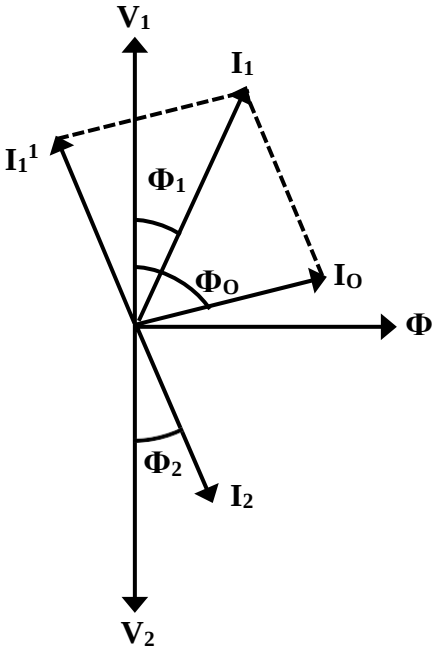
The phasor diagram for the working of a transformer with different varieties of loads are shown below -



PHASOR DIAGRAM FOR TRANSFORMER WITH RESISTIVE LOAD
Fig. - 5



PHASOR DIAGRAM FOR TRANSFORMER WITH R-L LOAD
Fig. - 6



PHASOR DIAGRAM FOR TRANSFORMER WITH R-C LOAD
Fig. - 7

The applied voltage V_1 leads the magnetic flux ϕ by 90° and the secondary voltage V_2 is equal and opposite toV_1. Let a R-L load be considered which draws a secondary current I_2 lagging V_2 by an angle ϕ_2 The current I_1^1 represents the primary current that neutralizes the demagnetizing effect of secondary current I_2. But $I_1^1 = KI_2$ is opposite to I_2. I_O is the no-load current of the transformer which lags the applied voltage by an angle ϕ_O . The primary current I_1 is the phasor sum of I_O and I_1^1 which lags the applied voltage V_1 by an angle ϕ_1. The load power factor = Cos ϕ_2 , The primary power factor = Cos ϕ_1

The input power to the transformer, $P_1 = V_1 I_1 \cos\phi_1$

The output power of the transformer, $P_2 = V_2 I_2 \cos\phi_2$

The phasor diagram for a transformer with resistive load is shown in fig.- 5, and phasor diagram for a transformer with R-L load is shown in fig.- 6. The phasor diagram for a transformer with R-C load is shown in fig.- 7.

<u>Equivalent circuit of transformer</u>:

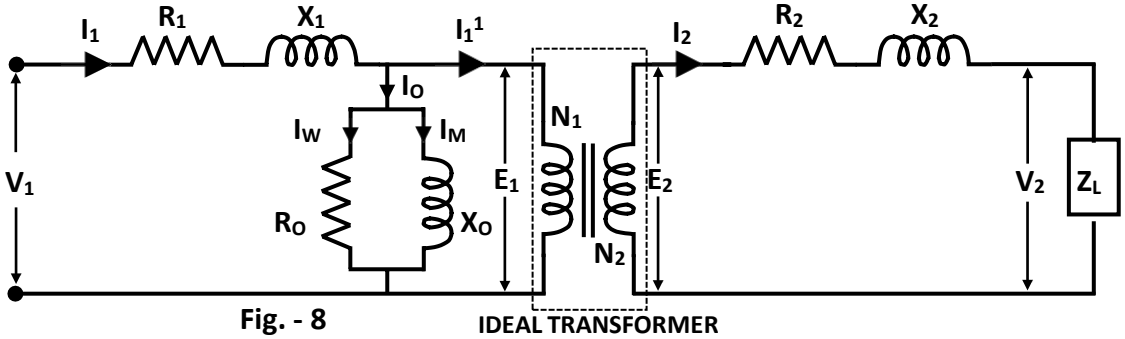


Fig. - 8 IDEAL TRANSFORMER

An actual transformer has two electric circuits linked by a magnetic circuit. To simplify calculations, a transformer is often represented by its equivalent circuit as shown in fig. - 8.The effects of the core and the windings are represented by equivalent basic circuit elements and the transformer gets reduced to a simple circuit. An equivalent circuit is merely a circuit interpretation of the equations that describe the behavior of the device. The transformer windings are shown as ideal. The resistance and leakage reactance of the primary and secondary are shown separately in the primary and secondary circuits. The effect of magnetising current is represented by a reactance X_O connected in parallel across the winding. The effect of core loss is represented by a non-inductive resistance R_O. The no-load current I_O in a transformer is only 1 to 3 % of its rated primary current; hence, it may be neglected, as it is not going to cause any serious error.

Approximate equivalent circuit of transformer: If theno-load current is neglected, we get the approximate equivalent circuit of the transformer. The equivalent circuit can be simplified by transferring the secondary resistance and reactance to the primary side in such a way that the ratio of E_2 to E_1 is not affected in magnitude or phase. If all the secondary quantities are referred to the primary, resistance and reactance are divided by K^2, voltages are divided by K and currents are multiplied by K.

We get the equivalent circuit of the transformer referred to primary as shown in fig. - 9.

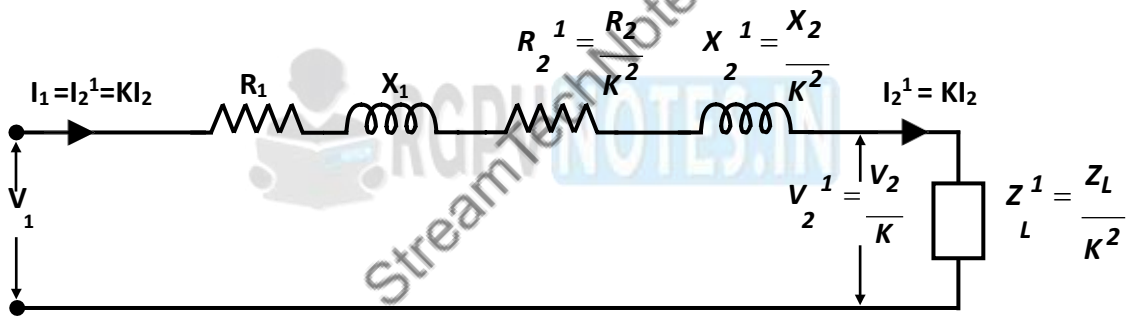


Fig. - 9

If all the primary quantities are referred to secondary, we get the equivalent circuit of the transformer referred to secondary. When primary quantities are referred to secondary, resistance and reactance are multiplied by K^2, voltages are multiplied by K and currents are divided by K.

Voltage regulation of a transformer: It is defined as the change in the output terminal voltage of the transformer from no-load to load condition, expressed as a fraction or percentage of the no-load terminal voltage.

$$\% \text{ Voltage Regulation} = \frac{oV_2 - V_2}{oV_2} \times 100$$

Where $oV_2$is the no-load secondary voltage and $V_2$is the secondary voltage on load.

Losses in transformer: The losses occurring in a transformer are of two types-

1. **Iron loss**
2. **Copper loss.**

These losses appear in the form of heat and produce an increase of temperature and drop in efficiency.

Core or Iron Losses: It comprises of Hysteresis and Eddy current losses and occur in the transformer core due to the alternating flux. We have Hysteresis loss = $P_h = K_h B_m^{1.6} f V$ watts,

and Eddy current loss = $P_e = K_e B_m^2 t^2 f^2 V$ watts

Where K_h and Ke are constants, 'f' is the frequency of the supply, 'B_m' is the Maximum flux density in the core, 'V' is the volume of magnetic material and 't' is the thickness of the lamination.

Both the losses depend on frequency and maximum flux density in the core. Since transformers are connected to constant frequency and constant supply voltage, both 'f' and 'B_m' are constant. Hence, core or iron losses are practically the same at all loads.

Iron or core losses, P_i = Hysteresis loss + Eddy current loss = Constant losses.

Copper losses: These losses occur both in primary and secondary windings due to their ohmic resistance.

Copper loss = $P_c = I_1^2 R_1 + I_2^2 R_2$ = Variable losses

Where I_1 = Primary current, R_1 = Resistance of primary winding, I_2 = Secondary current,

R_2 = Resistance of secondary winding.

Total loss in Transformer = Iron loss + Copper loss = Constant loss + Variable loss = $P_i + P_c$

Efficiency of Transformer:

The efficiency of a transformer is defined as the ratio of out put power to the input power.

$$\therefore \text{Efficiency} = \frac{\text{Output power}}{\text{Input power}} = \frac{\text{Output}}{\text{Output} + \text{Losses}} \quad \text{or} \quad \text{Efficiency } \eta_x = \frac{x.KVA.Cos\phi}{x.KVA.Cos\phi + P_i + x^2 P_c}$$

Where KVA is the out put power rating of the transformer and 'x' is load factor,

x = 1 for Full load, x = 0.5 for Half full load and x = 0.25 for Quarter full load.

As Iron losses are independent of load they are considered as constant.

As Copper losses are proportional to the square of the load current, the copper losses = $x^2 P_c$

$$\% \ \eta_x = \frac{x.KVA.Cos\phi}{(x.KVA.Cos\phi) + P_i + x^2 P_c} \times 100$$

Transformer tests: The efficiency and voltage regulation of a transformer can be determined by two simple tests - Open circuit test and Short circuit test. These tests provide the required information using which the performance of the transformer can be ascertained without actually loading the transformer.

Open circuit test or no-load test: In this test the secondary winding is kept open and the rated voltage of the transformer is applied to its primary winding. The voltmeter measures the applied voltage V_1. The ammeter measures the no-load current I_O . The wattmeter measures the no-load input power W_O . As the no-load current is very small and flows only in the primary, the copper losses due to it are negligible. Hence, the wattmeter reading practically gives the iron losses in the transformer.The circuit connection to perform this test is shown in fig. - 10.

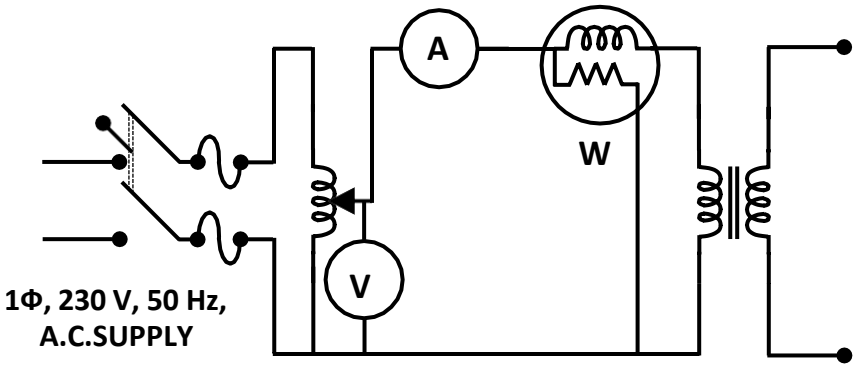


Fig. - 10

The input power on no-load = Iron losses = $P_i = W_O = V_1 I_O Cos\Phi_O$

$$No\ load\ power factor, \quad Cos\Phi_O = \frac{W_O}{V_1 I_O}$$

Magnetising component of the no-load current, $I_M = I_O Sin\Phi_O$

Working component of the no-load current, $I_W = I_O Cos\Phi_O$

$$Core\ loss\ component\ resistance, \quad R_O = \frac{V_1}{I_W} \quad ; \quad Magnetising\ Reactance, \quad X_O = \frac{V_1}{I_M}$$

<u>Short circuit or Impedance test</u>: In this test the secondary winding is short circuited and the voltage across the primary winding is adjusted such that the rated current flows through the primary winding. The voltmeter measures the applied voltage V_{1SC}. The ammeter measures the full load primary current I_1. As the applied voltage is very small the iron losses in the core will be negligible. Under short circuit condition there is no output from the transformer. Hence, the wattmeter measures the full load copper losses W_S in the transformer windings. The circuit connection to perform this test is shown in fig. - 11

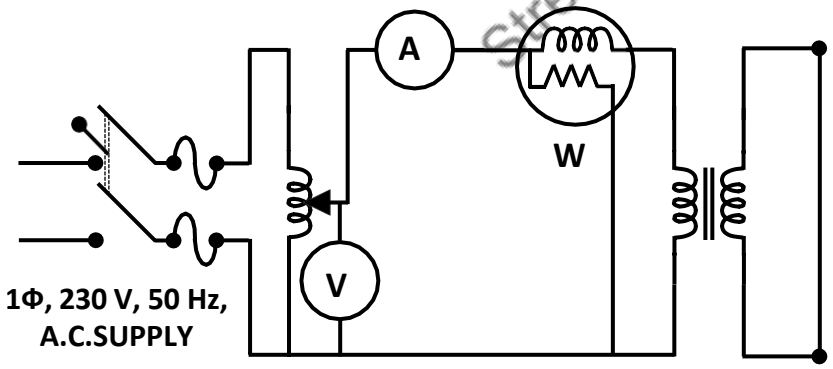


Fig. - 11

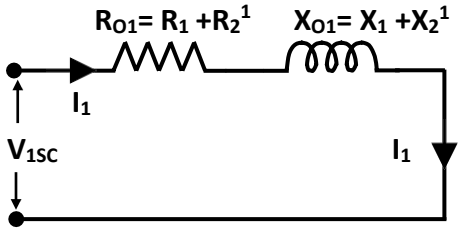


Fig. - 12

The equivalent circuit of a transformer on short circuit as referred to the primary is shown in fig. -12, as the no-load current is very small it is neglected.

The input power under short circuit condition = Copper losses = $P_C = W_S$

If total resistance of transformer referred to primary is R_{O1}**; total reactance referred to primary is** X_{O1}

Then total impedance referred to primary is Z_{O1}

$$\therefore R_{O1} = \frac{W_S}{I_1^2} \; ; \; Z_{O1} = \frac{V_{1SC}}{I_1} \; ; \; X_{O1} = \sqrt{Z_{O1}^2 - R_{O1}^2} \qquad Short\ circuit\ power\ factor,\ Cos_{\Phi 2} = \frac{W_S}{V_{1SC} I_1}$$

Relations for Efficiency and Voltage regulation: The efficiency of the transformer at any load factor 'x' and any power factor can be determined if the KVA rating of the transformer, Iron losses and the Full load copper losses are known. The relation given below helps in finding the efficiency from the OC and SC tests conducted on the transformer.

$$\% \ \eta_x = \frac{x.KVA.Cos\phi}{(x.KVA.Cos\phi) + P_i + x^2 P_c} \times 100$$

The voltage regulation of the transformer can be calculated by using the relation given below -

If the resistance and reactance of the transformer referred to the secondary side are known then

$$\% \ Voltage \ Regulation = \frac{I_2 (R_{O2} Cos\phi_2 \pm X_{O2} Sin\phi_2)}{V_2} \times 100$$

(+ ve for lagging power factor and – ve for leading power factor)

V_2 is the secondary voltage of the transformer on no-load.

Unit - IV Electrical Machines - Syllabus:

Construction, Working Principle, Classification and Application of DC machine, Induction machine and Synchronous machine. Working principle of 3-Phase induction motor, Concept of slip in 3-Phase induction motor, Explanation of Torque-slip characteristics of 3-Phase induction motor. Types of losses occurring in electrical machines.

D.C. MACHINE

A DC machine can work as a motor as well as a generator. There is no constructional difference between a DC motor and a DC generator.

Constructional Features: Fig. - 1 shows the constructional details of a DC Machine. Some of the essential parts of a DC machine are Yoke, Main poles, Field coil, Armature core, Armature winding, Commutator, Brushes, Bearings and End Covers.

Yoke: It is the outermost covering made of cast iron which provides support for the main poles. It also carries the magnetic flux produced by the poles.

Main poles: They are made up of laminations bunched together and fixed to the yoke. The pole core accommodates the field coils. The pole shoe helps in spreading the flux in the air gap.

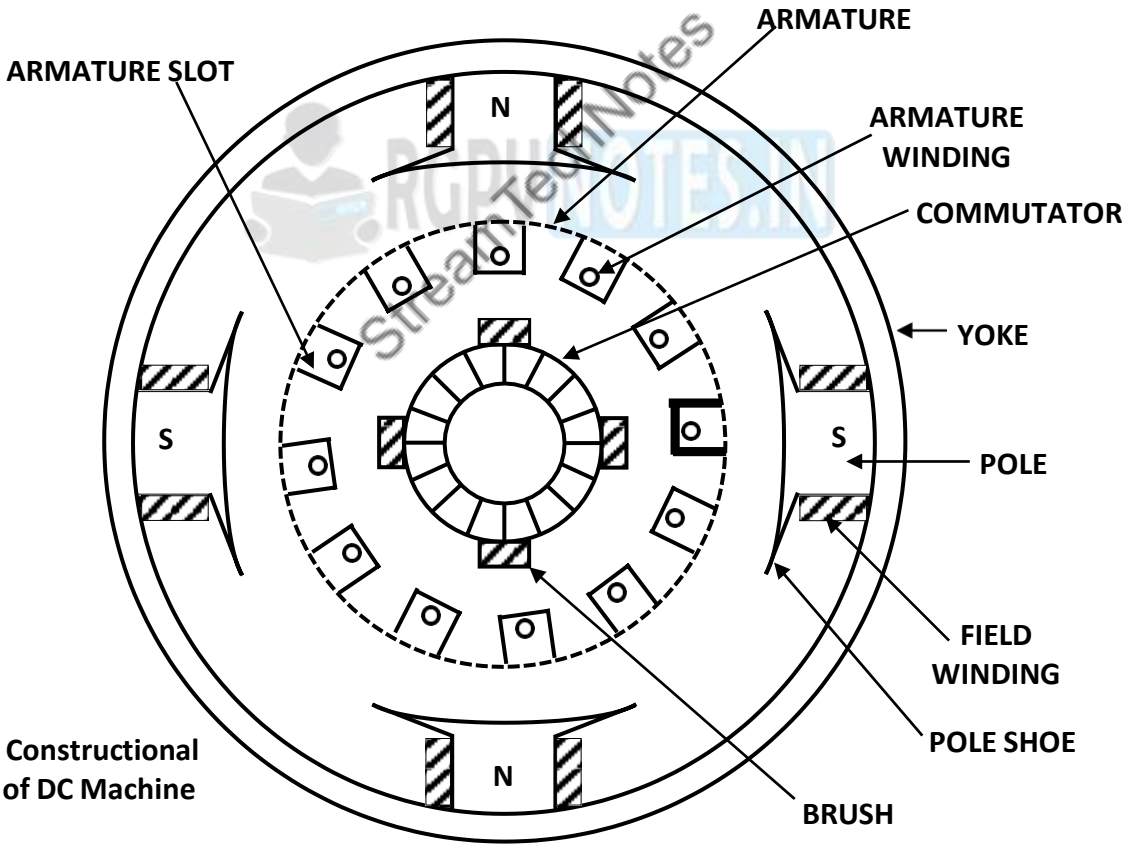


Fig. - 1 Constructional details of DC Machine

Field coil: They are placed around the pole core supported by the pole shoe. The field coils after being mounted on the main poles are connected such that, when a DC exciting current flows through them, the main poles alternately become north and south poles producing the necessary flux.

Armature core: It is a laminated cylindrical core keyed to the machine shaft with slots on the outer periphery to accommodate the armature winding as shown in Fig. - 2. The important function of the core is to provide a path of very low reluctance to the flux through the armature from North pole to South pole.

Armature winding: Copper wire is used to make the armature winding in the slots of the armature core, which form the conductors. The conductors are insulated from each other as well as from the core. The armature winding of a DC machine forms a closed circuit. Depending on the manner in which the conductors are connected to the commutator segments, we have lap winding and wave winding.

Commutator: It converts the alternating current induced in the armature conductors into unidirectional current in the external load circuit. It is a cylindrical structure mounted on the shaft of the armature core on one side. It has many segments of copper that are insulated from each other by mica sheets. The number of segments will be equal to the number of armature coils. The commutator facilitates for the collection of current from the armature conductors.

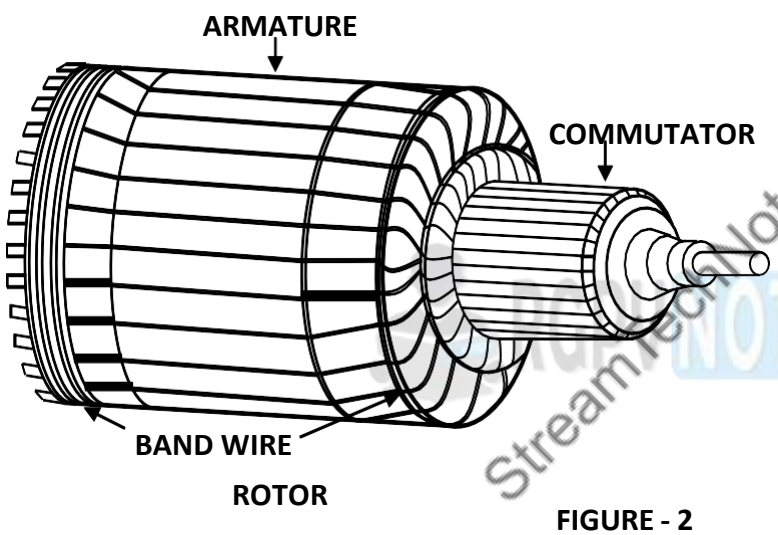
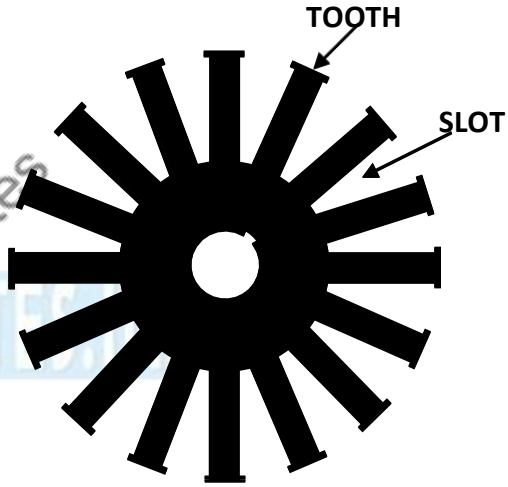


FIGURE - 2



ROTOR CORE LAMINATION

Brushes: They are made of carbon and will be equal to the number of main poles. They rest on the commutator and help in collection of current from the commutator. The brushes are placed in brush holders,which are accommodated inside the end covers.

Bearings: The bearings are fixed in the end covers. The shaft of the armature core is held on either side by the bearings. Their function is to reduce friction.

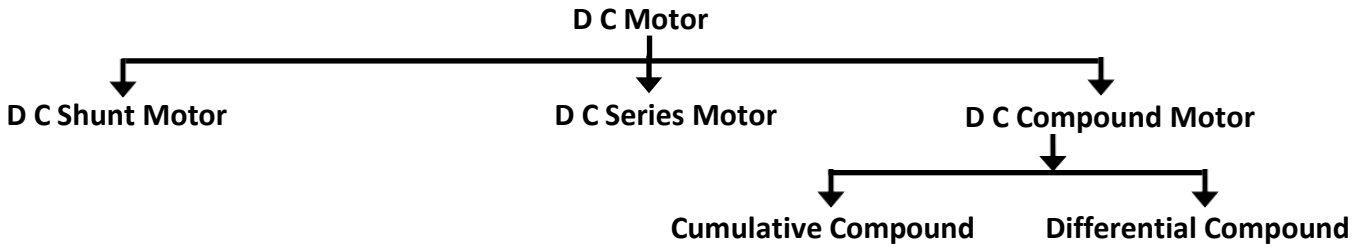
End Covers: They cover the yoke of the machine on either side. They are made of thick sheet metal. They accommodate bearings and brush holders. They also provide ventilation.

D.C. MOTOR

Working principle of DC machine as motor: A DC motor converts electrical energy into mechanical energy. Its operation is based on the principle that when a current carrying conductor is placed in a magnetic field, the conductors experience a mechanical force, whose direction is given by Fleming's left hand rule and its magnitude is given by $F = Bil$ Newtons

Working as a motor: The field winding is excited such that the main poles become alternately north and south, the magnetic field is established in the air gap between the main poles and armature core. The DC supply is also given to the armature terminals so that current flows through the armature conductors. The current carrying conductors when placed in a magnetic field experience a mechanical force. The direction of the force developed in all the conductors will be in the same direction. These forces acting on the shaft give rise to torque.

Types of DC Motor:



Applications of DC Motors: Shunt motors are used for applications which require medium level torque such as Blowers, Fans, Centrifugal and Reciprocating pumps, Lathe machines, Machine tools.

Series motors are used for applications which require high starting torque such as in Cranes, Trolleys, Conveyers, Elevators and Electric locomotives.

Cumulative Compound motors are also used for applications which require high starting torque such as in Rolling mills, Heavy Planers and Elevators.

Differential Compound motors are not suitable for practical applications.

D.C. GENERATOR

Working principle of DC machine as generator: A DC generator is a machine that converts mechanical energy into electrical energy. The energy conversion in a DC generator is based on Faradays laws of electromagnetic induction **i.e.** the principle of production of dynamically induced emf. Whenever a conductor cuts magnetic flux an emf is induced, which will cause a current to flow, if the conductor circuit is closed. The direction of induced emf and hence current is given by Fleming's right hand rule. Hence, the basic requirement for a generator will be a magnetic field, some number of conductors and motion of the conductors with respect to the magnetic field.

Working as a generator: When DC supply is given to the field coils, the main poles get magnetized and the pole shoes spread the magnetic flux through the air gap over the armature conductors accommodated in the armature core. If the armature core is rotated by a prime mover, armature conductors cut the magnetic flux and have emf induced in them. The armature coils connected to the commutator segments form a

closed loop. The brushes moving over the commutator segments collect the current. If the brushes are externally connected to a load circuit, current flows in the external circuit.

Emf equation of DC generator:

Let Φ = Flux per pole in weber ; Z = Total number of armature conductors ; P = Number of poles

N = Speed of armature in rpm ; A = Number of parallel paths, where A = 2 for wave winding and A = P (i.e. No. of poles) for lap winding

Eg = emf of the generator = emf per parallel path

Flux cut by one conductor in one revolution of the armature, dΦ = PΦ weber

Time taken to complete one revolution, $dt = 60/N$ seconds

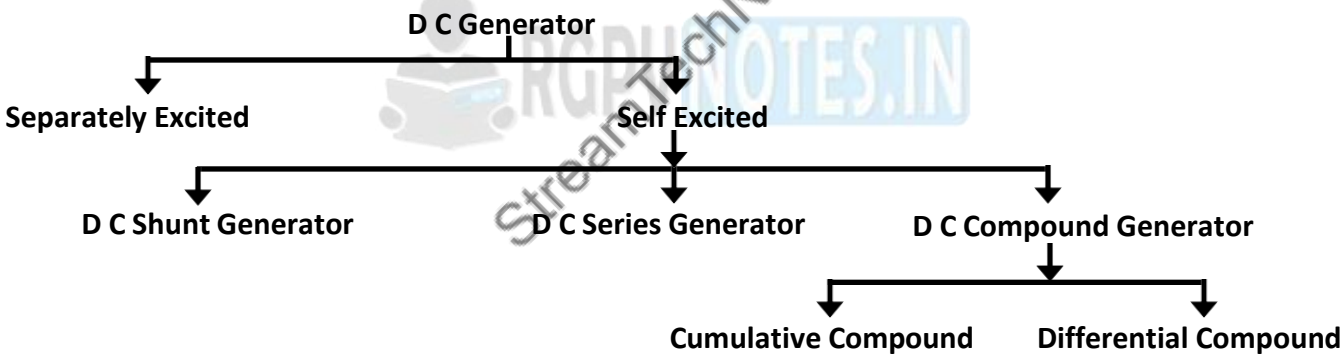
$$emf\,generated\,per\,conductor = \frac{d\Phi}{dt} = \frac{P\Phi}{60/N} = \frac{P\Phi N}{60} \quad volts$$

$$emf\,of\,generator, \quad E_g = emf\,per\,parallel\,path$$

$$= emf\,per\,conductor \times No.\ of\,conductors\,in\,series\,per\,parallel\,path$$

$$\therefore E_g = \frac{P\Phi N}{60} \times \frac{Z}{A} = \frac{P\Phi ZN}{60\,A}\,volts$$

Types of DC Generator:



Applications of DC Generators: Separately excited generators are used for feeding supply to equipment used for Electro-plating and Electro-refining of materials.

Shunt generators feed supply to equipment used for Battery charging and Lighting loads.

Series generators are used as Boosters on DC feeders and for applications that need constant current.

Cumulative compound generators are usually used for Lighting purposes.

Differential compound generators are used for feeding supply to Electric arc welding equipment.

THREE PHASE INDUCTION MOTOR

An induction motor is an AC machine that converts electrical energy into mechanical energy. The rotor of the Induction motor gets its excitation through induction hence it is called Induction motor.

Production of Rotating magnetic field: Let us consider the 3 windings of the three phases of an induction motor stator with assumed positive directions of currents and the mmf space phasors as shown in Fig. -3.

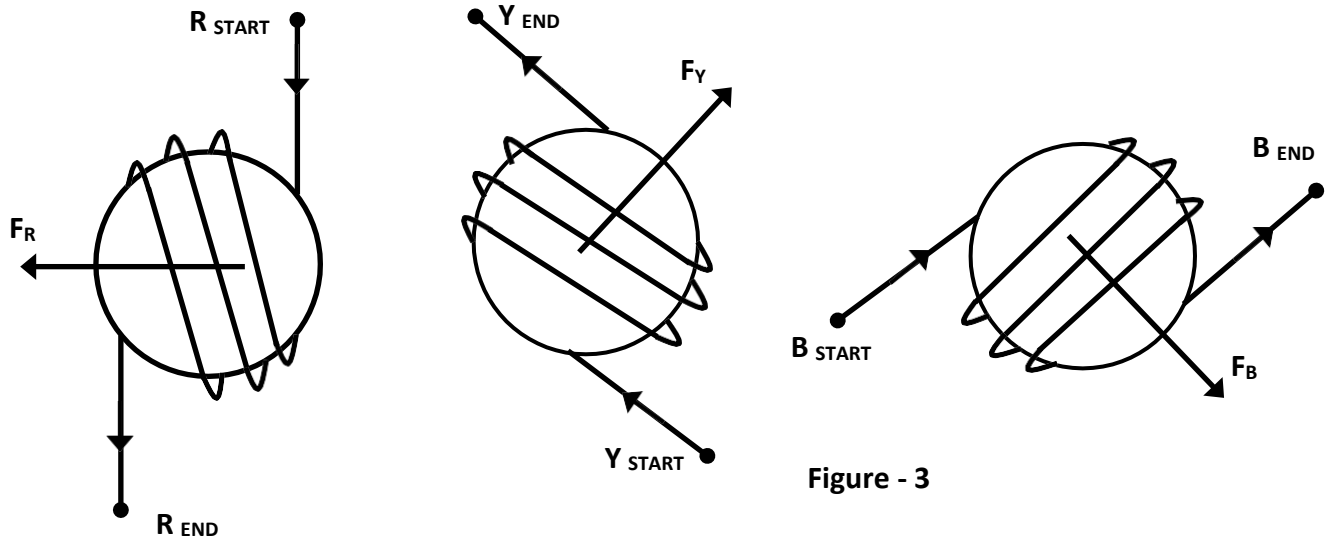


Figure - 3

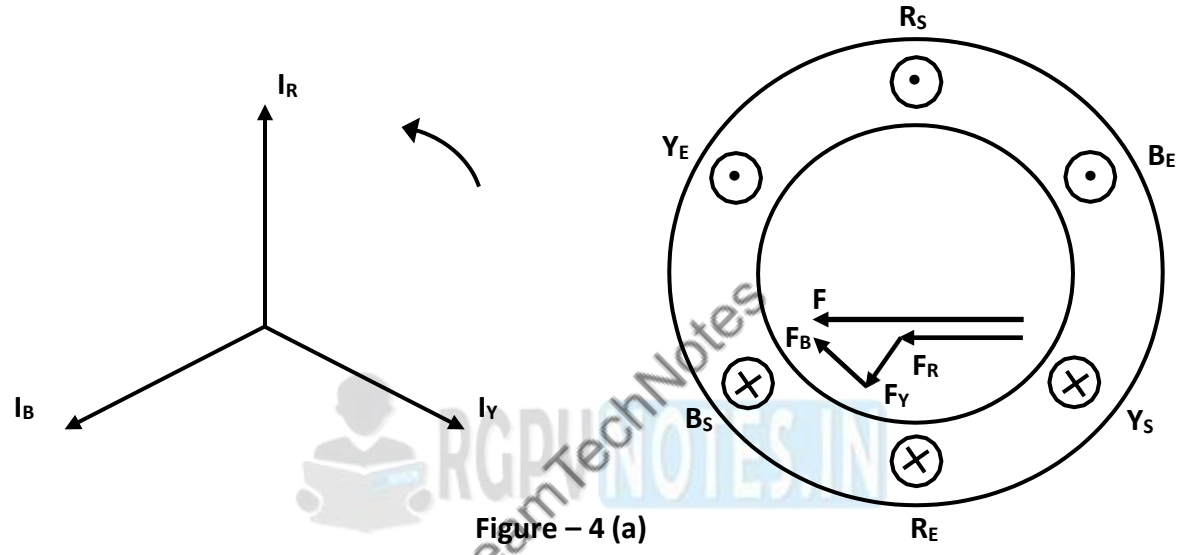


Figure – 4 (a)

The winding of phase Y is displaced from the winding of phase R by 120° and the winding of phase B is displaced from the winding of phase Y by120°. F_R, F_Y and F_B denote the mmf of the three windings at the instant when currents in them are at their positive maximum values. As the currents alternate, the individual mmf will vary in magnitude and change direction so as to follow the changes in the currents. Let us consider two instants as shown in Fig -4.

Figure - 4(a) corresponds to the instant when I_R is at its positive maximum value, I_Y is negative and half its maximum value, I_B is also negative and half its maximum value. So F_Y and F_B have half the magnitude of F_R since currents in phases Y and B are negative, F_Y and F_B are shown opposite to that shown in Figure - 3, F is the resultant of F_R, F_Y and F_B.

Fig 4(b) corresponds to the instant 30° later when I_R is positive and $\sqrt{3}/2$ of its maximum value, I_Y is zero, I_B is negative and $\sqrt{3}/2$ of its maximum value. So F_Y is zero, F_R and $F_B$are equal in magnitude. It is observed that the resultant mmf, F has the same magnitude but has advanced by 30°. So an elapse of 30 electrical degrees in time results in a rotation of mmf by 30°. By considering more instants of time it will be seen that the movement of current phasor by a certain angle in the anticlockwise direction results in the rotation of the resultant mmf by the same angle in the clockwise direction.

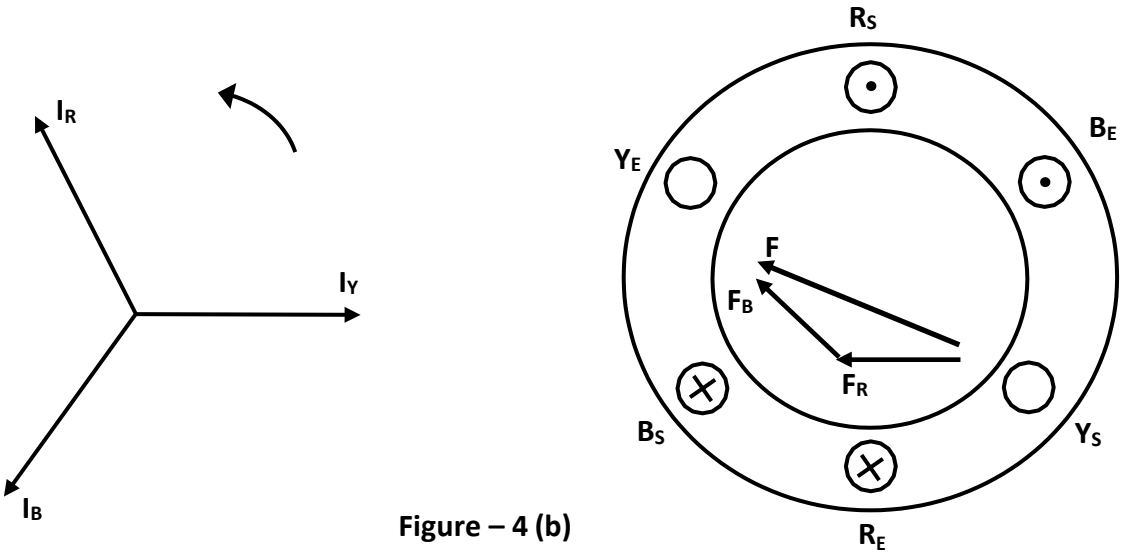


Figure – 4 (b)

Hence, it is clear that when three phase voltages are applied to three phase windings, the currents flowing through the windings produce a rotating magnetic field that is of constant amplitude and constant speed.

Construction:The two main parts of an induction motor are Stator and Rotor.

Stator: It consists of a steel frame which encloses a hollow, cylindrical core made up of thin laminations of silicon steel to reduce hysteresis and eddy current loss. A number of evenly spaced slots are provided on the inner periphery of the laminations. The insulated conductors are placed in the stator slots and are suitably connected to form a balanced three-phase star or delta-connected circuit. The three phase stator winding is wound for a definite number of poles as per the requirement of speed.

Rotor: The rotor is mounted on a shaft with a laminated core having slots on the outer periphery. Depending on the type of winding placed in the slots, we have two types of rotors - Squirrel cage rotor and Slip ring or wound rotor.

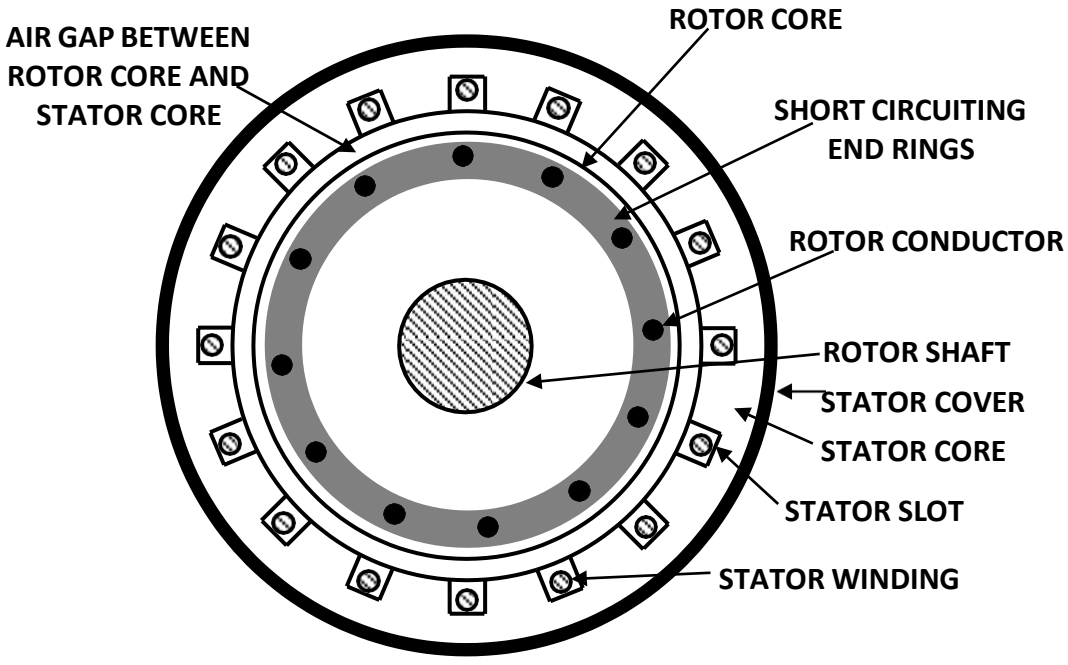


Fig. - 5 Constructional details of a squirrel cage induction motor

Squirrel cage rotor: It consists of a laminated cylindrical core having parallel slots on its outer periphery. Copper or Aluminum bars are placed in each slot. All these bars are joined at either ends by copper or aluminum rings called end rings. This forms a permanently closed circuit winding. As the placing of bars and end rings resembles a squirrel cage it is called squirrel cage rotor. As the rotor circuit is a closed one external resistance cannot be added.

Wound rotor:

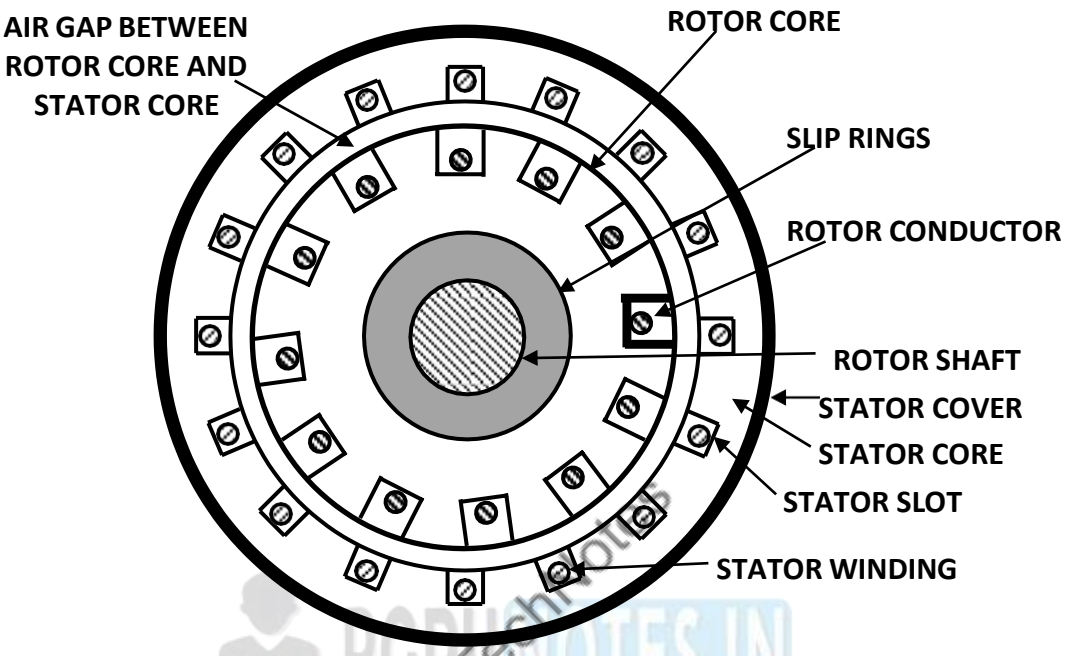


Fig. - 6 Constructional details of a slip ring induction motor

It consists of a laminated cylindrical core and carries a three phase winding similar to that on the stator. The rotor winding is uniformly distributed in the slots and is usually connected in star. The open ends of the rotor windings are brought out and connected to three insulated slip rings mounted on the rotor shaft with one brush resting on each slip ring. The three brushes are connected to a three phase star connected rheostat to vary the resistance of the rotor circuit. At starting the resistance is included to enhance the starting torque and gradually reduced as the motor picks up speed.

Working and Principle of operation: When three phase voltages are applied to the three phase stator winding, currents flow through the stator winding and a rotating magnetic field is set up. This rotating magnetic field rotates around the rotor at synchronous speed given by $N_S = 120f / P$. This rotating magnetic field passes through the air gap and cuts the rotor conductors that are initially stationary. Due to the relative speed between the rotating flux and the stationary rotor, emf's are induced in the rotor conductors. Since the rotor circuit is a closed one, currents start flowing in the rotor conductors. When current carrying conductors are placed in a magnetic field produced by the stator, the rotor conductors are acted upon by a mechanical force. The sum of the mechanical forces of all the conductors produces a torque that tends to move the rotor in the same direction as the rotating field.

Concept of slip in three phase induction motor:

A three phase induction motor will function similarly as a transformer when viewed in a specific manner. The stator and rotor winding is always made for three phase and for a specific number of poles. The three phase induction motor at rest is similar to a transformer wherein the stator winding becomes the primary and rotor winding becomes the secondary.

The rotating magnetic field which rotates at synchronous speed is given by $N_S = \frac{120 f_1}{P}$

Where N_S is Synchronous speed, which is the speed at which the stator magnetic field rotates

f_1 = Frequency of supply voltage impressed across the stator winding

P = Number of poles of induction motor

This rotating magnetic field cuts the rotor coils inducing emf and hence current as they form a closed circuit. The current carrying rotor coils in the midst of a rotating magnetic field experience mechanical forces which yield torque. As the rotor starts rotating, the rate at which the rotating field cuts the rotor coils decreases. This in turn reduces the induced emf per phase in the rotor coils. As the rotor picks up speed, it starts rotating at a speed lesser than the synchronous speed. As the current flowing in the rotor coils is produced only due to induction, it is necessary that there has to be a difference between the rotating magnetic field due to stator and the rotor. This difference in speed is called slip speed which is a basic requirement for the functioning of an induction motor.

We have, $Slipspeed = N_S - N\ rpm$ Where N is the actual speed with which the rotor is rotating

The term slip describes the lagging behind of the rotor in comparison with the rotating magnetic field of the stator. The value of Slip for an induction motor lies between zero and unity.

The slip expressed on a per unit basis using synchronous speed as reference is -

$Fractional\ Slip,\ S = \frac{N_S - N}{N_S}$ and $Percentage\ Slip,\ \%S = \frac{N_S - N}{N_S} \times 100$

When the induction motor is rotating, the emf induced in the rotor coils will be dependent on the slip S. The frequency of voltage or current induced in the rotor coils due to the relative speed or slip speed is given by $f_2 = Sf_1$

Where f_2 is the slip frequency or frequency of the induced emf in the rotor coils when the induction motor is rotating.

Torque-Slip characteristics of three phase induction motor:

When S = 0, T = 0, so the torque-slip characteristic starts from the origin. At normal speed, slip is small so the product of slip and rotor reactance per phase at stand still is negligible compared to R_2.

As R_2 i.e. rotor resistance per phase is constant. We have $T \propto S$

The torque-slip curve is a straight line from zero slip to a value of slip that corresponds to full load.

As the slip increases beyond full load slip, the torque increases and becomes maximum at $S = \frac{R_2}{X_2}$

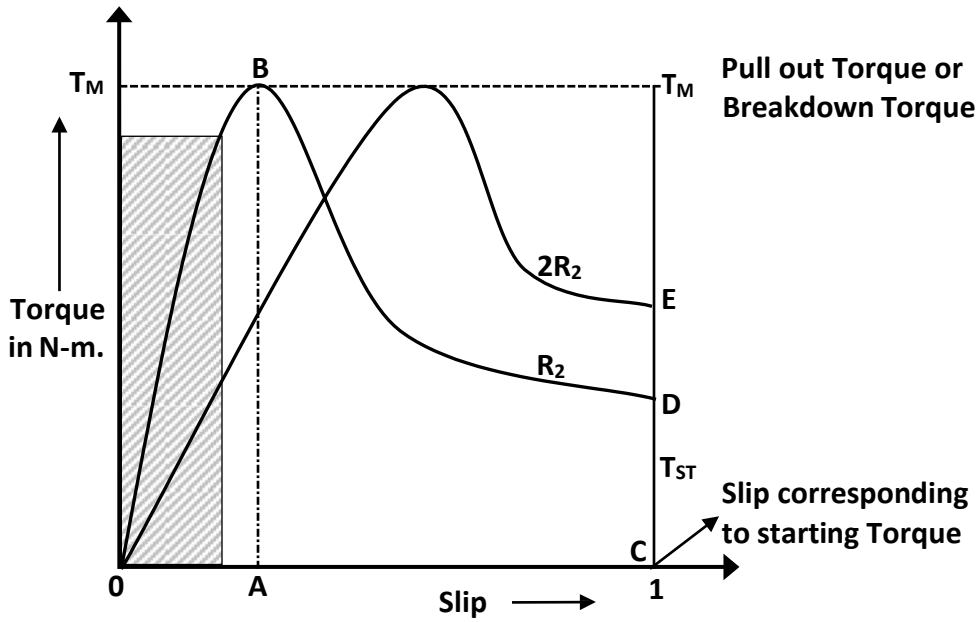


Fig. - 7 Torque - Slip Characteristics of Three phase induction motor

This maximum torque in an induction motor is called Pull out torque or Break down torque. When slip increases further due to load on induction motor the term $S^2X_2^2$ increases very rapidly so that R_2^2 may be neglected as compared to $S^2X_2^2$; $\therefore T \propto \frac{S}{S^2X_2^2}$ or $T \propto \frac{1}{S}$ as X_2 is constant.

Now the torque is inversely proportional to slip so the torque-slip curve will resemble a rectangular hyperbola. It is observed that the addition of resistance to the rotor circuit does not change the value of maximum torque T_M but it only changes the value of slip at which T_M occurs.

Referring to the torque-slip characteristic, the hatched area shows the normal operating range for the induction motor. Within the region OB the operation of the motor will be stable and the range BD is the unstable region. CD represents the torque at S = 1 ; i.e. stand still condition or the starting torque.

The torque-slip characteristics for a slip range from S = 0 to S = 1 for some values of rotor resistance are also shown in fig. - 7.

<u>Applications</u>: Squirrel cage induction motors are simple and rugged in construction, cheap and require less maintenance. They are preferred for many industrial applications. They are used in - Lathes, Drilling machines, Industrial and Agricultural pumps, Compressors and Industrial drives.

Slip ring induction motors when compared to squirrel cage induction motors have high starting torque, smooth acceleration under heavy loads, adjustable speed and good running characteristics. They are used in - Lifts, Cranes and Conveyers.

SYNCHRONOUS MACHINES

Synchronous machines are three phase electrical machines which rotate at synchronous speed. A synchronous machine can work as a motor as well as a generator. There is not much constructional difference between a synchronous motor and a synchronous generator. The stator core will be identical but the rotors shall be different.

Construction: The main parts of a synchronous machine are - Stator frame, Stator core and Rotor. The stator frame usually holds the stampings of the stator core and windings in position. The frame is cast for small machines and for large machines the frame is fabricated from mild steel plates. Holes are provided in the stator frame for ventilation as the stator core has radial ventilating spaces provided in the stampings.

Stator core: It is made up of laminations of special magnetic iron or steel alloy. The core is laminated to minimize eddy current loss. The lamination may be a single stamping or made up of segments. The laminations are insulated from one another and have radial spaces between them for allowing the cooling air to pass through. The slots may be open or semi closed in which the windings of the stator are placed.

SYNCHRONOUS GENERATOR

Rotor for generator: Rotor used in synchronous machines which work as a generator are of two types - Salient pole and Non - Salient pole.

Salient pole or Projecting pole type: The rotor has laminated projecting poles shaped in a specific manner and fixed to the cast iron rotor wheel. The projecting pole makes provision for placing the field coil for DC excitation. The individual field windings are connected in series in such a way that when energized, adjacent poles become north and south. The DC supply to the field coils is fed through brushes sliding over slip rings fixed to the shaft of the rotor. These rotors have large diameters and short axial lengths. This type of rotor is employed for slow and medium speed machines mostly driven by diesel engines.

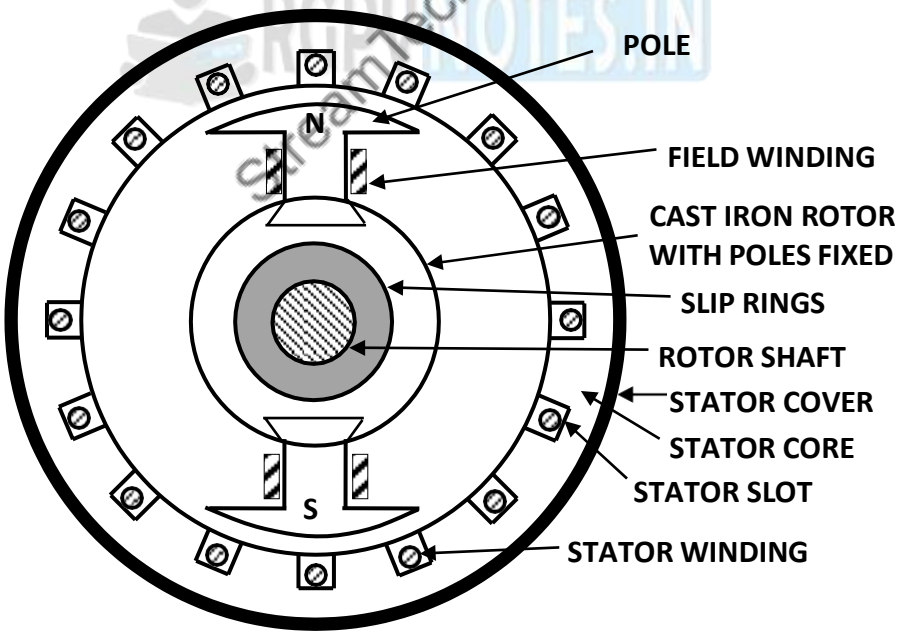


Fig. - 8 Constructional details of a salient pole synchronous machine

Non-Salient or smooth cylindrical type: The rotor is made of smooth solid forged steel radial cylinder having a number of slots along the outer periphery. The field winding is placed in these slots and connected in series. The un-slotted part of the rotor forms the pole faces. These rotors have smaller diameters and large axial length. The number of poles is restricted to 2 or 4 poles. The windings are placed in the slots around the pole faces in such a way that, the flux density is maximum on the polar central line and decreases on

either side. DC supply is given to the field winding through slip rings and brushes so that alternate north and south poles are formed. These rotors are used for high-speed machines driven by turbines.

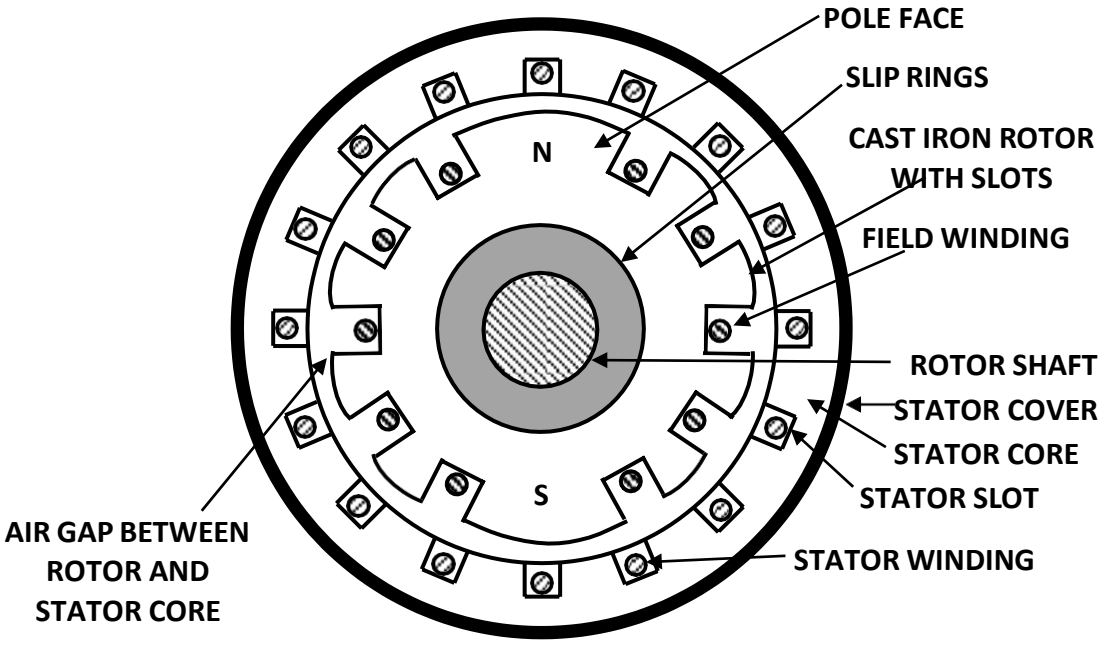


Fig. - 9 Constructional details of a non-salient pole synchronous machine

Working and Principle of operation as a generator: A synchronous generator operates on the fundamental principle of electromagnetic induction. It has a field winding on the rotating part and is fed with DC supply through two slip rings. The field windings develop alternate N and S poles on the rotor. The armature winding which is made for three phase is placed in the slots of the stator which is stationary. When the rotor is rotated by a prime mover, the magnetic flux of rotor poles cut the armature conductors placed in the slots of the stator. Consequently emf is induced in the armature conductors due to Electromagnetic Induction. The induced emf is alternating since N and S poles of rotor pass under the armature conductors. The direction of induced emf can be found by Fleming's right hand rule and the frequency is given by f = PN/120. The magnitude of the induced emf in each phase of the armature winding is the same but they differ in phase by120°.

Emf equation:

Let Z = Number of conductors in series per phase, Φ = Flux per pole in weber

P = Number of rotor poles, N = Rotor speed in rpm

In one revolution (i.e. $60/N$ sec) each stator conductor is cut by $P\Phi$ weber

$i.e. \quad d\Phi = P\Phi$ and $dt = 60/N$

$$Average\ emf\ induced\ in\ one\ stator\ conductor = \frac{d\Phi}{dt} \ ; \qquad \therefore \frac{d\Phi}{dt} = \frac{P\Phi}{60/N} = \frac{P\Phi N}{60}$$

$As\ there\ are\ Z\ conductors\ in\ series\ per\ phase$

$$Average\ emf\ per\ phase = \frac{P\Phi N}{60} \times Z \quad ; \ we\ have \ \ f = \frac{PN}{120} \quad or \ \ N = \frac{120f}{P}$$

$$Average\ emf per phase = \frac{P\Phi Z}{60} \times \frac{120f}{P} = 2f\Phi Z \text{volts}$$

$$rms\ value\ of\ emf\ per\ phase = Average\ emf\ per\ phase \times Form\ factor = 2f\Phi Z \times 1.11$$

$$E_{rms}/phase = 2.22f\Phi Z \quad \text{or} \quad E_{PH} = 2.22K_pK_df\Phi Z$$

where K_p - Pitch factor and K_d - Distribution factor.

$$Finally we have E_L = \sqrt{3}E_{PH} \ ; \qquad \therefore E_L = \sqrt{3} \times 2.22K_pK_df\Phi Z$$

Applications: Synchronous generators are used in all power plants for generation of Electricity.

SYNCHRONOUS MOTOR

Rotor for synchronous motor: There are two types of rotors - With amortisseur winding on rotor pole faces and without amortisseur winding.The rotor used for the motor has laminated projecting poles shaped in a specific manner fixed to the cast iron rotor wheel. The projecting poles make provision for placing the field coil for DC excitation. The pole faces have slots for placing the amortisseur winding for starting. The amortisseur winding consist of copper or bronze bars embedded in the slots and short circuited at both ends by conducting rings, similar to the squirrel cage winding to develop starting torque by induction motor action. This winding also serves to damp out oscillations of speed during normal operation.

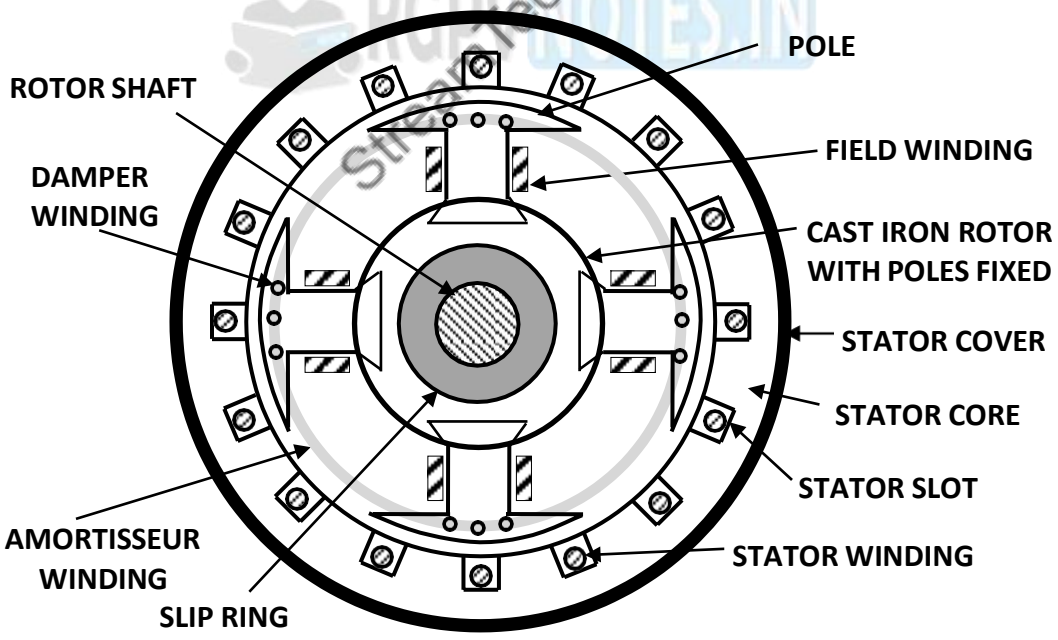


Fig. - 10 Constructional details of a synchronous machine with ammortisseur winding

Working and Principle of operation as a motor: The stator of a synchronous motor when fed by a three phase AC supply, produces a magnetic flux of constant magnitude but rotating at synchronous speed. The rotor pole faces have the amortisseur winding which helps in developing the starting torque by induction motor action. As the motor approaches the synchronous speed, the rotor field winding is excited by a DC source which creates alternate N and S poles on the rotor. The poles of the rotor will face the poles of

opposite polarity on the stator and a strong magnetic attraction is setup between them. The rotor poles lock in with the poles of rotating flux. Consequently the rotor rotates at the same speed as the stator field i.e. at synchronous speed. When the rotor rotates at synchronous speed, i.e. the same speed as that of rotating magnetic field, there will be no emf induced in the amortisseur winding. Hence due to the magnetic locking the synchronous motor can only run at synchronous speed.

Applications: Synchronous motors with speeds below 500 rpm are used in Electroplating, Reciprocating compressors, Centrifugal pumps, Rolling mills and Paper mills.

Synchronous motors with speeds above 500 rpm are used in Fans, Blowers and Frequency changers. Over excited Synchronous motors on no load draw leading power factor current which can be used in Electrical sub-stations to improve power factor of the power system.

Types of losses occurring in Electrical machines:

The losses occurring in electrical machines can be listed as:

1. Constant losses
2. Losses occurring in the machine which are proportional to the current drawn by the machine
3. Losses in machines which are proportional to the square of the current drawn by the machine

- Losses can be classified as Constant losses and Variable losses
- Constant losses comprise of Core losses and Mechanical losses
- Core losses are made up of Hysteresis and Eddy current loss
- Mechanical losses comprise of Windage and Friction loss
- Variable losses comprise of Copper losses and Stray load losses
- Copper losses comprise of Stator copper loss and Rotor copper loss
- Stray load losses can occur in the core as well as in the winding

NUMBER SYSTEMS

***NUMBER SYSTEM* :-** A number system is a code having an assigned symbol for each distinct magnitude. The symbols are called "digits". The number of digits in a number system will determine the base of the system. In all number systems, the weight of a number depends on its relative position.

***BASE or RADIX* : -** The base or radix of a number system is the total number of different digits or basic symbols used in a number system. In the binary system we have 0 & 1 as digits , so the base or radix is 2. In the decimal system we have 10 digits ie. 0 through 9, so the base or radix is 10.

***BINARY SYSTEM* : -** This number system has a base or radix of 2. The symbols or digits used in this system are 0 & 1.

***OCTAL SYSTEM* : -** This number system has a base or radix of 8. The symbols or digits used in this system are 0 through7.(0, 1, 2, 3, 4, 5, 6, 7)

***DECIMAL SYSTEM* :-** This number system has a base or radix of 10. The symbols or digits used in this system are 0 through 9. (0, 1, 2, 3, 4, 5, 6, 7, 8, 9)

***HEXA DECIMAL SYSTEM* :-** This number system has a base or radix of 16. The symbols or digits used in this system are 0 through F. (0, 1, 2, 3, 4, 5, 6, 7, 8, 9, A, B, C, D, E, F)

CODE CONVERSIONS

(1) BINARY TO DECIMAL CONVERSION:-

(i) (101111 . 11010)$_2$ = (?)$_{10}$

Integeral part : $(101111)_2 = (1 \cdot 2^5) + (0 \cdot 2^4) + (1 \cdot 2^3) + (1 \cdot 2^2) + (1 \cdot 2^1) + (1 \cdot 2^0)$

$= 32 + 0 + 8 + 4 + 2 + 1$

$= 47$

ie. $(101111)_2 = (47)_{10}$

Fractional Part : $(0.11010)_2 = (1 \cdot 1/2) + (1 \cdot 1/4) + (0 \cdot 1/8) + (1 \cdot 1/16) + (0 \cdot 1/32)$

$= 0.5 + 0.25 + 0 + 0.0625 + 0$

$= 0.8125$

ie. $(0.11010)_2 = (0.8125)_{10}$

Thus $(101111.11010)_2 = (47.8125)_{10}$

(ii) (111010 . 101101)$_2$ = (?)$_{10}$

Integeral part : $(111010)_2 = (1 \cdot 2^5) + (1 \cdot 2^4) + (1 \cdot 2^3) + (0 \cdot 2^2) + (1 \cdot 2^1) + (0 \cdot 2^0)$

$= 32 + 16 + 8 + 0 + 2 + 0$

$= 58$

ie. $(111010)_2 = (58)_{10}$

Fractional Part : $(0.101101)_2 = (1 \cdot 1/2) + (0 \cdot 1/4) + (1 \cdot 1/8) + (1 \cdot 1/16) + (0 \cdot 1/32) + (0 \cdot 1/64)$

$= 0.5 + 0 + 0.125 + 0.0625 + 0 + 0.015625$

$= 0.703125$

ie. $(0.101101)_2 = (0.703125)_{10}$

Thus $(111010.101101)_2 = (58.703125)_{10}$

(2) OCTAL TO DECIMAL CONVERSION:-

(i) (457 . 245)$_8$ = (?)$_{10}$

Integeral part :

$(457)_8 = (4 \cdot 8^2) + (5 \cdot 8^1) + (7 \cdot 8^0)$

$= 256 + 40 + 7$

$= 303$

ie. $(457)_8 = (303)_{10}$

Fractional Part :

$(0.245)_8 = (2 \cdot 1/8) + (4 \cdot 1/64) + (5 \cdot 1/512)$

$= 0.25 + 0.0625 + 0.0097656$

$= \mathbf{0.3222656}$

ie. $(0.245)_8 = (0.3222656)_{10}$

Thus $(457.245)_8 = (303.3222656)_{10}$

(ii) (1427 . 3426)$_8$ = (?)$_{10}$

Integeral part :

$(1427)_8 = (1 \cdot 8^3) + (4 \cdot 8^2) + (2 \cdot 8^1) + (7 \cdot 8^0)$

$= 512 + 256 + 16 + 7$

$= 791$

ie. $(1427)_8 = (791)_{10}$

Fractional Part :

$(0.3426)_8 = (3 \cdot 1/8) + (4 \cdot 1/64) + (2 \cdot 1/512) + (6 \cdot 1/4096)$

$= 0.375 + 0.0625 + 0.00391 + 0.001465$

$= \mathbf{(0.442875)_{10}}$

ie.$(0.3426)_8 = (0.442875)_{10}$

Thus $(1427.3426)_8 = (791.442875)_{10}$

(3) HEXADECIMAL TO DECIMAL CONVERSION :-

(i) (F9AC . 5D8B)$_{16}$ = (?)$_{10}$

Integeral part :

$(F9AC)_{16} = (F \cdot 16^3) + (9 \cdot 16^2) + (A \cdot 16^1) + (C \cdot 16^0)$

$= (15 \cdot 16^3) + (9 \cdot 16^2) + (10 \cdot 16^1) + (12 \cdot 16^0)$

$= 61440 + 2304 + 160 + 12$

$= 63916$

ie. $(F9AC)_{16} = (63916)_{10}$

Fractional Part :

$(0.5D8B)_{16} = (5 \cdot 1/16) + (D \cdot 1/16^2) + (8 \cdot 1/16^3) + (B \cdot 1/16^4)$

$= 0.3125 + 0.051 + 0.00195 + 0.000168$

$= \mathbf{(0.36562)_{10}}$

ie. $(0.5D8B)_{16} = (0.36562)_{10}$

Thus $(F9AC . 5D8B)_{16} = (63916 . 36562)_{10}$

(ii) (9EA6 . 2FA)$_{16}$ = (?)$_{10}$

Integeral part :

$(9EA6)_{16} = (9 \cdot 16^3) + (E \cdot 16^2) + (A \cdot 16^1) + (6 \cdot 16^0)$

$= (9 \cdot 16^3) + (14 \cdot 16^2) + (10 \cdot 16^1) + (6 \cdot 1)$

$= 36864 + 3584 + 160 + 6$

$= 40614$

ie. $(9EA6)_{16} = (40614)_{10}$

Fractional Part :

$(0.2FA)_{16} = (2 \cdot 1/16) + (F \cdot 1/16^2) + (A \cdot 1/16^3)$

$= (2 \cdot 1/16) + (15 \cdot 1/256) + (10 \cdot 1/4096)$

$= 0.125 + 0.0586 + 0.00244$

$= 0.18604$

ie. $(0.2FA)_{16} = (0.18604)_{10}$

Thus $(9EA6.2FA)_8 = (40614.18604)_{10}$

(1) DECIMAL TO BINARY CONVERSION :-

(i) $(47.8125)_{10} = (?)_2$

Integeral part :

2	47	1
2	23	1
2	11	1
2	5	1
2	2	0
	1	

ie. $(47)_{10} = (101111)_2$

Fractional Part :

$(0.8125 \cdot 2) = 1.625$	1
$(0.625 \cdot 2) = 1.25$	1
$(0.25 \cdot 2) = 0.5$	0
$(0.5 \cdot 2) = 1.0$	1

ie. $(0.8125)_{10} = (0.1101)_2$

Thus $(47.8125)_{10} = (101111.1101)_2$

(ii) $(58.703125)_{10} = (?)_2$

Integeral part :

2	58	0
2	29	1
2	14	0
2	7	1
2	3	1
	1	

ie. $(58)_{10} = (111010)_2$

Fractional Part :

$(0.703125 \cdot 2) = 1.40625$	1
$(0.40625 \cdot 2) = 0.8125$	0
$(0.8125 \cdot 2) = 1.625$	1
$(0.625 \cdot 2) = 1.25$	1
$(0.25 \cdot 2) = 0.5$	0
$(0.5 \cdot 2) = 1.0$	1

ie. $(0.703125)_{10} = (0.101101)_2$

Thus $(58.703125)_{10} = (111010.101101)_2$

(2) DECIMAL TO OCTAL CONVERSION :-

(i) $(303.3222656)_{10} = (?)_8$

Integeral part :

8	303	7
8	37	5
	4	

ie. $(303)_{10} = (457)_8$

Fractional Part :

$(0.3222656 \times 8) = 2.5781248 \cdot 2$
$(0.5781248 \times 8) = 4.6249984 \cdot 4$
$(0.6249984 \times 8) = 4.9999872 \cdot 4$
$(0.9999872 \times 8) = 7.9998976 \cdot 7$
$(0.9998976 \times 8) = 7.9991808 \cdot 7$
$(0.9991808 \times 8) = 7.9934464 \cdot 7$

ie. $(0.3222656)_{10} = (0.244777)_8$

Thus $(303.3222656)_{10} = (457.244777)_8$

(ii) $(791.442875)_{10} = (?)_8$

Integeral part :

8	791	7
8	98	2
8	12	4
	1	

ie. $(791)_{10} = (1427)_8$

Fractional Part :

$(0.442875 \times 8) = 3.543 \cdot 3$
$(0.543 \times 8) = 4.344 \cdot 4$
$(0.344 \times 8) = 2.752 \cdot 2$
$(0.752 \times 8) = 6.016 \cdot 6$
$(0.016 \times 8) = 0.128 \cdot 0$
$(0.128 \times 8) = 1.024 \cdot 1$

ie. $(0.442875)_{10} = (0.342601)_8$

Thus $(791.442875)_{10} = (1427.342601)_8$

(3) DECIMAL TO HEXADECIMAL CONVERSION :-

(i) $(63916.36562)_{10} = (?)_{16}$

Integeral part :

16	63916	12	→ **C**
16	3994	10	→ **A**
16	249	9	→ **9**
	15		→ **F**

ie. $(63916)_{10} = (F9AC)_{16}$

Fractional Part :

(0.36562 · 16) = 5.84992 · 5 · 5
(0.84992 · 16) = 13.59872 · 13 · D
(0.59872 · 16) = 9.57952 · 9 · 9
(0.57952 · 16) = 9.27232 · 9 · 9
(0.27232 · 16) = 4.35712 · 4 · 4

ie. **(0 . 36562)$_{10}$ = (0.5D994)$_{16}$**

Thus (63916 . 36562)$_{10}$ = (F9AC . 5D994)$_{16}$

(ii) (40614 . 18604)$_{10}$ = (?)$_{16}$

Integeral part :

16	40614	6	→ **6**
16	2538	10	→ **A**
16	158	14	→ **E**
	9		→ **9**

ie. **(40614)$_{10}$ = (9EA6)$_{16}$**

Fractional Part :

(0.18604 · 16) = 2.97664 · 2 · 2
(0.97664 · 16) = 15.62624 · 15 · F
(0.62624 · 16) = 10.01984 · 10 · A
(0.01984 · 16) = 0.31744 · 0 · 0
(0.31744 · 16) = 5.07904 · 5 · 5

ie. **(0 . 18604)$_{10}$ = (0 . 2FA05)$_{16}$**

Thus (40614 . 18604)$_{10}$ = (9EA6 . 2FA05)$_{16}$

(1) OCTAL TO BINARY CONVERSION :-

(i) (457 . 245)$_8$ = (?)$_2$

Integeral part :

(457)$_8$ = 4 5 7
{ 100 101 111 }
= (100101111)$_2$

ie. (457)$_8$ = (100101111)$_2$

Fractional Part :

(0.245)$_8$ = 2 4 5
{ 010 100 101 }
= (0. 010100101)$_2$

ie. (0.245)$_8$ = (0.010100101)$_2$

Thus (457 . 245)$_8$ = (100101111 . 010100101)$_2$

(ii) (1427. 3426)$_8$ = (?)$_2$

Integeral part :

(1427)$_8$ = 1 4 2 7
{ 001 100 010 111 }
= (1100010111)$_2$

ie. **(1427)$_8$ = (1100010111)$_2$**

Fractional Part :

$(0.3426)_8 = \underbrace{3}_{011}\ \underbrace{4}_{100}\ \underbrace{2}_{010}\ \underbrace{6}_{110}$

$= (0.01110001011)_2$

ie. $(0.3426)_8 = (0.01110001011)_2$

Thus $(1427.3426)_8 = (1100010111.01110001011)_2$

(2) HEXADECIMAL TO BINARY CONVERSION :-

(i) $(F9AC.5D8B)_{16} = (?)_2$

Integeral part :

$(F9AC)_{16} = \underbrace{F}_{1111}\ \underbrace{9}_{1001}\ \underbrace{A}_{1010}\ \underbrace{C}_{1100} = (1111100110101100)_2$

ie. $(F9AC)_{16} = (1111100110101100)_2$

Fractional Part :

$(0.5D8B)_{16} = \underbrace{5}_{0101}\ \underbrace{D}_{1101}\ \underbrace{8}_{1000}\ \underbrace{B}_{1011} = (0.0101110110001011)_2$

Thus $(F9AC.5D8B)_{16} = (1111100110101100.0101110110001011)_2$

(ii) $(9EA6.2FA)_{16} = (?)_2$

Integeral part :

$(9EA6)_{16} = \underbrace{9}_{1001}\ \underbrace{E}_{1110}\ \underbrace{A}_{1010}\ \underbrace{6}_{0110} = (1001111010100110)_2$

ie. $(9EA6)_{16} = (1001111010100110)_2$

Fractional Part :

$(0.2FA)_{16} = \underbrace{2}_{0010}\ \underbrace{F}_{1111}\ \underbrace{A}_{1010} = (0.001011111010)_2$

Thus $(9EA6.2FA)_{16} = (1001111010100110.001011111010)_2$

(1) BINARY TO OCTAL CONVERSION :-

(i) $(100101111.010100101)_2 = (?)_8$

Integeral part :

$\overleftarrow{(100, 101, 111)_2} = \{\underbrace{100}_{4}\ \underbrace{101}_{5}\ \underbrace{111}_{7}\} = (457)_8$

ie. $(100101111)_2 = (457)_8$

Fractional Part :-

$\overrightarrow{(0.010, 100, 101)_2} = \{\underbrace{010}_{2}\ \underbrace{100}_{4}\ \underbrace{101}_{5}\} = (245)_8$

ie. $(100101111)_2 = (0.245)_8$

Thus $(100101111.010100101)_2 = (457.245)_8$

(ii) (1100010111 . 01110001011)$_2$ = (?)$_8$

Integeral part :

$(1, \ 100, \ 010, \ 111)_2 = \{ \underbrace{001}_{1} \ \underbrace{100}_{4} \ \underbrace{010}_{2} \ \underbrace{111}_{7} \} = (1427)_8$

ie. (1100010111)$_2$ = (1427)$_8$

Fractional Part :

$(0. 011, 100, 010, 11)_2 = \{ 011 \underbrace{\ }_{3} \ \underbrace{100}_{4} \ \underbrace{010}_{2} \ \underbrace{110}_{6} \} = (0. 3426)_8$

ie. (0.01110001011)$_2$ = (0.3426)$_8$

Thus = (1100010111 . 01110001011)$_2$ = (1427 . 3426)$_8$

(2) BINARY TO HEXADECIMAL CONVERSION :-

(i) (1001111010100110 . 001011111010)$_2$ = (?)$_{16}$

Integeral part :

$(1001111010100110)_2 = \{ 1001, 1110, 1010, 0110 \}$

$= (\underbrace{1001}_{9}, \ \underbrace{1110}_{E}, \ \underbrace{1010}_{A}, \underbrace{0110}_{6})_2$

ie. (1001111010100110)$_2$ = (9EA6)$_{16}$

Fractional Part :

$(0. 001011111010)_2 = \{ \underbrace{0010}_{2}, \underbrace{1111}_{F}, \underbrace{1010}_{A}, \}$

ie. (0. 001011111010)$_2$ = (0.2FA)$_{16}$

Thus (1001111010100110 . *001011111010*)$_2$ = (9EA6 . 2FA)$_{16}$

(ii) (1111100110101100 . 010111011000101100)$_2$ = (?)$_{16}$

Integeral part :

$(1111100110101100)_2 = \{ 1111, 1001, 1010, 1100 \}$

$= (\underbrace{1111}_{F}, \ \underbrace{1001}_{9}, \ \underbrace{1010}_{A}, \underbrace{1100}_{C})_2$

ie. (1111100110101100)$_2$ = (F9AC)$_{16}$

Fractional Part :

$(0. 010111011000101100)_2 = \{ \underbrace{0101}_{5}, \underbrace{1101}_{D}, \underbrace{1000}_{8}, \underbrace{1011}_{B}, \underbrace{0000}_{0} \}$

ie. (0. 010111011000101100)$_2$ = (0. 5D8B)$_{16}$

Thus (1111100110101100 . 0101110110001011)$_2$ = (F9AC . 5D8B)$_{16}$

(1) HEXADECIMAL TO OCTAL CONVERSION :-

(i) (F9AC . 5D8B)$_{16}$ = (?)$_8$

Integeral part :

(F9AC)$_{16}$ = F 9 A C
{ 1111 1001 1010 1100 } = (1111100110101100)$_2$

ie. (F9AC)$_{16}$ = (1, 111, 100, 110, 101, 100)$_2$
= (001 111, 100, 110, 101, 100)$_2$ = 174654
1 7 4 6 5 4

ie. (F9AC)$_{16}$ = (174654)$_8$

Fractional Part :

(0 . 5D8B)$_{16}$ = 5 D 8 B
{ 0101 1101 1000 1011 } = (0 . 010, 111, 011, 000, 101, 100)$_2$
= (010, 111, 011, 000, 101, 100)$_2$
2 7 3 0 5 4
= (0 . 273054)$_8$

ie. (0.5D8B) = = (0 . 273054)$_8$

Thus (F9AC . 5D8B)$_{16}$ = (174654 . 273054)$_8$

(ii) (9EA6 . 2FA)$_{16}$ = (?)$_8$

Integeral part :

(9EA6)$_{16}$ = 9 E A 6
{ 1001 1110 1010 0110}

= (1001111010100110)$_2$

ie. (9EA6)$_{16}$ = (1, 001, 111, 010, 100, 110)$_2$
= (001, 001, 111, 010, 100, 110)$_2$
1 1 7 2 4 6
= (117246)$_8$

ie. (9EA6)$_{16}$ = (117246)$_8$

Fractional Part :

(0 . 2FA)$_{16}$ = 2 F A
{ 0010 1111 1010 }
= (0. 001011111010)$_2$

= (0 . 001, 011, 111, 010)$_2$
= (001, 011, 111, 010)$_2$
1 3 7 2
= (0 . 1372)$_8$

ie. (0 . 2FA)$_{16}$ = (0 . 1372)$_8$

Thus (9EA6 . 2FA)$_{16}$ = (117246 . 1372)$_8$

(2) OCTAL TO HEXADECIMAL CONVERSION :-

(i) (174654 . 273054)$_8$ = (?)$_{16}$

Integeral part :

(174654)$_8$ = { 1 (001) 7 (111) 4 (100) 6 (110) 5 (101) 4 (100) }

= (0000, 1111, 1001, 1010, 1100)$_2$

0 F 9 A C

ie. (174654)$_8$ = (F9AC)$_{16}$

Fractional Part :

(0.273054)$_8$ = 2 (010) 7 (111) 3 (011) 0 (000) 5 (101) 4 (100)

= (0 . 0101, 1101, 1000, 1011, 0000)

5 D 8 B 0

ie. (0.273054)$_8$= (0 . 5D8B0)$_{16}$

Thus (174654 . 273054)$_8$ = (F9AC . 5D8B)$_{16}$

(ii) (117246 . 1372)$_8$ = (?)$_{16}$

Integeral part :

(**117246**)$_8$ = { 1 (001) 1 (001) 7 (111) 2 (010) 4 (100) 6 (110) }

= (0000, 1001, 1110, 1010, 0110)$_2$

0 9 E A 6

ie (117246)$_8$ = (09EA6)$_{16}$

Fractional Part :

(0.1372)$_8$ = 1 (001) 3 (011) 7 (111) 2 (010)

= (0 . 0010, 1111, 1010,)

2 F A

ie. (0.1372)$_8$ = (0 . 2FA)$_{16}$

Thus (117246 . 1372)$_8$ = (9EA6 . 2FA)$_{16}$

BINARY ARITHMETIC

(1) BINARY ADDITION :

(i) Add (111011.1101)$_2$ and (11111 .011)$_2$

		1	1	1	0	1	1	.	1	1	0	1	Augend
+		0	1	1	1	1	1	.	0	1	1	0	Addend
	1	**0**	**1**	**1**	**0**	**1**	**1**	**.**	**0**	**0**	**1**	**1**	**Sum**

(ii) Add (10110.1111)$_2$ and (1000111 .1101)$_2$

	0	0	1	0	1	1	0	.	1	1	1	1	Augend
+	1	0	0	0	1	1	1	.	1	1	0	1	Addend
	1	**0**	**1**	**1**	**1**	**1**	**0**	**.**	**1**	**1**	**0**	**0**	**Sum**

(2) BINARY SUBTRACTION :

(i) Subtract (11111.011)$_2$ from (111011 .1101)$_2$

	1	1	1	0	1	1	.	1	1	0	1	Minuend
−	0	1	1	1	1	1	.	0	1	1	0	Subtrahend
		1	**1**	**1**	**0**	**0**	**.**	**0**	**1**	**1**	**1**	**Difference**

(ii) Subtract (10110.1111)$_2$ from (1000111 . 1100)$_2$

	1	0	0	0	1	1	1	.	1	1	0	0	Minuend
−	0	0	1	0	1	1	0	.	1	1	1	1	Subtrahend
		1	**1**	**0**	**0**	**0**	**0**	**.**	**1**	**1**	**0**	**1**	**Difference**

(3) BINARY MULTIPLICATION :

(i) Multiply (1110.110)$_2$ and (1010 .010)$_2$

Multiplicand									Multiplier								
1	1	1	0	.	1	1	0		1	0	1	0	.	0	1	0	
										0	0	0	0	0	0	0	
									1	1	1	0	1	1	0		
								0	0	0	0	0	0	0			
							0	0	0	0	0	0	0				Partial products
						1	1	1	0	1	1	0					
					0	0	0	0	0	0	0						
				1	1	1	0	1	1	0							
			1	**0**	**0**	**1**	**0**	**1**	**1**	**1**	**.0**	**0**	**1**	**1**	**0**	**0**	**Final Product**

(ii) Multiply (1010.11)$_2$ and (111 .01)$_2$

Multiplicand								Multiplier						
1	0	1	0	.	1	1		1	1	1	.	0	1	
								1	0	1	0	1	1	
							0	0	0	0	0	0		
						1	0	1	0	1	1			Partial products
					1	0	1	0	1	1				
				1	0	1	0	1	1					
			1	**0**	**0**	**1**	**1**	**0**	**1**	**.1**	**1**	**1**	**1**	**Final Product**

(4) BINARY DIVISION:

(i) Divide (110001)$_2$ by (111)$_2$

Dividend

Divisor 111 ⟌ 110001 ⟍ 11 Quotient

111

01010

111

000111

111

000 000 Remainder

(ii) Divide (10100.110)$_2$ by (11.101)$_2$

<u>NOTE</u> : { 10100.110 ⟌ 11.101 } is the same as {10100110 ⟌ 11101 }, therefore we can divide the numbers as shown below :

Dividend

Divisor 11101 ⟌ 10100110 ⟍ 101.1011 Quotient

11101

0110010

11101

000101010

11101

00000110100

11101

000000101110

11101

000000010001 Remainder

BINARY SUBTRACTION USING COMPLEMENTARY NUMBERS

(1) BINARY SUBTRACTION USING 1's COMPLEMENT :

1's COMPLEMENT : The 1's complement of any binary number is obtained by subtracting every binary digit from 1 , for example , the 1's complement of the number 11011 is obtained as follows :
(11111 - 11011) = 00100, therefore the 1's complement of $(11011)_2$ is $(00100)_2$.
The 1's complement is also obtained by complementing every digit of the given binary number, ie. The 1's complement of the number $(11111)_2$ is $(00000)_2$ & vice versa the 1's complement of $(00000)_2$ is $(11111)_2$
Negative numbers can be represented by 1's complement numbers, hence the process of subtraction in a processor can be carried out using an adder unit instead of a subtractor unit, as a result it minimizes the hardware in a computer.

(i) Subtract 25 from 45

45 → binary equivalent is : 101101 → write the positive number as it is
- 25 → binary equivalent is : 011001 → write the 1's complement of the negative number
20

ie. 45 → binary equivalent is :
- 25 → 1's complement is :
20

	1	0	1	1	0	1
-	1	0	0	1	1	0
1	0	1	0	0	1	1

since carry is generated, it has to be taken as end-around carry as shown below :

	1	0	1	1	0	1
-	1	0	0	1	1	0
1	0	1	0	0	1	1
						1
	0	1	0	1	0	0

→ end-around carry
→ **= 20**

(ii) Subtract 15 from 31

31 → binary equivalent is : 11111 → write the positive number as it is
- 15 → binary equivalent is : 01111 → write the 1's complement of the negative number
16

ie. 31 → binary equivalent is →
- 15 → 1's complement is →
16

	1	1	1	1	1	
-	1	0	0	0	0	
1	0	1	1	1	1	

since carry is generated, it has to be taken as end-around carry as shown below :

	1	1	1	1	1	
-	1	1	0	0	1	
1	0	1	1	1	1	
						1
	1	0	0	0	0	

→ end-around carry
→ **= 16**

(iii) Subtract 31 from 15

15 ⟶ binary equivalent is : 01111 ⟶ write the positive number as it is
− 31 ⟶ binary equivalent is : 11111 ⟶ write the 1's complement of the negative number
− 16

ie. 15 ⟶ binary equivalent is ⟶

	0	1	1	1	1
−	0	0	0	0	0
	0	1	1	1	1

since carry is not generated, complement the result & attach a negative sign as shown below

− 31 ⟶ 1's complement is ⟶ ⟶ **= (□ 10000) = (□ 16)**

− 16

(iv) Subtract 45 from 25

25 ⟶ binary equivalent is : 011001 ⟶ write the positive number as it is
− 45 ⟶ binary equivalent is : 101101 ⟶ write the 1's complement of the negative number
− 20

ie. 25 ⟶ binary equivalent is ⟶

	0	1	1	0	0	1
−	0	1	0	0	1	0
	1	0	1	0	1	1

since carry is not generated, complement the result & attach a negative sign as shown

− 45 ⟶ 1's complement is ⟶ ⟶ **= (□ 010100) = (□ 20)**

− 20

(1) BINARY SUBTRACTION USING 2's COMPLEMENT :

2's COMPLEMENT : The 2's complement of any binary number is obtained by adding 1 to the 1's complement , for example , the 2's complement of the number 11011 is obtained as follows :
The 1's complement of $(11011)_2$ is $(00100)_2$, the 2's complement is obtained by adding 1 to $(00100)_2$, ie.
$(00100 - 1)_2 = (00101)_2$
The 2's complement is also obtained by writing the LSB of the given binary number as it is and complementing the rest of the digits . For example the 2's complement of (11011)$_2$ is (00101)$_2$. If the LSB is not a 1 but a 0 then all these initial 0's are retained unchanged & then the first 1 that is encountered is kept unchanged & the rest of the bits are complemented. For example the 2's complement of (1101100)$_2$ is (0010100)$_2$
Subtraction can be carried out through addition by using 2's complement numbers, hence subtraction in a processor can be carried out using an adder unit instead of a subtractor unit, as a result it minimizes the hardware in a computer. However the advantage of using 2's complement is that during the process of subtraction whenever a carry is generated , it need not be used as end-around carry but has to be just neglected. This means that the subtraction process using complementary numbers becomes simple. When a carry is not generated the resultant umber will be a negative number.

(i) Subtract 25 from 45

45 ⟶ binary equivalent is : 101101 ⟶ write the positive number as it is
− 25 ⟶ binary equivalent is : 011001 ⟶ write the 2's complement of the negative number
20

ie. 45 ⟶ binary equivalent is : ⟶

	1	0	1	1	0	1
−	1	0	0	1	1	1
1	0	1	0	1	0	0

since carry is generated, it has to be neglected & result is taken as shown below

− 25 ⟶ 2's complement is: ⟶

20

ie. (010100)$_2$ = (20)$_{10}$

(ii) Subtract 15 from 31

31 → binary equivalent is : 11111 → write the positive number as it is
− 15 → binary equivalent is : 01111 → write the 1's complement of the negative number
16

ie. 31 → binary equivalent is →
− 15 → 2's complement is →

	1	1	1	1	1
−	1	0	0	0	1
1	1	0	0	0	0

since carry is generated, it has to be neglected & result is taken as shown below

ie. (10000) $_2$ = (16)$_{10}$

(iii) Subtract 31 from 15

15 → binary equivalent is : 01111 → write the positive number as it is
− 31 → binary equivalent is : 11111 → write the 2's complement of the negative number
− 16

ie. 15 → binary equivalent is →
− 31 → 2's complement is →
− 16

	0	1	1	1	1
−	0	0	0	0	1
	1	**0**	**0**	**0**	**0**

since carry is not generated, complement the resultant number, add 1 to it & attach a negative sign as shown below

→ **Resultant number**

ie. Resultant number is(10000) & the answer will be complement of the resultant number plus 1 , with a negative sign,

ie. (□ 01111 □ 1)$_2$ = (□ 10000)$_2$ = (□ 20)$_{10}$

(iv) Subtract 45 from 25

25 → binary equivalent is : 011001 → write the positive number as it is
− 45 → binary equivalent is : 101101 → write the 1's complement of the negative number
− 20

ie. 25 → binary equivalent is →
− 45 → 2's complement is →
− 20

	0	1	1	0	0	1
−	0	1	0	0	1	1
	1	**0**	**1**	**1**	**0**	**0**

since carry is not generated, complement the resultant number, add 1 to it & attach a negative sign as shown below

→ **Resultant number**

ie. Resultant number is(101100) & the answer will be complement of the resultant number plus 1 , with a negative sign,

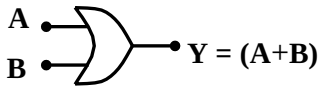
ie. (□ 010011 □ 1)$_2$ = (□ 010100)$_2$ = (□ 20)$_{10}$

LOGIC GATES

(1) **OR-GATE :-** Figure shows the logic circuit of a 2 input OR gate. The 2 inputs result in 4 input combinations of 0s & 1s. The operating conditions of the 4 combinations is summarized in the following truth table :-

A	B	Y = (A + B)
0	0	**0**
0	1	**1**
1	0	**1**
1	1	**1**

Logic symbol for OR Gate



The OR operation is represented by the operator " + "

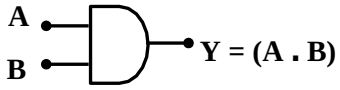
Input A = Logic 0 or 1
Input B = Logic 0 or 1

Logic – 0 = 0 Volt
Logic – 1 = 5 Volts

(2) **AND-GATE :-** Figure shows the logic circuit of a 2 input AND gate. The 2 inputs result in 4 input combinations of 0s & 1s. The operating conditions of the 4 combinations is summarized in the following truth table :-

A	B	Y = (A . B)
0	0	**0**
0	1	**0**
1	0	**0**
1	1	**1**

Logic symbol for AND Gate :



The AND operation is represented by the operator " . "

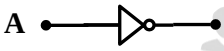
Input A = Logic 0 or 1
Input B = Logic 0 or 1

Logic – 0 = 0 Volt
Logic – 1 = 5 Volts

(3) **NOT-GATE :-** Figure shows the logic circuit of a NOT gate (Inverter). It is single input circuit in which the output is a complement of the input ie. if the input is logic-1 the output will be logic-0 & vice versa. As it has a single input, there are only two possible inputs 0 & 1.The NOT gate operation is explained for these two input combinations.

A	Y = (A)'
0	**1**
1	**0**

Logic symbol for NOT Gate :



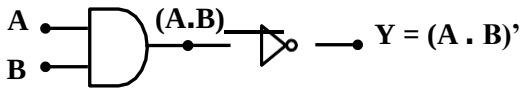
The NOT operation is represented by the operator " ' "

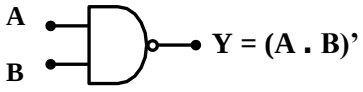
Input A = Logic 0 or 1

Logic – 0 = 0 Volt
Logic – 1 = 5 Volts

(4) **NAND-GATE :-** Figure shows the logic circuit of a 2 input NAND gate. A 2-input NAND gate is realised using an AND gate & a NOT gate. It is actually a combination of a two input AND Gate & a NOT Gate as shown in the logic circuit. It is also called a Negated AND gate (AND gate followed by a NOT gate). The logic symbol for a 2-input NAND gate is also shown along with the truth table .

A	B	Y = A . B	Y = (A . B)'
0	0	**0**	**1**
0	1	**0**	**1**
1	0	**0**	**1**
1	1	**1**	**0**



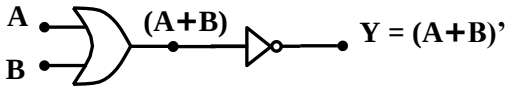


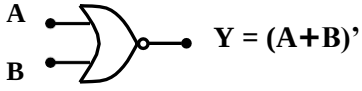
Input A = Logic 0 or 1
Input B = Logic 0 or 1

Logic – 0 = 0 Volt
Logic – 1 = 5 Volts

(5) **NOR-GATE :-** Figure shows the logic circuit of a 2 input NOR gate. A 2-input NOR gate is realised using an OR gate & a NOT gate. It is actually a combination of a two input OR Gate & a NOT Gate as shown in the logic circuit. It is also called a Negated OR gate (OR gate followed by a NOT gate). The logic symbol for a 2-input NOR gate is also shown along with the truth table .

A	B	Y = A+B	Y = (A+B)'
0	0	**0**	**1**
0	1	**1**	**0**
1	0	**1**	**0**
1	1	**1**	**0**



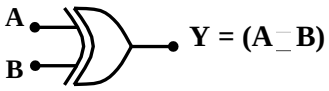


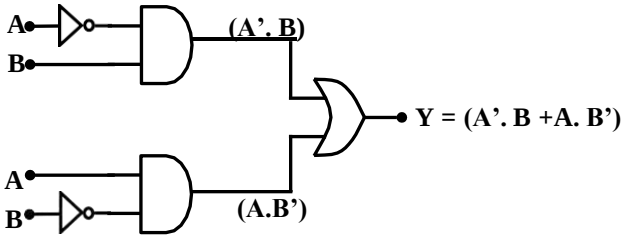
Input A = Logic 0 or 1
Input B = Logic 0 or 1

Logic – 0 = 0 Volt
Logic – 1 = 5 Volts

(6) **EXCLUSIVE-OR GATE[EX-OR GATE] :-** The Exclusive-OR gate can be derived using the basic gates ie. AND, NOT & OR gates, or the universal gates ie. NAND or NOR gates. The basic gate realisation for a 2-input EX-OR gate along with the logic symbol & truth table is as shown.

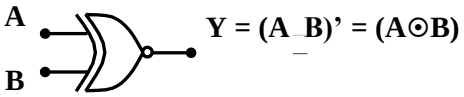
A	B	Y = (A⊕B)
0	0	**0**
0	1	**1**
1	0	**1**
1	1	**0**

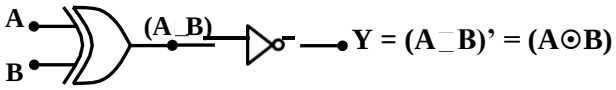




The EX-OR operation is represented by the operator "⊕" & output equation is given by : **Y = A ⊕B = (A'.B+A.B')**

(7) EXCLUSIVE NOR – GATE [Ex – NOR GATE]:-





A	B	Y = (A⊕B)	Y = (A⊕B)' =(A⊙B)
0	0	**0**	**1**
0	1	**1**	**0**
1	0	**1**	**0**
1	1	**0**	**1**

Figure shows the logic symbol of a 2 input EX-NOR gate .It is a combination of a two input EX-OR Gate & a NOT-Gate. It is also called a Negated EX-OR gate (EX-OR gate followed by a NOT gate). The realization of a 2-input EX-NOR gate using an EX-OR gate & a NOT gate along with the truth table is also shown .

The EX-NOR operation is represented by the operator "⊙"

The output equation is given by : **Y = A⊙B = (A.B+A'.B')**

***DE MORGAN'S THEOREM* : *Statement of De Morgan's Theorem* :**

I theorem* : *The complement of the sum is equal to the product of the complements.
ie. (A+B)' = (A' . B')

II theorem* : *The complement of the product is equal to the sum of the complements.
ie. (A.B)' = (A' + B')

Note* :** *Here the* ***sum *&* ***product*** *refer to the* ***Boolean sum & product*** *ie.* ***OR*** *&* ***AND*** *respectively*

Proof of De Morgan's I Theorem :

A	B	(A+B)	(A+B)'	A'	B'	(A' . B')
0	0	0	1	1	1	1
0	1	1	0	1	0	0
1	0	1	0	0	1	0
1	1	1	0	0	0	0

IDENTICAL

Since entries in the two columns shown are identical, the theorem is proved

Proof of De Morgan's II Theorem :

A	B	(A.B)	(A.B)'	A'	B'	(A'+ B')
0	0	0	1	1	1	1
0	1	0	1	1	0	1
1	0	0	1	0	1	1
1	1	1	0	0	0	0

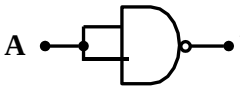
IDENTICAL

Since entries in the two columns shown are identical, the theorem is proved

UNIVERSAL LOGIC GATES :- A universal logic gate can be used to realize all the basic & derived gates (ie. OR, AND, NOT etc.) . Practically it is observed that NAND & NOR gates function as universal gates ie. it is possible to realize all basic & derived gates using NAND & NOR gates.

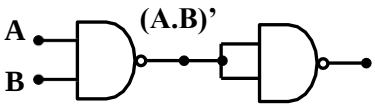
(1) NAND – GATE AS UNIVERSAL GATE :-

(i) Realisation of NOT gate :-



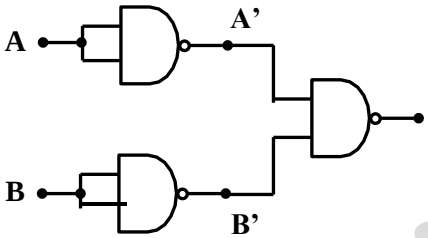
Y = (A . A)' =(A)'

(ii) Realisation of AND gate :-



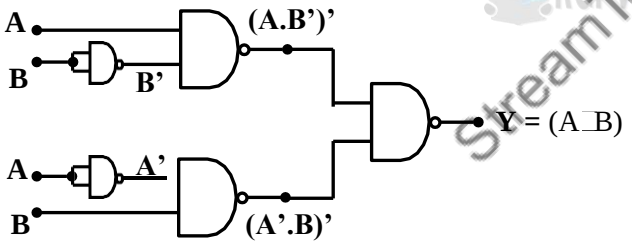
Y = [(A . B)']' = (A . B)

(iii) Realisation of OR gate :-

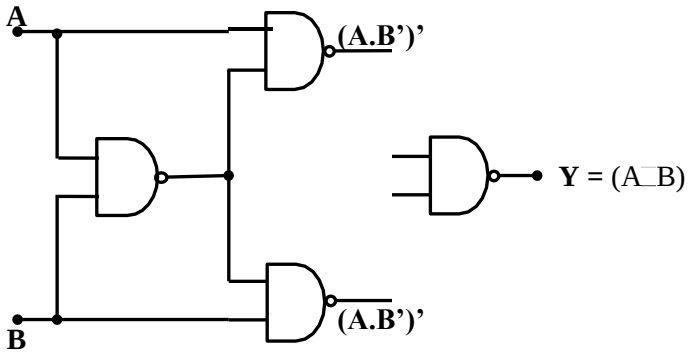


Y = (A'. B')' = (A +B)

(iv) Realisation of Ex – OR gate :-



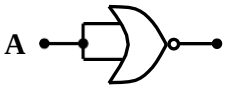
Y = (A. B')+(A'.B)



Y = (A. B')+(A'.B)

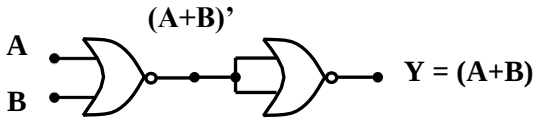
(2) NOR – GATE AS UNIVERSAL GATE :-

(i) Realisation of NOT gate :-



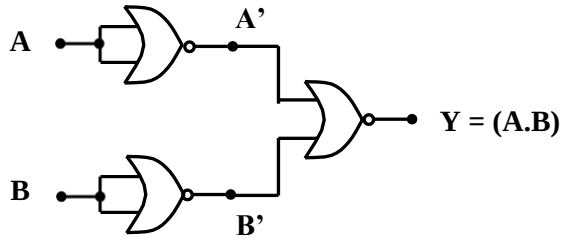
Y = (A +A)' =(A)'

(ii) Realisation of OR gate :-



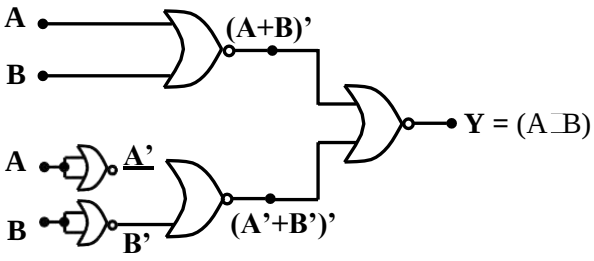
Y = [(A +B)']' = (A +B)

(iii) Realisation of AND gate :-



Y = (A'+ B')' = (A . B)

(iv) Realisation of Ex – OR gate :-



Y = (A. B')+(A'.B)

(1) **HALF ADDER :-** It is a logic circuit used to add 2 one bit binary numbers. A half adder circuit has two inputs & two outputs (sum & carry) . The addition of 2 bits can be shown using the following truth table:

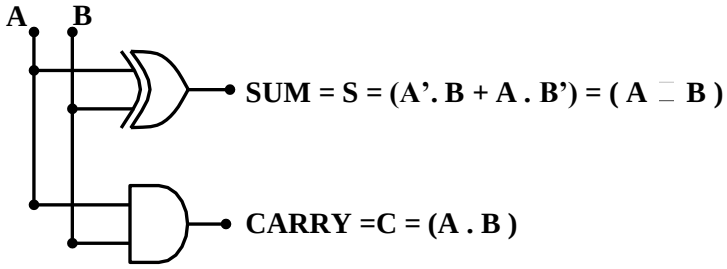
A	B	SUM(S)	CARRY(C)
0	0	0	0
0	1	1	0
1	0	1	0
1	1	0	1

The logic circuit for a half adder is realized using the Boolean expression obtained from the truth table :-

(i) Sum = S = (A'. B + A . B') = (A ⊕ B)

(ii) Carry = C = (A . B)

The Half Adder circuit is therefore realized as shown below :



(2) **FULL ADDER :-** The Half adder circuit can be used to add 2 one bit binary numbers effectively, but when multi bit numbers are to be added then the carry bit that is generated should also be taken care of. This carry bit has to be added to the existing two input bits, which means this circuit would require 3 inputs, ie. two input terminals to add the actual input bits & an additional input terminal to handle the carry bit generated from the previous addition. This is done using a Full adder circuit which is realized using 2 Half adders & a single OR – Gate as shown . The logic circuit for a Full adder is realized using the Boolean expression obtained from the truth table which is shown:-

A	B	C	SUM(S)	CARRY(C)
0	0	0	0	0
0	0	1	1	0
0	1	0	1	0
0	1	1	0	1
1	0	0	1	0
1	0	1	0	1
1	1	0	0	1
1	1	1	1	1

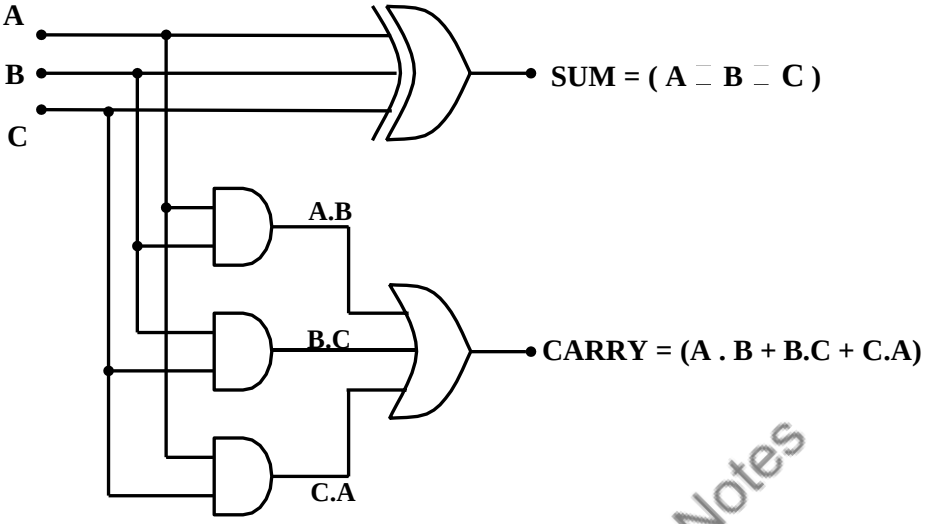
(i) SUM = (A'.B'.C + A'. B.C'+A.B'.C'+A.B.C)
= (A.B'.C'+ A'. B.C'+A'.B'.C +A.B.C)

SUM= (A ⊕ B ⊕ C)

(ii) CARRY = (A'.B.C + A . B'.C+A.B.C'+A.B.C)
= BC(A'+A) + A .B'.C+A.B.C'
= B.C + A.B'.C+A.B.C' = B(C+C'.A)+A.B'.C
= B(C+A)+A.B'.C = B.C + B.A + A .B'.C
= C(B+B'.A) + B . A = C.(B+A)+B.A

CARRY = A .B + B.C + C. A

The Full adder circuit is therefore realized as shown :



A Full adder can also be realized using two half adders & a single 2 – input OR – gate as shown :

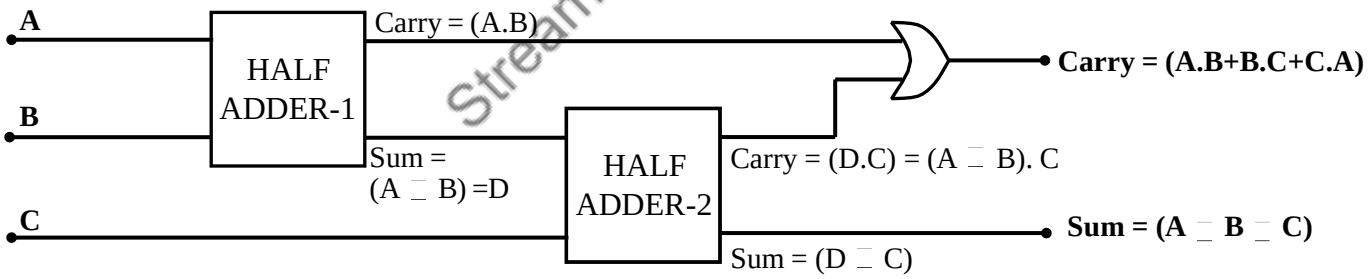
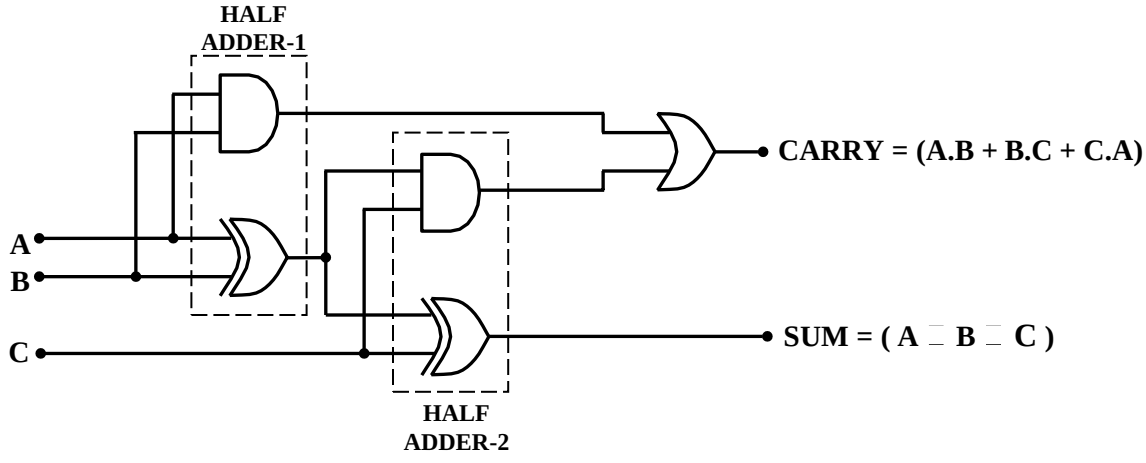
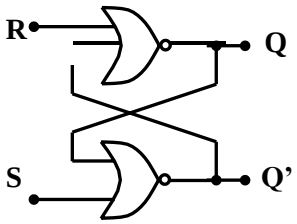


Figure below shows a Full adder realized using two half adders consisting of 2 input Ex-OR gates, 2-input AND gates & a 2-input OR – gate :



R-S FLIP FLOP : A flip flop is a basic memory element (data storage element). A flip flop is realised using a group of logic gates. A NAND gate or a NOR gate individually cannot act as a storage element but when two gates are cross coupled with feed back then they can work as storage or memory elements. Such cross coupled NAND gates or NOR gates with feedback are known as flip flops. A flip flop is a bistable electronic circuit that has two stable states , which means the flip flop output will permanently remain either 0 (low) or 1(high) until it is forced to change its state by an external trigger. A flip flop circuit will have two outputs, one is the Q output & the other is the Q' output which will always be the complement of the Q output , ie Q & Q' are always complementary to each other. Flip flops can be realised using two cross coupled inverters, hence we can use a NOR gate inverter or a NAND gate inverter as shown.

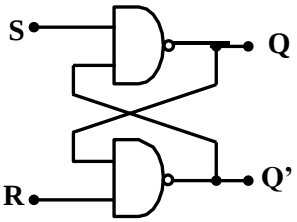


S	R	Q (Output)
0	0	**No Change**
0	1	**0 (Reset)**
1	0	**1 (Set)**
1	1	**Race**

 # No Change or Last State or Memory State

 # Race or Invalid or Not Allowed or ? State

The truth table shown for a NOR gate inverter flip flop is similar to that of a transistor flip flop .

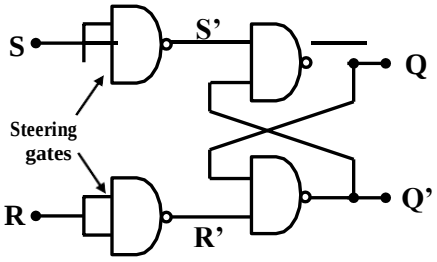


S	R	Q (Output)
0	0	**Race**
0	1	**1 (Set)**
1	0	**0 (Reset)**
1	1	**No Change**

 # Race or Invalid or Not Allowed or ? State

 # No Change or Last State or Memory State

The truth table shown for a NAND gate inverter flip flop is the inverted form of that shown for a NOR gate flip flop, hence inverters or steering gates are used to drive the inputs to the gates as shown :



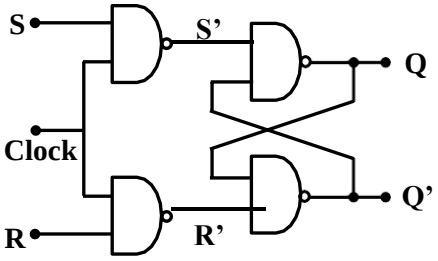
S	R	Q (Output)
0	0	**No Change**
0	1	**0 (Reset)**
1	0	**1 (Set)**
1	1	**Race**

 # No Change or Last State or Memory State

 # Race or Invalid or Not Allowed or ? State

The truth table shown for a NAND gate inverter flip flop with steering gates is similar to that shown for a transistor flip flop, hence inverters or driving gates are used to realize the desired practical R-S flip flop.
In order to overcome the RACE problem in R-S flip flops the J-K flip flop is used.

CLOCKED R-S FLIP FLOP :



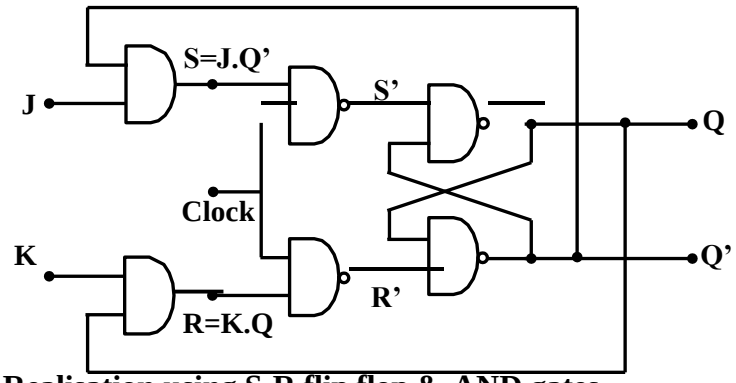
Clock	S	R	Q (Output)
X (0 or 1)	0	0	**No Change**
1	0	1	**0 (Reset)**
1	1	0	**1 (Set)**
1	1	1	**Race**

X – Don't Care Condition, ie. Clock is either 0 or 1

The clock signal is also known as the enabling signal which makes the logic circuit perform the required operation.If clock = 0 then the logic circuit will not respond to the input signals ie. the circuit output will remain unaltered. Only when the clock = 1(rising or falling edge) the logic circuit is enabled & will respond to the applied input signals.

J-K FLIP FLOP : A J-K flip flop is realized using a clocked S-R flip flop and two AND gates with appropriate feed back as shown in figure. The problem with the R-S flip flop is that it exhibits the RACE condition when both S & R are high ie when both are logic-1. This condition is a logically unpredictable state. The J-K flip flop eliminates the unpredictable condition that occurs in the S-R flip flop and hence can be practically used in logic circuits. The J input is analogous to the S input & the K input is analogous to the R input. This means that when J=1 & K=0 , the J-K flip

will Set , ie. Q=1, and when J=0 & K=1, the J-K flip flop will Reset, ie. Q=0. As usual there will be no change in the output condition when J=K =0. However the most important change when compared to the S-R flip flop is that the J-K flip flop will complement its output condition when J=K =1 with the clock high. The operation of a J-K flip can be clearly understood from the truth table given below.

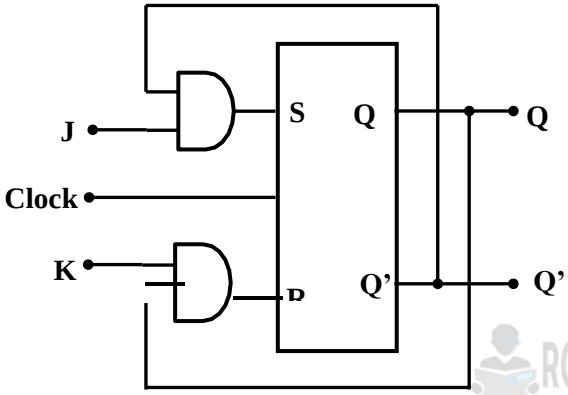


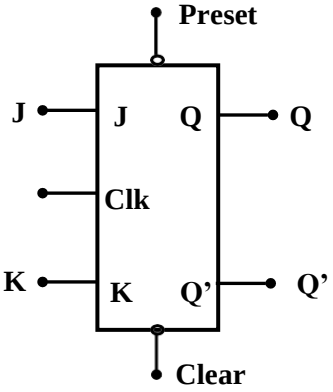
Realisation using S-R flip flop & AND gates

Input S = J . Q'

Input R = K . Q

Logic Symbol of J-K flip flop





Clk	J	K	Q_n	Q_n'	S = $J.Q_n$'	R= $K.Q_n$	Output (Q_{n+1})	Remarks
1	0	0	0	1	0	0	0	= Q_n ie. **No Change or Last State or Memory**
1	0	0	1	0	0	0	1	
1	0	1	0	1	0	0	0	= **0** , ie. **Reset** (Make Q = 0)
1	0	1	1	0	0	1	0	
1	1	0	0	1	1	0	1	= **1** , ie. **Set** (Make Q = 1)
1	1	0	1	0	0	0	1	
1	1	1	0	1	1	0	1	= Q_n' ie. **Toggle or Complement or Switch to opposite state**
1	1	1	1	0	0	1	0	

Q_n represents the Present State ; Q_{n+1} represents the Next State ie. the state of the output after the clock pulse is applied.

Race Around Condition in J-K Flip Flop : By using two AND gates & appropriate feed back the RACE problem that existed in the S-R flip flop could be eliminated in a J-K flip flop. However there is a problem of an unpredictable state occurring in the J-K flip flop also . Due to this problem the Q output will start oscillating between the 0 (low) & 1 (high) states .The output condition therefore could be either 0 or 1. This problem is known as the Race around Condition. The race around condition in a J-K flip flop occurs when J=1, K=1 and the clock is also =1, with the clock pulse width "t_p" greater than the propagation delay " • t" of the gates. We assume that the inputs of the J-K flip flop do not change during a clock pulse , but due to the feed back they change when the clock remains high (1), hence the output condition starts oscillating between the low & high states. This problem can be avoided by making the clock pulse width less than the propagation delay of the gates, but practically this is difficult because the propagation delay is very small, hence the problem of Race Around Condition is overcome using a Master-Slave J-K flip flop. In this flip flop the input conditions do not change when the clock remains high, hence the output does not oscillate.

PROPERTIES OF SEMICONDUCTOR MATERIAL :- A semiconductor is a material which exhibits the following properties :-

1) It has a resistivity lying between that of a conductor and an insulator.
2) It is tetravalent.
3) It exhibits negative temperature co-efficient of resistance .
4) It exhibits crystalline structure.
5) Its conductivity increases when doped with trivalent or penta valent atoms.

Silicon (atomic no. **14**) and Germanium (atomic no. **32**) are the two most important semiconductor materials.

INTRINSIC SEMICONDUCTOR :- A semiconductor material in its purest form is known as an intrinsic semiconductor. An intrinsic semiconductor behaves as an insulator at 0 K but acts as a conductor at 300 K (room temperature). At room temperatures due to the thermal generation of electron-hole pairs , free electrons & holes are generated in equal numbers , these mobile charges help in the conduction of current in an intrinsic semiconductor. Since electron-hole pairs that are responsible for conduction of current in an intrinsic semiconductor are internal to the semiconductor crystal , the material is known as an intrinsic semiconductor .

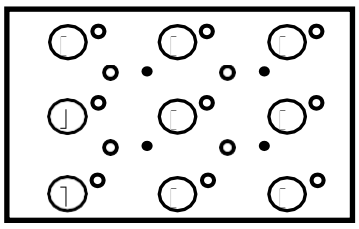
FREE ELECTRONS OR **CONDUCTION ELECTRONS :-** When external energy is supplied to a semiconductor crystal in the form of light or heat (increase in temperature), some covalent bonds break and produce free electrons. Every free electron has an associated vacant site (hole) in the covalent bond .These free electrons are not under the control of any of the nuclei within the crystal.. Since free electrons take part in the conduction of current , they are also known as conduction electrons. Conduction electrons or free electrons have energy levels much higher than valence electrons and take part in the conduction of current in a semiconductor.

VALENCE ELECTRONS OR **BOUND ELECTRONS :-** The outer most orbit electrons or valence electrons are shared by the neighboring semiconductor atoms to form covalent bonds in a crystal. A valence electron is always associated with a particular nuclei and is under it's control, hence a valence electron is also known as a bound electron. A valence electron by itself cannot take part in the conduction of current. A valence electron will take part in the conduction of current only when there is hole movement, in other words hole movement is actually the movement of valence electrons in the valence band. At 0 K all the electrons in a Silicon crystal exist as valence electrons (ie. there are no free electrons or holes) hence there is no current conduction & Silicon behaves as an insulator.

DOPING :- The process of adding a calculated quantity ($1:10^8$) of trivalent or pentavalent atoms to an intrinsic semiconductor is known as doping. Doping helps in generating a single type of charge carrier (either free electrons or holes). Doping thus increases the conductivity of a semiconductor at room temperatures.

EXTRINSIC SEMICONDUCTOR :- An extrinsic semiconductor is obtained by doping an intrinsic semiconductor with trivalent or pentavalent impurity atoms . Depending upon the valency of the impurity atoms added we obtain either p-type or n-type extrinsic semiconductor.

P-TYPE EXTRINSIC SEMICONDUCTOR :-

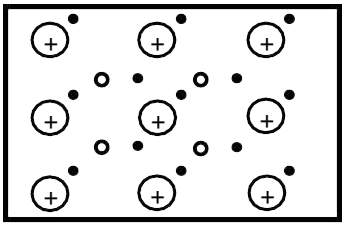


Hole (Majority Carrier)
Free electron (Minority Carrier)
Negative Immobile ion

A p-type extrinsic semiconductor is obtained by adding trivalent impurity atoms (Boron, Aluminum, Gallium or Indium) to an intrinsic semiconductor in the ratio of $1: 10^8$.

The three valence electrons of aluminum atom form three co-valent bonds with the three neighboring semiconductor atoms . The absence of a fourth valence electron creates a vacant site (hole) in one of the covalent bonds . The hole has a positive charge & is capable of accepting an electron from the semiconductor crystal to become a negative immobile ion. Thus a trivalent impurity atom is known as an acceptor impurity . Every trivalent atom added to a semiconductor crystal gives rise to a hole and a negative immobile ion. The conductivity of a p-type semiconductor is directly proportional to the doping density. In a p-type semiconductor, holes are in excess when compared to conduction electrons , hence holes are known as majority carriers and conduction or free electrons are known as minority carriers . The total current flowing through a p-type semiconductor is the sum of free electron and hole currents. Since majority of this current is due to holes (positive charges) the material is known as a p-type extrinsic semiconductor . A p-type semiconductor is electrically neutral because total number of negative charges is exactly equal to the total number of positive charges.

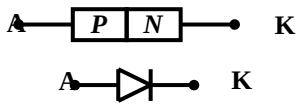
N –TYPE EXTRINSIC SEMICONDUCTOR :- A n-type semiconductor is obtained by adding pentavalent impurity atoms (phosphorus , arsenic or antimony) to an intrinsic semiconductor in the ratio of $1:10^8$ .The four valence electrons of phosphorus form four co-valent bonds with the four neighboring semiconductor atoms. The fifth valence electron cannot form a co-valent bond hence remains free. This free electron helps in the conduction of current. The pentavalent impurity atom loses one electron and becomes a positive immobile ion . When a pentavalent atom is added to an intrinsic semiconductor one electron is donated into the crystal, hence a pentavalent



- **Free electron (Majority Carrier)**
- **Hole (Minority Carrier)**
- **Positive Immobile ion**

impurity atom is also known as a donor impurity. Every pentavalent impurity atom added gives rise to a free electron and a positive immobile ion . The conductivity of a n-type semiconductor is directly proportional to the doping density. In a n-type semiconductor, electrons are in excess when compared to holes, hence electrons are majority carriers and holes are minority carriers. Since majority of the current is carried by negative charges (electrons), the material is known as n-type semiconductor. A n-type semiconductor is electrically neutral because the total number of positive charges is exactly equal to the total number of negative charges in the crystal

P-N JUNCTION DIODE :- Figure shows the construction and circuit symbol of a p-n junction diode. The arrow mark in the diode symbol indicates the direction of flow of conventional current. A p-n junction diode is fabricated using a single semiconductor crystal, in which one half is doped with p-type impurity, while the other half is doped with n-type impurity. A p-n junction diode is basically a unidirectional device (ie. it allows current to flow in one direction & blocks it in the other direction). A p-n junction diode is a high speed electronic switch & is widely used in rectifier circuits.



The operation of a semiconductor diode is studied under the following three conditions :-

(1) Unbiased condition :-

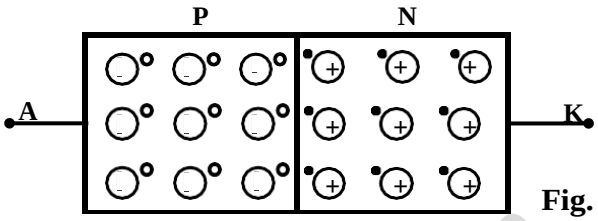


Fig. 1

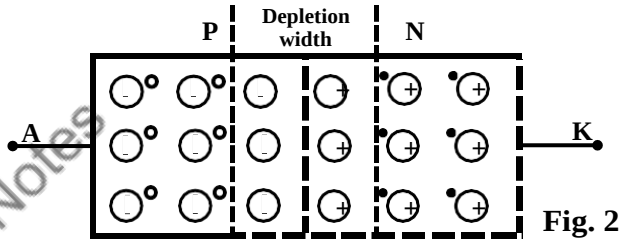


Fig. 2

Fig.2 shows a p-n junction diode under unbiased condition, ie. both the anode & cathode are at the same potential or both are at zero potential. For simplicity only impurity atoms are shown (semiconductor atoms are not shown) because for every impurity atom, there will be 10^8 semiconductor atoms (because doping density is $1:10^8$).

The p-region has negative immobile ions and their corresponding holes as the majority carriers , while the n-region has positive immobile ions and their corresponding free electrons as the majority carriers. Thermally generated electron-hole pairs are also not shown for simplicity. At the instant of junction formation, the p-material has excess holes and the n- material has excess electrons as shown in Fig.1. and the depletion region does not exist. As soon as the p & n regions are formed, electrons on the n-side recombine with holes by crossing onto the p-side of the junction due to diffusion. Soon after recombination both the electrons & the holes disappear and leave behind immobile positive ions on the n-side and immobile negative ions on p-side of the junction as shown in Fig.2. This electric field created by the immobile positive & negative ions on either side of the junction prevents further diffusion of charges. Thus a depletion region (width ' 50 ' m) is formed at the junction even under unbiased conditions as shown in Fig.2.

(2) Forward biased condition :-

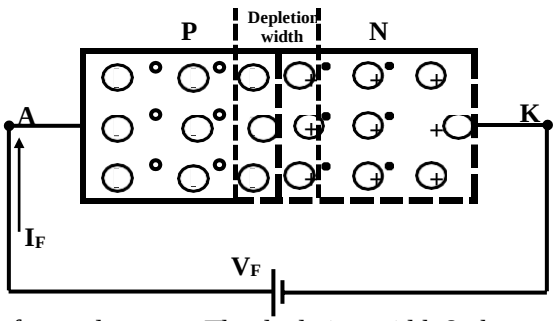
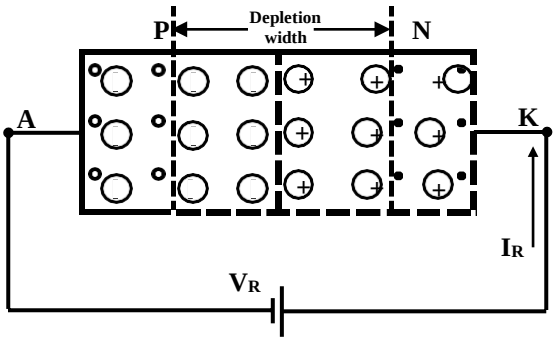


Figure shows a p-n junction diode under forward biased condition (ie. anode is at a higher potential than the cathode). The battery polarity is such that majority carriers in both p & n regions are pushed towards the junction. Since electrons & holes enter the depletion region, it causes a reduction in the depletion width & hence height of the potential barrier. The reduced potential barrier allows a few high- energy electrons on the n-side to cross the junction on to the p-side and constitute a small forward current. As the magnitude of forward bias voltage is increased the depletion width further reduces & thereby further increases the forward current. The depletion width & the potential barrier reduce to almost zero when the p-n junction is forward biased by a voltage greater than the cut-in voltage V (0.7 V for Silicon diode & 0.3 V for Germanium diode).

At voltages greater than V a p-n junction diode acts like a closed switch (offers zero resistance) and a heavy current starts flowing. Practically a very small value resistance is offered due to the existence of the bulk resistance of the semiconductor crystal.

The thermally generated electron-hole pairs present in both p and n regions & the minority carriers also move in the same direction as majority carriers , ie. they also add to the forward current.

(3) Reverse biased condition :-



When a p-n junction diode is reverse biased (ie. anode is at a lower potential than the cathode) a very small reverse current flows through the junction due to a small number of temperature dependent minority charge carriers (electrons in p-region & holes in n-region). This minority current or leakage current is also known as the reverse saturation current & is temperature dependent. The leakage current which has a very small value(1 or 2 μA) doubles itself for every 10° C rise in temperature . The diode therefore offers very high resistance (1 to 2 MΩ). This means that the diode acts as an open switch under reverse biased conditions. The battery connection is such that majority carriers in both p and n regions are pulled away from the junction. Thus both the depletion width and the potential barrier increase under reverse bias conditions. This reverse current flows until the reverse voltage is equal to the junction breakdown voltage. Beyond breakdown voltage, there is a drastic increase in the reverse current which is explained using the avalanche breakdown phenomenon. At voltages beyond V_{BD}, minority carriers (electrons) on the p-side gain sufficiently high velocities to knock out valence electrons from the semiconductor atoms. This is a cumulative effect and is known as ionisation due to collision. A large number of charges are thus available to constitute a large reverse current. If left uncontrolled, this reverse current can cause physical breakdown of the junction. A p-n junction diode under reverse biased condition is therefore operated well within its breakdown voltage.

V-I CHARACTERISTICS OF P-N JUNCTION DIODE :-

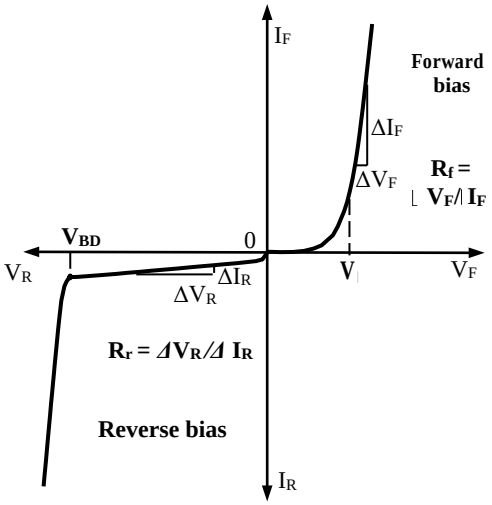


Figure shows the forward & reverse bias characteristics of a p-n junction diode.

Forward bias condition: When the forward bias voltage $V_f = 0$, the forward current I_f is also equal to 0. When the forward bias voltage is increased, current through the diode gradually increases because some high-energy electrons start crossing the junction. Any further increase in V_f causes an increase in forward current due to reduction in depletion width & potential barrier. When $V_f = V_\gamma$, the depletion width is zero & potential barrier is also zero. Now a large current starts flowing through the diode. Thus beyond V_γ the diode acts as a closed switch and offers very low resistance resulting in a rapid rise in current. The characteristics will be non-linear from the origin to V_γ because the total diode resistance $R_T = (R_J + R_B)$, where R_J is the voltage dependent junction resistance and R_B is the voltage independent semiconductor crystal bulk resistance.

The non-linearity in the characteristics from origin to V_γ is because of the junction resistance, which is reducing with an increase in voltage. The characteristic is linear beyond V_γ because the junction resistance becomes zero after V_γ & it is only the voltage independent bulk resistance R_B that remains . Thus the diode starts behaving as a closed switch only beyond V_γ with a very low value of forward resistance R_f.

Reverse bias condition :- When a p-n junction is reverse biased, a very small leakage current flows due to a very small number of temperature dependent minority carriers. The leakage current I_R is also known as reverse saturation current or minority current. This small current continues to flow until the applied reverse voltage is equal to the breakdown voltage V_{BD} . Beyond V_{BD} there is rapid increase in the leakage current due to Avalanche breakdown phenomenon. At voltages beyond V_{BD} ,minority electrons on the p-side of the junction gain sufficiently high velocities to knock out valence electrons from the semiconductor atoms within the crystal. This is a cumulative process & a large number of charges are made available to cause a large value of leakage current as shown in the characteristics. This phenomenon is also known as ionization due to collision. Hence a p-n junction diode under reverse bias condition, is operated well within its breakdown voltage if it has to work as an open switch.

DEPLETION REGION :- When a p-n junction is formed there is movement of charges across the junction due to diffusion even under unbiased conditions. This results in uncovering of the Donor ions (positive immobile ions) on the n-side & the Acceptor ions (negative immobile ions) on the p-side (Refer to Fig.2 on page-2). This region on either sides of the junction consisting of the uncovered immobile positive & negative ions is known as the Depletion Region. Since this region is depleted of mobile charges ie. there are no mobile charges it is known as the

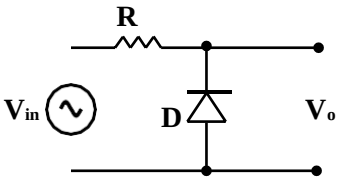
Depletion region or Transition Region. It is also known as the space charge region because it consists of immobile positive & negative ions. Since this region does not contain mobile charges it behaves as an insulator. The region across the junction which does not have mobile charge carriers is known as the depletion width.
When a p-n junction is forward biased, due to the applied voltage the Depletion Width gets reduced and the diode starts conducting because of the lower value of junction resistance.
When the p-n junction is reverse biased, due to the applied reverse bias voltage the Depletion Width increases and the diode offers a very high resistance to the flow of current due to the increased width of the insulator.
BARRIER POTENTIAL :- The electric field that exists across a p-n junction between the positive immobile ions on the n-side & negative immobile ions on the p-side of the depletion region is known as the Barrier. Uncovered donor & acceptor ions exist on either sides of a p-n junction. These are isolated positive & negative electrical charges which can result in an electric field at the junction. This electric field prevents further diffusion of holes & electrons across the junction under unbiased conditions, ie. it acts as an obstruction or barrier to the movement of electric charges, hence it is known as the potential barrier. The physical distance from one side of the barrier to the other side is known as the barrier width. The difference in potential between the two sides is known as the height of potential barrier. The potential barrier is approximately 0.7V for a Silicon diode & 0.3V for a Germanium diode.

DIODE APPLICATIONS :

Diode clipping circuits :

A clipper circuit is a diode network which can clip off a portion of the input signal without distorting the remaining waveform. Clipper circuits are also known as Slicers or Limiters. Depending on the diode connection in the circuit the positive or negative side of the input waveform is clipped. If a dc voltage source is connected in series with the diode it is known as a biased clipper if not it is known as an unbiased clipper. If the diode is in parallel with the output terminals the circuit is known as a parallel clipper (shunt clipper) and if the diode is in series with the output terminals it is known as a Series clipper. The reference voltage at which the waveform has to be clipped should always be less than the maximum or peak voltage of the input signal (ie. $V_R < V_m$).
In all clipper circuits it is assumed that the diode used for clipping is an ideal diode ie. it's cut-in voltage is zero (ie. $V_\gamma = 0$) & the forward resistance is also zero(ie. $R_f = 0$).

Negative wave clipper:



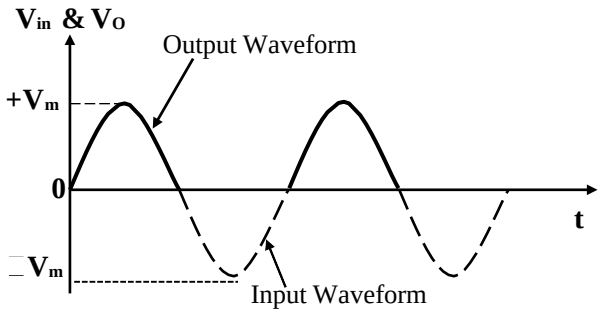


Figure shows the circuit diagram of a negative wave clipper. The diode D is assumed to be an ideal clipping device ie. its cut-in voltage $V_\gamma = 0$ & the forward resistance $R_f = 0$.
During the positive half cycle diode D gets reverse biased and acts like an open switch (infinite resistance) . Hence the output wave form follows the input waveform.
During the negative half cycle diode D gets forward biased and acts like a closed switch (zero resistance) . Hence the output voltage across a zero resistance will be zero.
In this circuit only the negative half cycles are clipped while the positive half cycles appear at the output.

Diode Clamping Circuits :

The circuit is also known as DC level shifter or DC level restorer. A diode clamping circuit is used to fix an AC signal to any desired DC level (zero, positive or negative) without changing the shape or amplitude of the input signal. Both the positive & negative peaks can be clamped to any desired DC level. It is important that the (R.C) time constant of the circuit is very large when compared to the time period of the input waveform. This condition will keep the output waveform undistorted (ie. the square wave will have constant amplitude during the entire half

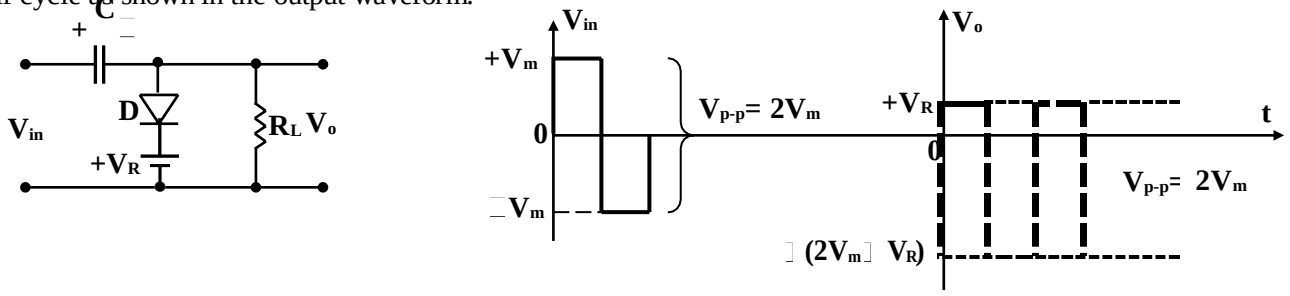
cycle). The reference voltage to which the waveform has to be fixed or clamped should always be less than the maximum or peak voltage (V_m) of the input signal.

In all clamper circuits it is assumed that the diode used for clamping is an ideal diode ie. it's cut-in voltage is zero (ie. $V_\gamma = 0$) & the forward resistance is also zero (ie. $R_f = 0$) .

Positive peaks clamped to positive reference voltage :

Figure shows the circuit diagram which clamps the positive peaks of the input waveform to a positive reference voltage level. The diode D is assumed to be an ideal clamping device ie. its cut-in voltage $V_\gamma = 0$ & the forward resistance $R_f = 0$.

During the positive half cycle , diode D gets forward biased and capacitor C charges to a voltage equal to (V_m ' V_R) with a polarity as shown in the circuit. Since the diode is a closed switch (zero cut-in voltage & zero forward resistance), the output voltage will be equal to the reference voltage($+V_R$ volts) during the entire positive half cycle as shown in the output waveform.



During the negative half cycle, the input voltage will be in series with the capacitor voltage which is already charged to (V_m ' V_R) , the diode is kept reverse biased by the sum of the input & capacitor voltages. The diode now behaves as an open switch and the output voltage will be equal to the sum of the input & capacitor voltages ie. equal to $[-(2.V_m - V_R)]$. Thus in the output voltage waveform the positive peaks appear to be clamped to a positive reference voltage level V_R during the entire negative half cycle. After clamping it is observed that the output peak to peak voltage swing remains unchanged at a value equal to ($2.V_m$).

Half wave rectifier :

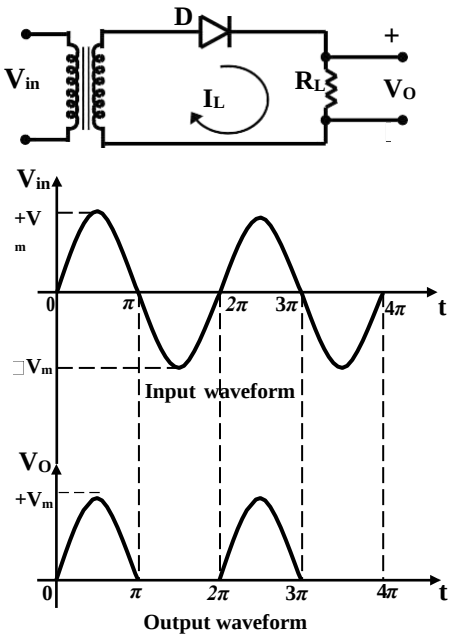


Figure shows the circuit diagram of a half wave rectifier. It consists of a silicon diode D connected to the secondary of a step down transformer. The load resistance R_L is connected in series with the diode.

During the positive half cycle (0 to ·), the diode D is forward biased and acts like a closed switch offering very low resistance. The load current I_L varies in accordance with the input voltage V_{in} (I_L · V_{in}) as shown in figure. The output voltage V_O is equal to ($I_L.R_L$) , since R_L is a constant the output voltage Vo · I_L. Thus during positive half cycle, the output voltage follows the load current & in turn the input voltage V_{in}.

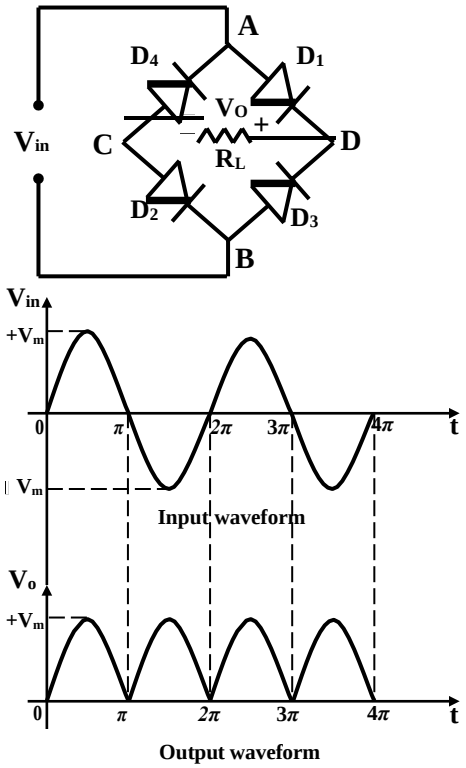
During the negative half cycle(· to 2·)., the diode D is reverse biased and acts like an open switch ie. the diode offers very high resistance. Thus the load current I_L is almost zero, so that V_O is zero during the negative half cycle

This cycle repeats and the circuit produces an output only during one half of the input cycle. This circuit is therefore known as a half wave rectifier. The output of this circuit is a pulsating DC whose frequency is equal to the input frequency. For a half wave rectifier we have the following important expressions:

$I_{DC} = (I_m / \pi)$; $I_{RMS} = (I_m/2)$

% η = 40.6 ; Ripple Factor =1.21

Full wave bridge rectifier:



A full wave bridge rectifier uses four diodes as shown in the circuit diagram. The load resistance R_L is connected between C and D, while the input voltage is applied between points A and B.

During the positive half cycle (0 to ·), point A is at a higher potential than B, hence diodes D_1 and D_2 are forward biased and act as closed switches. The current I_1 flows from points A to B through D_1, R_L and D_2. Both D_3 and D_4 are reverse biased during the positive half cycle and act as open switches. Thus the output current during positive half cycle due to diodes D_1 and D_2 flows through R_L and produces an output as shown in the waveforms.

During the negative half cycle (· to 2·), point B is at a higher potential than A, hence D_3 and D_4 are forward biased and act as closed switches. Current I_2 flows from point B to point A through D_3, R_L and D_4. Both D_1 and D_2 are reverse biased during the negative half cycle and act as open switches. The output current due to D_3 and D_4 flows through R_L producing an output as shown in the waveforms.

The direction of currents I_1 and I_2 through the load resistance R_L during both the half cycles is identical, hence the output voltage has the same polarity and is plotted in the same quadrant. As the circuit produces an output during both the half cycles, it is known as a full wave rectifier. In this case the output voltage is $+V_m$ if the input voltage has a peak value of V_m. The output frequency is twice the input frequency.

For a Full wave rectifier we have the following important expressions:

$I_{DC} = (2I_M / \pi)$; $I_{RMS} = (I_M/\sqrt{2})$

% η = 81.2 ; Ripple Factor = 0.48

Rectifier efficiency :- It is defined as the ratio of DC output power to the AC input power. It is a measure of the AC to DC conversion capacity of the rectifier circuit.

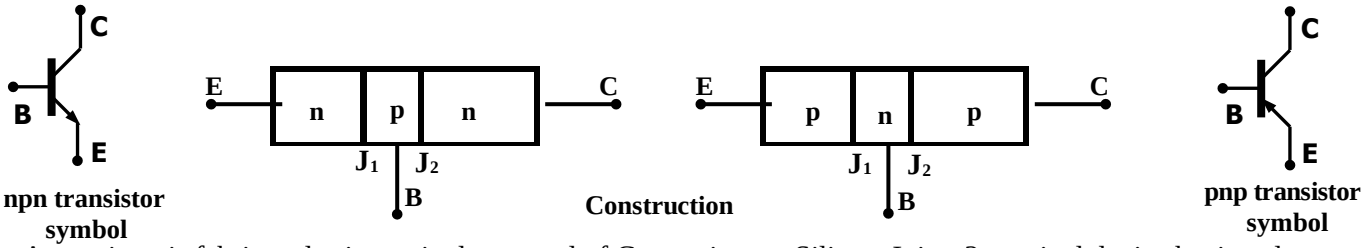
η = P_{DC} / P_{AC} = [output DC power / input AC power] = $[(V_{DC}.I_{DC}) / \{(V_{rms})^2/(R_f + R_L)\}]$

Ripple factor :- It is defined as the ratio of RMS value of AC component to the average value of the dc component. It is the measure of the pulsating component in the output.

Ripple factor = ripple voltage / DC value of output

Ripple factor = [RMS value of AC component / DC value of output] = $[(I_{rms} / I_{dc})^2 - 1]^{1/2}$

BIPOLAR JUNCTION TRANSISTORS :



npn transistor symbol

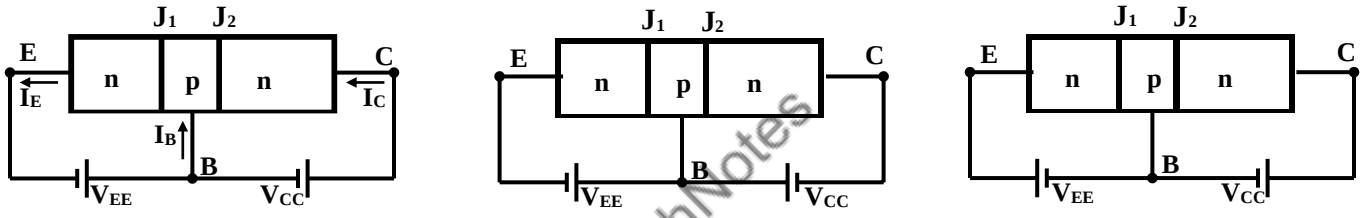
Construction

pnp transistor symbol

A transistor is fabricated using a single cryzstal of Germanium or Silicon. It is a 3 terminal device having alternate p and n layers with two junctions J_1 & J_2. This type of construction results in npn and pnp transistors. In a npn transistor, the p-layer is sandwiched between two n-layers. The first n-layer is the emitter which emits electrons. The n-type emitter layer is heavily doped to provide better injection efficiency. The other n-layer is the collector which collects electrons. The collector region is moderately doped and has a large width to help better heat dissipation. The p-type base layer forms one junction (J_1) with the emitter and another junction (J_2) with the collector layer. The base region is lightly doped and has a narrow width , this helps in reducing recombination in the base and in the process reduces the value of base current & increases the value of collector current.

In a pnp transistor the n-layer is sandwiched between two p-layers. The construction and symbol for npn and pnp transistors is as shown in figure. The arrow mark on the emitter lead indicates the direction of flow of conventional current.

TRANSISTOR BIASING:-



Transistor biased as Amplifier

Transistor biased as closed switch

Transistor biased as open switch

If a transistor has to work as an amplifier, the base-emitter junction J_1 must be forward biased and the collector-base junction J_2 must be reverse biased. Transistor biasing is a process of creating an appropriate potential difference across the base-emitter and the collector-base junctions. The base-emitter junction should always be forward biased by a voltage greater than its cut-in voltage (V_γ), while the collector-base junction should be sufficiently reverse biased for efficient collection of charges. If these two conditions are satisfied, the transistor provides faithful amplification while operating in the active region (linear region).

A transistor can also operate as a switch (in the non-linear regions). If both the emitter-base & collector-base junctions are forward biased then the transistor will behave as a closed switch offering almost zero resistance(saturation region) . If both the emitter-base & collector-base junctions are reverse biased then the transistor behaves as an open switch offering very high resistance(cut-off region)

TRANSISTOR OPERATION :-

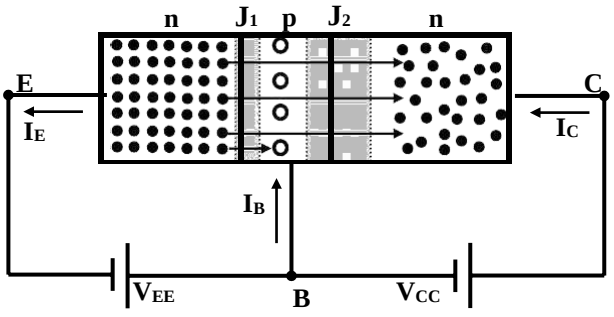


Figure shows the battery connections and directions of current in a npn transistor. V_{EE} is the emitter battery, which forward biases the base-emitter junction while V_{CC} is the collector battery which reverse biases the collector-base junction. I_B is the base current, I_C is the collector current and I_E is the emitter current. The forward biased base-emitter junction makes the emitter inject a large number of electrons into the base region. Electrons are minority carriers in the p-type base region, hence they easily diffuse into the collector region. Some electrons are lost due to recombination in the p-type base region and constitute a small base current. The base current magnitude is kept minimum by using a lightly doped narrow base region. The reverse biased collector-base junction will assist the diffusion of minority carriers (electrons) from base to the collector region. These electrons are then collected by the positive terminal of the battery V_{CC}. Electrons flowing out of the collector constitute a large collector current. Using Kirchoff's law, the fundamental transistor equation can be shown to be : $I_E = I_B + I_C$

I_B is very small when compared to I_C (3 to 4 % of I_C). Therefore $I_E \approx I_C$, ie. input current = output current.

A small reverse current flows through the collector-base junction when the emitter lead is open (when the input current is zero). This reverse current or leakage current is I_{CBO} (collector to base current with emitter open), ie. the output collector current $I_C = I_{CBO}$ when the input current is zero. I_{CBO} is temperature dependent and independent of the applied reverse voltage. In a transistor, a large emitter current flowing through a low resistance input circuit is transferred into a high resistance collector circuit (output circuit), hence it is called a transfer-resistor or a transistor.

TRANSISTOR CONFIGURATIONS :-

A transistor has only 3 leads hence any one of the 3 leads has to be common to the input & output circuits if the transistor is to be considered as a 2-port linear network . Depending on the lead that is common to both the input & output circuits there are three transistor configurations :

(1) Common-base configuration or Grounded-base configuration.
(2) Common-emitter configuration or Grounded-emitter configuration.
(3) Common-collector configuration or Grounded-collector configuration.

The behaviour of a transistor varies greatly with each configuration & can be understood by studying the input & output characteristics in all the 3 configurations.

COMMON BASE CONFIGURATION :-

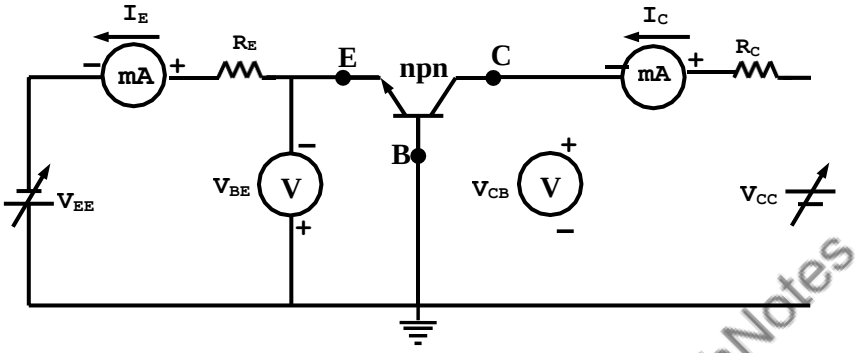


Figure shows the circuit arrangement for obtaining the input and output characteristics of a npn transistor in common-base configuration. V_{EE} is the emitter battery on the input side and R_E is the emitter current limiting resistor. The milliammeter is used to measure the emitter current(input current) while the voltmeter is used to measure the input voltage V_{BE}. V_{CC} is the collector battery on the output side and R_C is the collector resistance.

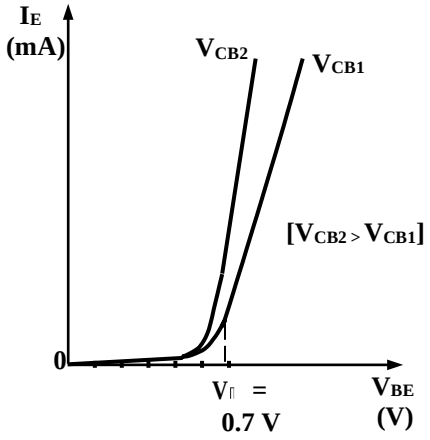
The milliammeter measures the collector current (output current) while the voltmeter measures the collector-base voltage, V_{CB} (output voltage). Here the base lead is common to both the input and output circuits, hence it is known as the common-base configuration.

Input Characteristic:-

The input characteristics is a plot of Input voltage v/s Input current keeping output voltage constant .

ie. V_{BE} v/s I_E keeping V_{CB} constant.

The input characteristics is obtained by varying V_{BE} in steps and noting down the corresponding values of I_E keeping V_{CB} constant. A family of curves can be obtained for different values of V_{CB}.



The dynamic input resistance r_i is obtained using the relation:

$$r_i = \Delta V_{BE} / \Delta I_E \mid V_{CB} = \text{constant.}$$

Output Characteristic:-

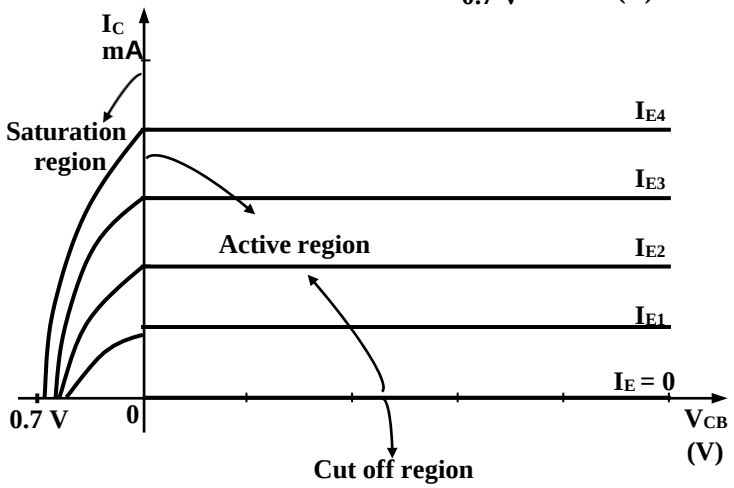
The output characteristic is a plot of output voltage v/s output current keeping input current constant,

ie. **V_{CB} v/s I_C keeping I_E constant.**

It is obtained by varying V_{CB} in steps and noting down the corresponding values of I_C keeping I_E constant.

A family of curves are obtained for different values of I_E. $I_C \approx I_E$ because I_B is very small.

The slope of the output characteristic is almost zero, this means that the output resistance is very large.



The dynamic output resistance is given by the relation:

$r_o = \Delta V_{CB}/\Delta I_C \mid I_E = \text{constant}.$

α is the current gain of a transistor in common base configuration and is determined using the relation:

$\alpha = \Delta I_C/\Delta I_E \mid V_{CB} = \text{constant}.$

The input resistance r_i has a very low value (5 to 15 Ω) while the output resistance has a very high value(Ω 1M Ω). The current gain β has a value less than 1 (0.95 to 0.995). The voltage gain is high (150-200).

Applications:- A transistor in common-base configuration is used as a Wide-band amplifier, a constant current source and a buffer amplifier (for impedance matching).

COMMON EMITTER CONFIGURATION :

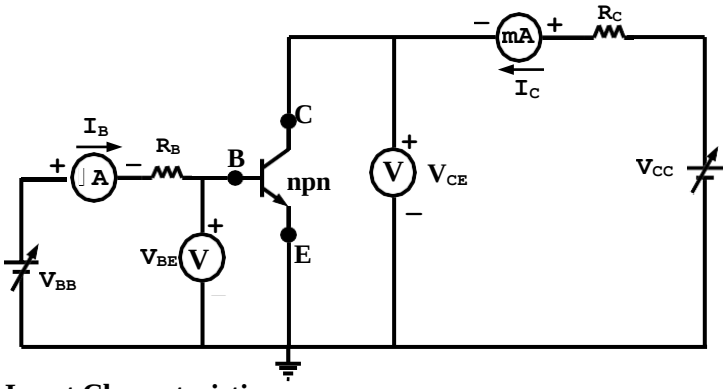


Figure shows the circuit diagram for a transistor in common-emitter configuration. Battery V_{BB} is used to forward bias the base-emitter junction. The microammeter measures the input current I_B and the voltmeter measures the input voltage V_{BE}. Battery V_{CC} is used to reverse bias the collector-base junction ($V_{CC}>V_{BB}$). The milliammeter is used to measure the output current I_C while the voltmeter measures the output voltage V_{CE}. R_B is the base resistor and R_C is the collector resistor. Here the emitter lead is common to both the input and output circuits, hence it is known as common-emitter configuration

Input Characteristic:-

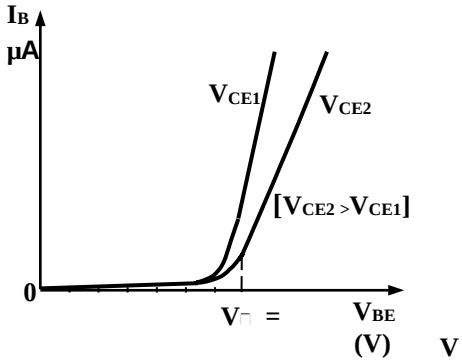
The input characteristics is a plot of Input voltage v/s Input current keeping output voltage constant .

ie. V_{BE} v/s I_B keeping V_{CE} constant

The input characteristics is obtained by varying V_{BE} in steps and noting down the corresponding values of I_B keeping V_{CE} constant. A family of curves can be obtained for different values of V_{CE}.

The dynamic input resistance r_i is obtained using the relation:

$r_i = \Delta V_{BE}/\Delta I_B \mid V_{CE} = \text{constant}.$



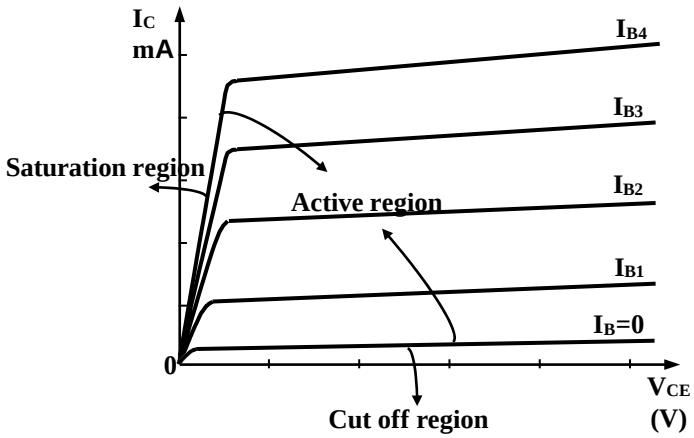
Output Characteristic:-

The output characteristic is a plot of output voltage v/s output current keeping input current constant,

ie. **V_{CE} v/s I_C keeping I_B constant.**

It is obtained by varying V_{CE} in steps and noting down the corresponding values of I_C keeping I_B constant.

A family of curves is obtained for different values of I_B. The slope of the output characteristic is appreciable, this means that the output resistance is not as large as in case of common-base configuration. The dynamic output resistance is given by the relation:



$r_o = \Delta V_{CE}/\Delta I_C \Delta I_B = \text{constant}.$

β is the current gain of a transistor in common-emitter configuration and is determined using the relation:

$\beta = \Delta I_C/\Delta I_B \Delta V_{CE} = \text{constant}.$

The input resistance r_i is high when compared to common-base configuration (500 Ω to 1.5k Ω).The output resistance has a high value (15 kΩ to 50 kΩ). The current gain β has a very large value (200 to 400). The voltage gain is very high (250 to 500).

Applications:- A transistor in common-emitter configuration is used as a voltage amplifier, power amplifier and multi-stage amplifier.

Important Equations For Transistor In Common Emitter Configuration:-

[1] $I_C = \beta.I_B + (1+\beta) I_{CBO} = \beta.I_B + I_{CEO}$. ; **[2]** $I_C = \beta.I_B$ (neglecting leakage current, ie. $I_{CEO} = 0$).

[3] $I_C = I_{CEO}$ (when input current $I_B = 0$) ; **[4]** $I_{CEO} = (1 + \beta).I_{CBO}$.

COMMON COLLECTOR CONFIGURATION :-

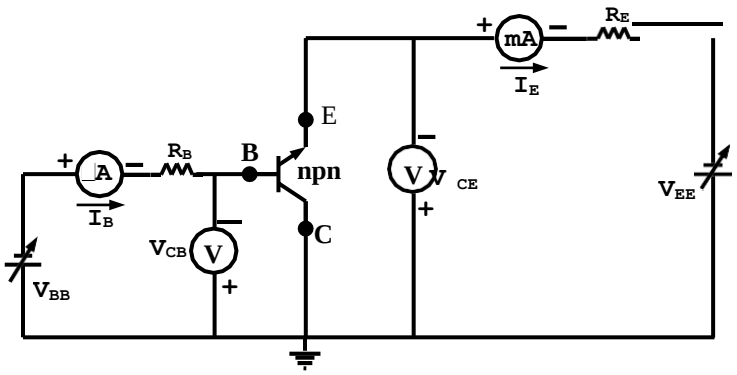
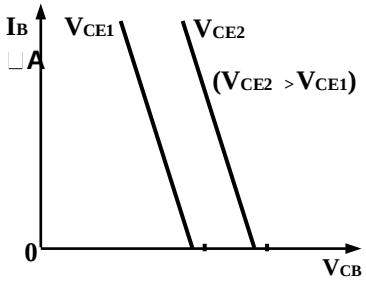


Figure shows the circuit diagram for a npn transistor in common-collector configuration. Battery V_{BB} is used to reverse bias the collector-base junction. The microammeter measures input current I_B and the voltmeter measures input voltage V_{CB}. Battery V_{EE} along with V_{BB} is used to forward bias the base-emitter junction (V_{EE} is at lower potential than V_{BB}). The milliammeter is used to measure output current I_E, while the voltmeter measures the output voltage V_{CE}. (I_E is the output current and V_{CE} is the output voltage).R_B is the base resistor and R_E is the emitter resistor. Here the collector lead is common to both the input and output circuits, hence it is known as common-collector configuration.

Input Characteristic:-

The input characteristics is a plot of Input voltage v/s Input current keeping output voltage constant .

ie.V_{CB} v/s I_B keeping V_{CE} constant.



The input characteristics is obtained by varying V_{CB} in steps and noting down the corresponding values of I_B keeping V_{CE} constant. A family of curves can be obtained for different values of V_{CE}.

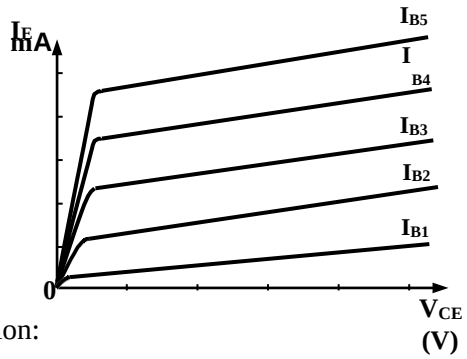
The dynamic input resistance r_i is obtained using the relation:

r_i = □V_{CB}/□I_B | V_{CE} = constant.

Output Characteristic:-

The output characteristic is a plot of Output voltage v/s Output current keeping Input current constant,

ie. **V_{CE} v/s I_E keeping I_B constant.**



It is obtained by varying V_{CE} in steps and noting down the corresponding values of I_E keeping I_B constant.

A family of curves are obtained for different values of I_B.

I_C ' I_E because I_B is very small.

The slope of the output characteristic is more appreciable than that of the common-emitter configuration, this means that the output resistance is much smaller than that of the common-emitter configuration. The dynamic output resistance is given by the relation:

r_o = □V_{CE}/□I_E | I_B = constant.

' is the current gain of a transistor in common-collector configuration and is determined using the relation:

] = □I_E/□I_B | V_{CE} = constant.

The input resistance r_i is very high when compared to common-emitter configuration (• 1 M •).The output resistance has a very low value (less than 500 •). The current gain ' has a very large value (' + 1). The voltage gain is very low (A_V • 1).

Applications:- It is used as a buffer amplifier to provide excellent impedance matching between two stages. The circuit is commonly known as an **Emitter follower.**

Comparison Of The Three Transistor Configurations:-

Sl. No.	PARAMETER	C-B Confgrn.	C-E Confgrn.	C-C Confgrn.
1	Current gain	Very low (<1)	Very high (200-400)	Very high (1+β)
2	Voltage gain	High (100-200)	Very high (250-500)	Very low (<1)
3	Input impedance	Very low (10-15 •)	Medium (~ 1 k •)	Very high (~ 1M •)
4	Output impedance	Very high (' 1 M •)	Medium (20-50 k •)	Very low (< 1 k •)
5	Applications	Wide-band Amp, Constant current source, Buffer Amp.	Voltage Amp, multi-stage Amp, power-Amp, Audio Amp.	Buffer Amp. (as Impedance matching network)

RELATIONSHIP BETWEEN □ AND □:-

□ is the current gain of a transistor in common-base configuration and is given by the relation, □ = □I_C / □I_E

□ is the current gain of a transistor in common-emitter configuration and is given by the relation, □ = □I_C / □I_B

(1) □ in terms of □:- The basic transistor equation is given by: $I_E = I_B + I_C$ ----------**(A)**

Considering the incremental values, we have ⋅ I_E = ⋅ I_B + ⋅ I_C ----------**(B)**

Divide equation **(B)** through out by ⋅ I_C, ie. (⋅ I_E / ⋅ I_C) = (⋅ I_B / ⋅ I_C) + (⋅ I_C / ⋅ I_C)----------**(C)**

But (⋅ I_C / ⋅ I_E) = ⋅ ⋅ (⋅ I_E / ⋅ I_C) = (1 / ⋅) **&** (⋅ I_C / ⋅ I_B) = ⋅ □ (⋅ I_B / ⋅ I_C) = (1 / ⋅)

ie. (1/⋅) = (1 / ⋅) + 1----------**(D).**

ie. (1 / ⋅) = (1+ ⋅) / ⋅ ; Taking the reciprocal we have :

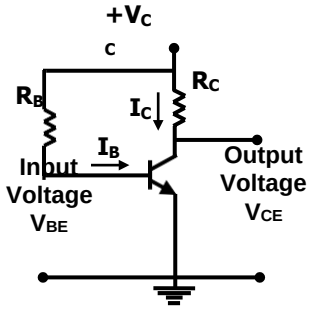
□ = □ / (□ + 1)

(2) □ in terms of □:- From equation **(D)**, we have 1 / ⋅ = 1 + (1 / ⋅) □ 1/ ⋅ = (1 / ⋅) – 1.ie.

(1 / ⋅) = (1 – ⋅) / ⋅ □ □ □ = □ / **(1** – □**)**

FIXED BIAS CIRCUIT or BASE BIAS CIRCUIT : Figure shows a fixed bias circuit . V_{CC} is the battery used for biasing both the junctions. R_C is the collector resistance & R_B is the base resistance. The Q-point is located in the active region by properly selecting the values of V_{CC}, R_B & R_C, so that a proper value of base current (I_B) will fix up the quiescent I_{CQ} & V_{CEQ} & hence the operating point.

The operating point position on the load line can be determined by calculating the values of I_C & V_{CE} in the circuit.



(1) The output Current or Collector Current (I_C):

The output current or the Collector current is given by the expression :

$I_C = \beta.I_B + I_{CEO}$ [but I_{CEO} is very small compared to $\beta.I_B$]

Hence $I_C = \beta.I_B$ ---------- **(A)**

But the base current or input current is given by : $I_B = [V_{CC}/R_B]$

Therefore the collector current is given by : $I_C = \beta.[V_{CC}/R_B]$ ---------- **(B)**

(2) The output voltage or the Collector- Emitter Voltage (V_{CE}):

The out put voltage or the Collector-Emitter voltage is given by:

$V_{CC} = I_C.R_C + V_{CE}$

ie. $V_{CE} = [V_{CC} – I_C.R_C]$----------**(C)**

Use the value of I_C from equation (B) in equation (C) ,

ie. $V_{CE} = V_{CC}[1 – \beta.(R_C/R_B)]$ ---------- (D)

The values of I_C and V_{CE} obtained using equations (B) and (D) will help in locating the operating point of the transistor on the DC load line .