BASIC ELECTRICAL AND ELECTRONICS ENGINEERING
Unit-1

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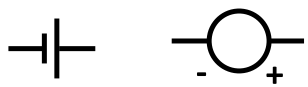
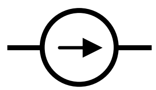
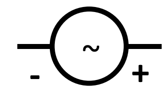
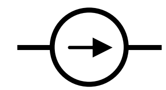
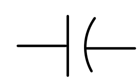
ELECTRIC CIRCUITS

Electric circuits are broadly classified as Direct Current (D.C.) circuits and Alternating Current (A.C.) circuits. The following are the various elements that form electric circuits.

D.C. Circuits

Elements	Representation
Voltage source	
Current source	
Resistor	

A.C. Circuits

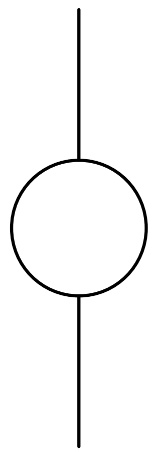
Elements	Representation
Voltage source	
Current source	
Resistor	
Inductor	
Capacitor	

We also will classified sources as **Independent** and **Dependent** sources

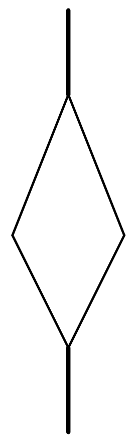
Independent source establishes a voltage or a current in a circuit without relying on a voltage or current elsewhere in the circuit

Dependent sources establishes a voltage or a current in a circuit whose value depends on the value of a voltage or a current elsewhere in the circuit

We will use circle to represent **Independent source** and diamond shape to represent **Dependent sources**



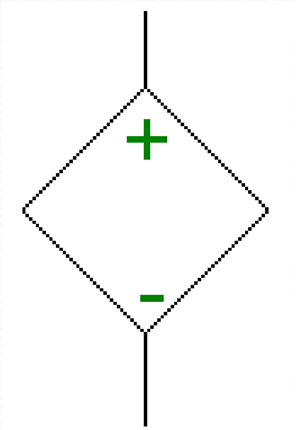
Independent source



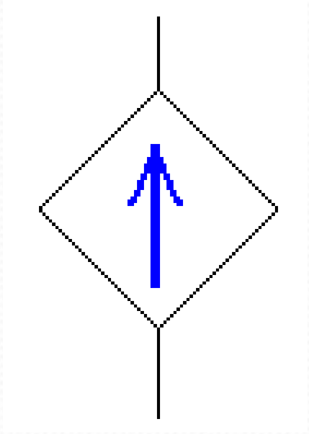
Dependent sources

Dependent Power Sources

- Voltage controlled voltage source
  - (VCVS)
- Current controlled voltage source
  - (CCVS)



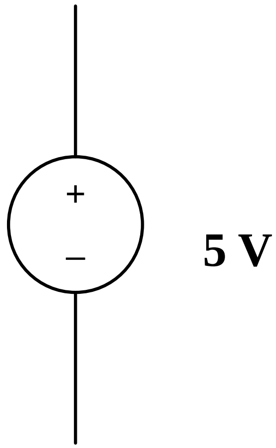
- Voltage controlled current source
  - (VCCS)
- Current controlled current source
  - (CCCS)



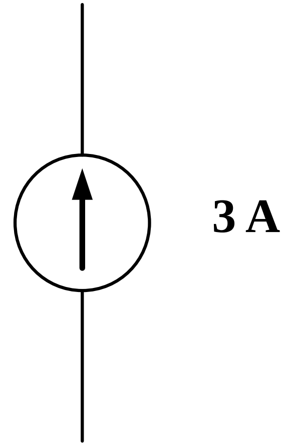
Summary

- Dependent sources are voltage or current sources whose output is a function of another parameter in the circuit.
    - Voltage controlled voltage source (VCVS)
    - Current controlled current source (CCCS)
    - Voltage controlled current source (VCCS)
    - Current controlled voltage source (CCVS)
- Dependent sources only produce a voltage or current when an independent voltage or current source is in the circuit.
- Dependent sources are treated like independent sources when using nodal or mesh analysis, but <u>**not**</u> with superposition.

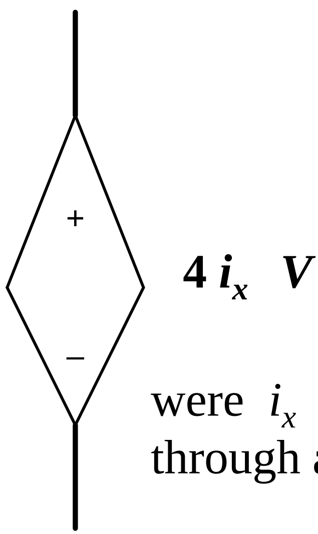
Independent and dependent voltage and current sources can be represented as



Independent voltage source

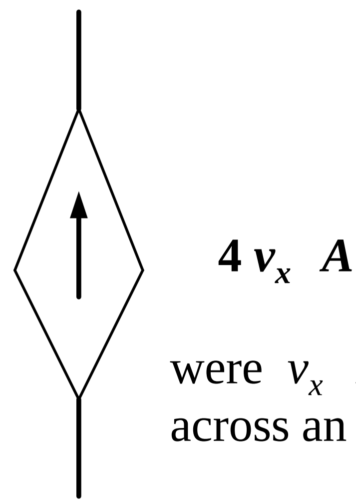


Independent current source



were i_x is some current through an element

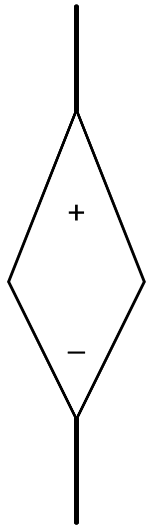
Dedependent voltage source
Voltage depend on current



were v_x is some voltage across an element

Dedependent current source
Current depend on voltage

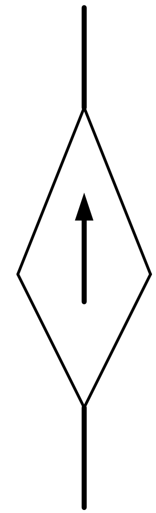
The dependent sources can be also as



$\boldsymbol{4\, v_x \quad V}$

were v_x is some current
through an element

Dedependent voltage source
Voltage depend on voltage



$\boldsymbol{7\, i_x \quad A}$

were i_x is some voltage
across an element

Dedependent current source
Current depend on current

First we shall discuss about the analysis of DC circuit. The voltage across an element is denoted as E or V. The current through the element is I.

Conductor is used to carry current. When a voltage is applied across a conductor, current flows through the conductor. If the applied voltage is increased, the current also increases. The voltage current relationship is shown in Fig. 1.

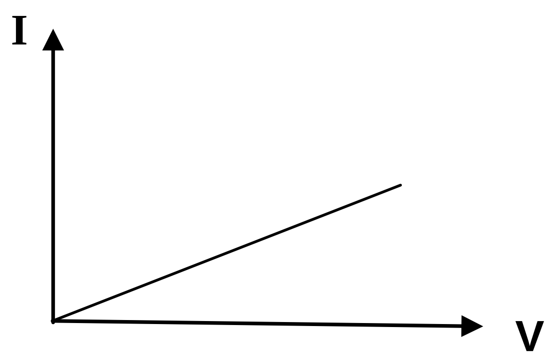


Fig. 1 Voltage – current relationship

It is seen that $I \infty V$. Thus we can write

$$I = G\,V \tag{1}$$

where G is called the conductance of the conductor.

Very often we are more interested on RESISTANCE, R of the conductor, than the conductance of the conductor. Resistance is the opposing property of the conductor and it is the reciprocal of the conductance, Thus

$$R = \frac{1}{G} \quad \text{or} \quad G = \frac{1}{R} \tag{2}$$

Therefore

$$I = \frac{V}{R} \tag{3}$$

The above relationship is known as OHM's law. Thus Ohm law can be stated as the current flows through a conductor is the ratio of the voltage across the conductor and its resistance. Ohm's law can also be written as

$$V = R\, I \tag{4}$$

$$R = \frac{V}{I} \tag{5}$$

The resistance of a conductor is directly proportional to its length, inversely proportional to its area of cross section. It also depends on the material of the conductor. Thus

$$R = \rho \frac{\ell}{A} \tag{6}$$

where ρ is called the specific resistance of the material by which the conductor is made of. The unit of the resistance is Ohm and is represented as Ω. Resistance of a conductor depends on the temperature also. The power consumed by the resistor is given by

$$P = V\,I \tag{7}$$

When the voltage is in volt and the current is in ampere, power will be in watt. Alternate expression for power consumed by the resistors are given below.

$$P = R\,I \times I = I^2 R \tag{8}$$

$$P = V \times \frac{V}{R} = \frac{V^2}{R} \tag{9}$$

KIRCHHOFF’s LAWS

There are two Kirchhoff’s laws. The first one is called Kirchhoff’s current law, KCL and the second one is Kirchhoff’s voltage law, KVL. Kirchhoff’s current law deals with the element currents meeting at a junction, which is a meeting point of two are more elements. Kirchhoff’s voltage law deals with element voltages in a closed loop also called as closed circuit.

Kirchhoff’s current law

Kirchhoff’s currents law states that the algebraic sum of element current meeting at a junction is zero.

Consider a junction P wherein four elements, carrying currents I_1, I_2, I_3 and I_4, are meeting as shown in Fig. 2.

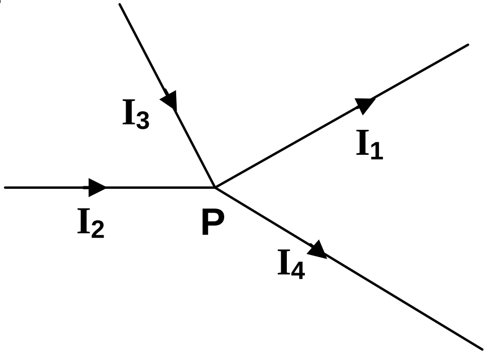


Fig. 2 Currents meeting at a junction

Note that currents I_1 and I_4 are flowing out from the junction while the currents I_2 and I_3 are flowing into the junction. According to KCL,

$$I_1 - I_2 - I_3 + I_4 = 0 \tag{10}$$

The above equation can be rearranged as

$$I_1 + I_4 = I_2 + I_3 \tag{11}$$

From equation (11), KCL can also stated as at a junction, the sum of element currents that flows out is equal to the sum of element currents that flows in.

Kirchhoff's voltage law

Kirchhoff's voltage law states that the algebraic sum of element voltages around a closed loop is zero.

Consider a closed loop in a circuit wherein four elements with voltages V_1, V_2, V_3 and V_4, are present as shown in Fig. 3.

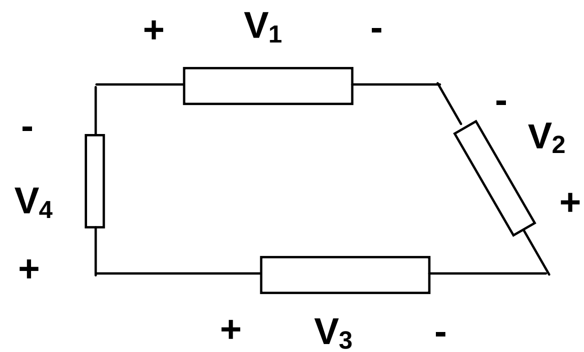


Fig. 3 Voltages in a closed loop

Assigning positive sign for voltage drop and negative sign for voltage rise, when the loop is traced in clockwise direction, according to KVL

$$V_1 - V_2 - V_3 + V_4 = 0 \quad (12)$$

The above equation can be rearranged as

$$V_1 + V_4 = V_2 + V_3 \quad (13)$$

From equation (13), KVL can also stated as, in a closed loop, the sum of voltage drops is equal to the sum of voltage rises in that loop.

Resistors connected in series

Two resistors are said to be connected in series when there is only one common point between them and no other element is connected in that common point. Resistors connected in series carry same current. Consider three resisters R_1, R_2 and R_3 connected in series as shown in Fig. 4. With the supply voltage of E, voltages across the three resistors are V_1, V_2 and V_3.

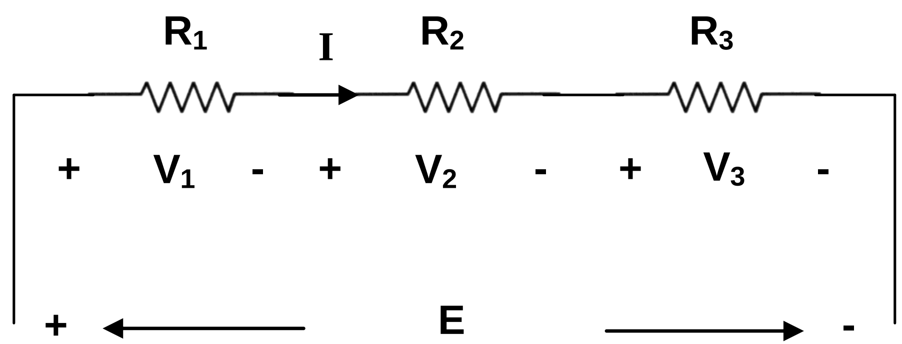


Fig. 4 Resistors connected in series

As per Ohm's law

$$\left.\begin{aligned} V_1 &= R_1\,I \\ V_2 &= R_2\,I \\ V_3 &= R_3\,I \end{aligned}\right\} \qquad (14)$$

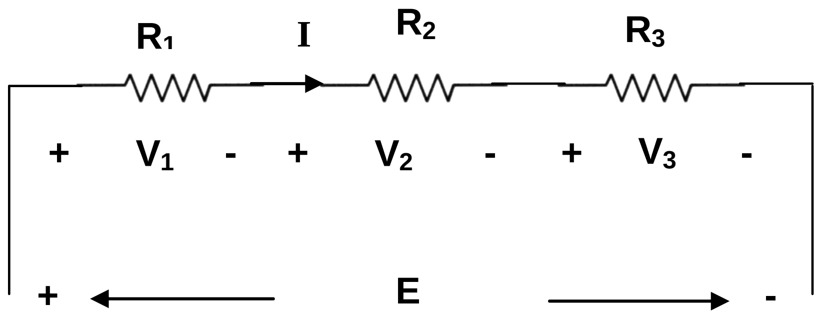


Fig. 4 Resistors connected in series

As per Ohm's law

$V_1 = R_1 I$

$V_2 = R_2 I$

$V_3 = R_3 I$

Applying KVL,

$$E = V_1 + V_2 + V_3 \tag{15}$$

$$= (R_1 + R_2 + R_3) I = R_{eq} I \tag{16}$$

Thus for the circuit shown in Fig. 4,

$$E = R_{eq} I \tag{17}$$

where E is the circuit voltage, I is the circuit current and R_{eq} is the equivalent resistance. Here

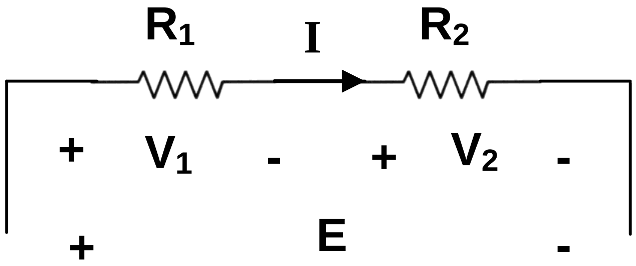
$$R_{eq} = R_1 + R_2 + R_3 \tag{18}$$

This is true when two are more resistors are connected in series. When n numbers of resistors are connected in series, the equivalent resistor is given by

$$R_{eq} = R_1 + R_2 + \ldots\ldots\ldots\ldots + R_n \tag{19}$$

Voltage division rule

Consider two resistors connected in series. Then



$V_1 = R_1 I$

$V_2 = R_2 I$

$E = (R_1 + R_2) I$ **and hence** $I = E / (R_1 + R_2)$

Total voltage of E is dropped in two resistors. Voltage across the resistors are given by

$$V_1 = \frac{R_1}{R_1 + R_2} E \quad \text{and} \tag{20}$$

$$V_2 = \frac{R_2}{R_1 + R_2} E \tag{21}$$

Resistors connected in parallel

Two resistors are said to be connected in parallel when both are connected across same pair of nodes. Voltages across resistors connected in parallel will be equal.

Consider two resistors R_1 and R_2 connected in parallel as shown in Fig. 5.

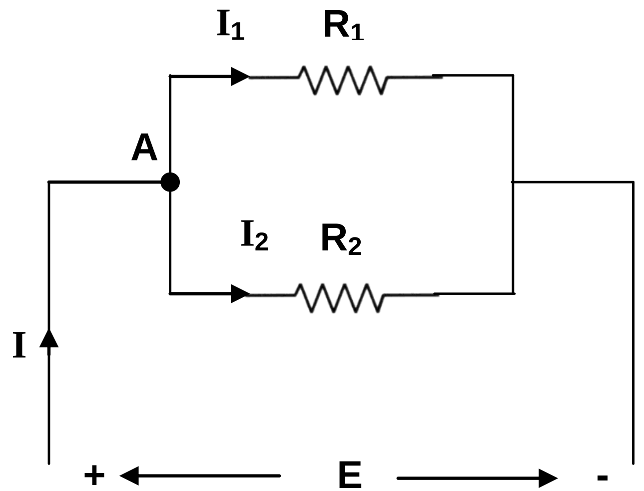
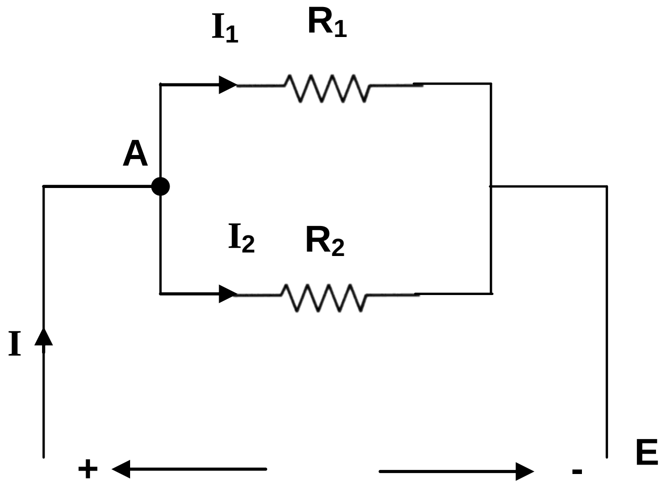


Fig. 5 Resistors connected in parallel

As per Ohm's law,

$$\left.\begin{aligned} I_1 &= \frac{E}{R_1} \\ I_2 &= \frac{E}{R_2} \end{aligned}\right\} \qquad (22)$$



As per Ohm's law

$$I_1 = \frac{E}{R_1}$$

$$I_2 = \frac{E}{R_2}$$

Applying KCL at node A

$$I = I_1 + I_2 = E\left(\frac{1}{R_1} + \frac{1}{R_2}\right) = \frac{E}{R_{eq}} \qquad (23)$$

Thus for the circuit shown in Fig. 5

$$I = \frac{E}{R_{eq}} \qquad (24)$$

where E is the circuit voltage, I is the circuit current and R_{eq} is the equivalent resistance. Here

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} \qquad (25)$$

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} \qquad (25)$$

From the above $\dfrac{1}{R_{eq}} = \dfrac{R_1 + R_2}{R_1 R_2}$

Thus $R_{eq} = \dfrac{R_1 R_2}{R_1 + R_2}$ **(26)**

When n numbers of resistors are connected in parallel, generalizing eq. (25), R_{eq} can be obtained from

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \ldots\ldots\ldots\ldots\ldots + \frac{1}{R_n} \qquad (27)$$

Current division rule

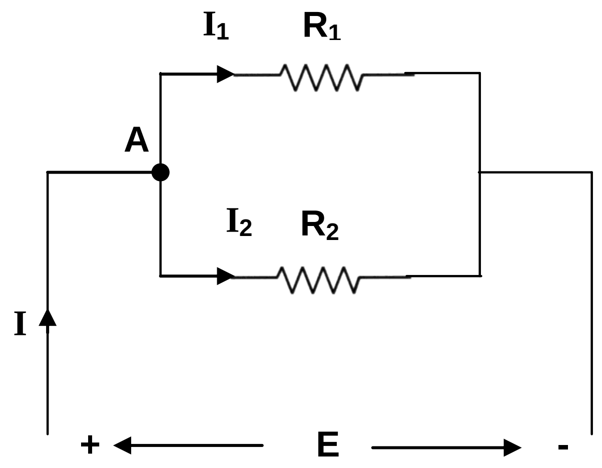


Fig. 5 Resistors connected in parallel

Referring to Fig. 5, it is noticed the total current gets divided as I_1 and I_2. The branch currents are obtained as follows.

From eq. (23)

$$E = \frac{R_1 R_2}{R_1 + R_2} I \tag{29}$$

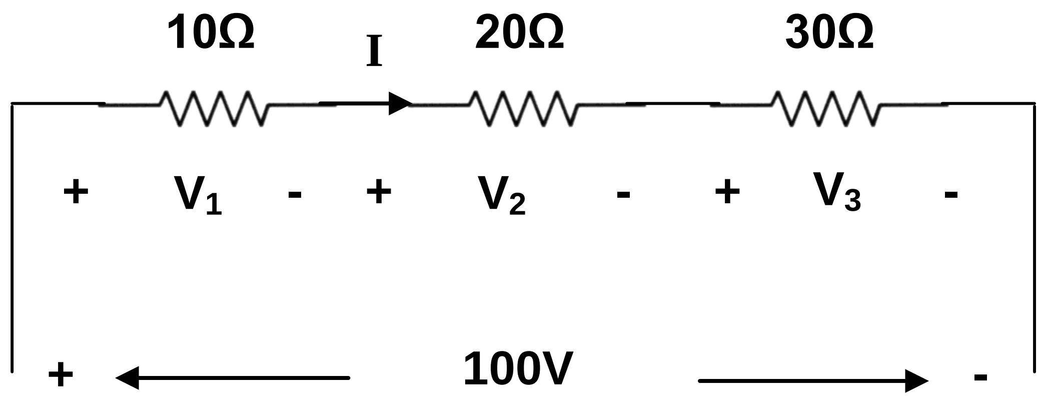
Substituting the above in eq. (22)

$$\left.\begin{aligned} I_1 &= \frac{R_2}{R_1 + R_2} I \\ I_2 &= \frac{R_1}{R_1 + R_2} I \end{aligned}\right\} \tag{30}$$

Example 1

Three resistors 10Ω, 20Ω and 30Ω are connected in series across 100 V supply. Find the voltage across each resistor.

Solution



Current I = 100 / (10 + 20 + 30) = 1.6667 A

Voltage across 10Ω = 10 x 1.6667 = 16.67 V

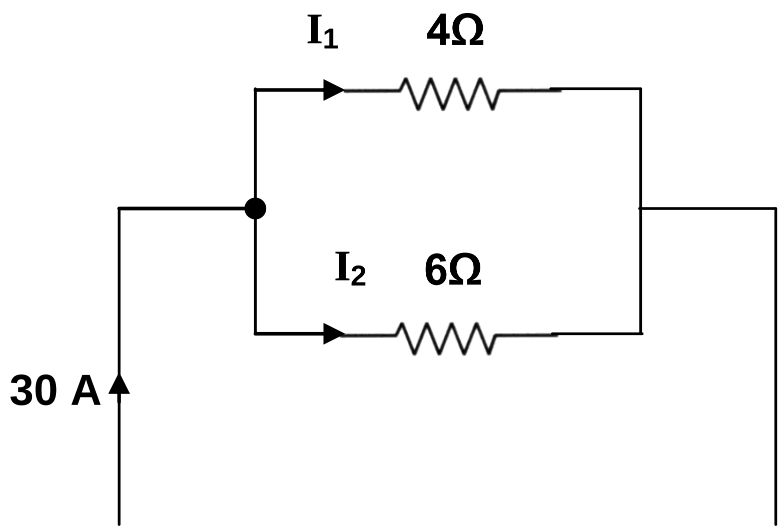
Voltage across 20Ω = 20 x 1.6667 = 33.33 V

Voltage across 30Ω = 30 x 1.6667 = 50 V

Example 2

Two resistors of 4Ω and 6Ω are connected in parallel. If the supply current is 30 A, find the current in each resistor.

Solution



Using the current division rule

$$\text{Current through } 4\Omega = \frac{6}{4+6} \times 30 = 18\text{ A}$$

$$\text{Current through } 6\Omega = \frac{4}{4+6} \times 30 = 12\text{ A}$$

Example 3

Four resistors of 2 ohms, 3 ohms, 4 ohms and 5 ohms respectively are connected in parallel. What voltage must be applied to the group in order that the total power of 100 W is absorbed?

Solution

Let R_T be the total equivalent resistor. Then

$$\frac{1}{R_T} = \frac{1}{2} + \frac{1}{3} + \frac{1}{4} + \frac{1}{5} = \frac{60+40+30+24}{120} = \frac{154}{120}$$

Resistance $R_T = \frac{120}{154} = 0.7792\,\Omega$

Let E be the supply voltage. Then total current taken = E / 0.7792 A

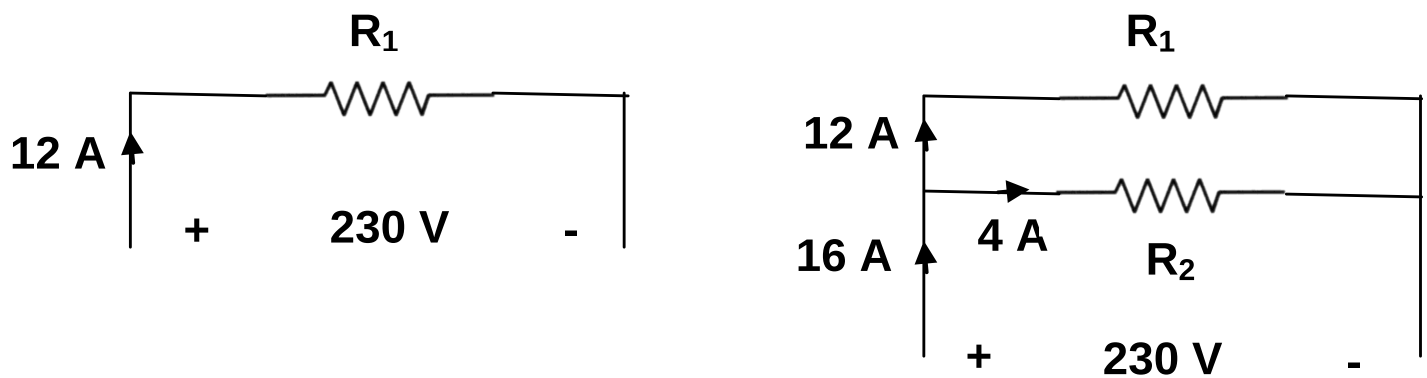
Thus $(\frac{E}{0.7792})^2 \times 0.7792 = 100$ **and hence** $E^2 = 100 \times 0.7792 = 77.92$

Required voltage = $\sqrt{77.92} = 8.8272$ **V**

Example 4

When a resistor is placed across a 230 V supply, the current is 12 A. What is the value of the resistor that must be placed in parallel, to increase the load to 16 A

Solution



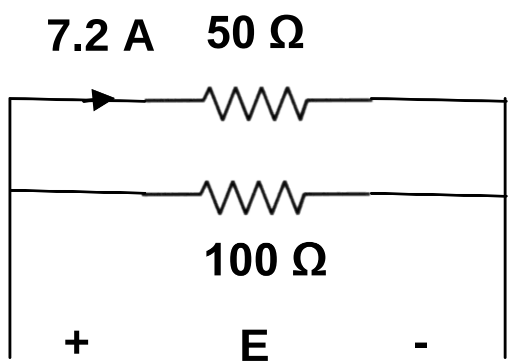
To make the load current 16 A, current through the second resistor = 16 –12 = 4 A

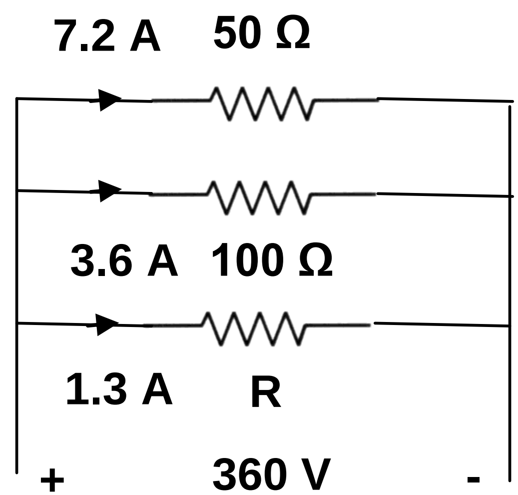
Value of second resistor R_2 = 230/4 = 57.5 Ω

Example 5

A 50 Ω resistor is in parallel with a 100 Ω resistor. The current in 50 Ω resistor is 7.2 A. What is the value of third resistor to be added in parallel to make the line current as 12.1A?

Solution





Supply voltage E = 50 x 7.2 = 360 V

Current through 100 Ω = 360/100 = 3.6 A

When the line current is 12.1 A, current through third resistor = 12.1 – (7.2 + 3.6)

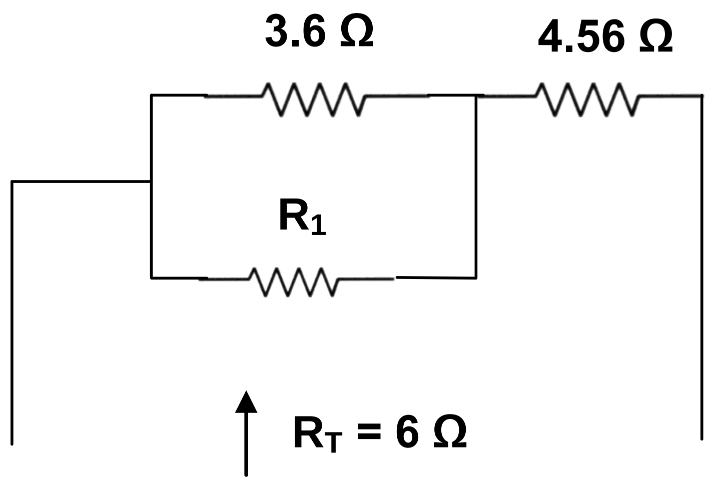
= 1.3 A

Value of third resistor = 360/1.3 = 276.9230 Ω

Example 6

A resistor of 3.6 ohms is connected in series with another of 4.56 ohms. What resistance must be placed across 3.6 ohms, so that the total resistance of the circuit shall be 6 ohms?

Solution



$$3.6 \parallel R_1 = 6 - 4.56 = 1.44\ \Omega$$

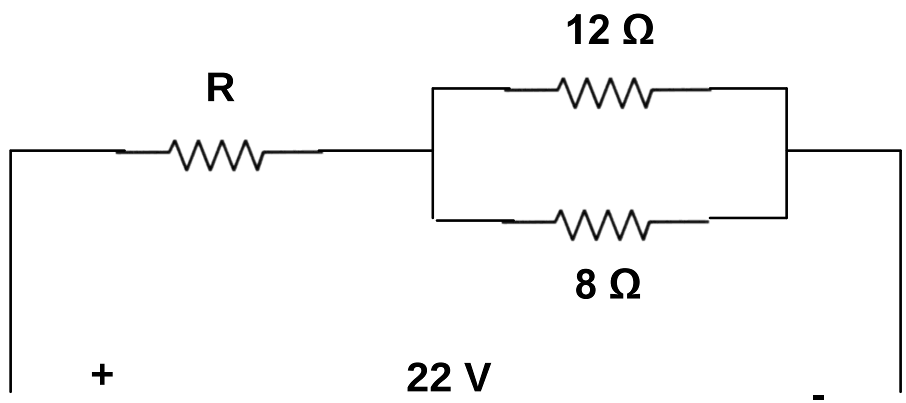
Thus $\dfrac{3.6 \times R_1}{3.6 + R_1} = 0.4$; Therefore $\dfrac{3.6 + R_1}{R_1} = \dfrac{1}{0.4} = 2.5$; $\dfrac{3.6}{R_1} = 1.5$

Required resistance $R_1 = 3.6/1.5 = 2.4\ \Omega$

Example 7

A resistance R is connected in series with a parallel circuit comprising two resistors 12 Ω and 8 Ω respectively. Total power dissipated in the circuit is 70 W when the applied voltage is 22 V. Calculate the value of the resistor R.

Solution



Total current taken = 70 / 22 = 3.1818 A

Equivalent of 12 Ω ‖ 8 Ω = 96/20 = 4.8 Ω

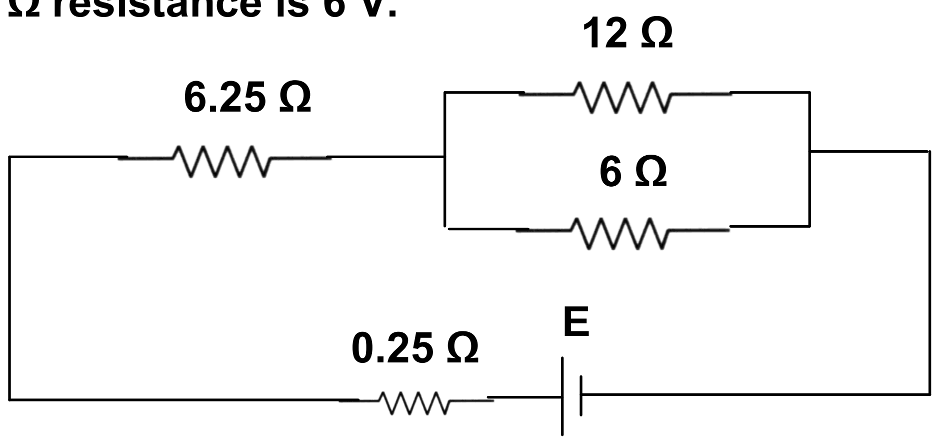
Voltage across parallel combination = 4.8 x 3.1818 = 15.2726 V

Voltage across resistor R = 22 – 15.2726 = 6.7274 V

Value of resistor R = 6.7274/3.1818 = 2.1143 Ω

Example 8

The resistors 12 Ω and 6 Ω are connected in parallel and this combination is connected in series with a 6.25 Ω resistance and a battery which has an internal resistance of 0.25 Ω. Determine the emf of the battery if the potential difference across 6 Ω resistance is 6 V.



Voltage across 6 Ω = 6 V

Solution

Current in 6 Ω = 6/6 = 1 A

Current in 12 Ω = 6/12 = 0.5 A

Therefore current in 25 Ω = 1.0 + 0.5 = 1.5 A

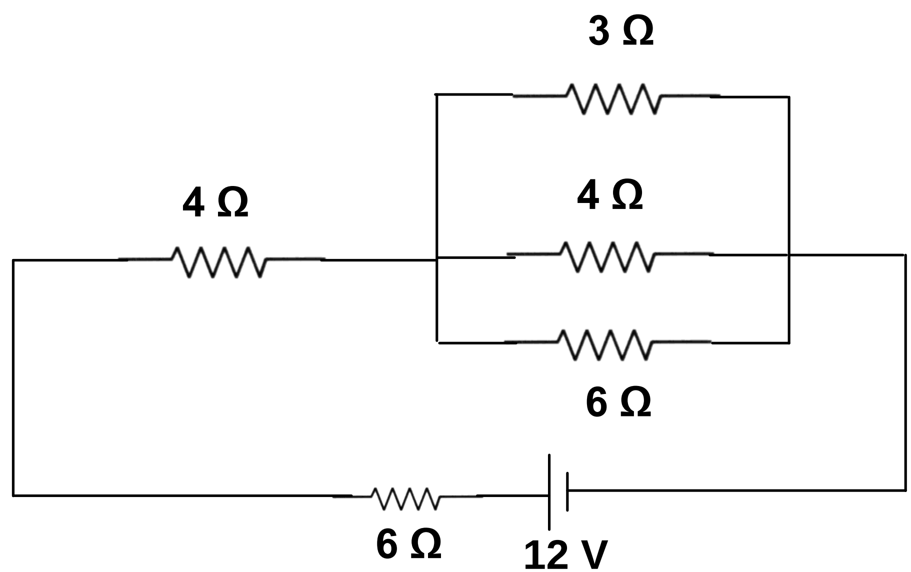
Using KVL E = (0.25 x 1.5) + (6.25 x 1.5) + 6 = 15.75 V

Therefore battery emf E = 15.75 V

Example 9

A circuit consist of three resistors 3 Ω, 4 Ω and 6 Ω in parallel and a fourth resistor of 4 Ω in series. A battery of 12 V and an internal resistance of 6 Ω is connected across the circuit. Find the total current in the circuit and the terminal voltage across the battery.

Solution



4 Ω ‖ 6 Ω = 24/10 = 2.4 Ω

1.4 Ω ‖ 3 Ω = 7.2/5.4 = 1.3333 Ω

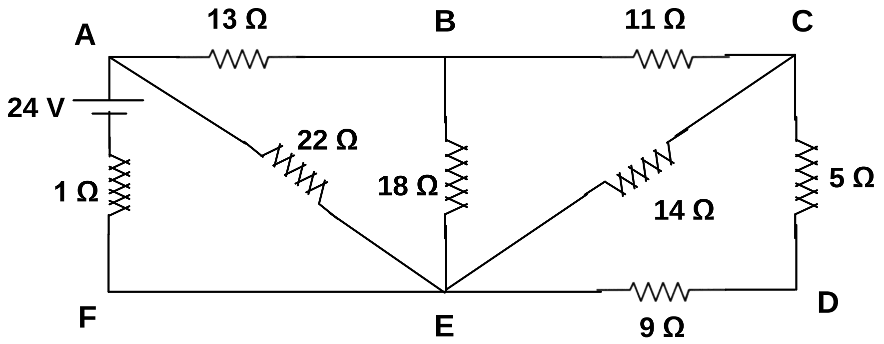
Total circuit resistance = 4 + 6 + 1.3333 = 11.3333 Ω

Circuit current = 12/11.3333 = 1.0588 A

Terminal voltage across the battery = 12 – (6 x 1.0588) = 5.6472 V

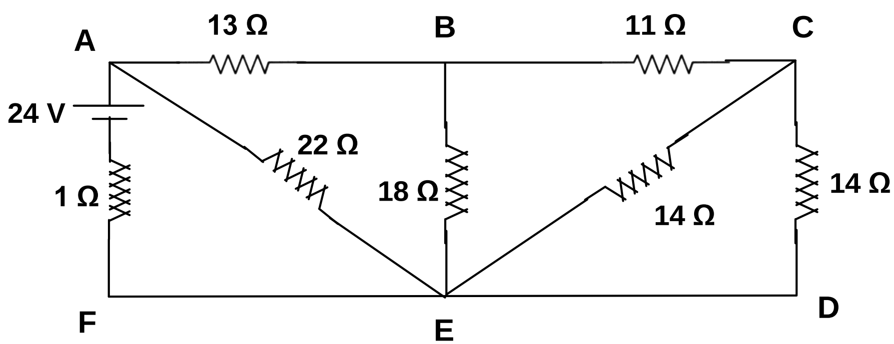
Example 10

An electrical network is arranged as shown. Find (i) the current in branch AF (ii) the power absorbed in branch BE and (iii) potential difference across the branch CD.



Solution

Various stages of reduction are shown.



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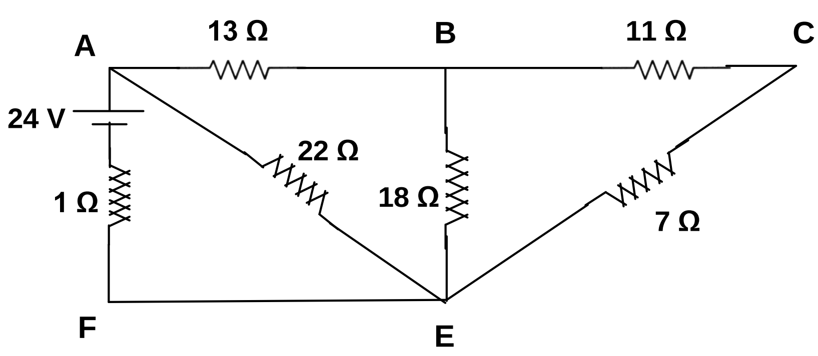

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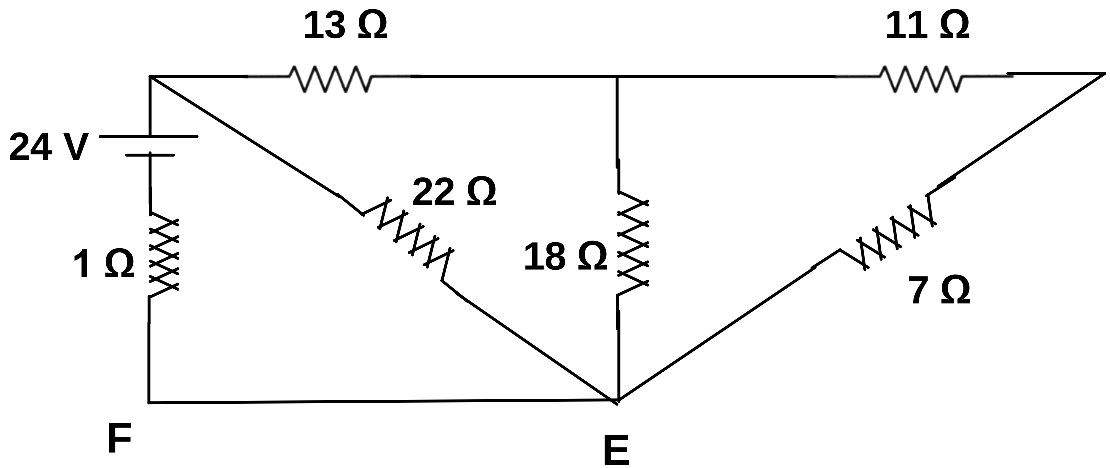
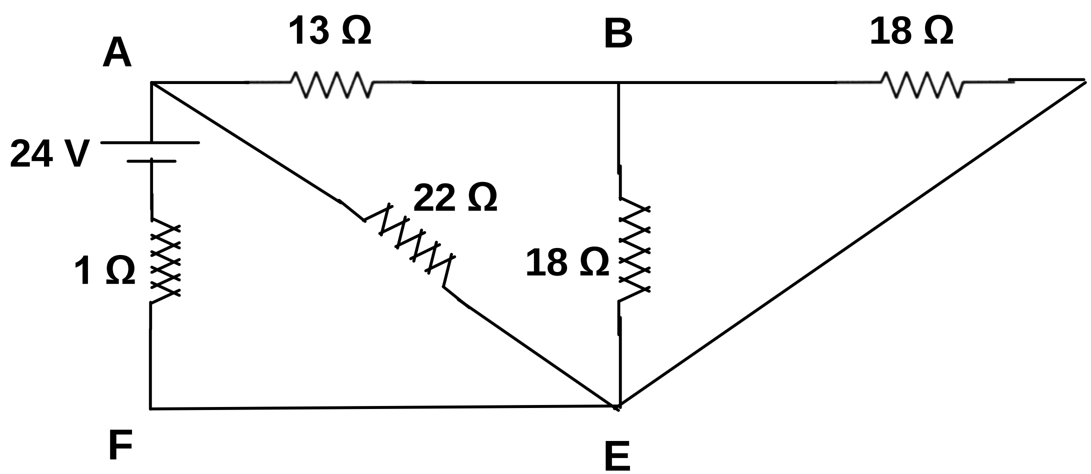


2



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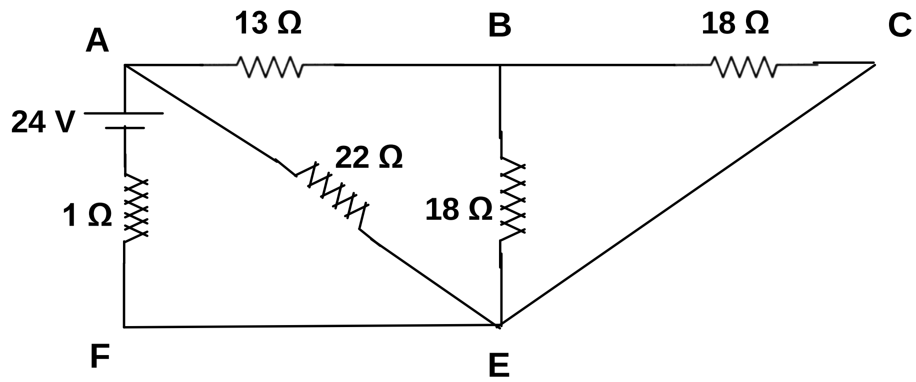
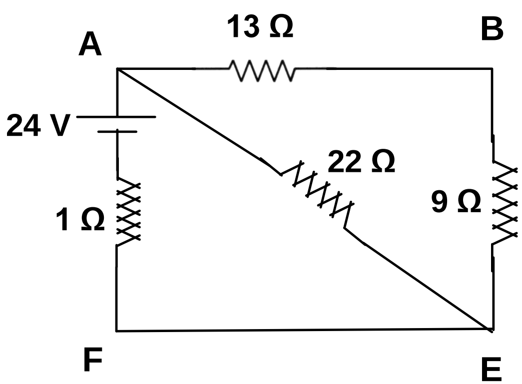
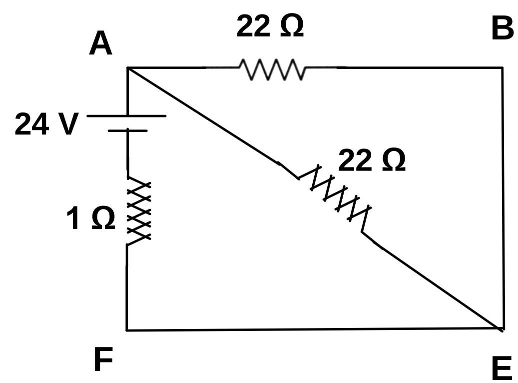

A
13 Ω
B
18 Ω
C
24 V
22 Ω
1 Ω
18 Ω
F
E

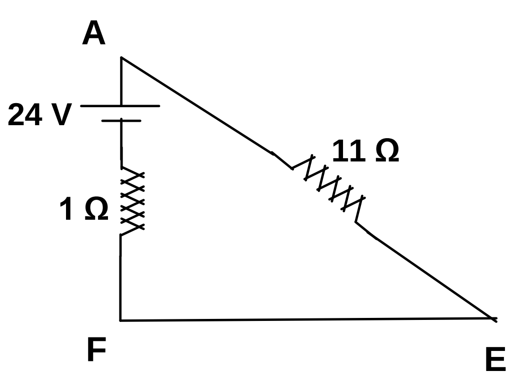
3


A
13 Ω
B
24 V
22 Ω
1 Ω
9 Ω
F
E

4


A
22 Ω
B
24 V
22 Ω
1 Ω
F
E

5


A
24 V
11 Ω
1 Ω
F
E

6

Current in branch AF = 24/12 = 2 A from F to A

Using current division rule current in 13 Ω in Fig. 4= 1 A

Referring Fig. 3, current in branch BE = 0.5 A

Power absorbed in branch BE = 0.5^2 x 18 = 4.5 W

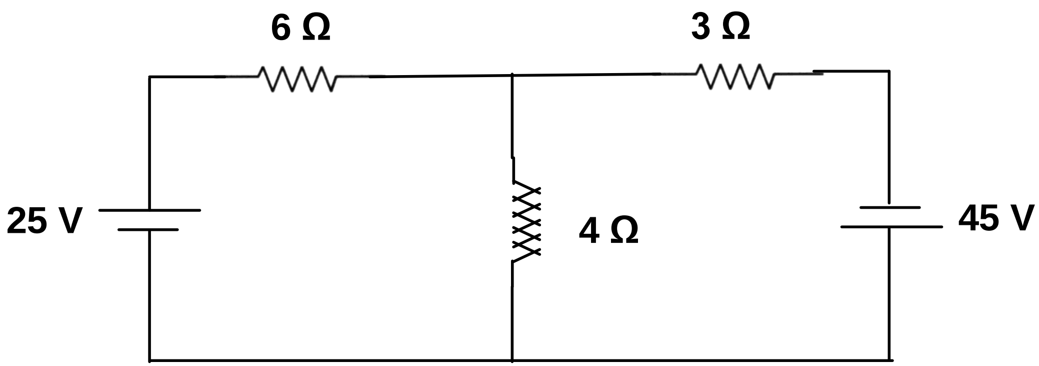
Voltage across BE = 0.5 x 18 = 9 V

Voltage across CE in Fig. 1 = $\frac{7}{18} \times 9 = 3.5$ V

Referring Fig. given in the problem, using voltage division rule, voltage across in branch CD = $\frac{5}{14} \times 3.5 = 1.25$ V

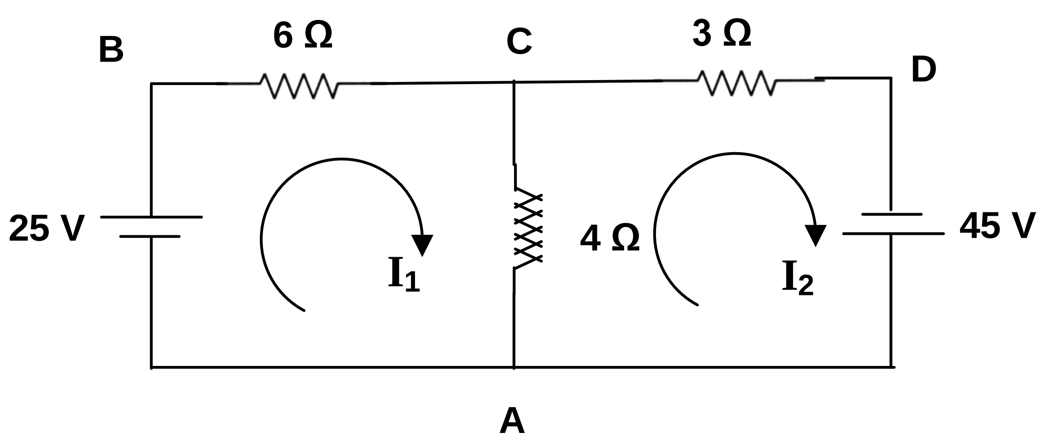
Example 11

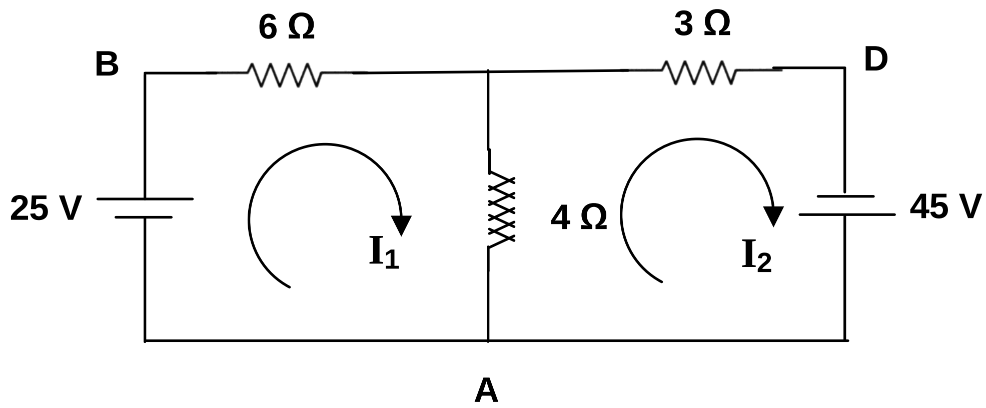
Using Kirchhoff's laws, find the current in various resistors in the circuit shown.



Solution

Let the loop current be I_1 and I_2





Considering the loop ABCA, KVL yields

$6\ I_1 + 4\ (I_1 – I_2) – 25 = 0$

For the loop CDAC, KVL yields

$3\ I_2 – 45 + 4\ (I_2 – I_1) = 0$

Thus $10\ I_1 - 4\ I_2 = 25$

$- 4\ I_1 + 7\ I_2 = 45$

On solving the above $I_1 = 6.574$ A; $I_2 = 10.1852$ A

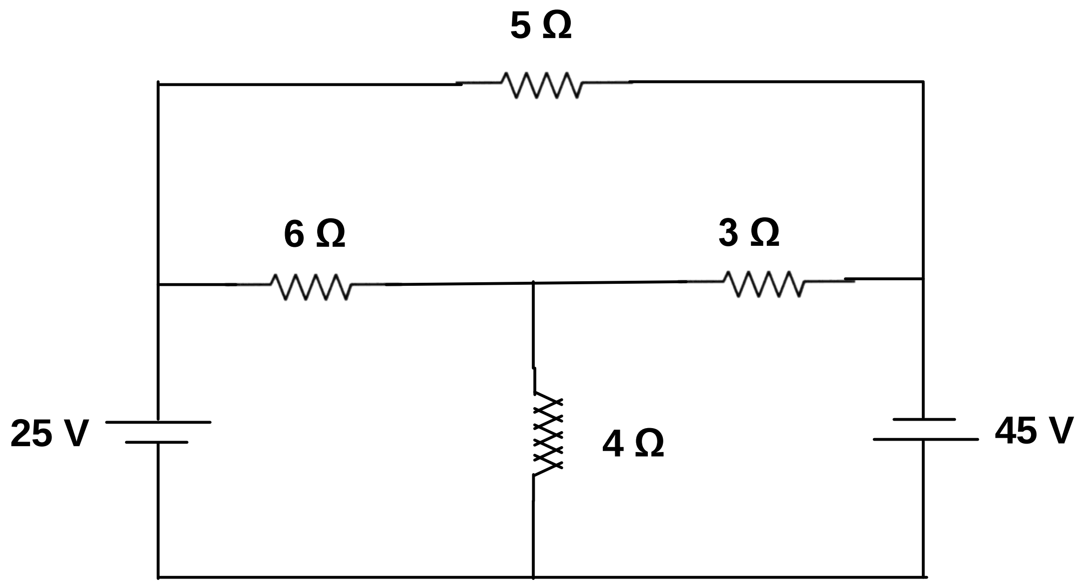
Current in 4Ω resistor = $I_1 – I_2 = 6.574 – 10.1852 = - 3.6112$ A

Thus the current in 4Ω resistor is 3.6112 A from A to C

Current in 6 Ω resistor = 6.574 A; Current in 3 Ω resistor = 10.1852 A

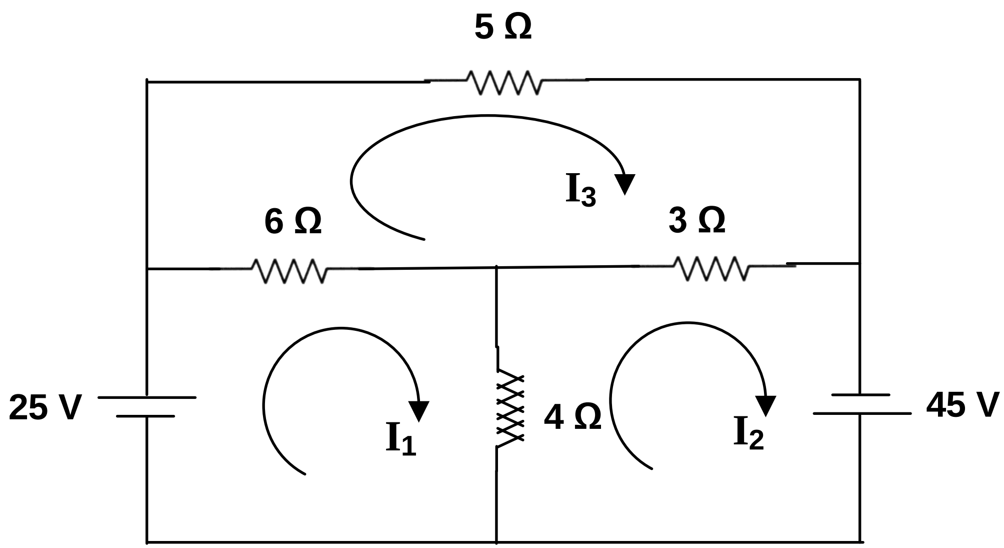
Example 12

Find the current in 5 Ω resistor in the circuit shown.



Solution

Let the loop current be I_1, I_2 and I_3.



Three loops equations are:

$$6(I_1 - I_3) + 4(I_1 - I_2) - 25 = 0$$

$$4(I_2 - I_1) + 3(I_2 - I_3) - 45 = 0$$

$$5I_3 + 3(I_3 - I_2) + 6(I_3 - I_1) = 0$$

On solving

Current in 5 Ω resistor, $I_3 = 14$ A

CIRCUIT THEOREMS

THEVENIN'S THEOREM

In many practical applications, we may not be interested in getting the complete analysis of the circuit, namely finding the current through all the elements and voltages across all the elements. We may be interested to know the details of a portion of the circuit; as a special case **it may be a single element such as load impedance.** In such a situation it is very convenient to use Thevenin's theorem to get the solution.

Fig. illustrates the Thevenin's equivalent of sub-circuit A.

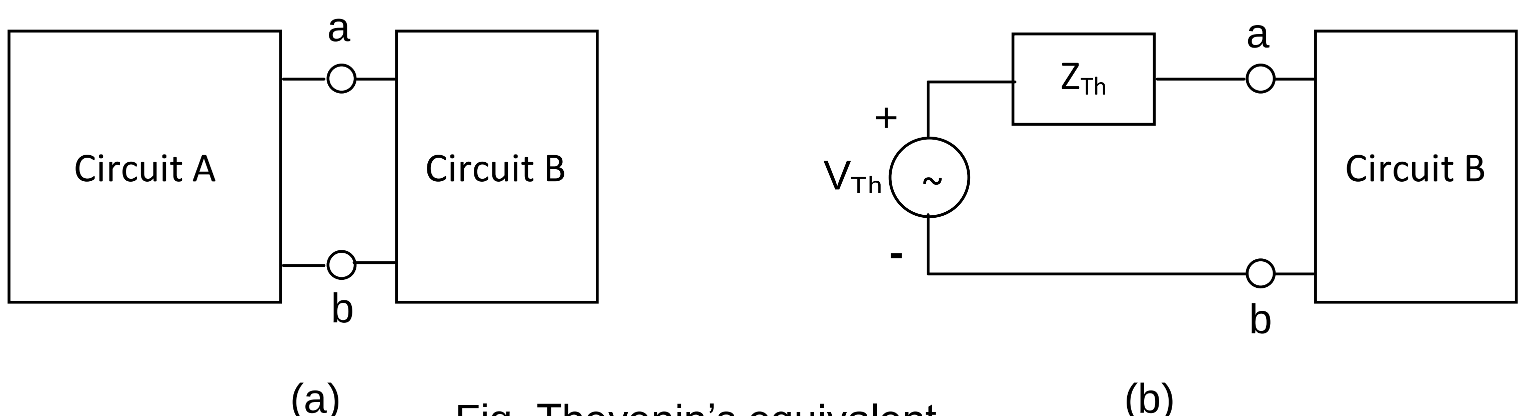


Fig. Thevenin's equivalent.

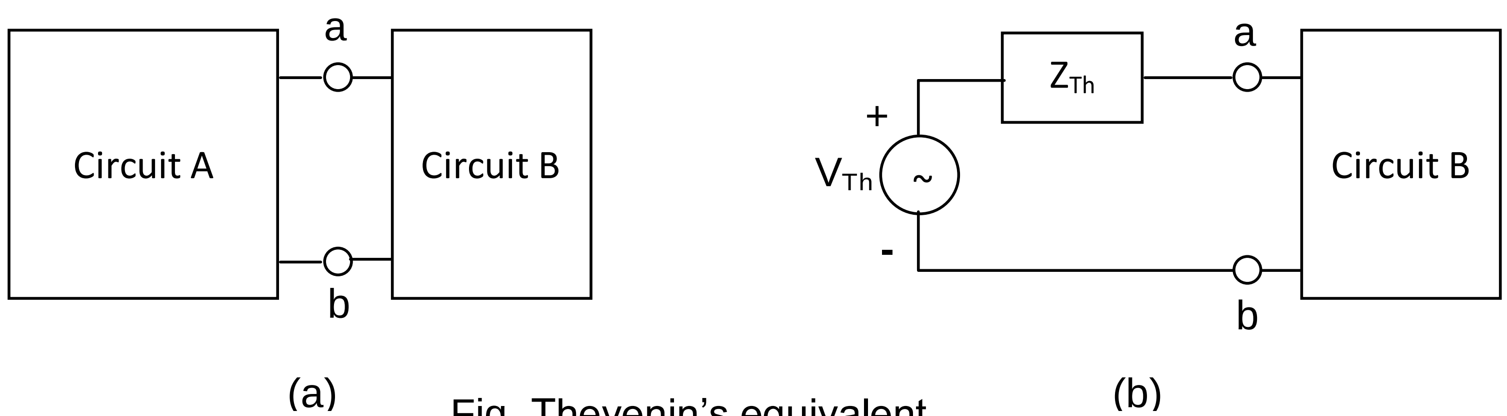


Fig. Thevenin's equivalent.

In Fig. (a) a circuit partitioned into two parts, namely circuit A and circuit B, is shown. They are connected by a single pair of terminals. In Fig.(b) circuit A is replaced by Thevenin's equivalent circuit, which consists of a voltage source V_{Th} in series with an impedance Z_{Th}.

To obtain the Thevenin's equivalent circuit, we need to find Thevenin's voltage V_{th} and Thevenin's impedance Z_{Th}. Unique procedure is available to find the Thevenin's voltage $V_{Th.}$ When we need the Thevenin's voltage of circuit A, measure or calculate the **OPEN CIRCUIT VOLTAGE of circuit A.** This will be the Thevenin's voltage.

Thevenin's impedance can be calculated in three different ways **depending on the nature of voltage and current sources** in the circuit of our interest.

The circuit for which Thevenin's impedance is to be calculated consists of impedances and **one or more independent sources.** That is, **the circuit does not contain any dependent source**. To determine Thevenin's impedance, circuit shown in Fig. (b) is to be used.

Fig. Determining Thevenin's equivalents.

The circuit AA in Fig. (b) is obtained from circuit A by replacing all the independent voltage sources by short circuits and replacing all independent current sources by open circuits. Thus in circuit AA, all the independent sources are set to zero. Then, Thevenin's impedance is the equivalent circuit impedance of circuit AA which can be obtained using reduction techniques.

The methods of finding the Thevenin's impedance depend on the nature of the circuit for which the Thevenin's equivalent is sought for. These methods are summarized below:

Circuit with independent sources only - ANY ONE OF THE FOLLOWING

1. **Make independent sources zeros and use reduction techniques to find Z_{Th}.**

2. Short circuit terminals a and b and find the short circuit current I_{sc} flowing from *a* to *b*. Then $Z_{Th} = V_{Th} / I_{sc}$

3. Set all independent sources to zero. Apply 1 V across the open circuited terminals *a*-*b* and determine the source current I_s entering the circuit through *a.* Then $Z_{Th} = 1 / I_s$. Alternatively introduce a current source of 1 A from *b* to *a* and determine the voltage V_{ab}. Then, Thevenin's impedance $Z_{Th} = V_{ab}$.

Example 1

Find the Thevenin's voltage with respect to the load resistor R_L in circuit shown in Fig.

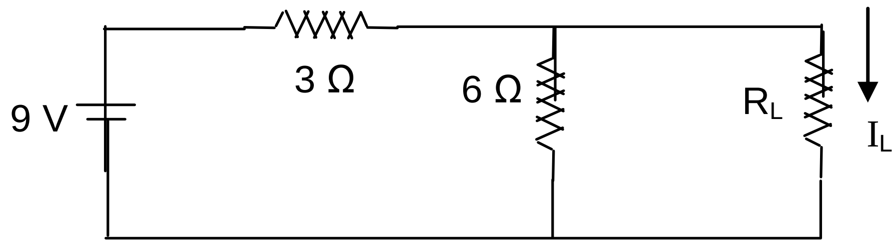
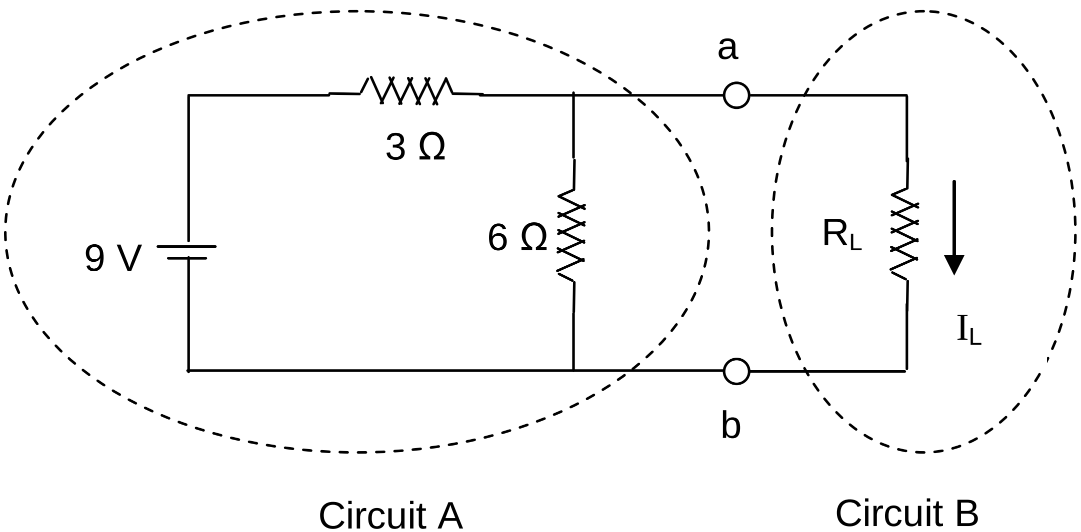
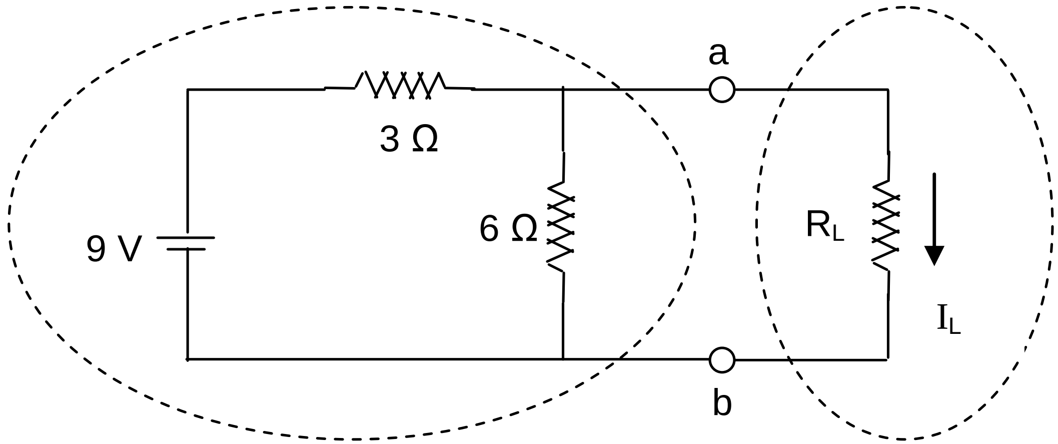


Fig. Circuit for Example1

Solution

The given circuit can be divided into two circuits as shown in Fig.





Thevenin's voltage of circuit A can be obtained from the circuit shown in Fig.

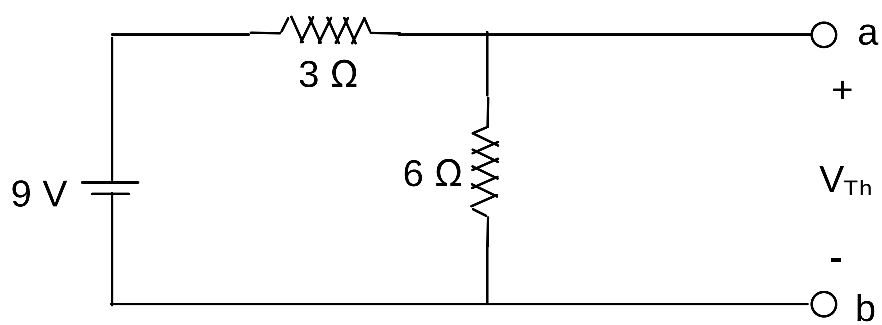


Fig. Circuit.

Using voltage division rule $V_{Th} = V_{6\Omega} = \frac{6}{9} \times 9 = 6\,V$

<u>Example 2</u>

Obtain the Thevenin's equivalent for the circuit shown in Fig.

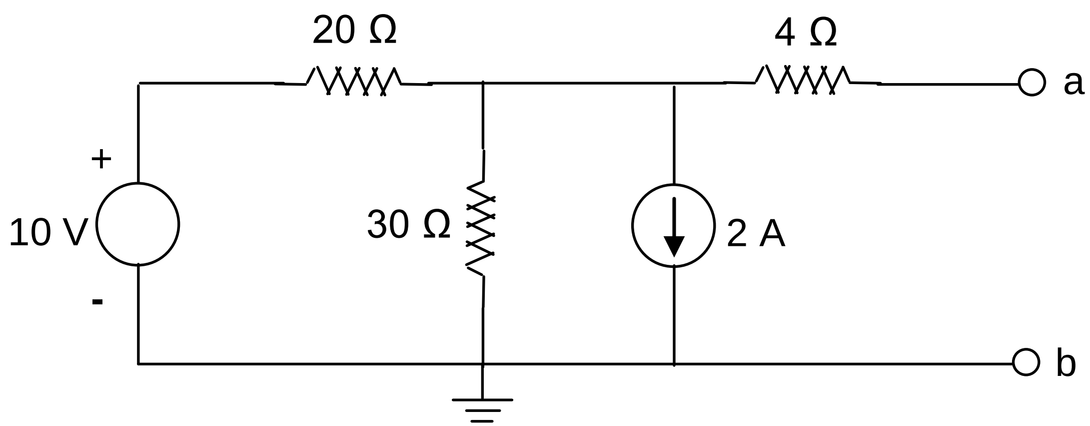


Fig. Circuit for Example 2.

<u>Solution:</u>

Open circuit voltage V_{ab} is the Thevenin's voltage V_{Th}.

To find Thevenin's voltage:

Note that there is no current flow in resistor of 4 Ω. Therefore, voltage V_{Th} is same as the voltage across 30 Ω resistor. Then, the node voltage equation is

$$\frac{V_{Th} - 10}{20} + \frac{V_{Th}}{30} + 2 = 0$$

On solving this, we get V_{Th} = - 18 V

To find Thevenin's impedance: Since the circuit has only independent sources, it falls under case 1

Reducing the sources to zero, the resulting circuit is shown in Fig.

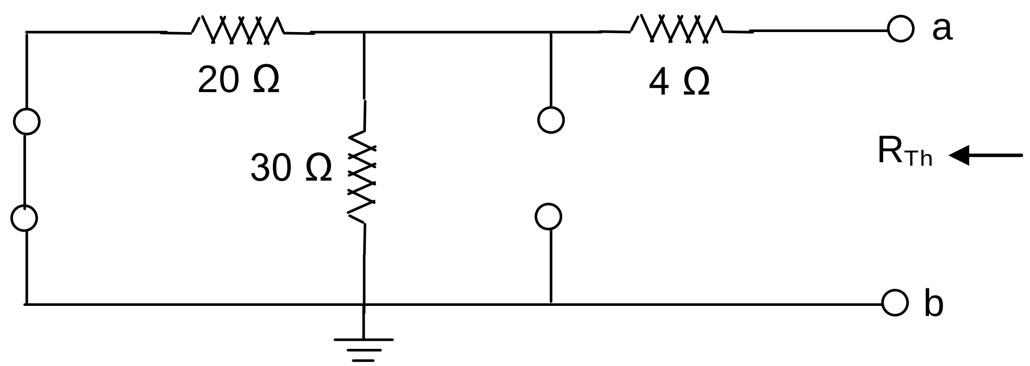


Fig. Circuit - Example 2.

Thus R_{Th} = 4 + 20||30 = 16 Ω   Thevenin's equivalent circuit is shown in Fig.

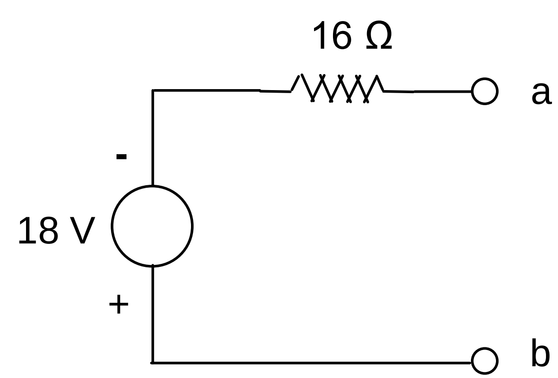
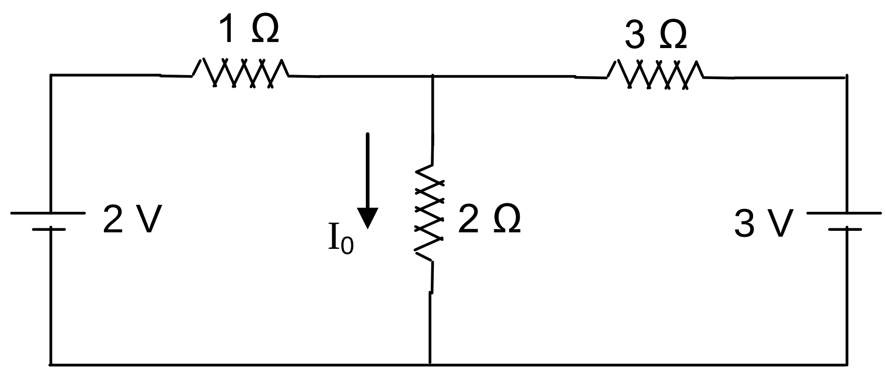


Fig. Thevenin's equivalent circuit – Example 2.

R_{Th} can be obtained by two other methods also

Example 3 Using Thevenin's equivalent circuit, calculate the current I_0 through the 2 Ω resistor in the circuit shown below.



Solution: Circuit by which V_{Th} and R_{Th} can be calculated are shown in Fig.

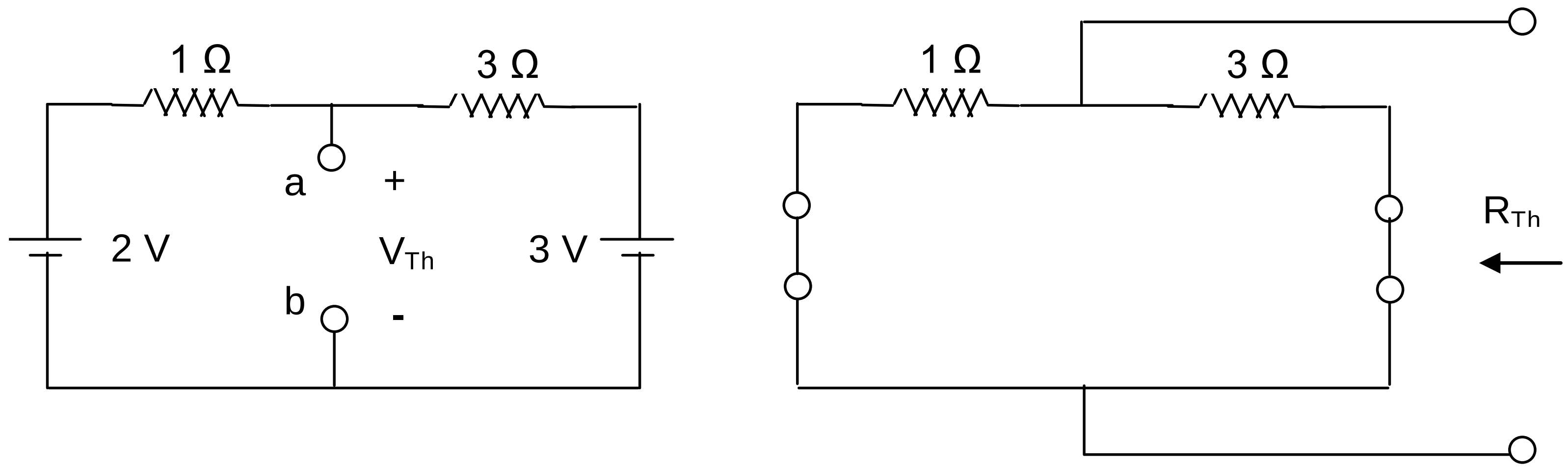
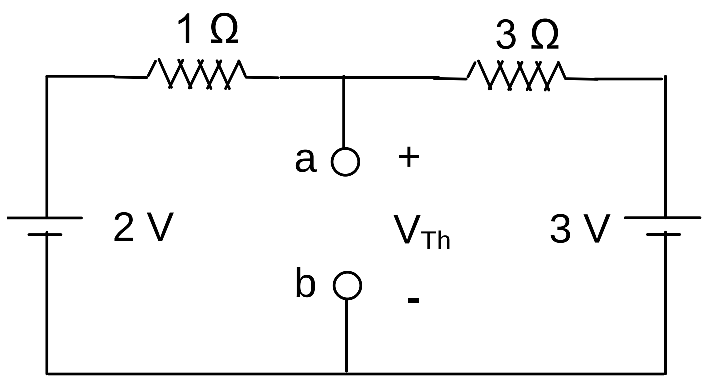
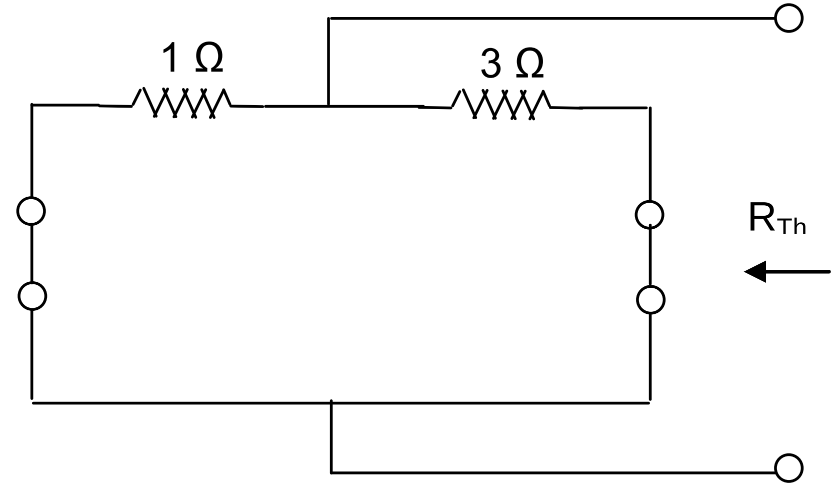


Fig. Circuits for V_{Th} and R_{Th} - Example 3.

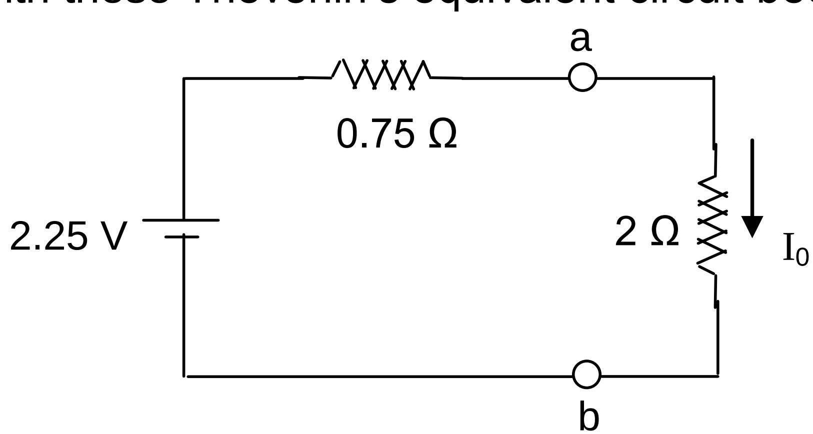




Knowing the anticlockwise current as 0.25 A

$- 2 - (1 \times 0.25) + V_{Th} = 0$. i.e. $V_{Th} = 2.25$ V; Also $R_{Th} = 1 || 3 = 0.75\ \Omega$

With these Thevenin's equivalent circuit becomes



Current $I_0 = 2.25 / 2.75 = 0.8182$ A

NORTON’S THEOREM

Much similar to Thevenin’s theorem, Norton’s theorem is also used to obtain the equivalent of two terminal sub-circuit.

Fig. illustrates the Norton’s equivalent of sub-circuit A.

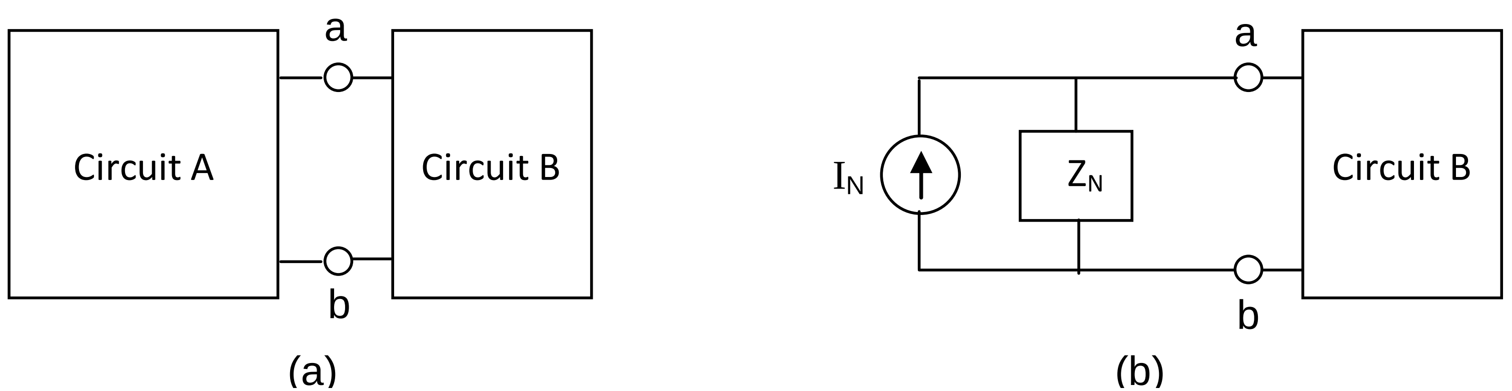


Fig. Norton’s equivalent.

In Fig. (a) a circuit partitioned into two parts, namely circuit A and circuit B, is shown. They are connected by a single pair of terminals. In Fig. (b), circuit A is replaced by Norton’s equivalent circuit, which consists of a current source I_N in parallel with an impedance Z_N.

Looking at the Thevenin's and Norton's equivalents shown in Fig. (a) and (b), it is clear that one can be obtained from the other through source transformation.

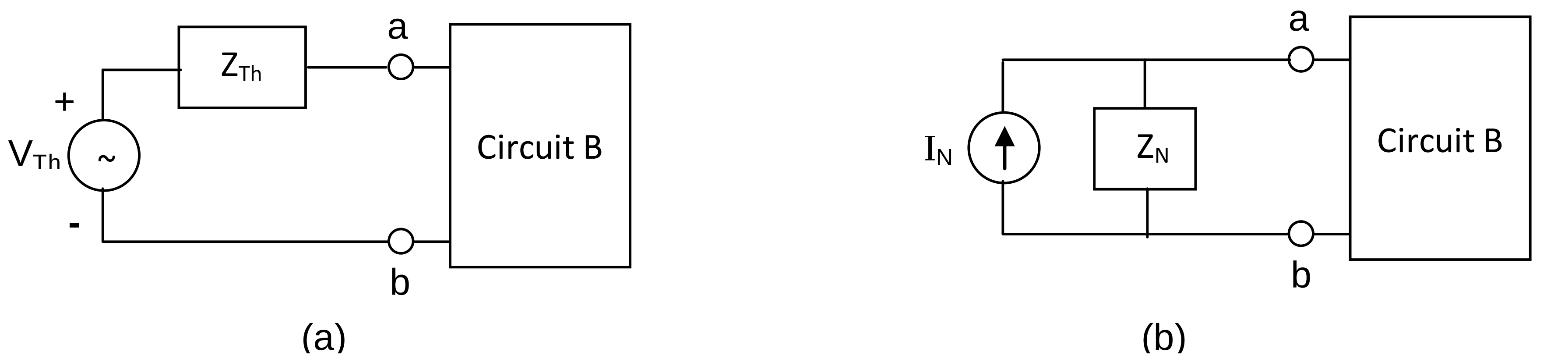


Fig. Thevenin's and Norton's equivalents.

It is to be noted that

$$Z_N = Z_{Th}$$

$$I_N = \frac{V_{Th}}{Z_{Th}} = \frac{V_{Th}}{Z_N}$$

To obtain Norton's equivalent circuit, we need to find current I_N and the impedance Z_N. They can be obtained from Thevenin's voltage and impedance.

Otherwise Norton's current can be obtained by finding the short circuit current as indicated in Fig.

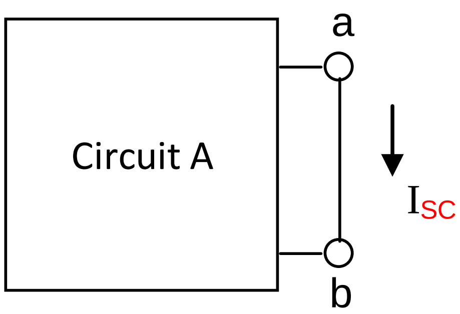


Fig. Getting short circuit current.

It is to be noted that the short circuit current is from terminal *a* to terminal *b* while Norton's current is from terminal *b* to terminal *a*.

The impedance Z_N can be got exactly same way we got Z_{Th} as discussed in previous section except that the method indicated under Case 2 is not applicable as it requires the value of V_{Th}.

Example 1

Using Norton's theorem, determine the current through the resistor R_L when R_L = 0.7, 1.2 and 1.6 Ω in the circuit shown in Fig.

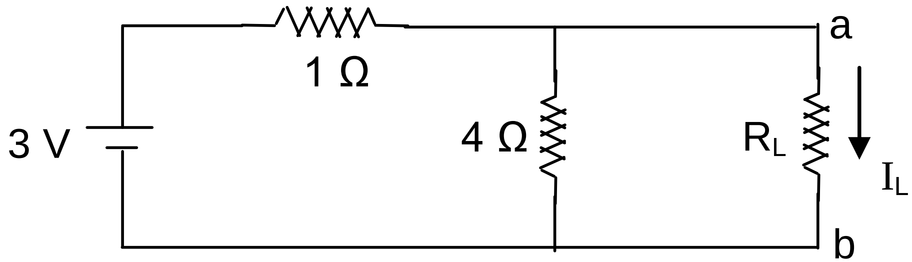


Fig. Circuit for Example 1.

Solution:

Circuits to determine I_{SC} and R_N are shown in Fig. (a) and (b).

Fig. Short circuit current and Norton's resistance.

It is to be noted that since there is a short circuit parallel to 4 Ω no current flows in it.

Norton's current I_N = 3 A; Norton's resistance R_N = 1||4 = 0.8 Ω

Norton's equivalent circuit is shown in Fig.

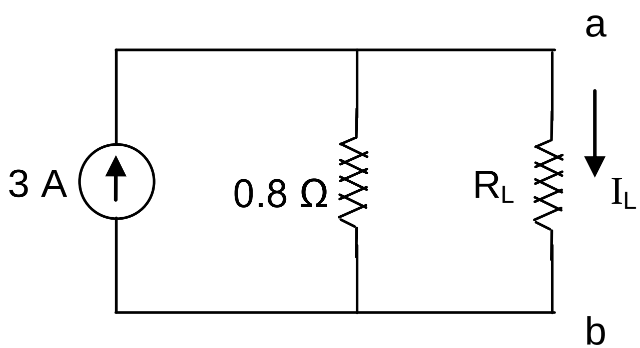


Fig. Norton's equivalent.

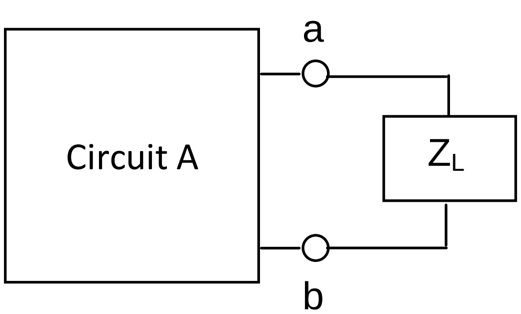
R_N can be obtained by another method also.

When R_L = 0.7 Ω, I_L = (0.8 / 1.5) x 3 = 1.6 A; When R_L = 1.2 Ω, I_L = (0.8 / 2) x 3 = 1.2 A

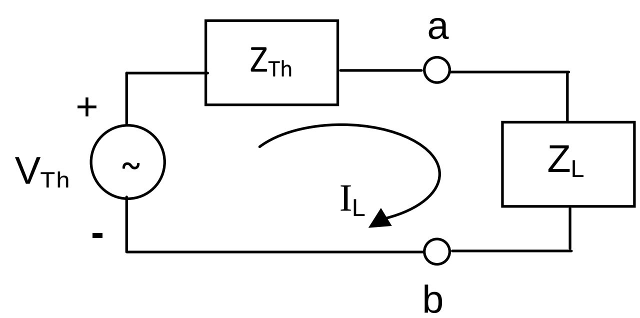
When R_L = 1.6 Ω, I_L = (0.8 / 2.4) x 3 = 1.0 A

MAXIMUM POWER TRANSFER THEOREM

There are some applications wherein maximum power needs to be transferred to the load connected. Consider a linear ac circuit *A*, connected to a load of impedance Z_L as shown in Fig. (a). It is required to transfer maximum real power to the load. The circuit A can be replaced by its Thevenin's equivalent as shown in Fig. (b).



(a)



(b)

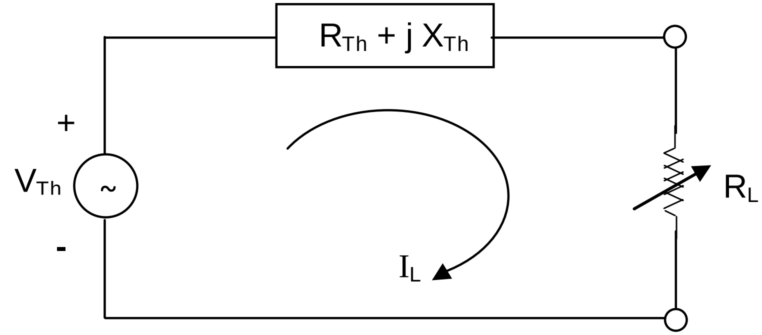
Fig. Maximum power transfer theorem - Illustration.

Let $Z_{Th} = (R_{Th} + j\,X_{Th})$ and $Z_L = (R_L + j\,X_L)$

The following maximum power transfer theorems determine the values of load impedance Z_L for which maximum real power is transferred to the load impedance.

Case 1:

Load is a variable resistance R_L



Load current $I_L = \dfrac{V_{Th}}{(R_{Th} + R_L) + jX_{Th}}$ This gives $|I_L| = \dfrac{|V_{Th}|}{\sqrt{(R_{Th} + R_L)^2 + X_{Th}^2}}$

Real power delivered to the load $P_L = |I_L|^2 R_L = \dfrac{|V_{Th}|^2 R_L}{(R_{Th} + R_L)^2 + X_{Th}^2}$

This can be written as $P_L = \dfrac{|V_{Th}|^2}{\dfrac{R_{Th}^2}{R_L} + 2R_{Th} + R_L + \dfrac{X_{Th}^2}{R_L}}$

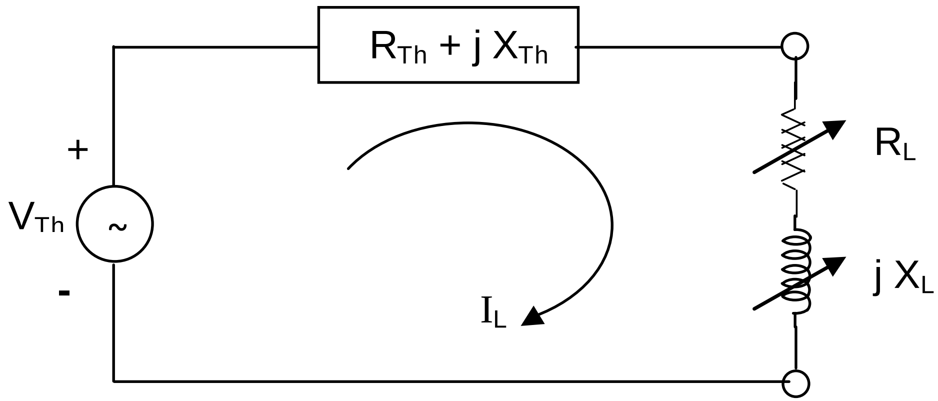
For power P_L to be maximum, $\dfrac{R_{Th}^2}{R_L} + 2R_{Th} + R_L + \dfrac{X_{Th}^2}{R_L}$ must be minimum. Thus power P_L will be maximum when

$\dfrac{d}{dR_L}\left(\dfrac{R_{Th}^2}{R_L} + 2R_{Th} + R_L + \dfrac{X_{Th}^2}{R_L}\right) = 0$ i.e. when $-\dfrac{R_{Th}^2}{R_L^2} + 1 - \dfrac{X_{Th}^2}{R_L^2} = 0$

i.e. when $R_L^2 = R_{Th}^2 + X_{Th}^2$ i.e. when $R_L = \sqrt{R_{Th}^2 + X_{Th}^2} = |Z_{Th}|$

Using this value of R_L, the current I_L and hence maximum power can be computed.

Case 2 In the load impedance, R_L and X_L are varied independently as shown.



Load current $I_L = \dfrac{V_{Th}}{(R_{Th} + R_L) + j(X_{Th} + jX_L)}$ Thus $|I_L| = \dfrac{|V_{Th}|}{\sqrt{(R_{Th} + R_L)^2 + (X_{Th} + X_L)^2}}$

Real power delivered to the load $P_L = |I_L|^2 R_L = \dfrac{|V_{Th}|^2 R_L}{(R_{Th} + R_L)^2 + (X_{Th} + X_L)^2}$

If R_L in Eq. is held fixed, the value of P will be maximum when $(X_{Th} + X_L)^2$ is minimum.

This will occur when $X_{Th} + X_L = 0$ i.e. when

$X_L = - X_{Th}$

Keeping $X_L = - X_{Th}$ Eq. becomes

$$P_L = \frac{|V_{Th}|^2 R_L}{(R_{Th} + R_L)^2} = \frac{|V_{Th}|^2}{\frac{R_{Th}^2}{R_L} + 2R_{Th} + R_L}$$

For P_L given by Eq. to become maximum, $\frac{R_{Th}^2}{R_L} + 2R_{Th} + R_L$ must be minimum. This will occur when $\frac{d}{dR_L}(\frac{R_{Th}^2}{R_L} + 2R_{Th} + R_L) = 0$ i.e. when $-\frac{R_{Th}^2}{R_L^2} + 1 = 0$ i.e. when

$R_L = R_{Th}$

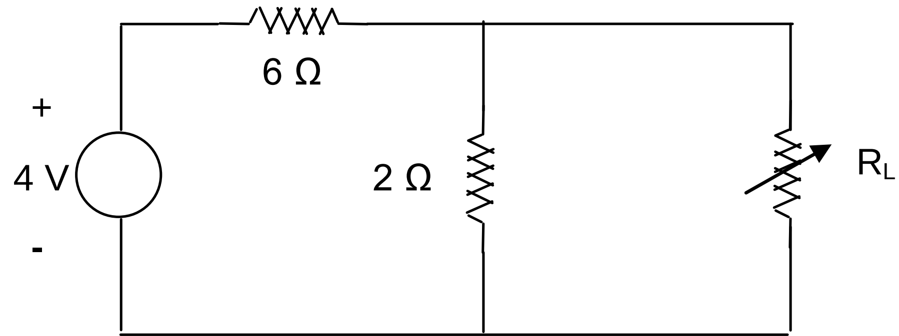
Combining Eqs. and, we can state that real power transferred to the load will be maximum when

$Z_L = R_{Th} - j X_{Th} = Z_{Th}^*$

Setting $R_L = R_{Th}$ and $X_L = - X_{Th}$ in Eq., maximum real power can be obtained as

$$P_{max} = \frac{|V_{Th}|^2}{4 R_{Th}}$$

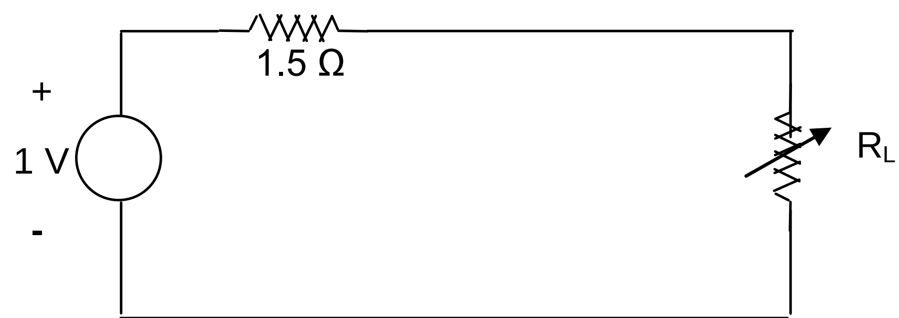
Example 1 Consider the circuit shown below. Determine the value of R_L when it is dissipating maximum power. Also find the value of maximum power dissipated.



Solution:

As a first step, Thevenin's equivalent across the load resistor is obtained.

$V_{Th} = \frac{2}{2+6} \times 4 = 1\,V$; $R_{Th} = 6 \| 2 = 1.5\ \Omega$ Resulting circuit is shown.



For P_L to be maximum, $R_L = 1.5\ \Omega$; Then circuit current = 1/3 = 0.3333 A

Maximum power dissipated $P_{max} = 0.3333^2 \times 1.5 = 0.16667$ W

SUPERPOSITION THEOREM

The idea of superposition rests on the linearity property. Superposition theorem is applicable to linear circuits having two or more independent sources.

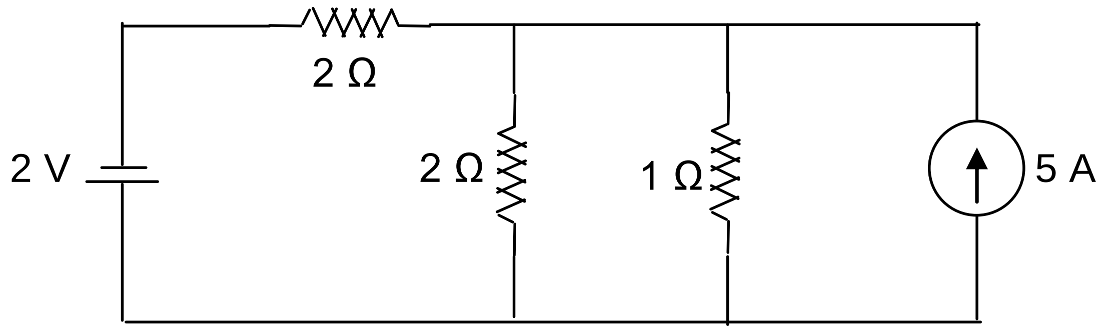
In a linear circuit having two or more independent sources, total response in an element (voltage across the element or current through the element) is equal to the algebraic sum of responses in that element due to each source applied separately while the other sources are reduced to zero.

To make a current source to zero, it must be open circuited. Similarly, **if any voltage source is to be made zero, it must be short circuited.** When this theorem is used in circuit with initial conditions, they are to be treated as sources. Further, dependent sources if any are left intact because they are controlled by circuit variables.

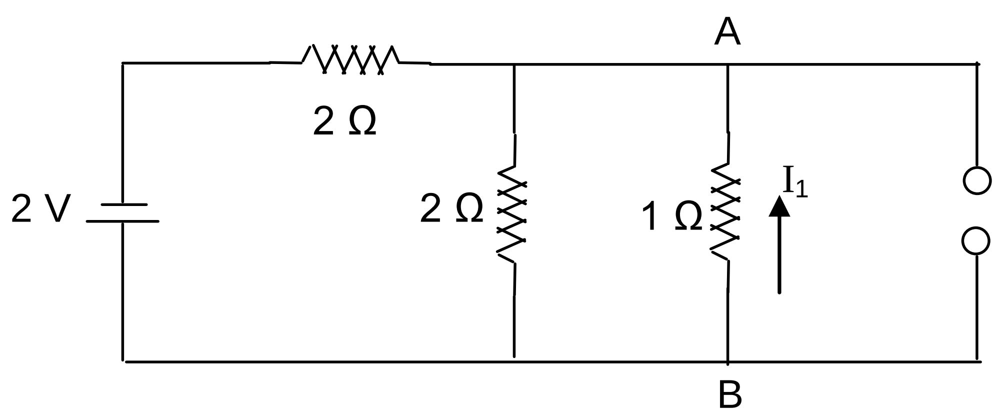
One disadvantage of analyzing a circuit using Superposition theorem is that it involves more calculations. If the circuit has three independent sources, we need to solve three simpler circuits each having only one independent source. However, when the circuit has only one independent source, several short-cut techniques can be readily applied to get the solution.

Major advantage of Superposition theorem is that it can be used to solve ac circuit having more than one source with **different frequencies.** In such case, solution in time frame is obtained corresponding to each source and added up to get the total solution.

Example 1 Calculate the current through the 1 Ω resistor in the circuit shown below.

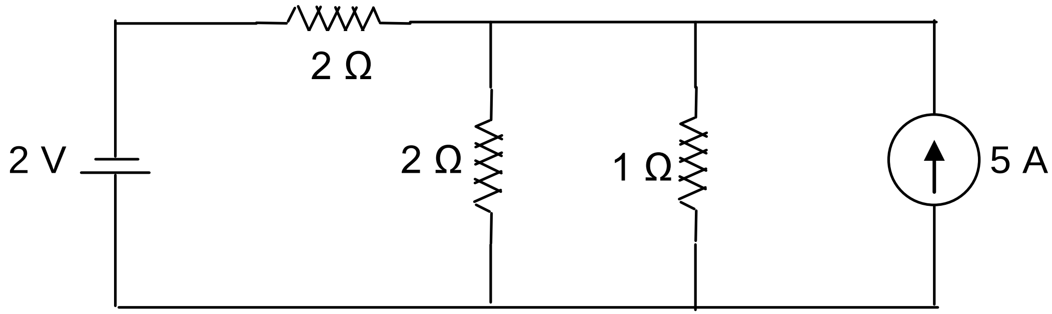


Solution: First calculate current I_1 due to voltage source alone. The current source is open circuited. The resulting circuit is shown below.



Total circuit resistance R_T = 2.6667 Ω. Circuit current $I_T = \frac{2}{2.6667} = 0.75$ A

$$\text{Current } I_1 = \frac{2}{3} \times 0.75 = 0.5 \text{ A from B to A}$$



Now calculate current I_2 due to current source alone. The voltage source is short circuited as shown in Fig.

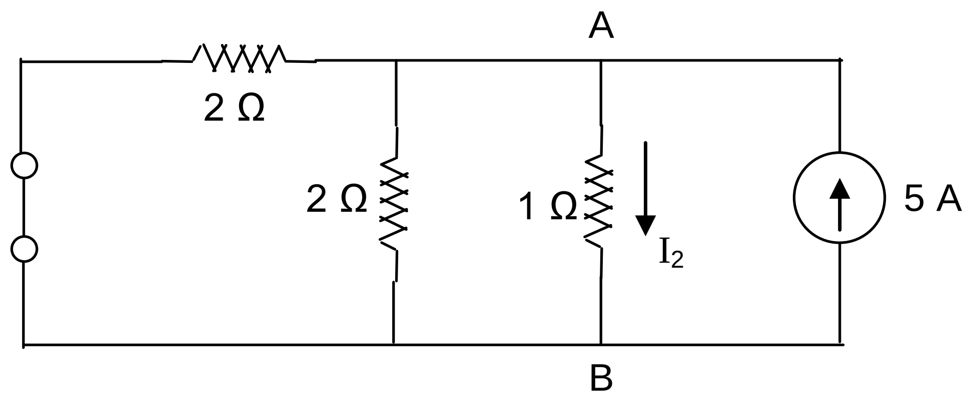


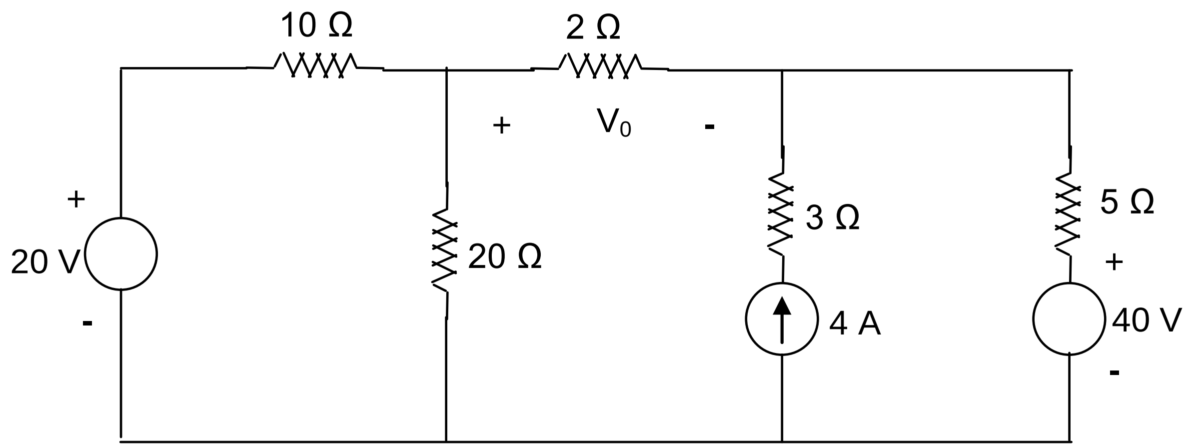
Fig. Circuit - Example 1

Noting that two 2 Ω resistors are in parallel, current I_2 = 2.5 A from A to B.

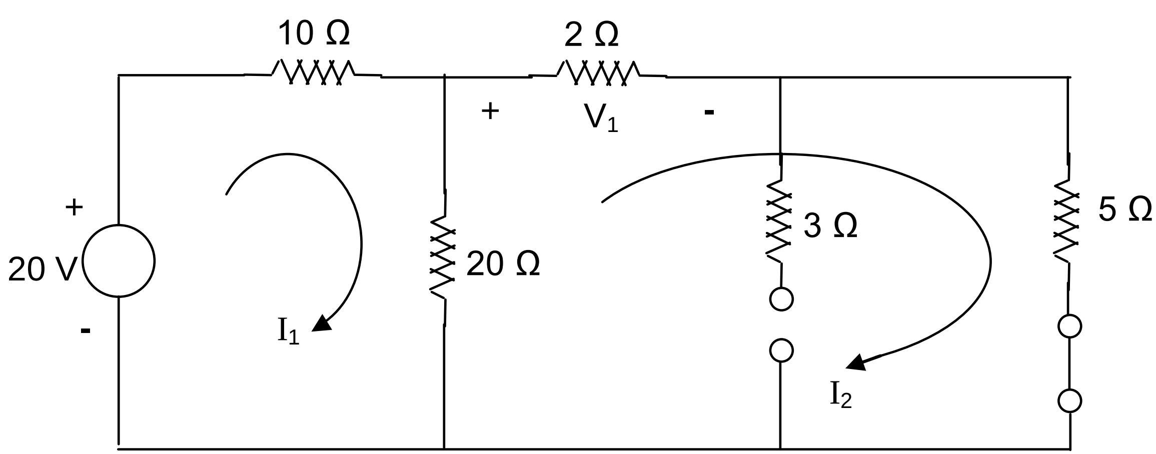
When both the sources are simultaneously present:

Current through 1 Ω resistor = 2.5 - 0.5 = 2 A from A to B.

Example 2 In the circuit shown, find the voltage drop, V_0 across the 2 Ω resistor using Superposition theorem.



Solution: 20 V source alone present: The circuit will be as shown below.

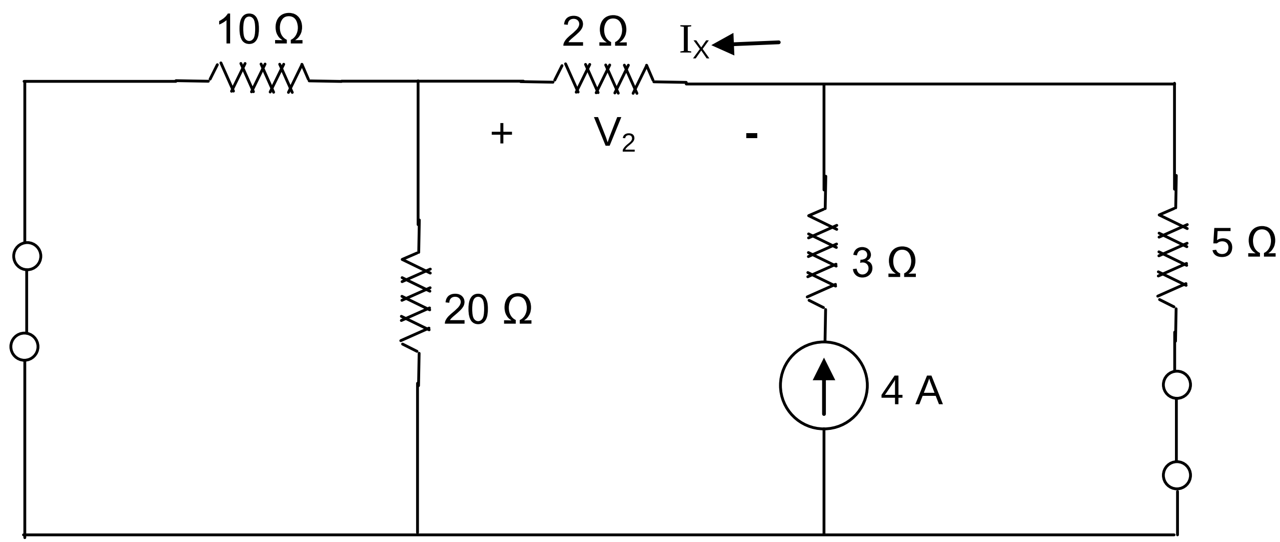


Mesh current equations: $\begin{bmatrix} 30 & -20 \\ -20 & 27 \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \end{bmatrix} = \begin{bmatrix} 20 \\ 0 \end{bmatrix}$ On solving, $I_2 = 0.9756$ A

Thus voltage $V_1 = 2 \times 0.9756 = 1.9512$ V

4 A source alone present:

The circuit will be as shown below.



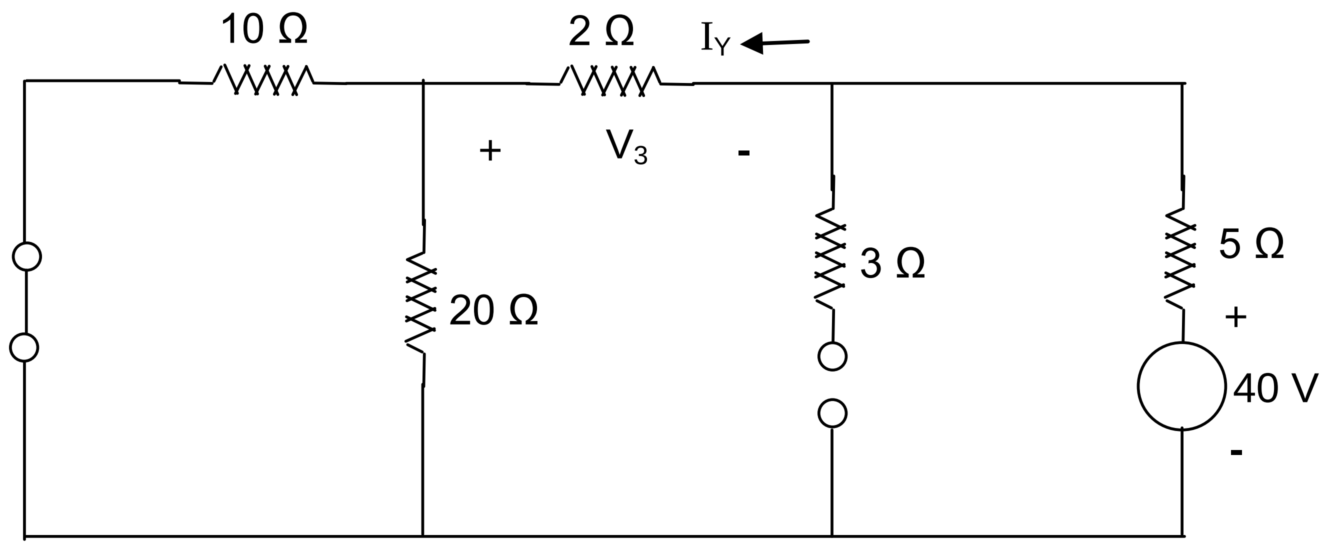
$$2 + 10 \,||\, 20 = 8.6667\ \Omega$$

$$\text{Therefore current } I_X = \frac{5}{13.6667} \times 4 = 1.4634 \text{ A}$$

$$\text{Thus voltage } V_2 = -2 \times 1.4634 = -2.9268 \text{ V}$$

40 V source alone present:

Resulting circuit is shown below.



Circuit resistance $R_T = 5 + 2 + (10||20) = 13.6667\ \Omega$

Current $I_Y = 40 / 13.6667 = 2.9268$ A; Thus voltage $V_3 = -\ 2 \times 2.9268 = -\ 5.8537$ V

When all the three sources are simultaneously present,

voltage across 2 Ω, i.e. $V_0 = V_1 + V_2 + V_3 = 1.9512 - 2.9268 - 5.8537 = -\ 6.8293$ V

BEEE-UNIT 2

D.C Machines & A.C Machines	
18	
Sinusoids, Generation of AC, Average, RMS values, Form and peak factors	Sinusoids, Generation of AC, Average, RMS values, Form and peak factors
Analysis of single phase AC circuit, Real, Reactive, Apparent power, Power factor	Analysis of single phase AC circuit, Real, Reactive, Apparent power, Power factor
Magnetic materials, B-H Characteristics Simple magnetic circuits	Magnetic materials, B-H Characteristics Simple magnetic circuits
Faraday's laws, induced emfs and inductances.	Faraday's laws, induced emfs and inductances.
1 - phase transformers: Construction, types, ideal, practical transformer	1 - phase transformers: Construction, types, ideal, practical transformer
EMF equation, Regulation, Efficiency	EMF equation, Regulation, Efficiency
Problem Solving Session	Problem Solving Session
Lab 4: Transformer Operation, Efficiency	Lab 4: Transformer Operation, Efficiency
Construction, working of DC Generators	Construction, working of DC Generators
Types of DC generators	Types of DC generators
Characteristics of Generators	Characteristics of Generators
Armature reaction, Losses	Armature reaction, Losses
Power stages of DC generators	Power stages of DC generators

GENERATION OF ALTERNATIVE EMF

Sinusoidal emf or Sinusoidal voltage

Consider a coil of n turns placed in a magnetic field of maximum value ϕ_m Webers [see Fig. 4.1 (a)]. The coil is initially along the reference axis. In this position, the field is perpendicular to the plane of the coil.

Let the coil be rotated in the anticlockwise direction with an angular velocity of ω rad/sec.

When the coil is along the reference axis at $\omega t = 0$, it is called as zero e.m.f. position. This is because the movement of the coil at this instant $\omega t = 0$ is along the field.

Let at any instant t sec. the coil takes a position as shown in Fig. 4.1(b).

At this instant, the coil makes an angle $\theta = \omega t$ with the reference axis.

At this position, the normal component of the mangnetic flux with respect to the plane of the coil is equal to

$$\phi_m \cos \theta \qquad (\therefore \quad \theta = \omega t)$$

The normal component $= \phi_m \cos \omega t$

Flux linkages (ψ) at this instant (y) is equal to $N\phi_m \cos \omega t$. According to Faraday's law.

The emf induced in the coil at the instant under consideration.

$$e = -\frac{d\psi}{dt} = \frac{-d}{dt}(N\phi_m \cos \omega t)$$

$$= -N\phi_m \omega(-\sin \omega t)$$

$$e = (N\phi_m \omega) \sin \omega t \tag{4.1}$$

With the above expression, we can calculate the emf induced at various instants.

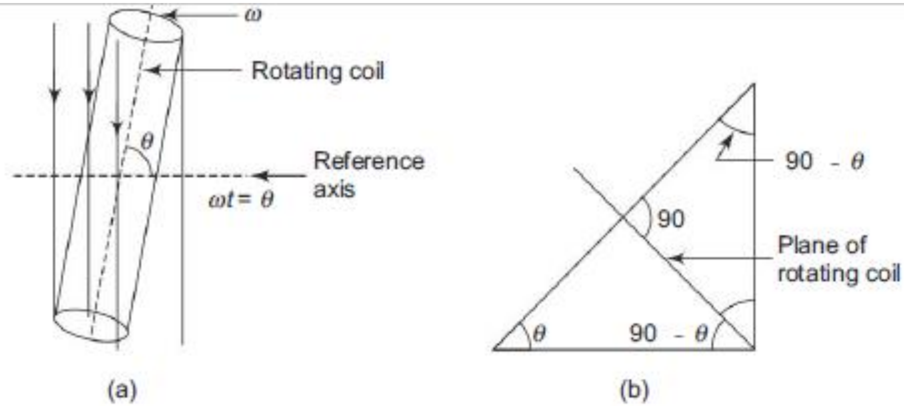


Fig. 4.1

When $\omega t = 0$ or $180°$

$$= (N\phi_m\omega) \sin 0 = (N\phi_m\,\omega) \sin 180°$$

$$e = 0$$

when $\omega t = 90°$ $e = (N\phi_m\omega) \sin 90°$

when $\omega t = 270°$ $e = N\phi_m\omega \sin (270°)$

$$e = -N\phi_m\omega$$

Let $N\phi_m\omega = E_m$ denote the maximum value of induced emf then from Eq. (4.1) we can write,

Instantaneous emf $e = E_m \sin \omega t$ (Refer Fig. 4.2) (4.2)

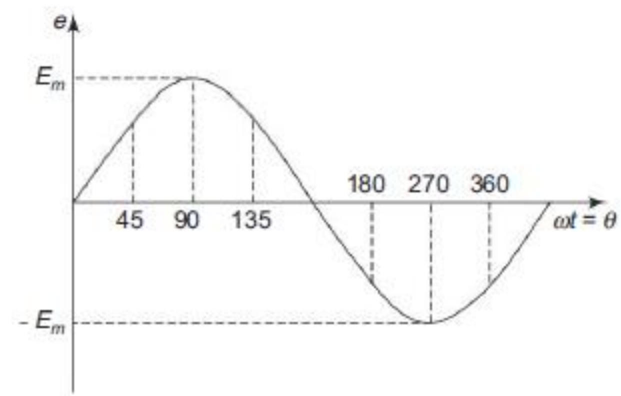


Fig. 4.2 Alternating emf wave for one complete cycle

4.2 TERMINOLOGY

1. *Waveform* A waveform is a graph in which the instantaneous value of any quantity is plotted against time. Examples of waveforms are shown in Fig. 4.3.

2. *Alternating Waveform* This is a wave which reverses its direction at regularly recurring intervals, e.g. Fig. 4.3(a).

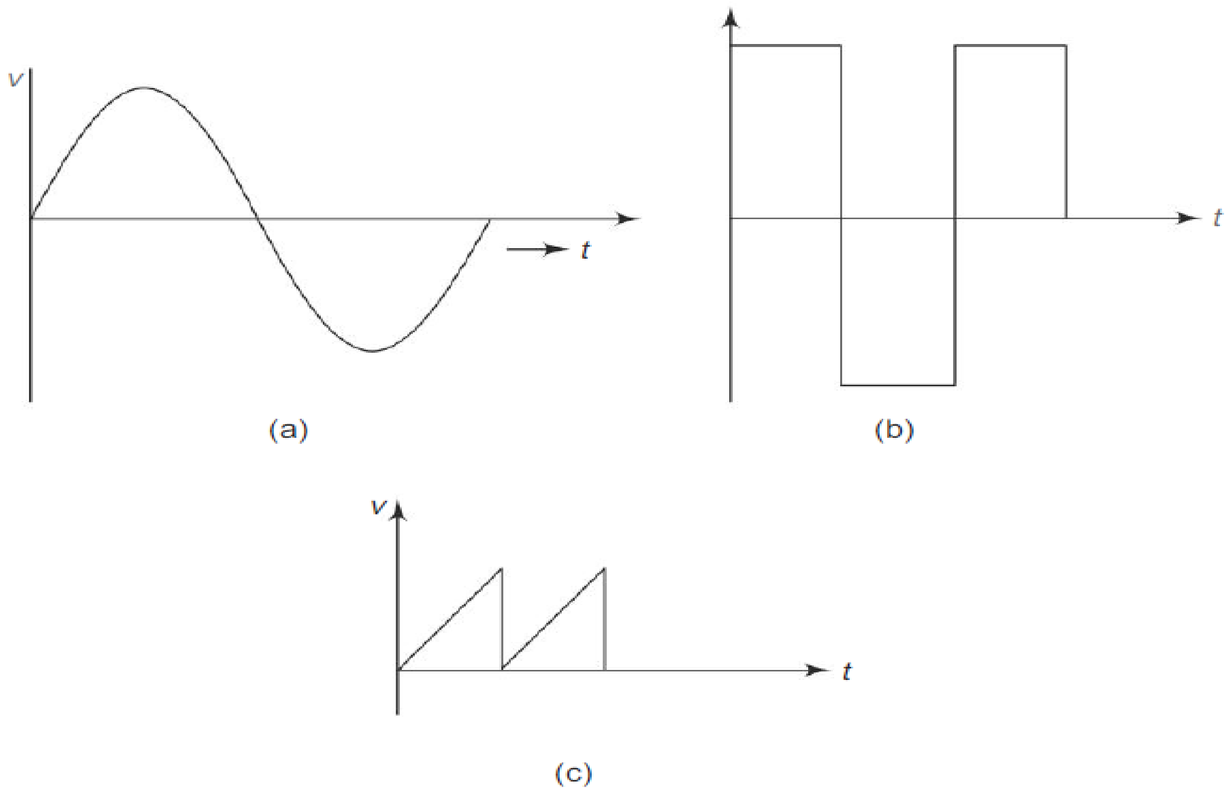


Fig. 4.3 (a) Sinusoidal waveform (b) Rectangular waveform (c) Sawtooth waveform

3. *Periodic Waveform* Periodic waveform is one which repeats itself after definite time intervals.

4. *Sinusoidal and Non-Sinusoidal Waveform*

Sinusoidal waveform It is an alternating waveform in which sine law is followed.

Non-sinusoidal waveform It is an alternating waveform in which sine law is not followed.

5. *Cycle* One complete set of positive and negative halves constitute a cycle.

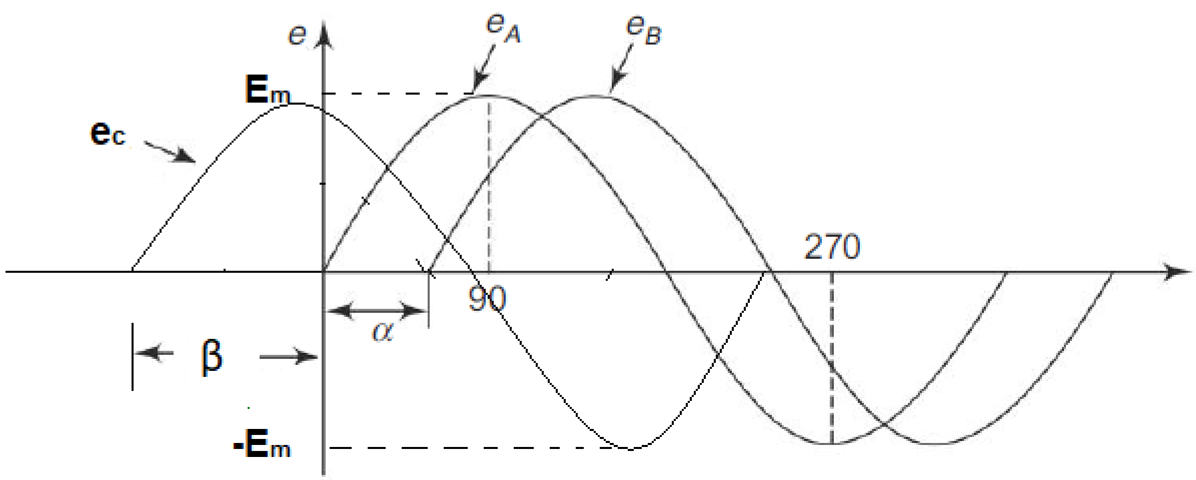
6. *Amplitude* The maximum positive or negative value of an alternating quantity is called the amplitude.

7. *Frequency* The number of cycles per second of an alternating quantity is known as frequency. Unit for frequency is expressed as c/s or Hertz (Hz).

8. *Period (T)* Time period of an alternating quantity is the time taken to complete one cycle. Time period is equal to the reciprocal of frequency. Time period is expressed in secs.

9. *Phase* The phase at any point on a given wave is the time that has elapsed since the quantity has last passed through zero point of reference and passed positively.

10. *Phase Difference* The term is used to compare the phase of two waveforms or alternating quantities.



$$e_A = E_m \sin \omega t$$

Voltage A is reference

$$e_B = E_m \sin(\omega t - \alpha)$$

Voltage B lags voltage A by an angle α

$$e_c = E_m \sin(\omega t + \beta)$$

Voltage C leads voltage A by an angle β

ROOT MEAN SQUARE (RMS) OR EFFECTIVE VALUE

Definition Effective or RMS value of an alternating current is deifned by that steady value of current (dc) which when flowing in a given circuit for a given time produces the same heat as would be produced by the alternating current flowing in the same circuit for the same time.

Method to Obtain the RMS Value for Sinusoidal Currents

Let the alternating current be represented by

$$i = I_m \sin \omega t$$

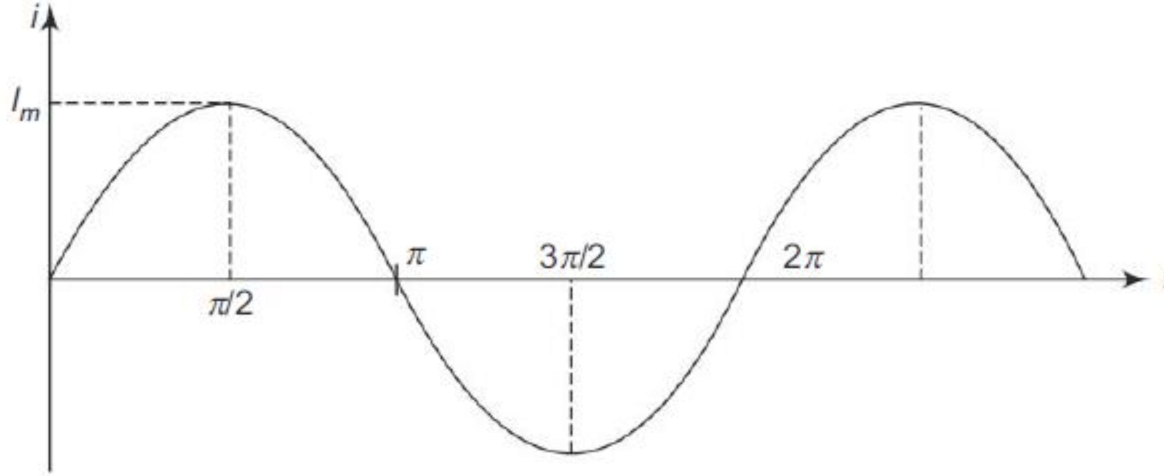
$$= I_m \sin \theta \, (\theta = \omega t)$$

$$i^2 = I_m^2 \sin^2 \theta$$

Mean square of $\quad \text{AC} = \int_0^{2x} \frac{I_m^2 \sin^2 \theta}{2\pi} d\theta$

$$= \frac{I_m^2}{2\pi} \int_0^{2\pi} \sin^2 \theta \, d\theta$$

$$= \frac{I_m^2}{2\pi} \int_0^{2\pi} \frac{I - \cos 2\theta}{2} \, d\theta$$



$$= \frac{I_m^2}{2\pi}\left[\frac{\theta}{2} - \frac{\sin 2\theta}{4}\right]_0^{2\pi}$$

$$= \frac{I_m^2}{2\pi}\frac{2\pi}{2} = \frac{I_m^2}{2}$$

RMS value of the alternating sinusoidal current is

$$I = \sqrt{\frac{I_m^2}{2}} = \frac{I_m}{\sqrt{2}} = 0.707\, I_m$$

$$I_{\text{RMS}} = 0.707\, I_m$$

Similarly, For a sinusoidal voltage

$$V_{\text{RMS}} = \frac{V_m}{\sqrt{2}} = 0.707\, V_m$$

AVERAGE VALUE OF AC

Definition The average value of an ac is given by that steady current which transfers across a circuit the same charge as would be transferred by the ac across the same circuit in the same time.

Method to Obtain the Average Value for Sinusoidal Current

Let $$i = I_m \sin\theta$$

Since this is a symmetrical wave it has two equal half cycles namely positive and negative halves.

Considering one half cycle for this symmetrical wave the average value is obtained by

$$I_{\text{av}} = \frac{1}{\pi}\int_0^{\pi} i\,d\theta = \frac{1}{\pi} I_m \sin\theta\,d\theta$$

$$= \frac{I_m}{\pi}(-\cos\theta)_0^{x}$$

$$= \frac{I_m}{\pi}(1+1) = \frac{I_m}{\pi} \times 2$$

$$I_{\text{av}} = \frac{2\,I_m}{\pi}$$

$$I_{\text{av}} = 0.637\,I_m$$

where I_m is the maximum value of current.

For a sinusoidal voltage wave,

$$V_{\text{av}} = 0.637\,V_m.$$

Form Factor and Peak Factor The relation between average, RMS and maximum values can be expressed by two factors namely form factor and peak factor.
Form factor (K_f): Form factor is defined as the ratio of RMS value to the average value.

i.e. $$\text{Form factor} = \frac{\text{RMS value}}{\text{Average value}}$$

Peak factor or Cost factor) (K_p): Peak factor is defined as the ratio of peak value to the R.M.S. value.

i.e. $$\text{Peak factor} = \frac{\text{Peak value}}{\text{RMS value}}$$

For a sinusoidal wave,

$$\text{Form factor } (K_f) = \frac{0.707\, I_m}{0.637\, I_m} = 1.11$$

$$\text{Peak factor } (K_f) = \frac{I_m}{I_m/\sqrt{2}} = \sqrt{2} = 1.414.$$

ANALYSIS OF AC CIRCUIT

1. Real power / True power / Average power/ Power

$P = V\,I\,COS\,\Phi$ **or**

$P = V_{RMS}\,I_{RMS}\,COS\,\Phi$

$P = |V|\,|I|\,COS\,\Phi$

$P = I^2 R$

Unit: Watts

Where Φ Angle between voltage and current

2. Reactive Power $Q = V\,I\,SIN\,\Phi$

$Q = V_{RMS}\,I_{RMS}\,SIN\,\Phi$

Unit: VAR

3. Apparent power $S = VI$

$S = \sqrt{P^2 + Q^2}$

Unit : VA

4. Power Factor = $COS\,\Phi$

$= \dfrac{R}{|Z|}$

No Unit

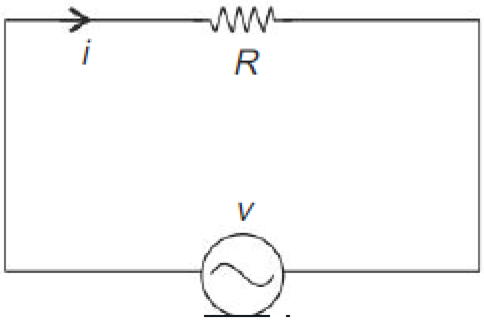
Where Φ Angle between voltage and current

Where $|Z| = R^2 + (X_L - X_C)^2$

ANALYSIS OF AC CIRCUIT

The response of electric circuits to alternating current can be studied by passing an alternating current through the basic circuit elements resistor (R), inductor (L) and capacitor (C).

1. Pure Resistive Circuit



Let the sinusoidal voltage applied across the resistance be

$$v = V_m \sin \omega t$$

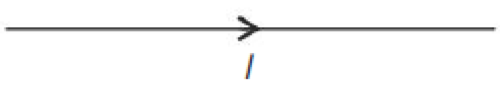
The resulting current has an instantaneous value, i By Ohm's law,

$$i = I_m \sin \omega t$$

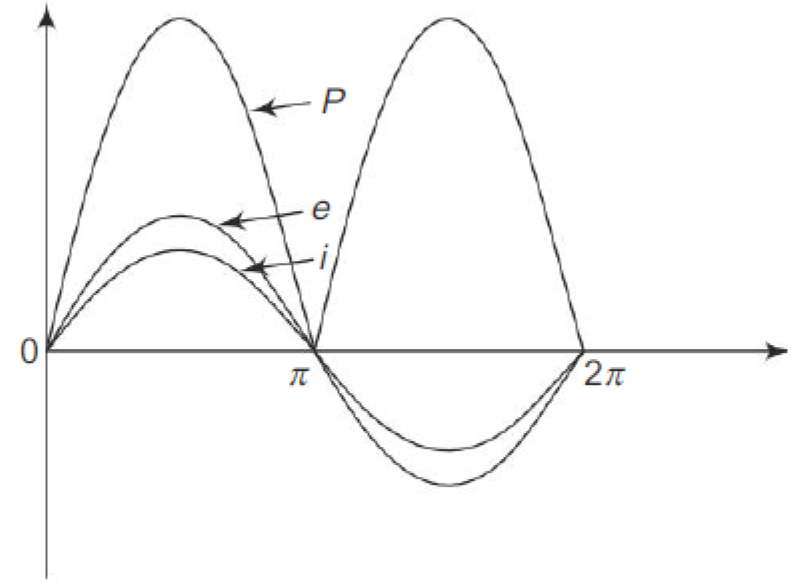
$$\text{where } I_m = \frac{V_m}{R}$$

Phasor Representation

In a pure resistive circuit,there is no phase difference between the voltage applied and the resulting current, i.e the phase angle $\phi = 0$. .If the voltage is taken as the reference phasor, thephasor representation for voltage and current in a pure resistive circuit is given in Fig.



Waveform Representation

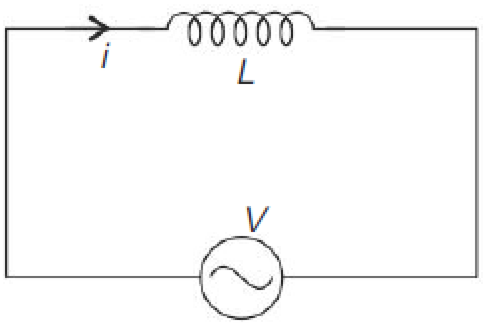


Power Factor It is the cosine of the phase angle between voltage and current

$\cos \phi = \cos 0 = 1$ (unity)

2. Pure Inductive Circuit

Consider the circuit of Fig. (4.16). In this circuit, an alternating voltage is applied across a pure inductor of self inductance L Henry.



Let the applied alternating voltage be

$$v = V_m \sin \omega t$$

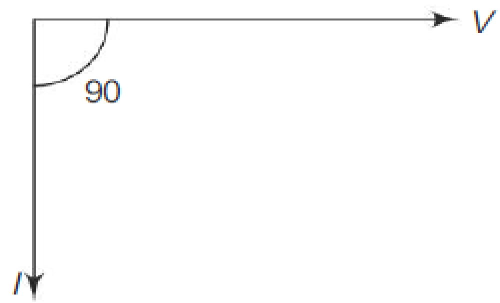
We know that the self induced emf always opposes the applied voltage.

$$v = L \frac{di}{dt}$$

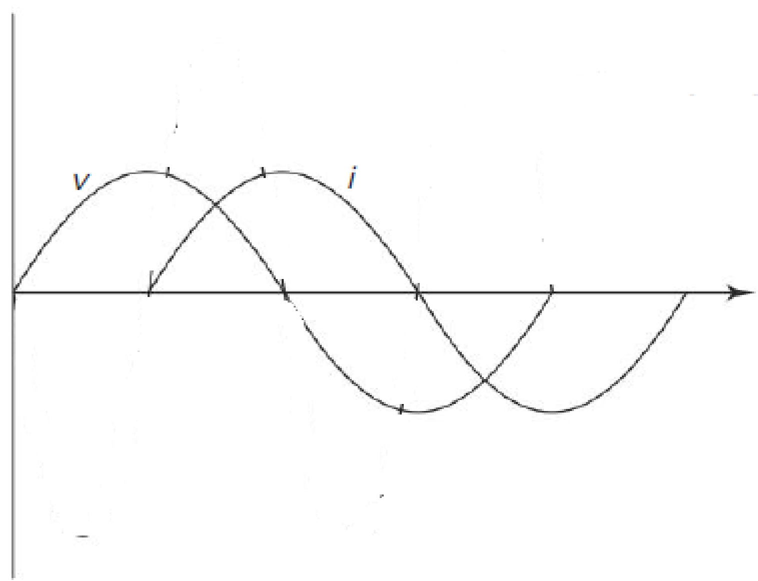
$$\therefore \quad i = \frac{1}{L}\int \cdot v \, dt = I_m \sin(\omega t - \pi/2)$$

we can say that the current through an inductor lags the applied voltage by 90°.

Phasor Representation Taking the voltage phasor as reference, the current phasor is shown to lag the voltage by 90° (Fig. 4.18).



Waveform Representation The current waveform is lagging behind the voltage waveforms by 90°.



Since $\phi = 90°$ Real power P=0

The pure inductor does not consume any real power

Power Factor In a pure inductor the phase angle between the current and the voltage phasors is 90°.

i.e. $\phi = 90°$; $\cos\,\theta = \cos 90° = 0$

Thus the power factor of a pure inductive circuit is zero lagging.

3 Pure Capacitive Circuit

Consider the circuit of Fig. 4.19 in which a capacitor of value C Farad is connected across an alternating voltage source.

Let the sinusoidal voltage applied across the capacitance be

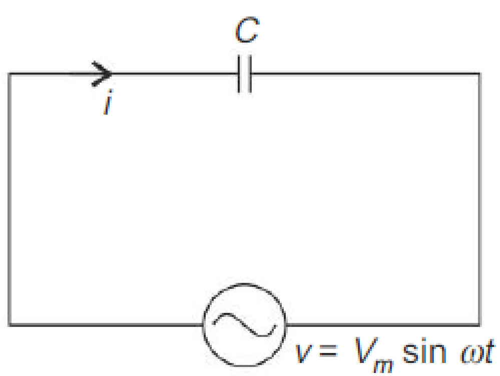
$$v = V_m \sin \omega t$$

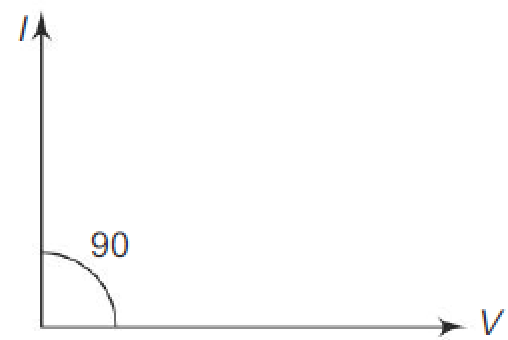
The characteristic equation of a capacitor is

$$V = \frac{1}{C}\int i dt$$

$$i = I_m \sin(\omega t + 90)$$

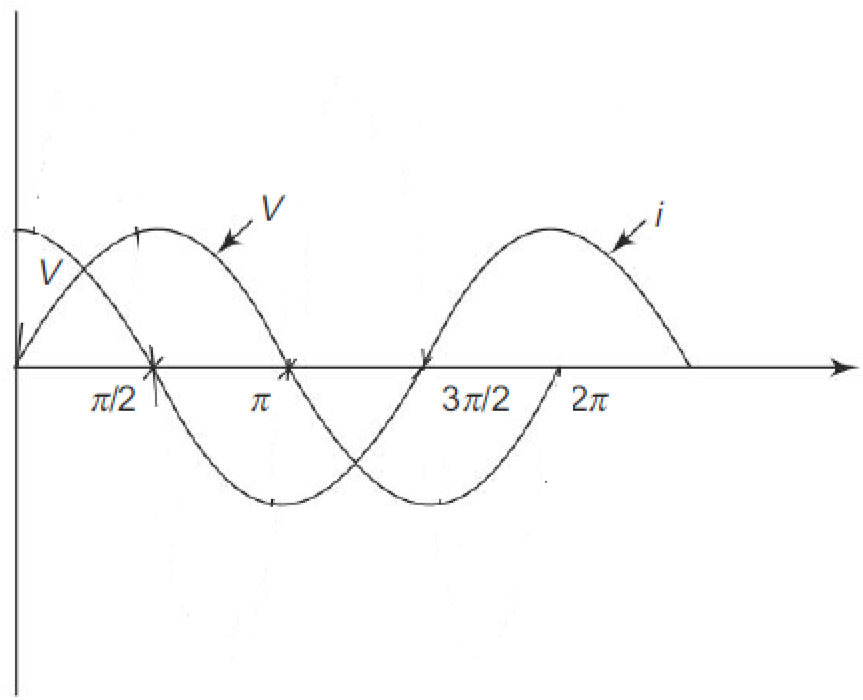
The current in a pure capacitor leads the applied voltage by an angle of 90°.



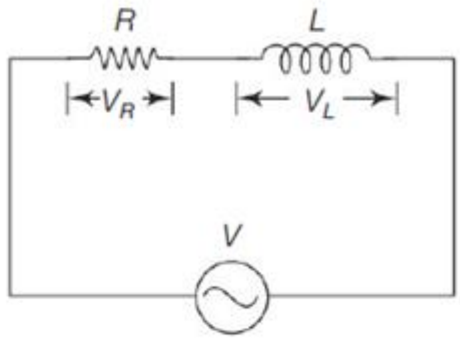


Phasor Representation In the phasor representation, voltage phasor is taken as the reference. The current phasor leads an angle of 90°

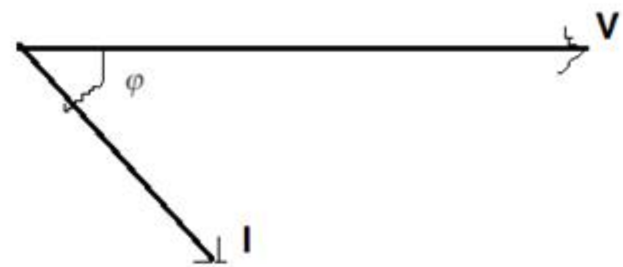
Waveform Representation The current waveform is ahead of the voltage waveform by an angle of 90°.



4 R–L SERIES CIRCUIT



Phasor

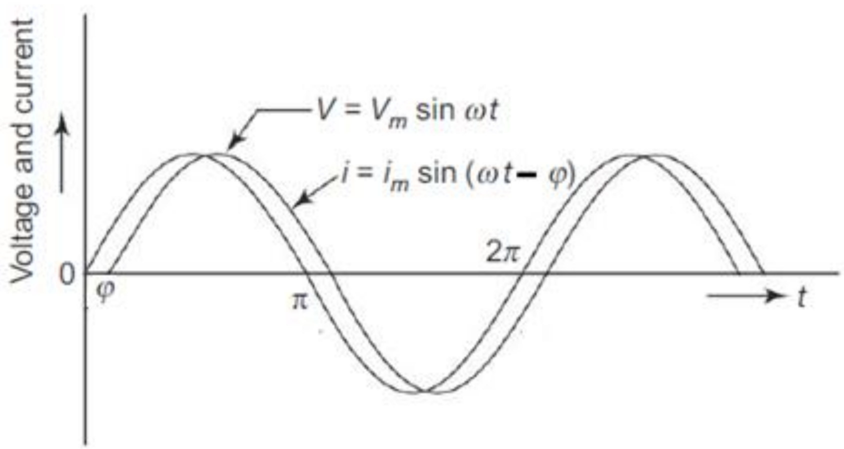


Let $v = V_m \sin \omega t$ be the applied voltage

then the current equation is

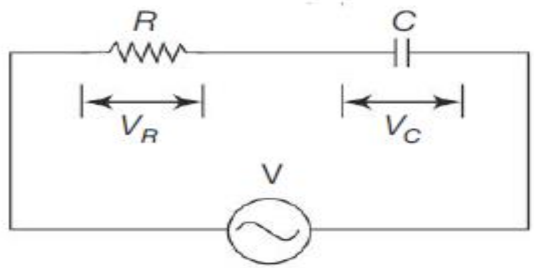
$$i = I_m \sin (\omega t - \phi)$$

Waveform



The current I lag Voltage V by an angle φ

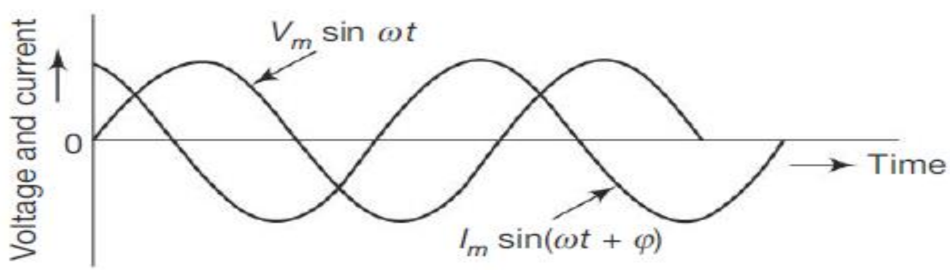
5 R-C SERIES CIRCUIT



Let $v = V_m \sin \omega t$ be the applied voltage

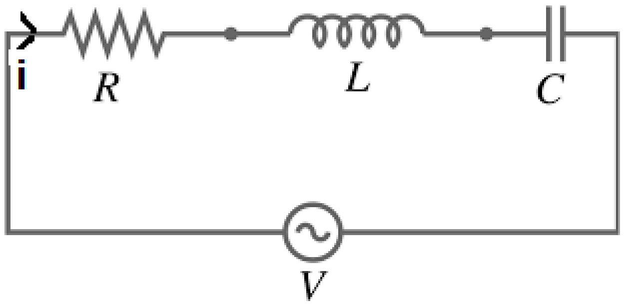
Then the current equation is $i = I_m \sin (\omega t + \phi)$

Waveform



Phasor

6. R-L-C SERIES CIRCUIT



Depends upon the value of X_L and X_C, the circuit behaves

If $X_L > X_C$, then the circuit behaves as RL circuit

If $X_L < X_C$, then the circuit behaves as RC circuit

Impedance $Z = R + j X_L - j X_C$ Unit: Ω

or

$Z = R + j(X_L - X_C)$

Where i or j = $\sqrt{-1}$

$X_L = 2\pi fL$ Unit: Ω

$X_C = \dfrac{1}{2\pi fC}$ Unit: Ω

f-Supply Frequency in Hz

PROBLEMS

1 A voltage 100 sin ωt is applied to a 10-ohm resistor. Find the instantaneous current, the current (rms) and the average power.

Solution: V or $e = 100 \sin \omega t$

$R = 10$ ohms

$i = e/R = 100/10 \sin \omega t = 10 \sin \omega t$ A

$I_{rms} = I_m / \sqrt{2}$

$= 10 / \sqrt{2}$

$= 7.07$ A

P= V I COS ϕ

$= \frac{100}{\sqrt{2}} \times \frac{10}{\sqrt{2}}$ X COS 0

= 500 Watts

2. A voltage v = 340 sin 314t is applied to a circuit and the resulting current, i = 42.5 sin 314t. Identify and hence find the values of the component. Find the value of power consumed.

Solution: $v = 340 \sin 314t = \frac{340}{\sqrt{2}} \angle 0$ Volts $= 240 \angle 0$ Volts

$i = 42.5 \sin 314\,t = \frac{42.5}{\sqrt{2}} \angle 0$ Amps $= 30 \angle 0$ Amps

From the above voltage and current equations, we find that they are in phase with each other. Thatis angle between V and I is 0. Hence, the basic component connected in the circuit must be resistor.

$R = V / I$

$= 240.4 / 30$

$= 8\ \Omega$

Note

$V_{rms} = |V| = V$

$P = VI \cos \Phi$

$= 240. \times 30 \times \cos 0$

$= 7200$ Watts

$P = I^2 R$

$= 30 \times 30 \times 8$

$= 7200$ Watts

3 In a series circuit containing pure resistance and pure inductance. the current and voltage expressed as $i\ (t) = 5 \sin\ (314\ t + 2\ \pi/3)$ and $V\ (t) = 20\,(314\ t + 5\ \pi/6)$.

(i) What is the impedance of the circuit?

(ii) What are the values of resistance, inductance and power factor?

(iii) What is the average power drawn by the circuit?

Solution

$$v(t) = 20 \sin\ (314t + 5\ \pi/6)$$

$$i(t) = 5 \sin\ (314t + 2\ \pi/3)$$

$$\text{Phase angle of voltage} = \frac{5\pi}{6} \text{ radians} = 5 \times \frac{180^\circ}{6} = 150^\circ$$

$$\text{Phase angle of current} = \frac{2\pi}{3} \text{ radians} = 2 \times \frac{180^\circ}{3} = 120^\circ$$

$$V = \frac{20}{\sqrt{2}} \angle 150^\circ \text{ Volts} = 14.14 \angle 150^\circ \text{ Volts}$$

$$I = \frac{5}{\sqrt{2}} \angle 120^\circ \text{ Amps} = \qquad \text{Amps}$$

Current lags the voltage by 150 –120° = 30°.
Lagging p.f. means that it is an R–L circuit.

$$Z = V / I$$

$$= \frac{14.14 \angle 150^\circ}{3.53 \angle 120^\circ} = 3.46 + j\,2 \text{ Ohms}$$

$$= R + j\,X_L$$

Therefore R= 3.46 Ohms

X_L = 2 Ohms

X_L = 2 Ohms

$\omega L =$ 2 Ohms

314L = 2 Ohms

ω = 314 rad/s [given]

L= 2/314
=6.36 mH

Power Factor = COS Φ
= COS 30
= 0.866 [LAGGING]

Average Power P = VI COS Φ

= 14.14 x 3.53 x cos 30
= 43.22 Watts

$P = I^2 R$
$= 3.53^2 \times 3.46$
= 43.22 Watts

4. Find the circuit constants of a two element series circuit which consumes 700 W with 0.707 leading p.f. The applied voltage is $V = 141.4 \sin 314\, t$.

Solution

$$v = 141.4 \sin 314t$$

$$P = 700 \text{ W}, \quad \text{p.f.} = 0.707 \text{ leading}$$

Leading p.f. means $R-C$ circuit

Max. value of supply voltage = 141.4 V

R.M.S. value of supply voltage $= \dfrac{141.4}{\sqrt{2}} = 99.98$ V

$$\cos\phi = 0.\,707 \text{ leading; Power} = VI\cos\phi$$

$$700 = 99.98 \times I \times 0.707; \quad I = 9.9 \text{ A}$$

Impedance $\quad |Z| = \dfrac{V}{I} = \dfrac{99.98}{9.9} = 10.09$ ohms

$$\cos\phi = \frac{R}{|Z|} \Rightarrow R = |Z|\cos\phi$$

$$R = 10.09 \times 0.707 = 7.13\ \Omega$$

$$X_C = \sqrt{Z^2 - R^2} = \sqrt{10.09^2 - 7.13^2} = 7.13 \text{ ohms}$$

$$\frac{1}{\omega C} = 7.13; \quad \frac{1}{314 \times C} = 7.13 \Rightarrow C = \frac{1}{314 \times 7.13}$$

$$C = 4.466 \times 10^{-4} \text{ F}$$

$$= 446.6 \times 10^{-6} \text{ F}$$

$$C = 446.6 \ \mu\text{F}$$

ANOTHER METHOD IN NEXT PAGE

ANOTHER METHOD

$$v = 141.4 \sin 314t$$

$$P = 700 \text{ W}, \quad \text{p.f.} = 0.707 \text{ leading}$$

Leading p.f. means $R-C$ circuit

Max. value of supply voltage = 141.4 V

R.M.S. value of supply voltage $= \dfrac{141.4}{\sqrt{2}} = 99.98$ V ; $V = 99.98 \angle 0^\circ$ V

$$\cos\phi = 0.707 \text{ leading; Power} = VI\cos\phi$$

$$700 = 99.98 \times I \times 0.707; \quad I = 9.9 \text{ A} ; \quad I = 9.9 \angle 45^\circ \text{ A}$$

Impedance $Z = V / I$ Since Current is leading, it is $+45^\circ$

$$= \frac{99.98 \angle 0^\circ}{9.9 \angle 45^\circ}$$

$= 7.13 - j\,7.13$ Ohms

$= R - j\,X_C$

$R = 7.13\ \Omega \quad X_C = 7.13$ ohms

$$\frac{1}{\omega C} = 7.13; \quad \frac{1}{314 \times C} = 7.13 \Rightarrow C = \frac{1}{314 \times 7.13}$$

$$C = 4.466 \times 10^{-4} \text{ F}$$

$$= 446.6 \times 10^{-6} \text{ F}$$

$$C = 446.6\ \mu\text{F}$$

3.12 MAGNETIC MATERIALS

Magnetic field is present around a current carrying conductor. It is also exist around magnet. An electron revolving around the nucleus of its atom in its orbit forms a tiny electric current loop. This current loop produces a magnetic field. Most of the substances would exhibit magnetic effects and some of them are magnetically weak. Depending on their magnetic behaviour, substances can be classified into three groups. They are

1. diamagnetic
2. paramagnetic
3. ferromagnetic

The metals and other elements having slight magnetic properties are called ***diamagnetic*** materials in which the magnetization is opposite to the applied field. If the magnetization is in the same direction as the applied field, such materials are called as ***paramagnetic*** materials. Infact these two materials which have feeble magnetic effects are called non-magnetic materials. Ferro magnetic materials show very strong magnetic effects. THe magnetization is in the same direction as the field. Iron, Steel, Nickel and Cobalt are known as ferromagnetic materials.

The metals and other elements having slight magnetic properties are called ***diamagnetic*** materials in which the magnetization is opposite to the applied field. If the magnetization is in the same direction as the applied field, such materials are called as ***paramagnetic*** materials. Infact these two materials which have feeble magnetic effects are called non-magnetic materials. Ferro magnetic materials show very strong magnetic effects. THe magnetization is in the same direction as the field. Iron, Steel, Nickel and Cobalt are known as ferromagnetic materials.

Relative permeability decides the material which belongs to whether diamagnetic, paramagnetic or ferromagnetic. For vacuum, $\mu_r = 1$, vacuum is taken as reference medium.

If $\mu_r \leq 1$, the materials are diamagnetic

If $\mu_r \geq 1$, the materials are paramagnetic

If $\mu_r >> 1$, the materials are ferromagnetic.

Substances classified according to their relative permeability are tabulated in Table 1.

Table-1

Classification of substances according to their relative permeability

Substance	Magnetic type	Relative permeability (μ_r)
Silver	Diamagnetic	0.99998
Copper	Diamagnetic	0.999991
Vacuum	Non-magnetic	1
Aluminium	Paramagnetic	1.00002
Palladium	Paramagnetic	1.0008
Cobalt	Ferromagnetic	250
Nickel	Ferromagnetic	600

3.13 MAGNETIZATION CURVE

The ratio between B and H may be constant for all values of H, especially in the case of ferromagnetic materials. The characteristic curve showing the variation of flux density (B) with field intensity (H) is called ***Magnetization Curve.***

Consider a toroid with ferromagnetic core which has primary and secondary coils. The primary coil is excited by a variable DC power supply which produces the change in field intensity H and its corresponding effect can be measured by a flux meter at the secondary coil as shown in Fig.3.11(a). The value of H can be increased or decreased by increasing or decreasing the current through the toroid. Now H is increased from zero to a certain maximum value and the corresponding value of B is noted. This is represented as **oc** in B-H curve as shown in Fig.3.11 (b). The point **c** is called magnetic saturation.

If H is reduced to zero gradually, B will not decrease to zero but has a value **od**. This is called ***residual*** or ***remanent*** value. In order to bring down the value of to zero (i.e. to demagnetize the toroid), H has to be applied in reverse (negative) direction. When H is reversed, then B is reduced to zero at point **e**. The field at **e** ($H = -H_e$) is called *Coercive force.* The value of H is further increased in the negative direction, the value of B is reached in saturation level in negative direction at f . By taking H back from its value for negative saturation to its value for positive saturation, a similar curve **fabc** is obtained.It is concluded that B always lags behind H. This is called ***hysteresis.*** The closed loop **cdefabc** is termed as ***BH loop*** or ***hysteresis loop.***

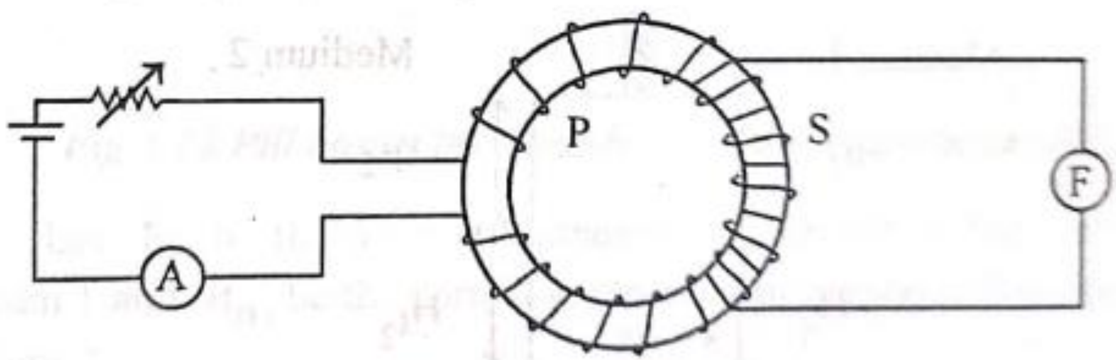
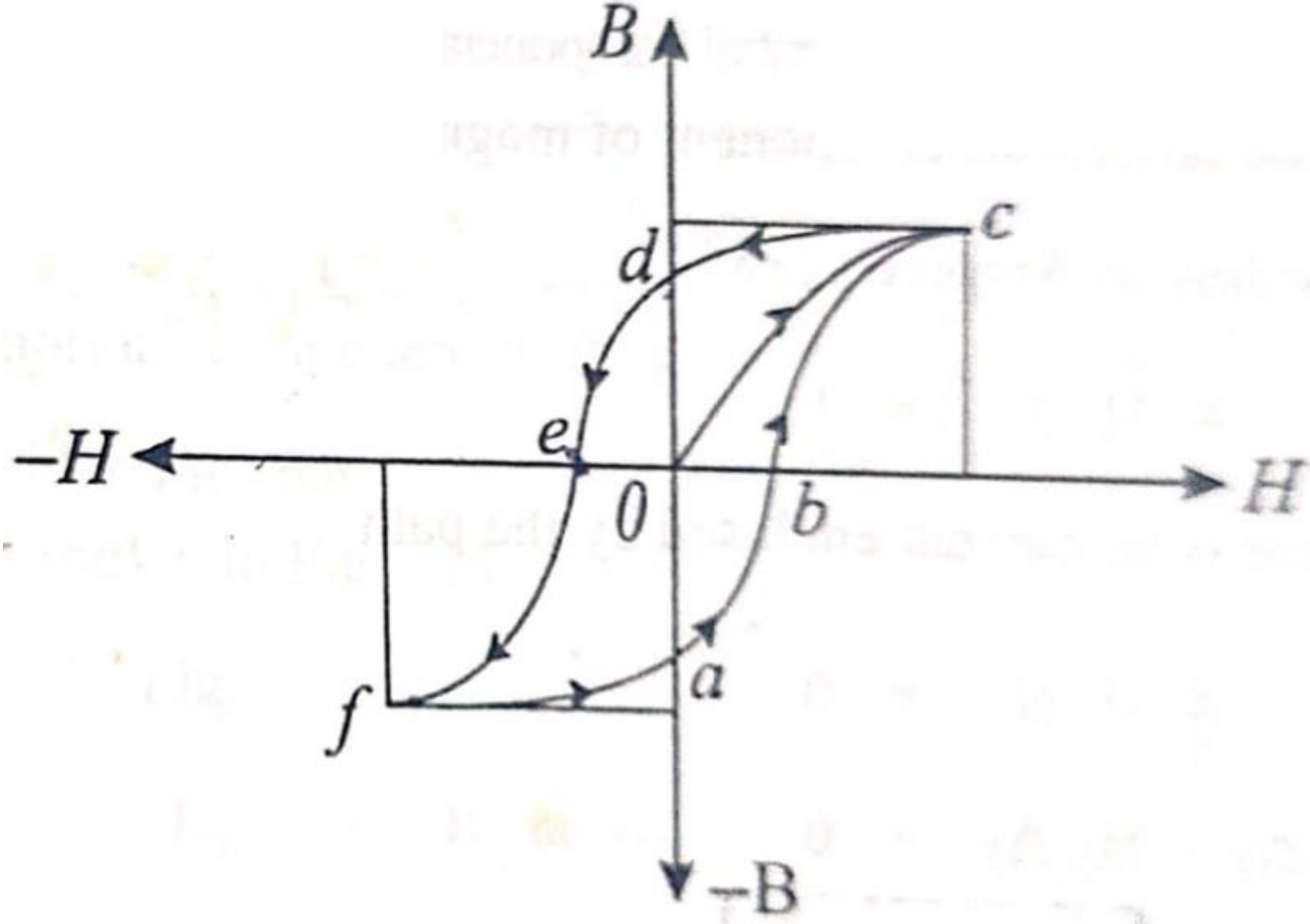


Fig 3.11 (a) Toroidal



B
c
d
e
−H
H
0
b
a
f
−B

MAGNETIC CIRCUITS

The various terms involved with magnetism are grouped as follows:

1. Magnetic Flux [Φ]

The magnetic lines of force produced by a magnet is called magnetic flux.
Its unit is Weber. 1 wb = 1 x 10^8 magnetic lines

.2 Magnetic Flux Density (B)

Magnetic flux density is the flux per unit area at right angles to the flux.

$$B = \frac{\phi}{a} \text{ wb/m}^2$$

where ϕ(wb) is the magnetic flux and a (m^2) is the area of cross section. Its unit is wb/m^2 or Tesla.

.3 Magneto Motive Force (F)

MMF is the cause for producing flux in a magnetic circuit. It is obtained as the product of the current (I amps) flowing through a coil of N turns. Its unit is Ampere.

Thus, $F = N\,I$ Amps.

The term, M.M.F. is normally referred to as Ampere Turns (AT).

4 Magnetic Field Intensity (or) Magnetising Force (H)

It is defined as M.M.F. per unit length of the magnetic flux path. It is a measure of the ability of a magnetised body to produce magnetic induction in other magnetic substances. Its unit is Ampere/metre.

With reference to Fig. 2.2 $H = \dfrac{N\,I}{l}$

.5 Permeability (μ)

This is the property of the magnetic medium. The flux density (B) is proportional to the magnetising force which produces it.

i.e.

$$B \propto H$$

$$B = \mu H$$

$$\mu = B/H$$

where μ is the constant of proportionality and is called permeability.

6 Relative Permeability (μ_r)

The relative permeability of a medium or material is defined as the ratio of the flux density produced in that medium or material to the flux density produced in vaccum by the same magnetising force.

$$\mu_r = \frac{\text{Flux density in the medium}}{\text{Flux density in vaccum}}$$

The absolute permeability of vaccum or free space has the value of $4\pi \times 10^{-7}$ Henry/m.

The permeability for any other medium is

$$\mu = \mu_r \times \mu_0$$

The relative permeability of vaccum or free space is unity and that of air and other non-magnetic materials is very nearly equal to unity.

7 Reluctance (S)

Reluctance is the property of an magnetic circuit by which the setting up of flux is opposed. It is defined as the ratio of the magnetomotive force to the flux.

The unit of reluctance is Amp./Weber and is denoted by *S*.

8 Permeance (P)

It is the reciprocal of reluctance and is the readiness with which magnetic flux is developed. It is analogous to conductance in an electric circuit. Its unit is weber per Amp.

MAGNETIC CIRCUIT

Magnetic circuit is the path followed by magnetic flux. Magnetic flux follows a complete loop or circuit coming back to its starting point. In any magnet, magnetic flux leaves its north pole, passing through air, enters the magnet at its south pole and finally reaches point where they start.

LEAKAGE FLUX

The flux which does not follow the desired path in magnetic circuit is known as *leakage flux*.

Usually, we assume that all the flux lines take the path of the magnetic medium. But, practically, it is impossible to confine all the flux to the iron path only. It is because, to prevent the leakage of flux, there is no perfect magnetic insulator. Even in air, flux is conducted fairly well. Hence, some of the flux leaks through air as shown in Fig. 2.8 and is known as leakage flux. All the magnetic flux which completes the desired magnetic circuit is the *useful flux*.

To account for the leakage flux, the term, "leakage coefficient" is introduced.

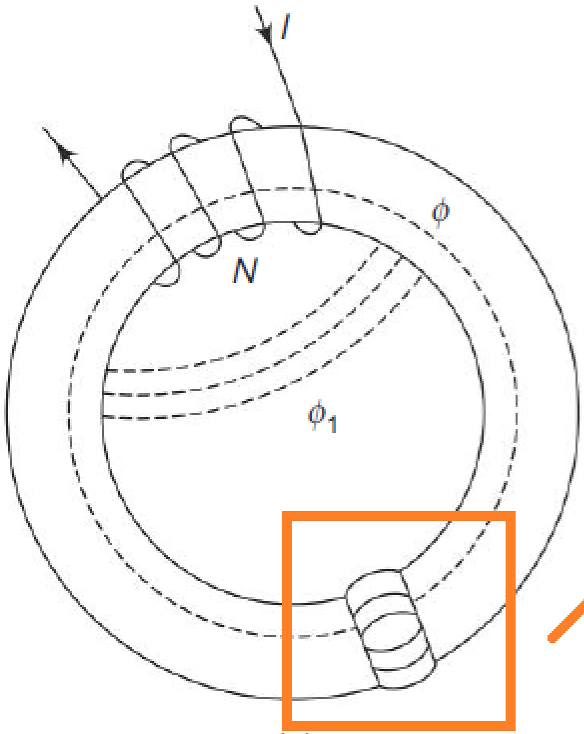
Leakage coefficient is defined as follows and it is defined by λ.

Leakage coefficient, $\lambda = \dfrac{\text{total flux}}{\text{useful flux}} = \dfrac{\phi + \phi'}{\phi}$

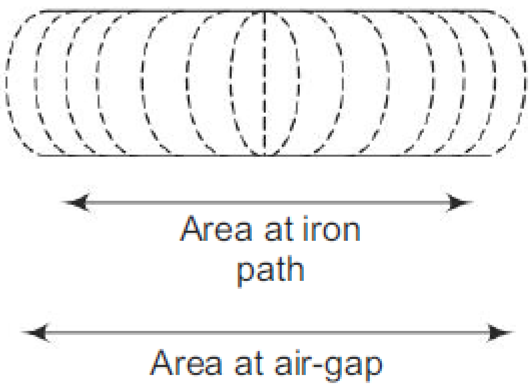
Usually, leakage factor is greater than unity.

FRINGING EFFECT

An air gap is often inserted in magnetic circuits out of necessity. When crossing an air gap, the magnetic lines of force have a tendency to bulge out. This is because the magnetic lines of force repel each other when they are passing through a non-magnetic material. This phenomenon is known as *fringing*.



(a)



(b)

Analysis of Simple Magnetic Circuit

Consider a circular solenoid or a toroidal iron ring having a magnetic path of l meters, area of cross-section, a m^2 and a coil of turns carrying I amperes wound anywhere on it as in Fig. 2.3.

M.M.F. Produced = NI Amps.

According to the definition of H, the field-strength inside the solenoid is

$$H = \frac{N\,I}{l} \text{ Amp./metre}$$

$$= \frac{NI}{2\pi R_m}$$

Now $$B = \mu_0 \mu_r H \qquad (\because \quad \mu = B/H)$$

$$B = \frac{\mu_0 \mu_r N\,I}{l} \text{ wb/m}^2 \ldots$$

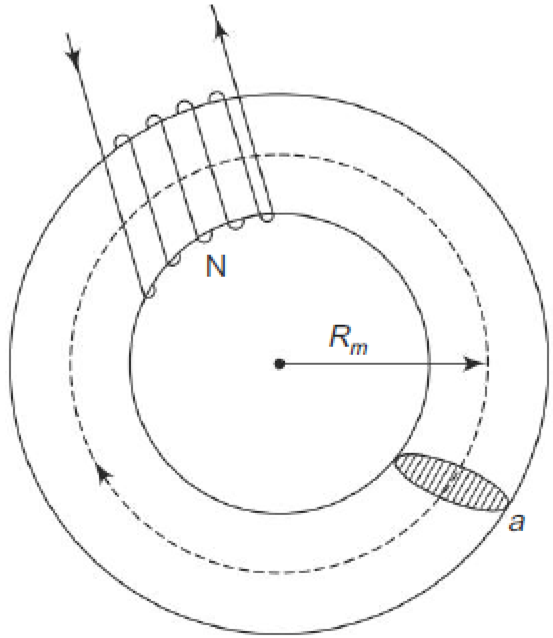
Total flux produced

$$\phi = Ba = \frac{\mu_0 \mu_r a\ NI}{l} \text{ wb}$$

Also, $$\phi = \frac{NI}{\dfrac{l}{\mu_0 \mu_r a}} = \frac{NI}{s} \text{ wb}$$

According to the definition of reluctance,

$$S = \frac{N\,I}{\phi}$$



Thus, the denominator $\frac{1}{\mu a}$ or $\frac{1}{\mu_0 \mu_r a}$ is the reluctance of the circuit and is analogous to resistance in electric circuit

$$S = \frac{1}{\mu_0 \mu_r a}$$

$$\text{Flux} = \frac{\text{mmf}}{\text{reluctance}}$$

The above equation is also known as 'Ohm's' law of magnetic circuit' because its resembles a similar expression in electric circuits,

$$\text{Current} = \frac{\text{emf}}{\text{resistance}}$$

Comparison between electric and magnetic circuit

Sl. No.	Magnetic circuit	Electric circuit
1	Magnetic flux, φ webers	Electric current, I ampere
2	Magneto motive force, AT	EMF, E volts
3	Reluctance, S AT / Wb	Resistance, R ohm
4	$\varphi = \frac{\text{mmf}}{\text{reluctance}}$	$\text{Current} = \frac{\text{emf}}{\text{resistance}}$

Problems

.1 A toroidal air cored coil with 2000 turns has a mean radius of 25 cm, diameter of each turn being 6 cm. If the current in the coil is 10 *A*, find *MMF*, (b) flux and (c) flux density.

Solution:

$N = 2000$ turns; $I = 10$ Amps; $R_m = 25$ cm

dia. of each turn, $d = 6$ cm.

(a) $MMF = NI = 2000 \times 10 = 20{,}000$ Amperes

(b) Flux = MMF/Reluctance

Reluctance = $l/a\mu$

$$l = 2\pi R_m = 2\pi \times \frac{25}{100}\text{ m} = 1.57\text{ m}$$

$$a = \frac{\pi d^2}{4} = \frac{\pi}{4} \times (6 \times 10^{-2})^2 = 2.8 \times 10^{-3}\text{ m}^2$$

$$\mu = \mu_0\mu_r = 4\pi \times 10^{-7} \times 1$$

$\therefore$ Reluctance $= \dfrac{1}{a\mu}$

$$= \frac{1.57}{2.8 \times 10^{-3} \times 4\pi \times 10^{-7} \times 1}$$

$$= 4.46 \times 10^8\text{ At/wb}$$

$$\text{Flux} = \frac{\text{mmf}}{\text{Reluctance}} = \frac{20{,}000}{3.47 \times 10^8}$$

$$= 4.48 \times 10^{-5}\text{ wb}$$

$$\text{Flux density} = \frac{\text{Flux}}{\text{Area of cross section}} = \frac{4.48 \times 10^{-5}}{2.8 \times 10^{-3}}$$

$$= 1.6 \times 10^{-2}\text{ wb/m}^2\text{ (or) Tesla}$$

2 The flux produced in the air gap between two electromagnetic poles is 5×10^{-2} wb. If the cross sectional area of the air gap is 0.2 m^2 find (a) flux density, (b) magnetic field intensity, (c) reluctance, and (d) permeance of the air gap. Find also the mmf dropped in the air gap given the length of the air gap to be 1.2 cm.

Solution:

$$\phi = 5 \times 10^{-2} \text{ wb}$$

$$a = 0.2 \text{ m}^2$$

$$l_g = 1.2 \text{ cm} = 0.012 \text{ m}$$

$$\mu_r = 1$$

(a) Flux density (B) $\dfrac{\phi}{a} = \dfrac{5 \times 10^{-2}}{0.2} = 0.25$ wb/sq.m

(b) Magnetic field intensity (H) $= \dfrac{B}{\mu_0 \mu_r}$

$$= \frac{0.25}{4\pi \times 10^{-7} \times 1}$$

$$= 1.9894 \times 10^5 \text{ A/m}$$

(c) Reluctance (S) of the air gap $= \dfrac{l_g}{a\mu}$

$$= \frac{0.012}{0.2 \times 4\pi \times 10^{-7} \times 1}$$

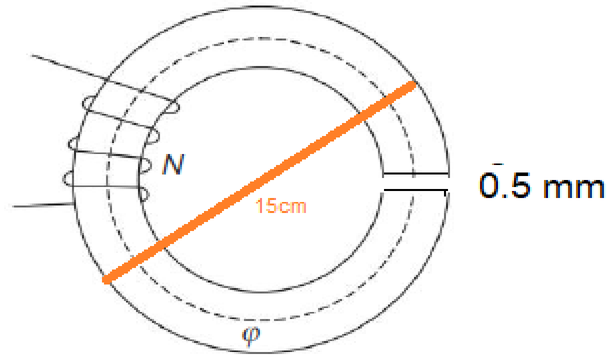
$$= 47746.48 \text{ A/wb}$$

(d) Permeance = 1/Reluctance $= \dfrac{1}{47746.48} = 2.0944 \times 10^{-5}$ wb/A

(e) mmf in the air gap = $\phi \times$ Reluctance $= 5 \times 10^{-2} \times 47747 = 2387$ A.

3. A ring has mean diameter of 15 cm, a cross section of 1.7cm^2 and has a radial gap of 0.5 mm in it. It is uniformly wound with 1500 turns of insulated wire and a current of 1 A produces a flux of 0.1 mwb across the gap.Calculate the relative permeability of iron on the assumption that there is no magneticleakage.

Solution:



$$\phi = 0.1 \times 10^{-3} \text{ wb}$$

$$a = 1.7\text{cm}^2 = 1.7 \times 10^{-4} \text{ m}^2$$

Total Reluctance = Reluctance of iron path+Reluctance of air gap

$$S_T = S_i + S_g$$

Total Reluctance $S_T = NI / \phi = 1500 \text{ X } 1 / 0.1 \times 10^{-3}$

$= 1{,}50{,}00{,}000$ A/Wb

Reluctance (S) of the air gap $= S_g = \dfrac{l_g}{a\mu} = \dfrac{l_g}{a\mu_0\mu_r}$ $[\mu_r = 1 \text{ for air}]$

$= 0.5\text{x}10^{-3} /[1.7 \text{ x } 10^{-4} \text{ x } 4\pi \text{ x}10^{-7} \text{ x } 1]$

$= 23{,}40{,}513.8$ A/Wb

$$S_i = S_T - S_g$$

$$= 15000000 - 2340513.8$$

$$= 1{,}25{,}69{,}486.2 \text{ A/Wb}$$

$$S_i = \frac{l_i}{a\mu} = \frac{l_i}{a\mu_0\mu_r}$$

l_i, Length of iron path = Total length = l_g

$$l_i = (\pi d - l_g)m = (\pi \times 0.15 - 0.005)$$

$$= 0.466 \text{ m}$$

$$\mu_r = \frac{l_i}{a\mu_0 S_i}$$

$$= 174$$

4. An iron rod of 1 cm radius is bent to a ring of mean diameter 30 cm and wound with 250 turns of wire. Assume the relative permeability of iron as 800. An air gap of 0.1 cm is cut across the bent ring. Calculate the current required to produce a useful of 20,000 lines if (a) leakage is neglected and (b) leakage factor is 1.1.

Solution:

$$l_g = 0.1 \text{ cm}$$

$$\frac{d}{2} = 1 \text{ cm}$$

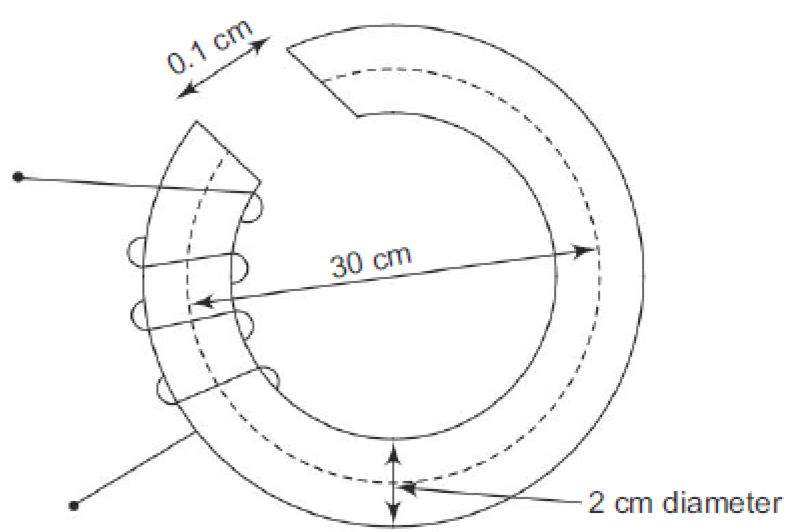
$$2R_m = 30 \text{ cm}$$

$$N = 250 \text{ turns}$$

$$\mu_r = 800$$

$$\phi = 20{,}000 \text{ lines}$$

$$= 20{,}000 \times 10^{-8} \text{ wb}$$



(a) Neglecting leakage:

$$\text{Total Reluctance} = \text{Reluctance of air gap} + \text{Reluctance of iron path}$$

$$\text{Reluctance of air gap} = \frac{l_g}{\mu_0 \mu_r a} = \frac{0.001}{(4\pi \times 10^{-7} \times 1 \times \pi \times 1 \times 10^{-4})}$$

$$= 2533029.59 \text{ A/wb}$$

$$l_i, \text{ Length of iron path} = \text{Total length} = l_g$$

$$l_i = (\pi d - l_g)m = (\pi \times 0.3 - 0.001)$$

$$\text{Reluctance of iron path} = \frac{(\pi \times 0.3 - 0.001)}{4\pi \times 10^{-7} \times 800 \times \pi \times 1 \times 10^{-4}}$$

$$= 2980988.896 \text{ A/wb}$$

$$\text{Total Reluctance} = 5514018.49 \text{ A/wb}$$

$$\text{MMF} = \text{Flux} \times \text{Reluctance}$$

$$= 20{,}000 \times 10^{-8} \times 5514018.49 \text{ A/wb}$$

$$= 1102.8 \text{ Amp. turns}$$

$$\text{Current required} = \frac{1102.8}{\text{No. of turns}} = \frac{1120.8}{250}$$

$$\text{Current required} = 4.41 \text{ Amps.}$$

(b) Including leakage:

To have a useful flux of 20,000 lines in the air gap, the *MMF* required the air gap porition is

$$= \phi \times \text{Reluctance of air gap}$$

$$= 20{,}000 \times 10^{-8} \times 2533039.59$$

$$MMF \text{ for air gap} = 506.606 \text{ Amp}$$

For the iron path, the flux has to be more.

$$\text{The total flux in iron path} = \text{Leakage factor} \times \text{Useful flux}$$

$$= 1.1 \times 20000 \times 10^{-8} \text{ wb}$$

$$\text{Hence, } MMF \text{ for iron path} = 1.1 \times 20{,}000 \times 10^{-8} \text{ Reluctance of iron path}$$

$$= 655.82 \text{ Amp.}$$

$$\text{Total } MMF = 655.82 + 506.606 \text{ A} = 1162.426 \text{ A}$$

$$\text{Current required} = \frac{1162.426}{250} = 4.649 \text{ Amps.}$$

$$\text{Current required} = 4.649 \text{ Amps.}$$

LAW OF ELECTROMAGNETIC INDUCTION

1 Statement of Faraday's Law

Whenever the magnetic flux linking a circuit changes an emf is always induced in it. The magnitude of such an emf is proportional to the rate of change of flux linkages.

2 Lenz's Law

The law states that any induced emf will circulate a current in such a direction so as to soppose the cause producing it.

Thus, Lenz's law gives the nature of induced emfs.

INDUCED EMF

An emf is induced in a coil or conductor whenever there is a change in flux linkages This change in flux linkages can be brought in the following two ways:

(i) The conductor is moved in a stationery magnetic field in such a way that there is a magnitude change in flux linkages. This kind of induced emf is known as dynamically induced emf (e.g generator).

(ii) The conductor is stationary and the magnetic field is moving or changing. This kind of induced emf is known as statically induced emf (e.g. transformer).

Statically Induced emf

In this case, the conductor is held stationary and the magnetic field varied. It may be self induced or mutually induced.

Self Induced emf If a single coil carries a current, a flux will be set up in it. If the current changes the flux will change. The change in flux will induce an emf in the coil. This kind of emf is known as "self induced emf".

The magnitude of this self-induced emf is $e = N\frac{d\phi}{dt}$

Mutually Induced emf It is the emf induced in one circuit due to change of flux linking it, the flux being produced by current in another circuit.

$$e_2 = N_2\frac{d\phi_{12}}{dt}$$ Where ϕ_{12} = 1 st coil flux linking 2 nd coil

SELF INDUCTANCE (*L*)

Definition

Self inductance of a circuit is the flux linkages per unit current in it. Its unit is Henry.

By definition, $L = \frac{N\phi}{I}$ Henry

Relationship between Self-Induced emf and Self Inductance

$$e = -L\frac{di}{dt}$$

MUTUAL INDUCTANCE (M)

Definition

Mutual inductance between two circuits is defined as the flux linkages of one circuit per unit current in the other circuit. Its unit is Henry.

$$M = \frac{N_2\phi_{12}}{I_1}$$

Where ϕ_{12} = 1 st coil flux linking 2 nd coil

Where ϕ_{21} = 2 nd coil flux linking 1 st coil

or

$$M = \frac{N_1\phi_{21}}{I_2}$$

Relationship between M and Induced emf

mutually induced emf in coil 2 due to change in current of coil 1 is,

$$e_{m,2} = -M\frac{di_1}{dt}$$

Similarly, mutually induced emf in coil 2 due to change in current of coil 2 is,

$$e_{m,1} = -M\frac{di_2}{dt}$$

COUPLING COEFFICIENT BETWEEN TWO MAGNETICALLY COUPLED CIRCUITS (K)

$$K = \frac{\phi_{12}}{\phi_1} \quad \text{or} \quad K = \frac{\phi_{21}}{\phi_2}$$

Where ϕ_{12} = 1 st coil flux linking 2 nd coil

Where ϕ_{21} = 2 nd coil flux linking 1 st coil

always $K \leq 1$.

Thus, coupling coefficient, $K = \dfrac{M}{\sqrt{L_1 L_2}}$

Problems

1. The number of turns in a coil is 250. When a current of 2 A flows in this coil, the flux in the coil is 0.3 m wb. When this current is reduced to zero in 2 milliseconds, the voltage induced in a coil lying in the vicinity of coil is 63.75 volts. If **K=0.75, Find** mutual inductance and number of turns in the second coil.

Solution: $N_1 = 250; I_1 = 2A: \phi_1 = 0.3$ wb

$dt = 2$ msec; $e_{m2} = 63.75$ V; $K = 0.75$

(a) Self inductance of first coil is

$$L_1 = N_1 \times \frac{\phi_1}{I_1}$$

$$= 250 \times \frac{0.3 \times 10^{-3}}{2}$$

$$= 37.5 \text{ mH.}$$

(b) Voltage in the second coil is

$$e_{m2} = M\frac{dI_1}{dt}$$

i.e. $$63.75 = M\frac{2-0}{2 \times 10^{-3}}$$

$$M = 63.75 \times 10^{-3} = 63.75 \text{ mH.}$$

we know that $$M = K\sqrt{L_1 L_2}$$

i.e. $$63.75 = 0.75\sqrt{3.75 \times L_2}$$

$$L_2 = 193 \text{ mH.}$$

(c) ϕ_{12} the flux in the second coil

$$\phi_{12} = k \times \phi_1$$

$$= 0.75 \times 0.3 \times 10^{-3}$$

$$= 0.255 \times 10^{-3}\ wb$$

$$e_2 = N_2 \frac{d\phi_{12}}{dt}$$

$$63.75 = N_2 \frac{0.255 \times 10^{-3}}{2 \times 10^{-3}}$$

$$N_2 = 500 \text{ turns.}$$

2. An air cored toroidal coil has 480 turns, a mean length of 30 cm and a cross-sectional area of 5 cm^2. Calculate (a) the inductance of the coil and (b) the average induced emf, if a current of 4 A is reversed in 60 millionseconds.

Solution:

$$l = 30 \text{ cm} = 0.3 \text{ m}$$

$$N = 450 \text{ turns}$$

$$a = 5 \text{ cm}^2 = 5 \times 10^{-4} \text{ m}^2$$

$$I = 4 \text{ Amps.}$$

$$dt = 60 \text{ m sec}$$

(a)

$$L = \frac{N^2}{(1/\mu_0 \mu_r a)}$$

$$= \frac{\mu_0 \mu_r a N^2}{l}$$

$$= \frac{4\pi \times 10^{-6} \times 1 \times 5 \times 10^{-4} \times (480)^2}{0.3} \text{ Henry} \quad (\because \mu_r = 1 \text{ for air})$$

$$= 483 \times 10^{-6} \, H$$

(b)

$$di = 4 - (-4) = 8 \text{ Amp}$$

$$dt = 60 \times 10^{-3} \text{ sec}$$

$$\text{Average induced emf } (E) = L \frac{di}{dt}$$

$$= 483 \times 10^{-6} \times \frac{8}{60 \times 10^{-3}}$$

$$= 0.064 \text{ V.}$$

3 The self inductance of a coil of 500 turns is 0.25 H. If 60% of the flux is linked with a second coil of 10500 turns, calculate (a) the mutual inductance between the two coils and (b) emf induced in the second coil when current in the first coil changes at the rate of 100 A/sec.

Solution:

$$L_1 = 0.25\ H$$

$$N_1 = 500 \text{ turns}$$

$$N_2 = 10500 \text{ turns}$$

$$\phi_{12} = \frac{60}{100}\phi_1 ;\ \phi_{12} = 0.6\ \phi_1.$$

Where ϕ_{12} = 1 st coil flux linking 2 nd coil

$$\frac{di_i}{dt} = 100 \text{ A/sec}$$

Flux/ampere in the first coil

$$= \frac{\phi_1}{I_1} = \frac{0.25}{N_1} = \frac{0.25}{500} = 5 \times 10^{-4}$$

Flux linking the second coil $= \phi_{12} = 0.6\ \phi_1$

$$\frac{\phi_{12}}{I_1} = 0.6\ (\phi_1/I_1)$$

$$= 0.6 \times 5 \times 10^{-4}$$

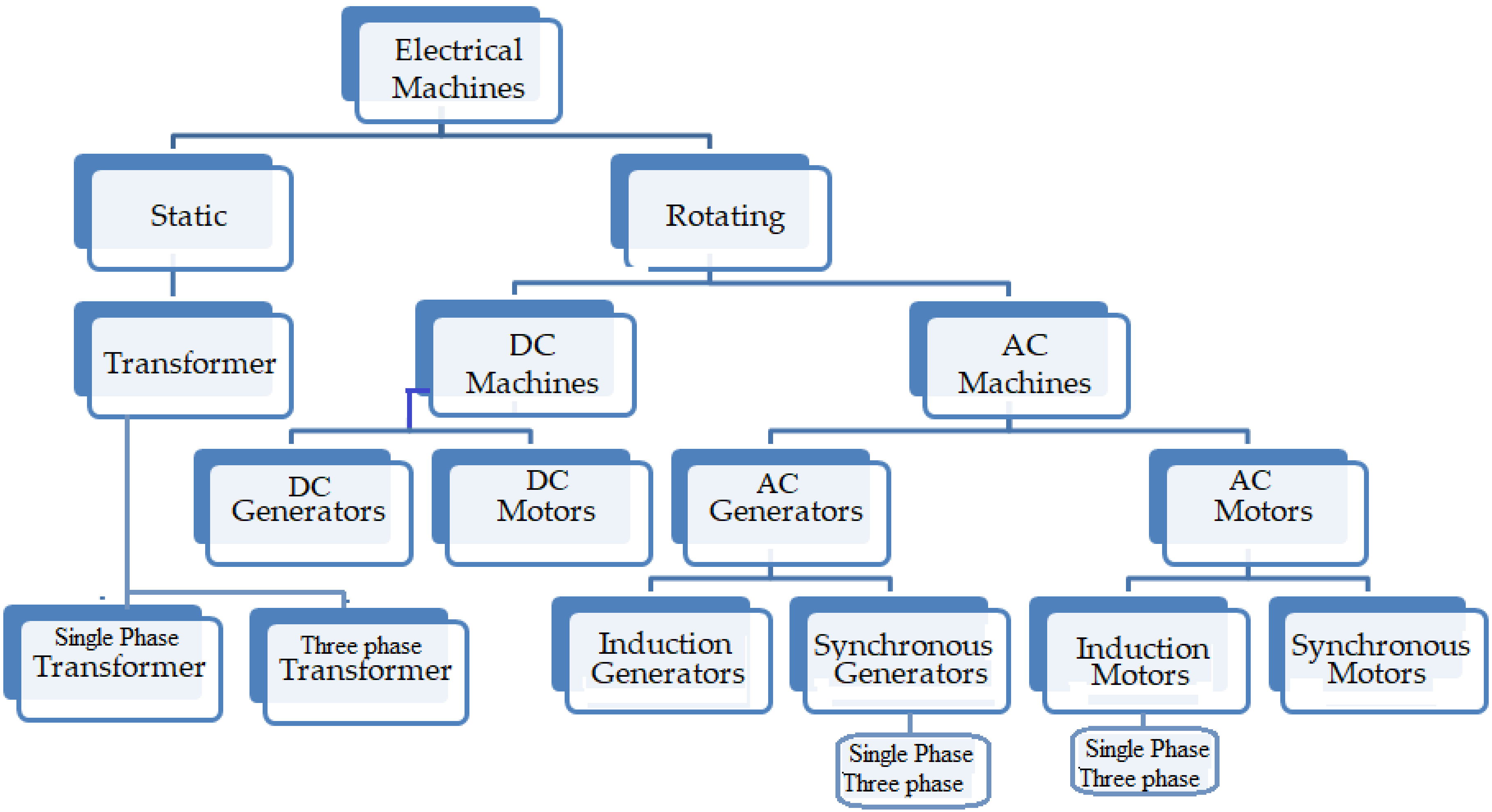
$$= 3 \times 10^{-4}$$

(a) $$M = N_2 \frac{\phi_{12}}{I_1} = 10500 \times 3 \times 10^{-4} = 3.15\ H$$

(b) $$e_m = M \frac{di_1}{dt} = 3.15 \times 100 = 315 \text{ V}$$

Electrical Machines

Classification of Electrical Machines

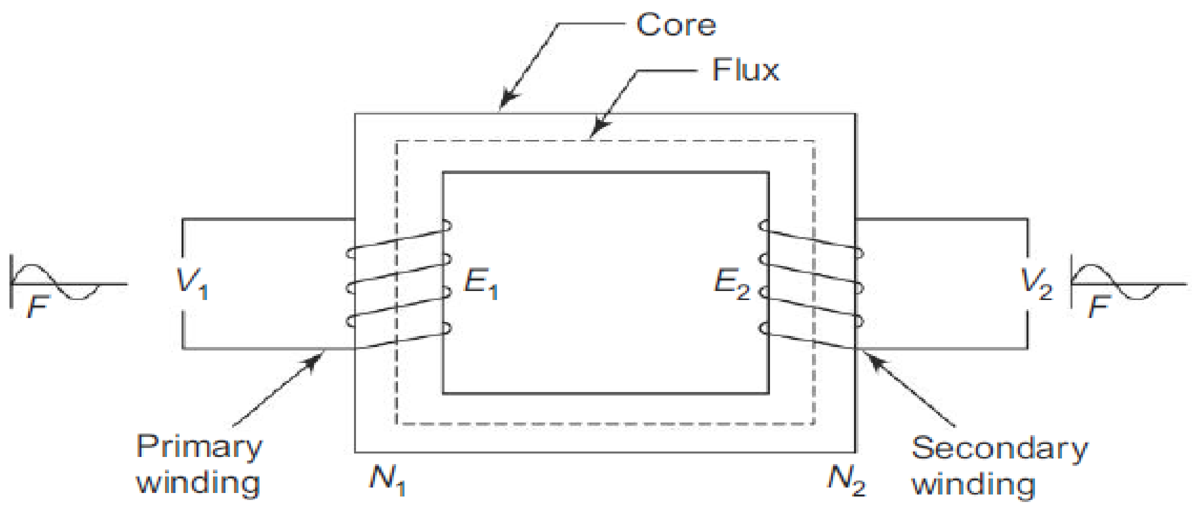


Single Phase Transformer

<u>Principle of operation</u>

The transformer works on the principle of electromagnetic induction. In this case, the conductors are stationary and the magnetic flux is varying with respect to time. Thus, the induced emf comes under the classification of statically induced emf.

The transformer is a static piece of apparatus used to transfer electrical energy
from one circuit to another. The two circuits are magnetically coupled. One of the circuits is energized by connecting it to a supply at specific voltage magnitude, frequency and waveform. Then, we have a mutually induced voltage available across the second circuit at the same frequency and waveform but with a change in voltage magnitude if desired. These aspects are indicated in Fig.



Construction

The following are the essential requirements of a transformer:

(a) A good magnetic core

(b) Two windings

(c) A time varying magnetic flux

The transformer core is generally laminated and is made out of a good magnetic material such as transformer steel or silicon steel. Such a material has high relative permeability and **low hysteresis loss**. In order to reduce the **eddy current loss**, the core is made up of laminations of iron. ie, the core is made up of thin sheets of steel, each lamination being insulated from others

Working

Let us say that a transformer has N_1 turns in its primary winding and N_2 turns in its secondary winding. The primary winding is connected to a sinusoidal voltage of magnitude V_1 at a frequency 'f' hertz. A working flux of ϕ webers is set up in the magnetic core. This working flux is alternating and sinusoidal as the applied voltage is alternating and sinusoidal. When this flux link the primary and the secondary winding, emfs are induced in them. The emf induced in the primary is the self induced emf and that induced in the secondary is the mutually induced emf. Let the induced voltages in the primary and the secondary be E_1 and E_2 volts respectively. These voltages will have sinusoidal waveform and the same frequency as that of the applied voltage. The currents which flow in the closed primary and the secondary circuits are respectively I_1 and I_2.

In any transformer, $K = \dfrac{N_2}{N_1}$, defines the transformation ratio.

Three categories of transformer action are possible:

$$E_2 < E_1 \text{ (i.e. } V_2 < V_1\text{) ... step down transformer}$$

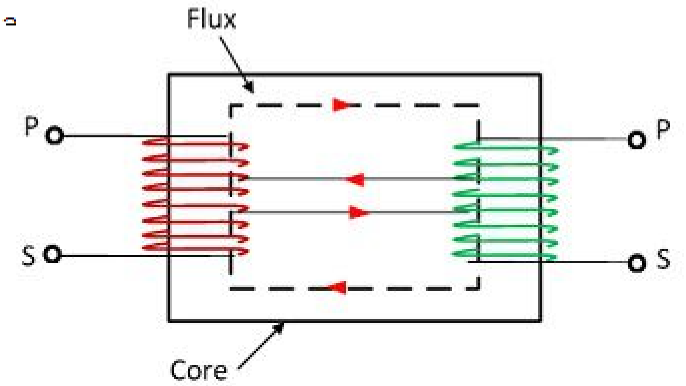
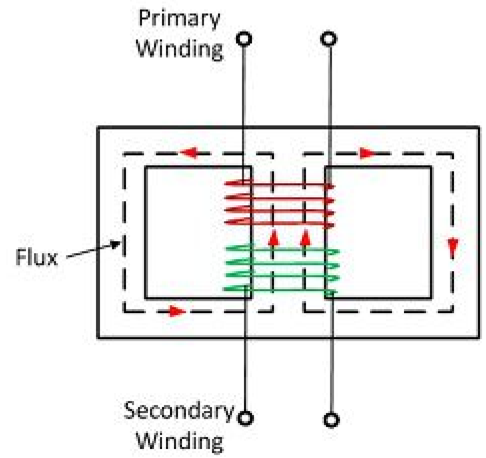
$$E_2 > E_1 \text{ (i.e. } V_2 > V_1\text{) ... Step up transformer}$$

The induced emfs are proportional to the number of turns. In any transformer, the primary ampere turns equals the secondary ampere turns.

i.e. $$N_1 I_1 = N_2 I_2$$

Thus, we have $$\frac{I_1}{I_2} = \frac{E_2}{E_1} = \frac{V_2}{V_1} = \frac{N_2}{N_1} = K$$

Whenever any load is put on the transformer (connected to secondary winding) the primary of the transmission draws the required amount of current in order to keep the working flux constant. Thus, the transformer works with a perfect static balance.

Basis for Comparison	Core Type Transformer	Shell Type Transformer
Da		
Winding	In this type, winding surrounds the core	In this type, core surrounds the winding
Limbs	It has two limbs	It has three limbs
Copper requirement	Requires less	Requires more
Lamination	Laminations are usually in the form of alphabet letter L	Laminations are usually in the form of alphabet letter E and L
Flux distribution	Flux is equally distributed on the side limbs	Side limbs carry the half of the flux while the central one carries the whole flux

Windings position	Primary and secondary both windings are wound on the side limbs	Both windings are wound on the central limb
Magnetic circuit	Only one magnetic circuit	There are two magnetic circuits
Types	Cylindrical	Multilayer and Sandwich type
Cooling	Better cooling because more surface is exposed to external atmosphere	Natural cooling is not very effective so fans are used
Repair	Easy to repair because assembly can be dismantled easily	Difficult to repair because both windings are on the same limb
Output	Output is less because of more losses so less efficiency	Output is high because of less losses so efficiency is high in this type
Design	Easy in design and construction	Comparatively complex
Mechanical strength	Low because of non-bracing	Possesses high mechanical strength
Leakage reactance	Leakage reactance is not easily possible	In this type, leakage reactance is highly possible
Heat dissipation	Better heat dissipation from windings	Windings are surrounded by core so heat dissipation is not easy
Application	Used for high voltage application like power transformers,	Used for low voltage application like transformers in an electronic

32.6. E.M.F. Equation of a Transformer

Let N_1 = No. of turns in primary

N_2 = No. of turns in secondary

Φ_m = Maximum flux in core in webers

$= B_m \times A$

f = Frequency of a.c. input in Hz

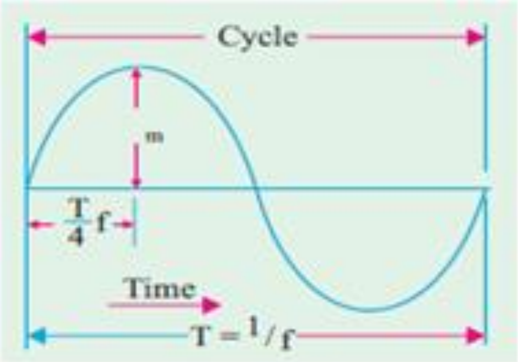


Fig. 32.14

As shown in Fig. 32.14, flux increases from its zero value to maximum value Φ_m in one quarter of the cycle *i.e.* in $1/4f$ second.

$$\therefore \quad \text{Average rate of change of flux} = \frac{\Phi_m}{1/4f}$$

$$= 4f\Phi_m \text{ Wb/s or volt}$$

Now, rate of change of flux per turn means induced e.m.f. in volts.

$$\therefore \quad \text{Average e.m.f./turn} = 4f\Phi_m \text{ volt}$$

If flux Φ varies *sinusoidally*, then r.m.s. value of induced e.m.f. is obtained by multiplying the average value with form factor.

$$\text{Form factor} = \frac{\text{r.m.s. value}}{\text{average value}} = 1.11$$

$$\therefore \quad \text{r.m.s. value of e.m.f./turn} = 1.11 \times 4f\Phi_m = 4.44f\Phi_m \text{ volt}$$

Now, r.m.s. value of the induced e.m.f. in the whole of primary winding

$$= (\text{induced e.m.f/turn}) \times \text{No. of primary turns}$$

$$E_1 = 4.44fN_1\Phi_m = 4.44fN_1B_mA \quad \text{...(i)}$$

Similarly, r.m.s. value of the e.m.f. induced in secondary is,

$$E_2 = 4.44fN_2\Phi_m = 4.44fN_2B_mA \quad \text{...(ii)}$$

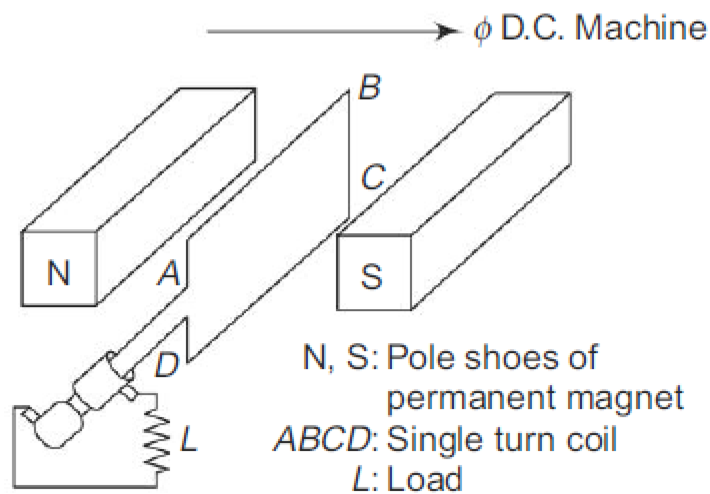
DC GENERATOR

Principle

The generator is a dynamic machine in which mechanical energy is converted into electrical energy. It operates on the principle based on the Faraday's Law of electro-magnetic induction. The emf generated is to be classified as dynamically induced emf. The basic requirements for the dynamically induced emf to exist are the following:

(i) A steady magnetic field
(ii) A conductor capable of carrying current
(iii) The conductor to move in the magnetic field

The working principle of a dc generator is illustrated in Fig. 6.1. It shows a steady magnetic field produced by the pole pieces of a magnet N and S. A single turn coil *ABCD* is placed in the field produced between the pole pieces. The coil is rotated by means of a prime mover. Thus, as per Faraday's law, an emf is induced in the coil. Such an emf is basically alternating. This bidirectional induced emf is made unidirectional using the commutator. Figure 6.2, illustrates the use of commutator.



Construction

For the satisfactory operation of a dc generator, it should consists of a stator and a rotor.

The stator accommodates the yoke, the main field system and the brushes. The rotor has the armature and the commutator as its main parts. Figure 6.3 shows these parts. Each of these parts is described as follows:

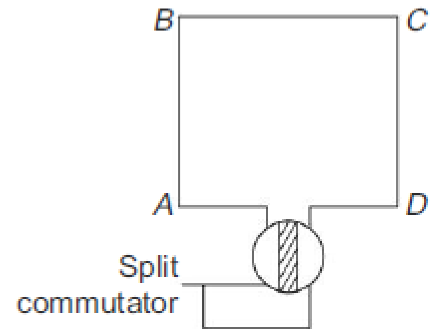
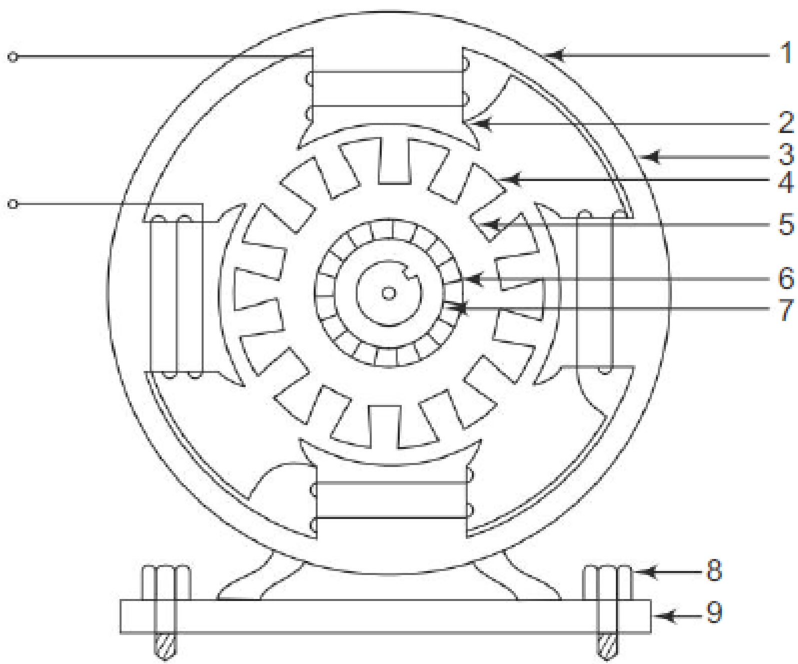


Fig. 6.2



1 Yoke or Frame
2 Main field pole
3 Field winding
4 Armature
5 Slot
6 Commutator
7 Shaft
8 Foundation bolt
9 Bed plate

Yoke or Frame It is the outermost solid metal part of the machine. It forms part of magnetic circuit and protects all the inner parts from mechanical damage.

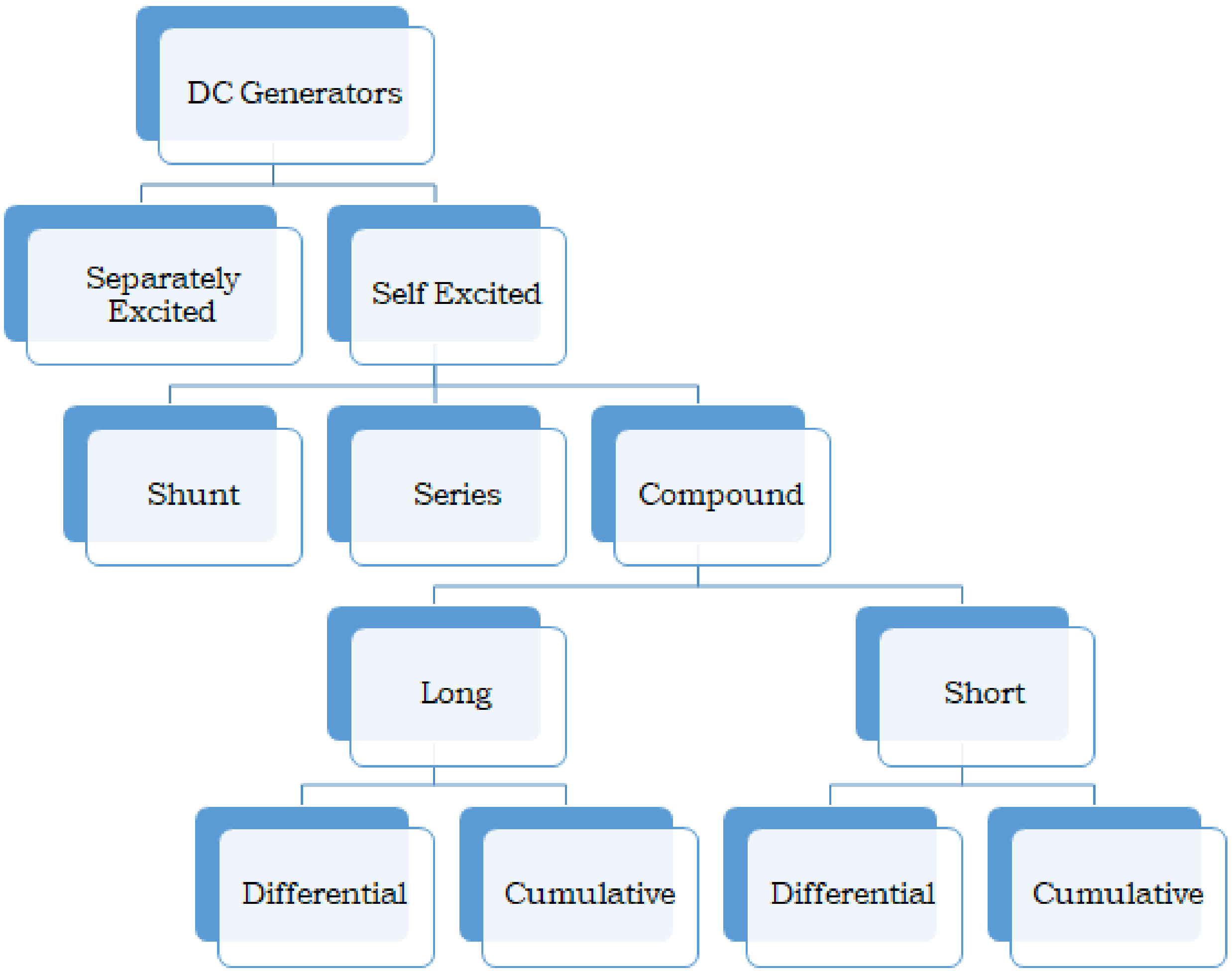
Field System This consists of main field poles and field winding. The field poles are made of laminations of a sutiable magnetic material. Such a magnetic material has very high relative permeability and very low hysteresis loss. The pole face is in the form of horse shoe so that a uniform flux distribution is obtained in the air gap between the poles and the rotating part. The field winding is placed over the each pole and all these are connected in series. Again the field winding is so arranged on the different poles that when a direct current is passed through this winding, the poles get magnetized to N and S polarities alternately. Thus, the field system is responsible for producing the required working flux in the air gap.

Brushes A set of brushes made of carbon or graphic are fixed such that they are always in gentle touch with the revolving armature. The generator is connected to external circuits by means of these brushes. Thus, the brushes are used to tap the generated electrical energy off the rotating part of the generator.

Armature The armature of a dc generator is in the form of laminated slotted drum. Slots are provided over the entire periphery of the armature

Commutator The commutator is similar in shape to armature. But, it has less diameter than that of the armature. Required number of segments are provided over the complete periphery of the commutator. There is an electrical insulation between every pair of segments. A minimum of two conductors are connected to each segment. But, at the same time the two conductors making a single coil are connected to different commutator segments. The brushes are so placed that they are always keeping to such with the revolving commutator segments.

Types of DC Generator



1. Separately Excited DC Generator

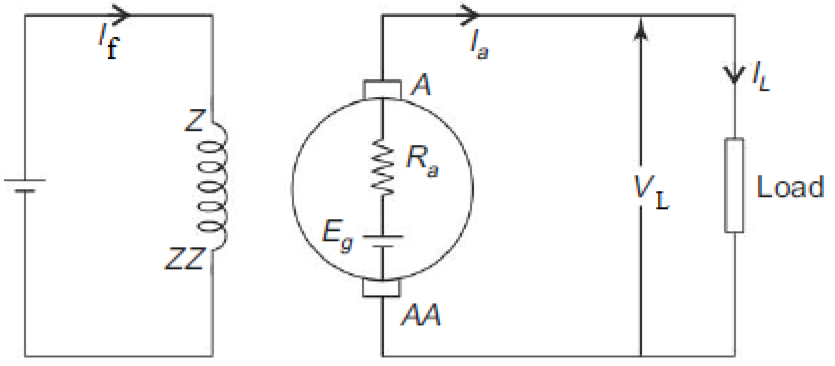
- Armature Current

  $I_a = I_L$

- Emf Equation

  $E_g = V_L + I_a R_a + V_b$

  V_b=brush drop for pair of brush



2.Self Excited DC Generator

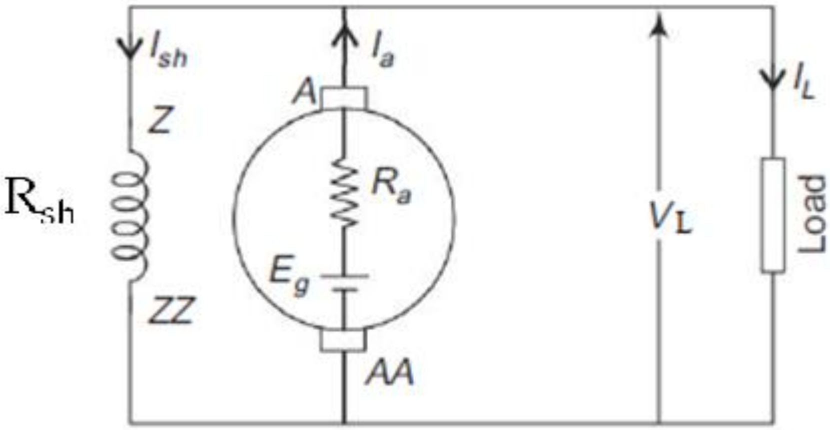
(i) DC Shunt Generator

- Armature Current

$$I_a = I_L + I_{sh}$$

- Emf Equation

$$E_g = V_L + I_a R_a + V_b$$



2.Self Excited DC Generator
(ii) DC Series Generator

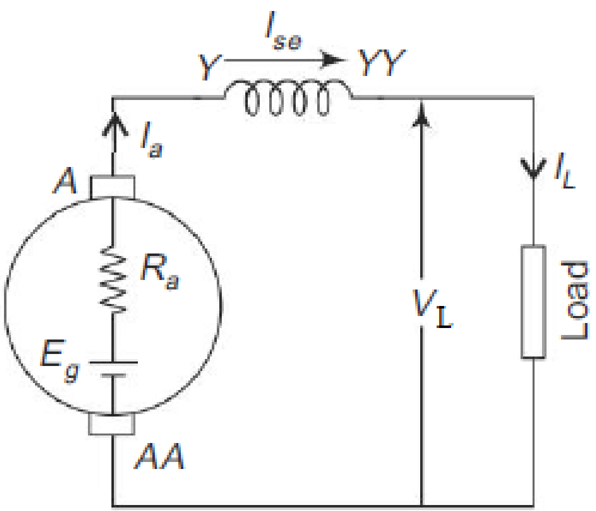
- Armature Current

$I_a = I_L = I_{se}$

- Emf Equation

$E_g = V_L + I_a R_a + I_{se} R_{se} + V_b$

$E_g = V_L + I_a (R_a + R_{se}) + V_b$



2.Self Excited DC Generator

(iii)DC Compound Generator

(a)Long Shunt

- Series Field Current

  $I_{se} = I_a$

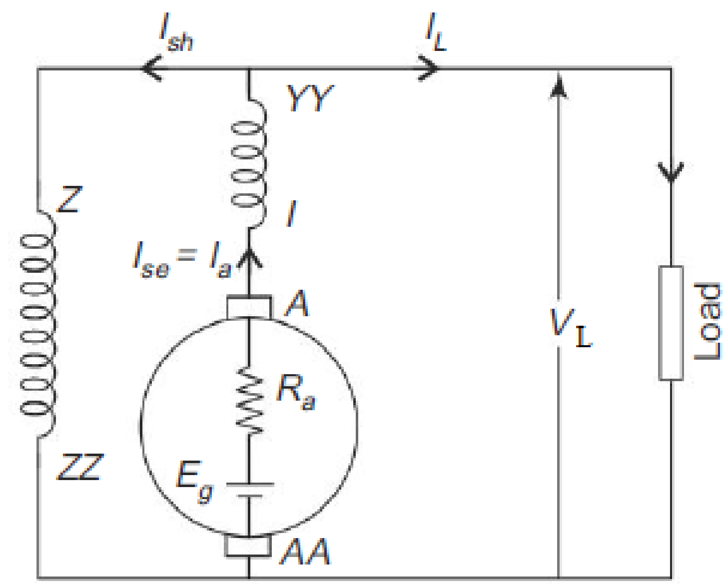
- Armature Current

  $I_a = I_L + I_{sh}$

- Emf Equation

  $E_g = V_L + I_a R_a + I_{se} R_{se} + V_b$

  $E_g = V_L + I_a (R_a + R_{se}) + V_b$



2.Self Excited DC Generator

(iii)DC Compound Generator

(b)Short Shunt

- Series Field Current

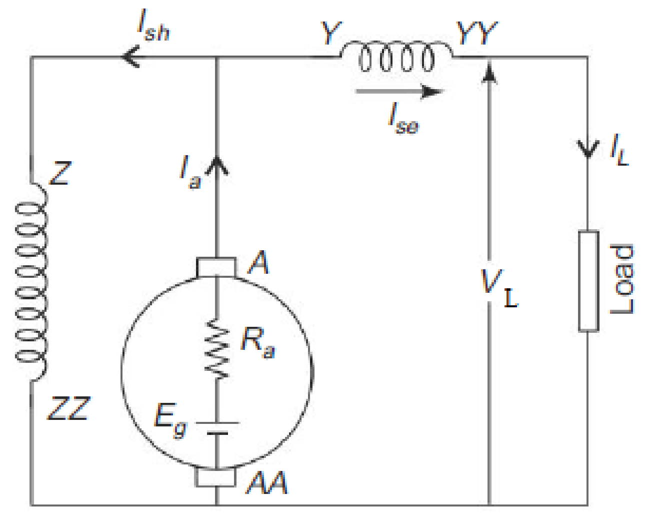
  $I_{se} = I_L$

- Armature Current

  $I_a = I_L + I_{sh}$

- Emf Equation

  $E_g = V_L + I_a R_a + I_{se} R_{se} + V_b$

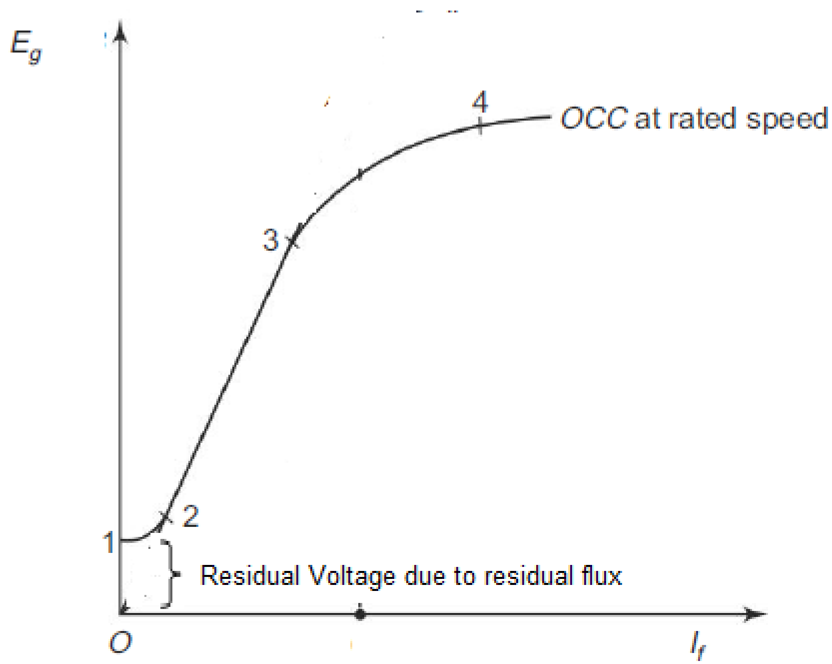


Characteristics of Generators

- Open Circuit Characteristics (I_f, E_{g0})
- Load Characteristics
  - Internal (I_a, E_g)
  - External (V_L, I_L)

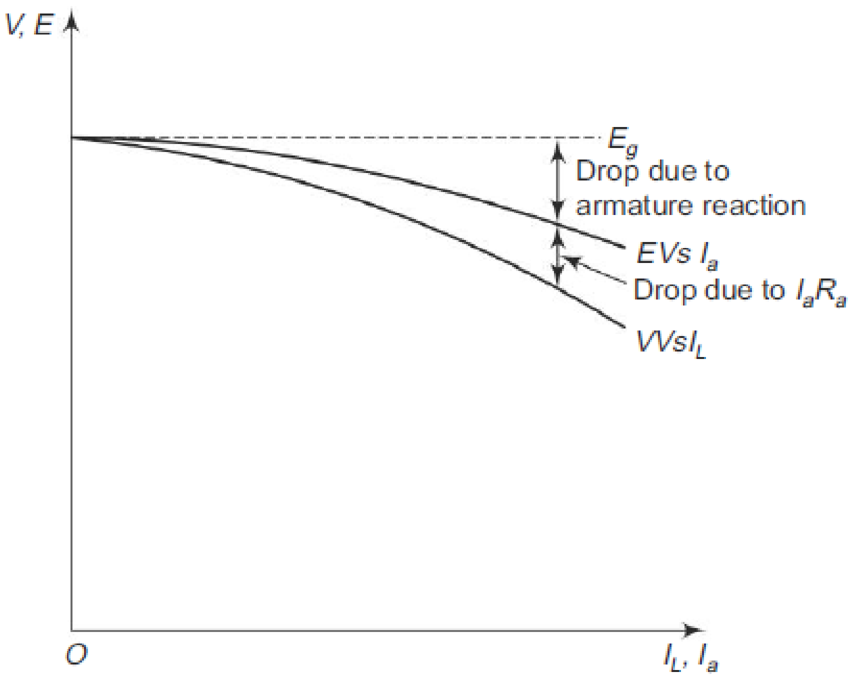
Separately Excited DC Generator and DC Shunt Generator - Characteristics [Both generators have same characteristics]

1. Open circuit characteristics (OCC) or No-load characteristics or magnetization characteristics. (I_f, E_{g0})



By removing the load connected , we obtain the no-load condition. When the generator is run at its rated speed with no-load, the terminal voltage appearing across the armature can be taken as the induced voltage. Thus, it is possible to obtain this open circuit voltage as a function of the field current. By varying the field current, we can obtain the variation in the no-load voltage. The curve thus obtained is known as open circuit characteristics. We can observe that the major portion of this characteristics (2-3) is linear. There are two non-linear portions namely 1-2 and 3-4. Beyond the operating point 4, we say that **saturation has occurred and so there will not be any appreciate increase in** the generated voltage even for large increase in field current. Because of the **residual flux in the magnetic poles there is a small amount of** induced voltage even when the field current is zero.

2.Internal (Ia, Eg) Characteristics
3.External (VL, IL) Characteristics



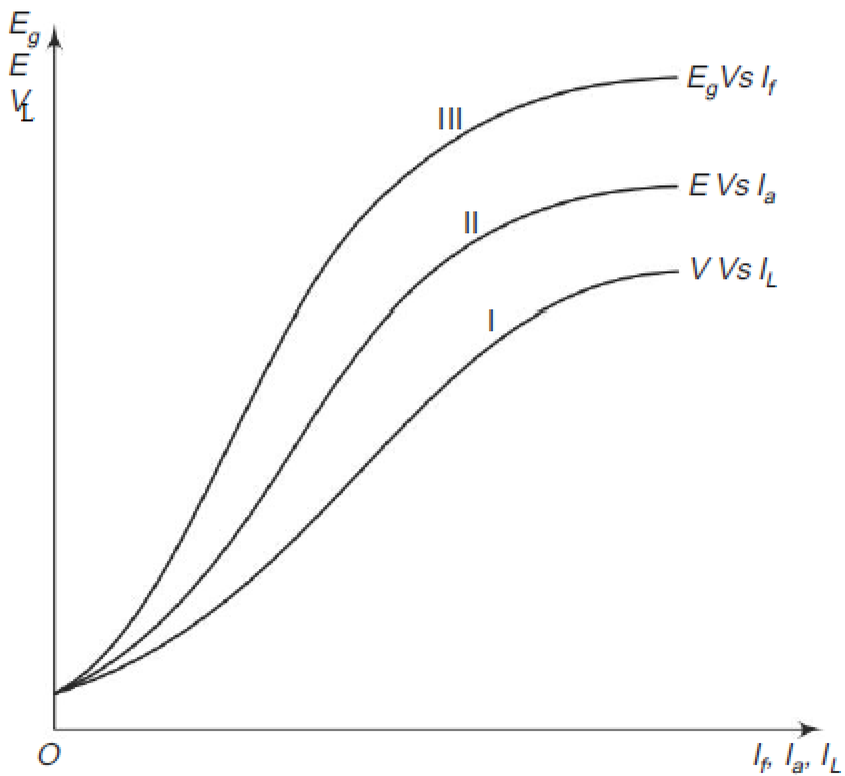
The generators should be made to run at its rated speed. The generator field current should be adjusted so that rated voltage is built up at no-load. Now by varying the load, the terminal voltage V as a function of load current I_L can be obtained as shown in Fig

The terminal voltage of the generator decreases on loading. This is because of (i) voltage drop due to armature resistance, Ra (ii) voltage drop due to armature reaction. So the generated emf and the terminal voltage go on decreasing.

External characteristics Variation of load terminal voltage with respect to the load current [i.e. V vs I_L]. These two quantities are external quantities and they can be measured directly. Hence the name external characteristics.

Internal characteristics Variation of induced voltage in loaded condition as a function of the armature current [i.e. E vs Ia]. These two quantities are internal quantities for the generation and E cannot be measured directly, but it can be estimated. Hence the name internal characteristics.

DC Series Generator- Characteristics [All 3 Characteristics]



The **OCC** of series generator can be obtained with the help of the no load and shape of OCC is similar and same as that for DC shunt generator.

The load characteristics is rising characteristics. The difference between curves I and II represents the voltage drop due to internal resistance of the generator, i.e. Ra (Ra + Rse) drop. The difference between curves II and III represents the drop due to armature reaction. If the load goes on increasing, then the terminal voltage may become zero because of heavy armature reaction.

Armature Reaction

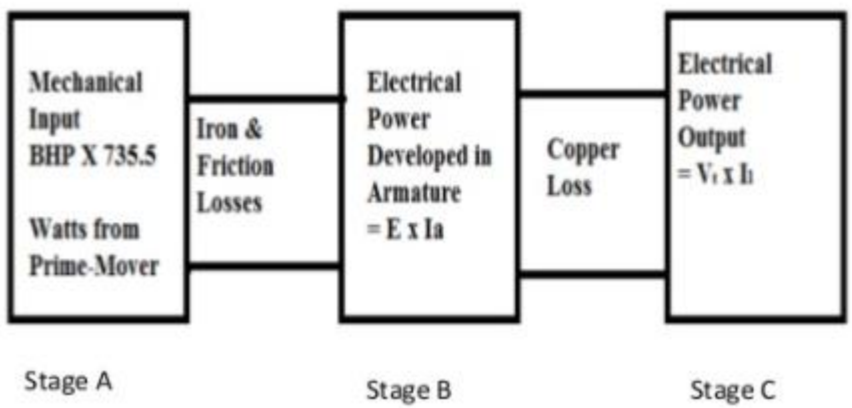
By armature reaction is meant the effect of magnetic field set up by armature current on the distribution of flux under main poles of a generator. The armature magnetic field has two effects :

(*i*) ***It demagnetises or weakens the main flux*** and

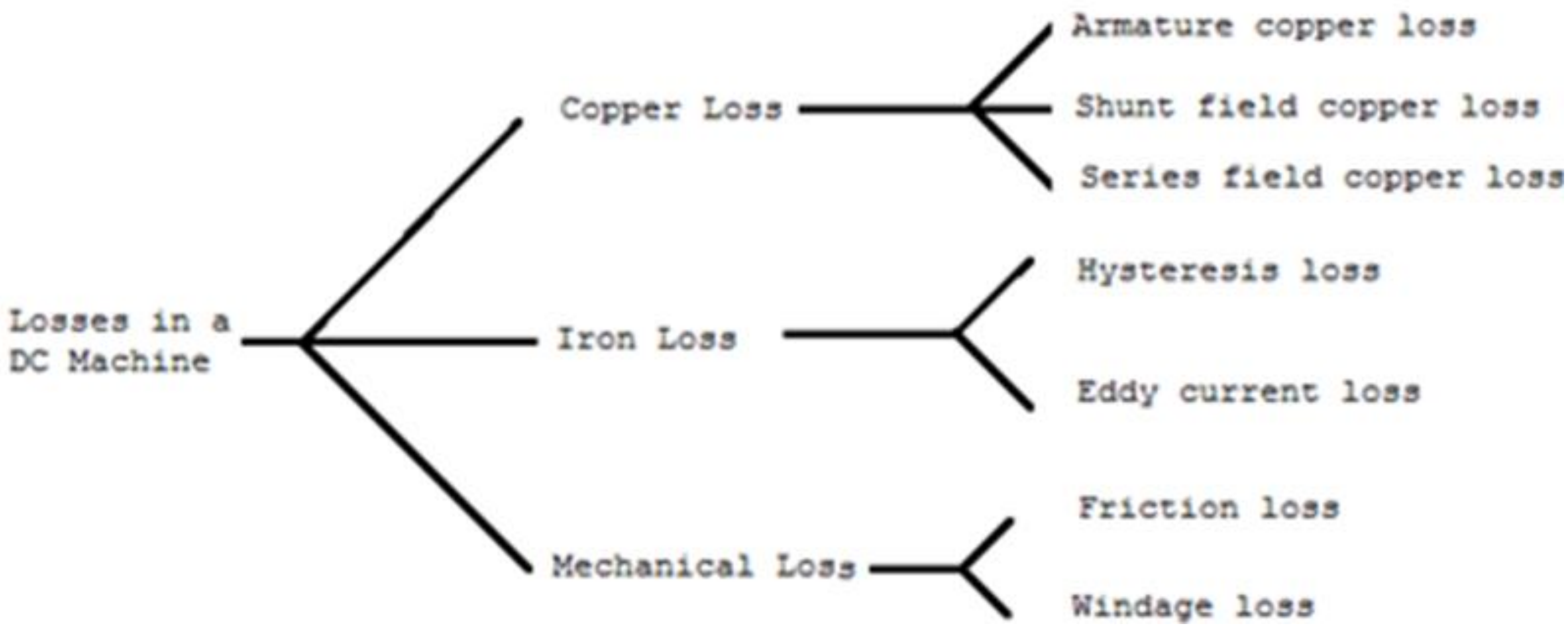
(*ii*) ***It cross-magnetises or distorts it.***

The first effect leads to reduced generated voltage and the second to the sparking at the brushes.

Power Stages in D.C. Generator



Losses in DC Generator



Applications of DC Generators

DC Shunt Generator

1. Separately excited generators are preferred where the characteristics of dc shunt generators is not upto the expected level.
2. They can be used to excite the field magnets of ac generators.
3. A s the drop in voltage is very small, these generators can be used for supplying loads needing constant voltage.
4. They are used as source for battery charging purpose.
5. These generators are used for electroplating and electrolytic purpose.

DC Series Generators

1. They are used for series arc lighting.
2. They are used for series incandescent lighting.
3. They are used as booster, for the purpose of compensating the drop in voltage in the lines on loading.
4. Used for regenerative braking of dc locomotives.

Compound Generators

1. By means of compound generators it is possible to give constant voltage at the line by proper compounding.
2. Differentially compounded generator may be used for welding purposes.
3. They are used to supply power to railway circuits, incandescent lamps, elevator motors, etc.

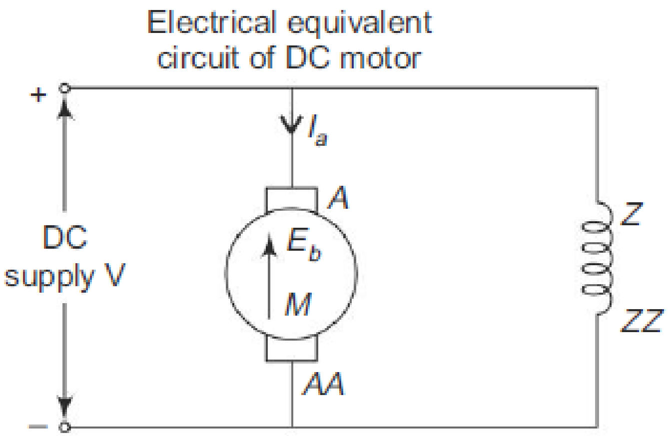
DC MOTOR

Principle

Whenever a current carrying conductor is kept in a stationery magnetic field an electromagnetic force is produced. This force is exerted on the conductor and hence the conductor is moved away from the field. This is the principle used in d.c. motors.

Construction

The construction of dc motor is exactly similar to dc generators. The salient parts of a dc motor are yoke or frame, main field system, brushes, armatures and commutator.



Working

In a dc motor, both the armature and the field windings are connected to a dc supply. Thus, we have current carrying armature conductors placed in a stationery magnetic field. Due to the electromagnetic torque on the armature conductors, the armature starts revolving. Thus, electrical energy is converted into mechanical energy in the armature. When the armature is in motion, we have revolving conductors in a stationery magnetic field. As per Faraday's Law of electromagnetic induction, an emf is induced in the armature conductors. As per Lenz's law, this induced emf opposes the voltage applied to the armature. Hence, it is called the counter or back emf. There also occurs a potential drop in the armature circuit due to its resistance. Thus, the applied voltage has to overcome the back emf in addition to supplying the armature circuit drop and producing the necessary torque for the continuous rotation of the armature.

Figure gives the electrical circuit of a d.c. shunt motor where

E_b = back EMF

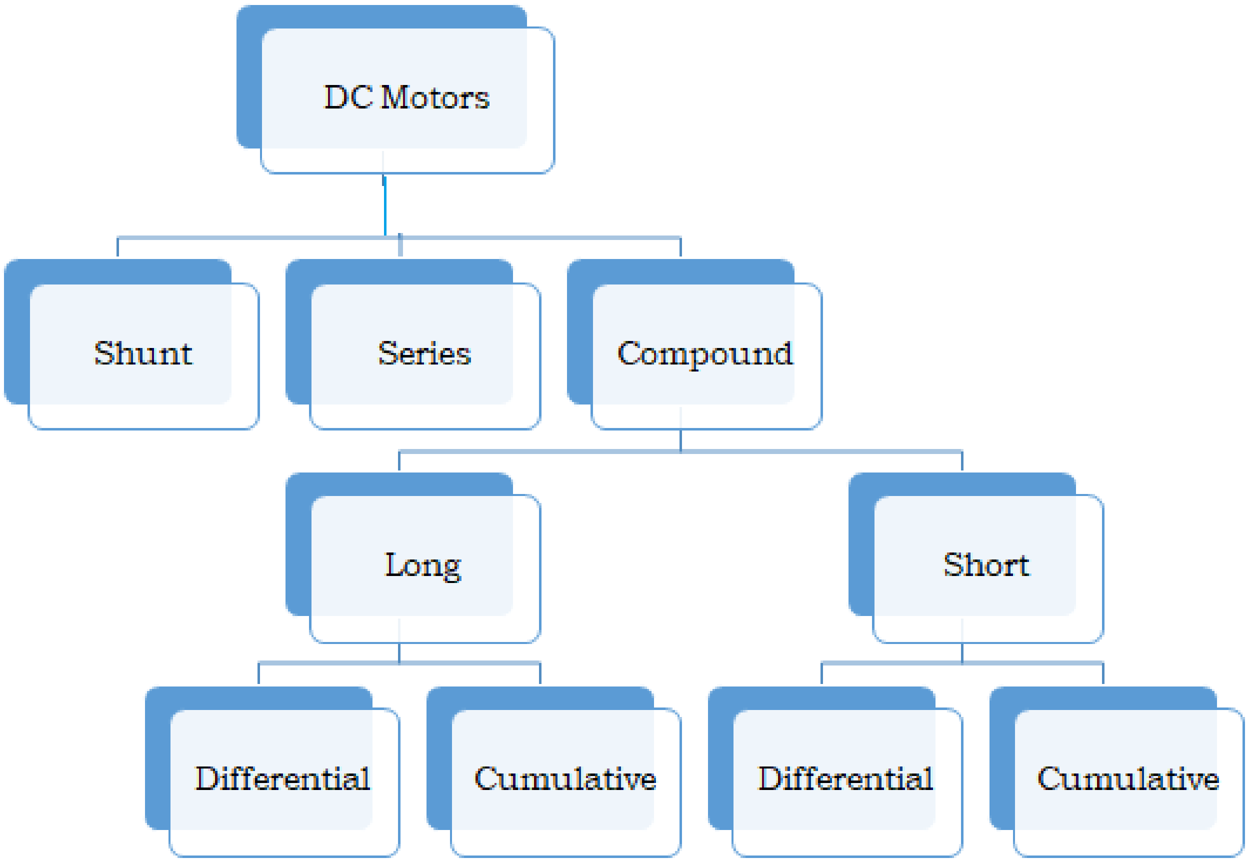
I_a = current flowing in the armature circuit

R_a = resistance of armature circuit

V = applied voltage

Thus, the characteristics equation of a dc motor is $V = E_b + I_aR_a$, where I_aR_a represents the potential drop in the armature circuit.

Types of Motor

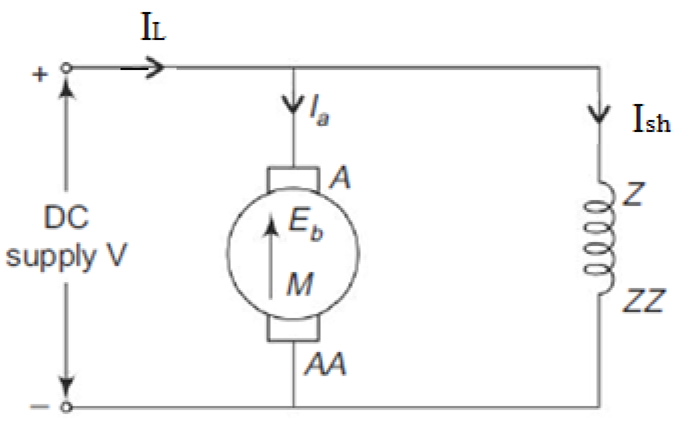


1. DC Shunt Motor

- Line Current

  $I_L = I_a + I_{sh}$ Where $I_{L=}$ Line or supply current
- Emf Equation

  $V = E_b + I_a R_a + V_b$



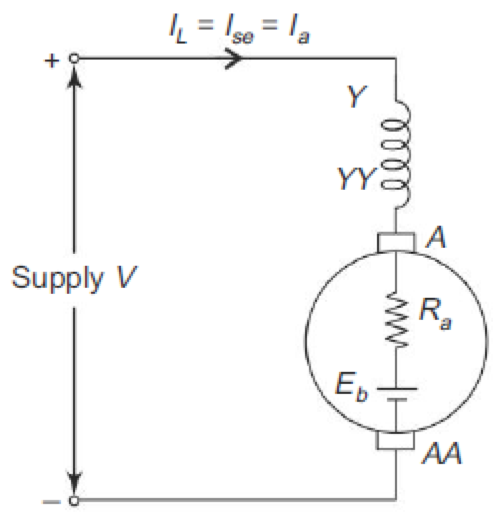
2. DC Series Motor

- Line Current

  $I_L = I_a = I_{se}$

- Emf Equation

  $V = E_b + I_a R_a + I_{se} R_{se} + V_b$



3. DC Compound Motor-Long Shunt

- Line Current

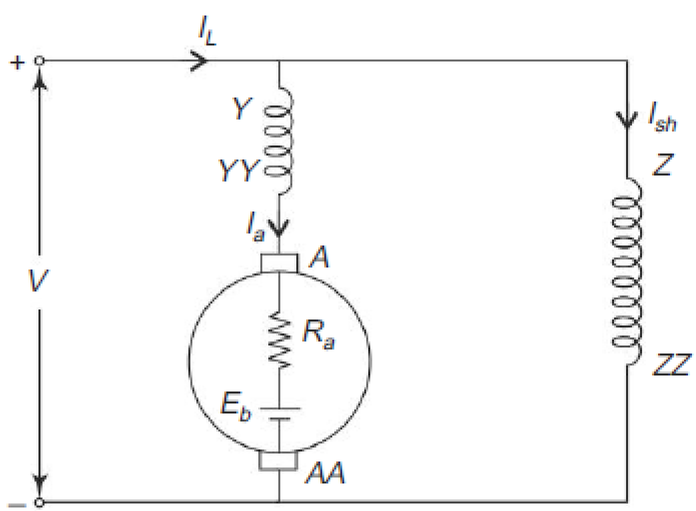
  $I_L = I_a + I_{sh}$

- Series Field Current

  $I_a = I_{se}$

- Emf Equation

  $V = E_b + I_a R_a + I_{se} R_{se} + V_b$



4. DC Compound Motor-Short Shunt

- Line Current

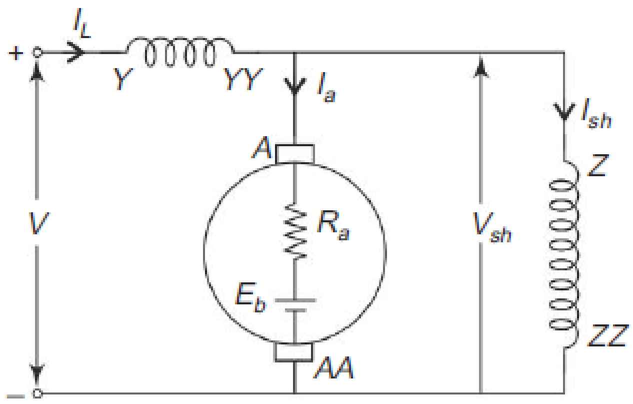
  $I_L = I_a + I_{sh}$

- Series Field Current

  $I_L = I_{se}$

- Emf Equation

  $V = E_b + I_a R_a + I_{se} R_{se} + V_b$



Torque and Speed Equations DC Motor

Armature Torque T_a of Motor $T_a \; \alpha \; \phi \, I_a$

Speed Equation $N \alpha \frac{E_b}{\phi}$

Characteristics of DC Motors

The characteristics of dc show the relationship between the following quantities.

(i) Torque and armature current (T vs I_a). It is also known as the electrical characteristic.

(ii) Speed and armature current (N vs I_a).

(iii) Speed and armature torque (N vs T_a). It is also known as mechanical characteristics.

The above characteristics can be obtained for all types of motors with the help torque and speed equations.

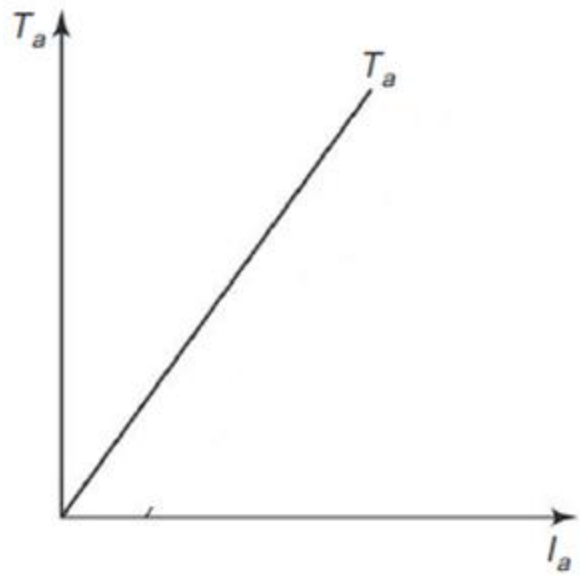
1. Characteristics DC Shunt Motor

(i) T_a Vs I_a

(i) T_a vs I_a Characteristics The flux, ϕ reduces slightly on heavy loads only. Thus, flux can be considered to remain constant.

$$T_a \,\alpha\, I_a$$

So, T_a vs I_a characteristics is a straight line characteristics as shown in Fig.



1. Characteristics DC Shunt Motor

(ii) N Vs I_a

(ii) N vs I_a Characteristic

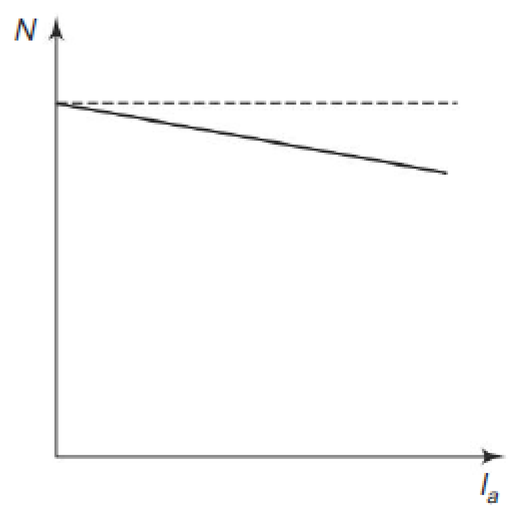
$$N \,\alpha\, \frac{Eb}{\phi} \qquad (1)$$

For shunt motor ϕ is almost constant on load $\therefore N \,\alpha\, E_b$

$$N \,\alpha\, V - I_a R_a \qquad (2)$$

As load increases, I_a increases, but the drop $I_e R_a$ is very small as R_e is very small. So there will be a small change in speed from no-load to full load as shown in Fig. The drop in speed from no-load to full-load is 5 to 10% of no-load speed.

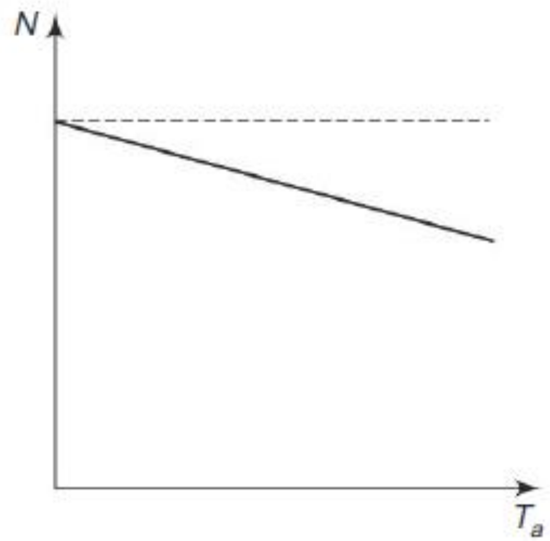
Shunt motor is a constant speed motor



1. Characteristics DC Shunt Motor

(iii) N Vs Ta

(iii) N vs T_a Characteristics This can be deduced from the above two characteristics and is shown in Fig. 6.24.



2. Characteristics DC Series Motor

(i) T_a Vs I_a

(i) T_a vs I_a Characteristics

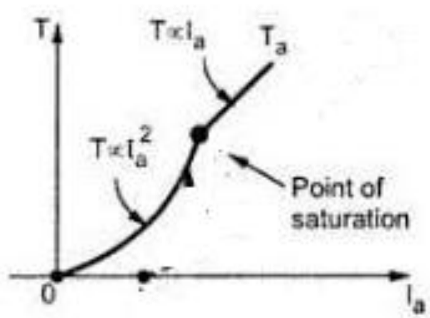
$$T_a \,\alpha\, f I_a;$$

In series motor $\phi \,\alpha\, I_{Se}$ and $I_{Se} = I_a$

At light loads, $T_a \,\alpha\, I_a^2$ (prior to saturation of field poles)

At heavy loads, $T_a \,\alpha\, I_a$ (after saturation of magnetic poles, ϕ is constant for any value of I_a)

So, T_a vs I_a characteristics is a parabola prior to saturation, and it is a straight line after saturation, as shown in Fig. . On heavy loads, the series motor exerts higher starting torque as $T_a \,\alpha\, I_a^2$ prior to saturation.



2. Characteristics DC Series Motor

(ii) N Vs Ia

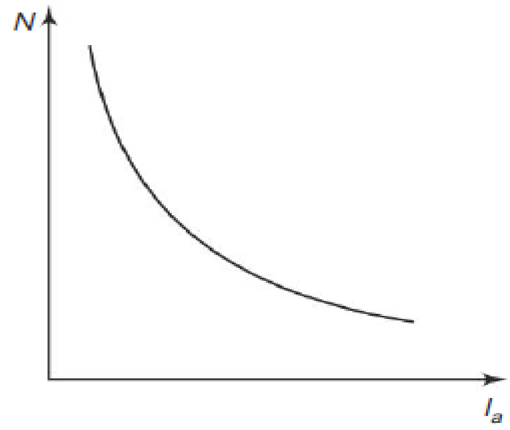
(ii) N vs I_a Characteristic

$$N \alpha \frac{E_b}{\phi}; \qquad (1)$$

$$E_b = V - I_a (R_a + R_{se}) \text{ and } \phi \, \alpha \, I_{se} \, (I_{se} = I_a) \qquad (2)$$

Change in E_b is very small with changes in load. So it can be regarded as constant on all loading

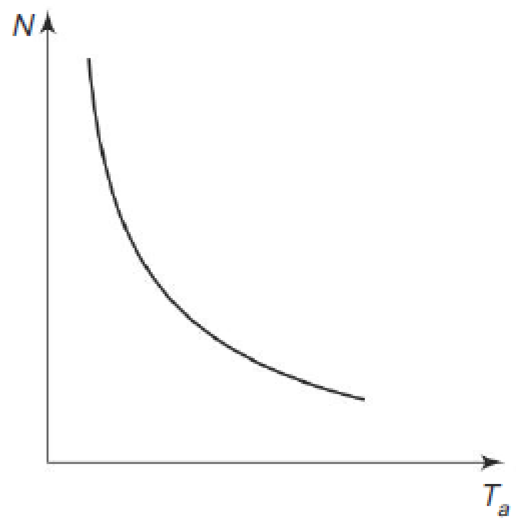
$$\therefore \qquad N \alpha 1/\phi \quad \text{or} \quad N \alpha 1/I_a \qquad (3)$$



The speed-armature current characteristic is a regular parabola as shown in Fig. 6.26. On light load or no-load, the armature current I_a is very small, and so the motor will run at dangerously high speeds. So, series motor should always be started with some load on it. Series motor is a variable speed motor.

2. Characteristics DC Series Motor
(iii) N Vs Ta

(iii) N vs T_a Characteristics From the above two characteristics, this characteristics can be deduced, as shown in Fig. 6.27.

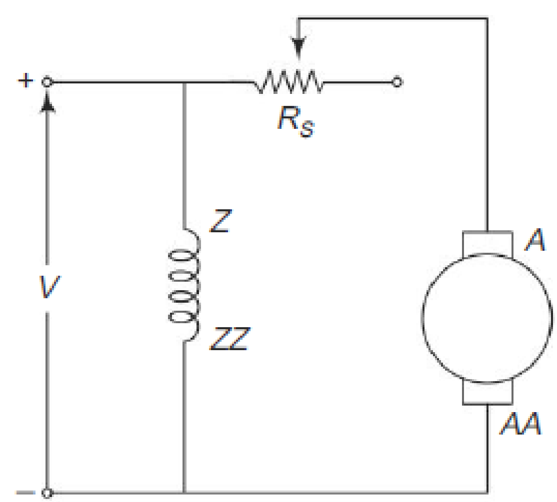


STARTERS

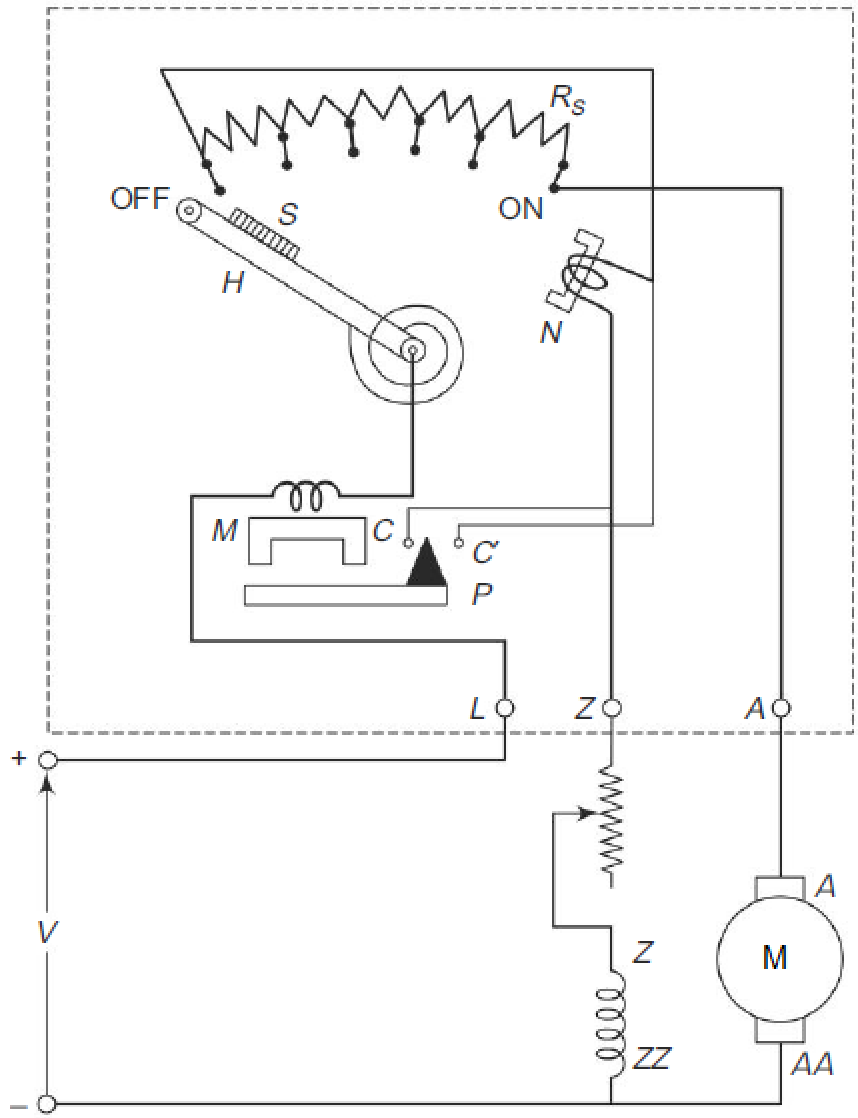
Starting of D.C. Motors

If the motor is directly switched on to the supply, the current drawn by the motor will be many times its full load current. This is because at the moment of switching on, there is no back emf developed by the motor. So, the current drawn by the motor is controlled by its internal resistance which is very small in value. This current is $I_a = \frac{V}{R_a}$ which is sometimes around 25 to 30 times of full load current of motor. This starting current will affect the power system supply quality. Specifically, there will be a heavy drop in system voltage momentarily. So, the starting current has to be limited. This can be achieved by connecting a resistance in the armature circuit. Once the motor picks up speed the back emf is developed and so the external resistance can be gradually cut out from the circuit. This is shown in Fig. 6.40. This resistance can be called as starting resistance.

To start the dc motor a device called starter can be used. The main function of the starter is to control the starting current drawn by the motor. The main component of a starter is resistance R_s. In addition to this they have protective devices like no-voltage release coil and overload release coil. There are 2-point starters meant for starting dc series motors 3-point and 4-point starters which are used for starting dc shunt and compound motors. The construction and working of a 3-point starter alone is discussed here.



3-POINT STARTER



DC 3-point Starter The components and the internal wiring of a 3-point starter is shown in Fig.

When the starter handle is moved from OFF position to stud (1) of R_s, the armature circuit of motor is closed through the starting resistance R_s and the overload release coil [OLR coil], thereby the starting current is controlled. Field circuit of motor is also closed through the voltage coil [NVC]. The motor starts running and back emf develops. Now the starter handle can be moved gradually from one stud to another and finally to ON.

The starter handle should be moved against the restraining force offered by the spring mounted in the starter handle. Once the starter handle comes to ON position, the NVC holds the starter handle firmly, i.e. the electromagnetic attracts the soft iron piece attached to the starter handle.

Whenever supply fails, the NVC gets de-energised and the electromagnetic N is demagnetized. Because of spring "force, the starter" handle comes to OFF position. When the motor is over loaded, electromagnetic force offered by the OLR coil is sufficient to attract the iron strip *P*. The contacts *CC* are bridged which results in short circuiting of NVC. So in this case also the electromagnet. "*N*" is demagnetized and the starter handle comes to OFF position. In this way the motor is protected against failure of supply and against overloading.

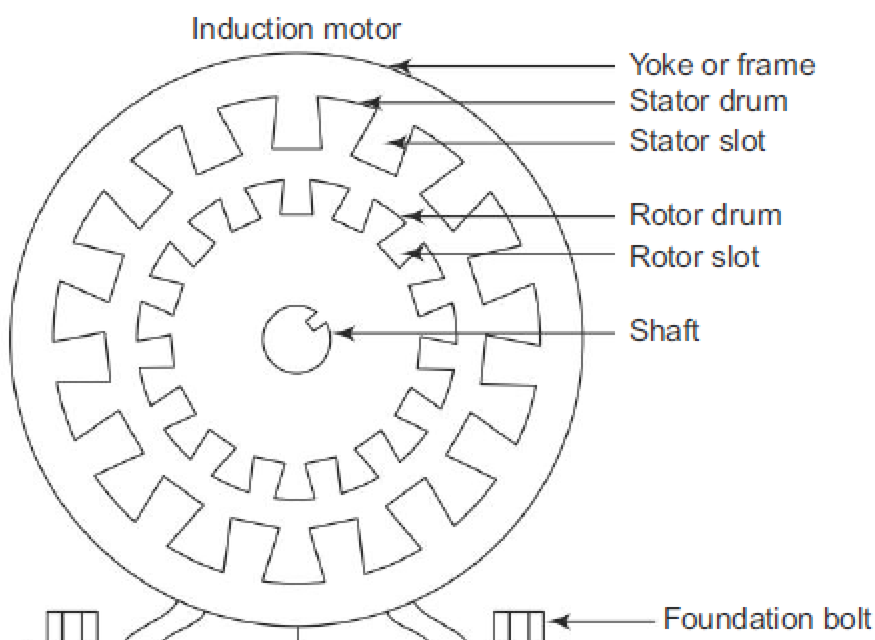
THREE PHASE INDUCTION MOTOR

Principle

When a three phase balanced voltage is applied to a three phase balanced winding, a rotating magnetic field is produced. This field has a constant magnitude and rotates in space with a constant speed. If a stationary conductor is placed in this field, an emf will be induced in it. By creating a closed path for the induced current to flow, an electromagnetic torque can be exerted on the conductor. Thus, the conductor is put in rotation.

Construction

The important parts of a three phase induction motor are schematically represented in Fig. 6.47. Broadly classified, they are stator and rotor. Each of these is described below.



Stator This is the stationary part of the motor. It consists of an outer solid circular metal part called the yoke or frame and a laminated cylindrical drum called the stator drum. This drum ash number of slots provided over the entire periphery of it. Required numbers of stator conductors are embedded in the slots. These conductors are electrically connected in series and are arranged to form a balanced three phase winding. The stator is wound to give a specific number of poles. The stator winding may be star or delta connected.

Rotor This is the rotating part of the induction motor. It is also in the form so slotted cylindrical structure. The air gap between stator and rotor is as minimum as mechanically possible. There are two types of rotors—squirrel cage rotor and slip-ring or wound rotor.

Working

A three phase balanced voltage is applied across the three phase balanced stator winding. A rotating magnetic field is produced. This magnetic field completes its path through the stator, the air gap and the rotor. In this process, the rotor conductors, which are still stationary, are linked by the time varying stator magnetic field. Therefore, an emf is induced in the rotor conductors. When the rotor circuit forms a closed path, a rotor current is circulated. Thus, the current carrying rotor conductors are placed in the rotating magnetic field. Hence, as per the law of interaction, an electromagnetic force is exerted on the rotor conductors. Thus, the rotor starts revolving.

According to Lenz's law, the nature of the rotor induced current is to oppose the cause producing it. Here the cause is the rotating magnetic field. Hence, the rotor rotates in the same direction as that of the rotating magnetic field.

In practice, the rotor speed never equals the speed of the rotating magnetic field (called the synchronous speed). The difference in the two speeds is called slip. The current drawn by the stator is automatically adjusted whenever the motor is loaded.

SINGLE PHASE INDUCTION MOTORS

Single phase induction motors are widely used in domestic, industrial and machine tool applications. The capacity of this motor varies from fractional horse power to 5 HP. Fractional horse power motors are used in variety of applications.

Construction and Non-Self Starting of 1-phase Induction Motor

The construction of 1-phase is similar to 3-phase induction motors. The starter has a single winding. The rotor is squirrel cage type as in 3-phase induction motor. When starter winding is energised with single phase supply an alternating flux is set up, but it is not a revolving field as in 3-phase induction motor. This alternating flux when acting on stationery motor cannot produce rotation. Only a revolving starting. However if the rotor is given an initial start by hand or by other means, then motor may start and run.

To make the single phase induction motors self starting, the following type of 1-phase induction motors were developed.

(a) Split-phase induction motors

(i) Resistance-start motor

(ii) Capacitor-start motor

1 Split Phase Resistance Start 1-Phase Induction Motor

In addition to the main winding of the motor, an auxillary winding is also placed in the starter. Both these windings are uniformly distributed in the stator slots. The two windings are displaced by 90° (electrical) in space. The main winding is called running winding and the auxillary winding is called the starting winding. The arrangement of these two windings in stator is shown in Fig. 6.53. The main winding is

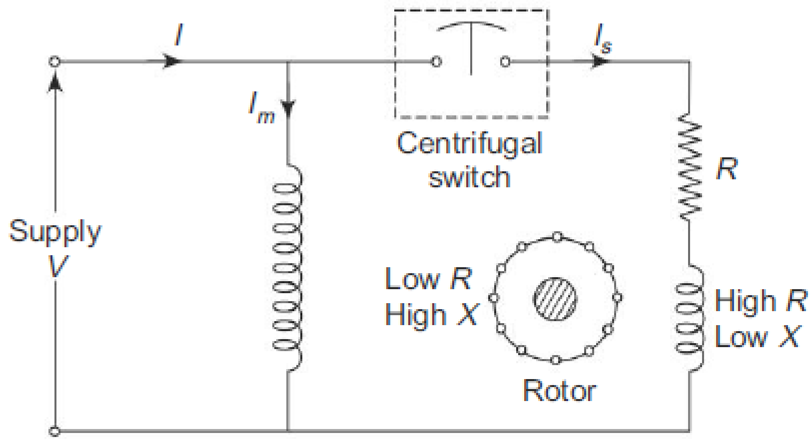
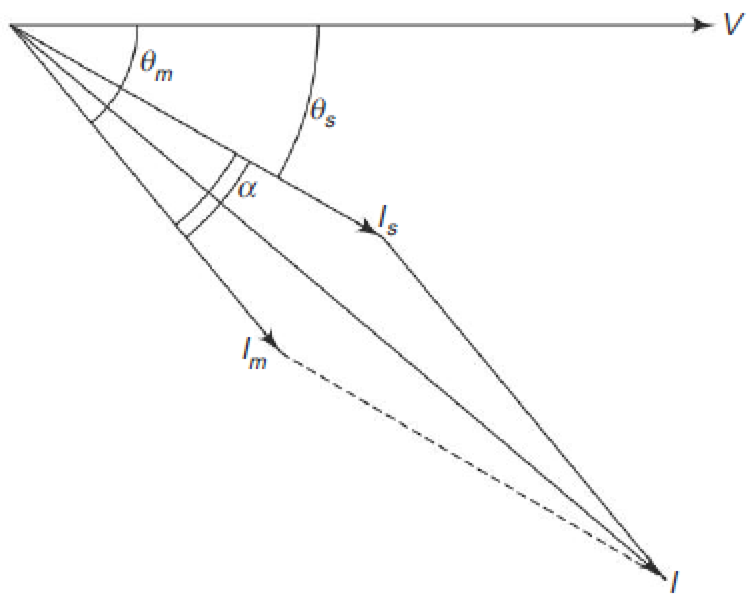


Fig. 6.53

highly inductive and the auxillary winding should be highly resistive. For this purpose, the auxiliary winding is provided with less number of turns. To make it highly resistive external resistance can be used in the auxiliary winding circuit. A centrifugal switch placed in the auxiliary winding circuit. The switch is in closed condition when the motor is at rest.

The 1-phase supply is given to the two windings, which are I parallel across the supply. The currents through the main winding and starting winding are displaced by an angle α as shown in Fig. 6.54. This angle α should be kept nearer to 90° by proper design of starting winding. The starting torque developed is proportional to sin α. When the motor attain 75% of rated speed, the centrifugal switch is opened and hence starting winding is disconnected from the supply. The starting torque developed is 150 to 200% full load torque of the motor.

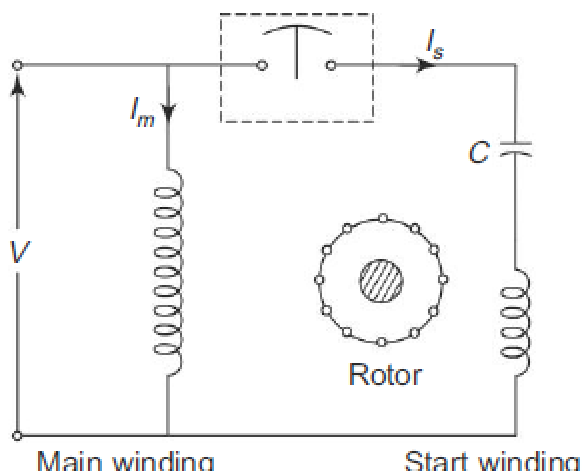
This type of motor is used in oil burns, machine tools, grinders, dish washes, washing machines, airblowers and air compressors.



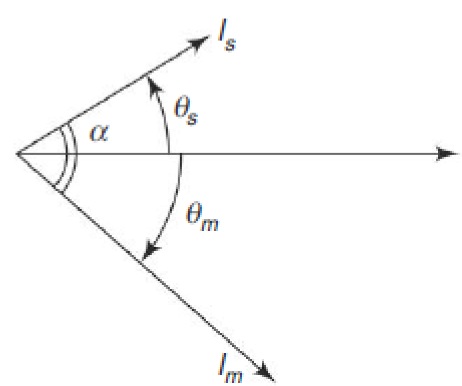
2. Split Phase Capacitor Start Induction Run Single Phase Induction Motor

The single phase supply given to the stator winding, can be split into two phases by connecting a suitable capacitor in series with the starting winding, as shown in Fig. 6.55 (i). The value of capacitance should be such that the phase angle α between I_s and I_m should be nearer to 90°. Then the fluxes due to this current is also displaced by the same angle α. This causes revolving field. The starting torque developed depends on sin α. The starting torque developed is about 300 to 450% of full load torque. This is more as compared to the previous type motor as α is more here. The value of α in the previous type motor is around 40° only. When the motor attains 75% of rated speed, the centrifugal switch opens and the starting winding is isolated from the circuit.

This motor is used where high starting torque is needed under loaded condition. They are used for pumps, refrigerations units, air-conditioners, large size washing machines, etc.



(i)



(ii)

3-PHASE AC GENERATOR OR ALTERNATOR

An alternator works on the principle of electromagnetic induction. If a conductor is placed in a moving magnetic field an emf is induced in the stationery conductor as per Faraday's first law of electromagnetic induction.

Construction

The two important parts of AC generators are stator and rotor. The construction of ac generator showing all main parts is given in Fig. 6.56.

Stator The stator consists of a cast iron or mild steel frame, which supports the armature core. This frame acts as an enclosure and provides a closed path for the magnetic flux. The armature core is made of laminated sheets. The material for armature core may be special magnetic iron or steel alloys. The inner periphery of

the armature core is slotted, in order to accommodate the armature winding. The armature winding may be single layer or double layer. The 3-phase armature winding should be a balanced one. The number of turns and size of wire should be same for all the 3-phase winding and the 3-phase winding are displaced in space by 120° (electrical) between them. The three ends of three phase winding are connected together to make the starprint, and the other three terminals of the three phase windings are brought out of the generator.

Rotor The rotor is like a flywheel having alternate N and S poles on its outer periphery. These electromagnets are magnetised by means of low dc voltage of 125 or 250 V. As rotor and hence the field magnets are rotating, this dc excitation voltage is given through slip rings which are fixed on the frame.

There are two types of rotors used in ac generators.

(i) *Salient or projecting pole type* It is used for engine driven generators, which are run at low and medium speed. The rotor has even number of projecting poles, whose cores are boiled to a heavy magnetic wheel of cast iron. The axial length of rotor is short and the diameter is large.

(ii) *Smooth cylindrical type* It is used for steam turbine driven generators or turbo alternators which are run at high speed. The rotor is made up of cast iron and cylindrical in shape. The outer periphery of the rotor is slotted to receive the field windings. The field windings are wound, such that N and S poles occur alternately. The number of field poles may be two or four. The axial length of rotor is large and its diameter is less.

Working of Alternator

The field magnets are magnetised by applying 125 volts or 250 volts through slip rings. The field windings are connected such that, alternate N and S poles are provided. The rotor and hence the field magnets are driven by the prime movers (steam driven turbine or engine driven). As the rotor rotates, the armature conductors are cut by the magnetic flux. Hence emf is induced in the armature conductors. As the magnetic poles are alternately N and S pole, the emf acts in one direction and then in the other direction. Hence an alternating emf induced in the stator conductors. The frequency of induced emf is depends on the number of N and S poles moving past an armature conductor in one second. The frequency of induced emf is given by,

$$f = \frac{PN}{120}; \; \text{P} \rightarrow \text{No. of magnetic poles}$$

$$N \rightarrow \text{Speed of rotor in rpm.}$$

The direction of induced emf can be obtained by Fleming's Right hand rule.

SYNCHRONOUS MOTOR

Synchronous motor runs only at synchronous speed, $N_s = \frac{120\,f}{P}$ on no-load and loaded conditions. It maintains speed while running. The only way to change the speed is by varying the supply frequency. It is not a self starting motor. This motor has to run upto its synchronous speed by some method, and then it can be synchronised.

Construction

The construction of synchronous motor is same as that of 3-phase ac generator. A synchronous machine may be run as synchronous motor and as synchronous generator.

Working Principle of Operation

When a 3-phase balanced winding is supplied with a balanced 3-phase supply, a rotating magnetic field of constant magnitude and synchronous speed is produced. Let the motor stator have 2-poles marked as N_s and S_s as shown in Fig. 6.57. The stator poles are rotating at synchronous speed. Let us assume that it moves in clockwise direction. The rotor is positioned as shown in Fig. 6.58 initially with reference to the position AB marked. As like poles repel, the rotor will tend to move in anticlockwise direction. At the end of first half cycle of supply, the rotor poles occupy the position as shown in Fig. 6.58 with respect to the reference plane AB. Now, because of attractive force between the unlike poles, the rotor will tend to move in the opposite, i.e. clockwise direction. So, with rapid movement of the stator poles, the rotor is subjected to a torque which is also rapidly reversing. But because of the inertia of the rotor, it will not respond to such a rapid reversing torque. So, the rotor remains stationary, which shows that it is not a starting motor.

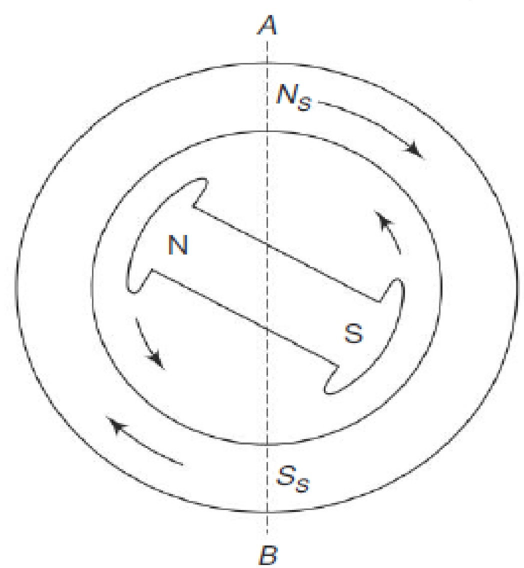


Fig. 6.57

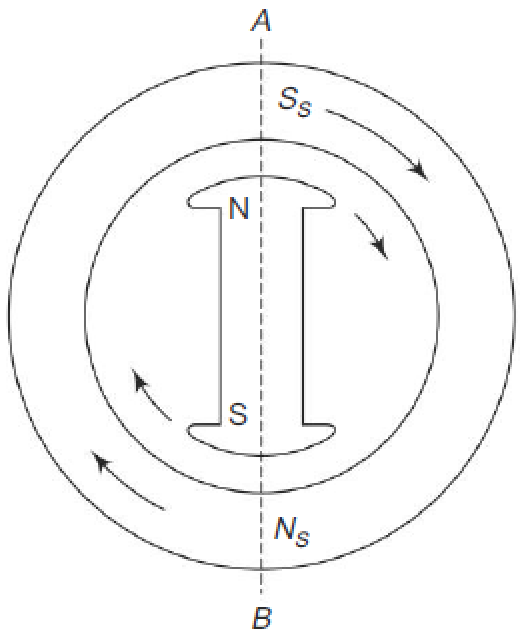


Fig. 6.58

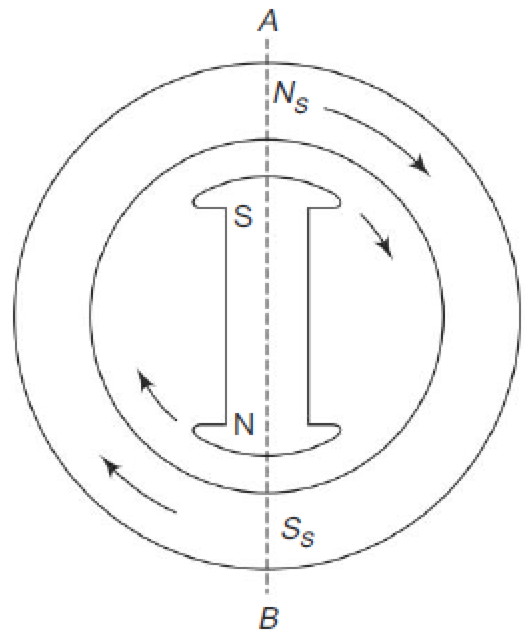


Fig. 6.59

Now consider the position of the rotor as shown in Fig. 6.59. The stator and rotor poles attract each other. Let the rotor also be rotating in clockwise direction at synchronous speed as that of stator field. So, the stator and rotor poles attract each other, at any instant, which results in unidirectional torque production, in clockwise direction in this case.

Sychronous Motor Starting Method

The methods for starting synchronous motor are:

(i) A dc motor coupled to the synchronous motor shaft: (discussed above)

(ii) Using the damper windings as a squirrel cage induction motor.

(iii) Using the field excited generator as a dc motor [similar to method (i)].

Synchronous Motor-application

(i) It is used in power house and in major substations to improve the power factor.

(ii) Used in textile mills, rubber mills, mining and other big industries for power factor improvement purpose and to maintain the facility of system voltage.

(iii) It is used to drive continuously operating and constant speed equipments like fans, blowers, centrifugal pumps, air comparators, etc.

BEEE-UNIT 3

Electronic Devices	
18	
Safety measures in electrical systems	*Clippers and clampers*
Types of wiring, wiring accessories	*Problem Solving Session*
House wiring for staircase, fluorescent lamp, LED lamp & corridor wiring	*Lab 8: Characteristics of semiconductor devices*
Basic principles of earthing, Types of earthing. Grounding in DC circuits	*BJT construction, operation*
Basic principles and classification of instruments	*BJT characteristics (CB, CE and CC configurations) and uses*
Moving coil and moving iron instruments	*JFET construction, operation*
Problem Solving Session	*JFET characteristics (CS configuration) and uses.*
Lab 7: Types of wiring (fluorescent lamp wiring, staircase wiring, godown wiring)	*MOSFET construction, operation*
Overview of Semiconductors	*MOSFET characteristics (CS configuration) and uses*
PN junction diode	*Problem Solving Session*
Zener diode	*Lab 9: Wave shaping circuits*
Diode circuits: rectifiers, half and full wave	
Bridge type rectifier, filter circuit	

HOUSE WIRING

- House wiring is to deal with the distribution system within the domestic premises.
- The wiring requirements may vary among the different consumers.
- House wiring is generally done for consumption of electrical energy at 230 V, 1-phase or at 400 V,3-phase.
- In the three phase system, the total load in the house is expected to be divided among the three phases.
- An earth wire is also run connecting all the power plugs from where large quantity of electrical energy is tapped by using electrical appliances like heater, electric iron, hot plate, etc. This chapter deals with the wiring materialsand accessories, different systems of wiring and earthing methods.

WIRING MATERIALS AND ACCESSORIES

1. **Switches:** A switch is used to make or break the electric circuit.
2. **Lamp Holders**: A lamp holder is used to hold the lamp for lighting purposes.
3. **Power point:** Power points (plugs, wall sockets) need to be installed throughout the house in locations where power will be required.
4. **Main Switch:** This is used at the consumer's premises so that he may have self-control of the entire distribution circuit.

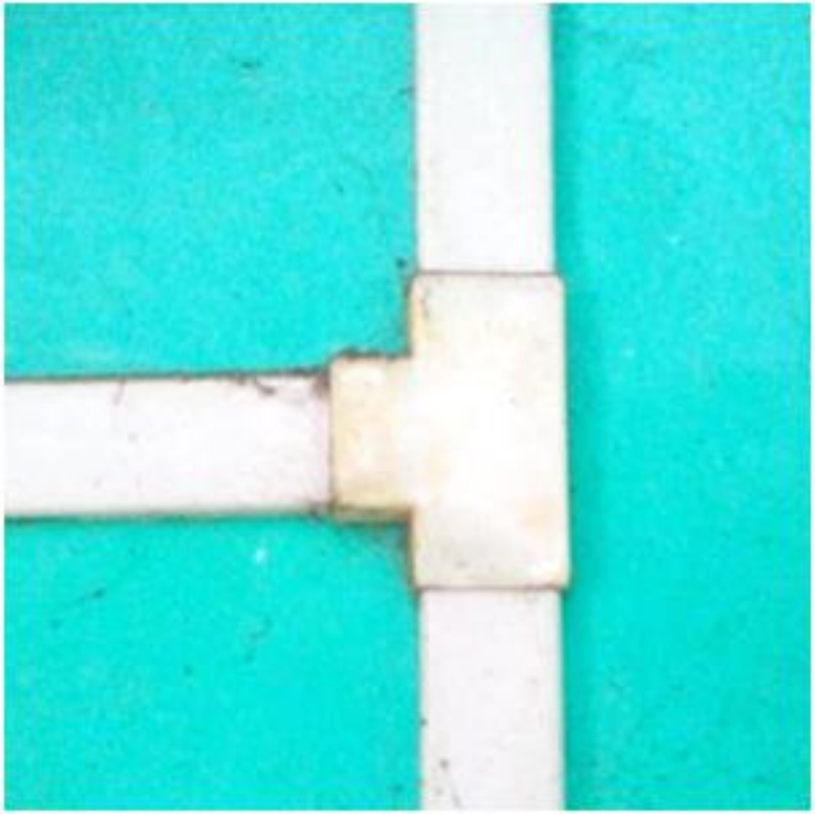
5. **Circuit Breakers**: Domestic Electrical Circuit Breakers provide essential protection to house from electrical hazards. It is essential to use domestic circuit breakers to get protected from electrical overloads and short circuit conditions. The most widely used electrical circuit breakers are Miniature circuit breakers (MCBs) , Residual current circuit breaker (RCCB) and Mounded Case Circuit Breaker (MCCB)

Electrical wiring system is classified into five categories:

1. Cleat wiring
2. Casing wiring
3. Batten wiring
4. Conduit wiring
5. Concealed wiring

1. Cleat wiring

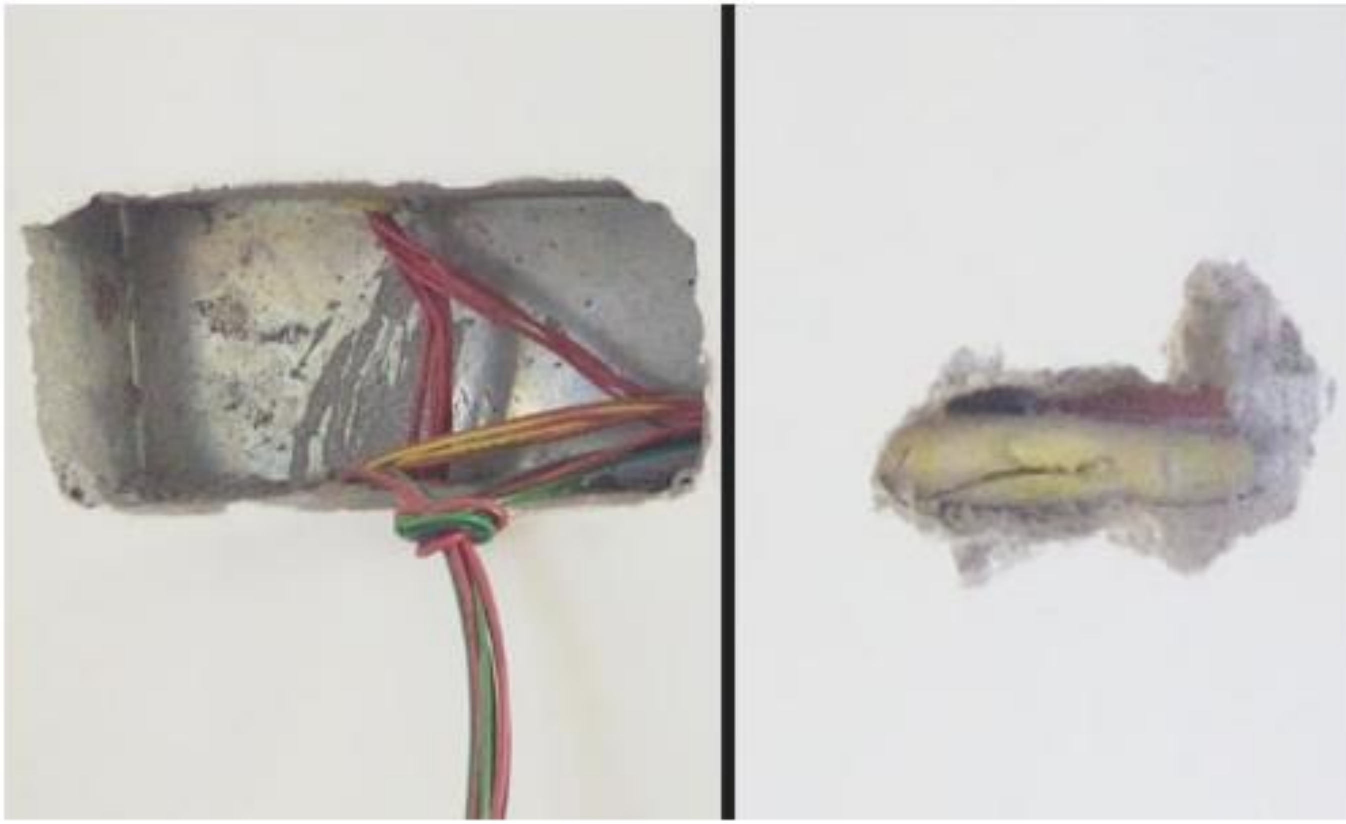
2. Casing wiring



3.Batten wiring

4. Conduit wiring

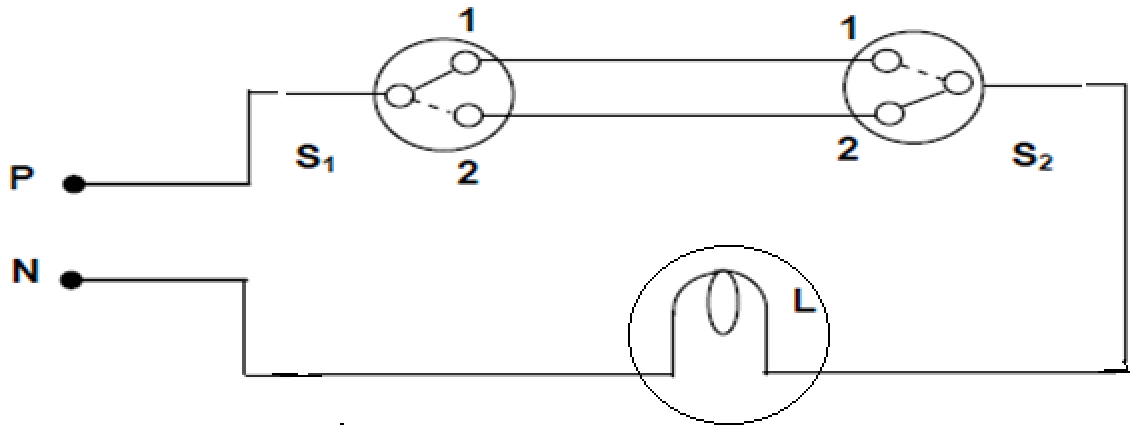
5. Concealed wiring



1-WAY SWITCH

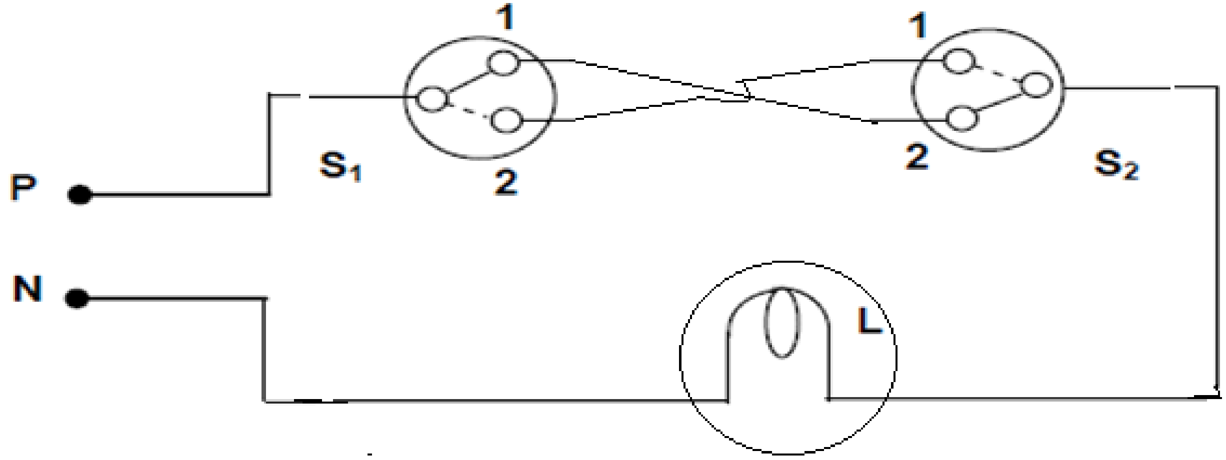
STAIRCASE WIRING

In staircase wiring a single lamp, placed at the middle of the staircase, is controlled by switches at two places, one at the beginning of the staircase and the other at the end of the staircase. For this purpose two-way switches are required. The wiring circuit is shown below.



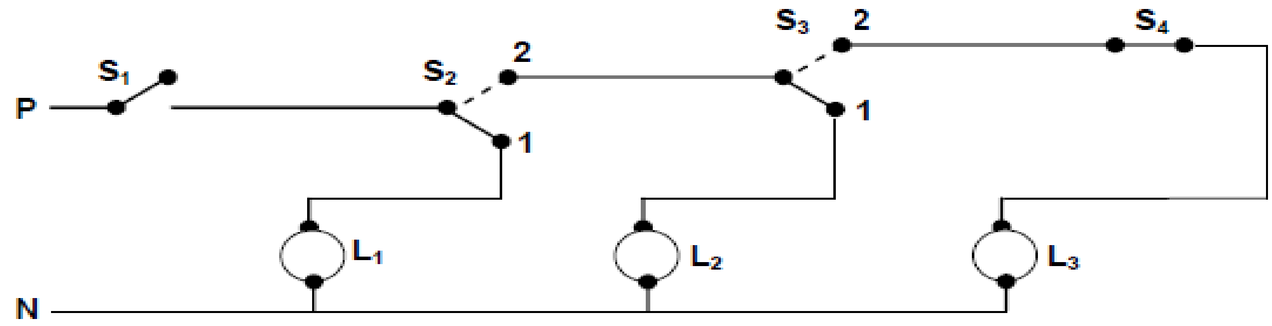
Position of switch S_1	Position of switch S_2	Condition of lamp
1	1	ON
1	2	OFF
2	1	OFF
2	2	ON

STAIRCASE WIRING- Another type of connection



Position of switch S$_1$	Position of switch S$_2$	Condition of lamp
1	1	OFF
1	2	ON
2	1	ON
2	2	OFF

CORRIDOR WIRING



<u>Moving from left to right:</u>

Enters	Closes S_1	L_1 ON
Reaches S_2	Put S_2 to 2	L_1 OFF and L_2 ON
Reaches S_3	Put S_3 to 2	L_2 OFF and L_3 ON
Reaches S_4	Opens S_4	L_3 OFF

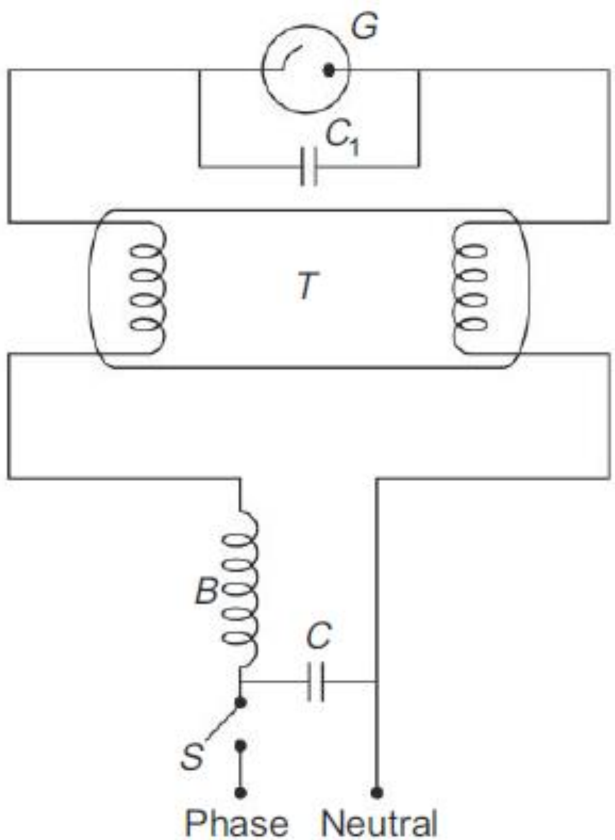
<u>Moving from right to left:</u>

Enters	Closes S_4	L_3 ON
Reaches S_3	Put S_3 to 1	L_2 ON and L_3 OFF
Reaches S_2	Put S_2 to 1	L_1 ON and L_2 OFF
Leaves	Opens S_1	L_1 OFF

FLUORESCENT LAMP

A fluorescent lamp or fluorescent tube is a gas-discharge lamp that uses electricity to excite mercury vapor. The excited mercury atoms produce short-wave ultraviolet light that then causes a phosphor to fluoresce, producing visible light. A fluorescent lamp converts electrical power into useful light more efficiently than an incandescent lamp. Lower energy cost typically offsets the higher initial cost of the lamp. The lamp is more costly because it requires a ballast to regulate the flow of current through the lamp.

While larger fluorescent lamps have been mostly used in commercial or institutional buildings, the compact fluorescent lamp is now available in the same popular sizes and is used as an energy-saving alternative in homes.



T – Fluorescent tube
G – Glow switch starter
B – Ballast or choke
S – Switch
C – Capacitor for P.F. improvement
C_1 – Capacitor to suppress radio interference

LED lamp

An LED lamp or LED light bulb is an electric light for use in light fixtures that produces light using one or more light-emitting diodes (LEDs). LED lamps have a **lifespan** many times longer than equivalent incandescent lamps, and are significantly **more efficient** than most fluorescent lamps, with a luminous efficacy of up to 303 lumens per watt. However, LED lamps require an electronic LED driver circuit when operated from mains power lines. Many LEDs use only about **10%** of the energy an incandescent lamp requires.

Safety Precautions when Working with Electricity

1. Never touch or try repairing any electrical equipment or circuits with **wet hands**. It increases the conductivity of electric current.

2. Never use equipment with **damaged insulation** or **broken plugs**.

3. If you are working on any electrical socket at your home then always **turn off the mains**.

4. Always **use insulated tools while working**.(never_use aluminium or steel ladder)

5. Electrical hazards include exposed **energized parts** and unguarded electrical equipment which may become **energized unexpectedly** -carries warning signs like "**Shock Risk**". Always be observant such electrical signs.

6. when working electrical circuit always use appropriate insulated rubber gloves and goggles.

7. Never try repairing energized equipment. Always check that it is de-energized first by using a tester. When an electric tester touches a live or hot wire, the bulb inside the tester lights up showing that an electrical current is flowing through the respective wire.

8. Know the wire code of your country.

9. Always use a circuit breaker or fuse with the appropriate current rating. Circuit breakers and fuses are protection devices that automatically disconnect the live wire when a condition of short circuit or over current occurs. The selection of the appropriate fuse or circuit breaker is essential.

BASIC PRINCIPLES OF EARTHING

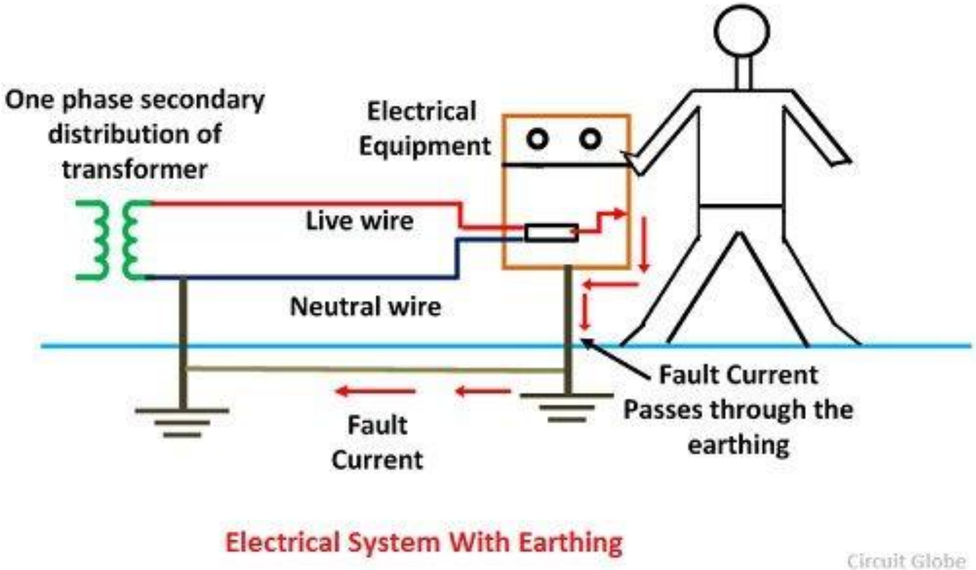
Earthing and its Necessity

Earthing means generally connected to the mass of the earth. It shall be in such a manner as to ensure at all times an immediate and safe discharge of electric current due to leakages, faults, etc.

All metallic parts of every electrical installation such as conduit, metallic sheathing, armouring of cables, metallic panels, frames, iron clad switches, instrument frames, household appliances, motors, starting gears, transformers, regulators etc, shall be earthed using one continuous bus (barewire). If one earth bus for the entire installation is found impracticable, more than one earthing system shall be introduced. Then, the equipment and appliances shall be divided into sub-groups and connected to the different earth buses.

The earthing conductors, when taken out doors to the earthing point, shall be encased in pipe securely supported and continued up to a point not less than 0.3 more below ground level. No joints are permitted in an earth bus. Whenever there is a lightning conductor system installed in a building, its earthing shall not be bonded to the earthing of the electrical installation.

Before electric supply lines or apparatus are energized, all earthing system shall be tested for electrical resistance to ensure efficient earthing. It shall not be more than two ohms including the ohmic value of earth electrode.


One phase secondary distribution of transformer
Electrical Equipment
Live wire
Neutral wire
Fault Current Passes through the earthing
Fault Current
Electrical System With Earthing
Circuit Globe

.1 Earthing through a G.I. Pipe

In this method a G.I. pipe used as an earth electrode. The size of the pipe depends upon the current to be carried and type of soil in which the earth electrode is buried.

For ordinary soils the length of the G.I. pipe used as an earth elctrode is 2 m long and 38 mm in diameter or 1.37 m long and 51 mm in diameter. For dry and

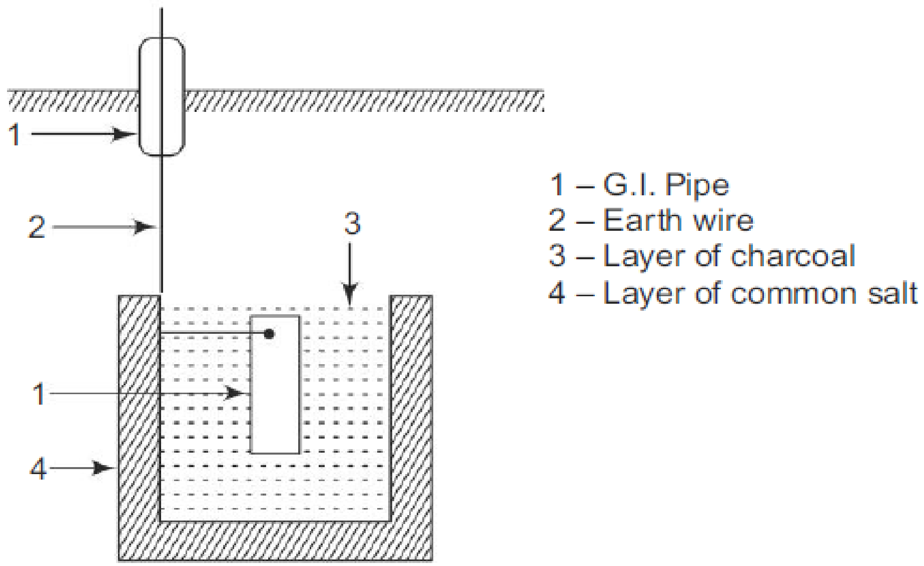
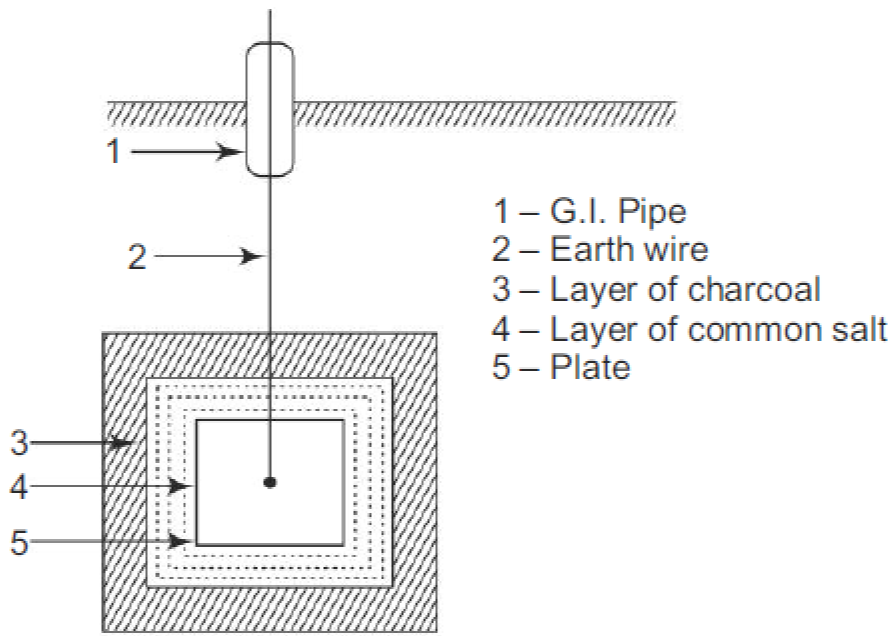


Fig. 8.3

rocky soils the length may be increased to about 2.75 metres and 1.85 metres respectively. The pipe is placed vertically, burying to a depth not less than 2 metres in as moist a place as possible, preferably in close proximity of water tap, water pipe or water drain and at least 0.6 metre away from all building foundations, etc as shown in Fig. 8.3. The pipe shall be completely covered by 80 mm of Charcoal with the layer of common salt 30 mm all around it. The charcoal and salt decreases the earth resistance.

.2 Earthing through a Plate

A G.I. or copper plate is used as an earth electrode. If a G.I. plate is used it shall be of dimensions 0.3 m × 0.3 m and 6.35 mm thick and if a copper plate is used it shall be of dimensions 0.3 m × 0.3 m and 3.2 mm thick. The plate is buried to a depth of not less than 2 m in as moist a place as possible preferably in close proximity of water tap, water pipe or water drain and at least 0.6 m away from all building foundations, etc. The plate shall be completely covered by 80 mm of charcoal with a layer of common salt of 30 mm all around it, keeping the faces of the vertical as shown in Fig. 8.4.



CLASSIFICATION OF INSTRUMENTS

Electrical measuring instruments are classified as follows:

I. Depending on the quantity measured	e.g.	Voltmeter, Ammeter, Wattmeter, Energymeter, Ohmmeter.
II. Depending on the different principles used for their working	e.g.	Moving Iron type, Moving coil type, Dynamometer type, Induction type.
III. Depending on how the quantity is measured?	e.g.	Deflecting type, Integrating type, Recording type.

The different types of torques associated with measuring instruments

1.Deflecting Torque

This torque acts on the moving system of the instrument to give the required deflection. It exists as long as the instrument is connected to the supply.The deflecting torque shall ensure a deflection proportional to the magnitude of the quantity being measured.

2. Opposing Torque

This torque always opposes the deflecting torque. The moving system attains a steady deflected position when the opposing torque equals the deflecting torque. The components of the opposing torque are inertia torque, control torque and damping torque.

2 (a) Inertia Torque

This is due to the inertia of the moving system. The deflecting has to overcome this and make the moving system move from its rest position.

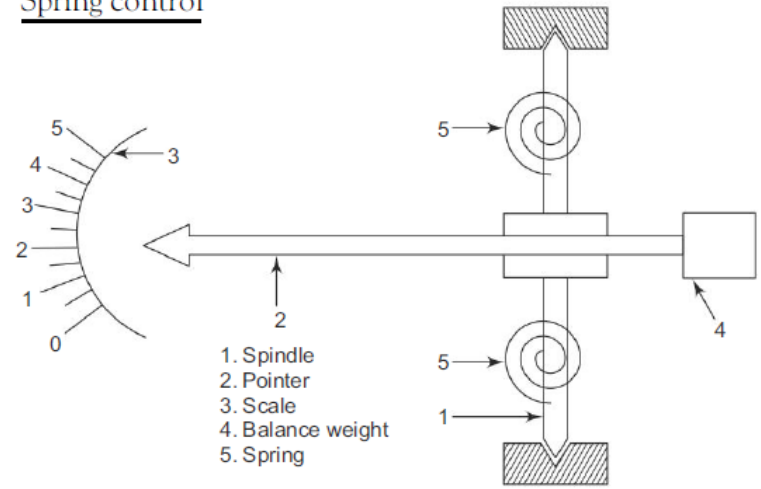
2 (b) Control Torque

This torque is always present in the instrument whether it is connected to the supply or not. The control torque increases with the deflection of the moving system. **It opposes the deflecting torque**. The moving system is brought to a steady deflected position when the control torque is balanced by the deflecting torque. The control torque is also essential to bring back the moving system to its initial or rest or zero position once the instrument is disconnected from the supply.

The control torque can be produced using spring or gravity:

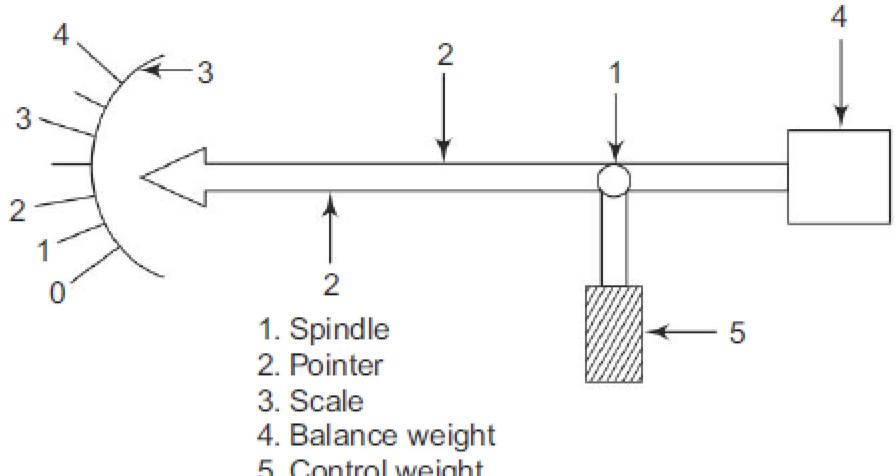
2 (b) (i) Spring control (Refer Fig.). Two helical springs of rectangular cross section are connected to the spindle of the moving system. With the movement of the pointer, the springs bet twisted in the opposite direction. Thus, the required amount of control is affected on the moving system. Also, once the instrument is disconnected from the supply, the pointer (moving system) is brought back to its initial position due to the twisted spring.

Spring control



2 (b) (ii) Gravity control

(Refer Fig.). In this method, adjustable small weights are added to some part of the moving system. When the pointer deflects, this weight also takes a deflected position. The gravitational force acting on the moving weight produces the required control torque



2 (c) *Damping Torque* This torque is produced only when the instrument is in operation. This ensures that the moving system takes just the required time to reach its final deflected position.

Electrical measuring instruments

- MOVING COIL INSTRUMENTS
  - PERMANENT MAGNET TYPE
  - DYNAMOMETER TYPE
- MOVING IRON INSTRUMENTS
  - ATTRACTION TYPE
  - REPULSION TYPE

1 MOVING COIL INSTRUMENTS

1 A. PERMANENT MAGNET MOVING COIL INSTRUMENT [PMMC]

Principle A current carrying coil is placed in a magnetic field, a force is exerted. It tends to act on the coil and moves it away from the field. This movement of the coil is used to measure current or voltage.

Construction (Refer Figs. 7.9 and 7.10). N and S refer to the pole pieces of a permanent magnet. A soft iron core in the form of a cylinder is placed in the space between the poles (C). In the permanent magnetic field is placed a rectangular coil of many turns (MC) wound on a former (AF). The former is made of aluminium or copper. To the moving coil is attached the spindle (S_P). Two helical springs (S_g) are connected to the spindle to give the necessary control torque. A pointer (p) attached to the spindle is made to move over a calibrated scale.

Working A magnetic field of sufficient density is produced by the permanent magnet. The moving coil carries the current or a current proportional to the voltage to be measured. Hence, an electromagnetic force is produced which tends to act on the moving coil and moves it away from the field. This movement makes the spindle move and so the pointer gives a proportionate deflection.

PMMC

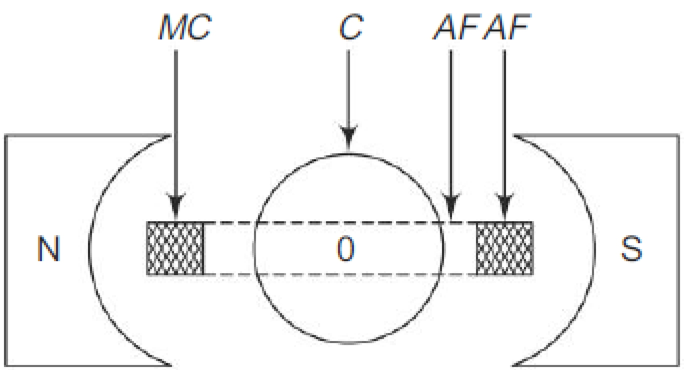


Fig. 7.9

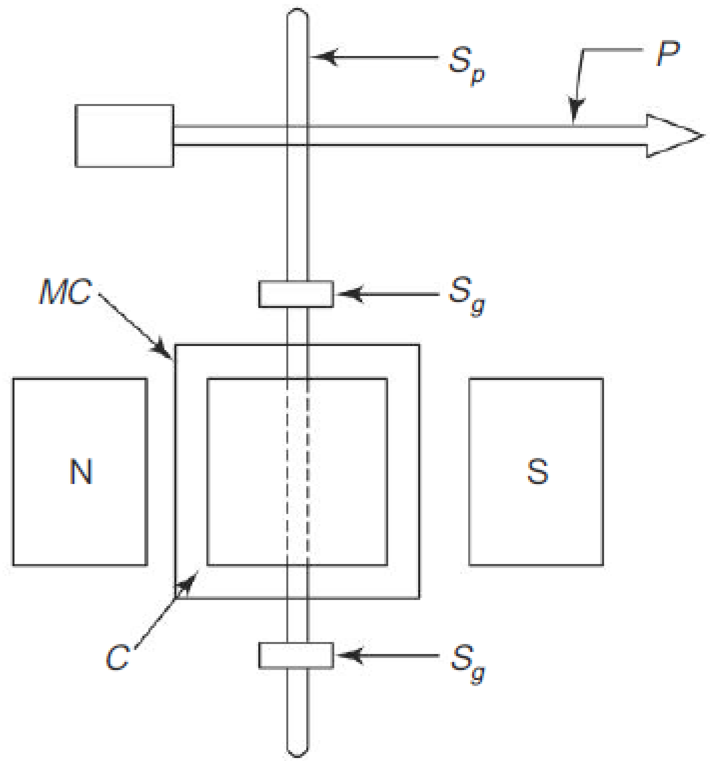


Fig. 7.10

Deflecting torque	...	It is directly proportional to the current or the voltage to be measured. So, the instrument can be used to measure direct current and dc voltage.
Control torque	...	Spring control
Damping torque	...	Eddy current damping. When the moving coil made of aluminium former is moved due to the force exerted on it, it cuts the magnetic flux lines produced by the permanent magnet. Hence, eddy currents are induced in the former.

As per Lenz's law, these eddy currents produce the required damping torque opposing the motion of the moving coil.

1 B DYNAMOMETER TYPE MOVING COIL INSTRUMENT

Principle Working principle of this type of instrument is same as that of permanent magnet moving coil type. But, the difference is that there is no permanent magnet in this instrument. Both the operating fields are produced by the current and/or the voltage to be measured.

Construction (Refer Fig. 7.11). The fixed coil (*FC*) is made in two sections. In the space between these two sections, a moving coil (*MC*) is placed. The moving coil is attached to the spindle to which is attached a pointer. The pointer is allowed to move over a calibrated scale. Two helical springs are attached to the spindle to give the required control torque. A piston attached to the spindle is arranged to move inside an air chamber.

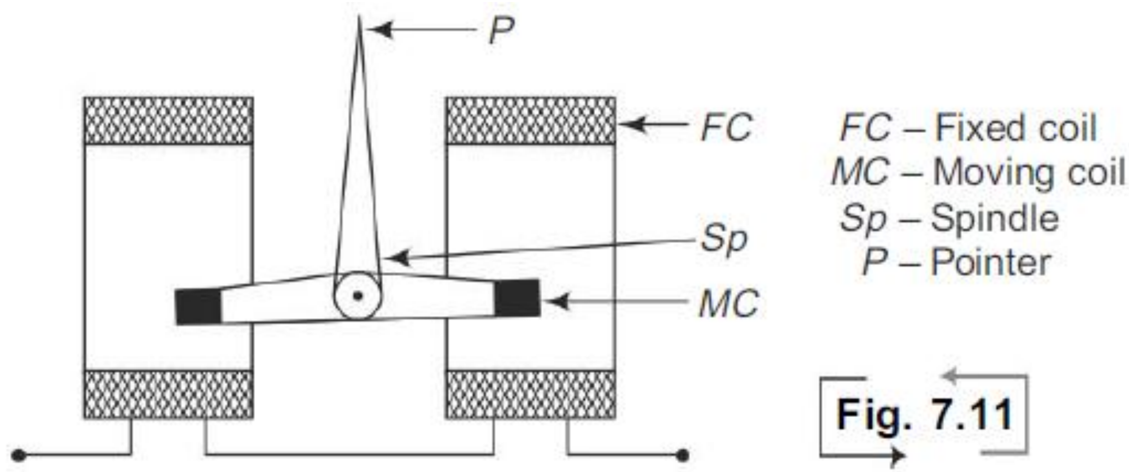


Fig. 7.11

Working The fixed coil and the moving coil carry currents. Thus, two magnetic field are produced. Hence, an electromagnetic force tends to act on the moving coil and makes it move. This makes the pointer give a proportionate deflection.

Deflecting Torque

(a) *As voltmeter* The two coils are electrically in series. They carry a current proportional to the voltage to be measured. The deflecting torque is proportional to $(\text{voltage})^2$. Hence, the instrument can be used for measuring dc and ac voltages.

(b) *As ammeter* The two coils are electrically in series. They carry the current to be measured. The deflecting torque is proportional to $(\text{current})^2$. Hence, the instrument can be used for measuring dc and ac.

(c) *As wattmeter* Fixed coils carry the system current. Moving coil carrys a current proportional to the system voltage. The design is such that the deflecting torque is proportional to $VI \cos \phi$, i.e power to be measured.

Control torque: Spring Control

Damping torque: Air damping

2 MOVING IRON INSTRUMENTS

2A ATTRACTION TYPE

Moving Iron Instruments are used mainly to measure voltage or current.

Principle It is well known that a soft iron piece gets magnetised when it is brought into a magnetic field produced by a permanent magnet. The same phenomenon happens when the soft iron piece is brought near either of the ends of a coil carrying current. The iron piece is attracted towards that portion where the magnetic flux density is more. This movement of the soft iron piece is used to measure the current or voltage which produces the magnetic field.

Construction (Refer Fig. 7.7). The instrument consists of a working coil. It carries the current to be measured or a current proportional to the voltage to be measured. A soft iron disc is attached to the spindle. To the spindle, a pointer is also attached. The pointer is made to move over a calibrated scale. The moving iron (soft iron disc) is pivoted such that it is attracted towards the centre of the coil where the magnetic field is maximum.

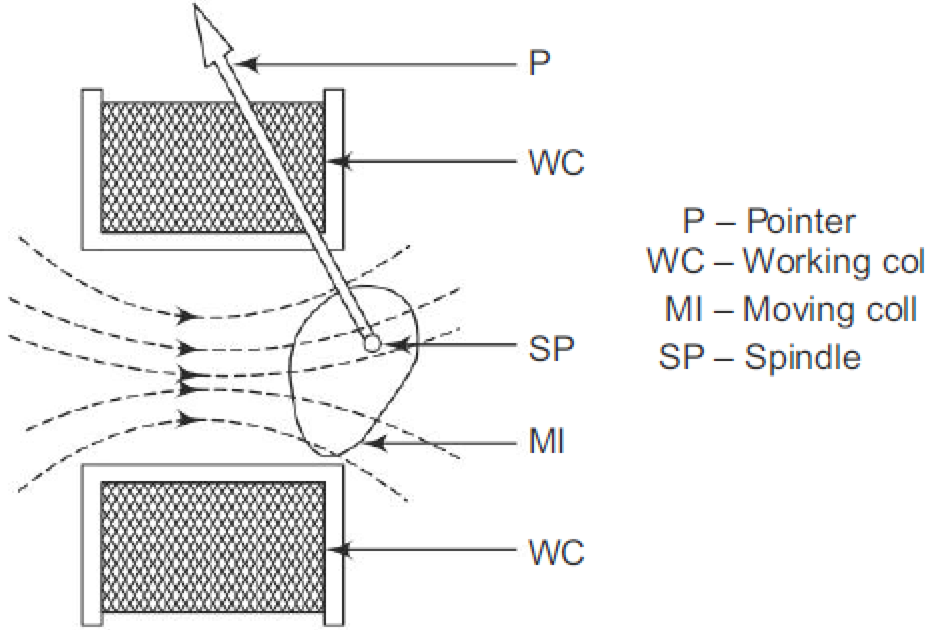


Fig. 7.7

Working The working coil carries a current which produces a magnetic field. The moving disc is attracted towards the centre of the coil where the flux density is maximum. The spindle is, therefore, moved. Thus, the pointer, attached to the spindle gives a proportional deflection.

Deflecting Torque Produced by the current or the voltage to be measured. It is proportional to the square of the current or voltage. Hence, the instrument can be used to measure d.c. or a.c scale is non-uniform.

Control torque: Spring or gravity

Damping: Air friction damping

2B REPULSION TYPE MOVING IRON INSTRUMENT

Principle Two iron pieces kept with close proximity in a magnetic field get magnetized to the same polarity. Hence, a repulsive force is produced. If one of the two pieces is made movable, the repulsive force will act on it and move it on to one side. This movement is used to measure the current or voltage which produces the magnetic field.

Construction (Refer Fig. 7.8). The instrument consists of a working coil which carries a current proportional to voltage or the current to be measured. There are two iron pieces-fixed and moving. The moving iron is connected to the spindle to which is attached a pointer. It is made to move over a calibrated scale.

Working When the operating coil carries current, a magnetic field is produced. This field magnetises similarly both the soft iron pieces. Thus, a repulsive force is produced which acts on the moving iron and pushes it away from its rest position. Thus, the spindle moves and hence the pointer gives a proportionate deflection. Whatever be the direction of current in the coil, the two irons are always similarly magnetised.

Deflecting Torque Produced by the current or the voltage to be measured it is proportional to the square of the current or voltage. Hence, the instrument can be used for dc and ac.

Control torque: Spring or Gravity

Damping: Pneumatic (i.e air damping)

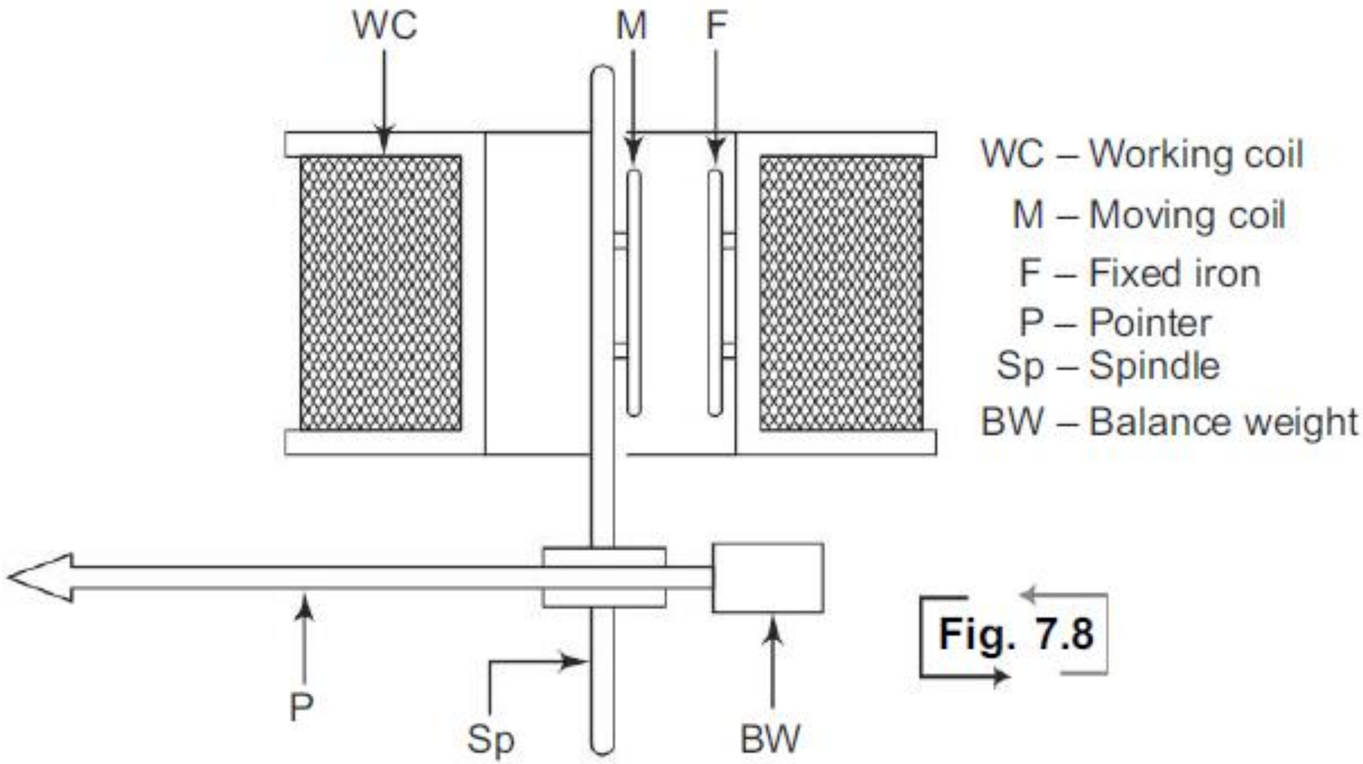


Fig. 7.8

NOTE:

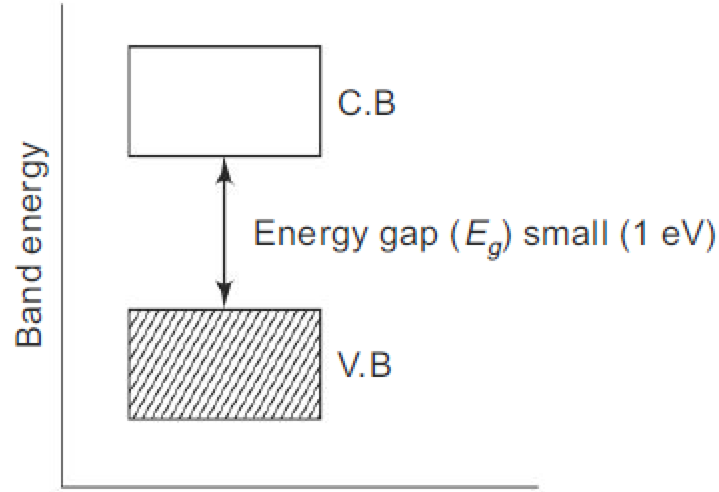
1. MC instruments are used for the measurement of DC Quantities only.
2. MI instruments are used for the measurement of both DC & AC Quantities.

OVERVIEW OF SEMICONDUCTORS

- Depending on their conductivity, materials can be classified into three types as conductors, semiconductors and insulators. Conductor is a good conductor of electricity. Insulator is a poor conductor of electricity. Semiconductor has its conductivity lying between these two extremes.

Energy Band of Semiconductor

In terms of energy band shown in Fig., the valence band is almost filled (partially filled) and conduction band is almost empty.



A comparatively smaller electric field (smaller than required for insulator) is required to push the electrons from the valence band to conduction band. At low temperatures, the valence band is completely filled and the conduction band is completely empty. Therefore a semiconductor virtually behaves as an insulator at low temperature. However even at room temperature some electrons crossover to the conduction band giving conductivity to the semiconductor. As temperature increases, the number of electrons crossing over to the conduction band increases and hence electrical conductivity increases. Hence a semiconductor has negative temperature coefficient of resistance.

Classifications of Semiconductors

Intrinsic Semiconductor: A pure semiconductor is called intrinsic semiconductor.

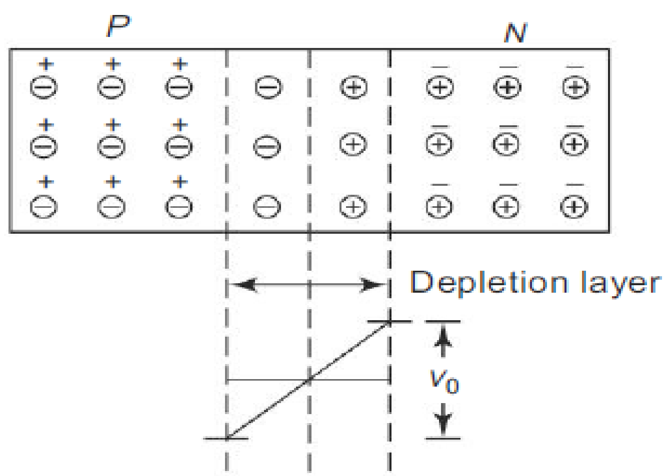
Extrinsic Semiconductor: Due to the poor conduction at room temperature, the intrinsic semiconductor, as such, is not useful in the electronic devices. Hence the current conduction capability of the intrinsic semiconductor should be increased. This can be achieved by adding a small amount of impurity to the intrinsic semiconductor, so that it becomes impurity semiconductor or extrinsic semiconductor. This process of adding impurity is known as **doping**.

N-type Semiconductor: A small amount of **pentavalent** impurities such as arsenic, antimony or phosphorus is added to the pure semiconductor (germanium or silicon crystal) to get N-type semiconductor. Thus, the addition of pentavalent impurity (antimony) increases the number of electrons in the conduction band thereby increasing the conductivity of N-type semiconductor. As a result of doping, the number of free electrons far exceeds the number of holes in an N-type semiconductor. So electrons are called majority carriers and holes are called minority carriers

P-type Semiconductor: A small amount of trivalent impurities such as aluminium or boron is added to the pure semiconductor to get the P-type semiconductor. The number of holes is very much greater than the number of free electrons in a P-type material, holes are termed as majority carriers and electrons as minority carriers.

THEORY OF PN JUNCTION DIODE

In a piece of semiconductor material, if one half is doped by P-type impurity and the other half is doped by N-type impurity, a PN junction is formed. The plane dividing the two halves or zones is called PN junction. As shown in Fig., the N-type material has high concentration of free electrons while P-type material has high concentration of holes. Therefore at the junction there is a tendency for the free electrons to diffuse over to the P-side and holes to the N-side. This process is called diffusion.



Formation of PN Junction

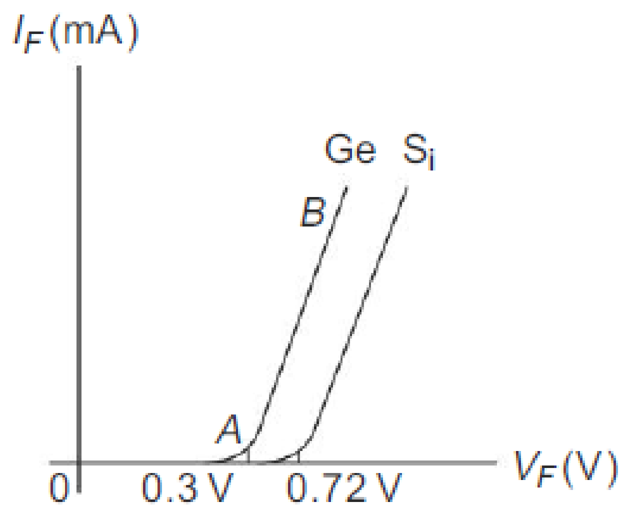
As the free electrons move across the junction from N-type to P-type, the donor ions become positively charged. Hence a positive charge is built. on the N-side of the junction. The free electrons that cross the junction uncover the negative acceptor ions by filling in the holes. Therefore a net negative charge is established on the P-side of the junction. This net negative charge on the P-side prevents further diffusion of electrons into the P-side. Similarly, the net positive charge on the N-side repels the holes crossing from P-side to N-side. Thus a barrier is set up near the junction which prevents further movement of charge carriers, i.e. electrons and holes. This is called potential barrier or junction barrier V_0. V_0 is 0.3 V for germanium and 0.72 V for silicon. The electrostatic field across the junction caused by the positively charged N-type region tends to drive the holes away from the junction and negatively charged P-type region tends to drive the electrons away from the junction. Thus the junction region is depleted to mobile charge carriers. Hence it is called **depletion layer.**

Under Forward Bias Condition

When positive terminal of the battery is connected to the P-type and negative terminal to the N-type of the PN junction diode, the bias applied is known as forward bias. Under the forward bias condition, the applied positive potential repels the holes in P-type region so that the holes move towards the junction and the applied negative potential repels the electrons in the N-type region and the electrons move towards the junction. Eventually when the applied potential is more than the internal barrier potential, the depletion region and internal potential barrier disappear.

V–I Characteristics of a Diode under Forward Bias

For $V_F > V_0$, the potential barrier at the junction completely disappears and hence, the holes cross the junction from P-type to N-type and the electrons cross the junction in the opposite direction, resulting in relatively large current flow in the external circuit.

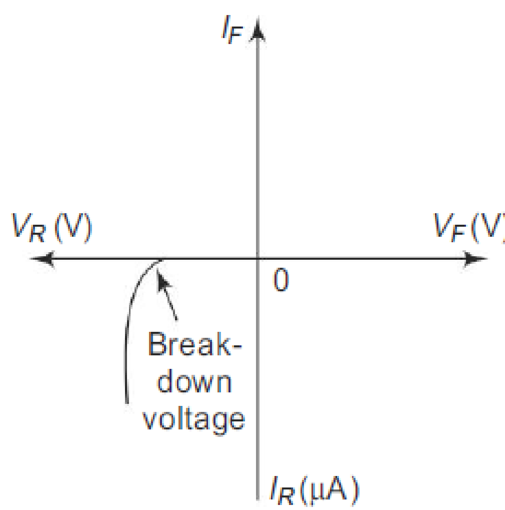


Under Reverse Bias Condition

When the negative terminal of the battery is connected to the P-type and positive terminal of the battery is connected to the N-type of the PN junction, the bias applied is known as reverse bias. Under applied reverse bias, holes which form the majority carriers of the P-side move towards the negative terminal of the battery and electrons which form the majority carrier of the N-side are attracted towards the positive terminal of the battery. Hence the width of the depletion region which is depleted of mobile charge carriers increases. Thus the electric field produced by applied reverse bias, is in the same direction as the electric field of the potential barrier. Hence, the resultant potential barrier is increased, which prevents the flow of majority carriers in both directions. Therefore, theoretically no current should flow in the external circuit. But in practice, a very small current of the order of a few microamperes flows under reverse bias.

V–I Characteristics of a Diode under Reverse Bias

For large applied reverse bias, the free electrons from the N-type moving towards the positive terminal of the battery acquire sufficient energy to move with high velocity to dislodge valence electrons from semiconductor atoms in the crystal. These newly liberated electrons, in turn, acquire sufficient energy to dislodge other parent electrons. Thus, a large number of free electrons are formed which is commonly called as an avalanche of free electrons. This leads to the breakdown of the junction leading to very large reverse current. The reverse voltage at which the junction breakdown occurs is known as **breakdown voltage**.



PN DIODE APPLICATIONS

An ideal PN junction diode is a two terminal polarity sensitive device that has zero resistance (diode conducts) when it is forward biased and infinite resistance (diode does not conduct) when reverse biased. Due to this characteristic the diode finds a number of applications as follows.

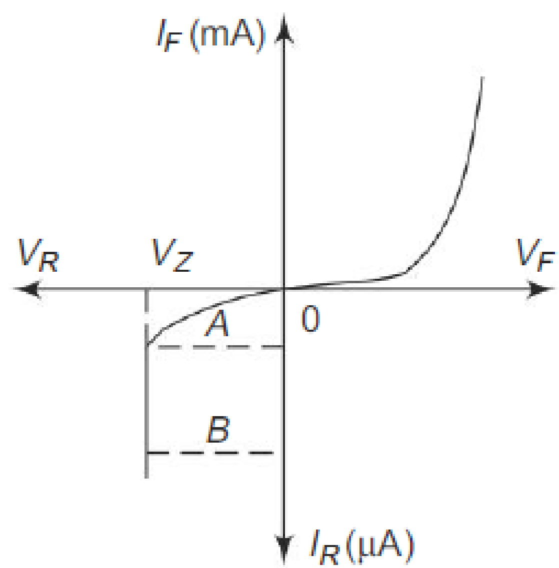
(i) rectifiers in dc power supplies
(ii) switch in digital logic circuits used in computers
(iii) clamping network used as dc restorer in TV receivers and voltage multipliers
(iv) clipping circuits used as wave shaping circuits used in computers, radars, radio and TV receivers
(v) demodulation (detector) circuits.

The same PN junction with different doping concentration finds special applications as follows:

(i) detectors (APD, PIN photo diode) in optical communication circuits
(ii) Zener diodes in voltage regulators
(iii) varactor diodes in tuning sections of radio and TV receivers
(iv) light emitting diodes in digital displays
(v) LASER diodes in optical communications
(vi) Tunnel diodes as a relaxation oscillator at microwave frequencies.

ZENER DIODE

Zener diode is heavily doped than the ordinary diode. From the V–I characteristics of the Zener diode, shown in Fig., it is found that the operation of Zener diode is same as that of ordinary PN diode under forward biased condition. Whereas under reverse-baised condition, breakdown of the junction occurs. The breakdown voltage depends upon the amount of doping.



If the diode is heavily doped, depletion layer will be thin and, consequently, breakdown occurs at lower reverse voltage and further, the breakdown voltage is sharp. Whereas a lightly doped diode has a higher breakdown voltage. Thus breakdown voltage can be selected with the amount of doping. The sharp increasing current under breakdown conditions are due to the following two mechanisms.

(1) Avalanche breakdown

(2) Zener breakdown.

Avalanche Breakdown

As the applied reverse bias increases, the field across the junction increases correspondingly. Thermally generated carriers while traversing the junction acquire a large amount of kinetic energy from this field. As a result the velocity of these carriers increases. These electrons disrupt covalent bonds by colliding with immobile ions and create new electron-hole pairs. These new carriers again acquire sufficient energy from the field and collide with other immobile ions thereby generating further electron–hole pairs. This process is cumulative in nature and results in generation of avalanche of charge carriers within a short time.

This mechanism of carrier generation is known as Avalanche multiplication. This process results in flow of large amount of current at the same value of reverse bias.

Zener Breakdown

When the P and N regions are heavily doped, direct rupture of covalent bonds takes place because of the strong electric fields, at the junction of PN diode. The new electron-hole pairs so created increase the reverse current in a reverse biased PN diode. The increase in current takes place at a constant value of reverse bias typically below 6 V for heavily doped diodes. As a result of heavy doping of P and N regions, the depletion region width becomes very small and for an applied voltage of 6 V or less, the field across the depletion region becomes very high, of the order of 107 V/m, making conditions suitable for Zener breakdown. For lightly doped diodes, Zener breakdown voltage becomes high and breakdown is then predominantly by Avalanche multiplication. Though Zener breakdown occurs for lower breakdown voltage and Avalanche breakdown occurs for higher breakdown voltage, such diodes are normally called Zener diodes.

Applications of Zener diode: Used as Voltage Regulator or Stabilizer.

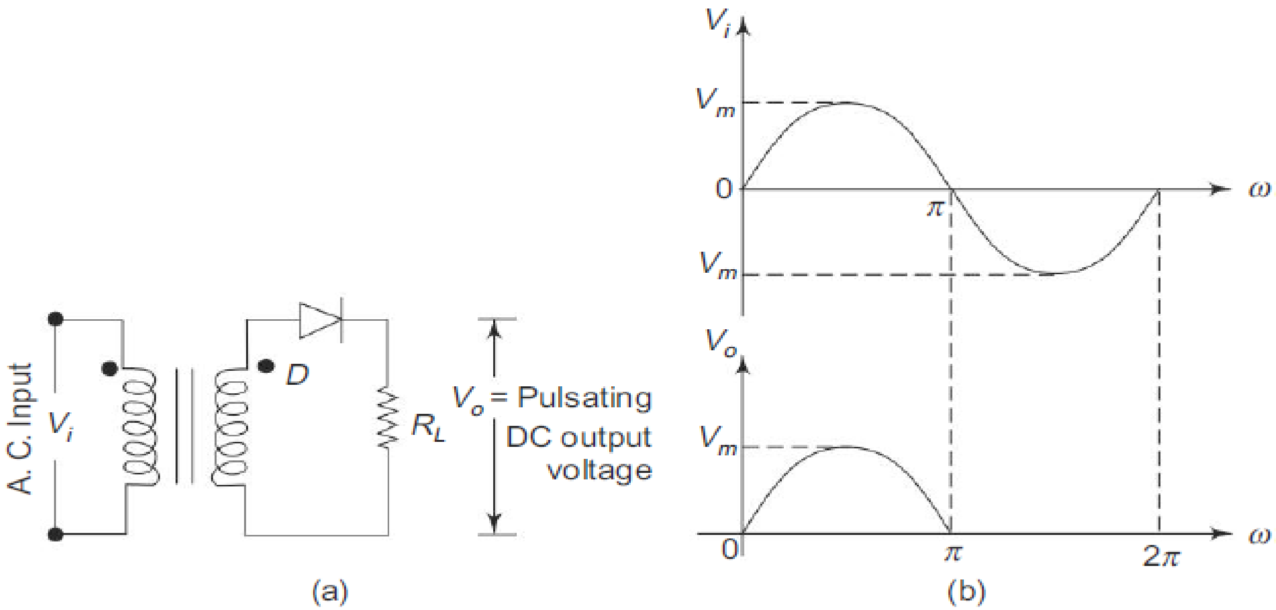
APPLICATIONS OF PN JUNCTION DIODE

RECTIFIERS, CLIPPERS, CLAMPERS ect..

RECTIFIERS-Rectifier is defined as an electronic device used for converting ac voltage into dc voltage

Half-wave Rectifier

It converts an ac voltage into a pulsating dc voltage using only one half of the applied ac voltage. The rectifying diode conducts during one half of the ac cycle only. Figure shows the basic circuit and waveforms of a half wave rectifier.



(a) Basic circuit of a Half-wave Rectifier and (b) Input and Output Waveforms of Half-wave Rectifier

Let V_i be the voltage to the primary of the transformer and given by the equation

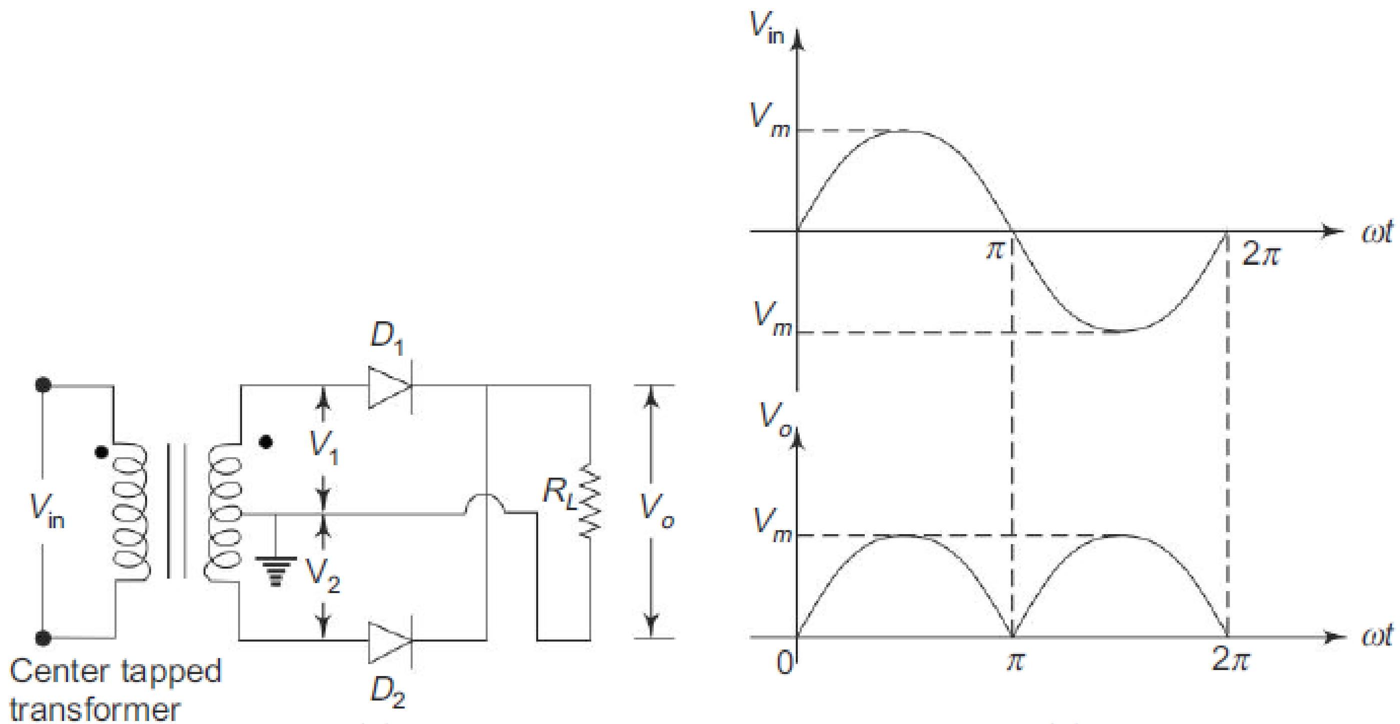
$$V_i = V_m \sin \omega t; V_m >> V_r$$

where V_r is the cut-in voltage of the diode. During the positive half-cycle of the input signal, the anode of the diode becomes more positive with respect to the cathode and hence, diode D conducts. For an ideal diode, the forward voltage drop is zero. So the whole input voltage will appear across the load resistance, R_L.

During negative half-cycle of the input signal, the anode of the diode becomes negative with respect to the cathode and hence, diode D does not conduct. For an ideal diode, the impedance offered by the diode is infinity. So the whole input voltage appears across diode D. Hence, the voltage drop across R_L is zero.

Full-wave Rectifier -Center Tapped

It converts an ac voltage into a pulsating dc voltage using both half cycles of the applied ac voltage. It uses two diodes of which one conducts during one half-cycle while the other diode conducts during the other half-cycle of the applied ac voltage. Figure shows the basic circuit and waveforms of full-wave rectifier.



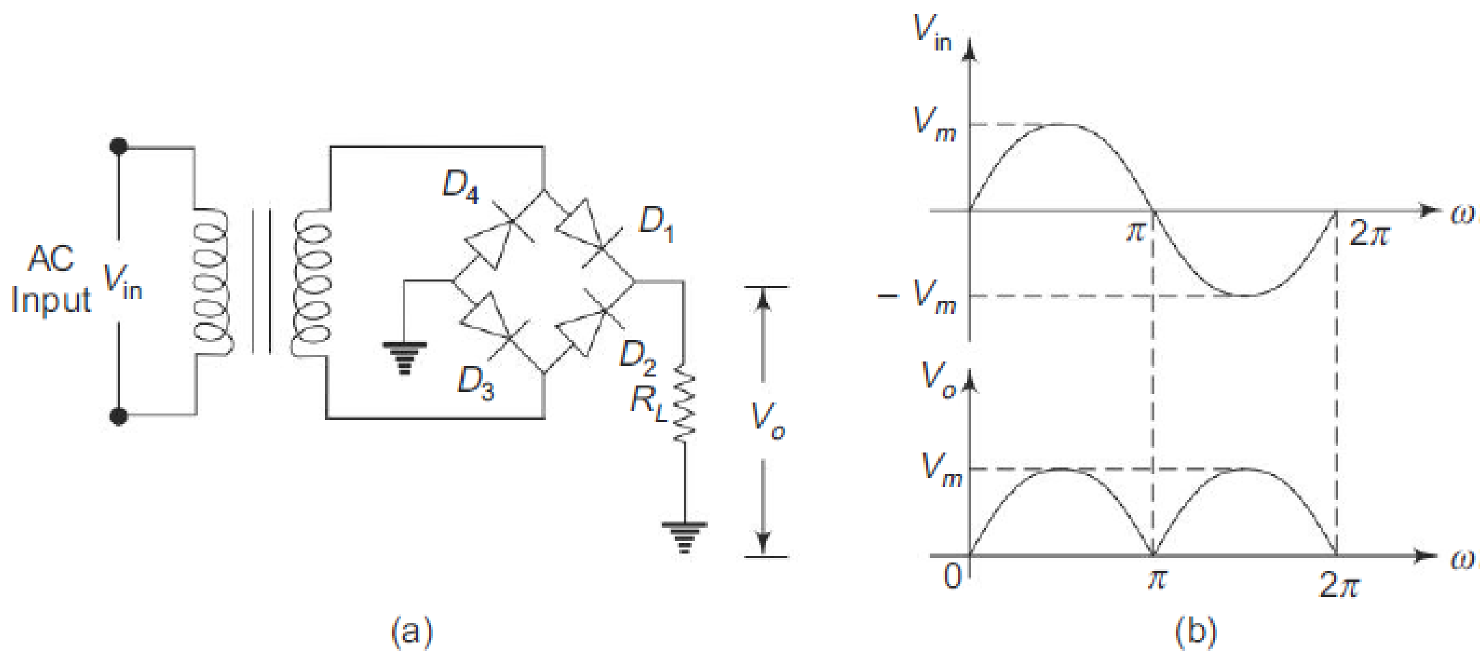
(a) (b)

During positive half of the input signal, anode of diode D_1 becomes positive and at the same time the anode of diode D_2 becomes negative. Hence D_1 conducts and D_2 does not conduct. The load current flows through D_1 and the voltage drop across R_L will be equal to the input voltage.

During the negative half-cycle of the input, the anode of D_1 becomes negative and the anode of D_2 becomes positive. Hence, D_1 does not conduct and D_2 conducts. The load current flows through D_2 and the voltage drop across R_L will be equal to the input voltage.

Full-wave Rectifier - Bridge Rectifier

The need for a center tapped transformer in a full-wave rectifier is eliminated in the bridge rectifier. As shown in Fig. the bridge rectifier has four diodes connected to form a bridge. The ac input voltage is applied to diagonally opposite ends of the bridge. The load resistance is connected between the other two ends of the bridge.



For the positive half-cycle of the input ac voltage, diodes D_1 and D_3 conduct, whereas diodes D_2 and D_4 do not conduct. The conducting diodes will be in series through the load resistance R_L. So the load current flows through R_L.

During the negative half-cycle of the input ac voltage, diodes D_2 and D_4 conduct, whereas diodes D_1 and D_3 do not conduct. The conducting diode D_2 and D_4 will be in series through the load R_L and the current flows through R_L in the same direction as in the previous half-cycle. Thus a bidirectional wave is converted into a unidirectional one.

The average values of output voltage and load current for bridge rectifier are the same as for a center-tapped full wave rectifier. Hence

Advantages of the bridge rectifier

The bulky center tapped transformer is not required.

Transformer utilisation factor is considerably high.

FILTERS

The output of a rectifier contains dc component as well as ac component. Filters are used to minimise the undesirable ac, i.e. ripple leaving only the dc component to appear at the output.

Some important filters are:

(i) Inductor filter

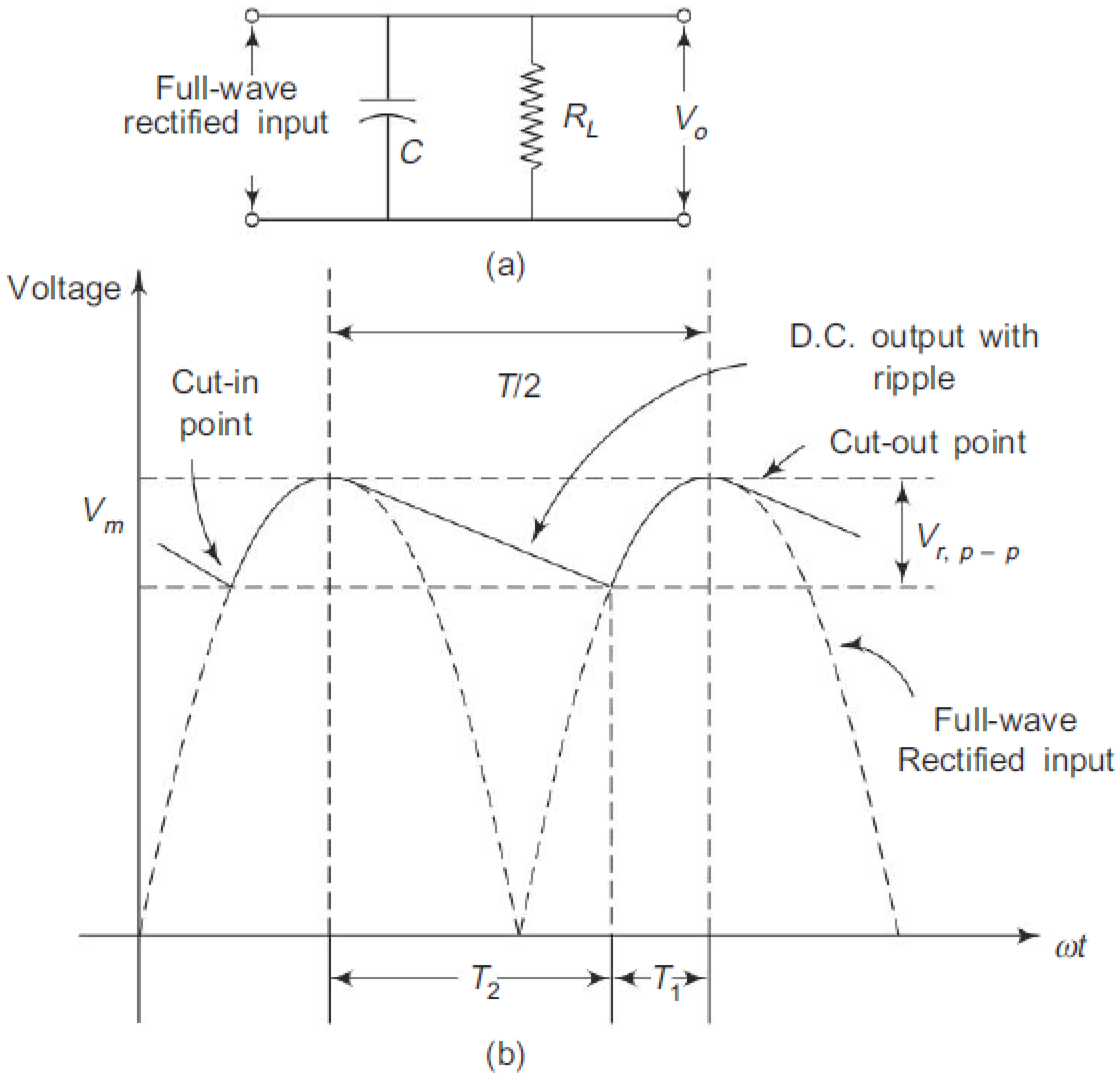
(ii) Capacitor filter

(iii) LC or L-section filter, and

(iv) CLC or π-type filter

Capacitor Filter

An inexpensive filter for light loads is found in the capacitor filter which is connected directly across the load, as shown in Fig. (a). The property of a capacitor is that it allows ac component and blocks the dc component. The operation of a capacitor filter is to short the ripple to ground but leave the dc to appear at the output when it is connected across a pulsating dc voltage.



(a) Capacitor Filter, (b) Ripple Voltage Triangular Waveform

During the positive half-cycle, the capacitor charges up to the peak value of the transformer secondary voltage, V_m, and will try to maintain this value as the full-wave input drops to zero. The capacitor will discharge through R_L slowly until the transformer secondary voltage again increases to a value greater than the capacitor voltage. The diode conducts for a period which depends on the capacitor voltage (equal to the load voltage). The diode will conduct when the transformer secondary voltage becomes more than the 'cut-in' voltage of the diode. The diode stops conducting when the transformer voltage becomes less than the diode voltage. This is called cut-out voltage.

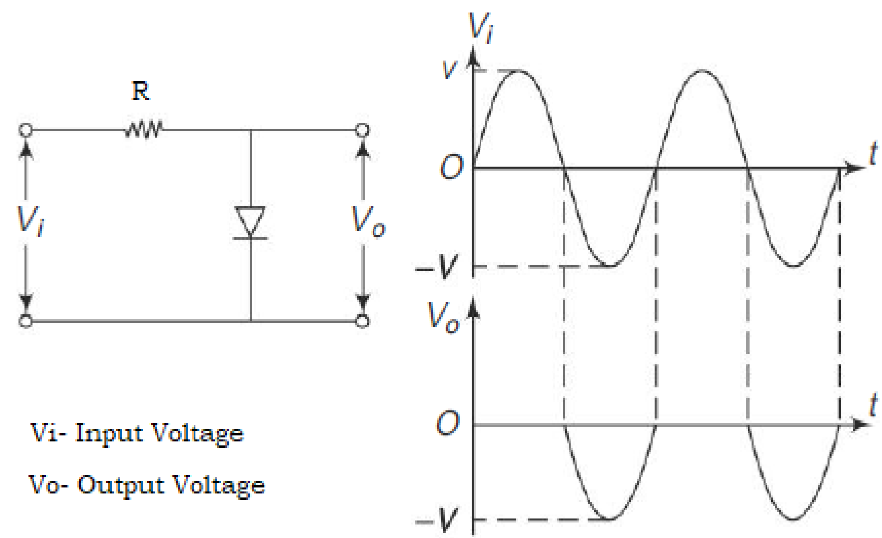
Referring to Fig. (b) with slight approximation, the ripple voltage waveform can be assumed as triangular. From the cut-in point to the cut-out point, whatever charge the capacitor acquires is equal to the charge the capacitor has lost during the period of non-conduction, i.e. from cut-out point to the next cut-in point.

The ripple may be decreased by increasing C or R_L (or both) with a resulting increase in dc output voltage.

CLIPPERS

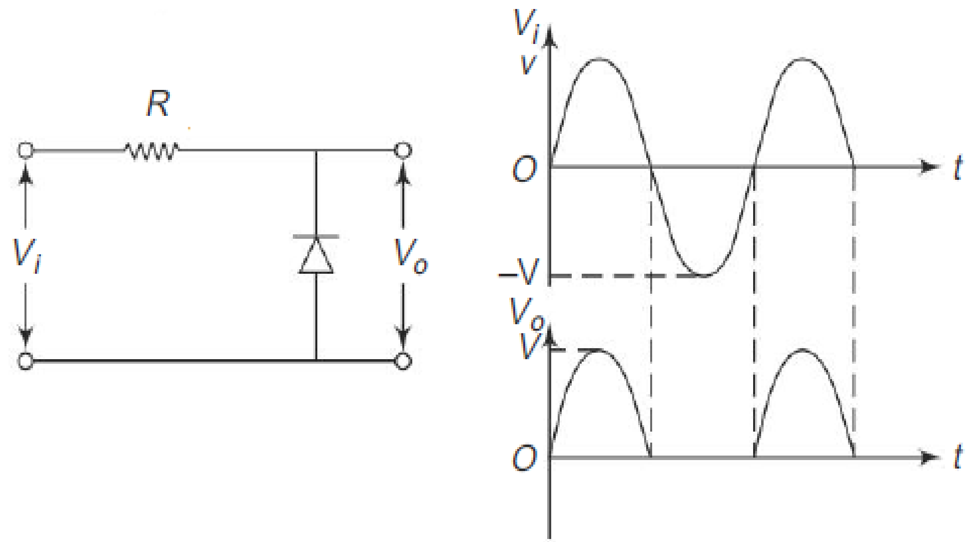
The circuit with which the waveform is shaped by removing (or clipping) a portion of the input signal without distorting the remaining part of the alternating waveform is called a clipper. These circuits find extensive use in radars, digital computers, radio and television receivers etc.

1.Positive clipper



When the input voltage is positive, diode conducts and acts as short-circuit and hence there is zero signal at the output, i.e. the positive half cycle is **clipped off**. When the input signal is negative, the diode does not conduct and acts as an open switch, the negative half cycle appears at the output as shown in Fig.

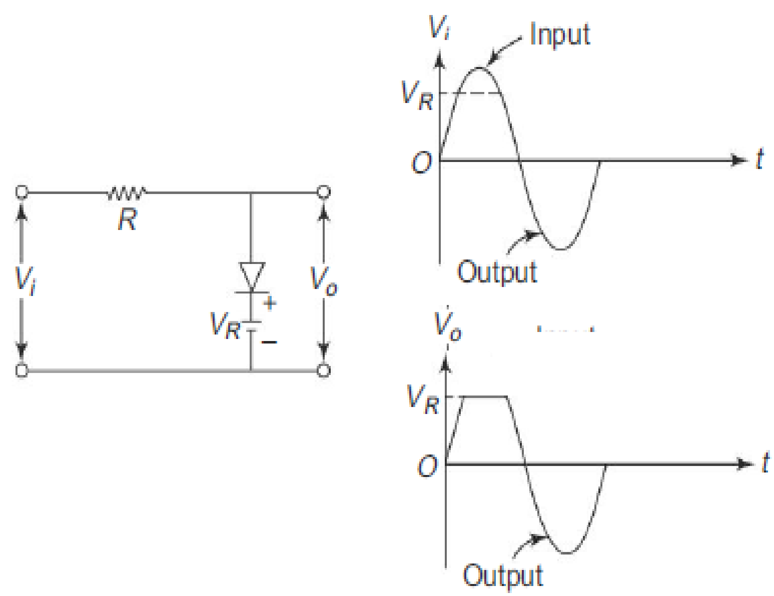
2.Negative clipper



When the input signal is positive, the diode does not conduct and acts as an open switch, the positive half cycle appears at the output as shown in Fig.. When the input voltage is negative, diode conducts and acts as short-circuit and hence there is zero signal at the output, i.e. the negative half cycle is **clipped off**.

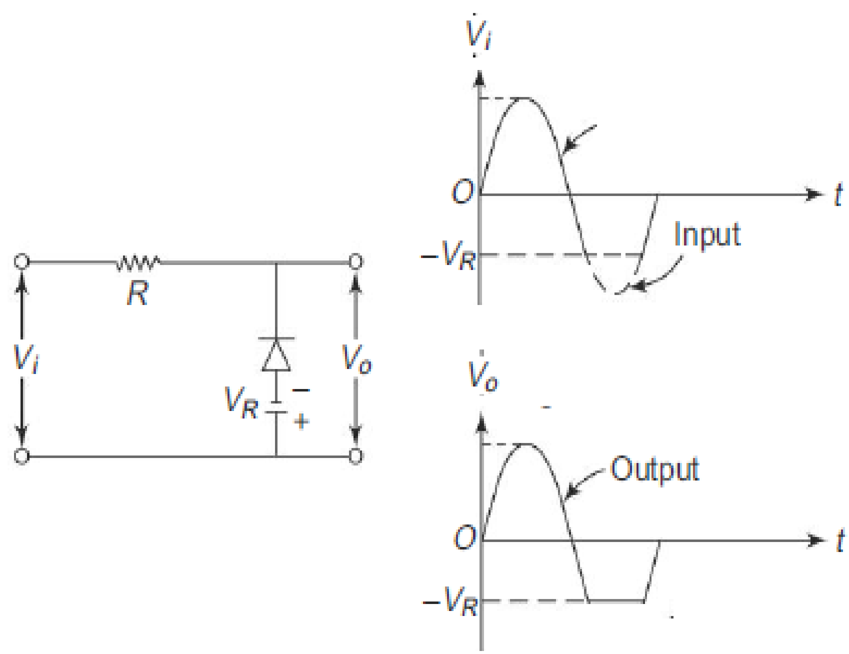
3.Biased Positive clipper

In the biased positive clipper as shown in Fig., the diode conducts as long as the input voltage is greater than $+V_R$ and the output remains at $+V_R$ until the input voltage becomes less than $+V_R$. When the input voltage is less than $+V_R$, the diode does not conduct and acts as an open switch. Hence all the input signal having less than $+ V_R$ as well as negative half cycle of the input wave will appear at the output, shown in Fig



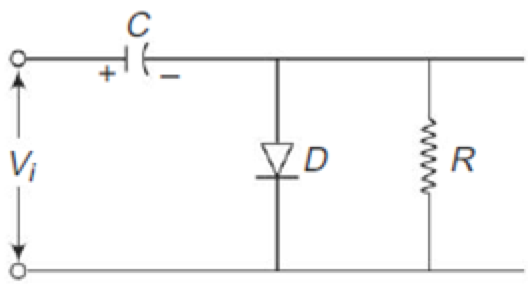
4.Biased Negative clipper

In the biased negative clipper shown in Fig. , when the input voltage $V_i \le V_R$ the diode conducts and clipping takes place. The clipping level can be shifted up and down by varying the bias voltage ($-V_R$).

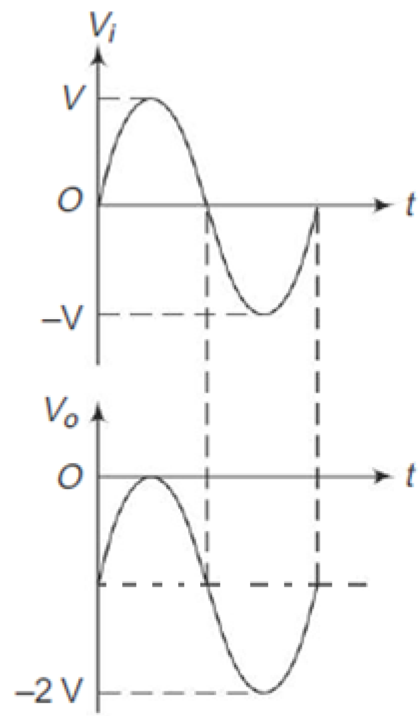


CLAMPERS

Clamping network shifts (clamps) a signal to a different dc level, i.e. it introduces a dc level to an ac signal. Hence, the clamping network is also known as dc restorer. These circuits find application in television receivers to restore the dc reference signal to the video signal.



Negative Clamper circuit



Consider the clamper circuit shown in Fig. A sine wave with maximum amplitude of V is given as the input to the network. During the positive half cycle, the diode conducts, i.e. it acts like a short circuit. The capacitor charges to V volts. During this interval, the output which is taken across the short circuit will be Vo = 0 V. During the negative half cycle, the diode is open. The output voltage can be found out by applying Kirchhoff's law.

$$-V - V - V_0 = 0$$

$$\text{Therefore, } V_0 = -2\ V$$

The analysis of the clamper circuit can be done as follows.

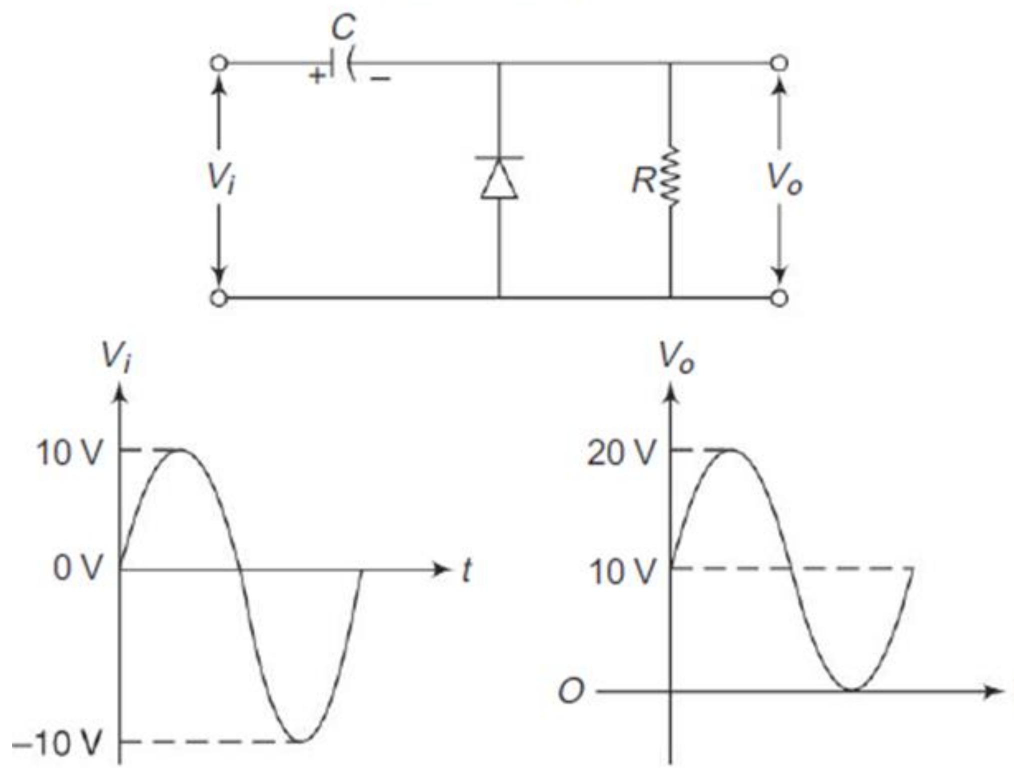
Determine the portion of the input signal that forward biases the diode. When the diode is in short circuit condition, the capacitor charges up to a level determined by the voltage across the capacitor in its equivalent open circuit state. During the open circuit condition of the diode, it is assumed that the capacitor will hold on to all its charge and therefore voltage. In the clamper networks, the total swing of the output is equal to the total swing of the input signal. **This is negative clamper**.

Positive clamper: Consider the clamper circuit shown in Fig. A sine wave with maximum amplitude of 10 V is given as the input to the network. During the negative half cycle, the diode conducts, i.e. it acts like a short circuit. The capacitor charges to10 V volts. During this interval, the output which is taken across the short circuit will be Vo = 0 V. During the positive half cycle, the diode is open. The output voltage can be found out by applying Kirchhoff's law.

$10V + 10\ V - V_0 = 0$

Therefore, $V_0 = 20\ V$

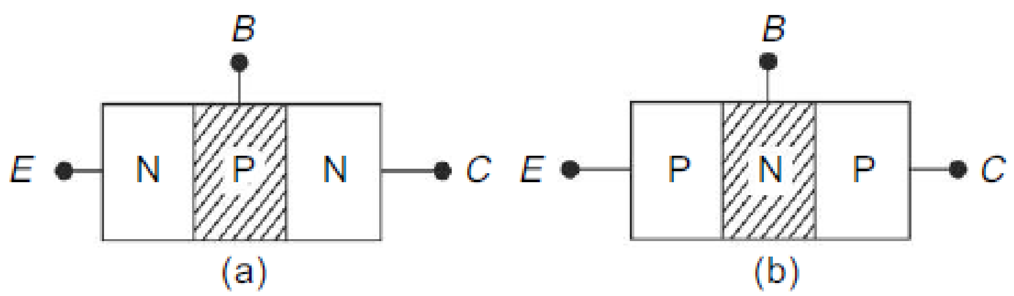
Positive Clamper



BIPOLAR JUNCTION TRANSISTOR [BJT]

A Bipolar Junction Transistor (BJT) is a three terminal semiconductor device in which the operation depends on the interaction of both majority and minority carriers and hence the name Bipolar. It is used in amplifier and oscillator circuits, and as a switch in digital circuits. It has wide applications in computers, satellites and other modern communication systems.

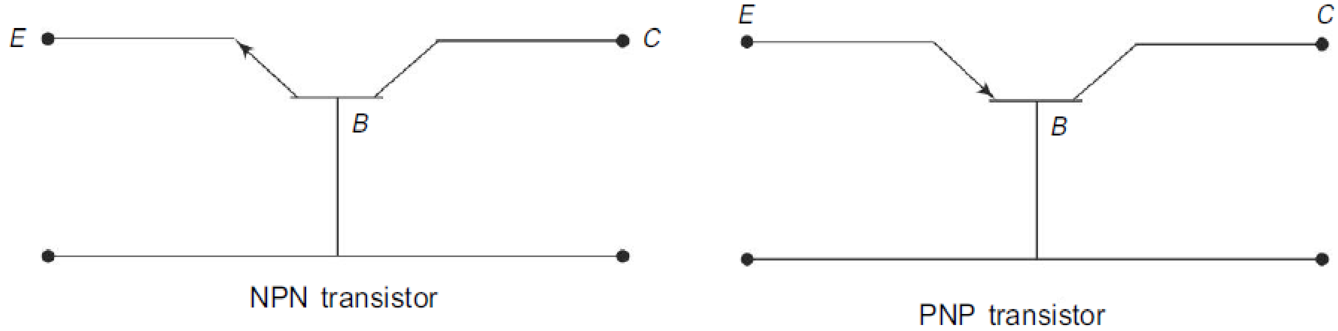
The BJT consists of a silicon (or germanium) crystal in which a thin layer of N-type Silicon is sandwiched between two layers of P-type silicon. This transistor is referred to as PNP. Alternatively, in a NPN transistor, a layer of P-type material is sandwiched between two layers of N-type material. The two types of the BJT are represented in Fig.



E- Emitter
B-Base
C-Collector

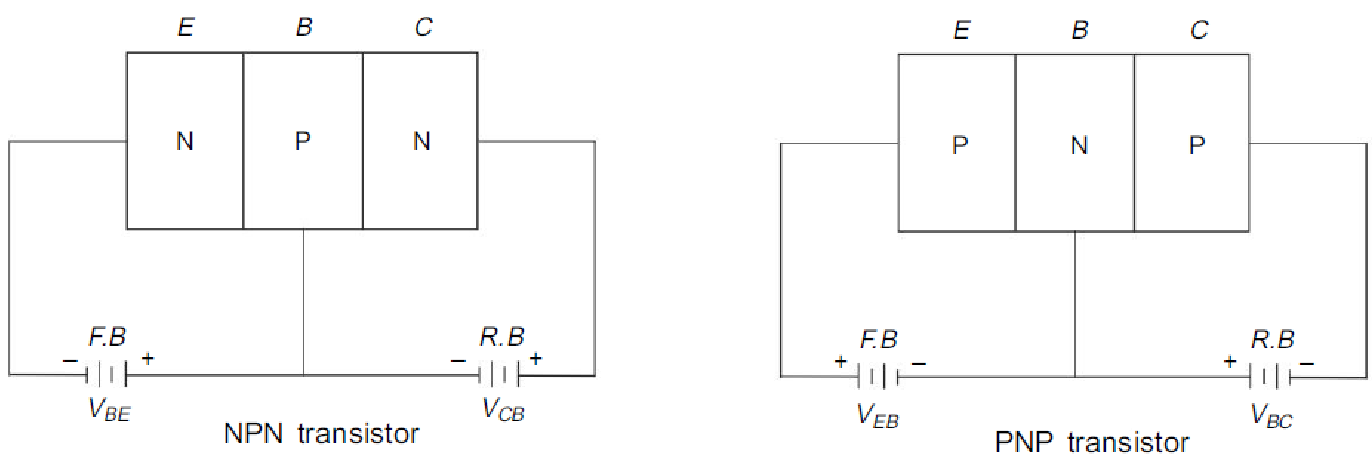
Transistor (a) NPN and (b) PNP

Circuit symbol



TRANSISTOR BIASING

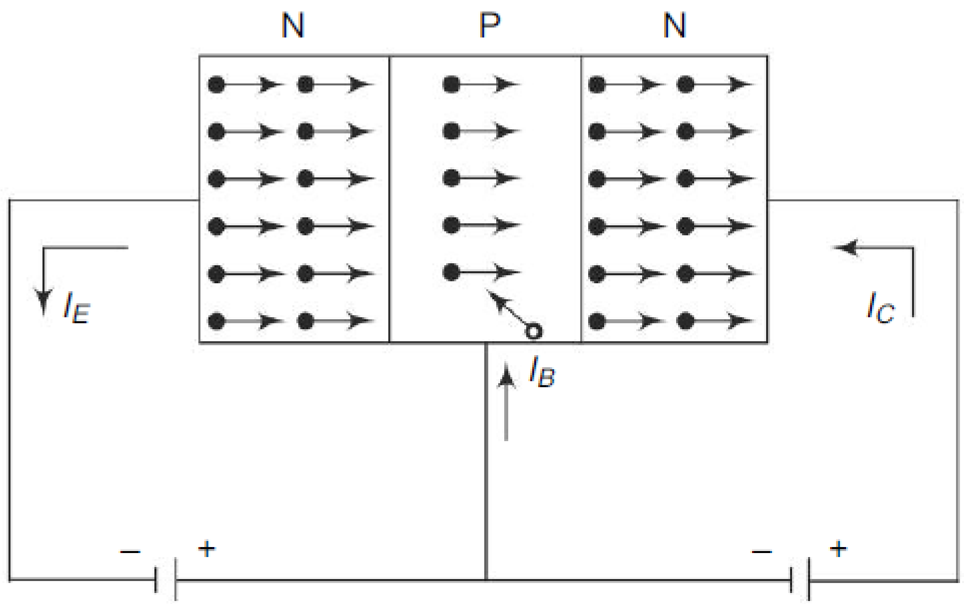
Usually the emitter-base junction is forward biased and collector-base junction is reverse biased. Due to the forward bias on the emitter-base junction an emitter current flows through the base into the collector. Though, the collector-base junction is reverse biased, almost the entire emitter current flows through the collector circuit.



OPERATION OF NPN TRANSISTOR

As shown in Fig. 13.4, the forward bias applied to the emitter base junction of an NPN transistor causes a lot of electrons from the emitter region to crossover to the base region. As the base is lightly doped with P-type impurity, the number of holes in the base region is very small and hence the number of electrons that combine with holes in the P-type base region is also very small. Hence a few electrons combine with holes to constitute a base current I_B. The remaining electrons (more than 95%) crossover into the collector region to constitute a collector current I_C. Thus the base and collector current summed up gives the emitter current, i.e. $I_E = -(I_C + I_B)$.

In the external circuit of the NPN bipolar junction transistor, the magnitudes of the emitter current I_E, the base current I_B and the collector current I_C are related by $I_E = I_C + I_B$.



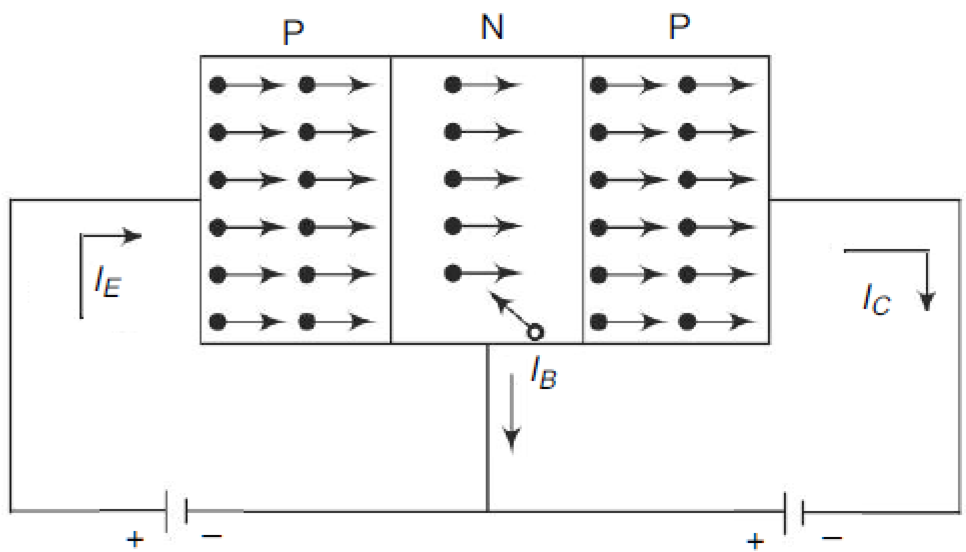
OPERATION OF PNP TRANSISTOR

As shown in Fig. 13.5, the forward bias applied to the emitter-base junction of a PNP transistor causes a lot of holes from the emitter region to crossover to the base region as the base is lightly doped with N-types impurity. The number of electrons in the base region is very small and hence the number of holes combined with electrons in the N-type base region is also very small. Hence a few holes combined with electrons to constitute a base current I_B. The remaining holes (more than 95%) crossover into the collector region to constitute a collector current I_C. Thus the collector and base current when summed up gives the emitter current, i.e. $I_E = -(I_C + I_B)$.

In the external circuit of the PNP bipolar junction transistor, the magnitudes of the emitter current I_E, the base current I_B and the collector current I_C are related by

$$I_E = I_C + I_B$$

This equation gives the fundamental relationship between the currents in a bipolar transistor circuit.

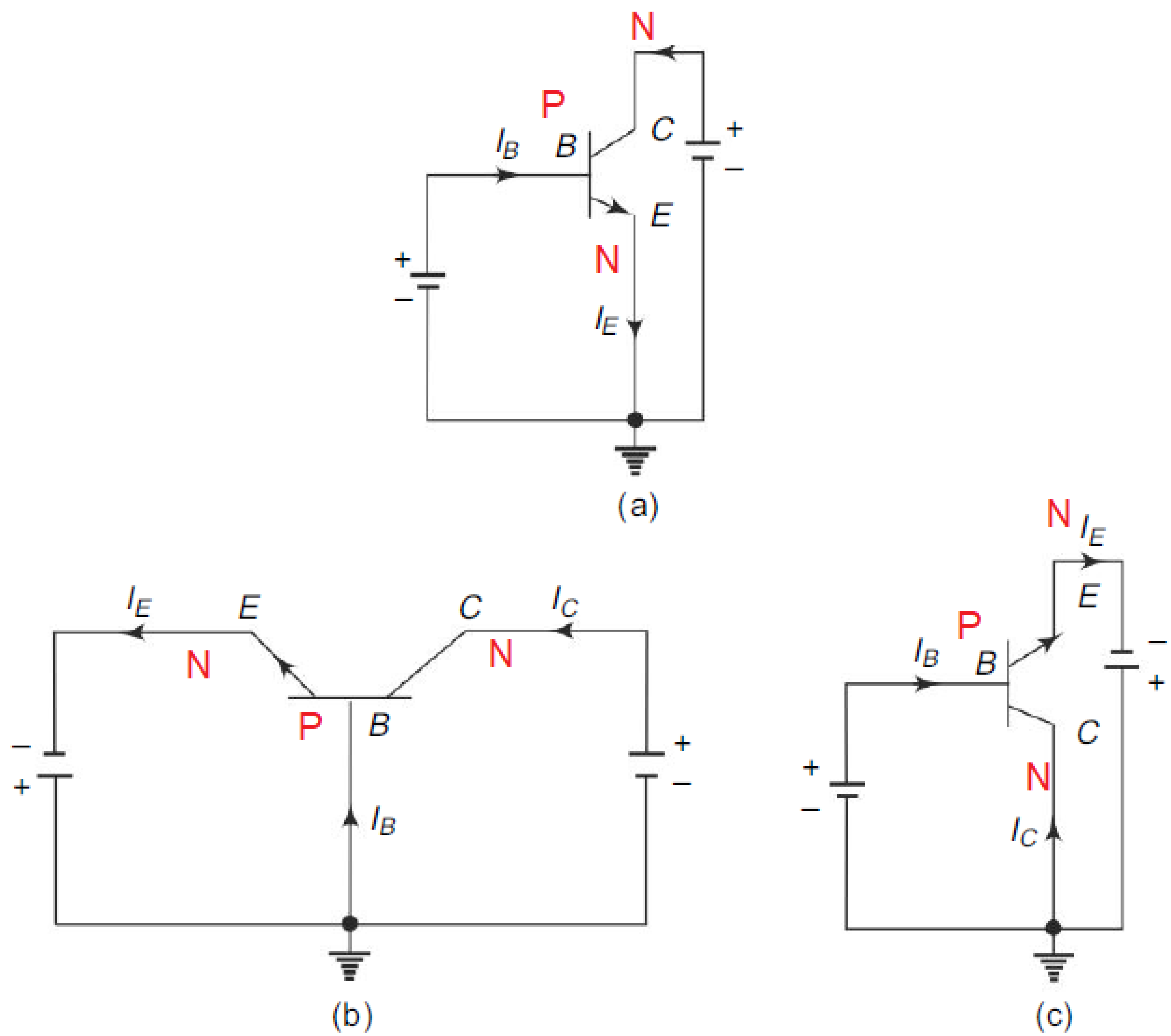


TYPES OF TRANSISTOR AMPLIFIER CONFIGURATION

(i) CE configuration This is also called grounded base configuration. In this configuration, emitter is the input terminal, collector is the output terminal and base is the common terminal.

(ii) CB configuration This is also called grounded emitter configuration. In this configuration, base is the input terminal, collector is the output terminal and emitter is the common terminal.

(iii) CC configuration This is also called grounded collector configuration. In this configuration, base is the input terminal, emitter is the output terminal and collector is the common terminal.



NPN Transistor configuration: (a) common base (b) common emitter and (c) common collector

CB Configuration

The circuit diagram for determining the static characteristics curves of an NPN transistor in the common base configuration is shown in Fig. 13.7.

Input characteristics To determine the input characteristics, the collector-base voltage V_{CB} is kept constant at zero volt and the emitter current I_E is increased from zero in suitable equal steps by increasing V_{EB}. This is repeated for higher fixed values of V_{CB}. A curve is drawn between emitter current I_E and emitter-base voltage V_{EB} at constant collector-base voltage V_{CB}. The input characteristics thus obtained are shown in Fig. 13.8.

When V_{CB} is equal to zero and the emitter-base junction is forward biased as shown in the characteristics, the junction behaves as a forward biased diode so that emitter current I_E increases rapidly with small increase in emitter-base voltage V_{EB}. When V_{CB} is increased keeping V_{EB} constant, the width of the base region will decrease. This effect results in an increase of I_E. Therefore, the curves shift towards the left as V_{CB} is increased.

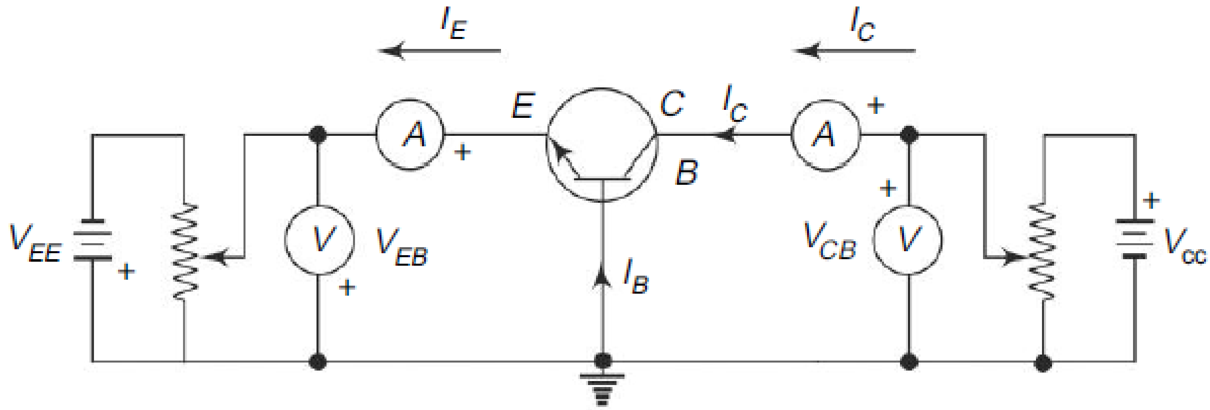


Fig. 13.7 Circuit to determine CB static characteristics

Output characteristics To determine the output characteristics, the emitter current I_E is kept constant at a suitable value by adjusting the emitter-base voltage V_{EB}. Then V_{CB} is increased in suitable equal steps and the collector current I_C is noted for each value of I_E. This is repeated for different fixed values of I_E. Now the curves of I_C versus V_{CB} are plotted for constant values of I_E and the output characteristics thus obtained is shown in Fig. 13.9.

From the characteristics, it is seen that for a constant value of I_E, I_C is independent of V_{CB} and the curves are parallel to the axis of V_{CB}. Further, I_C flows even when V_{CB} is equal to zero. As the emitter-base junction is forward biased, the majority carriers, i.e. electrons, from the emitter are injected into the base region. Due to the action of the internal potential barrier at the reverse biased collector-base junction, they flow to the collector region and give rise to I_C even when V_{CB} is equal to zero.

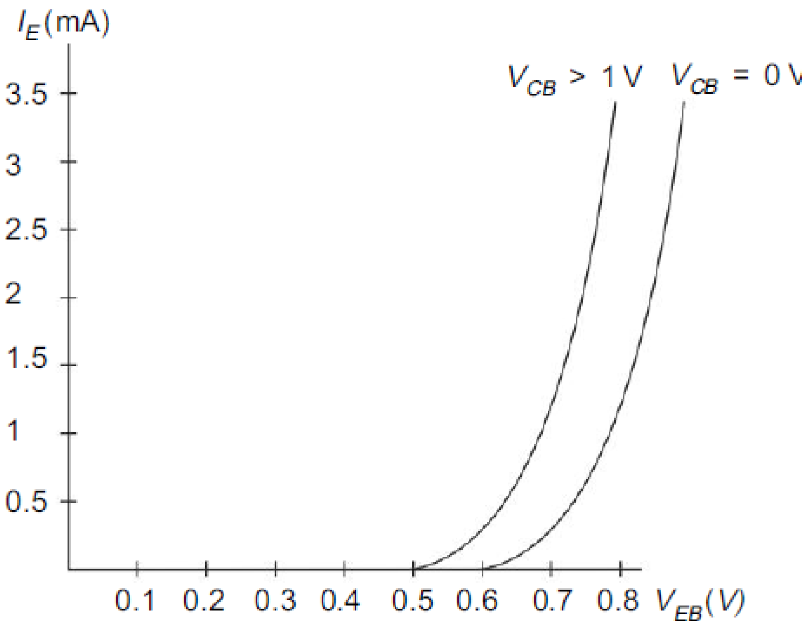


Fig. 13.8 CB Input characteristics

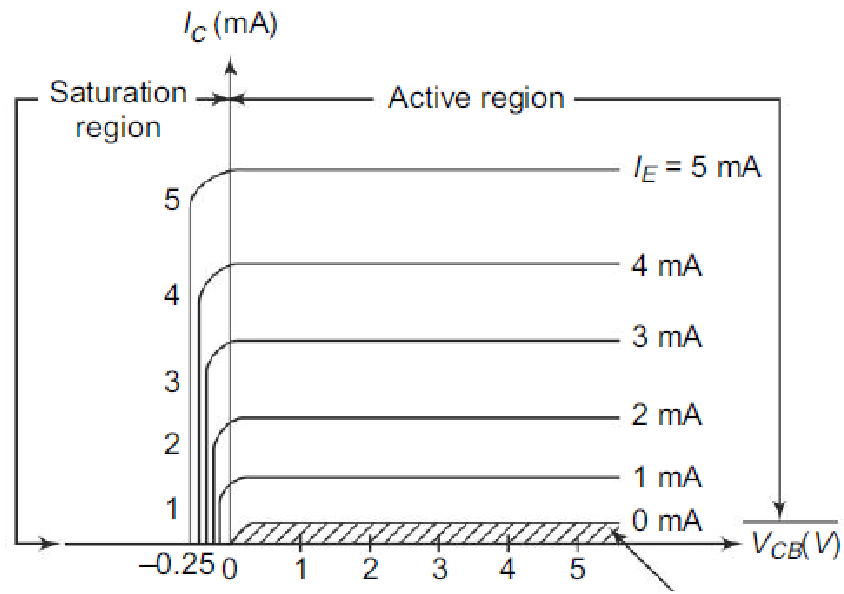


Fig. 13.9 CB Output Characteristics

CE Configuration

Input characteristics To determine the input characteristics, the collector to emitter voltage is kept constant at zero volt and base current is increased from zero in equal steps by increasing V_{BE} in the circuit shown in Fig. 13.10.

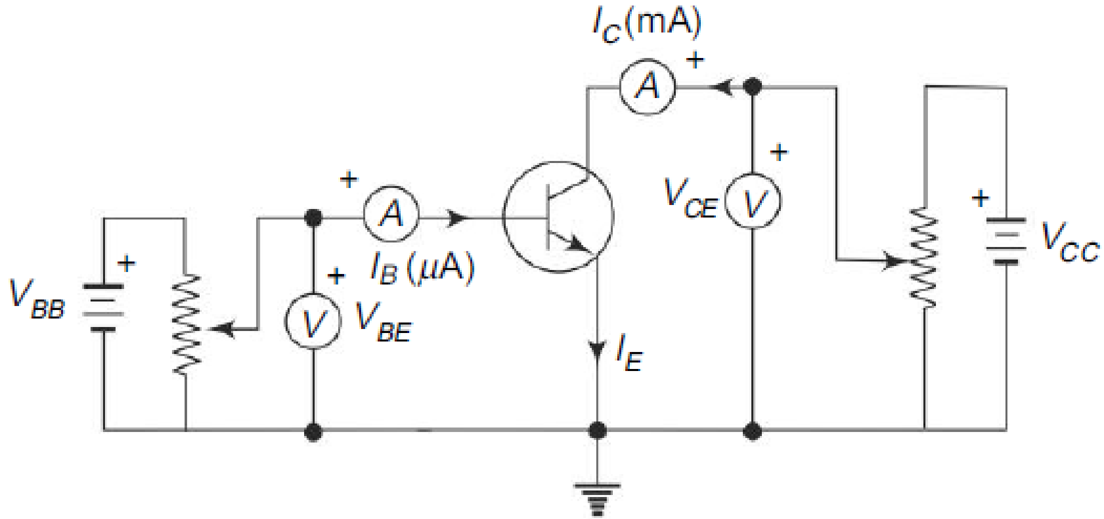


Fig. 13.10 Circuit to determine CE static characterisics

The value of V_{BE} is noted for each setting of I_B. This procedure is repeated for higher fixed values of V_{CE}, and the curves of I_B V_s V_{BE} are drawn. The input characteristics thus obtained are shown in Fig. 13.11.

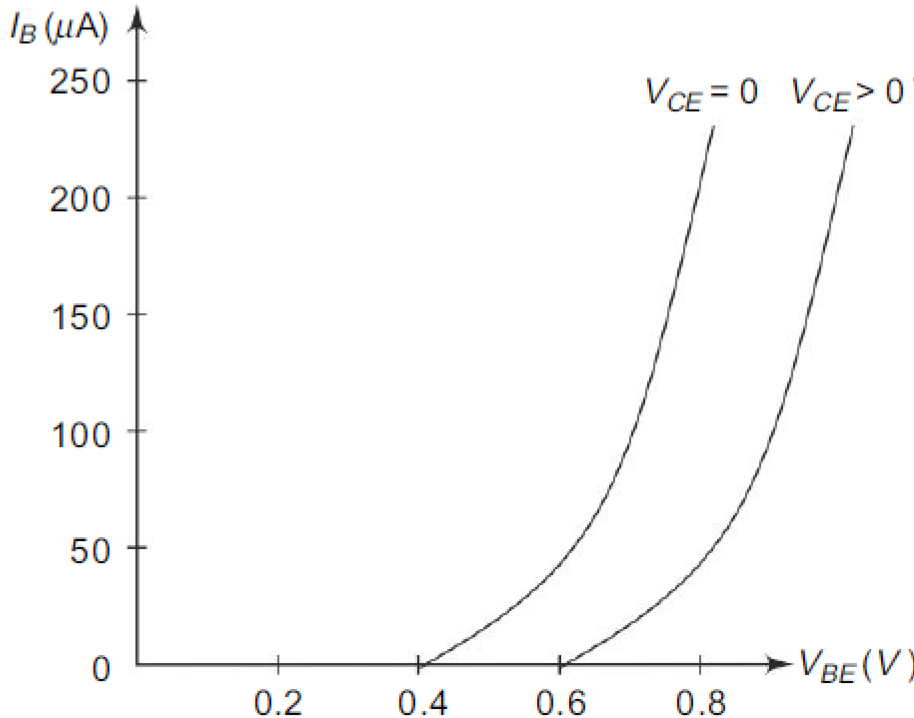


Fig. 13.11 CE input characteristics

When V_{CE} = 0, the emitter-base junction is forward biased and the junction behaves as a forward biased diode. Hence the input characteristic for V_{CE} = 0 is similar to that of a forward-biased diode. When V_{CE} is increased, the width of the depletion region at the reverse biased collector-base junction will increase. Hence the effective width of the base will decrease. This effect causes a decrease in the base current I_B. Hence, to get the same value of I_b as that for V_{CE} = 0, V_{BE} should be increased. Therefore, the curve shifts to the right as V_{CE} increases.

Output characteristics To determine the output characteristics, the base current I_B is kept constant at a suitable value by adjusting base-emitter voltage, V_{BE}. The magnitude of collector-emitter voltage V_{CE} is increased in suitable equal steps from zero and the collector current I_C is noted for each setting of V_{CE}. Now the curves of I_C versus V_{CE} are plotted for different constant values of I_B. The output characteristics thus obtained are shown in Fig. 13.12.

The output characteristics have three regions, namely, saturation region, cutoff region and active region. The region of curves to the left of the line OA is called the *saturation region* (hatched), and the line OA is called the saturation line. In this region, both junctions are forward biased and an increase in the base current does not cause a corresponding large change in I_C. The ratio of $V_{CE(sat)}$ to I_C in this region is called saturation resistance.

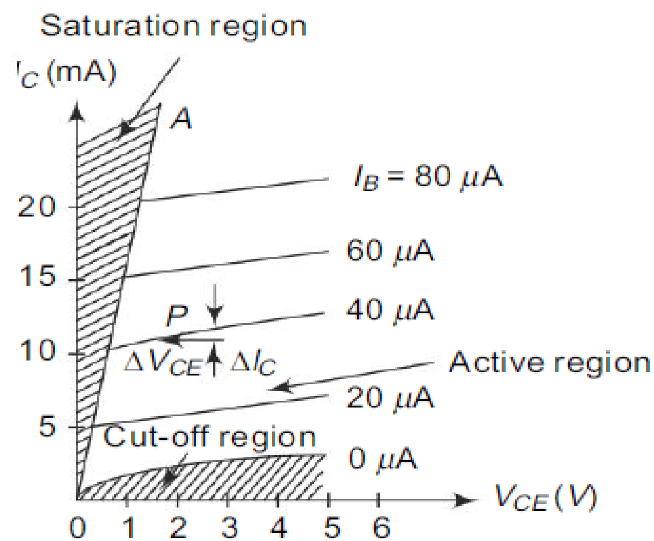


Fig. 13.12 CE output characteristics

The region below the curve for $I_B = 0$ is called the *cut-off region* (hatched). In this region, both junctions are reverse biased. When the operating point for the transistor enters the cut-off region, the transistor is OFF. Hence, the collector current becomes almost zero and the collector voltage almost equals V_{CC}, the collector supply voltage. The transistor is virtually an open circuit between collector and emitter.

The central region where the curves are uniform in spacing and slope is called the *active region* (unhatched). In this region, emitter-base junction is forward biased and the collector-base junction is reverse biased. If the transistor is to be used as a linear amplifier, it should be operated in the active region.

FIELD EFFECT TRANSISTOR

FET is a device in which the flow of current through the conducting region is controlled by an electric field. Hence the name Field Effect Transistor (FET). As current conduction is only by majority carries, FET is said to be a unipolar device.

Based on the construction, the FET can be classified into two types as Junction FET (JFET) and Metal Oxide Semiconductor FET (MOSFET).

Depending upon the majority carriers, JFET has been classified into two types named as (1) N-channel JFET with electrons as the majority carriers and (2) P-channel JFET with holes as the majority carriers.

Construction of N-Channel JFET

It consists of an N-type bar which is made of silicon. Ohmic contacts, (terminals) made at the two ends of the bar, are called Source and Drain.

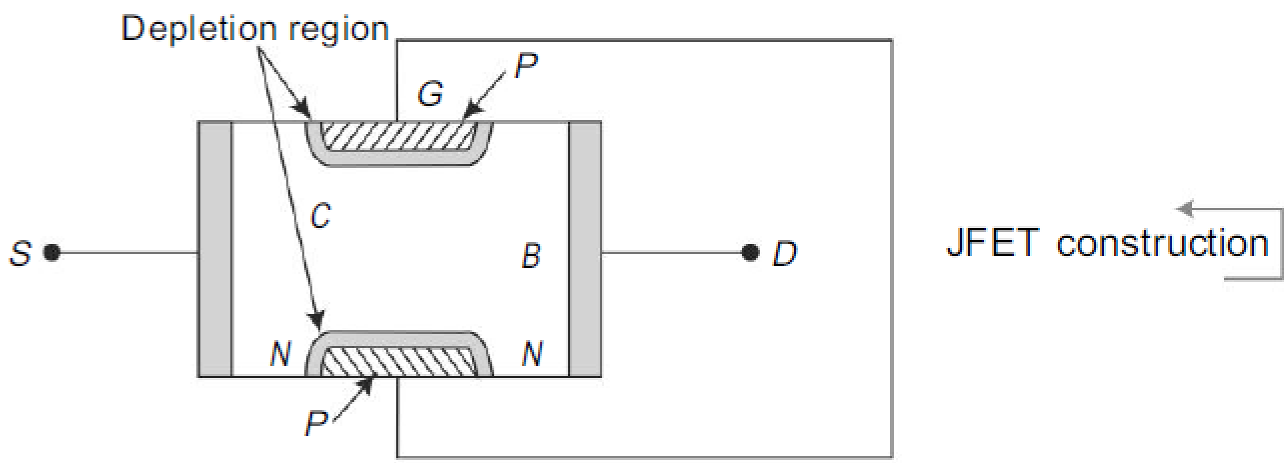
Source (S) This terminal is connected to the negative pole of the battery. Electrons which are the majority carriers in the N-type bar enter the bar through this terminal.

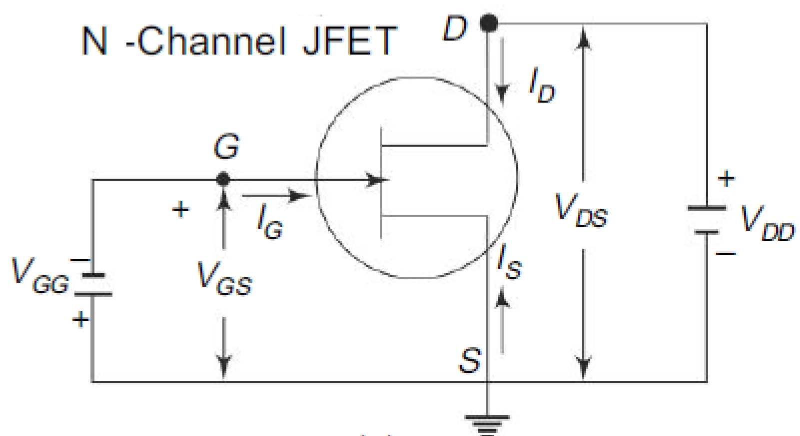
Drain (D) This terminal is connected to the positive pole of the battery. The majority carriers leave the bar through this terminal.

Gate (G) Heavily doped P-Type silicon is diffused on both sides of the N-type silicon bar by which PN junctions are formed. These layers are joined together and the called Gate *G*.

Operation of N-channel JFET

1. *When $V_{GS} = 0$ and $V_{DS} = 0$* When no voltage is applied between drain and source, and gate and source, the thickness of the depletion regions around the PN junction is uniform as shown in Fig.





2. *When V_{DS} = 0 and V_{GS} is decreased from zero* In this case PN junctions are reverse biased and hence the thickness of the depletion region increases. As V_{GS} is decreased from zero, the reverse bias voltage across the PN junction is increased and hence the thickness of the depletion region in the channel increases until the two depletion regions make contact with each other. In this condition, the channel is said to be cutoff. The value of V_{GS} which is required to cutoff the channel is called the cutoff voltage V_C.

3. *When V_{GS} = 0 and V_{PS} is increased from zero* Drain is positive with respect to the source with $V_{GS} = 0$. Now the majority carriers (electrons) flow through the N-channel from source to drain. Therefore the conventional current I_D flows from drain to source.

Because the resistance of the channel and the applied voltage V_{DS}, there is a gradual increase of positive potential along the channel from source to drain. Thus the reverse voltage across the PN junctions increases and hence the thickness of the depletion regions also increases. Therefore the channel is wedge shaped, as shown in Fig. 13.20.

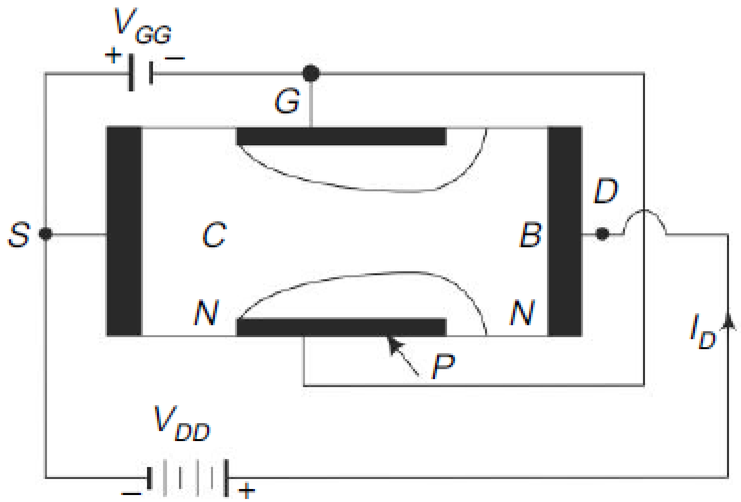


Fig. 13.20 JEFT Under Applied Bias

As V_{DS} is increased, the cross-sectional area of the channel will be reduced. At a certain value V_P of V_{DS}, the cross-sectional area at B becomes minimum. At this voltage, the channel is said to be pinched off and the drain voltage V_P is called the pinch-off voltage.

4. ***When V_{GS} is negative and V_{DS} is increased*** When the gate is maintained at a negative voltage less than the negative cutoff voltage, the reverse voltage across the junction is further increased. Hence for a negative value of V_{GS}, the curve of I_D versus V_{DS} is similar to that for $V_{GS} = 0$, but the values of V_P and BV_{DGO} are lower, as shown in Fig. 13.21.

From the curves, it is seen that above the pinch-off voltage, at a constant value of V_{DS}, I_D increases with an increase of V_{GS}. Hence a JFET is suitable for use as a voltage amplifier, similar to a transistor amplifier.

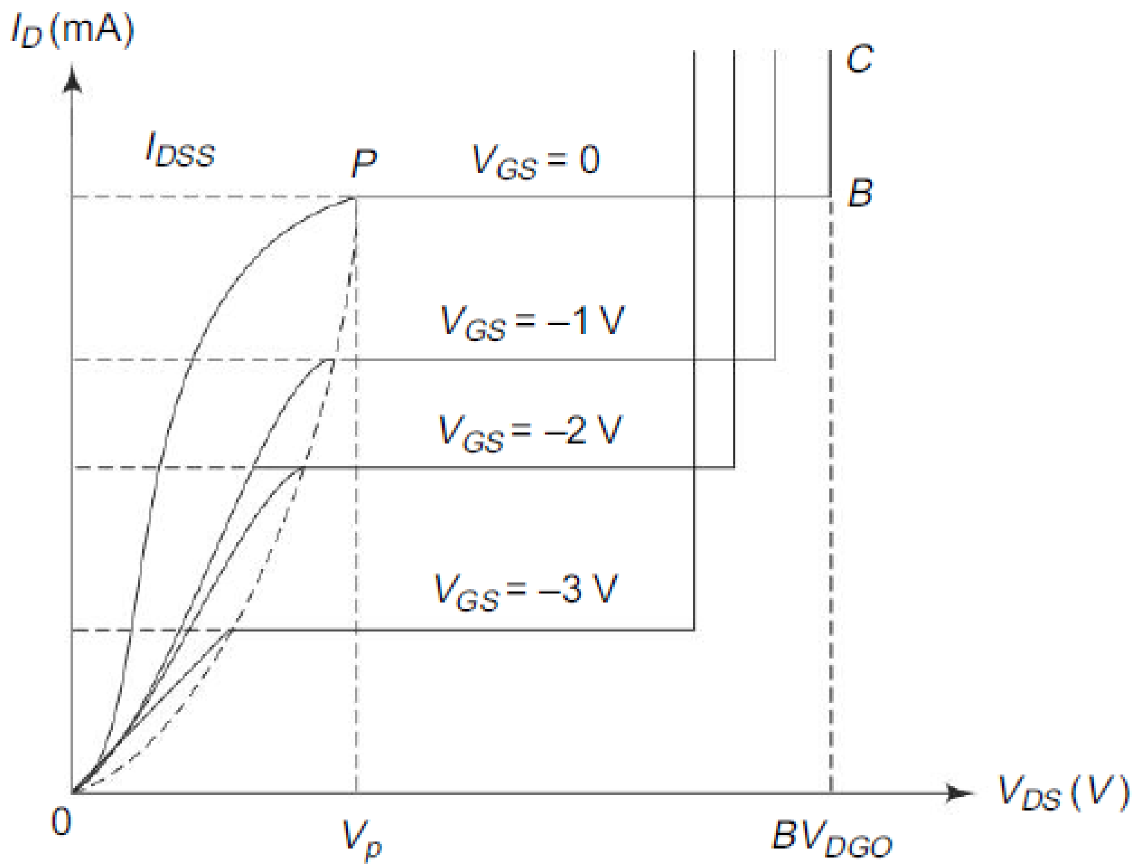


Fig. 13.21 Drain Characteristics

Comparison of JFET and BJT

1. FET operation depends only on the flow of majority carriers—holes for P-channel FETs and electrons for N-channel FETs. Therefore they are called Unipolar devices. Bipolar transitor (BJT) operation depends on both minority and majority current carriers.
2. FETs are less noisy than BJTs.
3. FETs exhibit a much higher input impedance (> 100 MΩ) than BJTs.
4. FETs are much easier to fabricate and are particularly suitable for ICs because they occupy less space than BJTs.
5. FET is normally less sensitive to temperature.
6. FET amplifiers have less voltage gain and produce more signal distortion except for small signal operation.

Metal Oxide Semiconductor Field Effect Transistor (MOSFET)

MOSFET is the common term of the Insulated Gate Field Effect Transistor (IGFET). There are two forms of MOSFET: (i) Enhancement MOSFET and (ii) Depletion MOSFET.

Principle By applying a transverse electric field across an insulator, deposited on the semiconducting material, the thickness and hence the resistance of a conducting channel of a semiconducting material can be controlled.

Enhancement MOSFET

Construction The construction of an N-channel Enhancement MOSFET is shown in Fig. 13.23. Two highly doped N^+ regions are diffused in a lightly doped substrate of P-type silicon substrate. One N^+ region is called the source S and the other one is called the drain D. They are separated by 1 mil (10^{-3} inch). A thin insulating layer of SiO_2 is grown over the surface of the structure and holes are cut into the oxide layer, allowing contact with source and drain. Then a thin layer of metal aluminum is formed over the layer of SiO_2. This metal layer covers the entire channel region and it forms the gate G.

The metal area of the gate, in conjunction with the insulating oxide layer of SiO_2 and the semiconductor channel forms a parallel plate capacitor. This device is called the insulated gate FET because of the insulating layer of SiO_2. This layer gives an extremely high input resistance for the MOSFET.

Operation If the substrate is grounded and a positive voltage is applied at the gate, the positive charge on G induces an equal negative charge on the substrate side between the source and drain regions. Thus an electric field is produced between the source and drain regions. The direction of the electric field is perpendicular to the plates of the capacitor through the oxide. The negative charge of electrons which are minority carriers in the P-type substrate forms an inversion layer. As the positive voltage on the gate increases, the induced negative charge in the semiconductor

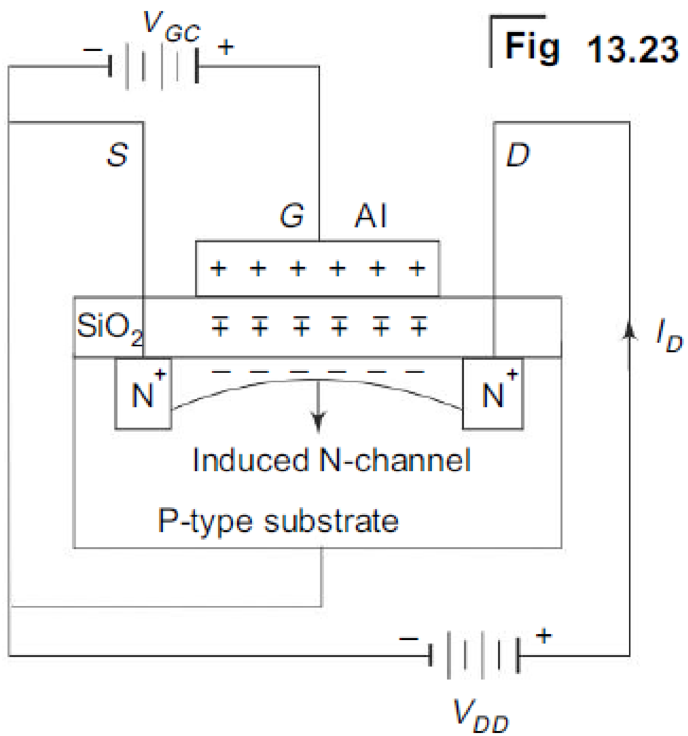


Fig 13.23 N-Channel Enhancement MOSFET

increases. Hence the conductivity increases and current flows from source to drain through the induced channel. Thus the drain current is enhanced by the positive gate voltage as shown in Fig. 13.25.

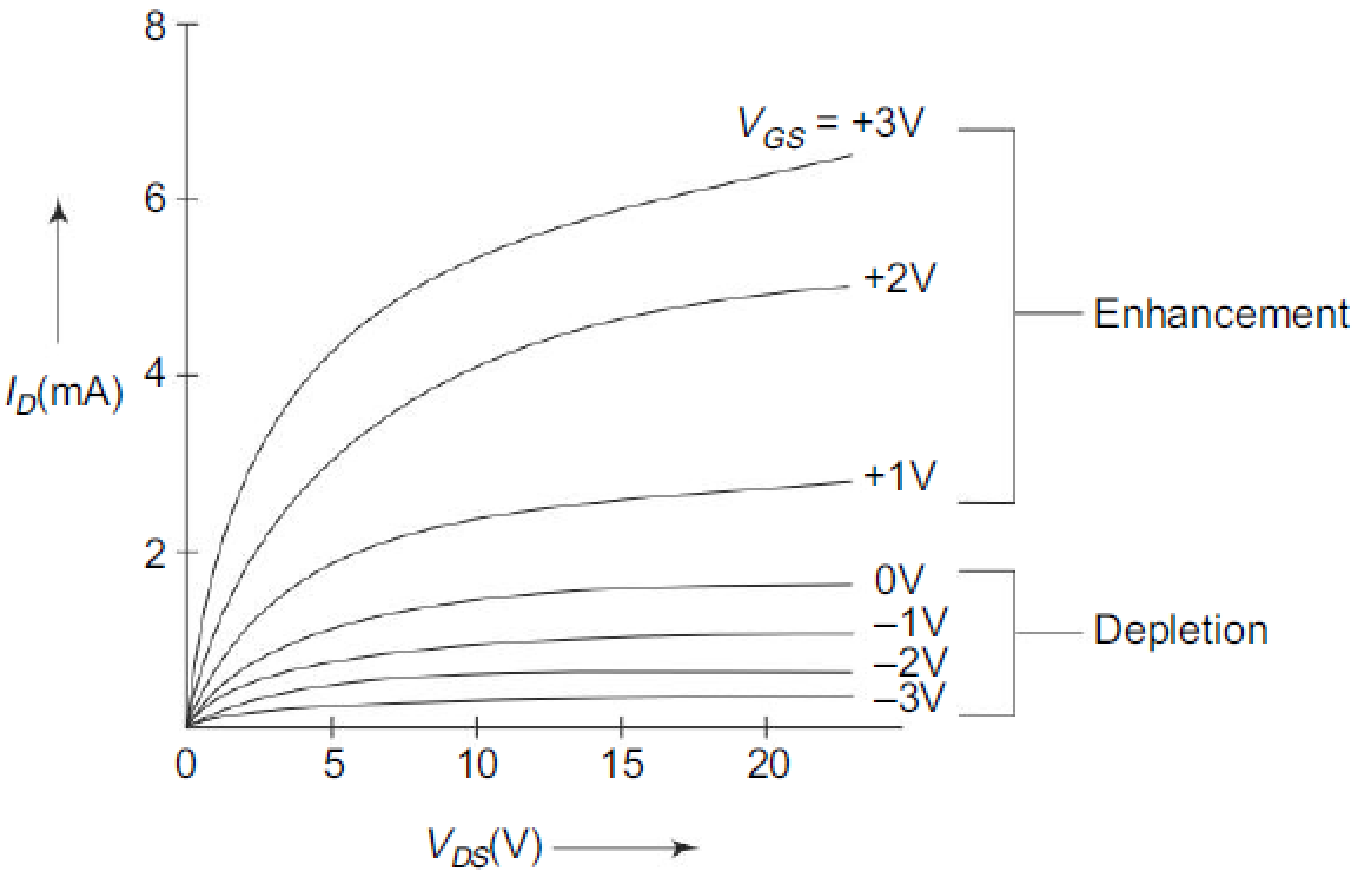


Fig. 13.25 Volt-Ampere Characteristics of MOSFET

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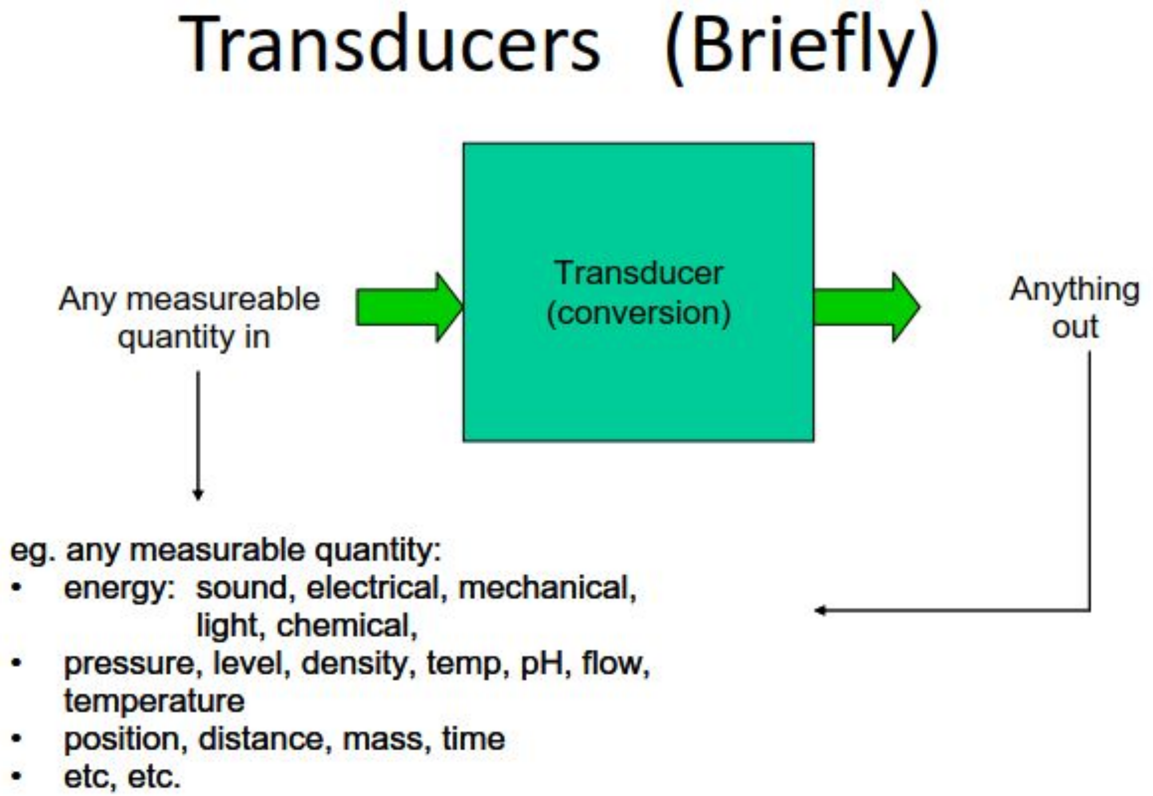
Transducers

Transducer

Define : A transducer is a device that converts energy from one form to another. Usually a transducer converts a signal in one form of energy to a signal in another form.



Requirements for Transducer

Linearity: Have linear input output characteristics

Repeatability: Produce the same result when the same input signal is applied repeatedly under same environmental conditions

Ruggedness: Capable of withstanding overload.

High Signal To Noise Ratio: Free from the internal and external noise

Highly Reliable: Possess minimum error in measurement

Good Dynamic Response: Must withstand sudden changes in input

No Hysteresis: Produce similar result while input signal is varied from its low value to high value and vice versa.

Residual Deformation: No deformation of testing material

Classification of Transducer

1. As active and passive transducer
2. According to transduction principle
3. As analog and digital transducer
4. As primary and secondary transducer
5. As forward transducer and inverse transducer

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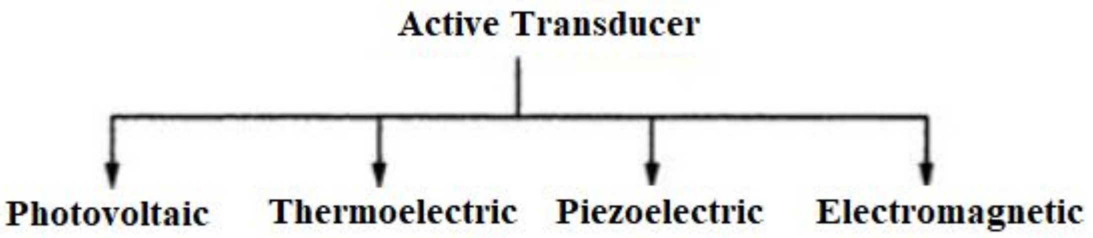
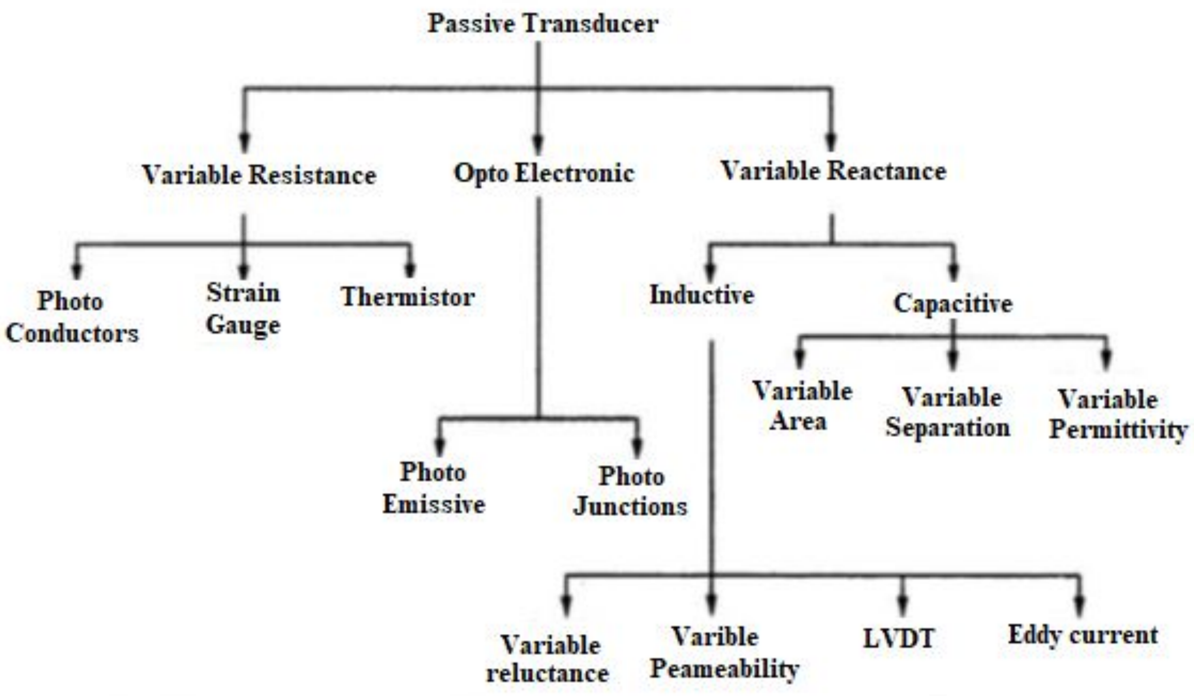
Active and Passive Transducer

Active Transducer	Passive Transducer
The active transducer is also called as self generating type transducer.	The passive transducer is also called as externally powered transducer.
The active transducer does not require any auxiliary (external) power supply.	The passive transducer requires auxiliary (external) power supply for transduction.
The signal conversion is simpler.	The signal conversion is more complicated.
The energy required to produce output is obtained from the physical quantity.	They also derived part of the power required for conversion from physical quantity under measurement.

Types of Active Transducer





Displacement Transducer

Define : A Displacement Transducer is an electromechanical device used to convert mechanical motion or vibrations into a variable electric signals.

Types:

- Capacitive Transducer
- Inductive
- Variable Inductance
- Linear Variable Differential Transformer

Capacitive Transducer

- A capacitor consists of two conductors (plates) that are electrically isolated from one another by a dielectric medium.
- The principle of operation of capacitive transducers is based upon the equation for capacitance of a parallel plate capacitor as shown below:

$$\boldsymbol{Capacitance}\ C = \frac{\varepsilon A}{d}$$

A = Overlapping area of plates; d = Distance between two plates; ε = Permittivity (dielectric constant)

- The capacitive transducers are commonly used for measurement of linear displacement, by employing the following effects.

1. Change in area of plates.
2. Change in distance between the two plates.
3. Change in dielectric between the two plates.

Capacitive Transducer Contd..

Variable capacitance pressure gauge –

Principle of operation: Distance between two parallel plates is varied by an externally applied force.

Applications: Measurement of Displacement, pressure.

Capacitor microphone -

Principle of operation: Sound pressure varies the capacitance between a fixed plate and a movable diaphragm.

Applications: Speech, music, noise.

Dielectric gauge -

Principle of operation: Variation in capacitance by changes in the dielectric.

Applications: Liquid level, thickness.

Inductive Transducer

- The inductive transducers work on the principle of the electromagnetic induction.
- Inductance of the magnetic material depends on a number of variables
  - The number of turns of the coil on the material,
  - The size of the magnetic material
  - The permeability of the flux path.
  - The change in the air gap

Inductive Transducer Contd..

Magnetic circuit transducer: Self inductance or mutual inductance of ac-excited coil is varied by changes in the magnetic circuit. Applications: Pressure, displacement.

Reluctance pickup: Reluctance of the magnetic circuit is varied by changing the position of the iron core of a coil. Applications: Pressure, displacement, vibration, position.

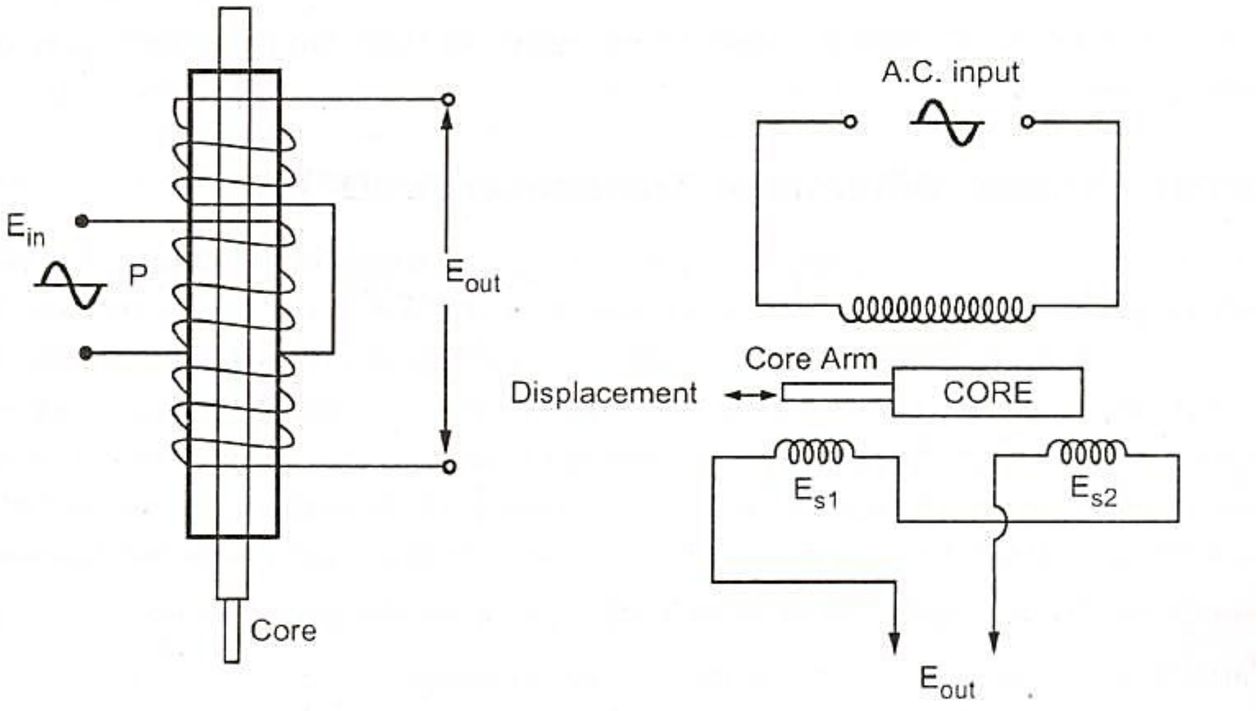
Differential transformer: The differential voltage of two secondary windings of a transformer is varied by positioning the magnetic core through an externally applied force. Applications: Pressure, force, displacement, position.

Eddy current gage: Inductance of a coil is varied by the proximity of an eddy current plate. Applications: Displacement, thickness.

Magnetostriction gauge: Magnetic properties are varied by pressure and stress. Applications: Force, pressure, sound.

Linear Variable-Differential Transformer(LVDT)

The linear variable-differential transformer(LVDT) is the most widely used inductive transducer to translate linear motion into electrical signal

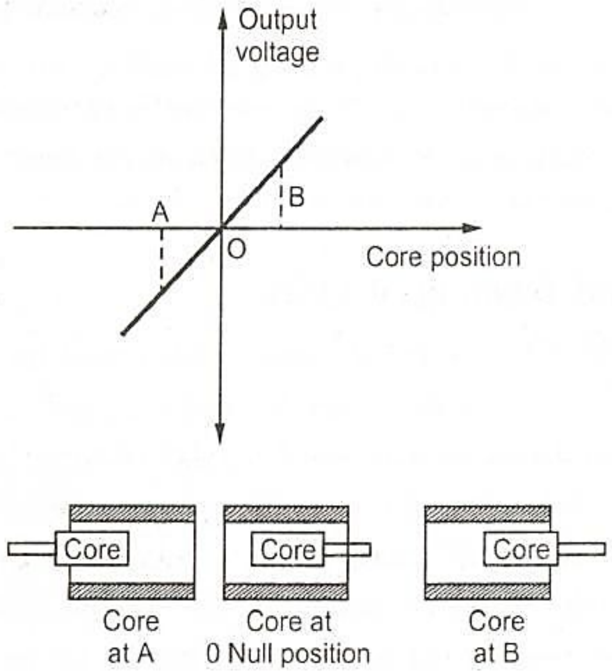


Construction of LVDT

- Consists of a primary winding and two secondary windings.
- A ferro-magnetic core(armature) in the shape of a rod or cylinder is attached to the transducer sensing which slides freely within the hollow portion of the bobbin.
- An a.c. excitation is applied across the primary winding and the movable core varies the coupling between it and the two secondary windings.
- As the core moves away from the centre position, the coupling to one secondary becomes more and hence its output voltage increases, while the coupling and the output voltage of the other secondary decreases.

Working Principle of LVDT

- Any physical displacement of the core causes the voltage of one secondary winding to increase while simultaneously, reducing the voltage in the other secondary winding.
- The difference of the two voltages appears across the output terminals of the transducers and gives a measure of the physical position of the core and hence the displacement.
- When the core is in the neutral or zero position, voltages induced in the secondary windings are equal and opposite and the net output is negligible.
- By comparing the magnitude and phase of output with input source, the amount and direction of movement of core and hence displacement may be determined



Advt, Disadvt and Uses of LVDT

Advt: 1. High Range -1.25mm to 250mm.

2. Low hysteresis

3. Simple,light in weight and easy to maintain.

4. Low Power Consumption

Disadvt: 1. They are sensitive to stray magnetic fields but shielding is possible.

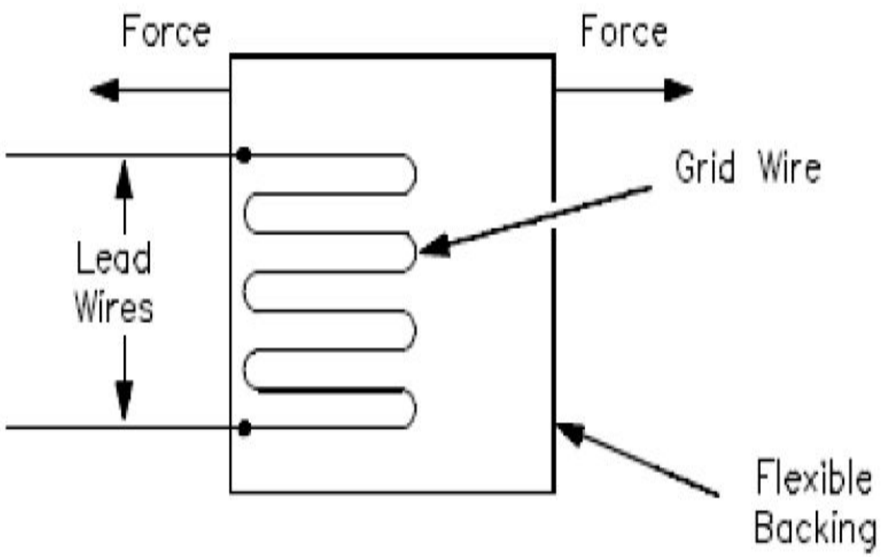
2. Temperature affects the perfomance of transducer.

Uses: 1. The LVDT can be used in all applications where displacements ranging from fraction of a mm to a few cm have to be measured.

2. Acting as a secondary transducer it can be used as a device to measure force, weight and pressure.

Strain Gauge

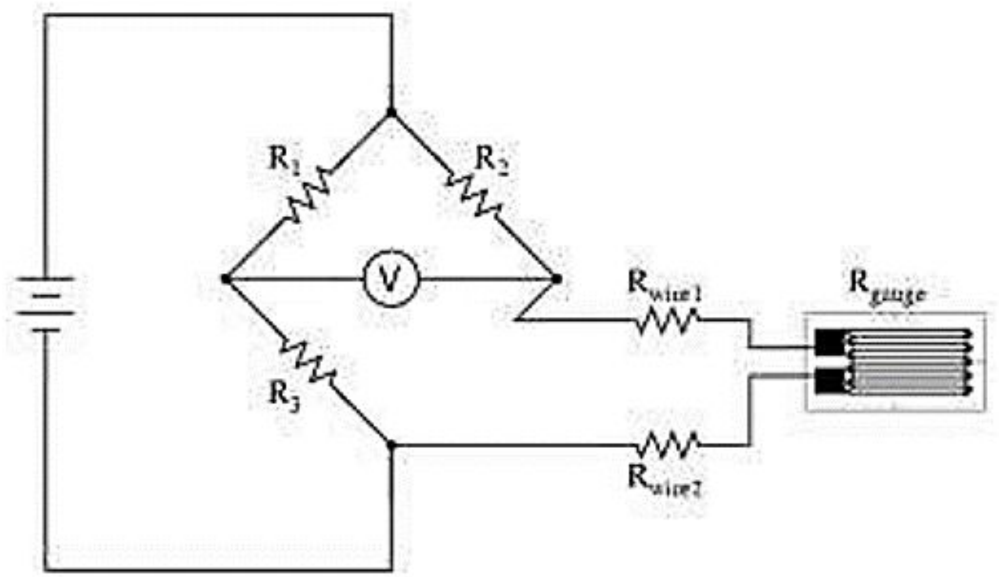
- When the tension is applied to the electrical conductor, its length increases while the cross section area decreases.
- So its resistance changes. This change can be measured to measured.
- Used for the measurement of force, stress and strain.
- A strain gauge is a passive type resistance pressure transducer whose electrical resistance changes when it is stretched or compressed.
- A pressure transducer contains a diaphragm which is deformed by the pressure which can cause a strain gauge to stretch or compress. This deformation of the strain gauge causes the variation in length and cross sectional area due to which its resistance changes.
- The wire filament is attached to a structure under strain and the resistance in the strained wire is measured.



Strain Gauge

- The strain gauge is connected into a Wheatstone Bridge circuit. The change in resistance is proportional to applied strain and is measured with Wheatstone bridge.
- The sensitivity of a strain gauge is described in terms of a characteristic called the gauge factor, defined as unit change in resistance per unit change in length.

$$K = \frac{\Delta R/R}{\Delta l/l}$$



Advt and Disadvt of Strain Gauge

Advt
- There is no moving part.
- It is small and inexpensive.

Disadvt
- It is non-linear.
- It needs to be calibrated.

Uses :

- Residual stress
- Vibration measurement
- Torque measurement
- Bending and deflection measurement
- Compression and tension measurement
- Strain measurement

Thermoelectric Transducers

Define – Converts Temperature to electrical signal and vice versa

Types -

1. RTD(Resistance Temperature Detector) -To predict change in electrical resistance of some materials with changing temperature.
2. Thermocouple - To convert thermal potential difference into electric potential difference.
3. Thermistor - Exhibits a large change in resistance proportional to a small change in temperature.

RTD

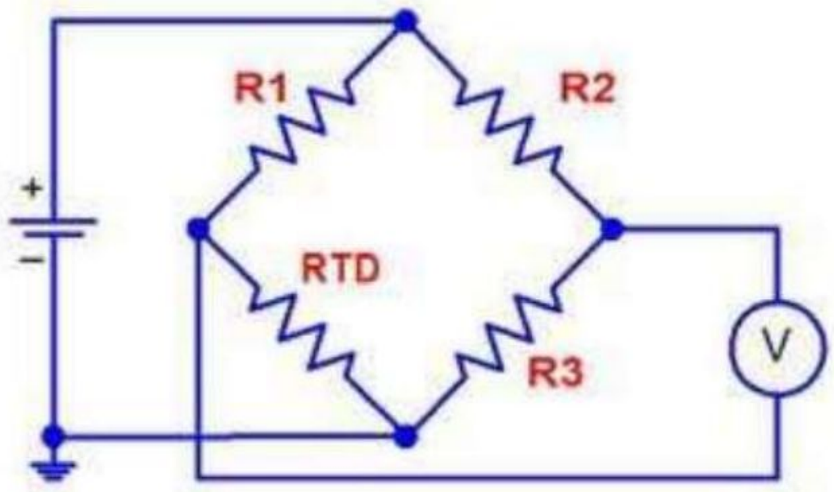
- RTD - Resistance Temperature Detector.
- The change in temperature is detected by the change in resistance of the wire.

- Types:

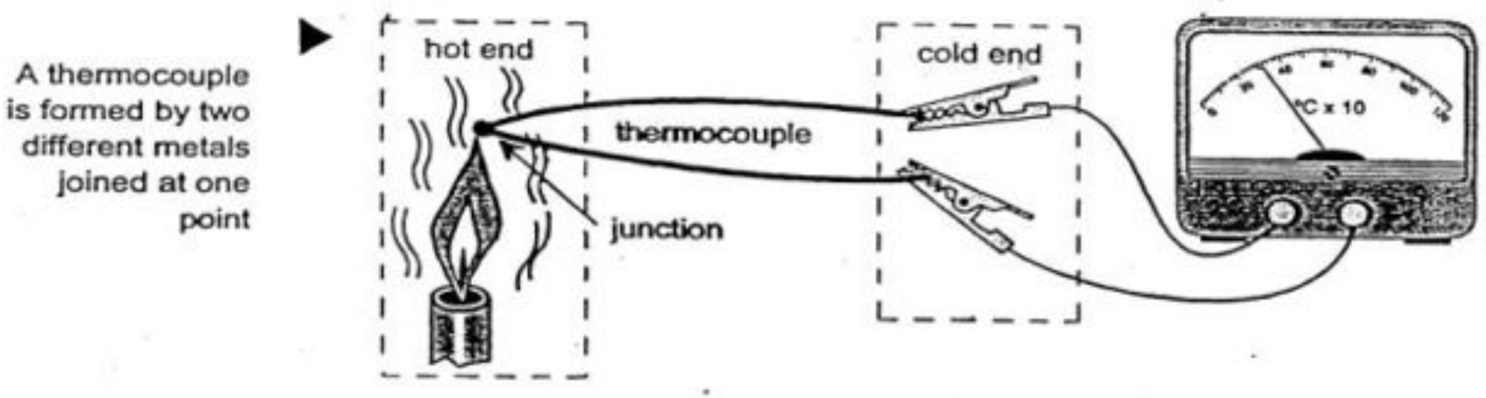
1. RTD with positive thermal coefficients of resistivity
2. RTD with negative thermal coefficients of resistivity

- Materials: Platinum (most popular and accurate), Nickel, Copper, Balco (rare), Tungsten (rare)

- RTDs are used for temperature measurements by using them in bridge circuits.
- The change in temperature causes considerable resistance change which gives a voltage drop in accordance with the thermal coefficient of resistance of the wire.



Thermocouple



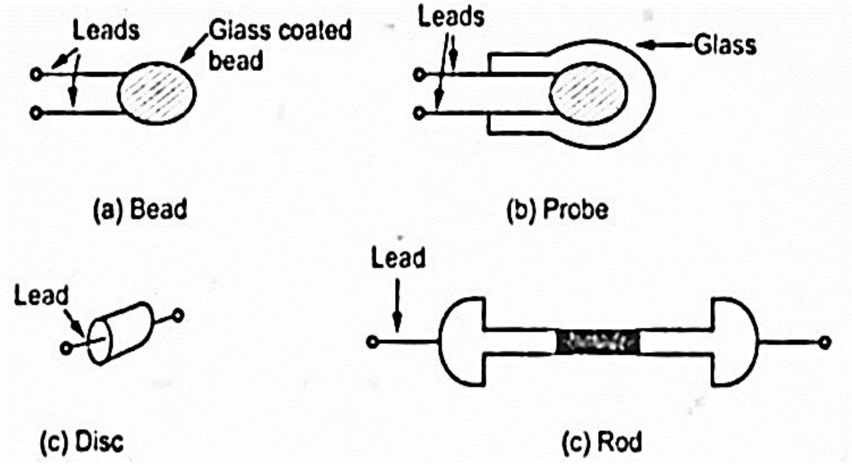
As the junction temperature increases a small voltage is created in the loop. The voltage produced at the junction of the dissimilar metals is due to a phenomenon called the "Seebeck Effect".

- The higher the temperature at the junction, the greater the voltage produced by that junction.

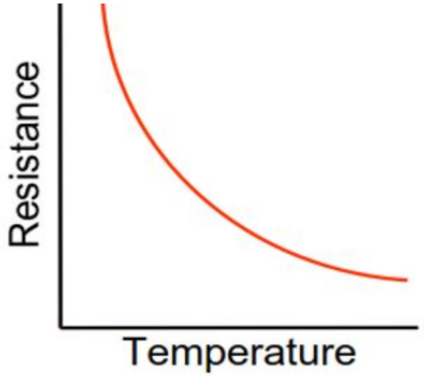
- The relationship between voltage and temperature is constant and therefore will graph as a linear line.

Thermistor

- Measures temperature according to change in resistance.
- Made of a sintered semiconductor material.
- Use ceramic or polymer materials
- Available in various shapes like disc, rod, washer, etc.



Semi-conductor thermistors have a Negative Temperature Coefficient (NTC). i.e. as temperature increases, the resistance decreases.



Photoelectric Transducers

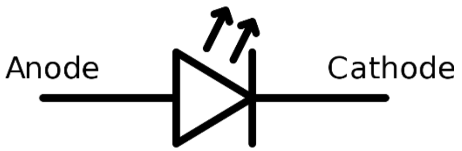
Define : Converts light energy to electrical energy and vice versa.

Types:

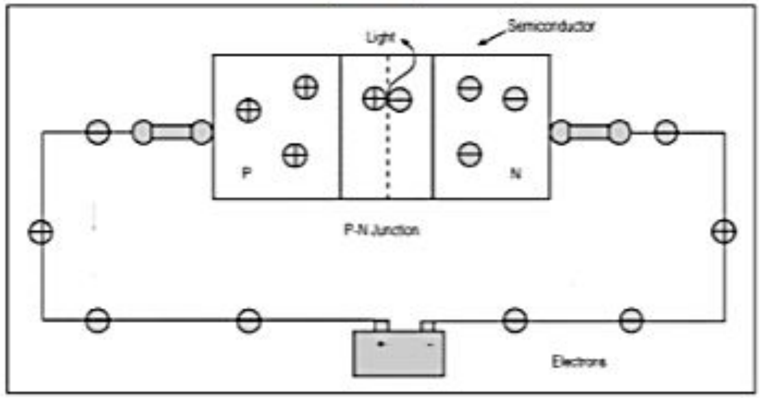
- Laser diode, light-emitting diode - convert electrical power into forms of light.
- Photodiode, photo resistor, phototransistor, photomultiplier tube - converts changing light levels into electrical form.

Light-Emitting Diode

- ❑ LEDs are ***semiconductor diodes***, electronic devices that permit current to flow in only one direction.
- ❑ The diode is formed by bringing two slightly different materials together to form a ***PN junction*** .
- ❑ In a PN junction, the ***P*** side contains excess positive charge ("**holes**," indicating the absence of electrons) while the **N** side contains excess negative charge (**electrons**).



A simplified PN junction diagram.



Light-Emitting Diode

- When sufficient voltage is applied to the chip across the leads of the LED, electrons can move easily in only one direction across the junction between the p and n regions.

- When a voltage is applied and the current starts to flow, electrons in the n region have sufficient energy to move across the junction into the p region.

- Each time an electron recombines with a positive charge, electric potential energy is converted into electromagnetic energy. • For each recombination of a negative and a positive charge, a quantum of electromagnetic energy is emitted in the form of a photon of light with a frequency characteristic of the semi-conductor material.

- LEDs are made from gallium-based crystals that contain one or more additional materials such as phosphorous to produce a distinct color. • Different LED chip technologies emit light in specific regions of the visible light spectrum and produce different intensity levels.

- • LEDs are available in red, orange, amber, yellow, green, blue and white.

Laser Diode

- LASER stands for Light Amplification by Stimulated Emission of Radiation.
- A laser diode is an electronic device, which converts electrical energy into light energy to produce high-intensity coherent light.
- Laser diode is very small in size and appearance.
- It is similar to a transistor and has operation like LED but it emit coherent light.
- The material which often used in Laser diode is the gallium Arsenide (GaAs).
- It work on forward biasing.

Laser Diode

- When DC voltage is applied across the laser diode, the free electrons move across the junction region from the n-type material to the p-type material.

- In this process, some electrons will directly interact with the valence electrons and excites them to the higher energy level and releases energy in the form of light. This process of emission is called spontaneous emission.

- The photons generated due to spontaneous emission will travel through the junction region and stimulate the excited electrons (free electrons). As a result, more photons are released.

- This process of light or photons emission is called stimulated emission.

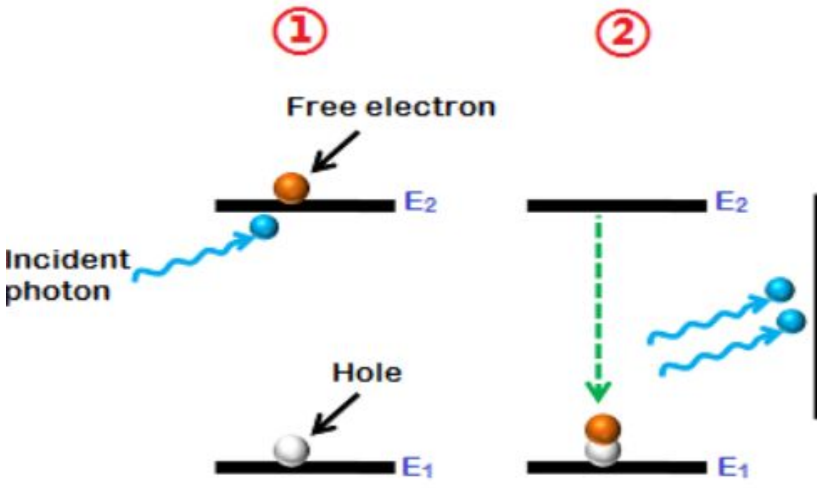
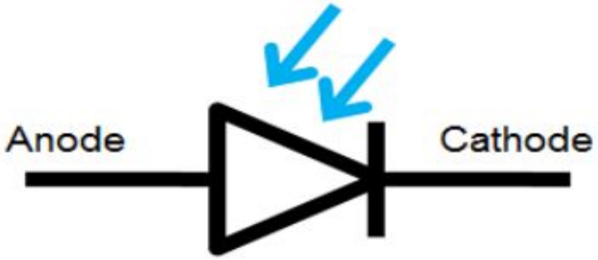
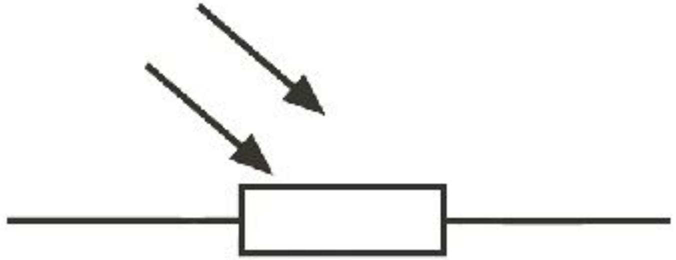


Photo Diode

- A photodiode is a PN-junction diode that consumes light energy to produce electric current.
- It is also called as photo-detector, a light detector, ai photo-sensor.
- A photodiode is one type of light detector, used to convert tl light into current or voltage based on the mode of operation oi the device.
- It comprises of optical filters, built-in lenses and also surface areas.
- These diodes are particularly designed to work in reverse bias condition.
- The working principle of a photodiode is, when a photon of ample energy strikes the diode, it makes a couple of an electron-hole.
- Therefore, holes in the region move toward the anode, and electrons move toward the cathode, and a photocurrent will be generated.



Photoresistor



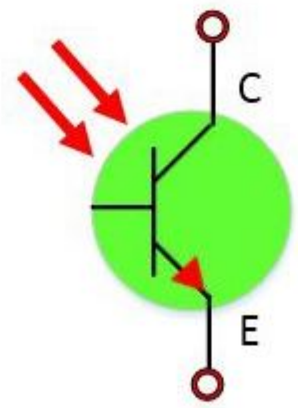
- Photoresistor is a variable resistor whose resistance varie inversely with the intensity of light
- Photoresistors are also known as photoconductive cells or jus photocell.
- When light is incident on the photoresistor, photons get absorbed by the semiconductor material.
- The energy from the photon gets absorbed by the electrons.
- When these electrons acquire sufficient energy to break the bond, they jump into the conduction band.
- Due to this, the resistance of the photoresistor decreases. With the decrease in resistance, conductivity increases.
- In the absence of light, the photoresistor can have resistance values in megaohms.
- During the presence of light, its resistance can decrease to a few hundred ohms.

Phototransistor

- It is a device to convert light energy into electrical energy.

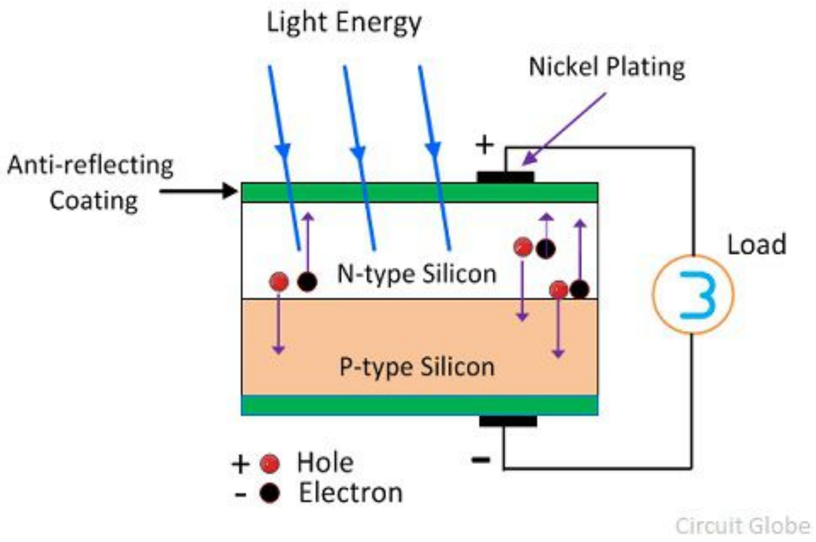
- The construction of phototransistor is similar to the ordinary transistor, except the base terminal. In phototransistor, the base terminal is not provided, and instead of the base current, the light energy is taken as the input.

- The phototransistor is a three-layer semiconductor device which has a light-sensitive base region. The base senses the light and converts it into the current which flows between the collector and the emitter region.



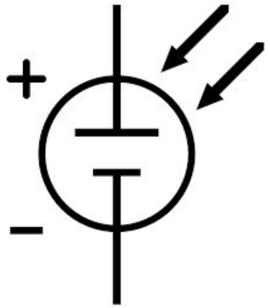
Photovoltaic or Solar Cell

- The Photovoltaic cell is the semiconductor device that converts the light into electrical energy.
- The voltage induces by the PV cell depends on the intensity of light incident on it.
- The semiconductor materials like arsenide, indium, cadmium, silicon, selenium and gallium are used for making the PV cells.
- Figure shows the constructions of the silicon photovoltaic cell.
- The upper surface of the cell is made of the thin layer of the p-type material so that the light can easily enter into the material.
- The metal rings are placed around p-type and n-type material which acts as their positive and negative output terminals respectively.



Photovoltaic or Solar Cell

- The multi-crystalline or monocrystalline semiconductor material make the single unit of the PV cell.
  - The mono-crystal cell is cut from the volume of the semiconductor material.
  - The multicell are obtained from the material which has many sides.
- The output voltage and current obtained from the single unit of the cell is very less.
- Many cells together is said to be Solar Panel.



Chemical Transducer

Define – Converts chemical energy into electrical energy and vice versa.

Types –

1) pH probe -

- A scientific instrument that measures the hydrogen-ion activity in water based solutions, indicating its acidity or basicity expressed as pH.
- The pH meter measures the difference in electrical potential between a pH electrode and a reference electrode, and so the pH meter is sometimes referred to as a "potentiometric pH meter".
- The difference in electrical potential relates to the acidity or pH of the solution.

2) Electro-galvanic sensor –

- An electrochemical device which consumes a fuel to produce an electrical output by a chemical reaction.
- One form of electro-galvanic fuel cell based on the oxidation of lead is commonly used to measure the concentration of oxygen gas in underwater diving and medical breathing gases.

Electroacoustic Transducer

Define : convert electrical signals to acoustic (related to hearing) signals or vice versa.

Types:

1) Mic - an instrument whereby sound waves are caused to generate or modulate an electric current usually for the purpose of transmitting or recording sound (such as speech or music).
2) Speaker - device that converts electric signals to audible sound
3) Sonar - a system for the detection of objects under water by emitting sound pulses and detecting or measuring their return after being reflected.
4) Ultrasonic - These transducers send the electrical signals to the object and once the signal strikes the object then it reverts to the transducer. In this process, this transducer measures the distance of the object.
5) Tactile - A **tactile sensor** is a device that measures information arising from physical interaction with its environment.

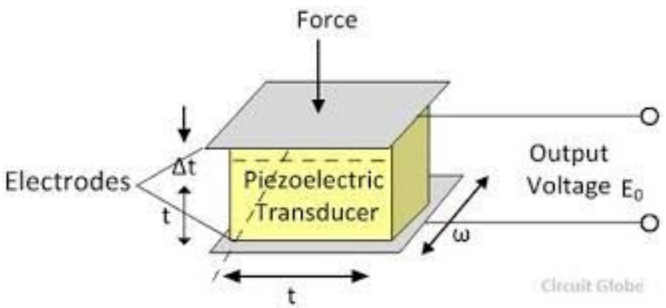
Electroacoustic Transducer

6) Geophone - is a ground motion transducer that has been used by geophysicists and seismologists to convert ground movement into voltage.

7) Hydrophone - A hydrophone is a microphone designed to be used underwater for recording or listening to underwater sound.

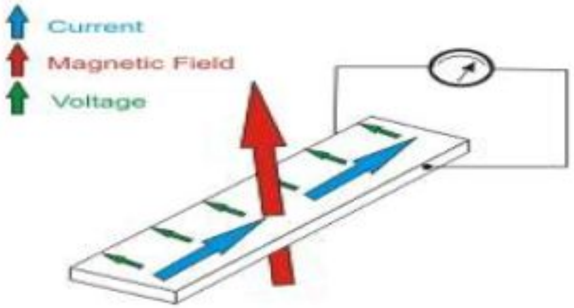
8) Piezoelectric-

- The Piezoelectric transducer is an electroacoustic transducer use for conversion of pressure or mechanical stress into an alternating electrical force. It is used for measuring the physical quantity like force, pressure, stress
- The piezoelectric transducer uses the piezoelectric material which has a special property, i.e. the material induces voltage when the pressure or stress applied to it.
- The Quartz is the examples of the natural piezoelectric crystals, whereas the Rochelle salts, ammonium dehydration, phosphate, lithium sulphate, dipotassium tartrate are the examples of the man made crystals. The ceramic material is also used for piezoelectric transducer.



Electromagnetic Transducer

1) Antenna - Which can convert radio waves (electromagnetic waves) into an electrical signal
2) **magnetic cartridge - A** type of transducer used in the playback of analog sound recordings called records on a record player. Commonly called a **turntable**
3) Hall Effect - The Hall Effect describes a condition if current flow in a conductor being affected by the presence of a magnetic field If an electric current flows through a conductor in a magnetic field, the magnetic field exerts a transverse force on the moving charge carriers which tends to push them to one side of the conductor. This is most evident in a thin flat conductor. A build up of charge at the sides of the conductors will balance this magnetic influence, producing a measurable voltage between the two sides of the conductor. The presence of this measurable transverse voltage is called the Hall effect after E. H. Hall who discovered it in 1879.



Radioacoustic Transducer

1)Geiger Muller Tubes – instrument used for the detection of Ionizing radiation. It is used for the detection of X-rays.

2) Radio Receiver - receives radio waves (electromagnetic) and converts the information carried by them to a usable form.

3) Radio Transmitter- Receives the information to be carried and convert that into radio waves (electromagnetic)

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Assignment Topics

- LCD
- Infrared Emitters
- Optocouplers

End of Session

BEEE-UNIT 5

Digital Systems
18
Number systems, binary codes
Binary arithmetic
Boolean algebra, laws and theorems
Simplification of Boolean expression
Logic Gates and Operations
Simplification of Boolean expression
Problem Solving Session
Lab 13: Verification of Boolean expression using logic gates
SOP and POS Expressions
Standard forms of Boolean expression
Simplify using Boolean Expressions
Minterm and Maxterm
K-Map Simple ReductionTechnique

Two, Three and Four Variable K-Map
Problem Solving Session
Lab 14: Reduction using Digital Logic Gates
Principles of Communication
Block diagram of a Communication System
Amplitude Modulation
Frequency Modulation
Phase Modulation
Demodulation
Problem Solving Session
Lab 15: Demo of Transmission and Reception using MODEM

NUMBER SYSTEM

Definition: In digital system, the number system is used for representing the information. The number system has different bases and the most common of them are the decimal, binary, octal, and hexadecimal.

BASE OR RADIX (r)

The base or radix of the number system is the total number of the digit used in the number system.

Sl No	Name of the number system	Symbol Used	Base or radix
1	Decimal	0,1,2,3,4,5,6,7,8,9	10
2	Binary	0,1	2
3	Octal	0,1,2,3,4,5,6,7	8
4	Hexadecimal	0,1,2,3,4,5,6,7,8,9, A,B,C,D,E,F	16

I. Decimal to any number system

1. Decimal to Binary

Problem:

Convert 53.62_{10} to binary

Sol :

2	53
2	26-1
2	13-0
2	6-1
2	3-0
	1-1

110101_2

0.62x2=1.24
0.24x2=0.48
0.48x2=0.96
0.96x2=1.92
0.92x2=1.84
0.84x2=1.68

100111_2

5 bit after decimal point enough

$53 = 110101_2$

$0.62 = 100\,111_2$

$53.62 = 110101.100\,111_2$

2. Decimal to octal

Problem:

Convert 444.456_{10} to octal

Sol :

8 | 444

8 | 55-4

8 | 6-7

674_8

0.456x8=3.648-3
0.648x8=5.184-5
0.184x8=1.472-1
0.472x8=3.776-3
0.776x8=6.208-6

0.35136_8

5 bit after decimal point enough

$444.456_{10} = 674.35136_8$

3. Decimal to hexadecimal

Problem:

Convert 444.456_{10} to hexadecimal

Sol :

16 | 444

16 | 27 -12

1-11

1BC

0.456X16=7.296-7
0.296X16=4.736-4
0.736X16=11.776-11

0.74B

A-10
B-11
C-12
D-13
E-14
F-15

444.456 = 1BC.74B

II. Any number system to Decimal [Use formula]

Decimal = $a_n \times r^n + a_{n-1} \times r^{n-1} + \ldots\ldots\ a_1 \times r^1 + a_0 \times r^0 + a_{-1} \times r^{-1} + a_{-2} \times r^{-2} \ \ldots\ a_{-m} \times r^{m-1}$

Where: r- base or radix of given number system

a_n – n^{th} bit/digit value

a_0 – 0^{th} bit/digit value (Left immediate bit/digit at decimal point)

a_{-1} – 1^{st} bit/digit value (Right immediate bit/digit after decimal point)

4. Binary to Decimal

Problem:

Convert 101111.0101_2 to decimal

Sol :

Decimal= $a_5 \times 2^5 + a_4 \times 2^4 + a_3 \times 2^3 + a_2 \times 2^2 + a_1 \times 2^1 + a_0 \times 2^0 + a_{-1} \times 2^{-1} + a_{-2} \times 2^{-2} + a_{-3} \times 2^{-3} + a_{-4} \times 2^{-4}$

$= 1 \times 2^5 + 0 \times 2^4 + 1\times 2^3 + 1\times 2^2 + 1 \times 2^1 + 1 \times 2^0 + 0 \times 2^{-1} + 1 \times 2^{-2} + 0 \times 2^{-3} + 1 \times 2^{-4}$ [Use calci to solve this]

= 32 +0+8+4+2+1+0_0.25+0+0.0625

$= 47.3125_{10}$

5. Octal to Decimal

Problem:

Convert 573. 26_8 to decimal

Sol :

Decimal= $a_2 \times 8^2 + a_1 \times 8^1 + a_0 \times 8^0 + a_{-1} \times 8^{-1} + a_{-2} \times 8^{-2}$

$= 5 \times 8^2 + 7 \times 8^1 + 3 \times 8^0 + 2 \times 8^{-1} + 6 \times 8^{-2}$

$= 320+56+3+0.25+0.09375$

$= 379.34375_{10}$

6. Hexadecimal to Decimal

Problem:

Convert D2A.$5C_{16}$ to decimal

Sol :

Decimal= $a_2 \times 16^2 + a_1 \times 16^1 + a_0 \times 16^0 + a_{-1} \times 16^{-1} + a_{-2} \times 16^{-2}$

$= 13 \times 16^2 + 2 \times 16^1 + 10 \times 16^0 + 5 \times 16^{-1} + 12 \times 16^{-2}$

$= 3370.359375_{10}$

A-10
B-11
C-12
D-13
E-14
F-15

III. Other than Decimal conversion

7. Octal to Binary

Oct-Bin
0-000
1-001
2-010
3-011
4-100
5-101
6-110
7-111

Problem:

Convert 365.71_8 to binary

Sol : For each octal digit, write 3 bit binary

3	6	5 .	7	1
011	110	101	111	001

$= 011110101.111001_2$

8. Binary to Octal

Problem:

Convert 11001111.1101_2 to Octal

Sol : Choose 3 bit binary before decimal point and after decimal point.

Note: You can add 0, in prefix/suffix if needed

011	001	111.	110	100
3	1	7	6	4

$= 317.64_8$

9. Hexadecimal to Binary

Problem:

Convert $AB85.2F_{16}$ to binary

Sol : For each hexadecimal digit, write 4 bit binary

A	B	8	5.	2	F
1010	1011	1000	0101	0010	1111

$= 1010101110000101.00101111_2$

Note

0-0000	8- 1000
1-0001	9- 1001
2-0010	A- 1010
3-0011	B- 1011
4-0100	C- 1100
5-0101	D- 1101
6-0110	E- 1110
7-0111	F-1111

10. Binary to Hexadecimal

Problem:

Convert 110111101.1010111_2 to Hexadecimal

Sol : Choose 4 bit binary before decimal point and after decimal point

Note: You can add 0 in prefix/suffix, if needed

0001	1011	1101.	1010	1110
1	B	D	A	E

$= 1BD.AE_{16}$

11. **Octal to Hexadecimal [Via Binary]**

Problem:

Convert 7320.12_8 to Hexadecimal

Sol : First convert Octal to Binary, then convert Binary to hexa

$$7320.12 = 111\ \ 011\ \ 010\ \ 000.001\ 010_2$$

1110 1101 0000. 0010 1000

E D 0 2 8

$$7320.12_8 = ED0.28_{16}$$

12. **Hexadecimal to Octal [Via Binary]**

Problem:

Convert $EEE.ECE_{16}$ to Octal

Sol : First convert hexa to Binary, then convert Binary to octal

$$EEE.ECE = 111011101110.111011001110_2$$

111 011 101 110.111 011 001 110

7 3 5 6 7 3 1 6

$$7356.7316_8$$

Why Binary used in Digital system

- Digital system use binary - the bits 0 and 1 - to store/process data. The circuits in Digital system are made up of billions of transistors. A transistor is a tiny switch that is activated by the electronic signals it receives.
- **The digits 1 and 0 used in binary reflect the on and off states of a transistor.**

SIGNED BINARY NUMBERS

To represent negative numbers, signed number system is used. The four best-known methods of extending the binary numeral system to represent signed numbers are: signed magnitude, ***ones' complement, two's complement***, and offset binary.

1. Signed magnitude / Sign-and-magnitude

In this approach, a number's sign is represented with a sign bit: setting that bit (often the **most significant bit**) to 0 for a positive number and setting it to 1 for a negative number. The remaining bits in the number indicate the magnitude (or absolute value). For example, in an eight-bit byte, only seven bits represent the magnitude, which can range from 0000000 (0) to 1111111 (127). Thus numbers ranging from -127_{10} to $+127_{10}$ can be represented once the sign bit (the eighth bit) is added. For example, -43_{10} encoded in an eight-bit byte is 10101011 while 43_{10} is 00101011.

2. One's Complement

The one's complement form of a negative binary number is the **bitwise NOT** applied to it, i.e. the "complement" of its positive counterpart.

$$43_{10} = 00101011$$
$$-43_{10} = 11010100$$

3. Two's Complement

In two's complement, negative numbers are represented by the bit pattern which is one greater than the ones' complement of the positive value. ie, one's complement it and add 1.

43_{10} = 00101011

-43_{10} = 11010100 (one's complement)

1

11010101 (Two's complement)

511_{10} = 0111111111

-511_{10} = 1000010000 (one's complement)

1 (Add 1)

1000000001 (Two's complement)

Note: In our calculator [Casio fx 991 MS], we have 10 bits. So maximum we can use 9 bit only. 10^{th} bit is used (MSB) to represent 0 for a positive number. [We can represent only 511 to -512 in our calculator]

Binary arithmetic [2's complement arithmetic]

Perform the following using 2's complement arithmetic. [Use 10 bit]

(i) Y=85-42

(ii) Z=42-85

Sol (i) Y = 85-42

= 85+(-42)

85 in 10 Bit : 0001010101

42 in 10 Bit : 0000101010

-42 in 1's complement : 1111010101

(+) 1

-42 in 2's complement : 1111010110

85 = 0001010101

(+)

-42 = 1111010110

$\cancel{1}$0000101011

Discard the carry.

Y=0000101011

$\boxed{Y=43}$

Sol (ii) Z = 42-85

= 42+(-85)

42 in 10 Bit : 0000101010

85 in 10 Bit : 0001010101

-85 in 1's complement : 1110101010

(+) 1

-85 in 2's complement : 1110101011

-85 = 1110101011

(+)

42 = 0000101010

1111010101

Since MSB is 1, it's a negative number.

To know its value, 2's complement it.

0000101010

(+) 1

0000101011

$\boxed{Z = -43}$

BCD CODES

Human can understand and use decimal number easily. But Digital system can understand only binary numbers. So, to interface among human and Digital system, BCD codes were developed. There are many types of BCD codes that were introduced by Scientist. But 8421 code is very much popular and widely used.

8421 code is a 4 bit BCD code having codes for 0 to 9 (Decimal Numbers). Each decimal digit represents 4 bit binary. It obeys positional weightage principle. It's easy to understand and remember because it's a normal 4 bit binary number from 0 to 9.

BINARY CODES FOR DECIMAL-BCD

Binary Codes for Decimal digits

The following table shows the various binary codes for decimal digits 0 to 9.

Decimal Digit	8421 Code BCD Code	2421 Code	84-2-1 Code	Excess 3 Code
0	0000	0000	0000	0011
1	0001	0001	0111	0100
2	0010	0010	0110	0101
3	0011	0011	0101	0110
4	0100	0100	0100	0111
5	0101	1011	1011	1000
6	0110	1100	1010	1001
7	0111	1101	1001	1010
8	1000	1110	1000	1011
9	1001	1111	1111	1100

BCD CODES

Express 7915_{10} in BCD and Excess-3

7915_{10} in BCD = 0111 1001 0001 0101

7915_{10} in Excess-3= 1010 1100 0100 1000

BCD Addition

BCD is a numerical code, and many applications require that arithmetic operations be performed. Addition is the most important operation because the other three operations like subtraction, multiplication and division can be accomplished using addition. The rule for adding two BCD numbers is given below.

1. Add the two numbers, using the rules for binary addition.
2. If a four-bit sum is equal to or less than 9, it is a valid BCD number.
3. If a four-bit sum is greater than 9, or if a carry-out of the group is generated, it is an invalid result. Add 6 (0110_2) to the four-bit sum in order to skip the six invalid states and return the code to 8421. If a carry results when 6 is added, simply add the carry to the next four-bit group.

Perform the following using BCD Arithmetic

459 + 278

Sol:

```
             1   1111
459 = 0100  0101  1001
278 = 0010  0111  1000
----------------------
      0111  1101  0001
            0110  0110
----------------------
      0111  0011  0111

       7     3     7
```

Legal Code but contains Carry, so add 0110

Illegal Code, So add 0110

Boolean Algebra

- **Invented by George Boole in 1854**
- **An algebraic structure defined by a set $B = \{0, 1\}$, together with two binary operators (+ and $\cdot$) and a unary operator ($-$)**

OR Laws	AND Laws
1. $A + 0 = A$	5. $A \cdot 0 = 0$
2. $A + 1 = 1$	6. $A \cdot 1 = A$
3. $A + A = A$	7. $A \cdot A = A$
4. $A + \overline{A} = 1$	8. $A \cdot \overline{A} = 0$

9. $\overline{\overline{A}} = A$		Involution
10. $A + B = B + A$	11. $AB = BA$	Commutative
12. $(A + B) + C = A + (B + C)$	13. $(AB)C = A(BC)$	Associative
14. $A(B + C) = AB + AC$	15. $A + BC = (A + B)(A + C)$	Distributive
16. $\overline{A + B} = \overline{A} \cdot \overline{B}$	17. $\overline{A \cdot B} = \overline{A} + \overline{B}$	$\boxed{\text{DeMorgan's}}$
18. A+AB = A	19. A(A+B) = A	Absorption

Prove A+A'B = A+B

A	B	A'	A'B	A+A'B	A+B
0	0	1	0	0	0
0	1	1	1	1	1
1	0	0	0	1	1
1	1	0	0	1	1

Similarly we can prove A'+AB = A'+B

State and prove DeMorgan's Theorem

1. $\overline{A+B} = \overline{A} \cdot \overline{B}$

2. $\overline{A \cdot B} = \overline{A} + \overline{B}$

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
			LHS			RHS

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
			LHS			RHS

Simplification of Boolean expressions using Boolean algebra

1. Simplify the following expressions using Boolean algebra

$$Y = A + AB + AB'C$$

Sol: $Y = A(1+B+B'C)$

$= A.1$

$Y = A$

2. Simplify the following expressions using Boolean algebra

$$Y = (A' + B)C + ABC$$

Sol: $Y = A'C + BC + ABC$

$= A'C + BC(1+A)$

$= A'C + BC$

3. Simplify the following expressions using Boolean algebra

$Y = AB'C(BD + CDE) + AC'$

$= AB'CBD + AB'CCDE + AC'$ | $B'B=0$; $CC=C$

$= 0 + AB'CDE + AC'$

$= A(C' + B'CDE)$ | $C'+CX = C'+X$

$= A(C' + B'DE)$

4. Simplify the following expressions using Boolean algebra

$Y=AB + \overline{AC} + A\bar{B}C\ (AB+C)$

Sol: $Y = AB + A' + C' + AB'CAB + AB'CC$	$B'B=0;\ CC=C$
$= AB + A' + C' + 0 + AB'C$	
$= AB + A' + C' + AB'C$	$C'+CX=C'+X$
$= AB + A' + C' + AB'$	
$= A[B+B'] + A' + C'$	$B+B'=1$
$= A + A' + C'$	$A+A'=1;$
$= 1$	$1+$ ANY$=1$

5. Simplify the following expressions using Boolean algebra

$Y(A,B,C) = A'B+BC'+BC+AB'C'$	
Sol: $Y = A'B+B[C'+C]+AB'C'$	
$= A'B+B+AB'C'$	
$= B[A'+1]+AB'C$	
$= B+AB'C'$	$B+B'X= B+X$
$Y = B+AC'$	Where $X=AC'$

6 Simplify the following expressions using Boolean algebra

$$Y=\{\overline{\overline{A + B\overline{\overline{C}} + D(\overline{E + \overline{\overline{F}}})}}$$

$$Y=\{\overline{\overline{A + B\overline{\overline{C}}}}\}\cdot\{\overline{D(\overline{E + \overline{\overline{F}}})}\}$$

$$Y=\{A + B\overline{C}\}\cdot\{\overline{D(\overline{E + \overline{\overline{F}}})}\}$$

$$Y=\{A + B\overline{C}\}\cdot\{\overline{D(\overline{E + \overline{\overline{F}}})}\}$$

$$Y=\{A + B\overline{C}\}\cdot\{\overline{D(\overline{E} \cdot \overline{\overline{F}})}\}$$

$$Y=\{A + B\overline{C}\}\cdot\{\overline{D(\overline{E}F)}\}$$

$$Y=\{A + B\overline{C}\}\{\overline{D} + (\overline{\overline{E}F})\}$$

$$Y=\{A + B\overline{C}\}\{\overline{D} + (\overline{\overline{E}F})\}$$

$$Y=\{A + B\overline{C}\}\{\overline{D} + (\overline{\overline{E}} + \overline{F})\}$$

$$Y=\{A + B\overline{C}\}\{\overline{D} + E + \overline{F}\}$$

Y = AD'+AE+AF'+BC'D'+BC'E+BC'F'

Simplify the given Boolean expression using Boolean laws and theorems SRM-MAY-2019 (3+3)

(1) $Y = ABC + A\overline{B}C + A\overline{B}C + AB\overline{C}$. **(2)** $Y = AB + A\overline{B}(\overline{\overline{A}\overline{B}})$,

Sol-1: $Y = ABC + A\overline{B}C + A\overline{B}C + AB\overline{C}$

$$Y = ABC + A\overline{B}C + AB\overline{C}$$

$$Y = AC(1 + \overline{B}) + AB\overline{C}$$

$$Y = AC + AB\overline{C} = A(C + B\overline{C}) = A(C + B) = AC + AB$$

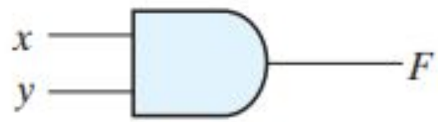
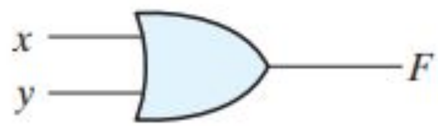
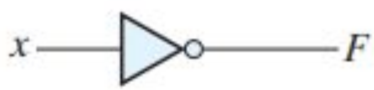
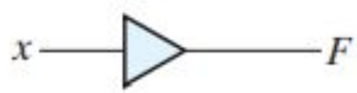
Sol-1: $Y = AB + A\overline{B}(\overline{\overline{A}\overline{B}})$

$$Y = AB + A\overline{B}(\overline{\overline{A}} + \overline{\overline{B}})$$

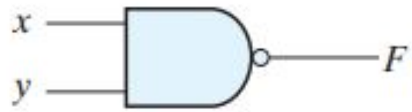
$$Y = AB + A\overline{B}(A + B)$$

$$Y = AB + A\overline{B}A + A\overline{B}B = AB + A\overline{B} = A$$

LOGIC GATES

Name	Graphic symbol	Algebraic function	Truth table
AND		$F = x \cdot y$	x y | F 0 0 | 0 0 1 | 0 1 0 | 0 1 1 | 1
OR		$F = x + y$	x y | F 0 0 | 0 0 1 | 1 1 0 | 1 1 1 | 1
Inverter		$F = x'$	x | F 0 | 1 1 | 0
Buffer		$F = x$	x | F 0 | 0 1 | 1

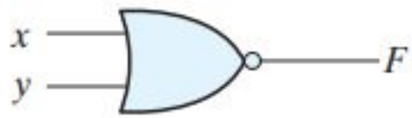
NAND



$F = (xy)'$

x	y	F
0	0	1
0	1	1
1	0	1
1	1	0

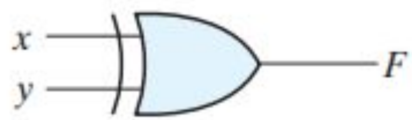
NOR



$F = (x + y)'$

x	y	F
0	0	1
0	1	0
1	0	0
1	1	0

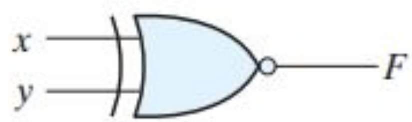
Exclusive-OR (XOR)



$$F = xy' + x'y = x \oplus y$$

x	y	F
0	0	0
0	1	1
1	0	1
1	1	0

Exclusive-NOR or equivalence



$$F = xy + x'y' = (x \oplus y)'$$

x	y	F
0	0	1
0	1	0
1	0	0
1	1	1

SUM OF PRODUCTS [SOP] AND PRODUCT OF SUMS [POS]

Logical functions (Boolean expression) are generally expressed in terms of logical variables (inputs) in following forms. (Each input variable can have the value, either 0 or 1 only)

- **SUM OF PRODUCTS [SOP] Ex: AB'+ BC+C'D**
- **PRODUCT OF SUMS [POS] Ex: (A'+B') (B'+C) (C'+D)**

MINTERMS

A product term containing all the inputs of the functions in either complemented or uncomplemented form is called ***MINTERMS.***

Let us consider 3 variable (input) function. It has 2^3 all possible combinations. [A 'n' variable (input) function has 2^n all possible combinations]. Let the inputs are A, B, C and output is Y.

TRUTH TABLE

	Inputs				Output
	A	B	C	MINTERMS	Y
0	0	0	0	A'B'C'	0
1	0	0	1	A'B'C	0
2	0	1	0	A'BC'	1
3	0	1	1	A'BC	1
4	1	0	0	AB'C'	1
5	1	0	1	AB'C	0
6	1	1	0	ABC'	1
7	1	1	1	ABC	0

- In minterms, 0 are assigned with bar letter and 1 are assigned with unbar letter.
- Within the row, all are multiplied (Product)
- Choose only the output 1.
- Add the minterms which having 1 output.
- In this example, we get Y= A′BC′ + A′BC+ AB′C′+ ABC′. This expression is called canonical SOP form. [Standard SOP form]
- Each input is assigned with it equivalent decimal value. In the truth table, only the output Y= 1 is chosen, it corresponding input′s decimal values are stated as below.

$$Y = \sum m\,(2,3,4,6)$$

MAXTERMS

A sum term containing all the inputs of the functions in either complemented or uncomplemented form is called ***MAXTERMS.*** Let us consider the same truth table.

	Inputs				Output
	A	B	C	MAXTERMS	Y
0	0	0	0	(A+B+C)	0
1	0	0	1	(A+B+C’)	0
2	0	1	0	(A+B’+C)	1
3	0	1	1	(A+B’+C’)	1
4	1	0	0	(A’+B+C)	1
5	1	0	1	(A’+B+C’)	0
6	1	1	0	(A’+B’+C)	1
7	1	1	1	(A’+B’+C’)	0

- In maxterms, 1 are assigned with bar letter and 0 are assigned with unbar letter.
- Within the row, all are summed (Added)
- Choose only the output 0.
- Product the maxterms which having 0 output.
- In this example, we get Y= (A+B+C) (A+B+C′) (A′+B+C′) (A′+B′+C′). This expression is called canonical POS form. [Standard POS form]
- Each input is assigned with it equivalent decimal value. In the truth table, only the output Y= 0 is chosen, it corresponding input′s decimal values are stated as below.

$$\mathbf{Y= \prod M\ (0,1,5,7)}$$

1. For the Boolean function given below, obtain the (i) canonical SOP form (ii) canonical POS form.

$Y(A,B,C) = A+B'C$

$= AXX + XB'C$

$= AB'C' + AB'C + ABC' + ABC + A'B'C + AB'C$

[Remove the common term; Since A+A=A]

$\mathbf{Y = AB'C' + AB'C + ABC' + ABC + A'B'C}$ [Canonical SOP form]

100 101 110 111 001

$\mathbf{(m_4 \quad m_5 \quad m_6 \quad m_7 \quad m_1)}$

$\mathbf{Y = \sum m\,(1,4,5,6,7)}$

$\mathbf{Y = \prod M\,(0,2,3)}$ **[** Minterms and Maxterms are complement with each other**]**

$\mathbf{M_0 \quad M_2 \quad M_3}$

000 010 011

$\mathbf{Y = (A+B+C)\,(A+B'+C)\,(A+B'+C')}$ [Canonical POS form]

Karnaugh maps/ K-map

If the number of input variables is more than 2, its very difficult to minimize the Boolean function by Boolean algebra. Karnaugh maps/ K map overcomes this difficulty.

Karnaugh maps/ K map

- A visual way to simplify logic expressions
- It gives the most simplified form of the expression
- K-Maps are a graphical technique used to simplify a logic equation.
- K-Maps can be used for any number of input variables, BUT are only practical for **two, three, and four variables**

General Structure of K-Map

Two variable (Inputs- A,B)

A \ B	0	1
0	0	1
1	2	3

Three variable (Inputs- A,B,C)

A \ BC	00	01	11	10
0	0	1	3	2
1	4	5	7	6

Four variable (Inputs- A,B,C,D)

AB \ CD	00	1	11	10
00	0	1	3	2
01	4	5	7	6
11	12	13	15	14
10	8	9	11	10

Procedure to minimize Boolean expression by K-map:

1. We have to cheek, number of variables (Inputs).

(i)If the maximum number in the Boolean expression is ≤3, it is 2 variable function.

(ii)If the maximum number in the Boolean expression is ≤7, it is 3 variable function.

(iii)If the maximum number in the Boolean expression is ≤15, it is 4 variable function.

Note: Some times, in the question itself, inputs will be given. Ex: $Y(A,B,C)=\sum(0,4,5,7)$

2. Check the given question is Minterms or Maxterms. If $\sum$ is given, it is Minterms. In K-map, for the given decimal location, we have to enter 1. In remaining location, we have to enter 0.

If $\prod$ is given, it is Maxterms. In K-map, for the given decimal location, we have to enter 0. In remaining location, we have to enter 0.

3. Draw the K-map and fill it. (use step 1 & 2)

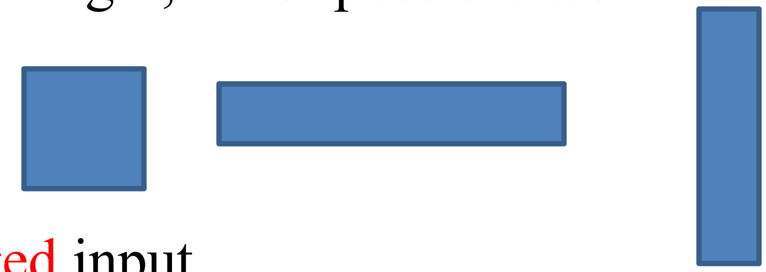
4 (a) Solution Procedure for SOP method

(i) We have box ALL the 1.

(ii) Larger the box, smaller the equation. Since all are minimization problem, we have chose larger box.

(iii) The number of 1′s inside the box must be 2^n. [ie we have to try boxing 16 , if not possible we have to try boxing 8, if not possible we have to try boxing 4, if not possible we have to try boxing 2, if not possible we have to box 1]

(iv) The shape of the box must be square or rectangular. ie



(v) For each box, we have to find unchanged input.

For that, we have see K-map from right to left, then bottom to top. The unchanged input within the box should be **product**. The product of one box should be sum with next box.[In input, 0 are assigned with bar letter and 1 are assigned with unbar letter]

(vi) Overlapping is allowed to make larger box.

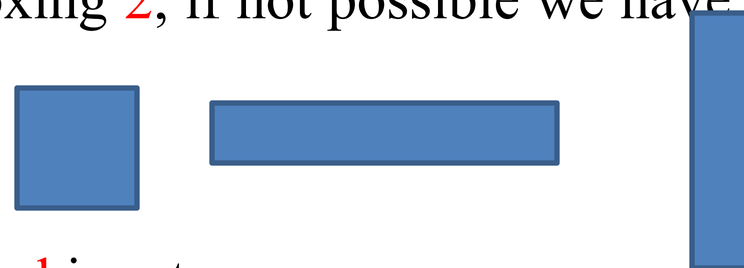
4 (b) Solution Procedure for POS method

(i) We have box ALL the 0.

(ii) Larger the box, smaller the equation. Since all are minimization problem, we have chose larger box.

(iii) The number of 0's inside the box must be 2^n. [ie we have to try boxing 16 , if not possible we have to try boxing 8, if not possible we have to try boxing 4, if not possible we have to try boxing 2, if not possible we have to box 1]

(iv) The shape of the box must be square or rectangular. ie



(v) For each box, we have to find unchanged inputs.

For that, we have see K-map from right to left, then bottom to top. The unchanged input within the box should be **summed**. The sum of one box should be product with next box.[In input, 1 are assigned with bar letter and 0 are assigned with unbar letter]

(vi) Overlapping is allowed to make larger box.

K-MAP-SOP METHOD

1 Simply the following Boolean expression

$Y(A,B,C) = \sum m(1,2,3,6,7)$

Method 1: Boolean Algebra

Binary of minterms: 001, 010, 011, 110, 111

$Y = A'B'C + A'BC' + A'BC + ABC' + ABC$

$Y = A'B'C + A'B[C' + C] + AB[C' + C]$

$Y = A'B'C + A'B + AB$

$Y = A'B'C + B[A + A']$

$Y = A'B'C + B$

$B + B'X = B + X$

$\mathbf{Y = A'C + B}$

1 Simply the following Boolean expression

Y (A,B,C)= $\sum m$ (1,2,3,6,7)

Method 2: K-MAP

Three variable (Inputs- A,B,C)

A \ BC	B'C' 00	B'C 01	BC 11	BC' 10
A' 0	0 (0)	1 (1)	1 (3)	1 (2)
A 1	0 (4)	0 (5)	1 (7)	1 (6)

1

2

Y=B+A'C

2 Simply the following Boolean expression

$Y\ (A,B,C) = \sum m\ (0,1,2,3,6)$

A \ BC	B'C' 00	B'C 01	BC 11	BC' 10
A' 0	1_{0}	1_{1}	1_{3}	1_{2}
A 1	$_{4}$	$_{5}$	$_{7}$	1_{6}

$Y = A' + BC'$

Three-Variable K-Map : Examples

$f = \Sigma(0,4) = \bar{B}\bar{C}$

A \ BC	00	01	11	10
0	1	0	0	0
1	1	0	0	0

$f = \Sigma(4,5) = A\bar{B}$

A \ BC	00	01	11	10
0	0	0	0	0
1	1	1	0	0

$f = \Sigma(0,1,4,5) = \bar{B}$

A \ BC	00	01	11	10
0	1	1	0	0
1	1	1	0	0

$f = \Sigma(0,1,2,3) = \bar{A}$

A \ BC	00	01	11	10
0	1	1	1	1
1	0	0	0	0

$f = \Sigma(0,4) = \bar{A}C$

A \ BC	00	01	11	10
0	0	1	1	0
1	0	0	0	0

$f = \Sigma(4,6) = A\bar{C}$

A \ BC	00	01	11	10
0	0	0	0	0
1	1	0	0	1

$f = \Sigma(0,2) = \bar{A}\bar{C}$

A \ BC	00	01	11	10
0	1	0	0	1
1	0	0	0	0

$f = \Sigma(0,2,4,6) = \bar{C}$

A \ BC	00	01	11	10
0	1	0	0	1
1	1	0	0	1

3. Simply the following Boolean expression

and implement it using logic gates

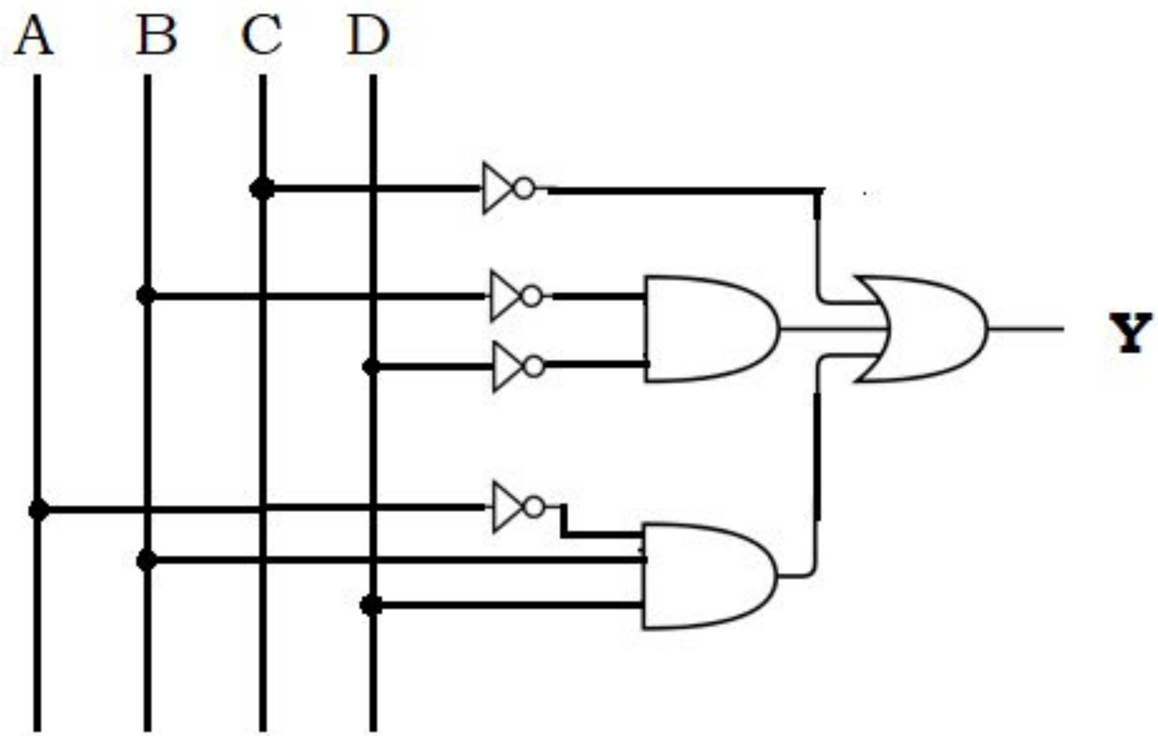
$Y(A,B,C,D) = \sum m(0,1,2,4,5,7,8,9,10,12,13)$

AB \ CD	C'D' 00	C'D 01	CD 11	CD' 10
A'B' 00	1 ₀	1 ₁	0 ₃	1 ₂
A'B 01	1 ₄	1 ₅	1 ₇	0 ₆
AB 11	1 ₁₂	1 ₁₃	0 ₁₅	0 ₁₄
AB' 10	1 ₈	1 ₉	0 ₁₁	1 ₁₀

$Y = C' + B'D' + A'BD$

Implementation

$Y=C'+B'D'+A'BD$



Four-Variable K-Maps Examples

AB \ CD	00	01	11	10
00	1	0	0	0
01	0	0	0	0
11	0	0	0	0
10	1	0	0	0

$f = \sum(0,8) = \overline{B} \bullet \overline{C} \bullet \overline{D}$

AB \ CD	00	01	11	10
00	0	0	0	0
01	0	1	0	0
11	0	1	0	0
10	0	0	0	0

$f = \sum(5,13) = B \bullet \overline{C} \bullet D$

AB \ CD	00	01	11	10
00	0	0	0	0
01	0	0	0	0
11	0	1	1	0
10	0	0	0	0

$f = \sum(13,15) = A \bullet B \bullet D$

AB \ CD	00	01	11	10
00	0	0	0	0
01	1	0	0	1
11	0	0	0	0
10	0	0	0	0

$f = \sum(4,6) = \overline{A} \bullet B \bullet \overline{D}$

AB \ CD	00	01	11	10
00	0	0	1	1
01	0	0	1	1
11	0	0	0	0
10	0	0	0	0

$f = \sum(2,3,6,7) = \overline{A} \bullet C$

AB \ CD	00	01	11	10
00	0	0	0	0
01	1	0	0	1
11	1	0	0	1
10	0	0	0	0

$f = \sum(4,6,12,14) = B \bullet \overline{D}$

AB \ CD	00	01	11	10
00	0	0	1	1
01	0	0	0	0
11	0	0	0	0
10	0	0	1	1

$f = \sum(2,3,10,11) = \overline{B} \bullet C$

AB \ CD	00	01	11	10
00	1	0	0	1
01	0	0	0	0
11	0	0	0	0
10	1	0	0	1

$f = \sum(0,2,8,10) = \overline{B} \bullet \overline{D}$

Four-Variable K-Maps Examples

AB \ CD	00	01	11	10
00	0	0	0	0
01	1	1	1	1
11	0	0	0	0
10	0	0	0	0

$f = \sum(4,5,6,7) = \overline{A} \bullet B$

AB \ CD	00	01	11	10
00	0	0	1	0
01	0	0	1	0
11	0	0	1	0
10	0	0	1	0

$f = \sum(3,7,11,15) = C \bullet D$

AB \ CD	00	01	11	10
00	0	0	0	1
01	0	0	0	1
11	0	0	0	1
10	0	0	0	1

$f = \sum(2,6,10,14)$

$f = C\overline{D}$

AB \ CD	00	01	11	10
00	0	0	0	0
01	0	0	0	0
11	1	1	1	1
10	0	0	0	0

$f = \sum(12,13,14,15) = AB$

AB \ CD	00	01	11	10
00	0	1	1	0
01	0	1	1	0
11	0	1	1	0
10	0	1	1	0

$f = \sum(1,3,5,7,9,11,13,15)$

$f = D$

AB \ CD	00	01	11	10
00	1	0	0	1
01	1	0	0	1
11	1	0	0	1
10	1	0	0	1

$f = \sum(0,2,4,6,8,10,12,14)$

$f = \overline{D}$

AB \ CD	00	01	11	10
00	0	0	0	0
01	1	1	1	1
11	1	1	1	1
10	0	0	0	0

$f = \sum(4,5,6,7,12,13,14,15)$

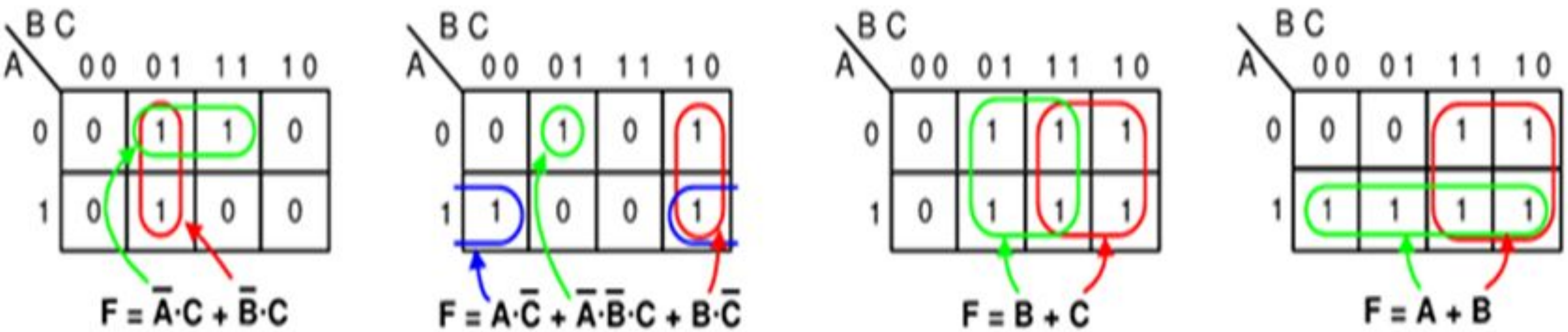
$f = B$

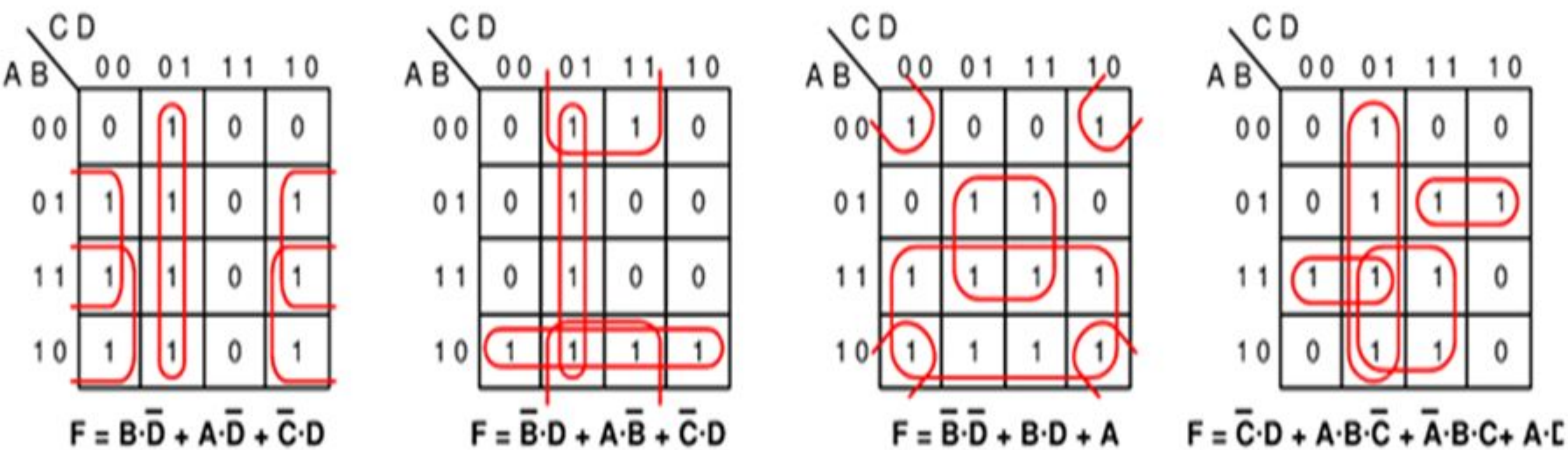
AB \ CD	00	01	11	10
00	1	1	1	1
01	0	0	0	0
11	0	0	0	0
10	1	1	1	1

$f = \sum(0,1,2,3,8,9,10,11)$

$f = \overline{B}$

3,4-Variable K-Maps Examples





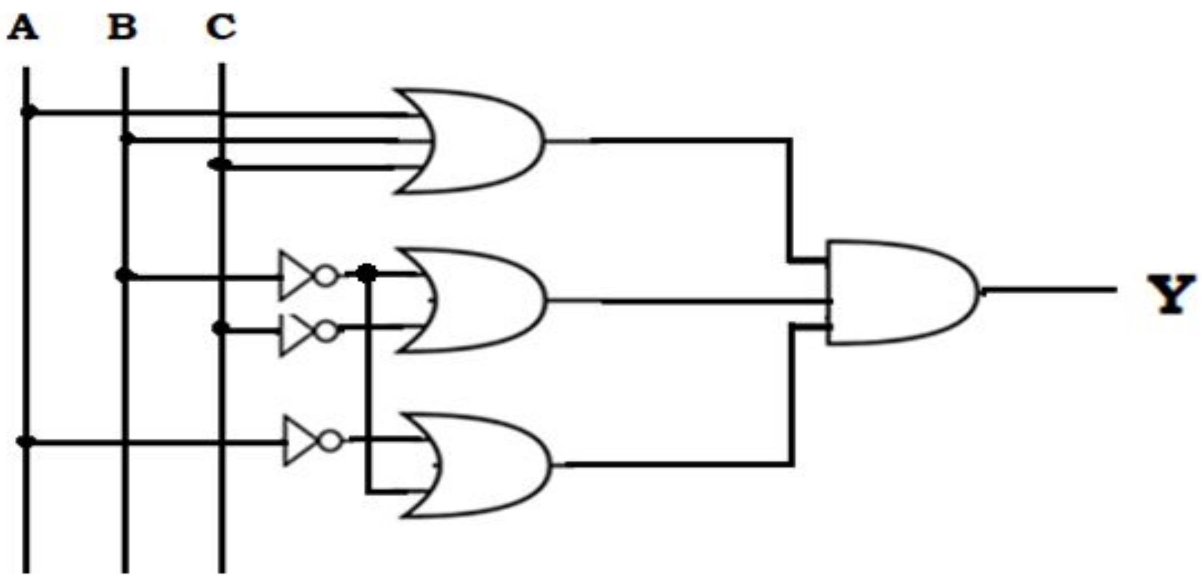
K-MAP-POS METHOD

1. Simply the following Boolean expression by POS method and implement it using logic gates

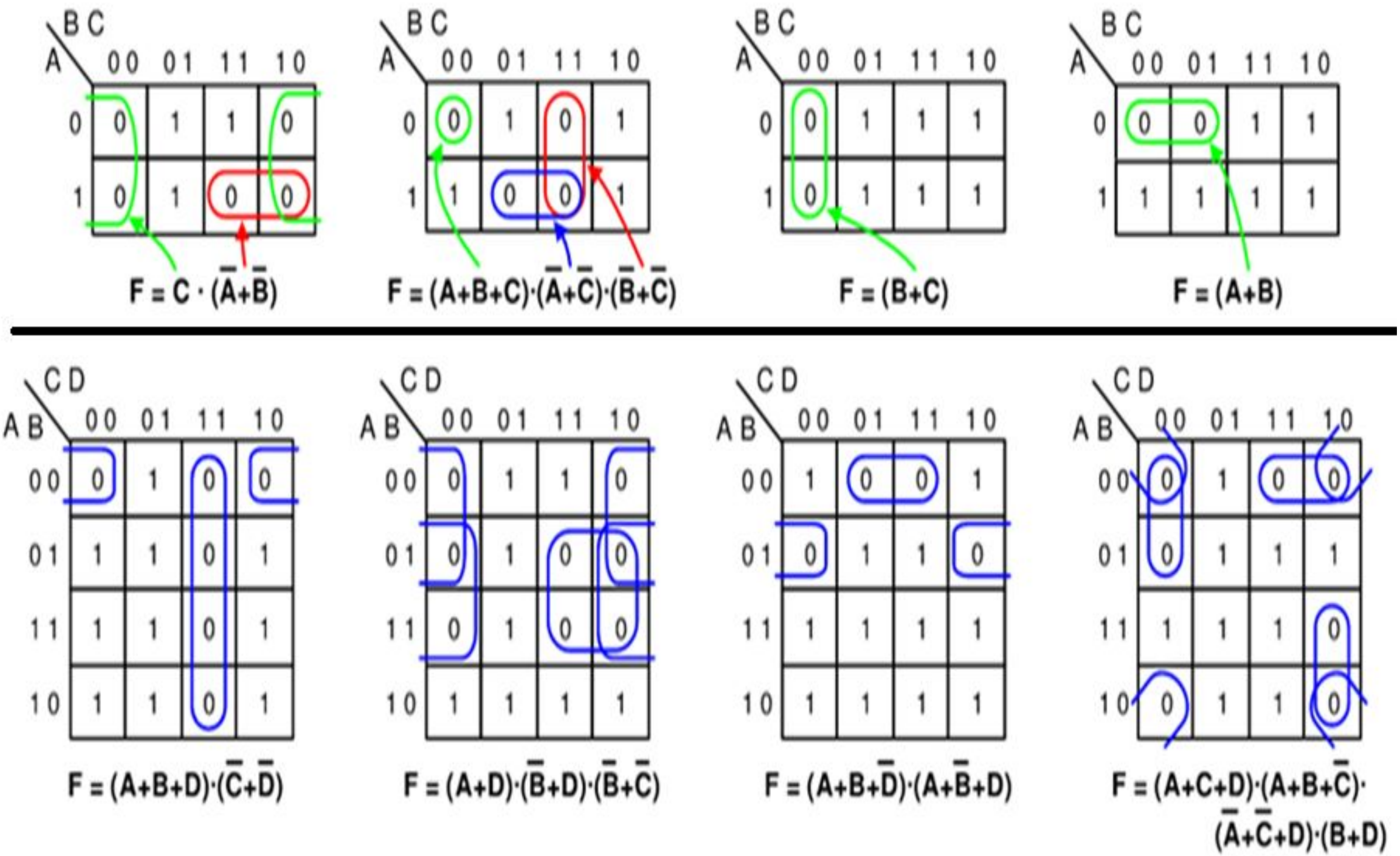
$Y(A,B,C) = \prod m(0,3,6,7)$

A \ BC	BC 00	BC' 01	B'C' 11	B'C 10
A 0	0 (0)	1 (1)	0 (3)	1 (2)
A' 1	1 (4)	1 (5)	0 (7)	0 (6)

$Y = (A+B+C).(B'+C').(A'+B')$



3,4-Variable K-Maps Examples [POS]

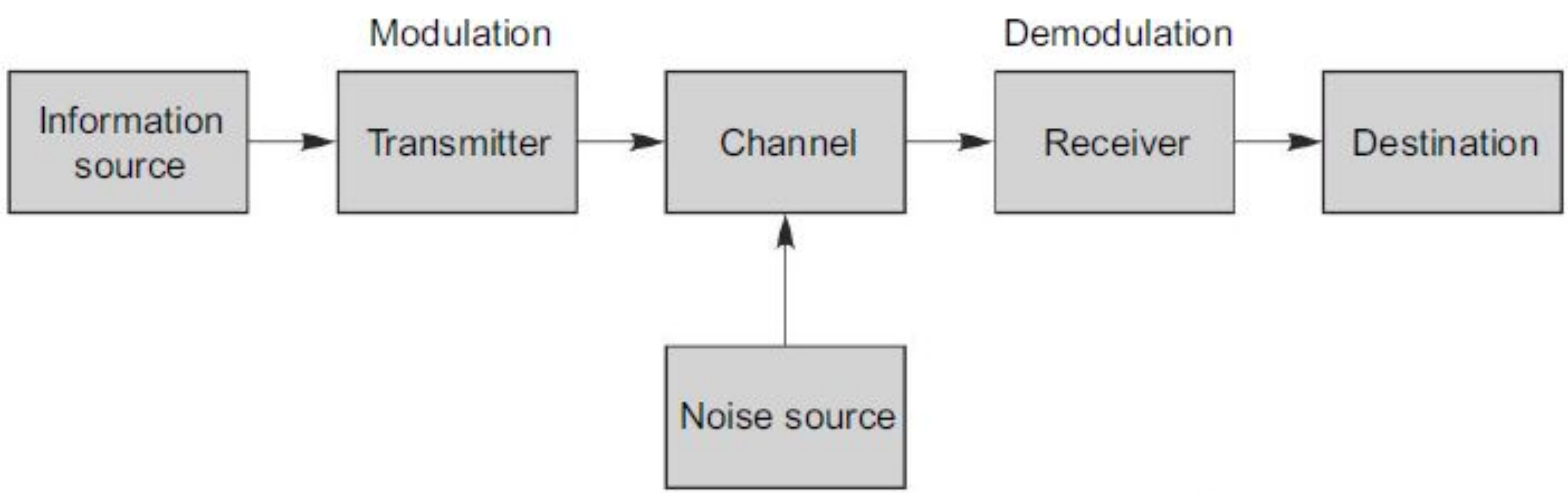


COMMUNICATION SYSTEMS

Communication is a process of transfer of information bearing signals from one place to another. The equipment that transmits the information is the transmitter and the equipment that receives the information is the receiver. Channel is the medium through which the signal travels from the transmitter to the receiver. Telegraphy, telephony, facsimile, radio broadcast, TV transmission and computer communication are a few examples of communication services.

Block Diagram of Communication System

The basic function of a communication system is to communicate a message. The block diagram of a communication system is shown



The information to be transmitted is given by the information source. In most of the cases, the information will be non-electrical in nature. For example, audio signals in speech transmission and picture signals in television transmission. This information in the original form is converted into a corresponding electrical variation known as the message signal by using a transmitter. This message signal cannot be directly transmitted due to various reasons. Hence this message signal is superimposed on a high frequency carrier signal before transmission. This process is referred to as modulation.

After modulation, the modulated carrier is amplified by using power amplifiers in the transmitter and fed to the transmitting antenna. Channel is a medium through which the signal travels from the transmitter to the receiver. There are various types of channels, such as the atmosphere for radio broadcasting, wires for line telegraphy and telephony and optical fibers for optical communication.

As the signal gets propagated through the channel, it is attenuated by various mechanisms and affected by noise from the external source. Noise is an unwanted signal that interferes with the reception, of wanted signal. Noise is usually of random nature and in the design of communication system, careful attention should be paid to minimize the effect of noise on the reception of wanted signals.

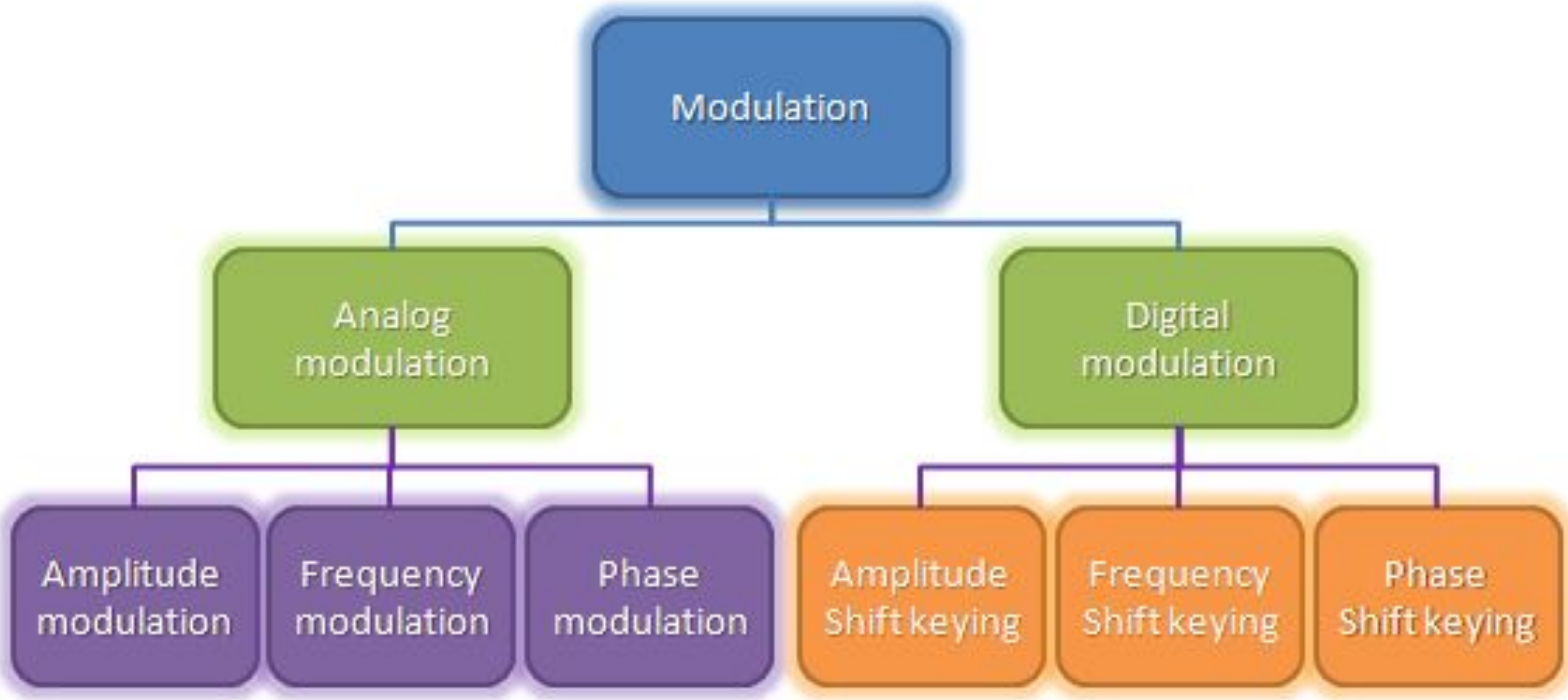
At the receiving end, a weak modulated carrier that is transmitted from the transmitter is received. As the received signal power will be very small, it is first of all amplified to increase the power level and the process of demodulation is done to recover the original message signal from the modulated carrier. The recovered message signal is further amplified to drive the output transducer such as a loud speaker or a TV receiver.

Electromagnetic Spectrum for Various Communication Services

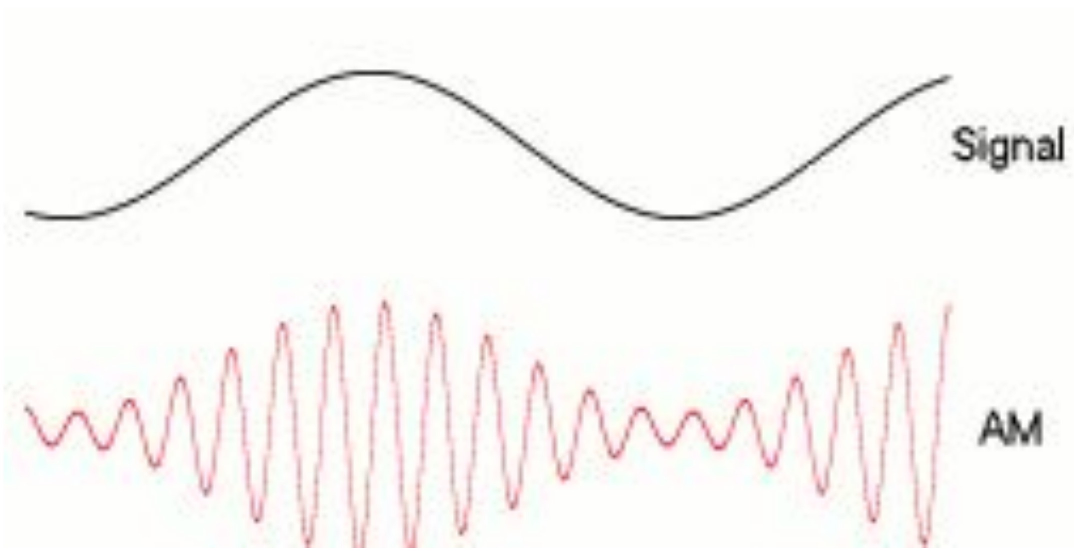
Classification	*Frequency Range*	*Wavelength*	*Uses*
Very Low Frequencies (V.L.F.)	10–30 kHz	30–10 km	Long distance point to point communications
Low Frequencies (L.F.)	30–300 kHz	10–1 km	Long distance point to point communication, Marine, Navigation, Power Line Carrier communication and Broadcast
Medium Frequencies (M.F.)	300–3000 kHz	1000–100 metres	Power Line Carrier communication, Broadcast, Marine communications, Navigation and harbour telephone
High Frequencies (H.F.)	3–30 MHz	100–10 metres	Moderate and long range communication of all types, Broadcast
Very High Frequencies (V.H.F.)	30–300 MHz	10–1 metres	Short distance communications, TV and FM broadcast, Data communication, Mobile and Navigation systems
Ultra High Frequencies (U.H.F.)	300–3000 MHz	1–0.1 metres	Short distance communications, TV broadcast, Radar, Mobile, Navigation and Microwave relay systems
Super High Frequencies (S.H.F.)	3–30 GHz	10–1 cms	Radar, Microwave relay and navigation systems
Extremely High Frequencies (E.H.F.)	30–300 GHz	1–0.1 cm	Radar, Satellite, Mobile, Microwave relay and navigations

BASIC PRINCIPLES OF MODULATION

Modulation is the process of changing some parameter of a high frequency carrier signal in accordance with the instantaneous variations of the message signal. The carrier signal has a constant amplitude and frequency. The function of a carrier signal is to carry the message signal and hence the name. The message or modulating signals are low frequency audio signals which contain the information to be transmitted. Generally message signal ranges from 20 Hz to 20 kHz.



Amplitude modulation (**AM**) is a modulation technique used in electronic communication, most commonly for transmitting messages with a radio carrier wave. In amplitude modulation, the amplitude (signal strength) of the carrier wave is varied in proportion to that of the message signal, such as an audio signal.



In amplitude modulation, the amplitude or *strength* of the carrier oscillations is varied. For example, in AM radio communication, a continuous wave radio-frequency signal (a sinusoidal carrier wave) has its amplitude modulated by an audio waveform before transmission. The audio waveform modifies the amplitude of the carrier wave and determines the *envelope* of the waveform. In the frequency domain, amplitude modulation produces a signal with power concentrated at the carrier frequency and two adjacent sidebands. Each sideband is equal in bandwidth to that of the modulating signal, and is a mirror image of the other. Standard AM is thus sometimes called "double-sideband amplitude modulation" (DSBAM). Single-sideband amplitude modulation.

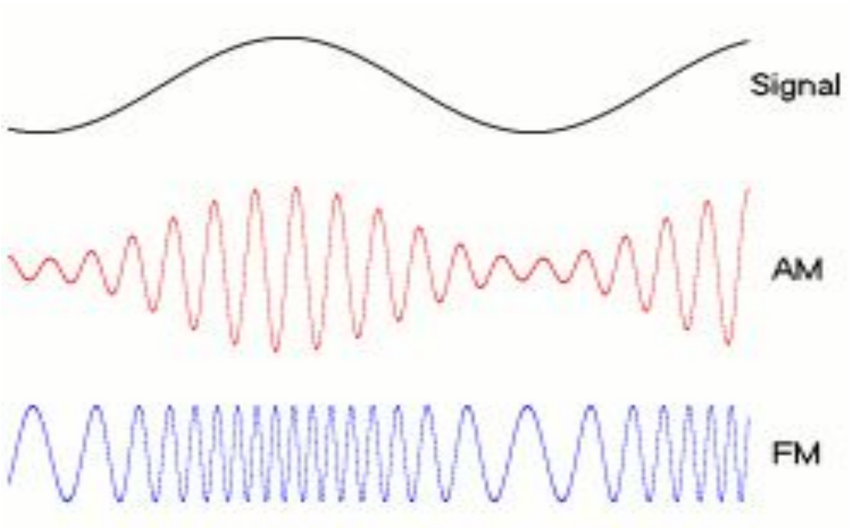
A disadvantage of all amplitude modulation techniques, not only standard AM, is that the receiver amplifies and detects noise and electromagnetic interference in equal proportion to the signal. AM broadcast is not favored for music and high fidelity broadcasting, but rather for voice communications and broadcasts (sports, news, talk radio etc.).

AM is also inefficient in power usage; at least two-thirds of the power is concentrated in the carrier signal.

Frequency modulation (FM) is the encoding of information in a carrier wave by varying the instantaneous frequency of the wave. The technology is used in telecommunications, radio broadcasting, signal processing, and computing.

In frequency modulation, such as radio broadcasting, of an audio signal representing voice or music, the instantaneous frequency deviation, i.e. the difference between the frequency of the carrier and its center frequency, has a functional relation to the modulating signal amplitude.

Frequency modulation is widely used for FM radio broadcasting.



It is also used in telemetry, radar, seismic prospecting, and monitoring newborns for seizures via EEG, two-way radio systems, sound synthesis, magnetic tape-recording systems and some video-transmission systems. In radio transmission, an advantage of frequency modulation is that it has a larger signal-to-noise ratio and therefore rejects radio frequency interference better than an equal power amplitude modulation (AM) signal. For this reason, most music is broadcast over FM radio.

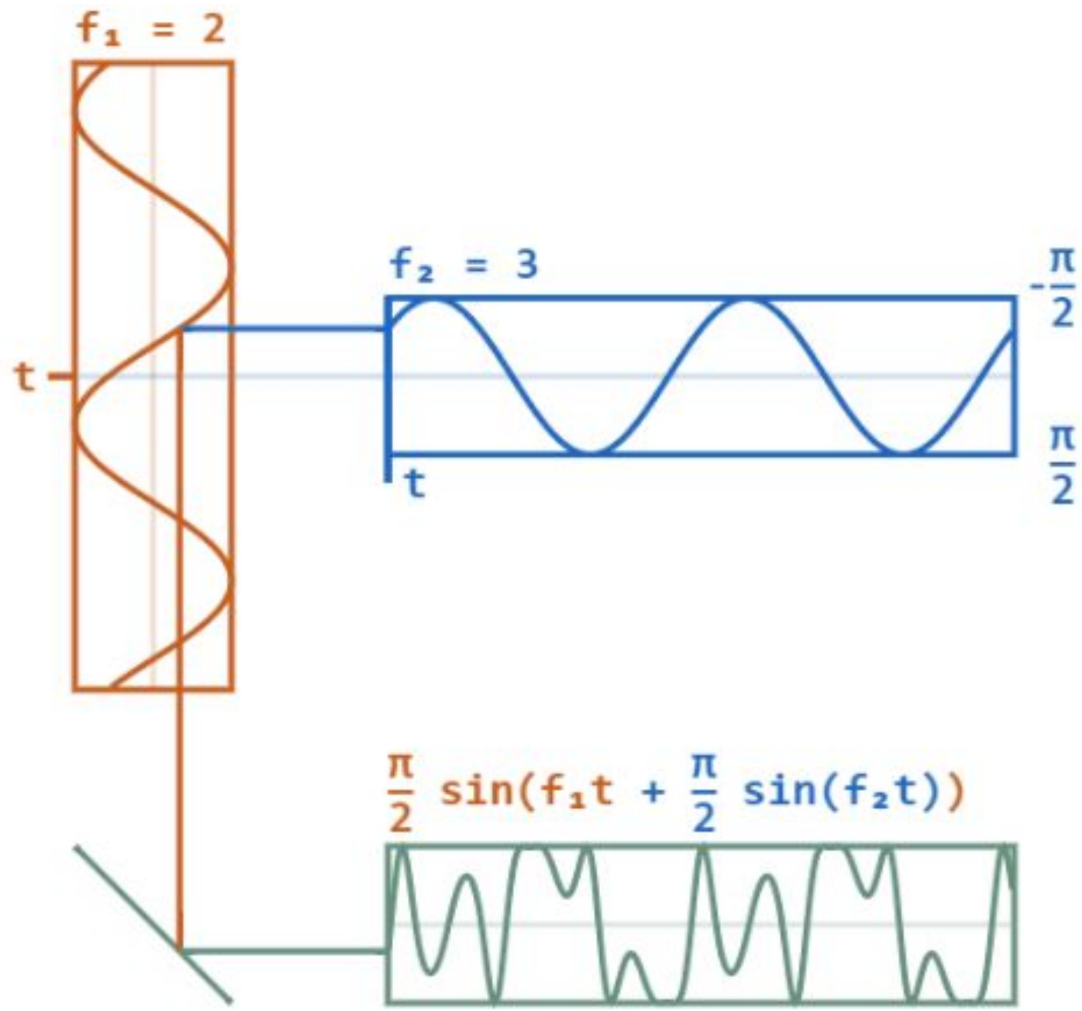
Frequency modulation and phase modulation are the two complementary principal methods of angle modulation; phase modulation is often used as an intermediate step to achieve frequency modulation. These methods contrast with amplitude modulation, in which the amplitude of the carrier wave varies, while the frequency and phase remain constant.

Phase modulation (PM) is a modulation pattern for conditioning communication signals for transmission. It encodes a message signal as variations in the instantaneous phase of a carrier wave. Phase modulation is one of the two principal forms of angle modulation, together with frequency modulation.

The phase of a carrier signal is modulated to follow the changing signal level (amplitude) of the message signal. The peak amplitude and the frequency of the carrier signal are maintained constant, but as the amplitude of the message signal changes, the phase of the carrier changes correspondingly.

Phase modulation is widely used for transmitting radio waves and is an integral part of many digital transmission coding schemes that underlie a wide range of technologies like Wi-Fi, GSM and satellite television.

PM is used for signal and waveform generation in digital synthesizers, such as the Yamaha DX7, to implement FM synthesis. A related type of sound synthesis called phase distortion is used in the Casio CZ synthesizers.



The modulating wave (blue) is modulating the carrier wave (red), resulting the PM signal (green). $g(t) = \pi/2 * \sin(2*2\pi t+ \pi/2*\sin(3*2\pi t))$

Demodulation is extracting the original information-bearing signal from a carrier wave. A **demodulator** is an electronic circuit that is used to recover the information content from the modulated carrier wave. There are many types of modulation so there are many types of demodulators. The signal output from a demodulator may represent, images or binary data.

There are several ways of demodulation depending on how parameters of the base-band signal such as amplitude, frequency or phase are transmitted in the carrier signal. For example, for a signal modulated with a linear modulation like AM , we can use a synchronous detector. On the other hand, for a signal modulated with an angular modulation, we must use an FM demodulator or a PM demodulator. Different kinds of circuits perform these functions.

Many techniques such as carrier recovery, clock recovery, bit slip, frame synchronization, rake receiver, pulse compression, Received Signal Strength Indication, error detection and correction, etc., are only performed by demodulators, although any specific demodulator may perform only some or none of these techniques.

AM demodulators:

An AM signal encodes the information into the carrier wave by varying its amplitude in direct sympathy with the analogue signal to be sent. There are two methods used to demodulate AM signals:

1.The **envelope detector** is a very simple method of demodulation that does not require a coherent demodulator. It consists of an envelope detector that can be a rectifier (anything that will pass current in one direction only) or other non-linear component that enhances one half of the received signal over the other and a low-pass filter. The rectifier may be in the form of a single diode or may be more complex. Many natural substances exhibit this rectification behavior, which is why it was the earliest modulation and demodulation technique used in radio. The filter is usually an RC low-pass type but the filter function can sometimes be achieved by relying on the limited frequency response of the circuitry following the rectifier. The crystal set exploits the simplicity of AM modulation to produce a receiver with very few parts, using the crystal as the rectifier and the limited frequency response of the headphones as the filter.

2.The **product detector** multiplies the incoming signal by the signal of a local oscillator with the same frequency and phase as the carrier of the incoming signal. After filtering, the original audio signal will result.

<u>FM demodulators</u>:

- The quadrature detector, which phase shifts the signal by 90 degrees and multiplies it with the unshifted version. One of the terms that drops out from this operation is the original information signal, which is selected and amplified.
- The signal is fed into a PLL and the error signal is used as the demodulated signal.
- The most common is a Foster-Seeley discriminator. This is composed of an electronic filter which decreases the amplitude of some frequencies relative to others, followed by an AM demodulator. If the filter response changes linearly with frequency, the final analog output will be proportional to the input frequency, as desired.
- A variant of the Foster-Seeley discriminator called the ratio detector
- Another method uses two AM demodulators, one tuned to the high end of the band and the other to the low end, and feed the outputs into a difference amplifier.

Using a digital signal processor, as used in software-defined radio.