Learning Objectives

After completing this unit, the student will be able to understand

- The meaning of resistance, its units and their types.
- The constructional details of various types of resistors.
- Colour coding of the resistors.
- Total resistance of two or more resistors connected in
  a) series and b) parallel.
- Difference between fixed resistors and variable resistors.
- Specifications of resistors.
- Specific resistance and temperature coefficient of resistance.
- Common troubles in resistors.

1.1 Introduction

It is one of the most important component used in electronic circuits. Resistance has been defined as the opposition to the flow of current. This opposition comes from the electrons present in the atom of a material. In materials like copper, the electrons are more free to move about than the electrons in a material like rubber. In other words, copper has less resistance than rubber.
1.2 The Unit of Resistance

The practical unit of resistance is ohm. A conductor is said to have a resistance of one ohm if it permits one ampere current to flow through it when one volt is impressed across its terminals. The symbol for ohm is $\Omega$ and resistance is denoted by the symbol R.

For insulators whose resistances are very high, a much bigger unit is used i.e., Megaohm = $1 \times 10^6$ ohm or Kilo-ohm = $10^3$ ohm. In the cases of very small resistances, smaller, units like milli-ohm = $10^{-3}$ ohm or micro-ohm = $10^{-6}$ ohm are used.

![Fig. 1.1 Circuit Symbol of Resistance]

<table>
<thead>
<tr>
<th>Prefix</th>
<th>Its meaning</th>
<th>Abbreviation</th>
<th>Equal to</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mega</td>
<td>One million</td>
<td>M</td>
<td>$10^6 \Omega$</td>
</tr>
<tr>
<td>Kilo</td>
<td>One thousand</td>
<td>KΩ</td>
<td>$10^3 \Omega$</td>
</tr>
<tr>
<td>Milli</td>
<td>One thousand</td>
<td>M Ω</td>
<td>$10^{-3} \Omega$</td>
</tr>
<tr>
<td>Micro</td>
<td>One Millianth</td>
<td>M Ω</td>
<td>$10^{-6} \Omega$</td>
</tr>
</tbody>
</table>

1.3 Types of Resistors

Basically there are two types of resistors. 1. Fixed resistors and 2. Variable resistors. Resistors whose value can not be changed are called fixed resistors. Resistors whose value can be changed or varied are known as variable resistors.

1.4 Types of Resistors

They are of two types carbon resistors and wire-wound resistors.

**Carbon resistors:** These can be either carbon composition resistors or carbon film resistors.
(a) Carbon Composition resistors are made by mixing granules of carbon with a binding material and moulded in the form of rods as shown in fig 1.2. wire leads are inserted at the two ends and the package is sealed with a non-conducting coating.

(b) Carbon Film Resistors are types of carbon resistors made by depositing a carbon film on a ceramic rod. The value of the resistance is set by cutting a spiral groove through the film. The groove adjusts the length and the width of the ribbon so that the desired value of the resistor is reached.

Carbon resistors are available in value varying from 1 Ω to 20 M Ω. These are made by wrapping a known length of wire of a nickel – chrome always called nichome over a from made of ceramic Advance and manganin wires are also used for the construction of wire wound resistors. All these materials have a much higher resistivity than copper. After taking out leads the entire winding is coated with a protective coating.

(c) Wirewound Resistors

Since the length of the wire required increases with the ohmic value of the resistance, the range of these resistors is from less than 1 Ω to several thousand ohms.
These resistors are used in circuits carrying high current when relatively high amounts of power are dissipated. Wire wound resistors are used in precision instruments where stable and accurate resistance values are required. Wire wound resistor is shown in fig 1.3.

### 1.5 Variable Resistors

The most common type of variable resistor is known as the potentiometer or simply POT as shown in the fig 1.4. This is used as volume control in radio and TV sets. The resistance value can be varied by the rotation of a shaft fixed at the end. A volume control is generally combined with an On/Off switch for power supply which can be operated from the common shaft.

The construction of a potentiometer is shown in fig 1.4. In this potentiometer, a movable contact slides over a strip of carbon. The resistance between terminals 1 and 3 is fixed and is the maximum value marked on the body of the potentiometer.

When the movable arm slides from left to right or a clockwise the resistance between points 1 and 2 increases and that between points 2 and 3 decreases. The variation of resistance is not uniform in the case of carbon potentiometers.

![Fig. 1.4 Potentiometer](image)

For uniform variation of resistance and for precision work, wire wound potentiometers are used. These have wire wound elements in place of carbon strips are available in 1, 2, 3 and 4 volts wire-wound potentiometer is shown in

When continuous variation of the resistance is not required, a tapped resistance is used. Fixed taps are provided at a number of points an a wire-wound resistance. A sliding contact on a bare wire resistance will vary the resistance in any of the convenient steps. Table 1.6 shows comparison of wire-wound and metal film carbon resistors.
The differences between the above three types of Resistors are shown in the table 1.2

<table>
<thead>
<tr>
<th>Carbon Resistors</th>
<th>Metal Film Resistors</th>
<th>Wire wound Resistors</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. These are manufactured using the carbon granuals mixed with resin, binder and flux.</td>
<td>1. These are manufactured by depositing a film of metal alloys us a ceramic or glass body.</td>
<td>1. These are manufactured using Nichrome wires.</td>
</tr>
<tr>
<td>2. These are available in high resistance values ranging from 1 Ω to 10 MΩ.</td>
<td>2. These are available in low resistance values.</td>
<td>2. These are available in the resistance values from 0.1 to Ω150K.</td>
</tr>
<tr>
<td>3. These are available in the low power ratings ranging from 1/8 watt to 2 watt.</td>
<td>3. These are available in the low power ratings ranging from 1/8 to 2 w.</td>
<td>3. These are available at high power ratings in the order of kilowatts.</td>
</tr>
<tr>
<td>4. Carbon resistors occupy less space in circuits due to their small in size.</td>
<td>4. These are also occupy less space in circuits due to their small in size.</td>
<td>4. Wire wound resistors occupy more space in circuits due to their large size.</td>
</tr>
<tr>
<td>5. The value of the resistor is coded using colour code.</td>
<td>5. The value of the resistor is coded using colour code.</td>
<td>5. The value of the resistor is printed on it.</td>
</tr>
<tr>
<td>6. These are used at high and low frequencies for their noise less operation.</td>
<td>6. These are also used for noise less operation at high frequency.</td>
<td>6. These are not used at high frequencies due to noisy operation.</td>
</tr>
<tr>
<td>7. These have low current carrying ability.</td>
<td>7. These have low and medium current carrying ability.</td>
<td>7. These have high current carrying ability.</td>
</tr>
</tbody>
</table>
1.7 Preset

These Presets are just smaller versions of a variable resistor. They can be easily placed on a PCB and can be adjustable when needed. The value of resistance is commonly adjusted with the help of a screw-driver. They are mostly used in applications like adjusting the frequency of an alarm tone or to adjust sensitivity of circuits. These are also highly precise presets which have multi-turn options. In this type, the resistance will increase/decrease only slowly and hence the screw has to be rotated many times. Here also the basic slider and track mechanism is used. The track mechanism is always linear.

![Fig. 1.7](image)

Most of the variable resistors are placed directly on the PCB some are mounted by drilling hole in the case containing the circuit and is connected to the terminals with the help of a wire.

In recent years, the size as well as the weight of such devices have been greatly reduced which makes it more suitable for any field of electronics.

1.8 Color Code for Carbon Resistors

The ohmic value and the tolerance of a carbon resistor is indicated by a color code. Ten colors are used to represent each of the digits from zero to nine as indicated below in table 1.4.

<table>
<thead>
<tr>
<th>Colour</th>
<th>Digit</th>
<th>Colour</th>
<th>Digit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black</td>
<td>0</td>
<td>Green</td>
<td>5</td>
</tr>
<tr>
<td>Brown</td>
<td>1</td>
<td>Blue</td>
<td>6</td>
</tr>
<tr>
<td>Red</td>
<td>2</td>
<td>Violet</td>
<td>7</td>
</tr>
<tr>
<td>Orange</td>
<td>4</td>
<td>Grey</td>
<td>8</td>
</tr>
<tr>
<td>Yellow</td>
<td>$</td>
<td>White</td>
<td>9</td>
</tr>
</tbody>
</table>
In the case of carbon resistors having aerial leads, the colour bands are printed near one edge of the resistor as shown in fig 1.2. Reading from left the first significant figure the second and the third band indicates the multiplier (X10) or the number of zeroes to be added after the two significant figures. The tolerance is indicated by the fourth band or by its absence. A gold band indicates 5% tolerance, silver band 10% tolerance and no band 20% tolerance.

**Examples:** What is the value and tolerance of a carbon resistor which has the following bands starting from the left: Brown, Black, Red, Gold.

Brown, Blank, Red, Gold

```
1  0  00  ""  5%
```

![Fig. 1.8 Colour code chart for Carbon Resistor](image)

Example: What is the value and tolerance of a carbon resistor which has the following bands starting from the left : Brown, Black, Red, Gold.

Brown  Black  Red  Gold

1 0 00  

Therefore, the resistor value is \(1000 \Omega \pm 5\%\)

### 1.9 Resistors Under 1 \(\Omega\)

In their case, the third band is either gold or silver which serves as fractional multiplier. If the third band is gold, multiply the first two digits by 0.1. If it is silver, then multiply by 0.01. However, fourth band, as before, gives tolerance.
Example 2: Find the value of the Carbon resistor with the following colour bands

Red, Black, Gold, Gold

\[ 2 \ 0 \ \times \ 0.1 \ \ 5\% = 2\Omega \pm 5\% . \]

1.10 Specifications of a Resistor

The three important specifications of a resistor are i) Resistance value ii) Tolerance and iii) The power rating or wattage.

(i) **Resistance value**: This is the value of the resistance expressed in ohms e.g. \(10\Omega\), \(47\Omega\) or \(1M\Omega\). This resistance value is either written or stamped on the body of the resistor as in the case of wire wound resistors. In the case of carbon resistors (film), the value of the resistance is indicated by a colour code.

(ii) **Tolerance**: This is the variation on the value of the resistance that is expected from the exact value indicated. 5% tolerance in the case of \(100\Omega\) resistor will mean that its value can vary brain \(95\Omega\) to \(105\Omega\). Wire wound resistors as they are more exact in value and their tolerances are low.

(iii) **Wattage**: This is the maximum amount of heat in watts that can be dissipated by a resistor without damage to it. The physical size of a resistor gives an idea of its wattage. The larger the size of a resistor, the higher will be its wattage rating.

Carbon resistors generally have an low wattage of value \(1/8\), \(1/4\), \(1/2\) 1 or 2w. Wire-round resistors are available in higher wattage ratings from 5 w to several hundred watts.

1.11 Standard Value of Resistors

In practical electronic circuits, the values of the resistors required may lie within a very wide range. In most of the circuits, it is not necessary to use resistors of exact values. Even if a resistor in a circuit has a value which differs from the desired value by as much as 20% the circuit still works quiet satisfactorily. Therefore, it is not necessary to manufacture resistors of all the possible values. A list of readily available standard values of resistors appears in table 1.5.
Table 1.5 standard values of commercially available resistors.

<table>
<thead>
<tr>
<th>Ohm (Ω)</th>
<th>kilo ohms (kΩ)</th>
<th>Megohms (MΩ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>10</td>
<td>1.0</td>
</tr>
<tr>
<td>1.2</td>
<td>12</td>
<td>1.2</td>
</tr>
<tr>
<td>1.5</td>
<td>15</td>
<td>1.5</td>
</tr>
<tr>
<td>1.8</td>
<td>18</td>
<td>1.8</td>
</tr>
<tr>
<td>2.2</td>
<td>22</td>
<td>2.2</td>
</tr>
<tr>
<td>2.7</td>
<td>27</td>
<td>2.7</td>
</tr>
<tr>
<td>3.3</td>
<td>33</td>
<td>3.3</td>
</tr>
<tr>
<td>3.9</td>
<td>39</td>
<td>3.9</td>
</tr>
<tr>
<td>4.7</td>
<td>47</td>
<td>4.7</td>
</tr>
<tr>
<td>5.6</td>
<td>56</td>
<td>5.6</td>
</tr>
<tr>
<td>6.8</td>
<td>68</td>
<td>6.8</td>
</tr>
<tr>
<td>8.2</td>
<td>82</td>
<td>8.2</td>
</tr>
</tbody>
</table>

1.12 Uses of Resistors

(a) To establish proper values of circuit voltages due to IR drops

(b) To limit current and

(c) To provide load.

1.13 Resistor Troubles

The most common trouble with resistor is ‘Open’ which happens due to excessive current and heat. A colour or discoloured resistor should be discarded straight away though it will usually check good with a Multimeter.

1.14 Measurement of Resistance

Usually an ohmmeter or a multimeter is used to measure the resistance value of a resistor.

A popular type of resistance measurement involves the voltmeter ammeter method. Since the instruments required are usually available in most laboratories. If the voltage V across the resistor and the current I through the resistor are measured. The unknown resistance R, can be calculated by ohm’s law.

\[ R = \frac{V}{I} \text{ ohms} \]
1.15 Resistors in Series

When some conductors having resistances $R_1$, $R_2$ and $R_3$ etc are joined end-on-end, they are said to be connected in series.

Being a series circuit, it should be remembered that

(i) Current is the same through all the three conductors.

(ii) But voltage drop across each is different due to its resistance and is given by ohm’s Law and

(iii) Sum of the three voltage drops is equal to the voltage applied across the three conductors

\[ V = V_1 + V_2 + V_3 \]
\[ = IR_1 + IR_2 + IR_3 \]

But $V = IR$

Where $R$ is the equivalent resistance of the combination.

Therefore $IR = IR_1 + IR_2 + IR_3$

or $R = R_1 + R_2 + R_3$

The main characteristics of a series circuit are

1. Same current passes through all parts of the circuit.
2. Different resistors have their individual voltage drops.
3. Voltage drops are additive.
4. Applied voltage equals the sum of different voltage drops.
5. Resistances are additive.
6. Powers are additive.
1.16 Resistors in Parallel

Three resistors, as joined in fig. 1.10 are said to be connected in parallel.

In a parallel circuit

(i) P.D. across all resistances will remain same.

(ii) Current in each resistor is different and is given by ohm’s law and

(iii) The total current is the sum of the three separate currents.

\[
I = I_1 + I_2 + I_3
\]

\[
= \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}
\]

Now, \( I \) = current

\( V \) is the applied voltage and

\( R \) is the equivalent resistance of the combination.

Since \( \frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \)

or \( \frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \)

The main characteristics of a parallel circuit are

1. Same voltage acts across all parts of the circuit.
2. Different resistors have their individual current.
3. Branch currents are additive.
4. Conductance are additive.
5. Powers are additive.

**Example 3:** Find the total resistance of the circuit given below.

![Fig. 1.11](image)

It is clear that the three resistors are connected in series.

\[ R = R_1 + R_2 + R_3 = 2.5 + 3 + 1.5 = 7 \, \Omega \]

**Example 4:** Find the total resistance of the circuit given below

The three resistors are connected in parallel.

\[
\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} = \frac{1}{3} + \frac{1}{6} + \frac{1}{2}
\]

\[
\frac{2 + 1 + 3}{6} = \frac{6}{6} = 1 \, \Omega
\]

### 1.17 Factors Affecting the resistance of a material

The resistance \( R \) offered by a conductor depends on the following factors.

(i) It varies directly as its length \( L \)

(ii) It varies inversely as the cross section \( A \) of the conductor.

(iii) It depends on the nature of the material.

(iv) It also depends on the temperature of the conductor.

Neglecting the last factor for time being we can say that

\[ R \propto \frac{L}{A} \quad \text{or} \quad R = \frac{pL}{A} \]

Where \( p \) is a constant depending on the nature of the material of the conductor and is known as its specific resistance or resistivity.

In other words, specific resistance of a material may be defined as the resistance between the opposite faces of a meter cube of the material.
Units = ohm-metre or
    ohm-centimetre

1.18 Conductance

Conductance (G) is a reciprocal of resistance.

Units: The unit of conductance is Siemens (S) earlier, this unit was called mho (Ω⁻¹).

1.19 Effect of Temperature on Resistance

The effect of rise in temperature of metals is large and fairly regular for normal range of temperature. The temperature or resistance graph is straight line. Therefore metals have positive temperature co-efficient of resistance.

The increase of resistance of alloys, though in their case, the increase is relatively small and irregular. For some high resistance alloys like Eureka and Manganin, the increase in resistance is negligible over a considerable range of temperature.

The resistance of electrolytes, insulators and semi conductors is practically negligible hence they are said to posses zero temperature co-efficient of resistance.

Rheostat is a variable resistor with one terminal fixed and the other terminal connected. Always it is connected to the circuit in the series. It is available in the form of wire-wound.

Potentiometer is a variable resistor and is used to taps off of voltage in the circuit. Always it is connected in parallel to the circuit. It has three terminals.

Summary

1. Resistance is defined as the property of opposition to the blow of electric current.

2. The practical unit of resistance is ohms.

3. Resistors are of two types a) fixed resistors b) variable resistors

4. Resistors whose value can’t be charged are called fixed resistors. Ex: carbon resistor and wire wound resistors.

5. Resistors whose value can be charged or varied are called variable resistors. Ex: potentiometer.

6. Presets are the smaller versions of the variable resistor used for finer adjustments of a circuit sensitivity, frequency etc.
7. The resistance values are directly printed on their body in the case of wire resistors whose values are stable and accurate and can carry high currents with high power dissipation capabilities.

8. In the case of carbon resistors their values indicated by means of colour code. They are available in the wattage ratings of 1/8, 1/4, 1/2, 1/2 W.

9. The important specifications of a resistor are a) Resistance value b) Tolerance and c) Wattage.

10. The main use of a resistor are a) to provide required voltage drop in a circuit b) To limit current and c) to provide load in a circuit.

11. The most common trouble with resistor is open due to excess current or heat.

12. When two or more resistors are connected in series the total resistance is \[ R = R_1 + R_2 + R_3 \]

13. When 2 or more resistors are connected in parallel, the total resistance is

\[
\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}
\]

14. The resistance of a material depends on a) length b) area of cross connection c) nature of material d) temperature.

15. Specific resistance of a material may be defined as the resistance between the opposite faces of a meter cube of the material.

Units=ohm meter of ohm-centimeter.

16. Conductance is the reciprocal of resistance.

17. Metals have PTC, insulators, electrolytes have NTC and for certain alloys like eureka, Marganis etc have negligible resistance charge over a wide range of temperature.

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**Short Answer Type Questions**

1. Define resistance and mention its units.

2. Classify different types of resistors.

3. What are the applications of resistors?

4. What are the specifications of resistors?

5. Define wattage rating of resistors.
6. Define specific resistance and write its unit.
7. Define tolerance of a resistor.
8. \(3 \, \Omega\) and \(6 \, \Omega\) are connected in a) series b) parallel. Calculate total resistance in both the cases?
9. What factors effects the resistance value of a material?
10. Define conductance and mention its units?
11. What is the difference between rheostat and potentiometer?
12. Find the value of resistor
   With the following colours are imprinted on their body
   (a) Brown, Black, Brown, Gold
   (b) Yellow, Violet, Black, Silver.
   (c) Brown, Red, Red
   (d) Grey, White, Brown, Gold
13. Write the colour code for the resistors given below
    a) \(1 \, \Omega \pm 5\%\)
    b) \(8.2 \, k\Omega \pm 10\%\)
    c) \(270 \, \Omega \pm 20\%\)
    d) \(10 \, \Omega \pm 10\%\)

**Long Answer Type Questions**

1. Derive an expression for the total resistance of three resistors \(R_1, R_2, R_3\) connected in series?
2. Derive the formula for calculations the equivalent resistors of three resistors \(R_1, R_2, R_3\) are connected in parallel.
3. Explain the constructural details of wire wound resistors.
4. Write short note on colour code of resistors.
5. What is the effect of temperature on resistance.
6. Distinguish between carbon resistors and wire wound resistors?
Learning Objectives

After completing this unit, the student will be able to understand

1. Faraday’s laws of electromagnetic induction.
2. Lenz’s law
3. Self inductance and mutual inductance.
4. Factors affecting the value of inductance.
5. Constructional details of transformers.
6. Different types of transformer
7. The applications of transformer
8. The specifications of transformer.

2.1 Introduction

In many electronic circuits like frequency tuning circuits, oscillators etc inductors and transformers form the basic part of the circuit. In generation and inducement of AC voltage and current inductors play a vital role. Similarly in power circuits transformers play a vital role. In this chapter you will learn about the basic laws that are used to induce voltages, using electromagnetic induction.
Further regarding self inductance, mutual inductance and construction of transformers are given in the subsequent topics.

### 2.2.1 Electro Magnetic Induction

It is well known that whenever an electric current flows through a conductor a magnetic field is immediately brought into existence in the space surrounding the conductor or the converse of this is also the true i.e. when a magnetic field embracing a conductor moves relative to the conductor it produces a flow of electrons. This phenomenon where by an emf and current is induced in any conductor that is cut by a magnetic flux is known as electromagnetic induction.

These are the basic principles which are used in the inducement of voltages in generators and force in the magnetic circuit. For example in generators if we can rotate a coil in the magnetic field then voltages or emf will be induced in it. Thus using electromagnetic induction we can generate voltages in generators.

Similarly whenever an electric current flows through a conductor magnetic field is immediately brought into existence in the space surrounding the conductor if such a conductor is placed in a magnetic field then due to interaction of these two magnetic fields some force or torque will be produced in the coil. Using this principle devices or gadgets like loudspeakers, fans, motors etc., are working.

Thus using electromagnetic induction principle in two ways. We can generate AC voltage or force or torque in electric circuits. These are illustrated in the following fig 2.1

![Figure 2.1 Principle of Inducing Voltage and Force](image-url)
2.2.2 Faraday’s Laws of Electro Magnetic Induction

Faraday summed up the above facts in to the laws known as faraday law of electromagnetic induction.

First Law: It states that Whenever a conductor cuts magnetic flux an emf is induced in that conductor,(or) whenever the magnetic flux linked with a circuit changes in emf is always induced in it.

Second Law: It states The magnitude of the induced emf is equal to the rate of change in the flux linkages.

Explanation: Let a coil has N turns and flux through it changes from an initial value of $\Phi_1$ wb, to. The final value of $\Phi_2$ wb in time ‘t’ seconds. Then we know that by flux linkages is meant the product of number of turns by the flux linked with the coil, we have

Initial flux linkages $= N\Phi_1$

Final flux linkages $= N\Phi_2$

According to second law induced emf ‘e’ is equal to rate of change of flux linkages.

$$e = \frac{N\Phi_2 - N\Phi_1}{t}$$

Putting the above expression in differential form we get $e = \frac{d(N\Phi)}{dt}$ or $e = N \frac{d\Phi}{dt}$. Volt.

Usually a minus sign is given to the right hand side expression to signify the fact that the induced emf sets up current in such a direction that magnetic effect produced by it opposes the very cause producing it.

$$e = \frac{d(N\Phi)}{dt} \quad \text{or} \quad e = N \frac{d\Phi}{dt}. \text{Volt.}$$

Applications Domestic apparatus like motor, generators, transformers, IK-s galvanometers, loud speakers, micro phones etc… are operated on the basic principles of electromagnetic induction.

2.2.3 Lenz’s Law

The direction of induced emf or current may be found by Lenz’s Law. Lenz law state that the electromagnetically induced current always flow in such a direction that the action of the magnetic field set up by it tends to oppose the very cause which produces it.
2.3 Inductance

Inductance is the ability of the conductor to produce induced voltage when the varying current flows through it or it is the property of the coil by which there produces a opposite polarity’ voltage is called inductance of the coli. This is measured using the unit ‘HENRY’. Inductance is represented symbolically as shown in fig.2.2

![Fig. 2.2 Symbol of Inductance](image)

2.3.1 Inductance

The component which gives a definite value of inductance by winding a insulated conductor or a coil on a core is known as an inductor.

2.3.2 Classification of Inductance

Inductance can be classified in to two types.

1. Self inductance

2.3.3 Self Inductance

The ability of a conductor to induce voltage in itself when the current or flux changes in it is called inductance (or) the property of the coil due to which it opposes any increases or decreases of current or flux through it is known as self inductance.

Imagine a coil of wire to one shown in below fig 2.3 connected to battery through Rheostat. It is found that when ever an effort is made to increase current through it. It is always opposed by the instantaneous production of counter emf of self induction. Energy required to overcome this opposition is supplied by the battery. Similarly if now an effort is made to decrease the current then again it is delayed due to production of self induced emf this time in the opposite direction. This property of coil due to which it opposes any increase or decrease of current or flux through it is known as self inductance. It is measured in terms of coefficient self induction L. We know by experience that initially it is difficult to set a heavy body on to motion, but once in motion it is actually difficult to stop it. Similarly a coil having large induction it is initially difficult to established a current through it, but once established, it is equally difficult to withdraw it. The co-
efficient of self inductance of a coil is defined as the weber-turns per ampere in the coil. By definition \( L = N \Phi / I \) henry.

![Fig. 2.3 Self Inductance](image)

### 2.4 Factors Affecting the Value of Inductance

The following factors affect the inductance of coil. These are

1. **Number of turns**: The inductance of a coil is directly proportional to the square of the turns. Thus greater the number of turns of the coil, more the inductance because more voltage can be induced. Thus in the same area and length if the number of turns are doubled then the inductance increases four times.

2. **Area of the Coil**: If the area of each turn or thickness of the wire is increased then its inductance increases. This is because the resistance of the thin wire is large when compared to the thick wire. If the resistance is less then it’s inductance is more. Thus the inductance of the coil is directly proportional to its area or thickness.

3. **Length of the Coil**: Inductance of the coil \( L \) increases with more length for the same number of turns.

4. **Permeability** of the core inductance of the coil also increases with the permeability of the core.
5. **Distance Between the Turns:** Inductance of the coil is inversely proportional to the distance between the turns. It means that if we increase the distance between no of turns then the inductance will increases and vice versa. Thus inductance \( L = \mu_0 \mu_r n^2 A/L \).

### 2.5 Inductive Reactance

The opposition offered due to AC supply in a conductor is known as it's inductive reactance. This is denoted by the letter \( X_L \). It depends on the following factors.

1. It is directly proportional to the inductance of the coil.
2. It is directly proportional to the frequency

Mathematically \( X_L = 2\pi fL \). This is measured in ohms.

### 2.6 Mutual Inductance

The ability of one coil to produce voltage in the near by coil due to flow of variable current in the first coil is known as mutual inductance. This is represented by the letter \( M \) and is measured in henrys.

**Explanation:** Let two coils \( L_1 \) and \( L_2 \) are placed side by side as shown in fig 2.4 let some variable current will be allowed to flow through the coil \( L \) due to this variable current magnetic field will be produced around the coil.

This magnetic field will be variable and also fraction of this field will flows through the coil \( L_2 \) which will be placed beside it. According to faradays law of electromagnetic induction this variable magnetic field cuts the turns of the coil \( L_2 \) and hence produces some voltage in the coil \( L_2 \). This magnitude of the induced
emf in turns equals to the rate of change of flux linkages. Thus the ability of one coil to produce voltage in the near by coil is known as mutual inductance. This principle is used in transformers.

2.7 Coefficient of Coupling

The fraction of the magnetic flux from one coil linking another coil is the coefficient of coupling $K$ between the coils.

It can be expressed as

$$K = \frac{\text{Flux linkage between } L_1 \text{ and } L_2}{\text{Flux produced by } L_1}$$

Thus if all the flux of $L_1$ links with $L_2$ then the coefficient of the coupling $K=1$. The coefficient of coupling increases if the coils are closely placed. Mathematically coefficient of coupling $K$ is expressed as

$$K = \frac{M}{L_1 - L_2}$$

2.8.1 Inductance in Series

Series connections are of two types

1. Series aiding
2. Series opposing

2.8.2 Series - Aiding

When two coils be so joined in series that their fluxes (mmf) are additive i.e. in the same direction then such type of connection is known as ‘inductance series aiding’. This is shown in the below figure 2.5. Let A and B are two coils connected in series Aiding (i.e. their fluxes be additive).

Let $M =$ Coefficient of mutual inductance

$L_1 =$Coefficient of self inductance of coil A

$L_2 =$Coefficient of self inductance of coil B

Then self induced emf in A is $= e_1 - L_1 \frac{di}{dt}$.

Mutually induced emf in A due to change of current in B is $e_2 = -M \frac{di}{dt}$

Then self induced emf in B is $e_2 = L_2 \frac{di}{dt}$
Mutually induced emf in B due to change of current in A is \[ e_2 = -M \frac{dI}{dt} \].

Total induced emf in the combination = \[ -\frac{dI}{dt} - \left( L \right) = L_2 = 2M \] \[ ..........1 \]

If ‘L’ is the equivalent inductance then total induced emf in that single coil would be \[ -L \frac{dI}{dt} \] \[ ..........(2) \]

Equating 1 and 2 we have \[ L = L_1 + L_2 + 2M \]

Thus equation for total inductance in series aiding is \[ L = L_1 + L_2 + 2M \]

2.8.3 Series Opposing

When two coils so joined that their fluxes are in opposite direction as shown in low fig 2.6. Then such type of connection is known as ‘series opposing’. Let A and B are two coils in series opposing (i.e. their fluxes are subtractive).

Let \( M \) = co-efficient of mutual inductance

\( L_1 \) = co-efficient of self inductance of coil A.

\( L_2 \) = co-efficient of self inductance of coil B.

Then self induced emf in A is \[ e_1 = -L_1 I \frac{dI}{dt} \]

Mutually induced emf in A due to change of current in B is \[ e_1 = +M \frac{dI}{dt} \]

Self induced emf in B is \[ e_2 = L_2 \frac{dI}{dt} \].

Mutually induced emf in B due to change of current \[ =e_2 = -M \frac{dI}{dt} \]

Total induced emf in the combination = \[ \frac{dI}{dt} \left( L_1 + L_2 - 2M \right) \] \[ ..........1 \]

If ‘L’ is the equivalent induced emf in the single coil = \[ -\frac{dI}{dt} \] \[ ..........(4) \]

Equating 3 and 4 we have \[ L = L_1 + L_2 - 2M \]
Thus equation for total inductance in series opposing is \( L = \frac{L_1 + L_2 - 2M}{L_1} \)

**Fig. 2.6 Inductance connected in Series Opposing**

### 2.9 Inductance in Parallel

As shown in figure 2.7 two inductances of values \( L_1 \) and \( L_2 \) are connected in parallel. Let \( I \) be the main supply in current and \( i_1 \) and \( i_2 \) be branch currents.

In parallel we know that the total current \( i = i_1 + i_2 \)

Since the coils are in parallel their emf’s are equal. Therefore as in parallel resistance here also total inductance in parallel

\[
\frac{I}{\Delta} = \left( \frac{1}{L_1} \right) + \left( \frac{1}{L_2} \right), \ldots
\]

**Fig 2.7 Inductances Connected in parallel**

### 2.10 Solved Problems

1. Two choke coils of 20H and 40H and inductances are joined a) in series b) in parallel. What is the effective inductance in both conditions (neglect mutual inductance).

**Ans.** In series connection we know that total inductance:
Let \( L_1 = 20 \) H and \( L_2 = 40 \) H

Substituting these values in the above equation \( L = 20 + 40 = 60 \) H in parallel connection we know that

Total inductance \( L = \frac{1}{L_1} + \frac{1}{L_2} \)

\[ = \frac{1}{20} + \frac{1}{40} = 2 + \frac{1}{40} \]

\[ = \frac{1}{L} = \frac{3}{40} \]

\[ L = \frac{40}{3} = 13.3 \text{ H} \]

2. The inductance of two coils are 10 mh, 20 mh respectively and its co-efficient of coupling is 0.75. Calculate mutual inductance.

\textbf{Ans:} Inductance of first coil \( L_1 = 10 \text{ mil} \)

Inductance of second coil \( L_2 = 20 \text{ mil} \)

Co-efficient of coupling \( K = 0.75 \)

Mutual inductance \( M = K \sqrt{L_1 - L_2} \)

\[ = 0.75 \sqrt{10 \times 10^{-3} - 20 \times 10^{-3}} \]

\[ = 0.0106 \text{ OR } 10.6 \text{ mH} \]

3. The combined inductance of the coils connected in series aiding is 0.6 H their self inductance are 0.2H and 0.15H respectively. Calculate mutual inductance and co-efficient of coupling.

\textbf{Ans:} Total inductance in series aiding \( L = 0.6 \text{ H} \)

\( L_1 = 0.2 \)

\( L_2 = 0.15 \)
We know that in series Aiding \[ L = L_1 + L_2 + 2M \]

Substituting the values: 

\[ 0.6 = 0.2 + 0.15 + 2M \]

\[ 0.6 = 0.35 + 2M \]

\[ 2M = 0.6 - 0.35 \]

\[ = 0.25 \]

\[ M = 0.25 / 2 = 0.125 \text{ H} \]

We know that \( K = M / \sqrt{L_1 L_2} \)

\[ = 0.125 / \sqrt{0.2 \times 0.15} \]

\[ = 0.72 \]

4. Find the resultant inductance in series aiding and opposing when 0.9 H and 0.4 H are connected and mutual inductance between them is 0.3 H?

Ans: From the problem

\[ L_1 = 0.9 \text{ H} \]

\[ L_2 = 0.4 \text{ H} \]

\[ M = 0.3 \text{ H} \]

In series aiding \[ L = L_1 + L_2 + 2M \]

\[ = 0.9 + 0.4 + 2 \times 0.3 \]

\[ = 0.9 + 0.4 + 0.6 = 1.9 \text{ H} \]

In series opposing \[ L = L_1 + L_2 - 2M \]

\[ = 0.9 + 0.4 - 0.6 + 0.7 \text{ H} \]

5. Find the total inductance in series and parallel when 4H and 6H are connected. Neglect mutual inductance between them.

Ans: Let \( L_1 = 4 \text{ H} \)

\[ L_2 = 6 \text{ H} \]

Total inductance in series \[ L = L_1 + L_2 \]

\[ = 4 + 6 = 10 \text{ H} \]

Total inductance in parallel \[ I / L = 1 / 4 + 1 / 6 \]

\[ = 3 + 2 / 12 \]
\[ \frac{5}{12} \]

\[ L = \frac{12}{5} = 2.4 \text{ H} \]

### 2.11 Applications of Inductors

1. Inductors are used in chokes
2. These are used in receivers as oscillator coils and as antenna coils.
3. These are used in filter circuits.

### 2.12 Construction and Working of Transformer

The transformer is constructed by winding a coil on a core. In power transformers, the core is constructed with sheets of soft magnetic material in different shapes. These are known as laminations. Two types of core shape are in use: one is “core type” and the other is the “shell type.” In power transformers, shell type core is used. These are shown in the below fig 2.8. Two copper coils are wound on this core. One coil is known as the primary winding and another coil is known as the secondary coil. The assembly is placed in a metal case and the ends of the winding are soldered on a strip for external connection.

![Shell type and Core type Transformer](image)

**Fig. 2.8 Transformer**

**Working**

Whenever we apply A.C. power to the primary winding according to the principle of mutual inductance, it can induce voltage in the secondary winding. Here the magnitude of the voltage depends on the number of turns of the secondary windings. Thus, the transformer induces voltage in the secondary.

**Applications**

1. These are used in power supplies.
2. These are used in stabilizers.

3. These are used in Radio’s, TV’s and other electronic circuits.

### 2.13 Audio Frequency Transformers

**Construction and Working**

If the AF transformer is of the same construction as the power transformer with two windings wound on a core of laminated silicon steel. The laminated type of construction is preferred to the wound cut because the former introduces an air gap in the core. The gap helps to stabilize the core flux in the event of DC magnetization by any quiescent direct current flowing into the winding. The use of light permeability and radio metals reduce the size or to increase the frequency range of the transformer.

Power transformers are used to transmit energy at single frequency, but communication transformers are used to transmit intelligence of information, which are usually in the form of continuous waves within a specified frequency range. The A.F transformers gives the good performance over a band of frequencies in the audio range which may be from 30HZ to 30KHZ.

**Specifications:** Impedance matching 200/250Q to 2/5Q frequency range 30HZ TO 3030KHZ.

**Applications**

1. These are used at high frequencies in radio T.V. and satellite receiver circuits.

2. These are used in AF amplifiers for impedance matching.

### 2.14 R.F Transformers

The radio frequency transformers are used for providing amplification at high frequencies and acts as the load impedance in Amplifiers. These are used in tuning circuits and can be tuned over a wide band of frequencies.

These transformers use air core powdered iron core or ferrite cores. The air core coils are wound with wire over a wax paper or fibre bobbins. It has a multilayer winding in which the conductor spirals back and forth across the width of the winding as the winding is built up. These type of winding decreases the capacitance and large inductance can be obtained from small size coils.

**Specified frequency range:** 50KHZ-20MHZ

**Inductance:** 10mH-100Mh
Applications: These are used at high frequencies in radio TV and satellite receiver circuits.

### 2.15 Specifications of a Transformer

Specifications are the input and output ratings of a transformer. These are different for different transformers. The following factors are known as specifications of transformer.

1. Rating in KVA OR VA.
2. Rated voltage
3. Voltage ratio primary to secondary
4. Rated frequency (50HZ).
5. Tappings Ex: center tapping or multi winding
6. Turns ratio 300/100
7. Type of transformer EX: power supply
8. Inductance Ex: 2/5 H

### 2.16 Applications of Transformers

The various transformers are used for different applications in electronic circuits. These are given below

1. Power transformers are used in power supply circuits
2. IFT’S are used in radio’s and TV receivers.
3. EHT’S are used in TV receivers.
4. Pulse transformers are used in digital and telephone circuits.
5. Bain transformers are used for impedance matching in TV receivers.
6. Auto transformers are used in stabilizers.
7. A,F transformers are used in AF amplifiers for impedance matching and amplification.

### Summary

1. The phenomenon where by an e.m.f will be induced in a conductor that is cut across by a magnetic flux is known as electromagnetic flux.
2. According to Faraday’s first law an e.m.f will be induced in a conductor, when it cuts the magnetic flux.
3. According to Faraday’s second law, the magnitude of the induced e.m.f is directly proportional to the rate of change of flux linkages.

4. Lenz’s law states that an induced current always flows in such a direction so as to oppose the cause that produces it.

5. Inductance is the ability of a conductor to produce induced voltage when the varying current flows through it.

6. The inductance of an inductor depends on a) Number of turns b) area of coil or thickness of wire c) length of coil d) permeability of the core e) distance between the two turns.

7. The opposition offered by an inductor to A.C is known as inductive reactance.

8. The ability of one coil to provide voltage in a nearby coil due to changing current in the first coil is known as mutual inductance.


10. Transformers are classified as a) power transformer b) RF transformer c) IF transformer d) AF transformer.

**Short Answer Type Questions**

1. Define self inductance and mention its unit.

2. Define mutual inductance and mention its unit.

3. What is meant by electromagnetic induction.

4. Define Lenz law.

5. Why Lenz law is used.

6. Write the principle on which generators, motors, transformers are working.

7. What is meant by inductor?

8. What is meant by inductive reactance?

9. Define co-efficient of coupling?

10. Write the specifications of transformers?

11. Write the applications of transformer.

12. Draw the symbols of inductor and transformer.
13. Write the principle on which transformer works?

**Long Answer Type Questions**

1. State and explain Faraday’s laws of electromagnetic induction.
2. Explain the construction, working, and applications of power transformers.
3. Explain the construction working of AF and RF transformers.
4. Derive the equation for series aiding and series opposing connection in case of inductance connected in series.
5. Explain how the factors effecting the value of inductance.
6. Explain about self inductance and mutual inductance.
Learning Objectives

After completing this unit, the student shall be able to understand

- The meaning of capacitor and types.
- Factors affecting the capacitance of a capacitor.
- Dielectric strength and dielectric constant.
- Colour coding of capacitors.
- Losses in a capacitor.

3.1 Introduction

Capacitor is an electronic component which is made by two metallic plates separated by an insulating material. The device which can store electric charge in the form of static electricity is called capacitor. Some times these are also called as condensors. The basic function of the capacitor is as follows

1. In a circuit it may bypass certain frequencies.
2. It can store electrical energy.
3. It can couple signal from one circuit to another circuit.

Hence the study of capacitors, types, dielectrics and characteristics are as important and is explained as follows.
3.2 Capacitance

The capacitance of a capacitor may be defined as an amount of charge required to create unit potential difference between its plates. Or capacitance is the ability of a capacitor to store charge on its dielectric. By definition

\[ C = \frac{Q}{V} \]

Where \( C \) is the capacitance in Farad’s

\( Q \) is the charge in coulombs

\( V \) is the voltage in volts.

3.2.1 U.I Units

The unit of the capacitance is Farads and it is very big unit for practical purposes. Hence sub multiple units micro farad (10⁻⁶F) and micro farads or pico farads (10⁻¹²F) are generally used.

3.2.2 Symbol

The capacitor is represented by the following symbol as shown in below fig 3.1.

![Fig. 3.1 Symbol of Capacitor](image)

3.2.3 Dielectric Material

The insulating material which is placed in between two metallic plates of a capacitor is known as “Dielectric Material”.

Ex: Air, Ceramic, Glass, Mica etc.

3.3 Factors Effecting the Capacitance of a Capacitor

The capacitance of a capacitor depends on so many no. of factors. These are as follows.

1. Area of the plates.

2. No. of plates.
3. Distance between the plates.

4. Permeability.

1. The capacitance of a capacitor is directly proportional to its area of plates i.e. as the area of plates increases then its capacitance also increases or vice-versa.

2. As the no. of plates in a capacitor increases, its capacitance also increases.

3. Capacitance also depends inversely on the distance between the plates i.e as the distance between the plates increases its capacitance decreases or vice versa.

4. Capacitance also depends on the permeability i.e. the medium which is used between the plates. Writing all these factors as an expression we can get.

\[ C = A \varepsilon_0 \varepsilon_r (N-1)/d \]

If the no. of plates are only two then

\[ C = A \varepsilon_0 \varepsilon_r /d \]

Where

- \( C \) is capacitance in farads
- \( \varepsilon_0 \) is space permittivity 8.854 \times 10^{-12} \text{ F/mt}
- \( \varepsilon_r \) is relative permittivity
- \( A \) is area of plates in square meters.
- \( N \) is the no. of plates.
- \( d \) is the distance between the plates in meters or thickness of dielectric in meters.

### 3.4 Dielectric Constant

The insulating material which is used between the plates of a capacitor is known as dielectric. The dielectric constant is the ability of an insulator to concentrate electric flux. It’s value is specified as the ratio of flux in the insulator is air or vacuum.

For example mica has an average dielectric constant of 6, It means it can provide density of electric flux 6 times as great as that of air or vacuum for the same applied voltage and size.

### 3.4.1 Dielectric Strength

Dielectric strength is the ability of dielectric material to withstand a potential difference without break down. It may be expressed in volts/mil.
This voltage ratio is very important because breakdown of the insulator provides a conducting path to the dielectric. Since the breakdown voltage increases with greater thickness. Capacitors of high voltage rating have more distance between the plates. This increased distance between the plates reduces the capacitance.

### 3.4.2 Breakdown Voltage

Breakdown voltage is defined as the maximum voltage that can be applied across a dielectric material for it’s safe operation. Hence the capacitors are fated much below the breakdown voltage of capacitors. If the capacitors are operated with more than this rated voltage it may be destroyed.

The Dielectric properties of different dielectric materials along with their electric strength are important in manufacturing the capacitors. These are given below in the tables 3.1 and 3.1

**Table 3**

<table>
<thead>
<tr>
<th>S.no</th>
<th>Material</th>
<th>Dielectric Material</th>
<th>Dielectric strength voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Air or vacuum</td>
<td>1</td>
<td>20</td>
</tr>
<tr>
<td>2</td>
<td>Ceramic</td>
<td>80-1200</td>
<td>600-1200</td>
</tr>
<tr>
<td>3</td>
<td>Glass</td>
<td>8</td>
<td>35-2000</td>
</tr>
<tr>
<td>4</td>
<td>Mica</td>
<td>3-8</td>
<td>600-1500</td>
</tr>
<tr>
<td>5</td>
<td>Oil</td>
<td>2-5</td>
<td>375</td>
</tr>
<tr>
<td>6</td>
<td>Paper</td>
<td>2-6</td>
<td>1250</td>
</tr>
</tbody>
</table>

Frequency response of dielectrics is also shown in the table. 3.2

**Table 3.2**

<table>
<thead>
<tr>
<th>S.no</th>
<th>Dielectric</th>
<th>Frequency range</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Mica</td>
<td>5KHZ-100MHX</td>
</tr>
<tr>
<td>2</td>
<td>Paper</td>
<td>100KHZ-1MHZ</td>
</tr>
<tr>
<td>3</td>
<td>Glass</td>
<td>5KHZ-1000KHZ</td>
</tr>
<tr>
<td>4</td>
<td>Ceramic</td>
<td>1KHZ-500MHZ</td>
</tr>
<tr>
<td>5</td>
<td>Polyster</td>
<td>100HZ-1MHZ</td>
</tr>
</tbody>
</table>
3.5 Classification of Capacitors

Capacitors are basically classified into two types.

1. Fixed capacitors.
2. Variable capacitors.

3.5.1 Fixed Capacitors

Fixed capacitors are further classified according to the dielectric material used in it as follows

1. Paper capacitor
2. Ceramic capacitor.
3. Polystyrene capacitor.
4. Mica capacitor
5. Tantalum capacitor

1. Paper Capacitors: Paper capacitors are manufactured by keeping paper as dielectric between two metal foils like tin or aluminium. These are further divided into two types

   1. Impregnated separated capacitors.

2. Ceramic Capacitors: In this capacitors ceramic is used as dielectric between two metallic plates. These are available in two shapes

   1. Disc type
   2. Tabular type.

3. Polystyrene capacitors: In these capacitors polystyrene is used as dielectric between two metal foils.

<table>
<thead>
<tr>
<th>6.</th>
<th>Polystyrene</th>
<th>10HZ-100KHZ</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.</td>
<td>Electrolyte</td>
<td>1HZ-100KHZ</td>
</tr>
</tbody>
</table>
4. Mica capacitors: In these capacitors mica plates are placed between the metal foils. These are also two types according to their construction.
   (a) Stacked mica capacitors
   (b) Silvered mica capacitors.

5. Tantalum capacitors: In these capacitors tantalum is used as dielectric between two metallic foils.

6. Electrolytic capacitors: The name electrolytic capacitors has come out only based on electrolyte, this in turn creates a medium to produce high dielectric constant. Thus in electrolytic capacitors using electrolytic process borox phosphate or carbonate electrolyte provides a thin layer of dielectric between two metal foils like aluminium. These are of two types 1. Polarised electrolytic capacitors 2. Non polarized electrolytic capacitors.

Different types of electric capacitors are shown in the figure 3.2
3.5.2 Variable Capacitors

As the name itself implies a variable capacitor is one whose value can be varied continuously. These are classified as follows.

1. Gangs
2. Trimmers or padders. Ex: Air type, button type. Ganges are further classified into the following types.

(a) Metal gangs
(b) PVC Gangs, Ex: 2X, 2J PVC Gangs. Different ganges are shown in the below fig 3.3.

Application: These are used in tuning circuits.

![Fig. 3.3 Different gang capacitors](image)

3.6 Colour Code of a Capacitor

Mica and tabular ceramic capacitors are colour coded to indicate the capacitance value. As the coding is necessary only for very small sizes. The colour code of capacitance value is always in PF. The colour used is same as the resistors coding from black and from 0-9. Mica capacitors use a six system as shown in the fig 3.4.
The top row is read from left to right and the bottom from right to left. The dots indicate the following:
1. White
2. Digit
3. Digit
4. Multiplier
5. Tolerance
6. Class
White for the first dot indicates the coding.

The capacitance value is read from the first three dots. For example, if the colour are red, green, and brown for dots 2, 3, 4, the capacitance is 250pF. If the first dot is silver, it indicates a paper capacitor. For tabular ceramic capacitors, the colour code is as shown in the figure. The wide colour band indicates the left end and specifies the temperature coefficient. The next three colours indicate the value of the capacitance. For example, brown, black, brown indicates 100pF. For very small values, grey and white are used as for 0.01 and white for 0.10. For example, green, white, and black means 50*0.1 or 5pF.
### Table 3.3 Colour code for ceramic capacitors

<table>
<thead>
<tr>
<th>Colour</th>
<th>Decimal Multiplier</th>
<th>Tolerance %</th>
<th>Temperature Co-efficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black</td>
<td>1</td>
<td>20</td>
<td>0</td>
</tr>
<tr>
<td>Brown</td>
<td>10</td>
<td>1</td>
<td>-30</td>
</tr>
<tr>
<td>Red</td>
<td>100</td>
<td>2</td>
<td>-80</td>
</tr>
<tr>
<td>Orange</td>
<td>1000</td>
<td>-150</td>
<td>-</td>
</tr>
<tr>
<td>Yellow</td>
<td>-</td>
<td>-</td>
<td>-220</td>
</tr>
<tr>
<td>Green</td>
<td>-</td>
<td>5</td>
<td>-330</td>
</tr>
<tr>
<td>Blue</td>
<td>-</td>
<td>-</td>
<td>-470</td>
</tr>
<tr>
<td>Violet</td>
<td>-</td>
<td>-</td>
<td>-750</td>
</tr>
<tr>
<td>Gray</td>
<td>-</td>
<td>-</td>
<td>30</td>
</tr>
<tr>
<td>White</td>
<td>-</td>
<td>-</td>
<td>500</td>
</tr>
</tbody>
</table>

### 3.7 Losses in A Capacitors

The following losses generally occur in capacitors:

1. **Resistance loss**: This is due to resistance of plates and leads of capacitors.
2. **Leakage loss**: This is caused by the electrons leaking through the dielectric. This increase with frequency, applied voltage and temperature.
3. **Dielectric loss**: This loss is caused due to energy absorbed by dielectric.
4. **Absorption loss**: When an ac voltage is applied to a capacitor their instantaneous charging and discharging of the capacitor. The reverse charging cannot take place instantaneously with high frequency charging of a capacitor. There may be difference between the amount of ac voltage applied and the ac. Voltage...
3.8 Capacitance in Series

Let $C_1$, $C_2$, $C_3$ be the three capacitors connected in parallel as shown in the below fig 3.7. This combination is applied to the supply of ‘V’ volts. In parallel combination p.d across each is same but charge on each is different. Let it be $Q_1$, $Q_2$, $Q_3$ on $C_1$, $C_2$, $C_3$ respectively.

![Diagram of capacitors connected in parallel](image)

Fig. 3.6

Now total charge $Q = Q_1 + Q_2 + Q_3$

$CV = C_1V + C_2V + C_3V$

Thus in parallel total capacitance $C = C_1 + C_2 + C_3$.

3.9 Solved Problems

1. Find the total capacitance of two capacitors 10 and 20 are connected in series?

**Ans:** Let $C_1 = 10F$, $C_2 = 20F$

In series total capacitance $1/C = 1/C_1 + 1/C_2$

$= 1/10 + 1/20 = (2+1)/20 = 3/20$
Therefore I/C=3/20, C=20/3 F.

2. Find the total capacitance between the points a and b?

![Diagram of capacitors connected in parallel]

**Ans:** Total capacitance in parallel
\[ C = C_1 + C_2 + C_3 \]
\[ = 100 \mu F + 200 \mu F + 300 \mu F \]
\[ = 600 \mu F \]

3. Two capacitors having ‘a’ capacity of 5µF when connected in parallel and 1.2 µF when connected in series. Calculate their capacities?

**Ans:**
- In Series
  \[ \frac{I}{C} = \frac{1}{C_1} + \frac{1}{C_2} \]
  \[ C = \frac{C_1 C_2}{C_1 + C_2} = 1.2 \mu F \]
- In parallel
  \[ C = C_1 + C_2 = 5 \mu F \]......1

Substituting \( C_1 + C_2 = 5 \mu F \) IN \( C = \frac{C_1 C_2}{C_1 + C_2} \)

We have \( C_1 C_2 = 6 \mu F \)

\[ (C_1 - C_2)^2 = (C_1 + C_2)^2 - 4C_1 C_2 \]
\[ (5)^2 - 4 \times 6 = 1 \]

\[ C_1 - C_2 = 2 \]......2

Solving equations 1 and 2

\( C_1 = 3 \mu F, \quad C_2 = 2 \mu F \)

4. Find the total capacitance of the following combination?

**Ans:**
- Capacitance between BC is 500 + 500 = 1000µF
- Capacitance between AD \( \frac{I}{C_{AD}} = \frac{1}{100} + \frac{1}{1000} + \frac{1}{100} \)
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\[ = 10 + 1 + \frac{10}{1000} \]
\[ = \frac{21}{1000} \]
\[ C_{AD} = \frac{1000}{21} \mu F \]

3.12 Applications

Capacitors are used in various places in electronic circuits. These are as follows

1. Capacitors are used as ‘filters’ in power supply circuits.
2. Capacitors are used as ‘signal bypass’ elements.
3. Capacitors are used as coupling devices in electronic circuits.
4. Variable capacitors are used in tuning circuits in receiver circuits.

Summary

1. The capacitance of a capacitor may be defined as the amount of charge required to create unit potential difference or it is the ability to store charge.
2. The unit of capacitance is farads (F).
3. The capacitance of a capacitor depends on
   (a) Area of plates (b) No. of plates (c) Distance
4. Various losses in a capacitor are
   (a) Resistance loss (b) Leakage loss (c) Dielectric loss (d) Absorption loss.
5. When \( C_1, C_2 \) and \( C_3 \) are the three capacitors connected in series, then
   \[ \frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} \]
6. When $C_1$, $C_2$ and $C_3$ are connected in parallel, $C_T = C_1 + C_2 + C_3$

7. Capacitors are classified as a) Fixed and b) Variable capacitor.

8. Fixed capacitor are further classified as paper capacitors, ceramic capacitors, polystyrene capacitors, mica capacitors, tantalum capacitors, electronic capacitors etc.

9. Capacitors are widely used as filters in power supply circuits, to bypass signals, as coupling devices and as a component in tuning circuits.

**Short Answer Type Questions**

1. Define capacitance and mention it’s unit?
2. Classify different types of capacitors?
3. What is meant by dielectric material. Give examples?
4. Define Dielectric constant and Dielectric strength of a capacitor?
5. What are the applications of capacitors?
6. What are the losses of capacitors?

**Long Answer Type Questions**

1. Explain the colour code of capacitors?
2. Derive the equation for total capacitance when three capacitance are connected in series?
3. Derive the equation for total capacitance when three capacitors are connected in parallel?
Learning Objectives

After completing this unit, the student will be able to understand

- The meaning of different terms like current, voltage, resistance, conductance, power, admittance.
- Ohm’s law and Kirchhoff’s law
- Find the total resistance, current and voltage across each branch in a DC circuit.
- The concept of alternating current and its principle of generation.
- Familiar with the terminology like cycle, frequency, time period, instantaneous value, average value, RMS value etc.
- The behavior of AC through series and parallel circuits containing elements like resistance, capacitance and inductance.
- Idea of resonance in A.C. circuit.
- Deriving an expression of resonance in RLC series circuit.
• Compare series and parallel resonant circuit performance features like current, impedance, power factor etc.

4.1 Introduction

4.1.1 Current

The flow of the free electrons is called electric current. It is defined as the rate of change of charge at any cross section of the conductor, \( I = \frac{d\phi}{dt} \).

It is measured in Amperes (A). One Ampere of current is said to flow through a wire if one coulomb of charge flows in one second.

4.1.2 Voltage

The work done to carry an electron or unit charge from one point to another point in a conductor is known as voltage. This is also called as potential difference or electromagnetic force. It is denoted by the letter \( V \) and is measured in volts.

4.1.3 Resistance

The opposition offered by a substance to the flow of electric current is called resistance. It is denoted by the letter \( R \) and is measured in ohms (\( \Omega \)).

4.1.4 Conductance

Conductance is the reciprocal of resistance. The unit of the conductance is mho (\( \Omega^{-1} \)).

4.1.5 Power

The rate of doing work is called power. In other words, power is the work done per unit time. The unit of power is watt. Bigger units applied are KW and MW.

\[ 1\text{KW}=1000\text{watts} \]
\[ 1\text{MW}=1000\text{KW}= (10^6)\text{watts}. \]

Sometimes power is measured in horse power (HP).

\[ 1\text{HP} = 746\text{watts}. \]

4.1.6 Admittance

Admittance is defined as the reciprocal of impedance, i.e. admittance, \( Y = \frac{1}{z} \).

The unit if admittance is Siemens (S).
4.2 Ohm’s Law

The ratio of potential difference (V) between any two points on a conductor to the current (I) flowing between them, is constant, provided the temperature of the conductor does not change.

In other words, \( V/I = \text{constant} \) or \( V/I = R \).

Where \( R \) is the resistance of the conductor between the two points considered.

4.3 Kirchhoff’s Law

Kirchhoff’s laws are quite useful for solving electrical networks which may not be readily solved by ohm’s law. The two laws are

1. Kirchhoff’s current law or point law: In any electrical network, an algebraic sum of the currents meeting at a point (or junction) is zero.

In other words the total current leaving a junction is equal to the total current entering that junction.

Consider the case of a few conductors meeting at a point A in Fig. 4.1.

Some conductors have currents leading to a point A, whereas some have currents leading away from point A. Assuming incoming currents with positive sign and outgoing currents negative, we have

\[ I_1 + (-I_2) + (-I_3) + (+I_4) + (-I_5) = 0 \]

or \( I_1 - I_2 - I_3 + I_4 - I_5 = 0 \)

or \( I_1 + I_4 = I_2 + I_3 + I_5 \)

Or sum of incoming currents = sum of outgoing currents.
Or $\Sigma I=0$

2. Kirchhoff’s mesh law or voltage law (KVL): The algebraic sum of the products of currents and resistance in each of the conductors in any closed path (or mesh) in a network plus the algebraic sum of the emf’s in that path is zero.

In other words, $\Sigma IR + \Sigma e.m.f = 0$.

### 4.4 Series and Parallel Circuit

It was already explained in chapter 1, that in a series circuit containing resistors $R_1, R_2, R_3$. The total resistance

$$R = R_1 + R_2 + R_3$$

In a parallel circuit containing resistors $R_1, R_2, R_3$ the total resistance

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

#### 4.4.1 Solved Problems

1. Find the total resistance of the following circuits.

   ![Series Circuit Diagram]

   It is clear that the above circuit, the three resistors are connected in series.

   $$R = R_1 + R_2 + R_3 = 12\,\Omega + 8\,\Omega + 6\,\Omega = 26\,\Omega$$

2. Calculate the equivalent resistance of the circuit given below

   ![Parallel Circuit Diagram]
The above three resistors are connected in parallel

\[
\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} = \frac{1}{3} + \frac{1}{6} + \frac{1}{2} = \frac{6}{6} = 1 \Omega
\]

\[\therefore R = 1 \Omega.\]

3. Determine the total resistance and the circuit current in the figure shown below.

![Circuit Diagram]

Resistance between points B and C

\[
\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} = \frac{4+1}{20} + \frac{6}{20} = \frac{6}{20}
\]

Therefore \( R_{BC} = 20/5 = 4 \Omega \)

Total resistance \( R_1 = R_1 + R_2 + R_3 = 2 + 4 + 4 = 10 \Omega \)

\[\therefore \text{Circuit current, } I = \frac{V}{R} = \frac{30}{10} = 3 \text{ A.}\]
4. Find the current and voltage in each branch in the circuit shown below

Resistance between points B and C

\[
\frac{1}{R_{BC}} = \frac{1}{R_1} + \frac{1}{R_2} = \frac{1}{6} + \frac{1}{12} + \frac{2+1}{12} = \frac{3}{12}
\]

\[
R_{BC} = \frac{12}{3} = 4 \Omega
\]

\[
R_{AC} = R_1 + R_2 = 4 + 4 = 8 \ \Omega
\]

Total Resistance = 8 \Omega

Total current \[ I = \frac{V}{R} = \frac{24}{8} = 3A \]

\[
\therefore \text{Current through } 4\Omega = 3A
\]

\[
\therefore \text{Voltage drops across } 4 \ \Omega = IR = 3 \times 4 = 12V
\]

Therefore Voltage drop between the points B and C = 24 – 12 = 12V

Since 6\Ω and 12\Ω are in parallel, same 12 V of voltage will be developed across each resistor.

Current through 6 \Ω = V/R = 12/6 = 2A

Current through 12 \Ω = V/R = 12/12 = 1A

Current through 6 \Ω = I, \[ \frac{R_2}{R_1+R_2} = 3 \ \frac{12}{6+12} = 2A \]

Current through 12 \Ω = 3x \[ \frac{6}{6+12} = 1A \]
4.5 Introduction to AC Circuits

Alternatively voltage may be generated by rotating a coil in a magnetic field or by rotating a magnetic field within a stationary coil. These are the fundamental principles which are used in AC voltage generation. This is also known as electromagnetic induction. According to Michael Faraday, the first law of electromagnetic induction explains how AC voltage is generated and the second law gives how much voltage is generated and on what factors the magnitude of the generated emf depends. These two laws are the basic principles for AC voltage generation and the basic circuit for generation of AC voltage is given in the below fig 4.2

![Basic Circuit for A.C. Voltage Generation](image)

Fig. 4.2 Basic Circuit for A.C. Voltage Generation

4.6 Generation of Sinusoidal AC Voltage

As already explained in the previous topic, the sinusoidal AC voltage is generated using electromagnetic induction. The magnitude of the voltage generated depends in each case upon the number of turns in the coil, strength of the field and the speed at which the coil or magnetic field rotates.
For instance consider a rectangular coil having \( N \) turns and rotating in a uniform magnetic field with an angular velocity of \( \omega \) radians/seconds. As shown in the fig 4.6. Let it be measured by X axis maximum flux \( \Phi_m \) is linked with the coil with its plane outside with the X axis. In time ‘t’ seconds coil rotates through an angle \( \theta = \Phi_m \cos \omega t \). Hence flux linkages of the coil at any time in the deflected position are \( N \theta = N \Phi_m \cos \omega t \)

According to faradays law of electromagnetic induction the emf induced in the coil is given by the rate of change of flux linkages of the coil. Hence the value of induced emf at this instant or the instantaneous value of the induced emf is

\[
e = \frac{d}{dt} (N\Phi).
\]

\[
= \frac{d}{dt} (N\Phi_m \cdot \cos \omega t)
\]

\[
= -N\omega \Phi_m (-\sin \omega t)
\]

\[
= \omega N\Phi_m \sin \omega t
\]

\[
= \omega N \Phi_m \sin \theta
\] ................................. (1)

When the coil has turned through 90° i.e., when \( \theta = 90^\circ \) then \( \sin \theta = 1 \). Hence ‘\( e \)’ has maximum value say \( E_m \). From eq.(1) we get

\[
E_m = \omega N \Phi_m = 2\pi f NB_m A \text{ volt}
\]

Where \( B_m = \) maximum flux density in \( \text{wb/m}^2 \).

\( A = \) Area of the coil in \( \text{mt}^2 \).

\( F – \) frequency of rotation of the coil in rev/sec.

Substituting this value of \( E_m \) in equation we get
\[ e = E_m \sin \theta \]
\[ = E_m \sin \omega t \] \hspace{0.5cm} \text{(2)}

This equation (2) represents the sinusoidally generated voltage. Similarly, the equation of the induced current is \[ I = I_m \sin \theta \]

The equation of the induced emf or current reveals that the emf or current varies as sine function of the time angle \( \omega t \). This is shown graphically in the below fig 4.3.

![Graph of sine function](image)

**Fig. 4.3**

### 4.7 Cycle Frequency Time Period

One complete set of positive and negative values of alternating quantity is known as a cycle. A cycle may also be defined in terms of angular measure as “if a coil is rotated for 360° in a magnetic field then it is said to be one cycle”.

This is graphically represented as shown in the below fig 4.4. The number of cycles/sec is called the frequency of alternating quantity. It is measured in Hertz. It is also defined as the reciprocal of the time period of the alternating quantity.

![Graph of alternating current](image)

**Fig. 4.4**
Therefore \( f = \frac{I}{T} \).

Hence the time taken by an alternating quantity to complete one cycle is called time period \( T \). It is measured in m sec. This is also graphically represented in the below fig 4.5

![Current waveforms](image)

### 4.8 Instantaneous Maximum, Average, RMS values and Factors

A quantity which varies in each and every instant of its time then it is called instantaneous quantity. For example you consider instantaneous voltage which varies at each and every instant of its time sinusoidally that’s why it is called instantaneous or sinusoidal AC voltage or quantity.

In alternating quantities the voltage or current starts from zero, reaches peak value and then falls to zero in 180° of rotation. Here the maximum value is defined as the peak value or the highest amplitude of the alternating quantity irrespective of its direction or sign and is known as maximum value.

The average value of an alternating current is expressed by that steady current which transfers across any circuit the same charge as is transferred by that alternating current. In case of symmetrical alternating current the average value over a complete cycle is zero. Hence in this case the average value is obtained by adding or integrating the instantaneous values of current over half cycle only. But in case of unsymmetrical alternating current the average value must be taken over by the whole cycle. This is given by two methods

1. Mid ordinate method
2. Analytical method.
In mid ordinate method the time base of the positive half cycle as shown in fig 4.7 divides into an equal intervals of time each of duration $t/n$ seconds. The average value of the current is

$$I_{avg} = \frac{i_1 + i_2 + \ldots + i_n}{n}$$

According Analytical method $I_{avg}$ is given by

$$I_{avg} = \frac{2 I}{\pi} \text{ or } 0.637 \times \text{max}$$

The Rms value of alternating current is given by that steady (dc) current which when flowing through a given circuit for given time produces the same heat as produced by the alternating current flowing through the same circuit for the same time. This is also given by two methods.

1. Mid ordinate method
2. Analytical method

It is also known as effective value of AC. For finding Rms value of a symmetrical sinusoidal alternating current either mid ordinate method or analytical method may be used. For symmetrical non sinusoidal waves the mid ordinate method would be found more convenient.

According to this mid ordinate method any positive half cycle as shown in fig 4.7 is divided into $n$ equal intervals of time each of the duration $t/n$ seconds. Let the mean instantaneous values of currents during these intervals be respective $i_1, i_2, \ldots, i_n$ in fig 4.6. Suppose this alternating current is passed through a circuit of resistance $R$ ohm.
Then

Heat produced in 1\textsuperscript{st} interval = 0.24i_1^2Rt / n cal.
Heat produced in 2\textsuperscript{nd} interval = 0.24i_2^2Rt / n cal
Heat produced in n\textsuperscript{th} interval = 0.24i_n^2Rt / n cal

Heat produced in ‘t’ second is

\text{Total heat produced in ‘t’ second is} = \frac{0.24 \ Rt \ (i_1^2 + i_2^2 + \ldots + i_n^2)}{n}

According to definition \(0.24 \ I^2 \ Rt = \frac{0.24 \ Rt \ (i_1^2 + i_2^2 + \ldots + i_n^2)}{n}\)

\[I^2 = \frac{(i_1^2 + i_2^2 + \ldots + i_n^2)}{n}\]

\[I = \sqrt{\frac{(i_1^2 + i_2^2 + \ldots + i_n^2)}{n}}\]

Square root of the mean squares of the instantaneous currents.

According to Analytical method  \(I_{\text{rms}} = 0.707 \times I_{\text{max}}\)
\(V_{\text{rms}} = 0.707 \times V_{\text{max}}\)

The Rms value of an alternating current is of considerable importance in practice, because the ammeters and volt meters record the rms value of alternating the current and voltage respectively.

**Form Factor**

Form factor is defined as the ratio between rms value of an alternating quantity to the average value of alternating quantity.

\[\text{Form Factor } kf = \frac{\text{Rms Value}}{\text{Average value}}\]

\[= \frac{0.707 \ I_{\text{max}}}{0.637 \ I_{\text{max}}} = 1.11\]
Crest or Peak or Amplitude factor

It is defined as the ratio between maximum value of an alternating quantity to the rms value of the alternating quantity.

\[
\text{Peak Factor} = \frac{\text{Maximal value}}{\text{Rms value}} = \frac{I_m}{I_{\text{rms}}} = \sqrt{2} = 1.414
\]

4.9 A.C Through Pure Resistance

When only a resistor is used in an ac circuit as shown in this 4.8 the voltage and current rises and fall simultaneously and it is said that the current and current are in the same phase.

![Circuit Diagram](image1)

Mathematically applied voltage

\[
V = V_m \sin \omega t
\]

\[
V_R = V_m \sin \omega t
\]

\[
I_R = I_m \sin \omega t
\]

Fig. 4.8

Circuit Diagram  Voltage and Current Wave form  Vector Diagram

4.10 A.C Through Pure Inductance

When AC is applied to pure inductor the current lags the voltage by 90° as shown in fig 4.9 when AC voltage is increased the inductor gives the opposition hence the back emf is produced which decreases the flow of current at this time. Increase of forward voltage increases the back emf at the instant of maximum peak voltage there is maximum back emf, hence no current will flow at this time.

When the voltage decreases the conductor gives back energy and rises to keep the status thus the current increases and reaches the maximum when the
voltage is zero. Thus the current is lagging the voltage at the time by 90° or the voltage is leading the current by 90°.

In pure Inductance applied voltage \( V = V_m \sin \omega t \)

\[
I_L = \frac{V_m}{X_L} \sin (\omega t - \pi/2)
\]

\[
I_L = I_m \sin (\omega t - \pi/2) \quad (\text{Since } I_m = \frac{V_m}{X_L})
\]

Here \( \pi/2 \) appears because of lagging characteristics. \( XL \) denotes the inductive reactance. The vector diagram also shown in fig 4.9.

**4.11 A.C Through Pure Capacitance**

When an AC flows through the capacitor as shown in the fig 4.10 the current leads the voltage by 90°. Initially when an emf starts from zero and rises in positive direction a flow of electrons takes place between the plates as there is no initial charge on the capacitor plates to oppose this flow of electron.
Thus when the voltage is at zero position the current is at it’s maximum position as the capacitor gets charged or the capacitor is fully charged the current is zero. This shows that the current leads the voltage by $90^\circ$. From the fig 4.10 it can be seen that in one half cycle energy is absorbed and in the next half cycle it is returned back resulting in no loss of energy. The voltage and current relationship can be expressed as

Applied voltage $V = V_m \sin \omega t$

$$i = \frac{V_m}{X_c} \sin (\omega t + \pi/2)$$

$$i = I_m \sin (\omega t + \pi/2) \text{ (Since } I_m = \frac{V_m}{X_c})$$

4.12 AC Through Resistance in Series with an Inductor

When an alternating voltage is applied to an RL series circuit as shown in fig 4.11. The current ‘I’ flows through the circuit which produces voltage drop across each element. The voltage drop across resistance $V_R$ is in phase with the current. This drop is equal to the IR. The voltage drop $V_L$ across the inductor is equal to $IX_L$, which is leading current by $90^\circ$. These voltage drops are shown in the vector diagram, where OA represents $V_R$ and OB represents $V_L$.

The applied voltage is given by the vector sum of the voltage drops

$$V = \sqrt{V_R^2 + V_L^2}$$

$$= \sqrt{(IR)^2 + (IX_L)^2}$$

$$= I \sqrt{(R^2 + X_L^2)}$$

$$= V / \sqrt{(R^2 + X_L^2)}$$

The quantity $\sqrt{R^2 + X_L^2}$ is known as the impedance of the circuit it has the same property as that of the resistance. In fig. 4.11. CDE triangle shows that impedance triangle. Here CD represents the resistance reactance and CE represents the impedance. This satisfies the relation as represented by the impedance equation. $Z = \sqrt{(R^2 + X_c^2)}$
The power in AC circuit is given by the product of the voltage and that part of the current which is in phase with voltage \( P = V|\text{cos}\phi \). 

PF: The power factor of RL series circuit is defined as the ratio between resistance and impedance of that circuit.

\[
PF = \frac{R}{Z} = \frac{R}{\sqrt{R^2 + X_L^2}}
\]

![Circuit Diagram](image1)

**Fig. 4.11**

### 4.13 AC Through Resistance in Series with the Capacitance

When a resistance is connected in series with a capacitor then alternating current produces voltage drop across it. The voltage drop across resistance \( V_R \) is in phase with current \( I \) whereas the voltage drop across capacitance \( V_C \) is lagging \( I \) by 90° as indicated in the vector diagram shown in the below figure 4.12.

The applied voltage is given by the vector sum of the voltage drops.

\[
V = \sqrt{V_l^2 + V_C^2} = \sqrt{(IR)^2 + (IX_C)^2} = \sqrt{I^2 (R^2 + X_C^2)} = I \sqrt{R^2 + X_C^2} = V / Z
\]

![Voltage Triangle](image2)

![Impedance Triangle](image3)
Here again $Z = \sqrt{R^2 + X}$ is the impedance of the RC series circuit this is shown in the above impedance triangle.

4.14 Resistance, Inductance And Capacitance in Series

When alternating voltage is applied across the series combination of resistance, capacitance and inductance as shown in the below fig 4.13. The current $I$ flowing through the circuit develops a voltage drop across each element.

Let the voltage across $R$ is $V_R = I_R$ (which is in phase with $I$).

The voltage drop across $L$ is $V_L = I X_L$ (which is lagging behind $I$ by $\pi/2$)

The voltage drop across $C$ is $V_C = I X_C$ (which is lagging behind $I$ by $\pi/2$)

These voltages are shown in the voltages triangle. From the voltage triangle OA represents voltage across $R$ and which is in the phase with the current $I$. AB and AC represents voltage drops across inductor and capacitor respectively both are 180° out of phase with each other. The applied voltage $V$ is represented by OD.
From the Triangle $AC = BD$

$AD = AB - CD$

$= AB - AC$

Applied voltage is the vector sum of voltage drops

$$V = \sqrt{V_L^2 + (V_L - V_C)^2}$$

$$= \sqrt{(IR)^2 + (IX_L - IX_C)^2}$$

$$= \sqrt{I^2 (R^2 + (X_L - X_C)^2)}$$

$$I = \frac{V}{\sqrt{R^2 + (X_L - X_C)^2}}$$

$$Z = \sqrt{(R^2 + (X_L - X_C)^2)}$$

Power factor is defined as the ratio between resistance and impedance of the RLC series circuit. $Pf = \frac{R}{\sqrt{(R^2 + (X_L - X_C)^2)}}$

### 4.15 RL Parallel Circuit

When an inductor $L$ and resistor $R$ are connected in parallel to a source then it is known as RL parallel circuit. Parallel RL circuit is shown in the below fig 4.14. In which voltage remains same but the currents will be different. The importance between a purely resistive parallel circuit and an RL parallel circuit is in finding out the total currents. In purely resistive parallel circuits simply the total of all the circuits the currents in the inductive branch currents wick be the total current. But in parallel RL circuit current in the inductive branches are $90^\circ$ out of phase with the currents of resistive branches. Thus vector addition approach will be utilized. First of all the inductive currents must be added up and they now added vertically to the resistive currents.

Thus total currents $I_t = \sqrt{I_{RT}^2 + I_{LT}^2}$

Where $I_{LT} = \text{Total current of resistive branches}$
\[ Y = \frac{I_L}{\sqrt{\left(\frac{1}{R_t}\right)^2 + \left(\frac{1}{X_{LT}}\right)^2}} \]

Where \( G = 1 / R_t \) is known as conductance.

\( B_L = 1 / X_{LT} \) which is inverse of inductive reactance and is known as susceptance.

\[ Y = \sqrt{(G)^2 + (B_L)^2} \]; \( Y \) is called as admittance and is measured in Mho’s.
4.16 R.C. Parallel Circuit

When capacitor C and resistor are connected in parallel across an ac source then it is known as RC parallel circuit. The voltage is same everywhere, however the current through the capacitor leads to the voltage by $90^\circ$ and the current through the resistor is in phase with the applied voltage as shown in the below fig 4.15. Thus the capacitive current leads the resistive current by $90^\circ$ and the resultant current or total line current is the vector sum of these currents.

![Fig. 4.15](image)

In making the vectors of this situation the current through the resistor is laid off no horizontal axis and current through the capacitor on the vertical axis because the capacitive current leads the resistive current by $90^\circ$ which is shown in below fig. Here the resistive current is in the phase with the applied voltage.

The resultant vector represents the total current in the circuit and the angle which makes the vector IR is the phase angle.

\[
I_t = \sqrt{I_R^2 + I_C^2}
\]

Tangent of the angle is equal to $I_{RT} / I_{CT} = V/R / V/X_C = X_c / R$

This it can be seen that total current in a parallel RC circuit is always greater than current in either branch.

\[
I_t = V_s \sqrt{(1/R_t)^2 + (1/X_{CT})^2}
\]

\[
= \sqrt{(G)^2 + (Bc)^2}
\]

\[
= I_t / Y
\]

4.17 RLC Parallel Circuit

When all the three elements i.e. resistance, inductance and capacitance are connected in parallel then the circuit is said to be RLC parallel circuit. These are
shown in fig 4.16 the circuit can be solved by converting the resistance into the corresponding reciprocals inductive, capacitive reactance into corresponding susptances by applying the following equations.

\[ Y = \sqrt{G^2 + B^2} \]

\[ V_s = I_1 / Y = I_1 / \sqrt{G^2 + B^2} \]

---

**Solved Problems**

1. Find the amplitude of the following quantity \( e = 100 \sin 200\pi t \)

**Ans:** We know that \( e = E_m = \sin \omega t \)

Comparing the above with the given equation \( e = 100 \sin 200 \pi t \)

Amplitude \( E_m = 100 \) V

2. Find the frequency of the following AC voltage \( e = 50 \sin 200 \pi t \)

**Ans.** We know that \( e = 50 \sin 200 \pi t \)

Comparing the above with the standard equation

\( E = E_m = \sin 2\pi ft \) we can get

\( E_m = 50 \) V \( 200 \pi t = 200 \pi t \)

\( f = 200 \pi t / 200 \pi t = 100 \) HZ
3. Write the equation of an alternating current its amplitude is 5 Amps and frequency is 60 Hz.

Ans : From the above problem we know that
\[ E_m = 5A, \, f = 60 \, Hz \]
Substituting these values in the standard equation
\[ I = I_m \sin 2 \pi f t \] we can get
\[ I = 5 \sin 2 \pi t \]
\[ 60 \, t = 5 \sin 120 \pi t \]

4. The maximum or peak value of a AC quantity is 220 V find out its average value.

Ans : We know that average value = 0.637 x max Value
Substituting the above in the equation we can get
\[ V_{avg} = 0.637 \times 220 \, V \]
\[ = 139.42 \, V \]

5. If a meter indicates 220 V \textit{rms} value find out its peak value

Ans : We know that \[ V_{rms} = 0.707 \times V_{max} \]
\[ V_{max} = V_{rms} / 0.707 \]
\[ = 311.08 \, V \]

6. If the peak value of an AC quantity is 240 V. Find out its effective value or RMS value.

Ans : We know that \[ V_{rms} = 0.707 \times V_{max} \]
\[ = 0.707 \times 240 \]
\[ = 169.98 \, V \]

7. Find the time period of 50 Hz frequency

Ans : We know that \[ Time \, period \, T = 1 / f = 1 / 50 = 0.02 \, sec \]

8. Find the frequency Time period and Amplitude of the AC quantity \( e = 200 \sin 100 \pi t \).

Ans : Comparing the equation \( e = 200 \sin 100 \pi t \) with the standard equation
We have amplitude \( E_m = 200 \, V \)
9. In a RL series circuit 3Ω resistance is connected in a series with an inductive reactance of 4Ω. Find its impedance.

\[ Z = \sqrt{R^2 + X_L^2} = \sqrt{3^2 + 4^2} = \sqrt{25} = 5\Omega \]

10. Find out the impedance of RC series circuits having the resistance of 1000Ω with 1μF capacitance connected across supply frequency of 60 Hz.

\[ \text{Ans : Given Data } R = 1000\Omega \quad C = 1\mu F, \quad f = 60 \text{ HZ} \]

We know that the capacitive reactance \( X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi \times 60 \times 1 \times 10^{-6}} = 2651.5 \Omega. \]

In RC series circuit \( Z = \sqrt{(R^2 + X_L^2)} \)
\[ = \sqrt{(1000)^2 + (2651.5)^2} = 2833.8\Omega \]

11. In a RL series circuit 300 Ω resistance is connected in series with an inductance of 80 mH across 25 V, 800 Hz, AC Supply find its impedance and power factor.

\[ \text{Ans : Given data } R = 300\Omega \quad L = 80 \text{ mH} \quad f = 800 \text{ Hz} \]

Inductive reactance \( X_L = 2\pi fL = 2 \times 2.14 \times 800 \times 80 \times 10^{-3} \)
\[ X_L = 402\Omega \]

Impedance of RL series circuit \( Z = \sqrt{(R^2 + X_L^2)} \)
\[ = \sqrt{(300)^2 + (402)^2} = 501.6\Omega \]

Power factor \( R / Z = 300 / 501.6 = 0.598 \)
12. A coil having a resistance of $6\Omega$ and an inductance of $0.03\, H$ is connected across a $50\, V$, $60\, Hz$, supply. Calculate its inductance, impedance and power factor.

Ans : We know that $X_L = 2\pi fL$

$$X_L = 2\pi \times 60 \times 0.03 = 11.3\, \Omega$$

Impedance of RL series circuit $Z = \sqrt{(R^2 + X_L^2)}$

$$Z = \sqrt{(6)^2 + (11.3)^2} = 12.8\, \Omega$$

13. A capacitor having a capacitance of $10\, \mu F$ is connected in series with a non inductive resistance of $120\, \Omega$ across a $100V$, $50\, Hz$ supply. Calculate its capacitance reactance, impedance and power factor.

Ans : Given data $C = 10\, \mu F$ \hspace{1em} $R = 120\, \Omega$ \hspace{1em} $F = 50\, Hz$

Capacitive reactance $X_C = \frac{1}{2\pi fC}$

$$X_C = \frac{1}{2 \times 3.14 \times 50 \times 10 \times 10^{-6}} = 318.47\, \Omega$$

Impedance of RL series circuit $Z = \sqrt{(R^2 + X_L^2)}$

$$Z = \sqrt{(120)^2 + (318.47)^2} = 340\, \Omega$$

Power factor $R/Z = 120 / 340 = 0.3529$

14. A coil resistance $10\, \text{ohms}$ and inductance $0.1\, \text{H}$ is connected in series with a capacitance of $150\, \mu F$ across a $200V$, $50\, Hz$ supply. Determine impedance and power factor.

Ans : Given data $R = 10\, \Omega$ \hspace{1em} $L = 0.1\, \text{H}$ \hspace{1em} $C = 150\, \mu F$ \hspace{1em} $f = 50\, Hz$

From the data $X_L = 2\pi \, fL$

$$X_L = 2 \times 3.14 \times 50 \times 0.1 = 31.4\, \Omega$$
Capacitive reactance \( XC = \frac{1}{2\pi fC} = \frac{1}{2 \times 3.14 \times 50 \times 150 \times 10^{-6}} = 21.2 \Omega \)

Impedance of RL Series circuit \( Z = \sqrt{R^2 + (X_L - X_C)^2} \)

\[ = \sqrt{(10)^2 + (31.4 - 21.2)^2} \]
\[ = 14.26 \Omega \]

Power factor \( \frac{R}{Z} = \frac{10}{14.26} = 0.7 \)

15. A resistance of 1 \( \Omega \), an impedance of 1 Hz and a capacitance of 1 \( \mu \)F are in series across a voltage of 100V, 50 Hz supply. Find its impedance, current through the circuit and voltage across each element.

Ans: Given data P = 1 \( \Omega \) \( L = 1 \)H \( C= \mu \)F \( f= 50 \text{ Hz} \) \( V=100 \)

From the data \( XL = 2 \pi \ fL \)
\[ = 2 \times 3.14 \times 50 \times 1 = 314 \Omega \]

Capacitive reactance \( X_c = \frac{1}{2\pi fC} = \frac{1}{2 \times 3.14 \times 50 \times 1 \times 10^{-6}} = 3185 \Omega \)

Impedance of RL series circuit \( Z = \sqrt{R^2 + (X_L - X_C)^2} \)

\[ = \sqrt{(10)^2 + (314 - 3185)^2} \]
\[ = 2871 \Omega \]

\( I = \frac{V}{Z} = \frac{100}{2871} = 0.0348 \) or 3.48 mA

Voltage across resistor \( V_r = IR = 0.0348 \times 1 = 0.0348 \)V

Voltage across inductor \( V_l = I \times X_L = 0.0348 \times 314 - 10.9 \)

Voltage across capacitor \( V_c = I \times X_C = 0.0348 \times 3185 = 110.8 \)

Power factor \( \frac{R}{Z} = \frac{10}{14.26} = 0.7 \)

4.18 Concept of resonance in AC circuits

In many of the electronic circuits resonance is very important phenomenon. The study of resonance is very useful particularly in the area of communications. For example the ability of a radio receiver to select the desired
frequency transmitted by a transmitter and to reject the frequencies from other stations or unwanted frequencies is based on the principle of resonance. A two terminal network in general offers a complex impedance consisting of resistive and reactive components. If a sinusoidal voltage is applied to such network then the current is then out of phase with the applied voltage. Under special circumstances however the impedance offered by network is purely resistive or if we can align the circuit in such a way that the current in circuit is in the phase. The applied voltage then the phenomenon is called frequency of resonance. The nature of resonance depends upon whether the inductance and the capacitance are in series or in parallel. Accordingly we classify the resonance circuits into the following two types.

1. Series resonance circuit
2. Parallel resonant circuit.

4.19 Resonance

A circuit is said to be under resonance when its net reactance is zero or the impedance offered by the circuit is purely resistive or the current in the circuit is in phase with the applied voltage. The frequency at which resonance occurs is known as resonant frequency.

4.20 Expression for resonant frequency in RLC series circuit

A series circuit is said to be in resonance when its net reactance is zero. The frequency \( f_o \) at which this happens is known as resonant frequency. Consider series RLC circuit shown in below fig 4.17

![Fig. 4.17. R.L.C Series Resonance Circuit](image-url)
According to the definition of resonance a series circuit is said to be in resonance if the current is in phase with the applied voltage.

This occurs when its net reactance equals to capacitive reactance. The frequency at which this occurs is known as resonant frequency. Since \( X_L = X_C \) the impedance in a series RLC circuit is purely resistive.

At the resonant frequency \( f_o \) the voltage across the capacitance and inductance are equal in magnitude. Since they are 180° out of phase with each other. They cancel each other and hence zero voltage appears across the LC combination.

At resonance net reactance is zero

\[
X = 0 \text{ or } X_L - X_C = 0
\]

\[
X_L = X_C
\]

\[
\omega L = \frac{1}{\omega C}
\]

\[
\omega^2 = \frac{1}{LC} \quad \text{(Since } \omega = 2\pi f)\]

\[
(2\pi f_o)^2 = \frac{1}{LC}
\]

\[
f_o = \frac{1}{2\pi \sqrt{LC}}
\]

**4.21 Current and impedance at Resonance**

The under resonance conditions \( X = 0 \) hence (formula). This is the minimum possible value of impedance. The current is maximum and is given by

\[
I_{max} = \frac{V}{Z} = \frac{V}{R}
\]

In this condition power factor is also equals to unity.

---

**4.22 Frequency Vs Current and impedance curves of a series RLC circuit**

The variation of impedance reactance with frequency is shown in the below fig. 4.18. Suppose an alternating voltage of constant magnitude but of varying frequency is applied to an RLC circuit.

If resistance \( R \) is independent of frequency hence it is represented by a straight horizontal line. Inductive reactance \( X_L \) is directly proportional to frequency hence its graph is a straight line through the origin \( f_o \). \( X_L \) increases linearly with frequency. Capacitive reactance \( X_C \) is inversely proportional to its frequency. Hence its graph is a rectangular hyperbola which is drawn in fourth quadrant because \( X_C \) is regarded negative.
Net reactance \( X = X_L - X_C \). Its graph is hyperbola and crosses the X axis at point A. The value of frequency at A is called resonant frequency \( f_0 \). Thus at resonant frequency reactance \( X \) is zero. Impedance \( Z = \sqrt{R^2 + (X_L - X_C)^2} \). At low frequencies impedance is large. AT (capacitive) high frequencies \( Z \) is again large (Inductive). At resonance impedance \( Z \) is equal to \( R \) and net reactance \( X = 0 \).

Current has low value on both sides of resonant frequency this is due to large impedance. But current has maximum value at resonance.

4.23 Resonance Curve

The curve drawn between current and frequency is known as resonance curve. This is shown in fig 4.19 for various values of \( R \). For smaller values of \( R \) current frequency curve is sharply peaked, but for larger values for \( R \) the curve is flat.
4.24 Band Width, Q factor and Selectivity

The band width of any system is the range of frequencies for which the current or output voltage is equal to 70.7% of its value at the resonant frequency and it is denoted by B.W. Below fig 4.20 shows the response of a series RLC circuit.

Here in the below fig 4.20 frequency \( f_1 \) is the frequency at which the current is 0.707 times the current at resonance value and it is called the lower cutoff frequency. The frequency \( f_2 \) is the frequency at which the current is 0.707 times the current at resonant value and is called upper cut off frequency. The Bandwidth or B.W. is defined as the frequency differences of \( f_2 \) and \( f_1 \).

Fig. 4.20

4.25 Q Factor

The quality factor Q is the ratio of the reactive power in the inductor or capacitor to the true power in the resistance in series with the coil or capacitor.

The quality factor \( Q = 2\pi \frac{\text{Maximum energy stored}}{\text{Energy dissipated / cycle}} \)

Q factor of a coil = \( \omega L/R \)
Q factor of a capacitor = \( 1/\omega CR \)
Thus Q factor = \( \omega L/R \) or \( 1/\omega CR \)

4.26 Selectivity

A series RLC circuit gives unequal responses to voltages of different frequencies. At the frequency of resonance the impedance is minimum and the
current is maximum. As the frequency of the applied voltage is either reduced or increased from this resonance frequency the impedance increases and the current fall. The below fig 4.21 shows the variation of current I with frequency. Thus series RLC circuits possess frequency selectivity.

Selectivity of a resonant circuit is defined as the ratio of resonant frequency $f_0$ to the 3dB bandwidth.

Thus selectivity = Resonance frequency/3dB Bandwidth

$$= f_0 / \text{3dB Bandwidth}$$

![Fig. 4.21 Current Vz Frequency curve of a series of RLC Circuit]

### 4.27 Comparison between series and parallel resonance.

<table>
<thead>
<tr>
<th>Sl. No</th>
<th>Impedance</th>
<th>Series circuit</th>
<th>Parallel Circuit</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Impedance at Resonance</td>
<td>Minimum</td>
<td>Maximum</td>
</tr>
<tr>
<td>2</td>
<td>Current at Resonance</td>
<td>Maximum($V/R$)</td>
<td>Minimum [$V/(L/CR)$]</td>
</tr>
<tr>
<td>3</td>
<td>Impedance at Resonance</td>
<td>$R$</td>
<td>$L/CR$</td>
</tr>
<tr>
<td>4</td>
<td>Power factor at resonance</td>
<td>Unity (1)</td>
<td>Unity (1)</td>
</tr>
<tr>
<td>5</td>
<td>Resonant frequency</td>
<td>$1/2\pi\sqrt{LC}$</td>
<td>$1/2\pi\frac{1}{\sqrt{LC - \frac{R^2}{L^2}}}$</td>
</tr>
<tr>
<td>6</td>
<td>It magnifies</td>
<td>Voltage</td>
<td>Current</td>
</tr>
</tbody>
</table>
Solved Problems on Resonance

1. Calculate the resonance frequency when 2 mH inductor and 80 pf capacitor is connected in a series circuit.

Ans : L = 2 mH
C = 80 x 10^{-12} F

Resonant frequency \( f_o = \frac{1}{2\pi\sqrt{LC}} \)

\[
= \frac{1}{2\pi\sqrt{2 \times 10^{-3} \times 80 \times 10^{-12}}}
\]

\[= 389 \text{ KHz} \]

2. Determine the resonant frequency for the circuit shown in fig 4.22

Ans : Resonant frequency \( f_0 = \frac{1}{2\pi\sqrt{LC}} \)

\[
= \frac{1}{2\pi\sqrt{10 \times 10^{-6} \times 0.5 \times 10^{-3}}}
\]

\[= 2.25 \text{ KHz} \]

3. For the circuit shown in Fig. determine the impedance and resonant frequency as resonance.
Ans: Resonant frequency \( f_0 = \frac{1}{2\pi} \frac{1}{\sqrt{LC}} \)

\[
= \frac{1}{2\pi \sqrt{0.1 \times 10 \times 10^{-6}}} = 159.2 \text{ KHz}
\]

Impedance at resonance is equal to \( R \) i.e. \( Z = 10\Omega \)

**Applications of Resonant Circuits**

Resonant circuits are nothing but tuned circuits

1. These are used as tank circuits in oscillators.
2. These are used in Receivers for frequency selection
3. These are used for flat frequency response in IF amplifiers
4. These are also used as load impedance.
5. Thus resonant circuits are very useful in all communications circuits like Radio receivers, TV receivers, Satellite receivers, Transmitters etc.

**Summary**

1. Current is the flow of electrons and its unit is ampere (A)
2. Voltage is the work done to carry an electron or unit charge from one point to another point in a conductor and its unit is volt.
3. Resistance may be defined as the opposition to the flow of current and its unit is ohms (\( \Omega \))
4. The rate of doing work is called power and its unit is W (watt)
5. Admittance is the reciprocal of impedance which is measured in Seimens (s)
6. Conductance is the reciprocal of resistance measured in mhos.
7. Ohm’s law states that the ratio of potential difference and the current flowing through a conductor between any two points is always constant provided that the temperature do not change.
8. Kirchhoff’s current law states that the algebraic sum of current meeting at a point or a junction in an electrical network of conductors is zero.
9. According to Kirchhoff’s second law, the algebraic sum of e.m.f.s and IR drops in a closed loop or mesh is zero.
10. One complete set of positive and negative half cycles is known as a cycle.

11. The total number of cycles completed in one second is known as frequency and it is measured in Hertz (Hz) or cycles/sec.

12. The average value of an alternating current is expressed by that steady current which transfers across any circuit the same charge as is transferred by that steady current.

13. The RMS value of an A.C is given by that steady or d.c. current which when flowing through a given circuit for given time produces the same heat as produced by that alternating current when flowing through the same circuit for the same time.

14. Any series RLC circuit is said to be in electrical resonance when its net reactance is zero.

15. In a series RLC circuit the current is maximum, and the impedance is minimum in series RLC circuit.

16. In a parallel resonant circuit, current is minimum and impedance is maximum at resonant frequency.

17. Resonant circuits are used in oscillators, radio and Television receivers for frequency selection.

**Short Answer Type Questions**

1. Define electric current and mention its units.

2. Define the term resistance and state its units.

3. Define (a) Conductance and (b) Admittance. Write its units.

4. Define power and state its units.

5. State and explain Ohm’s law.

6. State and explain Kirchhoff’s laws

7. Write the principle used in AC voltage generation.

8. Write the equation for AC voltage and write the meaning of each term in it.

9. What is meant by cycle and time period of a cycle.

10. What is meant by frequency and write its unit.
11. What is meant by average value of an AC quantity.

12. What is meant by Rms value of an AC quantity.

13. What is meant by peak or crest factor.


15. Draw the vector diagram of RC series circuit.

16. Write the equations for impedance of RL, RC series circuits.

17. Define Resonance? And write the equation for resonant frequency in RLC series circuit.

18. What is resonance curve and draw the diagram.

19. Define Quality factor

20. Define Bandwidth


22. Write the applications of Resonant circuits.

23. Write the equations for inductive, capacitive reactance and impedance in RLC series circuit.

24. Draw the vector diagram for RLC series circuit.

25. Write the relation between Q resonant frequency and bandwidth.

**Long Answer Type Questions**

1. Derive the equation for sinusoidal or instantaneous voltage?

2. Derive the equation for impedance in RL series circuit?

3. Derive the equation for impedance in RC series circuit?

4. Derive the equation for impedance in RLC series circuit?

5. Derive the equation for resonant frequency in RLC series resonance.

6. Write the comparison between series and parallel resonance.

7. Explain about selectivity and Bandwidth of resonant circuit.

8. Explain variations of current and impedance at resonance with neat graph.

9. A series RLC circuit consists a resistance of 10Ωand inductance of 0.1H and capacitance in Hz and in radians/second (A: 15920 Hz, \(10^5\) rad/sec)
Learning Objectives

After completing this unit, the student will be able to understand

- The different types of wires.
- Different gauges of wire and their current capacity.
- Familiar with different wire joints.
- Various connectors used in electronic circuits.
- Get an idea of terminators used in Electronic circuits.
- The need of contactor and their types
- Get an idea about a switch and their types and applications
- The concept of relay, types and their applications.

5.1 Wires

Single strand wire, consists of one piece of metal wire. Stranded wire is composed of a bundle of wires to make a larger conductor.

Stranded wire is more flexible than single strand wire of the same total cross-sectional area, is used where there is little need for flexibility in the wire.
single strand wire also provides mechanical ruggedness.

Stranded wire is used when higher resistance to metal fatigue is required. Such situations include connections between circuit boards in multi-printed circuits board devices. Where the rigidity of solid wire would produce too much stress as a result of movement during assembly or servicing. AC line cords for appliances, musical instrument cables; computer mouse cables; welding electrode cables; control cables connecting moving machine parts; mining machine cables, trailing machine cables, and numerous other applications.

### 5.2 Standard Wire Gauge

#### 5.1 Standard Wire Guage

The thickness of a wire is often given as a Standard Wire Guage, or SWG. This is a number from 0000000 or 7/0 (thickest) to 50 (thinnest). The gauge of most wires used in electronics between 20 and 30. Often a wire gauge will be stated followed by “swg”, like 26 swg, etc.

#### 5.2.1 Wire Joints

When working with the electronic equipments or with electrical wiring it becomes necessary to splice or join wires together. Splices and joints are essentially the same thing. Several different methods of doing this exist. The fundamental necessities of an effective splice includes each other even without solder and that they are well soldered to avoid corrosion. All wire joints must be taped with electrical tape after soldering.

#### 5.2.2 Western Union Splice

The western union splice works best to splice together small, solid conductors. It is the most common type of wire splice. To make the western union splice, first remove about five inches of insulation from both wires and
cross the exposed wires. Cut off the excess wires and pinch the ends down with pliers, solder the joint together and wrap tape around it.

5.2.3 Tap splice

A tap splice also called a tap joint and is used to connect a conductor to a running wire. To make a tap splice strip about 1 1/2 inches off running the wire. Taking the running wire and wrap it once round the running wire. Now wrap the end of the wire through the loop you just made. Then wrap the connecting wire around the running wire about six times. Make sure the wire points away from the original turn, solder the joint wrap around it.

5.2.4 Fixture splice

Fixture splices or fixture joints are used to connect wires of different sizes. This joint requires five inches of insulation stripped off the wire. Hold the wires together and then twist them few times with a pliers. Both wires must twist for the joint to be tightened. Cut both ends of the wire so that they are same length and then take the twisted joint and bend it, so that it lines up with wires. Take the cut ends, and extend them perpendicular to the wire, and twisted portion. Wrap these two ends in the same direction as the twist solder the joints together and wrap around it.

5.3 Connectors

Connectors are used in electronic circuits for various purposes and are of several types. When complex electronic circuits are assembled, it will not be possible to have all of the circuit functions in one circuit board or block and interconnecting one part with the others requires suitable connectors. Connectors are of several types, one has a particular area for its use.

1. Coaxial connectors, normal, BNC etc.
2. Instrumental connectors.
3. D series connection
4. Edge connectors of PCB
5. Euro card connectors
6. Jack and plug type connectors
7. Din series audio connectors
8. Modulator connectors for PCBs.
5.3.1 Coaxial connectors

Coaxial connectors are used to connect coaxial cable. The male type is always connected to the cable and the female type is fixed to the instrument. The connectors are housed in a outer metallic cylinder which is always connected to the earth. Coaxial connectors are manufactured as type BNC, type TVC, N type, C type, HN and UHF cables.

Each of these cables have different frequency response and impedance. Most of the cables have 50 ohms.

5.3.2 BNC Series

The BNC series are also called Bayonet Coupled is very popular because they are weather proof, light weight, small in size and have a constant impedance of 50 ohms. The bayonet locking provides quick locking arrangement. Coaxial cables are used to achieve maximum signal isolation.

BNC series has wide band width and can work satisfactorily up to 2 GHz. They have a insertion loss of 0.1 Db.

![Fig. 5.2 BNC Connector](image)

5.3.3 TNC Connector

Threaded coupled or TNC connectors are similar to the BNC connectors in construction. These connectors are available with constant impedance of 50 ohms. TNC series can be used up to 5 GHz. SMA or subminiature type connectors are available and can be used up to 18 GHz.

![Fig 5.3 TNC Connector](image)
5.3.4 N Connectors

These connectors have a threaded coupling. N connectors have a impedance of 50 ohms and has a rated voltage of 1000v. The frequency range over which these can respond connector is 10 GHz.

The ultra high frequency connectors can respond upto 200 MHZ. Theses connectors have a impedance of 50 ohms and rated voltage of 500v. UHF connectors have threaded coupling and are widely used in video applications. The manufacturing costs is comparatively lower than the other type of connectors.

5.3.5 PCB Connectors

PCB connectors are available as edge connectors and euro card connectors. Edge connectors are multi way single or double row connectors. The standard spacing for the connecting fingers is 4 mm. The spacing will be small for specific applications. Edge connectors are available with different pin configurations. The standard spacing for the connecting fingers is 4 mm. The spacing will be small for specific applications. The standard edge connectors have 10, 12, 16, 18 and 22 pins. The edge connectors are used to interconnect the circuit boards.

![Edge Connector](image)

**Fig 5.4 Edge Connector**

**Euro card connectors**

Euro card connectors differ from edge connectors in construction. The edge connectors have fingers where euro card connectors have holes and pins mating together. Two or more row of pins are used for larger no. of contacts. Bent pin euro card connectors are used for mounting on the PCB. The contacts are made of phosphor bronze and are gold plated. These cards can withstand currents upto few amperes.
5.3.6 Instrument connectors

The instrument connectors are used in the measuring instruments. Some of the instrument connectors are Jones plug, modular plug and X-plug socket.

5.3.7 Modular Connectors

Modular connectors are of small size they are made of brass plug silver plated contacts for panel mounting. Modular plugs may be directly mounted on the chasis. Modular plugs are available with 4,8,12,24 ways. Pins protrude from PCB. These are used to interconnect several modules. They are mostly used for low power applications.
5.3.8 Din connectors

Din connectors are multi pole connector’s plugs. These are circular in shape and 3 and 5 pin plugs are available.

5.4 Terminators

When constructing and using coaxial cable, it is important to close off any exposed coaxial cable ends. This is known as terminating the cable. Coaxial cable terminators also known as “F” terminators are screw in metal connectors that seal the exposed end of a coaxial cable. The terminators emulate a connection to a video measurement or computer accessory and formed a closed loop in the cabling system instead of an open one which can result in signal loss.

The terminator is a round non electrical component that allows the single wire exiting out of the coaxial cable to fit inside of it. These components keep extraneous signals from equipment or unwanted radio signals from entering into the signals being carried by the coaxial cable. A terminator also keeps the moisture from entering through the exposed end of the cable.

5.5 Contactors

A contactor is an electrically controlled switch used for switching a power circuit, similar to a relay except with higher current ratings. A contactor is a controlled by a circuit which has much lower power level than the switched circuit.
Contactors come in many forms with varying capacities and features. Unlike a circuit breaker a contactor is not intended to interrupt a short circuit current. Contactors range from those having a breaking current of several amperes and 24 VDC to thousands of amperes and many kilo volts. The physical size of the contactors ranges from a device small enough to pick up with one hand to large devices approximately a metre yard on a side.

Contactors are used to control electric motors, lighting, heating, capacitor banks and other electrical loads. Various types of contactors are

1. Power contactors
2. Capacitors switching contactors
3. DC contactors
4. MCH contactors
5. Definite purpose contactor etc.

5.6 Terminals

Terminals are connecting points on instruments or connecting boards. These are used to connect signal sources with the circuit or measuring instruments with the circuits one end of the terminal is rigidly fixed to the panel board and the other end has a threaded turntable knob. Terminals of various ratings are available 250v ,5A to 250V, 30A are available in the market.

If no. of points are to be connected a terminal block is used. These are available with blocks, sizes and ratings.

5.7 Introduction to Switches

A switch is a device which can connects two points in a circuit or disconnect two circuits. If a switch is acting so as to connect two points it is said to be in “ON” position. Such a switch is sometimes called as tap key or key it’s symbol is shown in the figure
In this switch it can be seen that there is only one throw and one pole to be connected. Hence it is also called as single pole throw switch. In short SPST according to no. of poles and throws used in a switch these are classified as follows.

1. Single pole sing throw (SPST) switch
2. Single pole double throw (SPDT) switch.
3. Double pole single throw(SPST) switch
4. Double pole double throw (DPDT) switch.

Single pole single throw switch is one in which there is one pole and one throw to be connected as shown in the figure.

Single pole double switch throw is one in which independent circuits are to be connected using two throws but still connecting one pole as shown in the fig. It is also called as SPDT.

Double pole single throw switch is one in which two poles are be connected in a single throw. In short it is called as DPST.

These types of switches are used in connecting an antenna to a receiver. Its symbol is shown in fig 5.13

A double pole double throw switch is one in which two poles are to be connected to two different circuits. In short it is called DPDL. Its symbol is shown in the fig 5.14. This type of switch is capable of connecting receiver to antenna or antenna to receiver.
5.7.1 Types of Switches

In electronic equipment different types of switches are used for the required application. They are as follows

1. Toggle switches
2. Push button switches
3. Knife switches
4. Key or lever switches
5. Slide switches
6. Rotatory wafer switches
7. Micro switches
8. Key board switches
9. Piano switches
10. Mercury switches.

5.7.2 Specification of switches

The different electrical characteristics of switches are known as ratings or specification of switches. They are as follows

1. Max operating voltage
2. Operating current
3. Type of load
4. Capacitance
5. Insulation resistance
6. Change over time and bound effects.

Some of the switches ranging are given below

1. **Toggle switch ratings**
   - Max operating voltage: 250/440V AC
   - Operating current: 5-10Amps
   - Life (electrical): 5000 Amperes
   - Mechanical: 100000 operations
   - Contact resistance: 100 milli ohms
   - Insulation resistance: 100 M ohms

2. **Rotatory switch ratings**
   - Contact resistance: 10 milli ohms
   - Insulation resistance: 100 M ohms
   - Life: 7500 operations at full load

5.7.3 **Applications of switches**

Switches are needed i) to switch power supplies to circuits ii) to pass electrical signals to selective parts of composite circuit iii) to switch one among several components parts in to a common circuit.

However specific applications of different switches are given below:
1. Toggle switches are used in electric and electronic instruments.
2. Rotatory switches are used in band switches in receivers.
3. Piano switches are used in tape recorders, radios, instruments where wide range of function is to be selected.
4. Keyboard switches are used in computers.
5. Key or level switches are used for motor vehicles for ignition.
6. Push button switches are used in power supplies.
7. DPDT switches are used as band switches in radios.
5.8 Relay

Relay is an electromechanical device employed to control large power to perform switching operation. Thus relays are actually switches. They can have several poles and several contacts. The type of contacts could be normally open and normally closed.

5.8.1 Classification of Relays

These can be broadly classified as

1. Electromagnetic relays
2. Thermal relays
3. Electronic relays and
4. Miscellaneous relays

According to their operating characteristics these are classified as follows

1. Solenoid type
2. Moving coil type
3. Armature type
4. Electro dynamic type

Depending on their applications they are classified as

1. General purpose relays
2. Telephone relays
3. Latch in relays
4. Time delay relays
5. Reed relays
6. Polarized relays
7. Inter locking relays
8. High temperature relays
9. Frequency relays

5.8.2 Electromagnetic relays

Electro magnetic relay is the first man made electrical device. It was invented in the year 1836 by the great scientist “Morse”. It was first used in telegraphy in
1850. Relay has got important place in the automatic and semi automatic equipments. Relay is such a electronic device which can turn ON/OFF any external circuit in special circumstances.

The principle of relay is mainly based on electromagnetism. A simple relay can be compared with 1 pole relay switch. The difference is only that simple switch is a normal switch where as relay is automatic switch to some extent. It has a coil in it when this coil gets supply, then it becomes electromagnet and attracts the strip pole towards itself and changes the position of the switch. When supply is cut off the coil demagnetizes and thus switch comes to normal position. In a simple single pole relay there are totally five ends. Out of these two ends p1 and p2 are one ends of the coil. End A is known as pole end C is known as normal connection and c is orderly connection. When coil of relay does not gets the supply then pole A remains touched with the end n/c and this state of relay is called normal state or off state. As it is shown in the fig 7.6 when the coil of relay gets the supply the core of the coil becomes electromagnet and the pole A which is connected with long strips gets attracted towards the electromagnet. As a result of which a pole A make contact with end o/c end c. In this way the contacts of relay switches only changes when it gets the supply. As soon as the supply to the coil cuts off the relay comes back to its normal position.

5.8.3 Specification and applications of relay

Different electrical characteristics of relay are known as specifications. They are as follows

1. Operating voltage-6V/9V/12V/24V
2. Current-150mA and less
3. Coil resistance-order of 1 kilo ohm and low
4. Contact resistance-low

5.8.4 Applications of relays

Relays are used in different fields in electronics. They are as follows
1. Relays are used in stabilizers
2. They are used in emergency lights
3. They are used in telephone circuits
4. They are used in telegraphy circuits.

Summary

1. Single strand wire consists of one piece of metal wire. Stranded wire composed of a bundle of wires to make a large conductor.
2. The thickness of a wire is often given as a standard wire gauge or SWG. Greater the SWG of a wire, smaller is its current carrying capacity.
3. Various types of wire joints are western union, splice, tap splice, fixture splice etc.
4. Connectors are used to inter connect one part of the circuit to the other.
5. Coaxial connectors, instrumental connectors, D-series connectors, PCB connectors etc., are widely used in electronic circuits.
6. A switch is a device which can connect two points in circuit or disconnect two points.
7. Relay is an electro mechanical device employed to control large power to perform switching operation.
8. Relays are extensively used in stabilizers, emergency lights, telephone and telegraph circuits.

Short Answer Type Questions

1. Write the difference between single stand and multi stand wire?
2. Name the different types of wire joints?
3. What is the need of connector in electric circuits and mention some connectors?
4. What is the use of terminator in electronic circuits?
5. State the need of contactors and write their different types?
6. What is meant by switch and write the symbols of different switches?
7. Write different types of switches?
8. Write the specifications of switches?
9. What is meant by relay and classify different types of relays?
10. What are the applications of relays?
11. Write the specifications of relays?

Long Answer Type Questions
1. Explain in detail about PCB connectors?
2. Explain the structural details and working of electromagnetic relay?
Learning Objectives

After completing this unit, the student will be able to understand:

- The concept of soldering
- The different types of soldering
- The need of soldering flux
- The importance of temperature controlled soldering and de-soldering station.
- The need of PCB’s in electronic equipment and their types.
- The steps involved in PCB preparation
- The steps involved in screen printing.

6.1 Introduction

Soldering is the process of joining two metallic conductors together at a relatively low temperature of 500 and 600° Fahrenheit. The joint where the two metal conductors are to be joined or fused is heated, with a device called soldering iron and then an alloy of tin and lead called solder is applied which melts and covers the joint. The solder cools and solidifies quickly to ensure good and
durable connection between the joined metals. Covering the joints with solder also prevents oxidation. Faulty solder joints remain one of the major causes of equipment failure.

### 6.2 Soldering Lead Types

Solder used for electronics is a metal alloy, made by combining tin and lead in different proportions. We can usually find this proportions marked on the various types of solder available.

The grades of solder available contain the percentage of tin to lead respectively as 40-60, 50-50 and 60-40. The 60-40 (60 tin 40 lead) solder melts easily and makes soldering easy and safe without damage to the surface or components being soldered. This type of solder is most suitable for electronic work. Solder is usually available in the form of wires of different sizes.

We need to be careful not to move any elements of the joint during the cool down period. Movements may cause what is known as disturbed joint. A disturbed joint has a rough, irregular appearance and looks dull instead of bright and shiny. A disturbed solder joint may be unreliable and may require rework.

### 6.3 Soldering Iron

![Fig 6.1](image1)

![Fig 6.2](image2)
A soldering iron is most commonly used hand tool in soldering. It supplies heat to melt the solder so that it can flow into the joint between two work pieces. Soldering irons are most often used for radio, television and other electronic equipment servicing. It consist of

1. Supply cord and plug
2. A wooden or plastic handle
3. Metallic shank containing the heating element and
4. Copper tip

All these parts are replaceable. Soldering irons are rated in watts. For electrical and electronic work the rating of a soldering iron varies from 10 W to 100 W. A 10 W to 35 W soldering is commonly used for radios and TV network.

To avoid damage to work table and other surfaces, a heated soldering iron should be placed on it’s holder or stand.

### 6.4 Soldering flux

A rosin solder flux or paste is generally used for soldering. The flux easily melts and cleans the surface of any oxide films to ensure a smooth and cleaned soldered joint. However solder wires with flux filled in the hollow core of the wire also available. Use of flux core solder wire makes the external application of flux unnecessary. Acid flux should not be used particularly when soldering copper wires.

### 6.5 Tips for good soldering

Good soldering practice is very important for assembling any electronic circuit. The following points should be kept in mind during the time of soldering.

1. Use the correct type of soldering iron and solder.
2. The tip of the soldering iron should be cleaned with a file and tinned before use.
3. Avoid overheating of components and PCBs.
4. Do not use too much solder.

### 6.6 Temperature controlled soldering and de soldering stations

One of the major elements that is always required in electronics production or PCB assembly area is the ability of rework. There will always be board
failures and as a result, components need to be removed and replaced. This needs to be done using skills, and the right equipment so that no damage is caused.

While de-soldering tools are helpful, a full holder station is an essential item. The solder station comprises equipments for solder and de-soldering. The de-soldering elements of the solder station normally comprises a heated element, with a central hole that is connected to a vacuum pump. In this way the solder station can be used, to effectively apply heat and remove the solder from the joint. This means that a solder station will be the most effective tool rework is undertaken, with minimum of risk to the board.

6.7 Need of PCB in electronic equipments

The printed circuit boards are usually termed as PCB. These are used to avoid most or all the disadvantages of conventional electronic boards. Due to the following advantages PCBs are needed in the electronic equipments.

These advantages are as follows

1. These are small in size and gives clear conception.

2. These are efficient in performance and gives all the information on the board.

3. Connections of the circuits on the PCB is solved and there is no chance for loose connections.

4. Servicing or fault tracing in PCBs is easy.

5. They are accurate. The only disadvantage is that once the board is prepared no more changes are possible.
6.8 Classification of printed circuit boards

PCBs are broadly classified into two types.

1. General purpose PCB’s.
2. Special purpose PCB’s.

Special purpose PCB’s are again classified into the following types. These are single aided boards

1. Single sided boards.
2. Double sided boards.
3. Multi layer PCB’s.

6.9 Types of laminates used in PCB

A laminate is a tin sheet obtained by pressing layers of a filler impregnated with resin under heat and pressure. The widely used fillers are paper (craft paper, alpha cellulose or rags) glass. The resins used are epoxy, polyester, polytra. Thus laminates are two types

1. Phonetic paper based laminates.
2. Glass epoxy material laminates.

Further glass epoxy laminates are of two types

1. Woven type
2. Non woven type.

Phonetic paper laminates PCBs are used where either high voltage or high frequencies are not required and when tracks are also not too close. Glass epoxy laminate PCBs are used where loose tracks layouts or high frequencies are involved.

The standard glass epoxy laminate is looking green but even white coloured boards are also available. In the woven type glass, fibre is spun woven in to a cloth and impregnated with epoxy resin. Non woven laminate boards have their a glass mat impregnated with epoxy resin. The non woven type is economical, but is not resistant to crack propagation. The holes are clean in the non woven type. Woven type boards are very hard to grill also.

Copper Clad Laminate

By the process of electro deposition, if a thin film of copper is deposited on a laminate then it is known as copper clad laminate.
The basic materials required for the manufacture of copper clad laminates are 1. Filler 2. Resin 3. Copper coil.

### 6.10 Preparation of PCB layout

Layout means components positions on a copper layout. The circuit diagram with components that is the diagram, which shows the spacing for their components, and their inter connection tracks on a copper clad is known as layout of PCB. This layout allocates spacing for different components, supply tracks, inter components connection track, as per the circuit diagram.

The various steps involved in the preparation of PCB layout are as follows:

1. Drawing or art work is the first step in the preparation of PCB layout.
2. While drawing a PCB layout we have to keep in mind about the sizes of components of the circuit.
3. The art work is usually carried out on a transparent base foil or on trace paper or drawing sheet according to the printing method used for PCB.
4. For small board ink drawing and strip art work is used whereas for large boards black taping is widely used.
5. For simple efficient design of art work, self adhesive tapes, and pads are used.
6. While drawing layout draw lines and small circles across each component; draw two parallel lines for supply, earth and circles associated with base collector and emitter of the transistor.
7. Draw the connections without overlapping and outline of the layout is prepared.
8. After completion of art work the lines and circles are fixed using self adhesive tapes and pads respectively.
9. The design of art work becomes simple and more efficient.
10. After fixing the boundaries of the PCB, pads exactly and properly wherever desired and taping of conductors is completed giving the actual circuit layout.
11. The below fig 6.4 shows the simple PCB layout for a power supply circuit.
12. While preparing a PCB layout some other considerations must be kept in mind. They are
(i) The diameter of the solder pad should be selected such that any component lead should fit in appropriately.

(ii) Sufficient solder pad size must be provided to avoid damage due to drilling of holes.

(iii) The conductor width should always be less than the solder pad diameter preferably about one third.

(iv) The pattern around the holes should be maintained uniformly as small as possible.

(v) When the components like transistors or diodes are to be mounted in a fixed direction then it is required to index the orientation, on the artwork. This helps not only in PCB assembling but also in trouble shooting.

Fig 6.4 P.C.B. of a regulated power supply unit

6.11 Methods of Transferring layout on to the copper clad sheet

Using the following methods we can transfer layout on to the copper clad sheet. These are 1. Screen printing. 2. Photo proven printing.

6.12 Steps involved in Screen printing

The following steps are used in screen printing of PCB.

1. A screen fabric with uniform mashces and opening is stretched and fixed, on a solid frame of wood or metal. This is known as screen.

2. This screen is washed, using soap and after that it is dried for a few minutes in the light.
3. The circuit pattern or circuit layout is then transferred on to the screen leaving the meshes in the pattern are open while meshes in the rest of the area are closed.

4. Then printing ink is forced by moving squeezer, through the open meshes, on to the surface of the material to be printed.

5. Thus the circuit to be printed is covered with the ink surface while the rest is left free.

6. The fixation of the screen printing is shown in the fig 7.8.

7. The primary selection of the fabric depends on the thickness of the ink to be deposited, durability of the screen, resistivity to chemical agents in the inks and mechanical sensibility.

8. The fabrics used for the PCBs are made of monofil polyster or stainless steel fabric. Mono file polyster fabrics are widely used in the PCBs. The stainless steel fabrics are used wherever accuracy is needed.

9. The frames for fixing the screen are made of seasoned wood or aluminium.

10. The screen is fixed to the frame and a drying operation is carried out. Caustic soda solution is splashed in the screen and evenly distributed by a brush. Thereafter the solution is thoroughly removed with water rinse and the screen is dried by blowing hot air. The screen is now ready for pattern transfer.

11. Cleaned up screen is coated with a photographic emulsion. This is then exposed in direct contact with the film master on which the circuit is prepared. On developing mesh opens in the pattern required and the rest is closed.

12. The ink for the screen printing must be capable of rapidly drying on the PCB but slowly on the screen. It should be easily visible and should not contaminate the cleaning liquids.

13. The prepared screen is put in a frame holder which is rigidly held. A squeezer of width 2 or 4 cm. More than the pattern width is selected. The squeezer is pulled and firmly pressed across the pattern on the screen. In this fashion the first few prints are made on white papers until the perfect patterns appear. The actual screen printing is now done on the copper clad sheets.
Materials used in screen printing of PCB.

The materials required for screen printing is as follows.

1. Copper clad laminate
2. Screen (mono file polyester fabric or stainless steel).
3. Frame wood or aluminium
4. Ink
5. Cleaning solution
6. Squeezer
7. Photographic emulsion.

6.13 Photo processing Technique for PCB preparation

In the photo processing method of preparing PCBs copper clad laminate itself is sensitized by applying a light sensitive emulsion. On exposure and development a fine acid resistance film of circuit pattern is obtained after stretching such a developed pattern. The light sensitive emulsion used for the above purpose is known as “Photo resist”. The laminate is heated with pumice powder in a dust free environment. After the cleaning process, the laminate is degreased with trichloro-ethylene. A fine layer of photo resist is applied by one of the following methods. These are

1. Brush coating
2. Flow coating
3. Dip coating
4. Roller coating

Fig 6.5 Set up for Screen printing
5. Whirler coating.

The photo resist coating dries up very fast and thus formed on the laminate is very sensitive to light. The entire preparation of the board is done in dark room under a safe red or orange light the dried on photo sensitive.

Laminate is then exposed to ultra violet light in contact with the circuit master negative. After exposure the laminate is developed with a suitable solvent developer. In this process of developing the unwanted photo resist layer is removed and the laminate is now ready for etching and finishing. Once the circuit pattern is obtained the board is drilled and the protective coating is applied as in the screen printing method. Holes are drilled using high speed micro drills. Sometimes the printed circuit boards are punched to make holes. Thus PCBs are prepared using photo processing method. This method is very useful for accurate printing. But is some costlier than screen printing. Due to accurate printing this method is used in professional applications.

6.14 Etching drilling and cleaning of PCB

The process of removing the unwanted copper and forming copper pattern on the laminate or PCB is known as etching. In the preparation of PCB sometimes we may obtain different copper patterns. Some of them are enlarged copper conductor size, track shorting, over hangings etc from actual copper pattern. In this case we have to remove their extra or unwanted copper patterns using this etching process. In this process using enchants like ferric chloride, cupric chloride chromic acid or alkaline ammonia. We can remove the unwanted copper. Spray etching and bubble etching methods are used for etching process. Among these spray etching offers high etching uniformity and a fast etching rate.

The printed circuits boards are to be cleaned and prepared for the layout of the circuit. Insufficient cleaning of the PCBs may leads to difficulties in final preparation. The organic elements like oil and greases are present variably. This may be due to the equipment used for shearing, drilling or punching. These are to be removed with a suitable solvent. The finger prints formed while handling PCBs may be removed by rinsing in water and blowing with compressed air or by scrubbing with abrasives.

6.15 Steps used in PCB printing

In the previous topics we have learned the different processes come across in PCB printing. These different steps are given here in the sequential order.

1. Preparation of copper clad laminate
2. Preparation of circuit layout using drawing or an art work on a transparent base foil using high quality water proof ink or using self adhesive tapes or pads.

3. Cleaning the board layout of the circuit.

4. Preparation of master copy of layout.

5. Checking the layout of the copper clad laminate using screen printing or photo process printing techniques.

6. Transferring the layout on to the copper clad laminate using screen printing or photo process techniques.

7. Etching the printed PCBs required.

8. Drilling the holes wherever required.

9. Scrubbing or clearing the PCBs for removing the loosely attached particles of the PCBs which are existing in drilling.

10. Finally drilling the PCBs are ready for external use. Thus using the above steps we can prepare PCB’s.

6.16 Soldering methods of PCBs

Soldering is process used for joining two metal parts or two conductors. The following soldering methods are used in PCB’s.

1. Manual soldering

2. Mass soldering

**Manual Soldering**

In manual soldering the surface to be soldered must be cleaned and fluxed. The soldering iron is switched and allowed to attain the soldering temperature. Let the form of wire is applied near the component to be soldered and heated with iron. The surfaces to be soldered are filled and iron is removed and the joint is cooled without disturbing. This is known as manual soldering process.

**Mass Soldering**

Mass soldering is used where a large no. of joints are to be soldered simultaneously. These are two types

1. Dip soldering

2. Wave soldering
1. **Dip Soldering**: A refluxed PCB with assembled component dipped vertically into a clean solder bath to a depth. The board is kept in bath for 2-3 seconds. While taking out the board an angled path should be allowed.

2. **Wave Soldering**: In wave soldering the assembly is applied flux. It is pre-heated while passing through conveyor or belt to 110° and then to 140° it passes over a wave of folder. The advance of lambda wave is that, while the board enters the components touch the flat top of the wave while, the board leaves the solder is drained away because of angle of wave with horizontal. Thus the various steps in mass soldering are as follows.

   1. Assembling the board.
   2. Flux application.
   3. Flux drying a Precheting.
   4. Soldering.
   5. Cooling
   6. Flux removal.

---

### 6.17 Use of edge Connectors and Plating

The modular nature of construction of electronic equipment led to the wide usage of edge board connectors. Edge connectors are mostly used in interconnecting add on circuits or circuit boards, to basic mother board. In all personal computers, and in some tv sets, these are strongly used. They are two basic types of printed circuit board, edge connection.

1. Plug and receptacle (indirect entry)
2. Care edge (direct entry).

Indirect entry type is used when the board is on non standard thickness. A plug type of connector and a separate receptacle connector is connected by dip soldering. This type is more expensive and non repairable.

Electroplating is the process at which the ions are deposited by the passage of current. In PCBs the base copper coating forming the conductor track is liable to damage when exposed to atmosphere over a long period of time. Thus the copper tracks has to be protected. This led to use of plating as a protection to the copper coating. This plating is used for protecting the copper coating or copper tracks in PCBs for long period of time.
6.18 Specification of PCB

The following characteristics are the specifications of PCBs. They are:

1. Current carrying capacities of PCB.
2. Contact resistance.
3. Insulation resistance.

Summary

1. Soldering is the process of jointing together two metallic conductors at relatively low temperature.
2. Solder used in electronics is a metal alloy made by combining tin and lead in different proportions. Common grades available are 40-60, 50-50 and 60-40.
3. A soldering iron is a hand tool used for soldering. 10 w to 35 w soldering irons are commonly used for servicing work.
4. Soldering flux cleans the surface so as to ensure for smooth and clean solder joint.
5. PCB’s are classified as (a) general purpose PCBs and (b) special purpose PCBs.
6. PCB preparation involves in (a) layout preparation (b) Etching (c) Cleaning and (d) drilling wise sequential steps.
7. Manual soldering and mass soldering methods are used for PCB soldering.
8. The main specifications of PCB’s are (a) current carrying capacity (b) contact resistance and (c) insulation resistance.

Short Answer Type Questions

1. What is soldering?
2. Name the different types of soldering leads used?
3. Write the different parts of soldering iron?
4. What is the use of soldering flux?
5. Give some tips for good soldering?
6. What is the need of PCB?
7. Write the classifications of PCBs?
8. Write the soldering methods used in PCBs?
9. What is meant by a laminate? Name the materials used for laminate?
10. What materials are used for screen printing of PCBs?
11. What are the specifications of PCBs?
12. What is meant by etching? Write the different types of etchants used in etching process?
13. What are the used of edge connectors and plating in PCBs?

**Long Answer Type Questions**

1. What are the steps used in screen printing of PCBs?
2. Explain the preparation of layout of PCB?
3. Explain in detail about photo printing process of PCB?
4. What are the sequential steps used in manufacturing of PCB?
5. Write the importance of temperature controlled soldering and desoldering station?
Learning Objectives

After completing this unit, the student will be able to understand

- The concept of Surface Mount Technology (SMT)
- The advantages and disadvantages of SMT over the pin through hole method of mounting components.
- Become familiar with various SMD components
- Become familiar with various SMD packages
- Explain the SMT soldering methods
- Become familiar with SMT soldering stations

7.1 Introduction

Surface mount technology (SMT): It is a method of constructing electronic circuits in which the components are mounted directly onto the surface of printed circuit boards (PCBs). In the industry it is largely replaced through hole technology construction method of fitting components with wire leads into holes in to the circuit board.
An SMT component is usually smaller than its through-hole counterpart because it has either smaller leads or no leads at all. It may have short pins or leads of various styles, flat contacts, a matrix of solder balls (BGAs), or terminations on the body of the component.

### 7.2 Advantages

The main advantages of SMT over the older through-hole technique are:

1. Smaller components.
2. Much higher number of components and many more connections per component.
3. Fewer holes need to be drilled through abrasive boards.
4. Simpler automated assembly.
5. Small errors in component placement are corrected automatically.
6. Components can be placed on both sides of the circuit board.
7. Lower resistance and inductance at the connection (leading to better performance for high frequency parts).
8. Better mechanical performance under shake and vibration conditions.
9. SMT parts generally cost less than through-hole parts.
10. Fewer unwanted RF signal effects in SMT parts when compared to leaded parts, yielding better predictability of component characteristics.
11. Faster assembly.

### 7.3 Disadvantages

1. The manufacturing processes for SMT are much more sophisticated than through-hole boards, raising the initial cost and time of setting up for production.
2. Manual prototype assembly or component-level repair is more difficult (more so without a steady hand and the right tools) due to very small sizes and lead spacing of many SMDs.
3. SMDs can’t be used directly with breadboards.
4. SMDs solder connections may be damaged by potting compounds going through thermal cycling.
7.4 SMD Components

Surface mount devices, SMDs by their nature are very different to the traditional leaded components. They can be split into a number of categories:

**Passive SMDs:** There is quite a variety of different packages used for passive SMDs. However the majority of passive SMDs are either resistors or capacitors for which the packages sizes are reasonably well standardized. Other components including coils, crystals and others tend to have more individual requirements and hence their own packages.

Resistors and capacitors have a variety of package sizes. These have designations that include: 1812, 1206, 0805, 0603, 0402 and 0201. The figures refer to the dimensions in hundreds of an inch. In other words the 1206 measures 12 hundreds by 6 hundreds of an inch. The larger sizes such as 1812 and 1206...
were some of the first that were used. They are not in widespread use now as much smaller components are generally required. However they may find use in applications where larger power levels are needed or where other considerations require the larger size.

The connections to the printed circuit board are made through metallised areas at either end of the packages.

**Transistors and Diodes:** These components are often contained in a small plastic package. The connections are made via leads which emanate from the package and are bend so that they touch the board. The leads are always used for these packages. In this way it is easy to identify which way round the device must go.

**Integrated circuits:** There is a variety of packages which are used for integrated circuits.

The package used depends upon the level of interconnectivity required. Many chips like the sample logic chips may only require 14 or 16 pins, whereas other likes the VLSI processors and associated chips can require up to 200 or more. In view of the wide variation of requirements there is a number of different packages available.

For the smaller chips, packages such as the SOIC (Small Outline Integrated Circuit) may be used. These are effectively the SMT version of the familiar DIL (Dual In Line) packages used for the familiar 74 series logic chips. Additionally there are smaller versions including TSOP (Thin Small Outline Package) and SSOP (Shrink Small Outline Package).

The VLSI chips require a different approach. Typically a package known as a quad flat pack is used. This has a square or rectangular footprint and has pins emanating on all four sides, Pins again are bent out of the package in what is termed a gull-wing formation so that they meet the board. The spacing of the pins is dependent upon the number of pins required. For some chips it may be as close as 20 thousandths of an inch. Great care is required when packaging these chips and handling them as the pins are very easily bent.

Other packages are also available. One known as a BGA (Ball Grid Array) is used in many applications. Instead of having the connections on the side of the package, they are underneath. The connection pads have balls of solder that melt during the soldering process, thereby making a good connection with the board and mechanically attaching it. As the whole of the underside of the package can be used, the pitch of the connections is wider and it is found to be much more reliable.
A smaller version of the BGA, known as the micro BGA is also being used for some ICs. As the name suggests it is a smaller version of the BGA.

### 7.5 SMT in Use

SMT is used almost exclusively for the manufacture of electronic circuit boards these days. Now it is found that SMDs are far more widely used than traditional leaded components, and as a result, traditional leaded components are considerably less common. Some components, particularly high density ICs may only be available in SMT packages. While there is still a need for many traditional components, SMDs now form the main line stream for components.

### 7.6 SMT/SMD Component Packages

Surface Mount Technology (SMT) components come in a variety of packages. The different SMT packages can be categorized by the type of component, and there are standard packages for each.

### 7.7 Passive Rectangular Components

These SMT components are mainly resistors and capacitors which form the bulk of the number of components used. There are several different sizes which have been reduced as technology has enabled smaller components to be manufactured and used.

<table>
<thead>
<tr>
<th>Size</th>
<th>Width (mm)</th>
<th>Height (mm)</th>
<th>Thickness (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1812</td>
<td>4.6 x 3.0</td>
<td>0.18 x 0.12</td>
<td></td>
</tr>
<tr>
<td>1206</td>
<td>3.0 x 1.5</td>
<td>0.12 x 0.06</td>
<td></td>
</tr>
<tr>
<td>0805</td>
<td>2.0 x 1.3</td>
<td>0.08 x 0.05</td>
<td></td>
</tr>
<tr>
<td>1603</td>
<td>1.5 x 0.8</td>
<td>0.06 x 0.03</td>
<td></td>
</tr>
<tr>
<td>0402</td>
<td>1.0 x 0.5</td>
<td>0.04 x 0.02</td>
<td></td>
</tr>
<tr>
<td>0201</td>
<td>0.6 x 0.3</td>
<td>0.02 x 0.01</td>
<td></td>
</tr>
</tbody>
</table>

Of these sizes, the 1812, and 1206 sizes are now only used for specialized components or ones requiring larger levels of power to be dissipated. The 1603 and 0402 SMT sizes are the most widely used.
7.8 Tantalum Capacitors SMD Packages

As a result of the different construction and requirements for tantalum SMT capacitors, there are some different packages that are used for them. These conform to EIA specifications.

<table>
<thead>
<tr>
<th>Size</th>
<th>Dimensions</th>
<th>EIA</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>3.2 x 1.6 x 1.6</td>
<td>3216-18</td>
</tr>
<tr>
<td>B</td>
<td>3.2 x 2.8 x 1.9</td>
<td>3528-21</td>
</tr>
<tr>
<td>C</td>
<td>6.0 x 3.2 x 2.2</td>
<td>6032-28</td>
</tr>
<tr>
<td>D</td>
<td>7.3 x 4.3 x 2.4</td>
<td>7343-31</td>
</tr>
<tr>
<td>E</td>
<td>7.3 x 4.3 x 4.1</td>
<td>7343-43</td>
</tr>
</tbody>
</table>

7.9 Semiconductor SMC Packages

There is a wide variety of SMT packages used for semiconductors including diodes, transistors and integrated circuits. The reason for the wide variety of SMT packages for integrated circuits results from the large variation in the level of interconnectivity required. Some of the main packages are given below.

7.10 Transistor Packages

SOT-23 – Small Outline Transistor. This is SMT package has three terminals for a diode of transistor, but it can have more pins when it may be used for small integrated circuits such as an operational amplifier, etc. It measures 3 mm x 1.75 mm x 1.3 mm.

SOT-223 – Small Outline Transistor. This package is used for higher power devices. It measures 6.7 mm x 3.7 mm x 1.8 mm. There are generally four terminals, one of which is large heat-transfer pad.

7.11 Integrated Circuit SMD Packages

SOIC – Small Outline Integrated Circuit. This is a dual in the configuration and gull wing leads with a pin spacing of 1.27 mm.

TSOP – Thin Small Outline Package. This package is thinner than the SOIC and has a smaller pin spacing of 0.5 mm.

SSOP – Shrink Small Outline Package. This has a pin spacing of 0.635 mm.

TSSOP – Thin Shrink Small Outline Package.
PLCC – Plastic Leaded Chip Carrier. This type of package is square and uses 3-lead pins with a spacing of 1.27 mm

- QSOP – Quarter Size Small Outline Package. It has a pin spacing of 0.635 mm.
- VSOP – Very Small Outline Package. This is smaller than the QSOP and has pin spacing of 0.4, 0.5 or 0.65 mm.
- LQFP – Low Profile Quad Flat Pack. This package has pins on all four sides. Pin spacing varies according to the IC, but the height is 1.4 mm.
- PQFP – Plastic Quad Flat Pack. A square plastic package with equal number of gull wing style pins on each side. Typically narrow spacing and often 44 or more pins. Normally used for VLSI circuits.
- CQFP – Ceramic Quad Flat Pack. A ceramic version of the PQFP.
- TQFP – Thin Quad Flat Pack. A thin version of the PQFP.
- BGA – Ball Grid Array. A package that uses pads underneath the package to make contact with the printed circuit board.

Before soldering the pads appear as solder balls, giving rise to the name. By placing the pads underneath the package there is more room for them, thereby overcoming some of the problems of the very thin leads required for the quad flat packs. The ball spacing on BGA is typically 1.27 mm.

7.12 SMD Package Applications

SMT surface mount technology packages are used for most printed circuit designs that are going to be manufactured in any quantity. Although it may appear there is a relatively wide number of different packages, the level of standardization is still sufficiently good. In any case it arises mainly out of the enormous variety in the function of the components.

7.13 SMD Resistor and its Construction

Surface Mount Device, SMD, resistors are the most widely used electronic component. Everyday millions are used to produce the electronic equipment from cell phones to televisions and MP3 players and commercial communications equipment to high technology research equipment.

SMD resistors are rectangular in shape. They have metallised areas at either end of the body of the SMD resistor and this enables them to make contact with the printed circuit board through the solder. The resistor itself consists of a ceramic
substrate and onto this is deposited a metal oxide film. The thickness, and the length of the actual film determines the resistance. In view of the fact that the SMD resistors are manufactured using metal oxide, means that they are quite stable and usually have a good tolerance.

7.14 SMD Resistor Packages

SMD resistors come in a variety of packages. As the technology has moved forward so the size of the resistor packages has fallen. The main packages with their sizes are summarized below:

<table>
<thead>
<tr>
<th>Code</th>
<th>Width x Height (mm)</th>
<th>Width x Height (in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2512</td>
<td>6.3 x 3.1</td>
<td>0.25 x 0.12</td>
</tr>
<tr>
<td>2010</td>
<td>5.00 x 2.60</td>
<td>0.20 x 0.10</td>
</tr>
<tr>
<td>1812</td>
<td>4.6 x 3.0</td>
<td>0.18 x 0.12</td>
</tr>
<tr>
<td>1210</td>
<td>3.20 x 2.60</td>
<td>0.12 x 0.10</td>
</tr>
<tr>
<td>1206</td>
<td>3.0 x 1.5</td>
<td>0.12 x 0.06</td>
</tr>
<tr>
<td>0805</td>
<td>2.0 x 1.3</td>
<td>0.08 x 0.05</td>
</tr>
<tr>
<td>0603</td>
<td>1.5 x 0.08</td>
<td>0.06 x 0.03</td>
</tr>
<tr>
<td>0402</td>
<td>1.0 x 0.5</td>
<td>0.04 x 0.02</td>
</tr>
<tr>
<td>0201</td>
<td>0.6 x 0.3</td>
<td>0.02 x 0.0</td>
</tr>
</tbody>
</table>

MLP package 28-pin chip, upside down to show the size

MLP package 28-pin chip, upside down to show the size
There are several stages required to solder SMDs to boards. However there are two basic methods of soldering that are used. These two processes require the board to be laid out with slightly different PCB design rules, and they also require the SMT soldering process to be different. The two main methods for SMT soldering are:

- Wave Soldering
- Reflow Soldering

Reflow Soldering is the most widely used method of soldering used with PCB assembly whether it is used for mass production or for prototype PCB assembly with surface mount components. The technology uses two main stages. First a solder paste is applied to the board, and then secondly the board is heated to enable the solder to melt. This stage in itself has several steps that are needed to ensure that the board is heated and cooled correctly.

Using Reflow Soldering technology it is possible to reliably solder surface mount components, and particularly those with very fine pitch leads. This makes it ideal for use with components used in mass produced electronics products.
7.16 Soldering Stations

One of the major elements that is always required in any electronics production or PCB assembly area is the ability for rework. There will always be board failures and as a result, components need to be removed and replaced. This needs to be done using skill and the right equipment so that no damage is caused. While de-soldering tools are helpful, a full solder station is an essential item. The solder station comprises equipment for solder and de-soldering. The de-soldering elements of the solder station normally comprise a heated element with a central hole that is connected to a vacuum pump. In this way, the solder station can be used to effectively apply heat and remove the solder from the joint. This means that a solder station will be the most effective way of ensuring that any network is undertaken with the minimum of risk to the board.

Summary

1. Surface-Mount Technology (SMT) is a method for constructing electronic circuits in which the components are mounted directly onto the surface of printed circuit boards (PCBs).

2. SMT offers many advantages such as low cost, better performance, greater component density, faster assembly etc.

3. The main disadvantage of SMT is its initial cost and the time of setting up for production.

4. The various SMT components include passive components like resistors, capacitors, coils and active component like transistors and ICs.

5. SMT is used almost exclusively for the manufacture of electronic circuit boards these days.

6. The two main methods for SMT soldering are: 1. Wave soldering and 2. Reflow Soldering.

7. The solder station can be used to effectively apply heat and remove the solder from the joint. This means that a solder station will be the most effective way of ensuring that any network is undertaken with the minimum of risk to the board.

Short Answer Type Questions

1. What is surface mount technology?

2. What are the advantages of SMT?
3. Write the disadvantages of SMT?
4. Give some examples of semiconductor SMD Packages?
5. Mention the methods of SMD Soldering?
6. What is the use of Soldering station?

**Long Answer Type Questions**

1. Give an idea of Surface Mount Technology?
2. Write the advantages and Disadvantages of Surface Mount Technology?
Learning Objectives

After completing this unit, the student will be able to understand:

- The difference between primary and secondary cells.
- Applications of batteries.
- The resultant voltage and current in series and parallel grouping of cells.
- The constructional details and working of lead acid cell, nicked iron cell and nickel cadmium cells.
- The indications of a fully charged cell and their maintenance.
- Maintenance free batteries and button cells.

8.1 Introduction

Batteries are extensively used as a power source in all portable electronic equipment. They can produce electrical (D.C) power at the expense of chemical energy.

Cell and Battery

A cell is a single unit whereas a battery is a group of cells.
8.2 Primary Cells

A cell is which chemical action is not reversible is called a primary cell. E.g. voltaic cell, Daniel Cell, Lechlanche Cell, dry cell etc. In other words, we can’t recharge them when completely discharged.

8.3 Secondary Cells

A cell in which chemical action is reversible is called secondary Eg. Nickel Iron Cell, Nickel Cadmium Cell, Lead Acid Cell etc. In other words, we can recharge them when completely discharged.

8.4 Types of Storage Cells

1. Lead Acid Cells.
5. Lithium-ion Cells.
8. Iron Silver Cells

8.5 Applications of Batteries

a. They are used is private generating plants both for industrial and domestic use.
b. They are used for Petrol Motor Car starting and ignition etc.
c. They are used in U.P.S and Inverters.
d. They are used in telephone exchanges, Radio broadcasting stations to energize the electronic systems during power interruption.
e. Batteries are extensively used as an emergency power supply in Banks, Theatres and Hospitals where continuous supply is absolutely essential.
f. They are used in remote rural areas where there exists no power lines.
8.6 Cells In Series

In the series combination of cells, the positive terminal of one cell is connected to the negative terminal of the other cell, and so on. In this case, the voltages add up. Thus if we connect four 1.5v cell in series, the total voltage of the series combination would be 6v.

Fig 8.1

8.7 Cells in Parallel

In a parallel combination of cells all the positive terminals are connected to each other and all the negative terminals are connected to each other. In this case, the total voltage of the parallel combination would be equal to single cell voltage.

Fig 8.2

It should be remembered that in a series combination, the current rating of the combination does not increase. The current rating of the combination is equal to the current rating of the weakest cell. But in parallel combination, current rating increases but the voltage rating remains the same as for one cell. In order to increase the current and voltage ratings, the cells may be connected in series-parallel combination.
8.8 Lead Acid Cell

The active materials are

a. Lead-Peroxide (PbO₂) is used as positive plate or anode which has chocolate brown colour.

b. Lead (Pb) is used as negative plate which has grey colour.

c. Dilute Sulphuric Acid (H₂SO₄) with a specific gravity of 1.28 is used as an electrolyte.

8.9 Chemical Changes, During Discharging

When the cell discharges, it sends current through the external load. Then H₂SO₄ is dissociated into positive H₂ and negative SO₄ ions. As the current within the cell is flowing from cathode to anode, H₂ ions move to the cathode.

\[
PbO₂ + H₂ + H₂SO₄ \rightarrow PbSO₄ + 2H₂O
\]

At the cathode, (Pb) SO₄ combines with it to form Pb SO₄.

\[
Pb + SO₄ \rightarrow PbSO₄
\]

It will be noted that during discharging:

1. Both the plates are converted into lead sulphate (PbSO₄) which is whitish in colour.

2. With the bornation of water, the specific gravity of the acid falls to about 1.18.

3. Cell voltage decreases to about 1.8V.

4. The cell gives out energy.

8.10 Chemical Changes during Charging

When the cell is recharged, the H₂ ions move to cathode and SO₄ ions to anode and the following changes take place.

At Cathode: PbO₂ + H₂ → Pb + H₂SO₄

At Anode: PbO₂ + 2H₂O → PbO₂ + 2H₂O₄

Hence, the anode and cathode again become PbO₂ and Pb respectively.

It will be noted that during charging.
1 The anode becomes dark chocolate brown in colour (PbO₂) and cathode becomes grey metallic lead (Pb).

2 Due to consumption of water, the specific gravity of H₂SO₄ is increased to about 1.28.

3 There is a rise in voltage to about 2V.

4 Energy is absorbed by the Cell.

### 8.11 Specifications of Storage Batteries

The following specifications are to be considered while selecting a storage battery.

1 Cell voltage in volts and Amp-hour capacity.
2 Power/weight in wats/kg.
3 Energy/weight in wh/kg.
4 Charge/discharge efficiency in percentage.
5 Self discharge rate in % per month.
6 Life period in years.
7 Conversion efficiency.

8 Storage capacity in Ampere-hour.

### 8.12 Indications of a Fully Charged Cell

**Voltage:** During charging, the terminal potential of a cell increases and provides an indication to its state of charge. A fully charged lead acid cell has a terminal voltage of about 2 volts.

(i) **Specific Gravity:** The specific gravity of the electrolyte of a fully charged lead acid cell is about 1.28. This can be measured by means of hydrometer.

(ii) **Gassing:** When the cell is fully charged, the charging current result is that hydrogen is given off at the cathode and oxygen at the anode. The process is being known as gassing and it will give another indication of a fully charged cell.

(iii) **Colour of Plates:** When the cell is fully charged, the positive plate gets converted into PbO₂ (chocolate brown) and the negative plate to spongy lead (grey).
8.13 Maintenance of Lead Acid Cells

1. It should not be left in discharged condition for long.

2. Keep the top of the batteries clean and dry.

3. The level of the electrolyte should always be 10 to 15 mm above the top of the plates.

4. Discharging should not be prolonged after the minimum value of the voltage for the particular rate of discharge is reached.

5. Do not charge the battery at a high rate.

6. Do not short circuit the battery.

8.14 Nickel Iron Cell or Edison Cell

The active materials of a Nickel Iron Cell are

1. Nickel Oxide (Ni₂O₃) is used as the positive plate.

2. Iron (Fe) is used as the negative plate and

3. 21% solution of potassium hydroxide (KOH) with a small amount of lithium added is used as an electrolyte.

4. When the cell is discharged the positive plate is reduced to lower oxide of nickel (i.e. nio) and the negative plate is reduced to iron oxide (FeO).

5. When the cell is recharged, the chemical process is reversed that is the positive plate is converted into Ni₂O₃ and the negative plate to Fe.

The equation of the chemical action is under

\[ \text{Ni}_2\text{O}_3 + 2\text{KOH} + \text{Fe} \rightarrow 2\text{Nio} + 2\text{KOH} + \text{FeO} \]

The emf of a nickel cell is about 1.2v when the cell is about 1.2v when charge falls to 0.9v when discharged. Since there is no change in the specific gravity of the electrolyte during charging and discharging a voltmeter may be employed to check whether the cell is charged up to its rated voltage.

8.15 Nickel cadmium cell

The active materials of the nickel cadmium cell are

1. Ni(OH) is used as positive plate.

2. Cadmium (cd) is used as negative plate.
3. 21% solution of potassium hydrochloride (KOH) with a small amount of lithium added is used as an electrolyte.

**Chemical Changes**

The electrolyte is split into K ions and negative OH ions. The chemical reactions at the two plates are as under.

During discharge

At anode Ni(OH)c

At cathode Cd+(2H)2+2k=CD+2KOH

The above reaction can be expressed by following reversible equation

\[ \text{Ni(oh)}4+koh+cd \rightarrow \text{Ni(OH)}2+\text{KOH}+\text{Cd(OH)}2 \]

The emf of nickel cadmium cell is about 1.2v when charged and falls to 1.1v when discharged. A vott meter may be employed to as certain whether the cell is charged upto its rated voltage or not.

### 8.16 Comparison of nickel iron nickel cadmium and lead acid cells

<table>
<thead>
<tr>
<th>S.No</th>
<th>Parameter</th>
<th>Lead Acid</th>
<th>Nickel Iron</th>
<th>Nickel Cadmium</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Anode</td>
<td>Pbo2, lead peroxide</td>
<td>Nickel hydroxide Ni(OH)4</td>
<td>Nickel hydrox-ide Ni(OH)4</td>
</tr>
<tr>
<td>2.</td>
<td>Cathode</td>
<td>sponge lead pb</td>
<td>Nickel hydroxide Ni(OH)4 or NiO₂</td>
<td>Cadmium(cd)</td>
</tr>
<tr>
<td>3.</td>
<td>Electrolytic</td>
<td>Diluted</td>
<td>Iron (Fe)</td>
<td>KOH</td>
</tr>
<tr>
<td>4.</td>
<td>Internal resistance</td>
<td>Low</td>
<td>High</td>
<td>KDH</td>
</tr>
<tr>
<td>5.</td>
<td>Cost</td>
<td>Low</td>
<td>High</td>
<td>Higher</td>
</tr>
<tr>
<td>6.</td>
<td>Life</td>
<td>Cives nearly 1250 charges and discharges</td>
<td>Five years</td>
<td>Life upto 20 years canbe expected</td>
</tr>
<tr>
<td>7.</td>
<td>Average e.m.f.</td>
<td>2 v/cell</td>
<td>12 V/cell</td>
<td>12 V/Cell</td>
</tr>
<tr>
<td>8.</td>
<td>Efficiency</td>
<td>90-95%</td>
<td>80%</td>
<td>90%</td>
</tr>
</tbody>
</table>
8.17 Maintenance free batteries

Maintenance free batteries come from factory under sealed condition however initial charges can be done by the supplier before marketing. These batteries do not require pouring of distilled water by opening the top knobs.

The maintenance free batteries also called “sealed maintenance free batteries” which are primarily designed and used for slow charges and discharges. They need not higher charging currents have than the conventional type batteries.

The main disadvantage of maintenance of free batteries is its higher initial costs. They are extensively used in systems, inverters, emergency lights, railway signaling systems, telecommunications.

8.18 Miniature button cells

A miniature battery defined as a small round battery whose diameter is greater than its height. Miniature batteries can either be button shaped or coin shaped. These cells generally have diameters ranging from less than millimeters to about 25 millimeters and heights ranging from less than 1 mm to 15mm. These button cells are used in toys, hearing aids, buttons, mobiles etc. The alkaline type silver oxide, zinc and lithium type button cells are commonly used type of buttons cells.

Summary

1. A cell is a source of emf in which chemical energy is converted into electrical energy.
2. A cell is a single unit where a battery is a group of cells.
3. A cell is which chemical action is not reversible is called primary cell. Eg: Dry and voltaic cell.
4. A cell in which chemical action is reversible is called a secondary cell. Eg: Dry and voltaic cell etc.
5. In series grouping of cells the voltages added up by current rating is equal to the rating of single cell.
6. In parallel grouping of cells the total voltage is equal to the voltage of the single cell and current ratings increases.
7. The active materials of the lead acid are $\text{PbO}_2$ for anode. Pb for cathode and dilute $\text{H}_2\text{SO}_4$ for electrolyte.
8. The indications of a fully charged lead cell are traced by means of it’s a) voltage b) specific gravity c)colour of plates d) gassing
9. In alkaline cells the specific gravity of the electrolyte does not change during charging and discharging.

10. Button cells are miniature type cells used in toys, hearing aids, etc.

**Short Answer Type Questions**

1. What is the difference between a cell and a battery?
2. Distinguish between primary and secondary cells?
3. Write the applications of batteries?
4. What are the active materials contained in the lead acid cell?
5. Write the different types of batteries used in daily life?
6. Write some important specifications of storage batteries?
7. Give the indications of fully charged cell?
8. What precautions should be taken to enhance the life of lead acid battery?
9. Determine the total voltage in the given grouping of cells?

\[
\begin{align*}
a) & \quad 1.5V \quad 1.5V \quad 1.5V \\
b) & \quad 1.5V \quad 1.5V \\
c) & \quad 1.5V \quad 1.5V \quad 1.5V \\
\end{align*}
\]

10. What are maintenance free batteries?

**Long Answer Type Questions**

1. Explain in detail about the constructural details and working of lead acid cell with necessary sketches?
2. Give the constructural details and working of nickel iron cell?
3. Describe the constructural details and working of nickel cadmium cell?
4. Compare lead acid cell, nickel iron cell and nickel cadmium cell?
Learning Objectives

After completing this unit, the student will be able to understand

- Microphones and their specifications
- Classification of microphones
- Constructional details and working of carbon, moving coil, condenser, crystal and ribbon microphones
- Constructional details and working of PMMC loud speaker
- The need for baffle and their types.

9.1 Introduction

Microphones and Loud Speakers are used as input and output devices in electronic units like Amplifiers, Receivers and Transmitters. These are also known as Transducers. Transducers are the devices which converts one type of energy in to another form. For example microphone converts sound signal into corresponding electrical signal. Similarly loudspeaker converts electrical signal into corresponding sound waves. This chapter deals with the principles involved in various microphones and loudspeakers their construction working and applications.
9.2 Microphones

Microphones is an acoustic transducer which converts sound pressure variations into electrical signals of the same proportions as in pressure variations. Its circuit symbol is represented as shown in fig 9.1

![Fig 9.1](image)

9.3 Specifications

Microphones can be specified using the following characteristics. They are

1. Sensitivity
2. Signal to noise ratio
3. Frequency response
4. Output Impedance
5. Non-linear distortion
6. Directivity.

9.4 Familiarization of Different Microphones

Microphones are familiar according to their manufacturing. These are

1. Moving Coil Microphone (or) Dynamic Microphone.
2. Ribbon Microphone
3. Carbon Microphone
4. Condenser Microphone
5. Crystal Microphone.

9.5 Different Types of Microphones based on Impedance

Based on impedance among these conductor and crystal microphones are high impedance microphones, carbon has medium impedance, Ribbon and moving coil has lowest impedance. The impedance values of different microphones are shown in below table.
9.6 Different Types of Microphones based on Polar Characteristics

Polar characteristics are also known as directivity. Generally there are three types of directivities are existing. These are

1. Omini Directivity.
2. Figure of eight or Bidirectional Directivity.
3. Cardiod or Heart Shaped Directivity.

1. Omini Directivity

If a microphone receives signals from all directions then it is known omini directivity. Graphically this is represented as a circle as shown in below fig 9.2. Ex. Moving Coil, Crystal, Condenser and Carbon Microphone are omini directional microphones.

![Fig 9.2](image1)

2. Bidirectional Directivity

If a microphone pick ups or receives signals only in opposite directions then such type of microphone is known as bidirectional microphone. Ex. Ribbon microphone has Bidirectional Directivity. Polar diagram of Bidirectional directivity in shown in fig 9.3.

![Fig 9.3](image2)
3. Cardial or Hearted shaped directivity

In order to get the best frequency and noiseless output sometimes omni directional microphone is connected in series with a bidirectional microphone. This type of connection gives a heart shaped polar characteristics. This is shown in the below fig 9.4

![Fig 9.4](image)

9.7 Microphones and their working principles

Each microphone works with a different principle. These are as follows:

1. **Moving call microphone**: Moving coil microphones works on electromagnetic induction.

2. **Ribbon microphone**: It works on the same principal as in above i.e. on electromagnetic induction.


4. **Condenser Microphone**: Condenser Microphone works on the principle of Capacitance.

5. **Crystal Microphone**: Crystal Microphone works on the principle of “Piezeo Electric Effect”.

9.8 Moving Coil Microphone (or) Dynamic Microphone

**Principle**

Moving coil microphone uses the principle of electro magnetic induction. When sound pressure variations moves a coil placed in magnetic field there is a change of magnetic flux passing through the coil an emf is therefore induced in the coil and thus emf forms output of the microphone.

**Construction**

The construction detail of the microphone is shown in fig 9.5. The main components of a moving coil microphone are magnet, diaphragm and coil. The magnet is a permanent magnet with a south pole as central pole piece and North
Pole as peripheral pole piece. This type of magnet gives uniform magnetic field in the gap between the pole pieces. Diaphragm is of non-magnetic material and is light weight. It is fixed to the body of the magnet with the help of springs coil is wound on card board cylinder which is attached to the diaphragm. The coil is single layered enameled wire. A protective cover is used to save the delicate diaphragm and coil assembly from being mishandled. A silk cloth partition is used to separate the upper chamber from the lower chamber. A small tube is used in the lower chamber to give access to the free atmosphere.

Working

When sound waves strike the diaphragm it moves and hence coil moves in and out in the magnetic field. This motion changes the flux through the coil which results in emf being produced in the coil due to electromagnetic induction. The value of emf depends on the rate of change of flux and hence on the motion of the coil. The displacement of the coil depends on the pressure of sound waves on the diaphragm. Thus this microphone induces more voltage. The induced voltage is the faithful replica of the sound pressure variation.

Specifications

1. Sensitivity: 30 Micro Volts
2. S/N Ratio: 30 db
3. Frequency Response: 60Hz – 8KHz.
4. Distortion less than 5%
5. Output Impedance = 25 ohms.

Applications

These are widely used in PA System and in broadcast studios.
### 9.9 Ribbon Microphone

#### Principle

Ribbon Microphone also works on the Principle of electromagnetic induction. In this microphone we can increase the high frequency response by using light aluminium ribbon instead of using diaphragm and coil assembly. Here ribbon acts as a conductor as well as a diaphragm.

![Fig 9.6 Ribbon Microphone](image)

**Output Terminals**

**Built-in matching transformer**

**Permanent magnet with pole pieces extended**

#### Construction

The main parts of ribbon microphone are permanent magnet and ribbon conductor. The permanent magnet is a specially designed horse shoe magnet with extended pole pieces. It provides strong magnetic field. These are shown in the fig 9.6.

The ribbon is a light aluminium foil. It is corrugated at right angles to its length to provide greater surface area. It is suspended in the magnetic field of the permanent and the stiffness of suspension is small. The whole unit is enclosed in a circular or rectangular baffle. The shape of the baffle is not purely circular or rectangular, but is rather irregular and depends on the structure of the magnet.

#### Working

When the ribbon placed in a magnetic field is made to move at right angles to the magnetic field by the force of sound pressure there is a change of magnetic flux through the ribbon conductor. Due to this change of magnetic flux an emf is induced across the ribbon. This emf is proportional to the rate of change of flux which is proportional to the force of sound waves striking the ribbon. It is also called pressure gradient microphone or Velocity Microphone.

#### Applications

It is very suitable for dramas due to its figure of eight polar diagram.
9.10 Carbon Microphone

Principle

When the fine carbon granules enclosed in a case are subjected to variation of pressure the resistance of granules changes. When such device of carbon granules is connected in series with a load through a d.c. supply the current through the load will vary in accordance with pressure variations on the carbon granules.

Construction

The construction of a carbon microphone is shown in below figure 9.7. Fine carbon granules are enclosed between two metal plates. The upper plate is attached to a movable metal diaphragm through a metal piston or plunger. The lower metal plate is fixed and is insulated from the diaphragm. A protective cover with holes is used to protect the unit.

Working

When sound waves strike the diaphragm it moves to and fro. During compression condition it presses the carbon granules and during rarefaction it loosens them. When carbon granules are passed the resistance decreases and hence the current though the circuit increases. When carbon granules loosen, the resistance increases decreasing the current through circuit. In the absence of sound a steady current flow through the circuit. Thus sound waves superimposes a varying current or audio current on the steady d.c. current.
The net resistance of the carbon granules is given by
\[ R_t = R_o + \delta r \] where \( R_t \) = net resistance in ohms.
\( R_o \) = Steady resistance in ohms for no sound.
\( \delta r \) = Variation of resistance due to sound pressure.

The development of Voltage \( V \) across a load resistance \( R_L \) is given below. If \( E \) is battery voltage and \( R_L \) is the load resistance the current \( I \) in \( R_L \) will be given by
\[ I = \frac{E}{R_o + \delta r + R_L} \]
Thus the voltage of the load is the faithful replica of the sound pressure variations.

**Characteristics or Specifications**

- Sensitivity = 20 dB(100mV)
- S/N Ratio = Poor
- Frequency Response = 200 to 5 KHz.
- Distortion = 10%.
- Directivity = Omini
- Output impedance = 100 ohms.

**Applications**

Due to limited frequency range it is useful only in Telephones. It is also sometimes useful in radio communications sets.

### 9.11 Condenser Microphone

**Principle**

When capacitance of a capacitor changes the charge on the capacitor tends to remain the same and hence voltage changes in accordance with equation \( V = \frac{q}{C} \). The above equation shows that if \( C \) increases \( V \) will decrease and if \( C \) decreases \( V \) will increase.

Diaphragm of the microphone acts as one plate of the condenser. The other plate called back plate is fixed. When sound pressure moves the diaphragm in the capacitance increases and when it moves out the capacitance decreases. The change in capacitance results in change in voltage.
Condenser microphone is shown in the above fig 9.8. It consists of a light weight metal diaphragm, which is suspended above a fixed metal back plate. The two metals form the two plates of a capacitor. The diaphragm is the movable plate and the back plate is a fixed plate. A fixed dc voltage of about 200V is applied between the back plate and the movable plate. The diaphragm is in stretched condition as it remains attached to the supporting fixtures with the help of spider springs. The two plates are insulated from each other.

**Working**

When sound waves strike the diaphragm it moves. During compression waves it moves towards the fixed back plate and increases capacitance. During rarefaction it moves away from the back plate and decreases capacitance. The change in capacitance changes the d.c voltage across the capacitor plates. The net voltage $V_t$ at any instant is given by $V_t = V_{dc} + V_{ac}$

Where $V_t$ = Instantaneous voltage  
$V_{dc}$ = d.c. bias applied to the condenser plates.  
$V_{ac}$ = Audio signal corresponding to the sound pressure variation.

The output of a condenser microphone is quite low and hence high gain amplifier is built inside the microphone.

**Characteristics (Specifications)**

- Sensitivity = 3mV
- S/N Ratio = 40dB
- Frequency response = 40 Hz to 15 KHz excellent.
- Distortion = 1%
- Directivity = Omni
- Output Impedance = High 100 M ohms
Applications

1. It is used as standard microphone for calibrating other microphones.
2. It is used in sound level meters.
3. It is used in professional high fidelity recording

9.12 Crystal Microphone

Principle

A crystal microphone is based on the principle of “Piezo electric effect” which is defined as “Difference of potential between the opposite faces of some crystals is produced when these are subjected to mechanical pressure”. The crystals which shows this effect are Quartz, Tourmaline, Rochelsalt and Ceramic.

Construction

The constructional details of Crystal Microphone are shown in the above fig 9.9. The crystal is cut along certain planes to form a slice. Metallic foil electrodes are attached to the two surfaces to carry the potential differences to the output terminals. Two thin crystal slices suitably cut are placed in an insulating holder with an air space between them. A large number of such elements are combined and increase an emf. A diaphragm made of aluminium is attached to the crystal surface through a push rod. The whole unit is encases in a protective case. There is a protective cover over the diaphragm.

Working

When there is a sound waves of compression it compresses the crystal. In case of rare fraction converse takes place and the crystal is extended and is under tension. Due to this compression and extension a varying potential difference is generated which is proportional to the mechanical pressure applied to the crystal by the sound waves.
Specifications

S/N Ratio: 40dB

Frequency Response: 100 – 8KHz.

Distortion = < 1%

Directivity = omni directional

Output Impedance = 1M ohm.

Applications

These are used for the following purposes

1. Home recording system
2. Amateur communications
3. Mobile Communications.

9.13 Loud Speaker

Loudspeaker is a Transducer which converts electrical signals of Audio frequency to sound waves of the same frequency. Loudspeakers are used as output devices in Radio Receivers, T.V. Receivers and P.A. systems. According to construction these are as follows:

1. PMMC Local speakers
2. EMMC Loudspeakers
3. Horn Loud Speakers
4. Head Phones

Further according to frequency reproduced these are classified as follows:

1. Woofer  2. Squeaker  3. Tweeter

The speakers which reproduce low frequencies from 16Hz to 1000 Hz are called Woofers. The speakers which reproduce high frequencies from 1000Hz to 20000 Hz are called tweeters. Squeaker is used to reproduce frequencies from 500 to 5000 Hz. The symbol of Loudspeaker is as shown in fig 9.10.
### Comparison of Microphones

<table>
<thead>
<tr>
<th>Sl.No</th>
<th>Parameter</th>
<th>Moving Coil</th>
<th>Ribbon</th>
<th>Carbon</th>
<th>Condenser</th>
<th>Crystal</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Sensitivity</td>
<td>90dB</td>
<td>110dB</td>
<td>20dB</td>
<td>50dB</td>
<td>26dB</td>
</tr>
<tr>
<td>2</td>
<td>S/N ratio</td>
<td>30dB</td>
<td>50dB</td>
<td>Poor</td>
<td>40dB</td>
<td>40dB</td>
</tr>
<tr>
<td>3</td>
<td>Frequency Response</td>
<td>60 to 8KHz</td>
<td>20 to 12KHz</td>
<td>250 to 5KHz</td>
<td>40 to KHz</td>
<td>100 to KHz</td>
</tr>
<tr>
<td>4</td>
<td>Impedance</td>
<td>2.5Ω</td>
<td>0.25Ω</td>
<td>100Ω</td>
<td>100MΩ</td>
<td>1MΩ</td>
</tr>
<tr>
<td>5</td>
<td>Distortion</td>
<td>5%</td>
<td>1%</td>
<td>10%</td>
<td>1%</td>
<td>1%</td>
</tr>
<tr>
<td>6</td>
<td>Directivity</td>
<td>Omini</td>
<td>Bidirectional</td>
<td>Omini</td>
<td>Omini</td>
<td>Omin</td>
</tr>
<tr>
<td>7</td>
<td>Size</td>
<td>Big</td>
<td>Big</td>
<td>Small</td>
<td>Big</td>
<td>Small</td>
</tr>
<tr>
<td>8</td>
<td>Cost</td>
<td>Medium</td>
<td>High</td>
<td>Lowest</td>
<td>High</td>
<td>Low</td>
</tr>
</tbody>
</table>
9.15 PMMC Loudspeaker

Principle

The moving coil loudspeaker works on the principle of interaction between magnetic field and current in the same way as an a.c. motor works.

A coil called voice coil is placed in a uniform magnetic field when audio current passes through the voice coil there is an interaction between the magnetic field and the coil, resulting in the force working on the movable coil. This force is proportional to the Audio current and hence cases vibratory motion in the coil, which makes a conical paper diaphragm to vibrate and produce pressure vibration in air resulting in sound waves.

Construction & Working

The moving coil Loudspeaker consists of a voice coil wound on a card board or fibre cylinder as shown in fig 9.11. Audio current is fed to it through two terminals. The coil is placed in a magnetic field. The magnet is a pot type permanent Magnet which has a central pole and peripheral pole. The magnet is so shaped as to give strong radial magnetic field in the annular space between the central and peripheral poles. The voice coil is free to move in the annular space having strong and uniform magnetic field. Because of the use of permanent
magnet it is also called permanent magnet type speaker. The coil is attached to a conical diaphragm made of paper. It is called paper cone. The cone is corrugated having circular corrugation. A flexible strip of rubber around its periphery is used to support it. The spider springs are used to support the complete diaphragm and also provide the required stiffness to restrain the motion. The spiders also keep the coil centered so that the motion is vertical and linear. Leads from the voice coil are centered to the cone surface. From there these are brought to the terminals mounted on the metal frame.

When audio current flow through the voice coil placed in a magnetic field a force equal to BIL newtons act on the coil and moves it to and fro. The paper cone attached to the coil also moves and causes compression and rarefaction cycles in the air. Thus audio current is finally converted into sound waves.

**Ratings**

Different characteristics like power handling impedance frequency response and directivity etc. are known as rating of loud speakers. These are as follows:

- **Power Handling**: Few mill watts to hundreds of watts.
- **Impedance**: 2 to 32 ohms
- **Frequency response**: 200 Hz – 5000 Hz
- **Directivity**: Omni directional

**9.16 Baffles**

Rigid flat material used to extend the edges of a loudspeaker cone is called Baffles. The term Baffle is commonly used for a place surface. A baffle increases the effective length of the acoustical transmission path between the front and the back of the radiator.

**Necessity of a Baffle**

There is air on both sides of the cone, the front as well as the back. Hence the cone radiates sound from both sides. However when the cone moves forward there is compression of the air in the front but rarefaction at the back. When the cone moves backwards compression in the back and rarefaction in the front occurs. Thus the sound waves produced in the rear air are of opposite phase. The sound waves from the rear leak round the sides and meet the sound waves in the front. If the path difference is small as compared to $\frac{\theta}{2}$ the two waves will almost cancel each other causing response of the speaker to drop off sharply. When the frequency of radiated waves is low the wavelength is large and hence the path difference between rear and front sides is quite small. This will allow
low frequency waves to arrive from rear to the front almost 180° out of phase, reducing the radiated energy substantially. To save the low frequencies from attenuation it is necessary to increase the path difference by using a physical barrier the baffle. This is explained with the fig 9.12 shown in below.

![Diagram of waves and baffle]

**Fig 9.12**

### 9.17 Types of Baffles

There are four types of Baffles. They are

1. Finite baffle
2. Infinite baffle
3. Enclosure

**Finite Baffle**

The wooden cabinets as in radio receivers or T.V. receivers acts as finite baffle such baffles being of finite size are not very effective and do cause some loss of low frequency signals.

**Infinite Baffle**

An ideal infinite baffle is the one which has infinite lateral dimensions. Such a baffle will not be feasible. However if battle dimensions are so large that the frequency at which the path length is ë/2 is far below the lowest frequency to be used such as baffle can be called infinite baffle. For example let a speaker be fixed in a hole in the wall or a house.
Encloures

When a loud speaker is mounted in a closed box with an opening in the front that serves the purpose of infinite baffle because the waves from the back of the cone will not be able to come to the front side. Such a closed box is called an enclosure and is shown in below figure 9.13.

Bass Reflex Enclosures

In this system radiation from the back of the cone is used to strengthen the front radiation rather than weaken it. This design is shown in fig 9.13. Here the port or cut is so designed that it permits flow of air from the rear to the front with additional path difference of \( \frac{\pi}{s} \). Thus the phase difference between the back wave coming out from the port and the front wave caused directly by the cone is \( 180 + 180 = 360^0 \) and therefore the two waves reinforce each other.

![Fig 9.13](image)

### 9.18 Comparison of Loud Speakers and Headphones

<table>
<thead>
<tr>
<th>Sl. No</th>
<th>Parameter</th>
<th>Loudspeaker</th>
<th>Headphone</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Power</td>
<td>They can produce large power.</td>
<td>They can produce small powers</td>
</tr>
<tr>
<td>2.</td>
<td>Size</td>
<td>These are larger in size compared to headphones.</td>
<td>These are small in size compared to less loudspeaker</td>
</tr>
<tr>
<td>3.</td>
<td>Cost</td>
<td>Costlier</td>
<td>Lost Costlier</td>
</tr>
<tr>
<td>4.</td>
<td>Applications</td>
<td>These are used for Radio Receivers, TV Receivers, PA systems &amp; in Audio Ckts. The sound produced by loud speakers are heard by large number of persons at a time.</td>
<td>These are used in Type Recorders, Walkmans for Lower power consumers. The sound produced by Headphones are heard by only one or two persons at a time.</td>
</tr>
</tbody>
</table>
Summary

1. Microphone is an acoustic transducer which converts sound waves into corresponding electrical signals.

2. The important specifications of microphones are (a) sensitivity (b) S/N ratio (c) frequency response and (d) output impedance.

3. Moving coil microphone works on Faraday’s laws of electromagnetic induction. It has better frequency response of 60 Hz to 8 kHz.

4. Ribbon microphone also works on electromagnetic induction. It has an excellent audio frequency response and is particularly used for studio work.

5. Crystal microphone works on the principal of Piezo electrical effect.

6. Loud crystal is a transducer which converts electrical signals into sound waves.

7. A single loudspeaker cannot cover the entire audio frequency range. Therefore, Woofer, Driver and Tweeter speakers are used to cover low, mid, and high frequency ranges.

8. A baffle increases the effective length of the acoustical transmission path between the front and the back of the radiation path.

Short Answer Type Questions

1. Define Microphone and Loudspeaker?

2. What is meant by Transducer?

3. What is meant by Piezo electric effect?

4. What are the applications of Microphones and Loudspeakers?

5. Write the ratings of a Loudspeakers?

6. What is meant by Baffle and what are the 3 types?

7. Write the differences between the Loudspeaker and headphone?

8. Classify different types of Microphones?

Long Answer Type Questions

1. Write the principles construction and working of moving coil microphones.

2. Explain the principles construction and working of Ribbon microphones.
3. Explain the principles, construction, and working of Carbon microphones.

4. Explain the principles, construction, and working of Condenser microphones.

5. Explain the principles, construction, and working of Crystal microphones.

6. Explain the principles, construction, and working of PMMC microphones.