ELECTRONICS-I

CIT-134

FOR DAE 1ST YEAR

TECHNICAL EDUCATION & VOCATIONAL TRAINING AUTHORITY PUNJAB

PREFACE

The text book has been written to cover the syllabus of Electronics-I, 1st year D.A.E (CIT) according to the new scheme of studies. The book has been written in order to cater the needs of latest concepts and needs of the course i.e. Electronics-I and to be able to attempt D.A.E Examination of PBTE Lahore.

The aim of bringing out this book is to enable the students to have sound knowledge of the subject. Every aspect has been discussed to present the subject matter in the most concise, compact lucid & simple manner to help the subject without any difficulty. Frequent use of illustrative figures has been made for clarity. Short Questions and Self-tests have also been included at the end of each chapter which will serve as a quick learning tool for students.

The author would like to thank the reviewers whose valuable recommendations have made the book more readable and understandable. Constructive criticisms and suggestions for the improvements in future are welcome.

AUTHORS

MANUAL DEVELOPMENT COMMITTEE

ENGR. SHAHBAZ HUSSAIN
Chief Instructor Govt.Swedish Pakistani College of Technology, Gujrat
(CONVENER)

ENGR. HAFIZ TAIMOOR UL HASSAN
Instructor CIT- Govt. College of Technology, Bahawalpur
(MEMBER)

CIT-134 ELECTRONICS-I

Total Contact Hours		T	P	C
Theory:	96 Hours	3	3	4
Practical:	96 Hours			

Prerequisite: Applied Mathematics & Physics

AIMS This course is designed so that the student will be able to learn basic knowledge of electricity and electronics.

Understand the operation and application of electrical and electronic principles, devices and circuits.

1. Identify the different electrical /electronic component, devices and types of circuits.
2. Explain the principles of operations and applications of electrical and electronic components, devices and circuits.
3. Use different electrical/electronic components and devices in different circuit's configuration.
4. Describe the ratings, tolerances, coding and troubles in different electrical and electronics components and circuits
5. Calculate current, voltage, power and power factor using circuit laws and network theorems.
6. Use filters and coupling in electronics circuits.

Table of Contents

TEXT/REFERENCE BOOKS

1. Bird J O — *Electrical and Electronic Principles and Technology, Second Edition* (Newnes, 2004) ISBN 0750665505
2. Bird J O — *Electrical Circuit Theory and Technology* (Newnes, 2004) ISBN 0750657847
3. Grob, Bernard, *Basic Electronics*, Eight Editions.

CHAPTER 01 BASIC PRINCIPLES OF ELECTRICITY

Objectives

After completion of this chapter students will be able to:

1. Understand electron theory
2. Learn the structure of atom and the number of shells.
3. Learn about energy levels
4. Learn about valence electrons.
5. Learn about energy bands with reference to conductors, insulators and semiconductors.
6. Understand electrical quantities, potential, current, & resistance
7. Learn units of potential, current & resistance
8. Learn Difference between conventional current and electron current.

1.1 UNDERSTAND ELECTRON THEORY:

According to the modem electron theory, atom is composed of the three fundamental particles, which are invisible to bare eyes. These are the neutron, the proton and the electron. The proton is defined as positively charged while the electron is defined as negatively charged. The neutron is uncharged i.e. neutral in nature possessing no charge. The mass of neutron and proton is same while the electron is very light, almost 1/1840th the mass of the neutron and proton.

1.1.1 STRUCTURE OF ATOM:

Everything which occupies space and has some weight is known as matter. Matter has three state i.e. solid, liquid and gas. All the mattes are composed of small particles which are called as atoms. Atom cannot exist freely as a single particle and combines with other atoms and forms molecules. A substance which has same nature of molecules is called as an element. At present, almost 118 elements have been discovered.

According to the present theory of the structure of an atom, an atom consists of three fundamental particles which are called electrons, protons and neutrons.

An atom consists of following parts.

(i) External Part.

(ii) Internal Part.

External Part:

External part consists of electrons. Electrons are negatively charged particles and the value of this charge is 1.602×10^{-19} coulombs and has mass 9.11 x 10–28 grams or 9.11 x 10–31 Kg. It radius is 1.9 x 10–15 meter. Electrons are the lightest part of an atom.

Internal Part:

Internal part of the atom is called as **Nucleus** and it consists of two particles i.e. protons and neutrons. Proton is positively charged particle and the amount of this charge is same as the charge of an electron i.e. 1.6 x 10^{-19} coulombs the mass of proton is 1836 times heavier than that of the mass of the electron.

The neutrons have no charge and its mass is equal to the mass of the proton. So the total mass of an atom is due to the mass of the protons and neutrons.

Electron revolves around the nucleus in fixed paths which are called as **orbits**. The structure of an atom is shown in figure below.

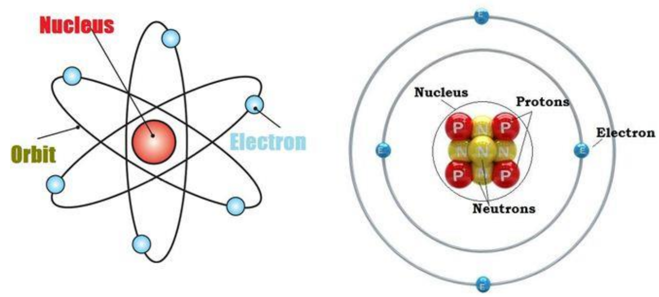


Fig.1.1 The structure of Atom

The number of protons and electrons in an atom is same. Since the electrons are negatively charged and protons are positively charged, a force of attraction exists among these charges. This force keeps the electron continuously revolving around the nucleus in an atom.

1.1.2 K, L AND M SHELLS:

Electrons revolve around the nucleus in the orbits. These orbits are called shells. These shells are represented by K, L and M etc.

The shell which is closest to the nucleus is called as K shell; next shells are L, M and so on. Every shell has a fixed number of electrons and is determined by the rule as described below.

No. of electron is shell No. n = $2n^2$

Where n = No. of shell.

No. of electrons in K shell is $= 2\,(1)^2 = 2$

No. of electrons in L shell is $= 2\,(2)^2 = 8$

No. of electrons in M shell is $= 2\,(3)^2 = 18$

and so on. Every atom follows the formula $2n^2$ to fell the orbit. However last orbit can be considered as filled if it has at least 8 electrons. Electron shells are shown in figure below.

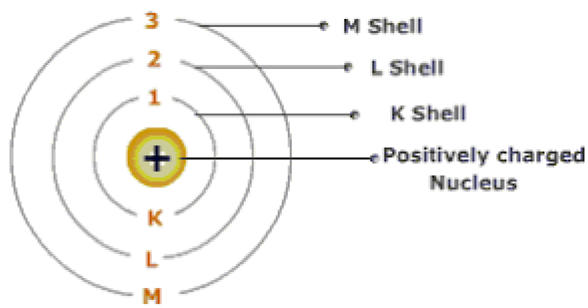


Fig.1.2 Number of shells in atom

Problem:

Draw the electronic configuration of copper atom having atomic number 29 and 35 numbers of neutrons in the nucleus.

Solution:

No. of electrons in K orbit $= 2(1)^2 = 2$

No. of electrons in L orbit $= 2(2)^2 = 8$

No. of electrons in M orbit $= 2(3)^2 = 18$

No. of electrons in N orbit $= 1$

No. of Protons = No. of electrons = 29

No. of Neutrons = 35

It is shown in figure below.

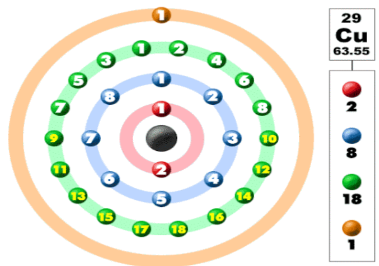


Fig.1.3 Number of electros in different shells

SELF TEST PROBLEMS

Draw electronic configuration of the following atoms having atomic Numbers and atomic weights as follows:

(i) **Cd** (Cadmium) Atomic No = 48, Atomic Weight = 112

(ii) **Au** (Gold) Atomic No = 79, Atomic Weight = 197

(iii) **Pb** (Lead) Atomic No = 82, Atomic Weight = 207

1.1.3 ENERGY LEVELS:

Electrons revolve around the nucleus in fixed orbit. Electrons have a fixed energy in the orbit which is called as is Energy Level. The energy level of K orbit is lowest. However, being nearest to the nucleus it is bound with strong force. As we move away from the nucleus energy level is increased but the force of the nucleus on the electrons is decreased.

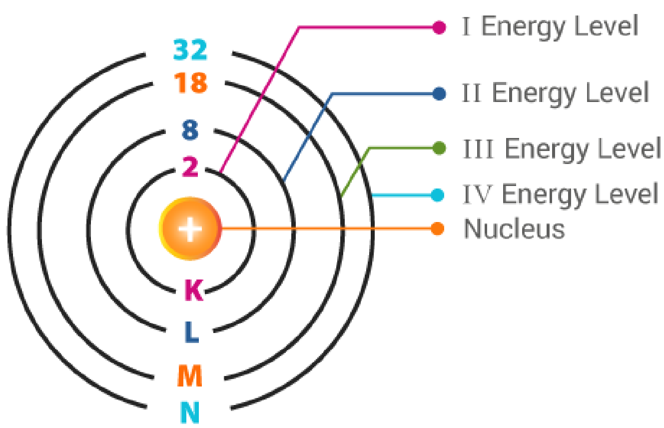


Figure 1.4 Energy level

1.1.4 VALANCE ELECTRONS:

Electrons in outer most shell are called as the **Valence Electrons** and this shell is called as the **Valence Shell**. Valence electrons lightly bound to the nucleus compared with those electrons which are closer to the nucleus. The reason is that the force of attraction between the positively charged nucleus and negatively charged electrons decreases with the increase in distance from the nucleus.

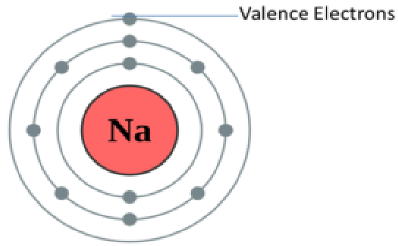


Figure 1.5 Valance electrons

Electrons which have highest energy levels exists the outermost shell of an atom, and are relatively loosely bound to the atom.

1.1.5 ENERGY BANDS WITH REFERENCE TO CONDUCTORS, INSULATORS AND SEMICONDUCTOR:

Energy Bands:

Electrons revolve around the nucleus in fixed shells and have specific value of energy. Since a substance consists of billions of atoms, these energy levels of individual atoms overlap and form a band which is called as **Energy Bands**.

These energy bands are of the following types:

(i) Valence Bands:

The energy band formed by a series of energy levels containing the valence electrons is known as valence band. It has following characteristics.

(a) This band is always filled by electrons.

(b) This is the band of maximum energy.

(c) Electrons are not capable to gain energy from the external electric field.

(d) No flow of current due to such electrons.

(e) The highest energy occupied by the electron at 0 K° in the valence band is called as Fermi Level.

(ii) Conduction Band

The higher energy level band is called the Conduction Band.

(a) It is also called as empty band of minimum energy.

(b) This band is partially filled by the electrons.

(c) In this band the electron can get energy from the external electric field.

(d) The electrons in the conduction band are called as free electrons. They are able to move anywhere within the volume of the solid.

(e) Current flows due to such electrons.

(iii). Forbidden Energy Gap:

The energy gap found between the conduction band and the valence band is called as Forbidden Energy Gap.

Based on energy bands materials can also be classified as Conductors, Insulators and Semiconductors. Following figure shows the difference between conductors, insulators and semiconductors.

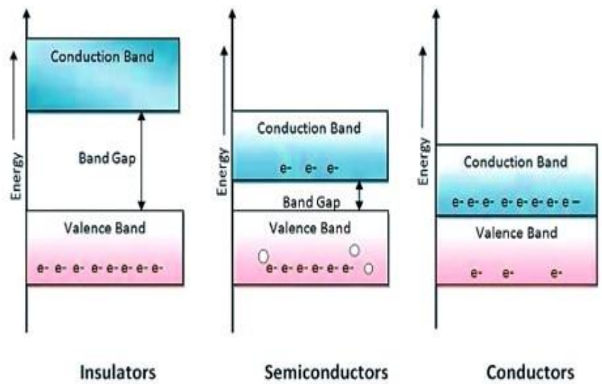


Fig.1.6 Energy band gaps of different material

Insulator:

In an insulator, there is a wide energy gap between valence band and conduction band, typically its value is 1.5eV or more. And expressed as ΔEg_1 Large energy gap means that a large amount of energy is required to free the electrons by moving then from the valence into conduction band. At room temperature valence electrons cannot easily jump into conduction band so the insulators have extremely low conductivity. So insulators are the materials which do not conduct electrical current under normal conditions. Examples of insulators are glass, paper, mica, wood etc.

Conductor

A conductor is a material that easily conducts electrical current. The energy band criteria of the conductor are shown in figure 1.6

As shown in figure 1.6, valence band and conduction bands have very small or no gap. As a result a very small amount of energy is required to move the electrons from the valence band into the conduction band.

All that metals are conductors; however all of them are not good conductors. Copper is supposed to be one of the best conductors.

Semiconductor

A semi-conductor is a material that exists between the conductors and insulators in its ability to conduct electrical current. The energy band model of the semi-conductor is shown in figure 1.6. It is evident that the forbidden energy gap is relatively small compared with the insulators and expressed as ΔEg_2.

1.2 ELECTRICAL QUANTITIES:

1.2.1 POTENTIAL, CURRENT AND RESISTANCE:

Potential:

Potential is a force or pressure which maintains the flow the charge through a conductor. It is represented by V and its unit is volt.

Normally potential is measured by specifying a certain reference value. The reference value is normally 0-V. Term Potential difference is also used for potential.

The potential between two points will be 1 volt if one coulomb of charge requires one joule of energy to move this charge between these points.

Mathematically we can say: 1 Volt = 1 Joule/ 1 Coulomb

Or

$$V = \frac{W}{Q}$$

$$W = VQ$$

Where W represents work done in joules

Electric Current:

The rate of flow of charge in a conductor is called current. It is denoted by I. Mathematically,

$$I = \frac{Q}{t}$$

Where Q is charge in coulomb and t is time in second.

The unit of current is Ampere. It can be define as: “If one coulomb of charge flows in one second through a conductor, the amount of current is one ampere”

Resistance:

Resistance is a property of a material which opposes the flow of current through it. The resistance of a material is represented by R and its unit is “Ohm” which is denoted by Ω (Ω is Greek alphabet “omega”).

The value of the resistance is different for different materials. It depends on the nature and atomic structure of the material. Wood, glass, mica, plastic have very large resistance. Materials having low value of resistance are called as conductors. Copper has very low value of resistance.

The unit of resistance is ohm which can be defined using Ohm's law (to be discussed in chapter 2):

$$V = IR \qquad \text{or} \qquad R = \frac{V}{I}$$

If a potential difference of 1 volt is applied to the ends of a conductor, and a current of 1 ampere flows through it, it is said that the value of the resistance is 1 ohm. The symbol of resistance is:

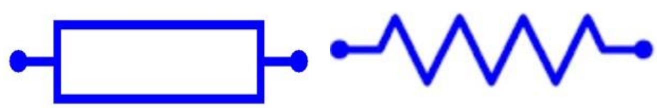


Fig.1.5 symbol of resistor

1.2.2 UNITS OF POTENTIAL, CURRENT AND RESISTANCE:

Unit of Potential (Volt):

The SI unit of electric potential is the volt, which is defined as a joule per coulomb. Hence, one joule per coulomb is equal to the unit of the potential difference. Therefore it will be equal to one Volt. It is denoted by letter "V".

Unit of Current (Ampere):

The SI unit of electric current is the ampere, or amp, which is the flow of electric charge across a surface at the rate of one coulomb per second. The ampere (symbol: A) is an SI base unit Electric current is measured using a device called an ammeter. It is denoted by letter "A".

Unit of Resistance (Ohm):

The SI unit of resistance is the ohm, which is defined as if one ampere current is flowing through the circuit by applying 1 volt, the resistance of that circuit will be one ohm. It is denoted by Ω.

1.2.3 CONVENTIONAL CURRENT AND ELECTRON CURRENT:

As the definition of electric current: The rate of flow of charge is called current. In respect of direction, current may be divided into two types.

Conventional Current

The motion of positive charge in the opposite direction to the flow of electrons is called as Conventional Current.

Electron Current

The motion of the negative charge due to the flow of the electrons is called electron current.

Solved Problems

<u>Problem No. 1</u>

How many coulombs of charge are carried by 95.2 × 1015 electrons?

Solution:

1 coulomb of charge = 6.25 × 1018 electrons

So, Charge of 95.2 × 1015 electrons in coulombs

=95.2 × 1015 ÷ 6.25 × 1018 coulombs.

= 15.232 x 10–3 coulombs.

= 15.232 milli coulombs.

<u>Problem No .2</u>

5A current flows through a washing machine for 80 seconds. Find the amount of charge that flows through the washing machine in this time.

Solution:

I = 5A

t = 80 seconds

Q=?

Formula: $I = \frac{Q}{t}$

Q = I × t = 5 × 80 = 400 coulombs

<u>Problem No.3</u>

A UPS (uninterrupted power supply) battery can supply 24.5 J of energy to move 15 coulomb of charge. Find the voltage of the battery.

Solution:

W = Energy = 24.5 J

Q = 15 Coulomb

V=?

Formula $V = \frac{W}{Q}$

$= \frac{24.5}{15}$

= 1.633 Volts

Problem No.4

A charge of 8.2 μ Coulomb flows through a conductor in 12 seconds. Find the current flowing through the conductor.

Solution:

Q = 8.2 μ coulombs
t =12 seconds

Formula $I = \frac{Q}{t} = \frac{8.2}{12}$ = 0.683 μ A.

Self-Test Problems:

Problem No.1

Find the charge carried by 75×10^{32} electrons in coulombs.

Problem No.2

Find the voltage of a battery, which uses 200 J of energy to move 100 Coulomb of charge.

Problem No .3

What is the current in amperes of 250×10^{12} electrons which flow through a microphone in 125 micro seconds?

Multiple Choice Questions

Q.1 A_______ is the smallest particle of an element.
(a) Atom (b) Element
(c) Substance (d) Matter

Q.2 An atom is the _______ of an element that retains its characteristics.
(a) Biggest (b) Smallest
(c) Largest (d) Heaviest

Q.3 The central part of atom is _______.
(a) Electron (b) Proton
(c) Neutron (d) Nucleus

Q.4 Proton has _______ charge.
(a) Negative (b) Positive
(c) Neutral (d) Random

Q.5 Proton is _______ times heavier than electron.
(a) 1842 (b) 1836
(c) 1840 (d) 1974

Q.6 The number of _______ and protons are equal in an atom.
(a) Electrons (b) Neutrons
(c) Nucleus (d) Shells

Q.7 A neutron is _______ times heavier than electron.
(a) 1836 (b) 1842
(c) 1846 (d) 1850

Q.8 Electron has _______ charge.
(a)Positive (b) Negative
(c) No (d) Constant

Q.9 Electron is _______ than the mass of proton.
(a)Heavier (b) Lighter
(c) Bigger (d) Smaller

Q.10 An atom has _______ number of electrons and protons.
(a) Equal (b) Greater
(c)Lesser (d) Unequal

Q.11 The shells around the nucleus are named as _______.
(a)A, B, C... (b) K, L, M...
(c) X, Y, Z... (d)None of above

Q.12 K shell has _______ electrons.
(a) 2 (b) 4
(c) 6 (d) 8

Q.13 The electron in incomplete outermost orbit is called _______ electron.
(a)Heavy (b) Lighter
(c)Valance (d) Unique

Q.14 The _______ is the closest shall to the nucleus.
(a)K (b) L
(c) M (d) N

Q.15 Valance electrons are _______ tightly bound to the atom.
(a) Very (b) Less
(c) Also (d) None of above

Q.16 The material that does not conduct current is called _______.
(a) Conductor (b) Insulator
(c)Semi-conductor (d) Composite

Q.17 The material between conductor and insulator is called _______.
(a) Matter (b) Composite
(c) Semiconductor (d) Ceramics

Q.18 A conductor is a material that _______ conducts electrical current.
(a) Swiftly (b) Easily
(b) (c) Sharply (d) Fast

Q.19 The unit of current is _______.
(a) Ampere (b) joule
(c) Volt (d) Ohm

Q.20 The unit of potential is _______.
(a) Current (b) Ampere
(c) Volt (d) Ohm

ANSWER KEY

1 (a)	2. (b)	3. (d)	4. (b)
5 (b)	6. (a)	7.(b)	8.(b)
9.(b)	10.(a)	11.(b)	12.(a)
13.(c)	14.(a)	15.(b)	16.(b)
17.(c)	18.(b)	19.(a)	20.(c)

Short Questions

1. Define Atom?
2. Describe structure of an atom?
3. What is proton?
4. What is Neutron?
5. What is electron?
6. Define energy level/shells?
7. Describe valance electrons?
8. Describe Conduction Band?
9. Describe valance band?
10. Describe forbidden energy gap?
11. Define potential and unit of potential?
12. Define current with its unit?
13. What is difference between electron current and conventional current?

Long Questions

1. Describe the structure of atom in detail?
2. Describe conductor , insulator and semiconductor with reference to the energy band diagram?
3. Explain electrical quantities such as potential, current and resistance with their units?

CHAPTER 02 DC FUNDAMENTALS

OBJECTIVES

After completion of this chapter students will be able to:

1. **Understand the direct current & dc fundamentals.**
2. **Understand the Difference between Voltage, current & Resistance**
3. **Understand the Ohm's law.**
4. **Solve the problems related to Ohm's law.**
5. **Understand & solve the problems related to series and parallel combination of Resistance.**
6. **Understand conductivity.**
7. **Understand & solve the problems related to Kirchhoff's laws.**
8. **Know the dc battery and series and parallel combination of dc batteries.**

2.1 OHM'S LAW:

HOW VOLTAGE, CURRENT, AND RESISTANCE RELATE

An electric circuit is formed when a conductive path is created to allow free electrons to continuously move. This continuous movement of free electrons through the conductors of a circuit is called current, and it is often referred to in terms of "flow," just like the flow of a liquid through a hollow pipe.

The force motivating electrons to "flow" in a circuit is called voltage. Voltage is a specific measure of potential energy that is always relative between two points. When we speak of a certain amount of voltage being present in a circuit, we are referring to the measurement of how much potential energy exists to move electrons from one particular point in that circuit to another particular point. Without reference to two particular points, the term "voltage" has no meaning. Free electrons tend to move through conductors with some degree of friction, or opposition to motion. This opposition to motion is more properly called resistance. The amount of current in a circuit depends on the amount of voltage available to motivate the electrons, and also the amount of resistance in the circuit to oppose electron flow. Just like voltage, resistance is a quantity relative between two points. For this reason, the quantities of voltage and resistance are often stated as being "between" or "across" two points in a circuit.

Here are the standard units of measurement for electrical current, voltage, and resistance shown in table 2.1

Quantity	**Symbol**	**Measurement Unit of**	**Abbreviation Unit**
Current	I	Ampere	A
Voltage	E or V	Volt	V
Resistance	R	Ohm	Ω

Table2.1

2.1.1 OHM'S LAW:

The statement of the relationship among current, voltage, and resistance; in a direct-current circuit, current varies directly with voltage when resistance is constant and varies inversely with resistance when voltage is constant.

Mathematically:

$I \propto V$ when resistance is constant

$I \propto \frac{1}{R}$ when voltage is constant

(Consider the temperature of the circuit remains constant.)

Combine these two statements, this relation becomes

$$I = \frac{V}{R} \qquad V = I R \qquad R = \frac{V}{I}$$

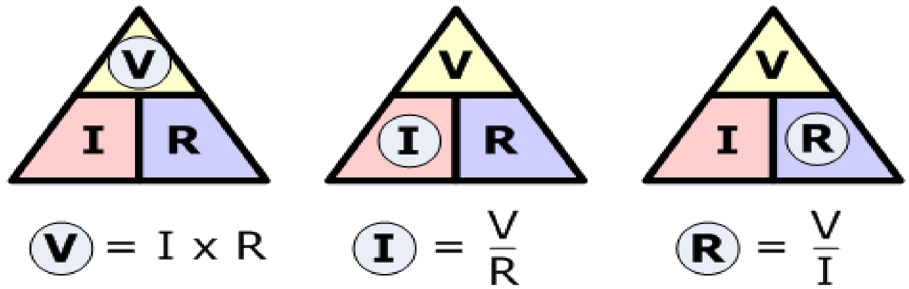


Fig.2.1. magic triangle

This mathematical form is known as the formula of Ohm's Law. We can use this triangle form to find any one value given remaining two values.
For a constant resistance, if the voltage in a circuit is increased more current will flow and if the voltage is decreased less current will flow.

Also for a constant voltage if the resistance is decreased more current will flow. This can be represented as follows. Ohm’s Law can be verified by the simple experimental arrangement as shown in the figure 2.2:

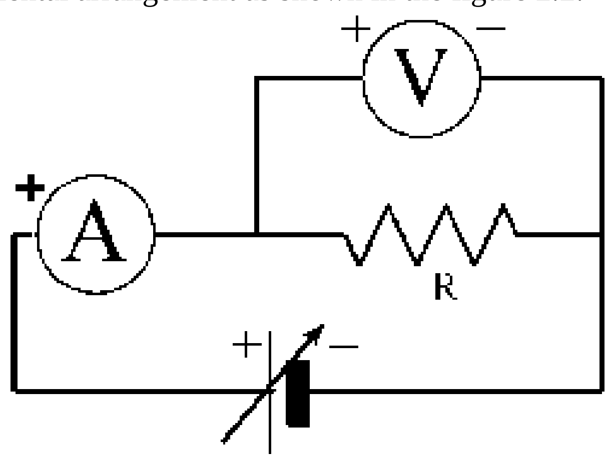


Fig.2.2 circuit for verification of ohm’s law

A constant 20Ω resistance R is connected across a variable power supply V, whose voltage can be measured on the volt meter V and the current flowing in the circuit can be found from the ampere meter A.

As we change the supply voltage V, the value of the current will change as indicated by the ampere meter. (Here resistance is constant) We can tabulate the value, of V and I as follows and shown in table 2.2:

Table 2.2

V(Volts)	10	20	30	40	50	60	70	80	90	100
I(Amps)	0.5	1	1.5	2.0	2.5	3.0	3,5	4.0	4.5	5.0

We can plot a graph between V and I characteristics. A curve is shown in figure2.3:

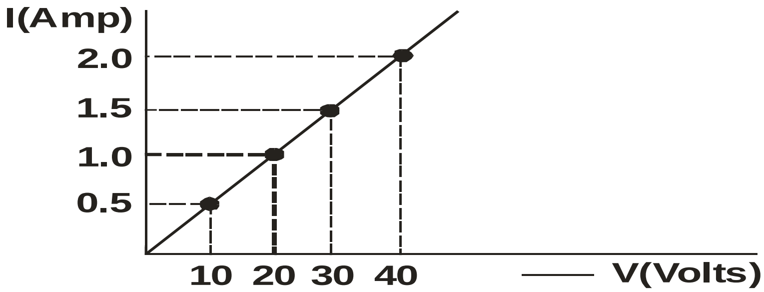


Fig.2.3 V and I characteristics curve

On the other hand a variable resistance (rheostat) R is connected across a fixed power supply 50V, and the current flowing in the circuit can be found from the ampere meter A.

As we change the value of resistance, the value of the current will change as indicated by the ampere meter (Here voltage is constant). We can tabulate the value, of R and I as showed in table 2.3.

Table2.3

Resistance (KΩ)	10	20	30	40	50	60	70	80	90	100
Current (milli amp)	5	2.5	1.67	1.25	1	0.83	0.71	0.625	0.55	0.5

Some of the prefixes and their abbreviations commonly used are tabulated in table 2.4

Prefixes

Tera-	T	1,000,000,000,000	10^{12}
giga-	G	1,000,000,000	10^{9}
mega -	M	1,000,000	10^{6}
kilo -	k	1,000	10^{3}
deci-	d	0.1	10^{-1}
centi-	c	0.01	10^{-2}
milli-	m	0.001	10^{-3}
micro-	µ	0.000001	10^{-6}
nano-	n	0.000000001	10^{-9}
pico-	p	0.000000000001	10^{-12}

Table2.4

2.2.2 SOLVED PROBLEMS ON OHM'S LAW

<u>Problem No .1</u>

How many amperes of current is following in the circuit shown in figure2.4?

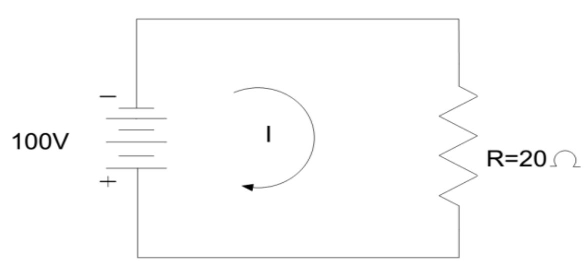


Fig.2.4 circuit for problem No. 1

Solution:

Given data is:

V= 100volts R= 20Ω I=?

By using Ohm's Law

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

$= \frac{100}{20} \quad = 5$ Amp

Problem No .2

Calculate the current shown in the figure 2.5:

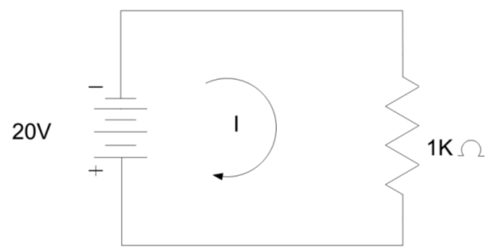


Fig.2.5 circuit for problem No. 2

Solution:

V =20-volts

R = 1-KΩ = $1 \times 10^3 \Omega$

I =?

$I = \frac{V}{R} \quad = \frac{20V}{1 \times 10^3 \Omega} \qquad = 0.02$Amp

Problem No .3

Find the current flowing in the circuit shown in figure: 2.6

Fig.2.6 circuit for problem No. 3

Solution:

V = 200 Volts

R = 5MΩ = 5×10^6 Ω

$I = \frac{V}{R} \quad = \frac{200}{5 \times 10^6}$

$= 40 \times 10^{-6}$ Amp $\qquad = 40\ \mu$ Amp

Problem No .4

For the circuit shown in Figure 2.7, find out the voltage when 6A currents flowing through 100-Ω resistor?

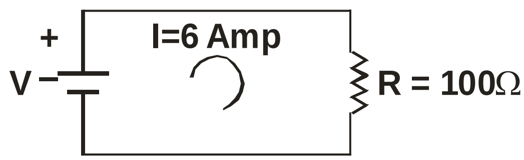


Fig.2.7 circuit for problem No.4

Solution:

I = 6-Amp

R= 100-Ω

V =?

Formula V= IR

V= 6 x 100

= 600 Volts

Problem No .5

A circuit shown in figure 2.8, how much resistance is required to flow 3-mA current from24-V battery?

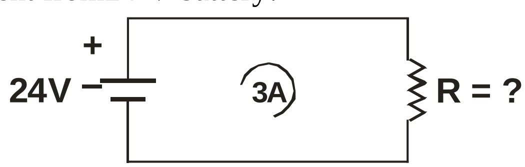


Fig.2.8 circuit for problem No. 5

Solution:

V = 24 volts

I = 3mA = $3x10^{-3}$ Amp

R =?

Using Formula $R = \frac{V}{I}$

R = $\frac{24\ V}{3x10^{-3}\ A}$

=8 x $10^3\Omega$ = 8 KΩ

2.2 LAWS OF RESISTANCE:

Resistance of a conductor is its opposition to flow of current. The resistance of a conductor depends upon following factors which are called as laws of resistance.

(1) **Length of the Material (L):**

The resistance of a conductor is directly proportional to the length of the conductor (L). Resistance is increased with the increase of length and is decreased with the decrease of length

$$R \propto L$$

(2) **Cross Sectional Area (A):**

The resistance of a conductor is inversely propositional to the cross-sectional area of the conductor. If A is the cross sectional area then

$$R \propto \frac{1}{A}$$

Cross-sectional area of the conductor increase, decrease in resistance and vice versa. So the resistance of a thin wire is more than the resistance of a thick wire.

(3) **Nature of Material**

The resistance of a conductor depends on the nature of the material also. The resistance of metals is quite less than the resistance of the ceramics. Resistance of different conductor material varies with its nature; this is called specific resistance of the material and abbreviated by ρ (Rho). It is Defined as: "The resistance between the opposite faces of a unit cube of a material"

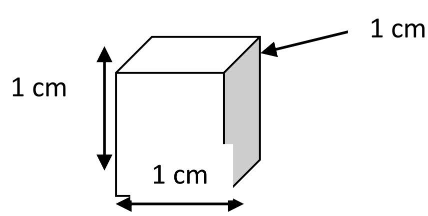


Fig.2.9 unit cube of a material

(4) **Temperature**

The resistance of the material also depends on the temperature. With the increase of temperature, generally the resistance increases for metals. However for semiconductors it decreases its resistance with the increase in temperature.

Combining above results, we get

$$R \propto \frac{L}{A}$$

$$R = \text{Constant} \times \frac{L}{A}$$

$$R = \rho \frac{L}{A}$$

Where ρ (Rho) (specific Resistance or resistivity) is a constant

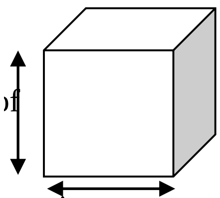
Mathematically,

$$R = \rho \frac{L}{A}$$

$$\rho \quad = R\,\frac{A}{L}$$

2.2.1 SPECIFIC RESISTANCE:

Specific resistance, or resistivity, is the resistance in ohm-m offered by a unit volume (centimeter cube) of a substance to the flow of electric current. The electrical resistivity of a material is denoted by ρ (rho) and is measured in ohm-meters.



Unit of specific resistance is

$$\Omega \frac{cm^2}{cm} = \Omega \text{ - cm}$$

So the unit of specific resistance or resistivity is "Ω cm"

Material	Resistivity, ρ (Ω m) at 20°C
Insulators	
Pure Water	2.5×10^{5}
Glass	10^{10} - 10^{14}
Hard Rubber	10^{13} - 10^{16}
NaCl	- 10^{14}
Fused Quartz	- 10^{16}
Semiconductors	
Germanium	0.46
Silicon	640
Conductors	
Silver	1.6×10^{-8}
Copper	17×10^{-8}
Aluminium	2.7×10^{-8}
Tungsten	5.6×10^{-8}
Iron	10×10^{-8}

Some examples for specific resistance of different materials are shown in table 2.5.

2.2.2 CONDUCTOR:

Conductor is a material through which current can pass easily. Metals are good conductors. All conductors have more free electrons in their outermost orbits.

2.2.3 CONDUCTIVITY:

Conductance

It is the ability of a conductor to pass current through it easily. It is denoted by G. Conductance is reciprocal of resistance.

Mathematically $G=\frac{1}{R}$

Its units is $\frac{1}{\text{ohm}}$ or $\frac{1}{\Omega}$ or "℧" or Siemens(S)

Conductivity

Electric conductivity refers to the measure of how electric current moves within a substance. Also, the greater the electrical conductivity within the material the higher the current density for a given applied potential difference.

In simple words, we can say that electrical conductivity is the ability of a substance to conduct electricity. Also, we can see it as the electrical conductance or conductivity of a material is important because some substance requires to conduct electricity and some not.

For example, the wire conductors need to let current flow as easily as possible. While, some other minerals required to restrict the flow of the current, as in the case of the resistor.

On the other hand, some other materials are required not to conduct electricity as in the case of the insulators.

2.2.4 EFFECT OF TEMPERATURE ON RESISTANCE:

The resistance of a material is not a constant quantity. It changes with the change in the temperature. It depends on the nature of the material. Different possibilities are:

(a) In case of the pure metals, the resistance increases with the increase in the temperature and decrease with the decrease in temperature. This property reflects that metals have positive temperature coefficient (PTC).

The change in the resistance is quite regular and fast. For metals, if we draw a graph between resistance and temperature, a curve is obtained as shown in Fig.2.10.

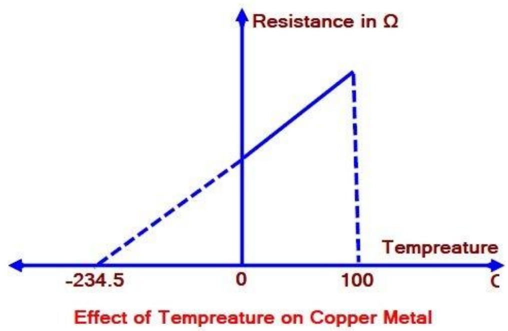


Fig.2.10 curve diagram of resistance versus temperature

(b) In case of alloys the resistance increases with the increase in temperature and vice versa. However the change is not regular.

(c) For non-metals, insulators and electrolytes the resistance decreases with the increase in temperature. This property reflects that metals have negative temperature coefficient (NTC). Semiconductors have negative temperature.

2.2.5 TEMPERATURE COEFFICIENT OF RESISTANCE:

Temperature coefficient is defined as the charge in the resistance per unit resistance per unit change in the temperature. It is denoted by α. The unit of temperature coefficient of resistance is ohm per ohm per degree Celsius or say resistance per resistance per degree Celsius.

Suppose the resistance of a material at some initial temperature say 0c° is R_o and change the temperature to t c° and its resistance is R_t.

Resistance of the material at 0 c° = R_o

Resistance of the material at t c° = R_t

Change in the Resistance = $\Delta R = R_t - R_o$

Change in the temperature = $\Delta t = t - 0 = t$

Change in the resistance per unit resistance = $\frac{R_t - Ro}{Ro}$

& change in the resistance per unit resistance per unit temperature = α

So Temperature coefficient $\alpha = \frac{Rt - Ro}{Ro\Delta t}$

$\alpha = \frac{Rt - Ro}{Ro\Delta t}$

$R_t - R_o = \alpha R_o \Delta t$

$R_t = R_o + \alpha R_o \Delta t$

$R_t = R_o [1 + \alpha \Delta t]$

The temperature coefficients of some common metals at 0c° are tabulated in table 2.

Metal	**Temperature Coefficient (α)**
Aluminum	0.00420
Brass	0.00208
Copper	0.00426
Gold	0.00365
Iron	0.00651

Table2.6

2.2.6 SOLVE PROBLEMS ON $R= \rho\frac{L}{A}$ & $R_t = Ro\ [1 + \alpha\ \Delta t]$

Problem No.1

Find the resistance of 1000 meters of copper wire 0.02 cm in diameter. Take the specific resistance of copper as 1.7 μ Ω cm.

Solution:

Length of the copper wire L $= 1000$ meter

$= 1000 \times 100 = 100000$ cm

Diameter of copper wire d $= 0.02$ cm

Specific resistance of copper ρ $= 1.7\ \mu\ \Omega$-cm

Area of copper wire A $= \pi \frac{d^2}{4}$

$=3.1416 \text{ x } \frac{(0.02)^2}{4} \text{cm}^2$

$= 0.00031416\text{cm}^2$

Formula R $= \rho\frac{L}{A}$

$= 1.7 \text{ x } 10^{-6} \times \frac{100000}{0.00031416}$

$= 541.125\ \Omega.$

Problem No.2

Find the resistance of 50 yards of iron wire, 0.02 inch in diameter. Take specific resistance of iron 3.6 micro ohm inches.

Solution:

Length of the iron wire L $= 50$ yards

$= 50 \times 36 = 1800$ inches

Specific resistance of iron	ρ	$= 3.6\ \mu$ -inches
Area of the wire	A	$=\pi\frac{d^2}{4}$
		$= \frac{3.1416 \times (0.02)^2}{4}$
		$= 0.000314\ cm^2$
	R	$= \rho\,\frac{L}{A}$
		$= 3.6 \times 10^{-6} \times \frac{1800}{0.000314}$
		$= 20.6264\ \Omega$

Problem No.3

A nichrome strip 0.635 cm wide has a resistance of 2.16 Ω and its length is 11.3 meter. Find its thickness if its specific resistance is 109 μΩ cm.

Solution:

$R = 2.16\ \Omega$
$L = 11.3\ m = 1130\ cm,$
$W = 0.635\ cm,$
$\rho = 109 \times 10^{-6}\Omega cm$
Thickness =?

$$R = \frac{\rho \times L}{A} =$$

$$2.16 = \frac{109 \times 10^{-6} \times 1530}{A}$$

$$A = \frac{109 \times 10^{-6} \times 1530}{2.16} = 0.07720\ cm^2$$

$$A = \text{Width} \times \text{Thickness}$$

$$\text{Thickness} = \frac{0.07720}{0.635} = 0.121\ cm$$

Problem No.4

A coil has a resistance of 10 Ohm at 20C°, what will be its resistance at 60 C°. The temperature co-efficient of resistance is 0.0039 $(C°)^{-1}$.

Solution:

Resistance of coil at 0 C°	$R_o = 10\ \Omega$
Temperature at 20 C°	$t_i = 20$ C°

$\alpha = 0.0039(C°)^{-1}$

Temperature at 60 C° $t_f = 60$ C°

Find R_t

$\Delta t = t_f - t_i = 60 - 20 = 40°C$

$R_t = R_o [1 + \alpha \Delta t]$

$R_t = 10 [1 + (0.0039 \times 40)]$

$R_t = 10[1 + 0.156]$

$= 10[1.156]$

$R_t = 11.56\Omega$

Problem No.5

Mercury has resistance of 5k Ω at 20C°. What will be its resistance at 80 C° that specific resistance of mercury is $0.0072(C°)^{-1}$

Solution:

$R_o = 5k\ \Omega$

$t_i = 20C°$

$t_f = 80C°$

$R_t = ?$

$\Delta t = t_f - t_i = 80 - 20 = 60C°$

$\alpha = 0.0072\ (C°)^{-1}$

Formula:

$R_t = Ro [1 + \alpha \Delta t]$

$R_t = 5k [1 + 0.0072 \times 60]$

$R_t = 5k (1 + 0.432)$

$R_t = 7.16K\ \Omega$

Problem No.6

A platinum resistance thermometer uses the change in R to measure temperature. Suppose $R_0 = 50\ \Omega$ at T_0=20 ºC. α for platinum is 3.92×10^{-3} (ºC)-1 in this temperature range. What is R when T = 50.0 ºC?

Data:

$R_0 = 50\ \Omega$

$T_0 = 20$ ºC

$\alpha = 3.92 \times 10^{-3}$ (ºC)-1

T = 50.0 ºC

$R = R_o [1 + \alpha (T - T_o)]$

$R = 50\Omega [1 + 3.92 \times 10^{-3}$ (ºC)-1 (50 ºC - 20.0 ºC)] = 55.9 Ω

Problem No.7

A platinum resistance thermometer has a resistance $R_0 = 50.0\ \Omega$ at T_0=20 ºC. α for Pt is 3.92×10^{-3} (ºC)-1. The thermometer is immersed in a vessel containing melting tin, at which point R increases to 91.6Ω. What is the melting point of tin?

Data:

R_0 = 50.0 Ω

T_0 =20 ºC

α = 3.92×10^{-3} (ºC)-1

R = 91.6 Ω

R = $R_o [1 + \alpha (T - T_o)]$

91.6Ω = 50Ω [1 + 3.92 $\times10^{-3}$ $(ºC)^{-1}$ (T–20ºC)]

1.83 = [1 + 3.92 ×10-3 (ºC)-^{1} (T–20ºC)]

0.83 = 3.92 $\times10^{-3}$ $(ºC)^{-1}$ (T–20ºC)

212ºC = T–20ºC

T = 232 ºC

2.2.7 RESISTANCES IN SERIES:

When two or more resistances are connected end to end across the voltage source such that there is only one path for the current to flow through the circuit then this combination is called as Series circuit. Three resistances R_1, R_2 and R_3 are connected end to end across a power supply V as shown in figure: 2.11

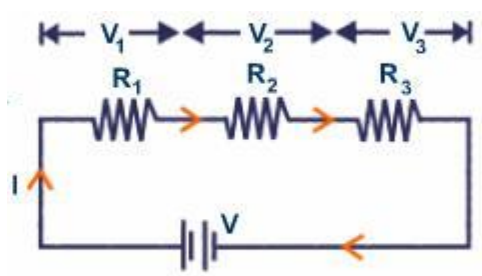


Fig.2.11 The series circuit

Characteristics of Series Circuit:

i. Current flows through each resistor in series circuit is the same as total current i.e.;

$I_1 = I_2 = I_3 = I_T$

ii. Voltage drop across each resistor is different according to the value of resistor. The sum of voltage drops across each resistor is equal to the supply voltage.

V $= V_1 + V_2 + V_3$

$= IR_1 + IR_3 + IR_3$

iii. The total or equivalent resistance of the circuit is equal to the sum of all individual resistance connected in series.

$R_{equ} = R_1 + R_2 + R_3$

Proof:

$V = V_1 + V_2 + V_3$

$IR_{equ} = IR_t = IR_1 + IR_2 + IR_3$

$IR_{equ} = I\,(R_1 + R_2 + R_3)$

$R_{equ} = R_1 + R_2 + R_3$

Total resistance is increased if there is increase in the individual resistances

iv. In series circuit if any resistor is burnt or becomes faulty or break in circuit from any place then the whole circuit will be off.

Problem No.1

Three resistances of 10Ω, 20Ω, and 30Ω are connected in series to a 24V power supply.

Calculate:

(a) Equivalent resistance

(b) Current in the circuit

(c) Voltage drop across each resistance

Solution:

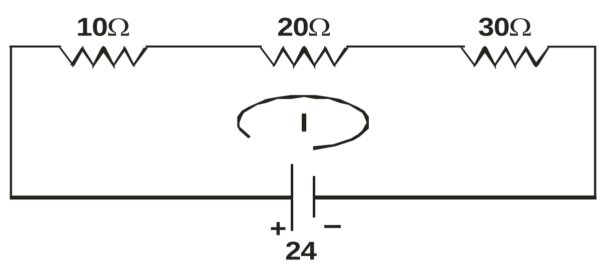


Fig.2.13 Circuit for problem No. 1

(i) We know that in series circuit

Rt = R1 + R2 + R3

Putting the values

Rt= 10 + 20 + 30 = 60 Ω

(ii)Current in series circuit is same in all resistors as well as total current. So

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

$$I = \frac{24}{60} = 0.4\ Amp$$

(iii) To find voltage drop across each resistor use ohm's law

V1 = I R1	V2= I R2	V3 = I R3
V1 = (0.4) (10)	V2 = (0.4) (20)	V3 = (0.4) (30)

V1 = 4 Volts V2 = 8 Volts V3 = 12 Volts

Total Voltage = 4 + 8 + 12 = 24 Volts

Problem No.2 (Self-Test Problem)

Three resistances of 1kΩ, 2kΩ and 3kΩ are connected in series to a power supply of 12V supply.

Find:

a) Total resistance
b) Current flowing in the circuit
c) Voltage drop across each resistance

Problem No.3 (Self-Test Problem)

Two resistances of 4MΩ and 8MΩ are connected in series to a power supply of 30 volts.

Find:

a) Total resistance
b) Current flowing
c) Voltage drop on each resistance

Voltage Division Rule

Voltage division rule is applied for the measurement of voltage drops for a series combination of resistances. Consider a series circuit consisting of two series resistances R_1 and R_2 as shown in figure 2.17

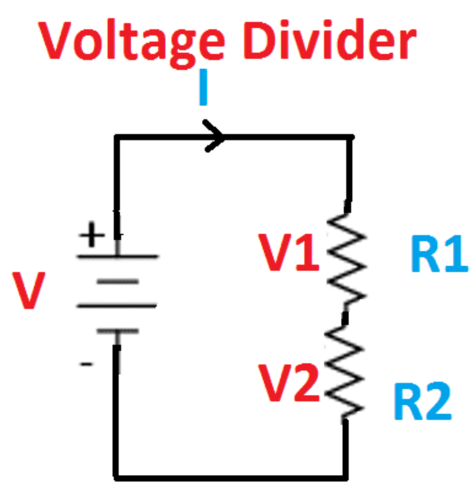


Fig.2.17 voltage divider circuit

According to voltage division rule:

$$V_{R1} = \frac{R1}{R1+R2} \times V$$

$$V_{R2} = \frac{R2}{R1+R2} \times V$$

So according to the voltage division rule, the voltage drops across any resistance in a series is equal to the ratio of that resistance to the total resistance, multiplied by the applied voltage.

Generalizing:

$$V_R = \frac{R}{Rt} \times V$$

Problem No. 1

Two resistances of 20Ω and 30Ω are connected in series across a 24V source. Using voltage division rule find the voltage drop across each resistance.

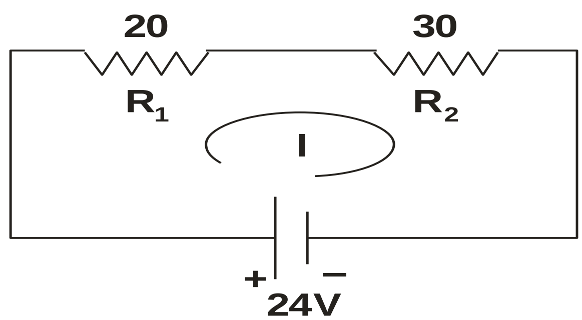


Fig.2.18 Circuit for problem No. 1

Solution:

$R_1 = 20\Omega$ $\quad$ $R_2 = 30\ \Omega$ $\quad$ $V = 24V$

$$V_{R1} = \frac{R1}{R1+R2} \times V = \frac{20}{20+30} \times 24 = 9.6 \text{ Volts}$$

$$V_{R2} = \frac{R2}{R1+R2} \times V = \frac{30}{20+30} \times 24 = 14.4 \text{ Volts}$$

Problem No. 2 (Self-Test Problem):

Three resistances of 1kΩ, 2Ωk and 3kΩ are connected in series across a 220V supply. Using voltage division rule find voltage drop across each resistance.

2.2.8 RESISTANCES IN PARALLEL:

In parallel combination of resistances, two or more resistances are connected in such a way their one ends at one side are joined together and other ends are joined together and across these ends a power supply is connected. It is shown in figure 2.12:

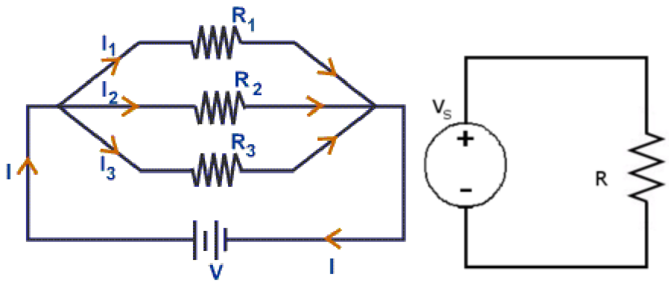


Fig.2.12 The parallel circuit

Characteristics of Resistances in Parallel:

i. The applied voltage across all resistances connected in parallel is the same.

$V_T= V_1=V_2=V_3$

Where V_1, V_2, V_3 are voltage drop across respective resistor

ii. There are two or more than two paths to flow the current compared with series combination, current in each resistor is called branch current. The sum of branch currents is equal to the total current of the circuit.

$I_T = I_1 + I_2 + I_3$ Where I_1, I_2, I_3 are branch currents respectively

iii. The equivalent resistance of the circuit is less than the resistance of any individual component/resistance in the circuit.

Refer to the circuit shown in figure above.

$I = I_1 + I_2 + I_3$

By Ohm's law $I = \frac{V}{R}$

$$\frac{V}{R_{equ}} = \frac{V}{R1} + \frac{V}{R2} + \frac{V}{R3}$$

$$\frac{1}{R_{equ}} = \frac{1}{R1} + \frac{1}{R2} + \frac{1}{R3}$$

This expression shows that the reciprocal of the equivalent resistance of the circuit is equal to the sum of the reciprocals of the individual resistances connected in the parallel combination.

If two resistances are connected in parallel, the total resistance can be found as: $R_{equ} = \frac{R_1 R_2}{R_1 + R_2}$

If more than two resistances are connected in parallel with same value the total resistance can be found as:

$$R_{equ} = \frac{\text{value of one resistance}}{\text{number of resistances}}$$

Problem No. 4

A parallel circuit of two resistances R_1 and R_2 is shown in figure 2.14:

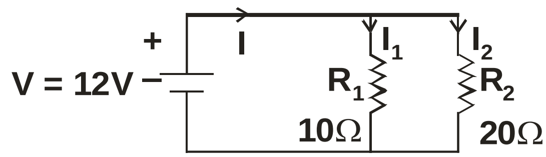


Fig.2.14 Circuit for problem No. 4

Find:

(i) Total resistance
(ii) Current in each resistance (branch currents)
(iii) Total current

Solution:

(i) R1 = 10Ω, R2 = 20Ω, V= 12Volts

$R_{equ} = \frac{R_1 R_2}{R_1 + R_2}$

$= \frac{10x20}{10+20}$ $R_{equ} = 6.66\ \Omega$

(ii) I_1 = Current in I_1 $= \frac{V}{R1}$

$= \frac{12}{10}$

=1.2 Amp

I_2= Current in I_2 $= \frac{V}{R2}$

$= \frac{12}{20}$

= 0.6 Amp

(iii) Total Current I $= I_1 + I_2$

= 1.2 + 0.6 =1.8 Amp

Problem No. 5

Three resistance of 2Ω, 6Ω, 4Ω are connected in parallel to a supply of 24V as shown in figure 2.15:

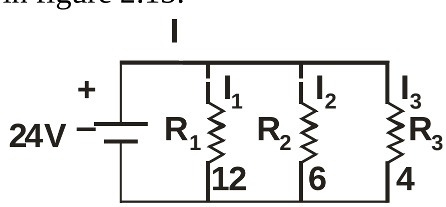


Fig.2.15 Circuit for problem No. 5

Find:

(i) Total resistance (ii) Current in each resistance
(iii) Total current (iv) Total conductance of the circuit

Solution:

(i). Total Resistance =?

$$\frac{1}{\text{Requ}} = \frac{1}{\text{R1}} + \frac{1}{\text{R2}} + \frac{1}{\text{R3}}$$

$$\frac{1}{\text{Requ}} = \frac{1}{12} + \frac{1}{6} + \frac{1}{4}$$

$$\frac{1}{\text{Requ}} = \frac{1+2+3}{12}$$

$$\frac{1}{\text{Requ}} = \frac{6}{12}$$

$$\text{R}_{\text{equ}} = \frac{12}{6} = 2\ \Omega$$

(ii) $I_1 = \frac{V}{R1} = \frac{24}{12} = 2$ Amp

$I_2 = \frac{V}{R2} = \frac{24}{6} = 4$ Amp

$I_3 = \frac{V}{R3} = \frac{24}{4} = 6$ Amp

(iii) Total Current I $= I_1 + I_2 + I_3$

$= 2 + 4 + 6 = 12$ Amp.

(iv) Total Conductance = $\frac{1}{\text{Requ}} = \frac{1}{2} = 0.5$ ℧ (Siemens)

Problem No. 6 (Self-Test Problem)

Three resistances of $\frac{1}{2}\Omega$, $\frac{1}{4}\Omega$, and $\frac{1}{8}\ \Omega$ are connected in parallel to a power supply of 6V as shown in figure 2.16.

Find:

a) Total resistance b)Total Conductance c) Current in each resistance d) Total current

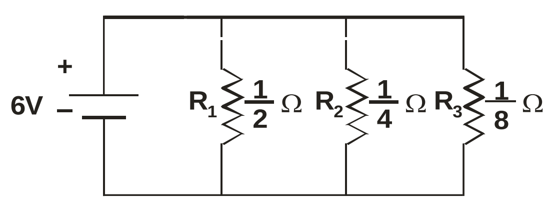


Fig.2.16 Circuit for problem No. 6

Current Division Rule

Current division rule is applicable to find the current, for the resistances connected in parallel. Consider two resistors R1 and R2 connected in parallel to R_1 and R_2.

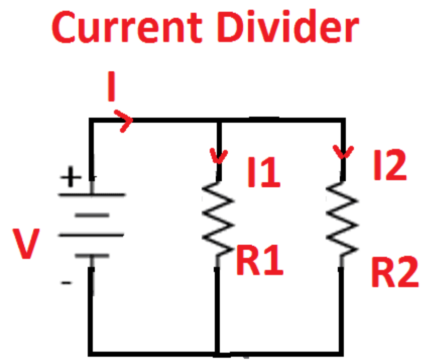


Fig.219 The current divider circuit

According to Current division rule

$$I_1 = \frac{R2}{R1+R2} \times I_T$$

$$I_2 = \frac{R1}{R1+R2} \times I_T$$

So current division rule states that

"Current in a resistance connected in parallel is equal to the other resistance divided by the total resistance multiplied by the total current."

Problem No. 1

Two resistances 5Ω and 10Ω are connected in parallel across a 24 Volt DC supply. Using current division rule find the amount of current flowing through each resistance.

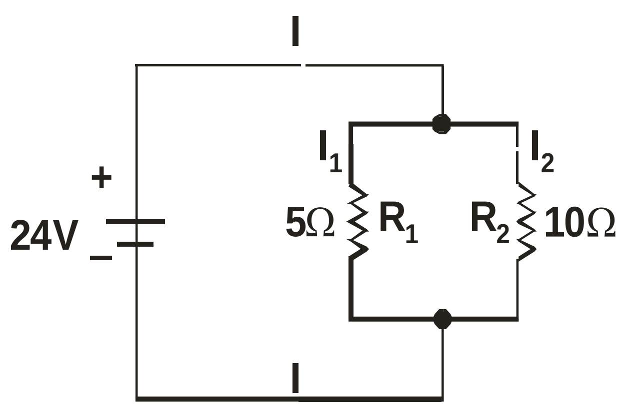


Fig.2.20 Circuit for problem No. 1

Solution:

V = 24 volts

R_1 = 5Ω

R_2= 10Ω

Using Current Division Rule

I_T =?

$$\frac{I}{Requ} = \frac{1}{R1} + \frac{1}{R2}$$

$$\frac{1}{Requ} = \frac{1}{5} + \frac{1}{10} = \frac{2+1}{10} = \frac{3}{10}$$

$$R_{equ} = \frac{10}{3} \qquad =3.333\ \Omega$$

$$I_T = \frac{V}{Requ} = \frac{24}{3.333} \qquad = 7.2\ Amp$$

$$I_1 = \frac{R2}{R1+R2} \times I_T$$

$$= \frac{10}{5+10} \times 7.2 \qquad = 4.8\ Amp.$$

$$I_2 = \frac{R1}{R1+R2} \times I_T$$

$$= \frac{5}{5+10} \times 7.2 \qquad = 2.4\ Amp.$$

<u>Problem No. 2</u>

Two resistances 5Ω and 10Ω are connected in parallel. Line current is 20 mA. Using current division rule find the amount of current flowing through each resistance.

Solution:

$$I_1 = \frac{R2}{R1+R2} \times I_T$$

$$= \frac{10}{5+10} \times 20 \quad = 13.3333\ mA$$

$$I_2 = \frac{R1}{R1+R2} \times I_T$$

$$= \frac{5}{5+10} \times 20 \quad = 6.6667\ mA$$

<u>Problem No. 03 (Self-Test Problem)</u>

Two resistances of 1kΩ and 2kΩ are connected in parallel to a supply of 12V. Find the current in each resistance using current division.

<u>Problem No. 03 (Self-Test Problem)</u>

To resistances 15KΩ and 50KΩ are connected in parallel. Line current is 20mA. Using current division rule find the amount of current flowing through each resistance.

2.2.9 RESISTANCES IN SERIES-PARALLEL:

In series parallel combination of the resistors both serial and parallel connections of resistances are connected together to form a network. A combination of series and parallel resistances is shown in figure below. Five resistances R_1, R_2, R_3, R_4, & R_5 are connected to a power supply V in series parallel combination.

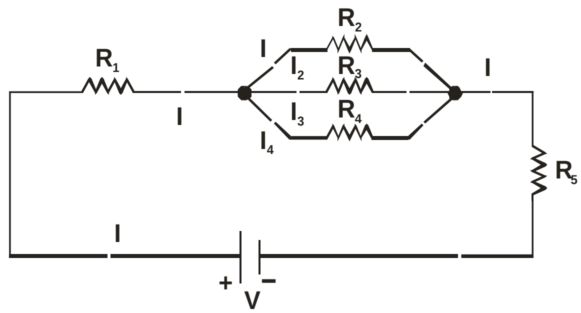


Fig.2.21 Circuit diagram of series parallel circuit

Compare Series and Parallel Circuit of Resistors

Table 2.7

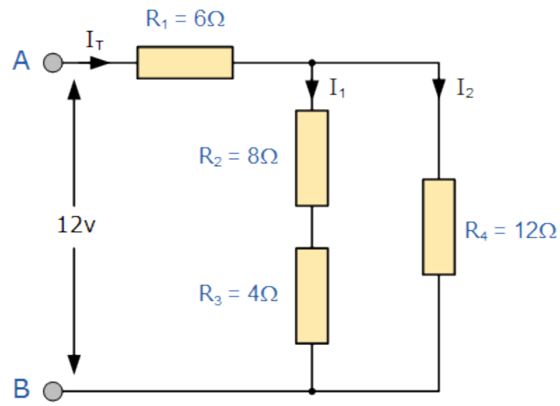
Series Combination	Parallel Combination
Current is same through all the elements of the series circuit i.e. $I = I_1 = I_2 = I_3$	Branch Current flows different in all parallel resistors according to the value of each resistor $I = I_1 + I_2 + I_3 + ...$
The sum of the voltage drops is equal to the applied voltage. $V = V_1 + V_2 + V_3 +\dots$	The voltage is same across all the voltage connected in parallel $V = V_1 = V_2 = V_3$
The total resistance is equal to the sum of all the resistance connected in series. So $R_{equ} = R_1 + R_2 + R_3 + \dots$	The reciprocal of total resistance is equal to the sum of the reciprocals of all the resistances connected in parallel. $\frac{1}{R_{equ}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} +\dots$
The Total resistance of the circuit is greater than any individual resistance of the circuit.	The total resistance of the circuit is less than any of the resistance connected in parallel.

2.2.10 PROBLEMS ON SERIES PARALLEL COMBINATION OF RESISTORS AND CELLS

If we want to connect various resistors together in "BOTH" parallel and series combinations within the same circuit to produce more complex resistive networks, how do we calculate the combined or total circuit resistance, currents and voltages for these resistive combinations.

Resistor circuits that combine series and parallel resistors networks together are generally known as **Resistor Combination** or mixed resistor circuits. The method of calculating the circuits equivalent resistance is the same as that for any individual series or parallel circuit and hopefully we now know that resistors in series carry exactly the same current and that resistors in parallel have exactly the same voltage across them.

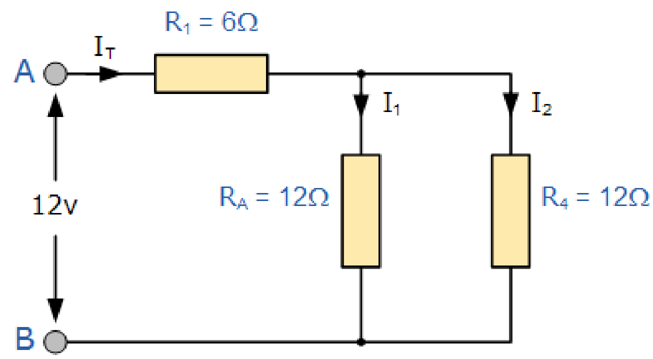
For example, in the following circuit calculate the total current (I_T) taken from the 12v supply.



Two resistors, R_2 and R_3 are actually both connected together in a "SERIES". The resultant resistance for this combination would therefore be:

$R_2 + R_3 = 8\Omega + 4\Omega = 12\Omega$

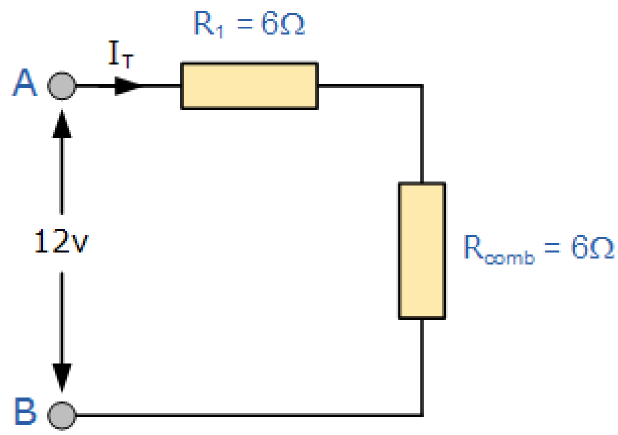
So we can replace both resistor R_2 and R_3 above with a single resistor of resistance value 12Ω



So our circuit now has a single resistor R_A in "PARALLEL" with the resistor R_4.

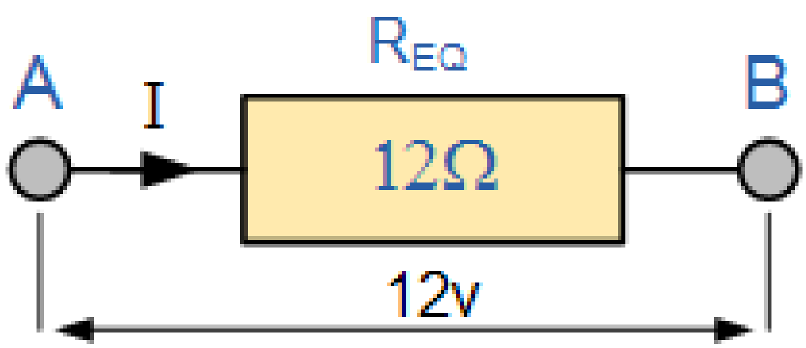
$$R(parallel) = \frac{RA \times R4}{RA + R4}$$
$$= \frac{12 \times 12}{12+12}$$
= 6 ohm

The resultant resistive circuit now looks something like this:



We can see that the two remaining resistances, R_1 and $R_{(comb)}$ are connected together in a "SERIES" combination and again they can be added together (resistors in series) so that the total circuit resistance between points A and B is therefore given as:

$R_{(ab)} = R_{comb} + R_1 = 6\Omega + 6\Omega = 12\Omega$



Total Current $I = \frac{V}{R} = \frac{12}{12} = 1\ Amp$

Problem No. 1

Find the equivalent resistance in the following circuits.

Part (a)

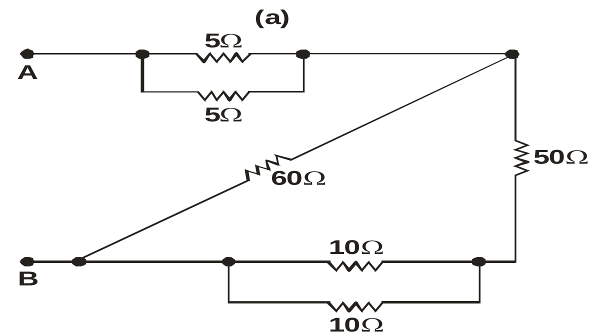


Fig.2.22 Circuit for problem No. 1

Solution:

The equivalent resistance of 5Ω and 5Ω parallel combination is evaluated and the equivalent resistance of parallel combination of 10Ω and 10Ω is evaluated.

$$R_{equ1} = \frac{5 \times 5}{5+5} = \frac{25}{10} = 2.5$$

$$R_{equ2} = \frac{10 \times 10}{10+10} = \frac{100}{20} = 5$$

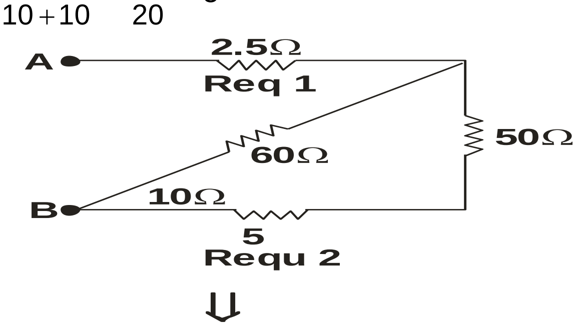


Fig.2.22 (B) Circuit for problem No. 1

Now 50 Ω and 5 Ω are in series so their equivalent is 55Ω,

$$R_{equ3} = 5 + 50 = 55\Omega$$

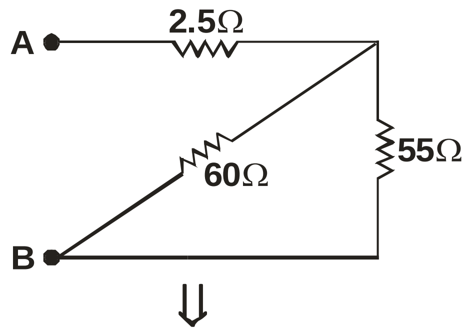


Fig.2.22 (c) Circuit for problem No. 1

Now 60 Ω and 55 Ω are in Parallel so their equivalent is,

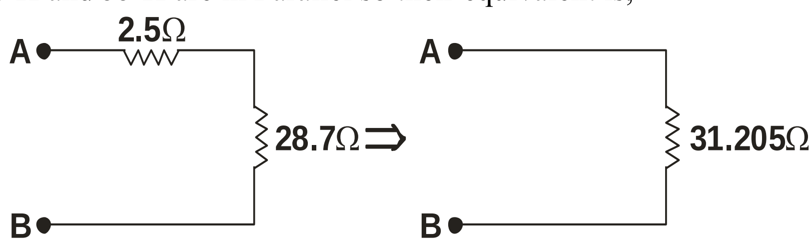


Fig.2.22 (D) Circuit for problem No. 1

So the equivalent resistance is 31.205Ω

Part (b)

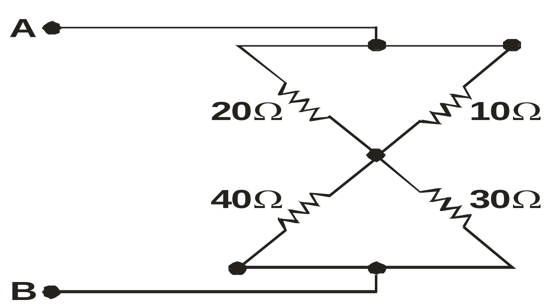


Fig.2.23 Circuit for problem No. 1 part (B)

Solution:

In the figure 10Ω and 20Ω are in Parallel and 30 Ω and 40 Ω are in parallel.

$$\frac{20 \times 10}{20 + 10} = \frac{200}{30} = 6.67\Omega$$

$$\frac{30 \times 40}{30 + 40} = \frac{1200}{70} = 17.14\Omega$$

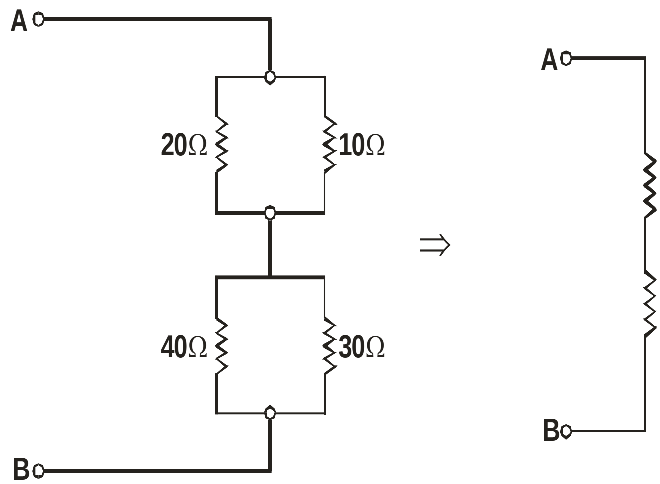


Fig.2.23 (B) Circuit for problem No. 1 part (B)

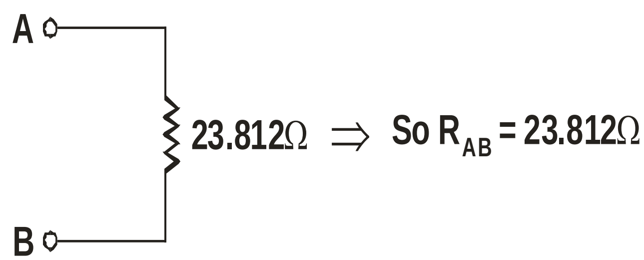


Fig.2.23 (c) Circuit for problem # 1 part (B)

Part (c)

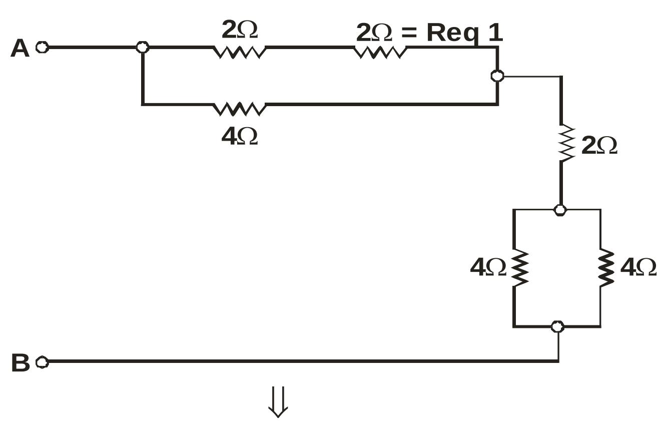
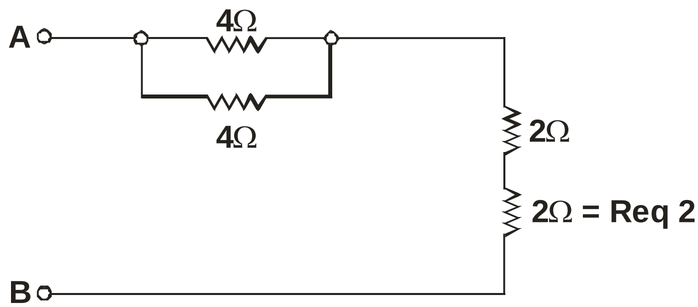


Fig.2.24 Circuit for Problem No 1 part (c)

Resistances 2Ω and 2Ω are in series and their equivalent is 4Ω, so we get;



⇓

Fig.2.4 (B) Circuit for problem No 1 part (c)

4Ω and 4Ω are in parallel and their equivalent is 2Ω and resistances 2Ω and 2Ω are in series and their equivalent is 4Ω and so we get;

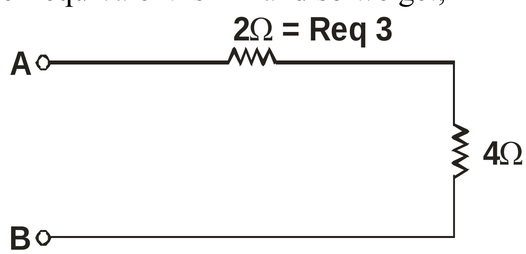


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Fig.2.24 (c) Circuit for problem No. 1 part (c)

<u>Problem No. 2</u>

Find the current and voltage drop across each resistance in the circuit shown in Fig.2.5

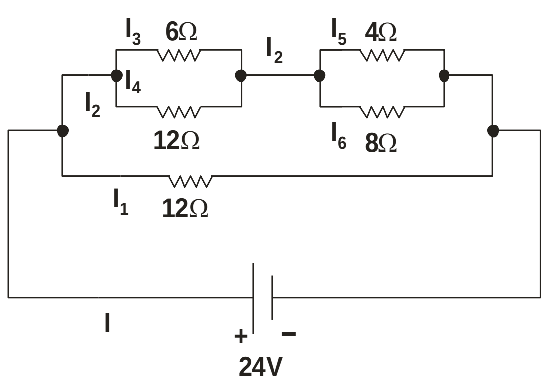


Fig.2.2.5 Circuit for problem No. 2

Solution:

$R_{equ1} = \frac{6 \times 12}{6+12} = 4\ \Omega$

$R_{equ2} = \frac{4 \times 8}{4+8} = 2.6\ \Omega$

Equivalent Resistance of R_{equ1} and R_{equ2} is

$R_{equ} = 4 + 2.6 = 6.6\ \Omega$

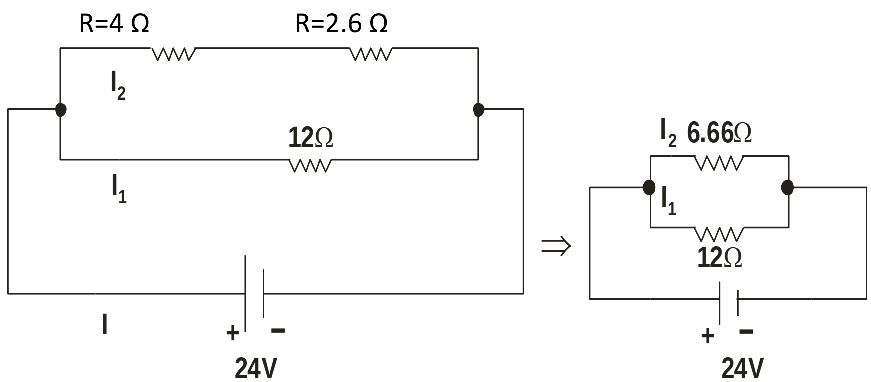


Fig.2.25 (B) Circuit for problem No. 2

$$R_{equ} = \frac{6.66x12}{6.66+12} = \frac{79.92}{18.66} = 4.289\Omega$$

So the current is;

$$I = \frac{V}{R_{equ}} = \frac{24}{4.289} = 5.595\,\text{Amp}$$

Using current division rule find currents I_1 and I_2so,

$I_1 = \frac{6.66}{12+6.66} \times 5.595$

$I_2 = \frac{6.66}{18.66} \times 5.595 = 1.996$ Amp

Voltage across 6.66 and 12 ohm resistor is same as applied voltage (parallel circuit).

<u>Problem No. 3</u>

A circuit consists of two resistors R_1 and R_2 which are connected in series and current of 2mA is flowing through it. Applied voltage is 24 V. Fid the value of R_2=1

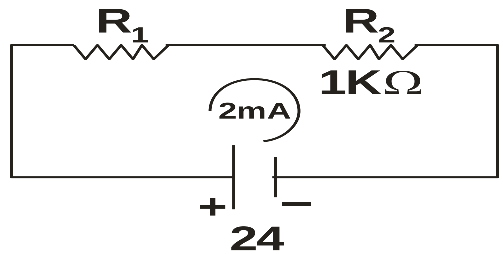


Fig.2.26 Circuit for problem No. 3

Solution:

R_1=?

R_2= 1KΩ

V=24 Volts

I= 2mA

By Ohm's law

$V = I\,R_{equ}$

$R_{equ} = \frac{V}{I} = \frac{24}{2x10^{-3}} = 12\ K\Omega$

$R_1 = R_{equ} - R_2 = 12\ K\Omega - 1\ K\Omega$

$R_1 = 11\ K\Omega$

<u>Problem No.4</u>

In the circuit shown 2.7, the current flowing through 10 Ω resistors is 0.5 Amp and the total current taken from the voltage source is 2 Amp.

(i) Current passing through the remaining resistors.

(ii) The value of the unknown resistor X

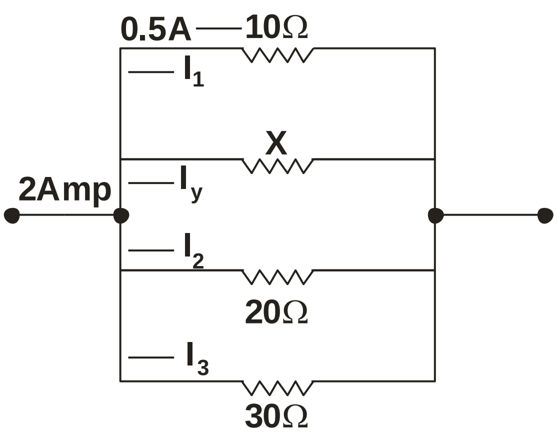


Fig.2.27 Circuit for problem No. 4

Solution:

Let $R_1 = 10\Omega$

$I_1 = 0.5$ Amp

Voltage drop across R_1that is

$V_{R1} = I_1 \times R_1$

$= 0.5 \text{ x } 10$

$= 5$ volts

$R_2 = 20\Omega$

$R_3 = 30\Omega$

R_1, R_2, $R_3$and R_X are connected in parallel

$V_{R1} = V_{R2} = V_{R3} = V_X = 5$ volts

$I_2 = \frac{5}{20} = 0.25$ Amp

$I_3 = \frac{5}{30} = 0.1666$ Amp

$I_X = 2 - I_1 - I_2 - I_3$

$I_X = 2 - 0.5 - 0.25 - 0.1666$

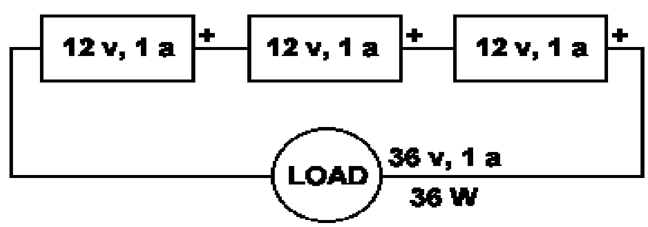
$I_X = 1.5834$ Amp

X or $R_X = \frac{V}{I_x} = \frac{5}{1.5834}$

Unknown resistance $X = 3.577\ \Omega$

Cells in Series:

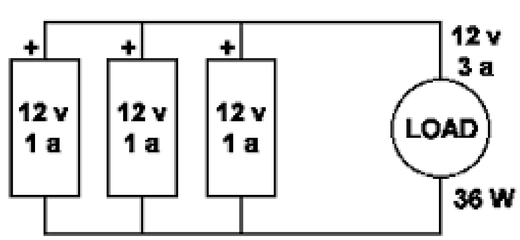
In a series connection, batteries of like voltage and amp-hour capacity are connected to increase the voltage of the overall assembly. The positive terminal of the first battery is connected to the negative terminal of the second battery and so on, until the desired voltage is reached.



Cells in series

Cells in Parallel:

In a parallel connection, batteries of like voltages and capacities are connected to increase the capacity of the overall assembly. The positive terminals of all batteries are connected together, or to a common conductor, and all negative terminals are connected in the same manner.



Cells in Parallel

2.2.11 POWER AND ENERGY:

Electric Power

The rate of doing work is called as Power. In other words we can say the rate at which energy is used is called as Power. It is represented by P. mathematically,

$$\text{Power} = \frac{\text{Energy}}{\text{Time}}$$

$$P = \frac{W}{t}$$

$$= \frac{V \times Q}{t}$$

$$= \frac{V \times I \times t}{t} \qquad (\text{As } Q = I \times t)$$

$$P = V\,I$$

Other formula of electric power $P = I^2 R$

$$P = \frac{V^2}{R}$$

Energy

"The capability of doing work of a body is called as energy."

There are different forms of energy and these are interring convertible. For example chemical energy, electric energy, and mechanical energy, Energy and work are same quantities. The unit of energy is Joule.

If the amount of the charge is Q and is moved in a potential difference V volts then energy or work done (W) can be found by using the following relation.

Work Done = Volts x Change

W = V x Q

2.2.12 UNITS OF POWER AND ENERGY:

Unit of Power:

The unit of power is watt. It is defined as if 1 Joule of work is done in one second then the power consumed is 1 watt.

1 Watt = 1 Joule/Second

Unit of Energy:

In electrical engineering energy is defined as:

"When a charge of one coulomb is moved in a potential difference of one volt then the amount of the work done on the charge is the energy spent and will be 1 Joule".

$$1 \text{ Joule} = 1 \text{ Volts} \times 1 \text{ Coulomb}$$

2.2.13 POWER DISSIPATION IN RESISTORS:

Any resistor in a circuit that has a voltage drop across it dissipates electrical power. This electrical power is converted into heat energy hence all resistors have a power rating. This is the maximum power that can be dissipated from the resistor without it burning out. The rate of conversion is the power of dissipation.

Using the formula for electrical power: $p = v \times i$. but $v = i \times R$ and thus substituting in the equation for electrical power $p = i^2 \times R$.

This also works substituting $I = \frac{V}{R}$, giving $P = \frac{V^2}{R}$.

Problem

Calculate the power dissipated in a 10kΩ resistor with a 5mA current through the resistor.

$$P = i^2 R$$

$$P = (5 \times 10^{-3})^2 \times (10 \times 10^3)$$

P = 250 m W

2.3 KIRCHHOFF'S LAW:

Kirchhoff's Laws are used for the analysis of circuits. Finding the unknown values of currents and voltages through all the resistors or components (or branches) in a circuit is called as Analysis of the circuit.

2.3.1 DEFINE KIRCHHOFF'S LAWS:

Kirchhoff's Laws are used for the analysis of circuits. Finding the unknown values of currents and voltages through all the resistors or components (or branches) in a circuit is called as Analysis of the circuit.

When a resistor network comprise of a single power source, Ohm's Law and series & parallel simplification principles are used to analyze the circuit. However when a circuit consists of more than one sources (either voltage or current) only Ohm's law and series parallel simplification are not sufficient to analyze the circuit. We use Kirchhoff's Laws. There are two Kirchhoff's Laws.

(i) Kirchhoff's current Law.

(ii) Kirchhoff's voltage Law.

Kirchhoff's Current Law

This law states that:

"The algebraic sum of all the current meeting at a node (junction of resistors) is zero."

Suppose three resistors R_1, R_2 and R_3 connected as shown in figure below.

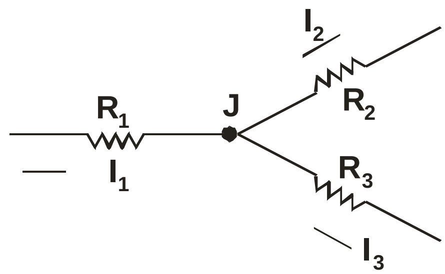


Fig.2.28 Circuit for Kirchhoff's Current Law

Current I_1 is flowing towards the junction J and currents I_2 and I_3 are moving out from the junction J. The direction of current towards a node may be considered as positive and the currents leaving the node may be assumed negative (It is arbitrary).

$$I_1 - I_2 - I_3 = 0$$

Or $$I_1 = I_2 + I_3$$

The analysis of the circuit based on Kirchhoff's current law is called as Node Analysis.

Kirchhoff's Voltage Law (KVL):

"This law states that the algebraic sum of all the voltages in a closed loop is zero. Consider a simple circuit comprising of three resistors R_1, R_2 and R_3 powered with V.

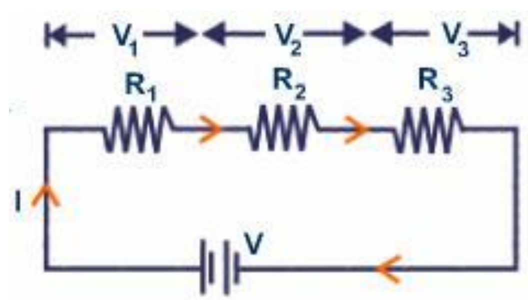


Fig.2.29 Circuit for Kirchhoff's voltage Law

The sign I is current flowing through the circuit. The point at which current enters a resistor is taken +Ve (positive) and the point at which is leaving is considered as –Ve (Negative).

A voltage drop from +Ve to –Ve is taken as negative. So apply KVL while moving clockwise from supply to cover all the components.

$$+V - V_{R1} - V_{R2} - V_{R3} = 0$$

$$V_{R1} + V_{R2} + V_{R3} = V$$

$$(I \times R_1) + (I \times R_2) + (I \times R_3) = V$$ Where "IR" voltage drop

The analysis of the circuit based on Kirchhoff's voltage Law is called as Loop/ Mesh analysis.

Node Analysis

Kirchhoff's current law is used to find the unknown currents and voltages in a circuit and the technique is called as Node Analysis. Following steps are used to solve the circuit based on node analysis.

i. Find out the number of nodes in the circuit i.e. the junction of two or more resistances.
ii. The node of maximum resistances is called as reference node and its potential is considered to be 0 V.
iii. Name the voltage at other nodes as V_A, V_B etc.
iv. Assume the currents at node 1, 2, 3 etc as I_1, I_2, and I_3...
v. Apply KCL for the no. of nodes present in the circuit.
vi. We find equation in the form of node voltages V_A, V_B etc.
vii. Solve the equation and get value, of V_A, V_B etc.
viii. Substitute these values in I_1, I_2, I_3... to find their values.
ix. Any –Ve value of the current obtained after calculation shows that current will flow in the opposite direction to the assumed and redraw the circuit.
x. Find the values of voltage drops using Ohm's law V = I × R.

2.3.2 & 2.3.3 SOLVE PROBLEMS USING KIRCHHOFF'S CURRENT LAW & KIRCHHOFF'S VOLTAGE LAW:

Problem No. 1

Find the currents and voltages across each resistance of the circuit shown below-using KCL (Node Analysis).

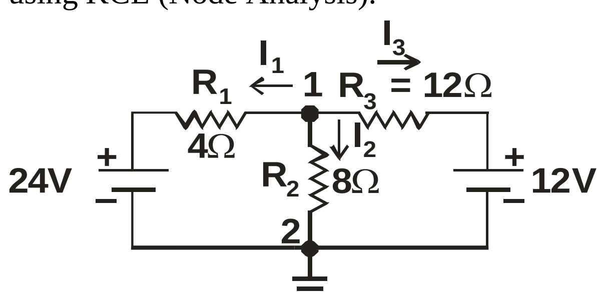


Fig.2.28 Circuit for problem # 1

Solution:

i. There are two nodes in the circuit i.e. 1 & 2.
ii. Consider node No. 2 as reference node

iii. Suppose the currents as I_1, I_2, and I_3 and all flowing out of the node 1 as shown below:

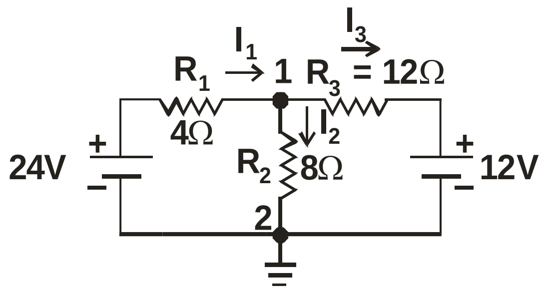


Fig.2.28 (B) Circuit for problem No 1

iv. Consider the node. 1 voltage V_A.

v. Apply KCL at node 1.

$$I_1 + I_2 + I_3 = 0$$

$$\frac{V_A - 24}{R_1} + \frac{V_A - 0}{R_2} + \frac{V_A - 12}{R_3} = 0$$

$$\frac{V_A - 24}{4} + \frac{V_A}{8} + \frac{V_A - 12}{12} = 0$$

$$6(V_A - 24) + 3V_A + 2(V_A - 12) = 0$$

$$6V_A - 144 + 3V_A + 2V_A - 24) = 0$$

$$11V_A - 168 = 0$$

$$V_A = \frac{168}{11} = 15.27\,\text{volts}$$

$$I_1 = \frac{V_A - 24}{4} = \frac{15.27 - 27}{4} = \frac{-8.727}{4}$$

$$I_1 = -2.18\,\text{Amps}$$

(-Ve shows that direction is opposite to the assumed one).

$$V_{R1} = I_1 R_1 = 2.18x4 = 8.72\text{Volts}$$

$$I_2 = \frac{V_A - 0}{8} = \frac{15.27}{8} = 1.908\,\text{Amps}$$

$$I_3 = \frac{V_A - 12}{12} = \frac{15.27 - 12}{12} = 0.2725\,\text{Amps}$$

$$V_{R3} = I_3 x R_3 = 0.2725x12 = 3.27\,\text{Volts}$$

So redraw the circuit

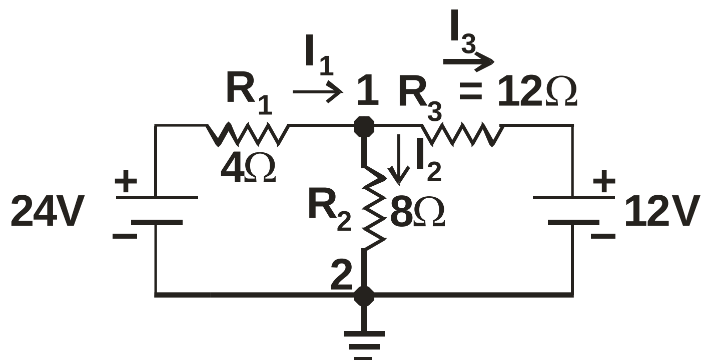


Fig.2.28 (C) Circuit for problem No 1

Problem No. 2 (Self-Test Problem)

Find the voltage and currents in all the branches of the circuit shown in figure below using KCL (Node Analysis).

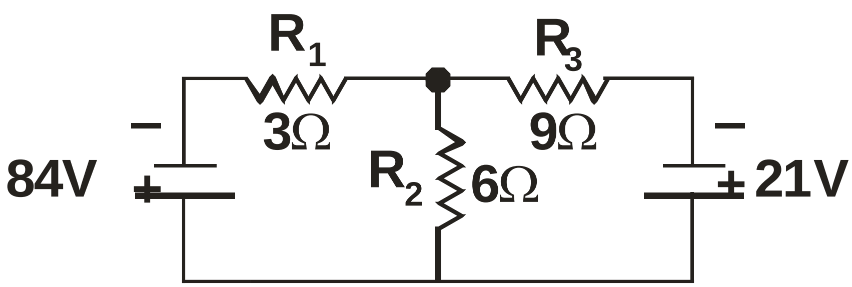


Fig.2.29 Circuit for problem No. 2

Problem No. 3 (Self-Test Problem)

Find the currents and voltage across all the elements of the circuit shown below using Kirchhoff's current law.

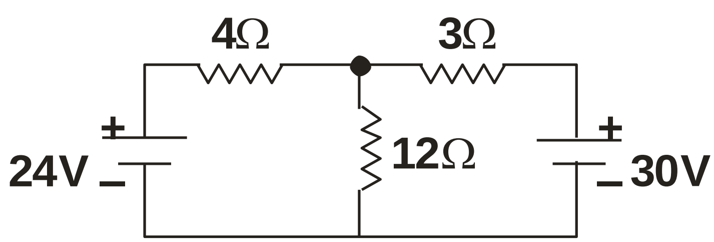


Fig.2.30 Circuit for Problem No. 3

Problem No. 4 (Self-Test Problem)

Find the currents and voltages across all the elements shown in figure below using Kirchhoff's current laws.

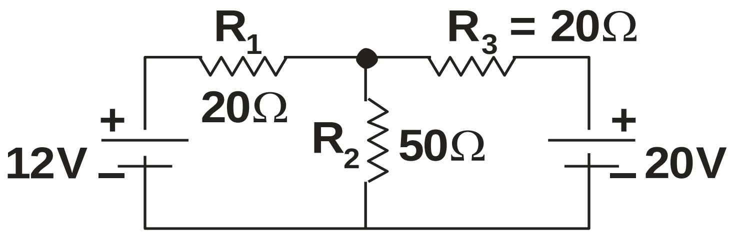


Fig.2.31 Circuit for problem No. 4

Loop /Mesh Analysis:

i. In order to solve the circuit using loop/mesh analyses following steps are followed.
ii. Assign loop currents say I_1, I_2, I_3 etc.
iii. Apply KVL for the individual loops.
iv. We get a set of simultaneous equations involving I_1, I_2 etc.
v. Solve the simultaneous equation and get the values of I_1, I_2
vi. Now find the currents in each branch as assigned in the KVL equations.
vii. Calculate the voltage drops using $V = IR$ and powers by $P = I^2R$ if required.

Problem No. 1

Using Kirchhoff's voltage law (Loop mesh analysis) find the currents and voltage across each resistance of the circuit shown below:

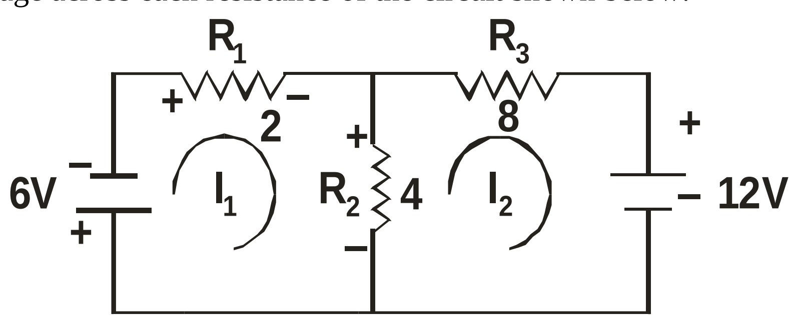


Fig.2.33 Circuit for problem No. 1

Solution:

Let I_1 and I_2 be the loop currents assigned to loop 1 and 2.

Apply KVL for the loop No. 1

$$\sum V.D = 0$$
$$-6 - R_1 I_1 - R2(I_1 - I_2) = 0$$
$$-6 - 2I_1 - 4(I_1 - I_2) = 0$$
$$-6 - 2I_1 - 4I_1 + 4I_2 = 0$$
$$-6I_1 + 4I_2 = 6 \qquad \_\_\_\_\_(1)$$

Apply KVL for loop.2

$$-12 - 4(I_2 - I_1) - 8I_2 = 0$$
$$-12 - 4I_2 + 4I_1 - 8I_2 = 0$$
$$4I_1 - 12I_2 = +12$$

Solving 1 & 2

$$\begin{array}{ll} 1 \times 2 \Rightarrow & -12I_1 + 8I_2 = 12 \\ 2 \times 3 \Rightarrow & \underline{12I_1 - 36I_2 = +36} \\ \text{Adding} & -24I_2 = -48 \end{array}$$

$$I_2 = \frac{-24}{24} = -1\text{Amp}$$

Put I2 in equation. (1)

$$-6I_1 + 4x - 1 = 6$$
$$-6I_1 = 10$$
$$I_1 = \frac{-10}{6} = \frac{-5}{3} = -1.667\text{ Amp}$$

Current through $R_1 = I_1 = 1.667\text{ Amp}$

$$V_{R1} = I_1 R_1 = 1.667 \times 2 = 3.3334\text{ volts}$$

Current through

$$R_2 = I_1 - I_2 = \frac{-5}{3} - (-1) = \frac{-5}{3} + 1$$
$$V_{R2} = \frac{-2}{3} x4 = \frac{-8}{3}\text{ Volts}$$

Current through $R_3 = I_2 - 1\text{Amp}$

$$V_{R3} = I_3 \, x R_3 = -1x8 = -8\text{ Volts}$$

Problem No. 2

Using Kirchhoff's voltage law, find the value of the unknown resistance R shown in figure below the value of the current is 2Amp.

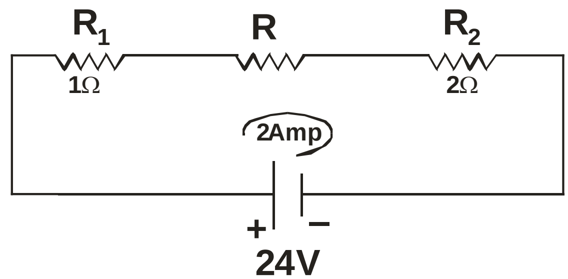


Fig.2.33 Circuit for problem No. 2

Solution:

Apply KVL for the circuit shown above.

$$\sum V.D = 0$$

$$+24 - IR_1 - IR - IR_2 = 0$$

$$24 - 21 - 2xR - 2x2 = 0$$

$$24 - 2 - 2R - 4 = 0$$

$$18 - 2R = 0$$

$$2R = 18$$

$$R = 9\Omega$$

Problem No. 3 (Self-Test Problem)

Find the currents, voltage and power drops across each resistance of the circuit shown below using Kirchhoff's voltage law.

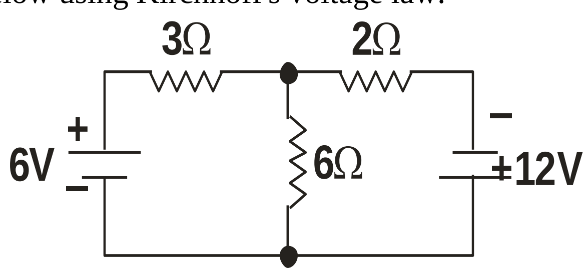


Fig.2.34 Circuit for problem No. 3

Problem No. 4 (Self-Test Problem)

Find the currents and voltage drop across each element of the circuit shown below using Kirchhoff's voltage law (loop analysis).

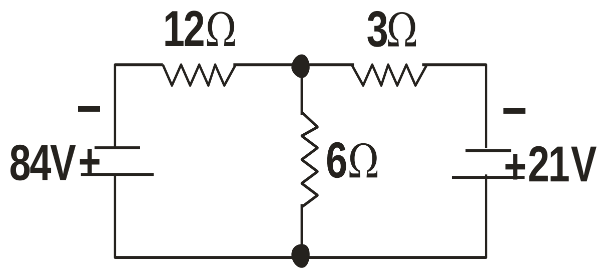


Fig.2.35 Circuit for problem No. 4

Problem No. 5

Find the current and voltage drop across each resistance of the circuit shown below using Kirchhoff's voltage law.

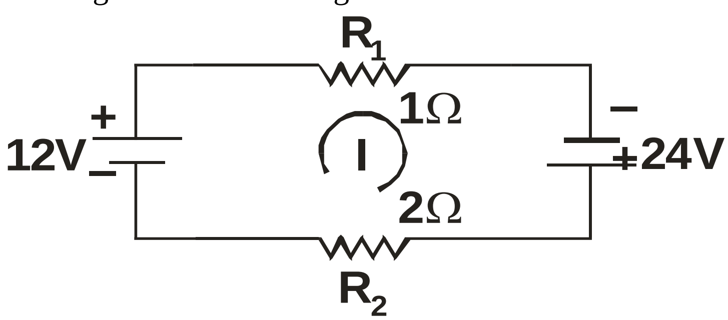


Fig.2.36 Circuit for problem No.5

Solution:

Apply KVL of the circuit shown in figure.

$$+24-2I+12V-1xI=0$$

$$+24-3I+12=0$$

$$36-3I=0$$

$$3I=36$$

$$I=12\,\text{Amp}$$

$$\therefore \quad V_{R1}=IR_1=12x1=12\,\text{volts}$$

$$V_{R2}=IxR_2=12x2=24\,\text{volts}$$

Problem No. 6 (Self-Test Problem)

Using KVL (loop/mesh analysis) find the value of currents and voltage drops across all the elements of the circuit shown in Fig2.37:

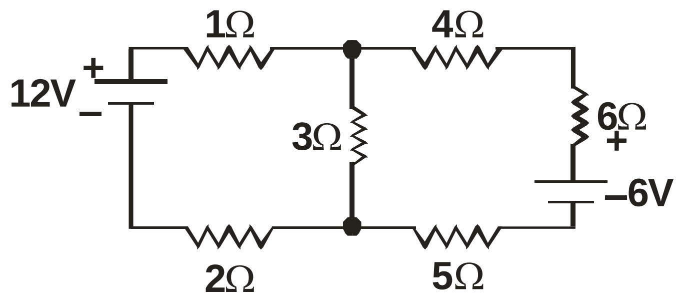


Fig.2.37 Circuit for problem No. 6

2.4 RESISTORS:

2.4.1 Resistance

Opposition to the flow of current is called as resistance. It is represented by R and denoted by the symbol **Ω**. The unit of resistance is Ohm.

Resistances of different materials are different and depend on the nature of the material. Metals have low resistance and are good conductors.

Resistor

A component that produces an opposition to the flow of current is called as Resistor.

2.4.2 TYPES OF RESISTORS:

Resistors can be divided into two major types:

(i) Linear Resistor:

These are the resistors in which the current is directly proportional to applied voltage. In such resistors the values of the resistance does not change with applied voltage and temperatures.

(ii) Non-Linear Resistors:

These are the resistors in which the value of the resistance changes with the applied voltage and temperature or current and voltage have no specific relation.

Linear and non-Linear resistor can be divided into following types:

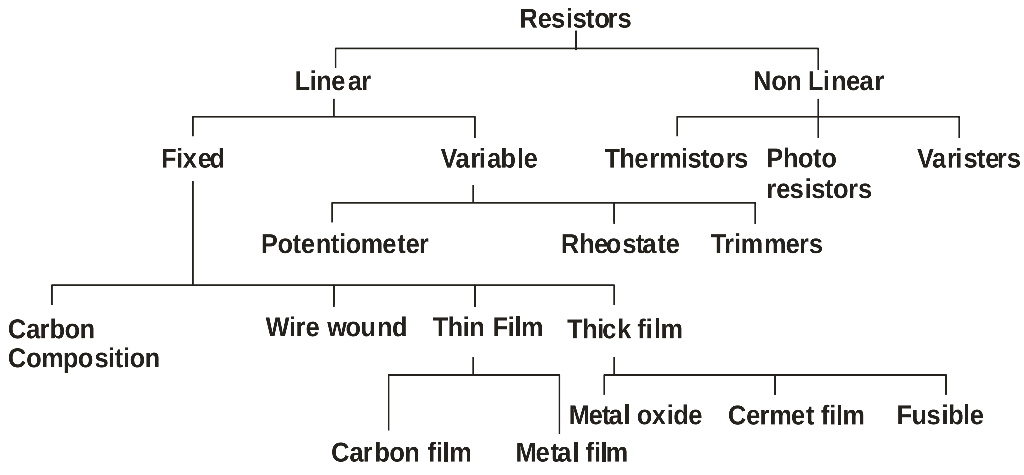


Fig.2.38 The resistor tree

Fixed Resistors

These are the resistors whose values do not change and are fixed during their production.

There are different types of fixed resistors

(i) Carbon Composition Resistors

A mixture of finely ground carbon or graphite mixed with a binder in a definite proportion is used to fabricate a desired resistance.

These resistors are made in the form of rods and at the two ends of the resistors are joined to metal. Leads are taken out for connection and soldering purposes. These are made in different ratings and values up to 22 mega Ohm and 1/10 watts to 2 watts. These are designed to carry small currents.

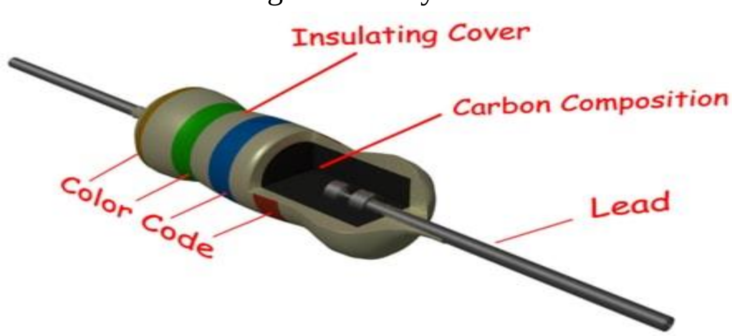


Fig.2.39 Carbon Composition Resistor

(ii) Wire Wound Resistors

Wire wound resistors are made by winding a resistance wire which is made of nichrome (Combination of chromium and nickel) on insulating case of materials like Bakelite. In order to protect the wire are covered with inorganic cement. These are available in power ratings of 1 watt to 10 watts with values

1Ω to 200kΩ, tolerance of 5% to 10% and operating temperature up to 350C°. These resistors are low in noise, good time stability, costly and not useful for high frequency.

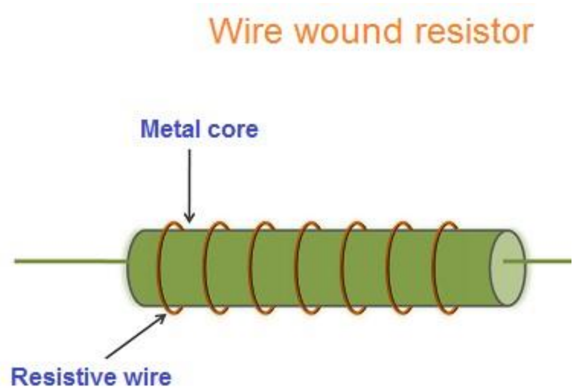


Fig.2.40 Wire Wound Resistor

(iii) Thin film Resistors:

Thin film resistors are produced by depositing a very thin layer of conducting material on an insulated rod, tube or place which is made of ceramic material or glass. Thin film resistors further can be divided into two groups.


Fig.2.41Thin film Resistor

(a) Carbon Film Resistors:

Carbon film resistors are made by depositing a thin film of carbon on an insulating high grade ceramic rod.

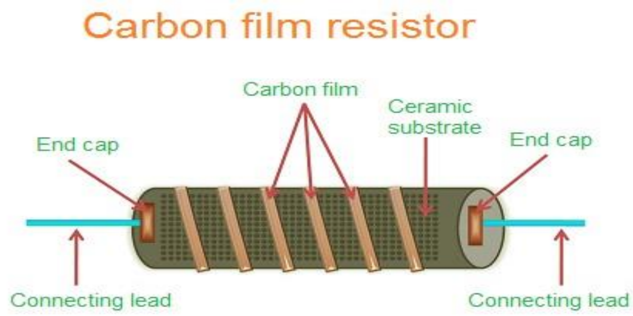


Fig.2.42 carbon film Resistor

These resistors have very low noise, good time stability and wide operating range.

(b) Metal film Resistors

Metal film resistors are made by depositing a film of a metal or metal alloy on an insulating rod.

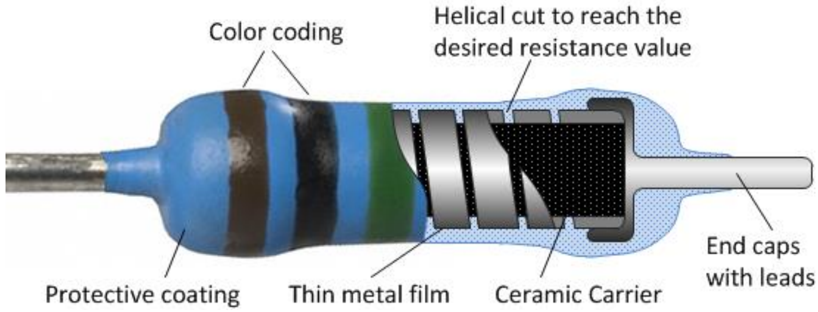


Fig.2.43 Metal film Resistor

These are very small in size and are very regicide, have very low noise level and high stability.

(iv) Thick Film Resistors

Thick film resistors are made with the techniques which are similar to the thin film resistors except that a thick film is deposited in place of thin film. Thick film resistors can be of following types.

(a) Metal Oxide Resistors

Metal oxide resistors are manufactured by oxidizing tin chloride on a heated glass rod. These resistors are available in high voltage ratings with wide range of values. Metal oxide resistors have low noise and good temperature stability.

(b) **Cermets film Resistors**

These resistors are made by depositing a layer of carbon or metal alloy on a ceramic rod (called substrate). These resistors are made for more precise values and greater stability for heat. These are in the shape of square or rectangle with leads as terminals and can be easily fixed on a printed circuit board.

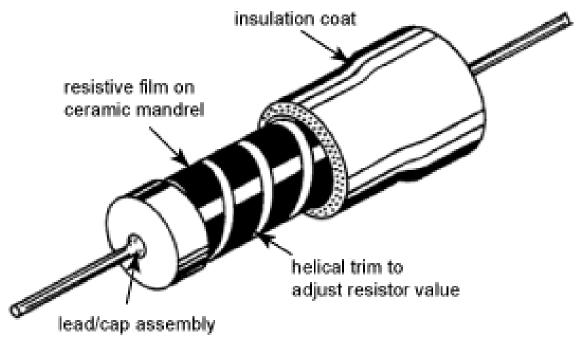


Fig.2.44Metal Oxide Resistor

(c) Fusible Resistors

Fusible resistors acts like a fuse in a circuit and consist of a wire wound resistor which can be burnt out easily whenever the power rating is exceeded a certain predetermined value. These resistors have value, less than 10**Ω**. These are used in TV sets and amplifiers to protect certain circuits.

Variable Resistors

Variable resistors are defined as the resistors whose resistance value can be changed from zero to specific maximum value. In order to change the value of the resistance a rotating knob, screw or sliding arm is used. Various types of variable resistors are:

(a)Potentiometers (b) Rheostats (c) Trimmers

Potentiometers:

Potentiometers are three terminal variable resistors. The outer terminals are fixed and other central terminals are variable. It is shown in figure below:

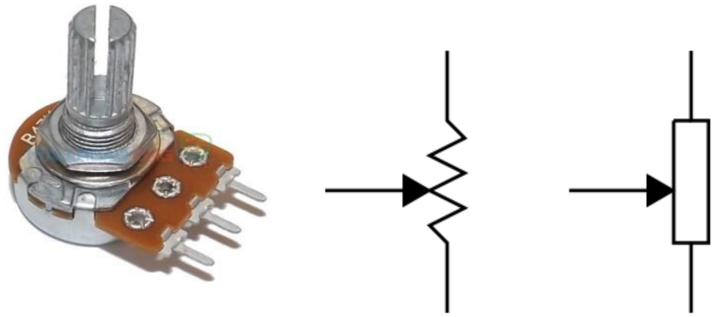


Fig.2.45Variable resistor (potentiometer)

Potentiometers are used for controlling the voltage and current in a circuit.

Rheostats

Rheostat is also a variable resistance which is used for high voltage. It is also called as variable wire wound resistor. Rheostats are manufactured by wounding a nichrome wire on a ceramic core.

A rheostat has 2 or 3 terminals and the resistance of the rheostat can be changed by moving a wiper attached to its body. It is shown in figure below:

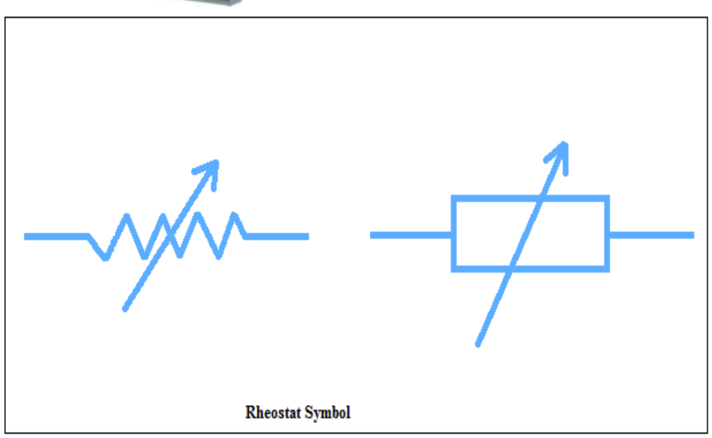


Fig.2.46 Rheostat

If a rheostat is used to change the voltage then it is called as Potentiometers. Potentiometers can be used as rheostat as shown in figure below:

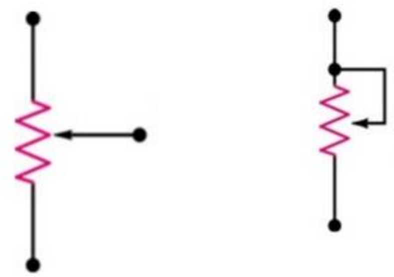


Fig.2.47 Potentiometers as rheostat

Trimmers:

Trimmers are variable resistors in which resistance is varied by losing or tightening a screw built at the body of the trimmer. Trimmers can be single turn or multi turn and resistances can vary from
50Ω to 5 mega Ω in power ratings of 1/4 to 3/4 watts Trimmers are shown in figure below.

Fig.2.48Trimmer

Non-Linear Resistors:
In non-linear resistors there is no specific relationship between current and voltage across the resistance. Different types of non-linear resistors are:

(a) Thermistor (b) Photo resistors (c) Varistors

Thermistors

Thermistor is a temperature sensitive resistor. It has two terminals and has variable resistance. It is used to detect very small changes in temperature.

Thermistors are found in both type's i.e. negative temperature coefficient (NTC) type and positive temperature coefficient (PTC) type.

In positive temperature coefficient type resistance, increases with the increase in the temperature In NTC type resistance decreases with the increase in the temperature.

Thermistors are found in the form of beads, Probes, discs, Washers and rods as shown in figure below:

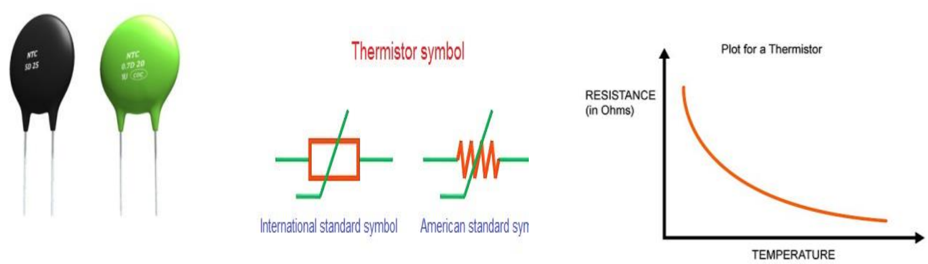


Fig.2.49 Thermistors

NTC thermostats are prepared from cobalt, nickel, strontium and manganese dioxide. PTC thermostats are manufactured from doped Barium tantalite semi-conductors.

Photo Resistors

Photo resistors are two terminal semi-conductor devices whose terminal resistance changes with the light intensity. Materials used to develop photo resistors are called as Photoconductors. Such materials are cadmium sulphide, Cadmium selenide and lead sulphide etc.

Photo resistors are shown in figure below:

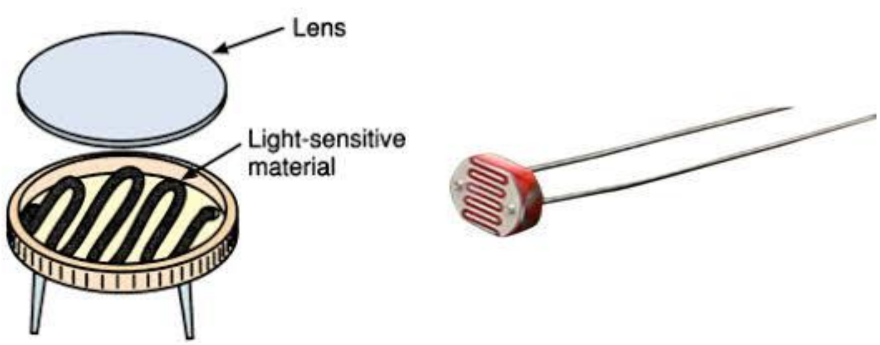


Fig.2.50 Photo resistors

When the light intensity on the surface of the photo resistors increases the no. of free carriers or hole pairs at the surface of the material increases, resulting in a decrease of resistance. When light intensity decreases, the photo resistor resistance increases.

Due the variations in resistance, the photo resistors are used in many industrial applications like light meters, light activated relay control circuits, Burglar alarms, smoke detectors etc. The photo resistors are NTC type.

Varitsors:

Varitsors are voltage dependent resistors (VDRs) i.e. the value of the resistance changes when the supply voltage changes. VDRs are used to suppress the high voltage transients which can cause harm to the devices.

Varitsors are found in a large variety of packages and operating voltage ranging from 12 volts to 650 volts and can handle currents up to 2000 Amps.

Varitsors are shown in figure below.

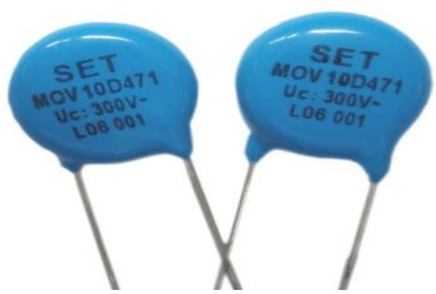


Fig.2.51 Varistors

2.4.3 APPLICATIONS (USES) OF RESISTORS:

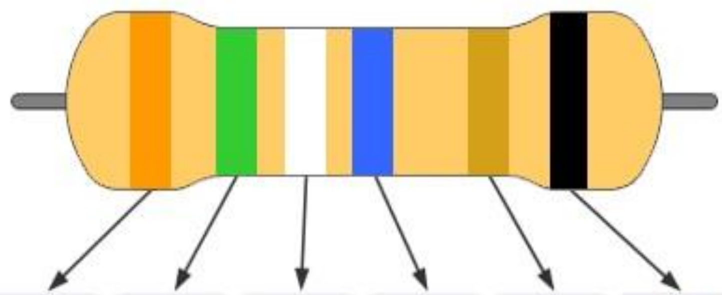
Resistors are used in my applications to limit the current and voltage in the circuits. Resistor shows the similar behavior at dc and ac supplies. Some of the many applications of resistors are enlisted as follows:

i. In order to control or divide the voltage.
ii. To control the current in the circuit.
iii. In electronics circuits for wave shaping and many other applications.
iv. In ampere meters and voltmeters.
v. In domestic application in electric iron, bulbs, heaters etc.
vi. To control the temperatures.
vii. In the protection of electric circuits and systems.

2.4.4 RESISTOR COLOUR CODING:

Resistor color coding is used to find the resistance value by using the different color bands found on the body of the resistor. Since the size of the resistor is very small so it is not possible to write the value of the resistance on the body of the resistor. In color coding 4 or 5 bands of various colors are printed on the body of the resistor. The value of the resistance is read by using the table and following technique.

i. First band represent the first significant digits of the value of the resistor.
ii. Second band represents the second significant digit of the value of the resistor.
iii. 3rd band specifies the no. of zero to be assigned to 1st two significant digits found in steps 1 & 2.
iv. Fourth band represents the possibility of tolerance. If its color is silver it represents 10% tolerance, if the color is gold it represents 5% tolerance and if there is no band it means 20% tolerance.



	1st digit	2nd digit	3rd digit	multiply	tolerance	TCR (ppm/K)
Black	0	0	0	1	1% (F)	100
Brown	1	1	1	10	2% (G)	50
Red	2	2	2	100		15
Orange	3	3	3	1K		25
Yellow	4	4	4	10K		
Green	5	5	5	100K	0.5% (D)	
Blue	6	6	6	1M	0.25% (C)	10
Violet	7	7	7	10M	0.1% (B)	5
Gray	8	8	8	100M	0.05% (A)	
White	9	9	9	1G		
Gold				0.1	5% (J)	
Silver				0.01	10% (K)	
None					20% (M)	

Fig.2.52Resistor color coding

2.4.5 POWER RATINGS OF RESISTOR:

In a properly designed circuit, apart from the value of the resistance, suitable selection of power rating is also very important. Since we know that

that power dissipated in a resistor is determined by $\mathbf{I^2R}$ and if a lesser power rating resistor is used, it will be burnt out and circuit will stop functioning. So manufacturers are designing the resistors for proper ratings. Power rating of a resistor represents its maximum power which it can handle safely. Normally carbon resistors are designed for $\frac{1}{10}, \frac{1}{8}, \frac{1}{4}, \frac{1}{2}$,2 watts wire wound resistors are made from $\frac{1}{4}$ watts to 200 watt values. By increasing the size of the resistor, the power handling ability can be increased.

2.5 BATTERIES:

Batteries are the most common power source for basic handheld devices to large scale industrial applications. A battery can be defined as; it is a combination of one or more electrochemical cells that are capable of converting stored chemical energy into electrical energy.

2.5.1 TYPES OF D.C SOURCES:

There are two types of currents i.e. ac and dc. DC means direct current and it has only one direction of flow i.e. from the positive terminal to the negative terminal of the source or vice versa.
DC can be obtained from the following sources.

(i) Cells

A cell is a device which produces dc voltage by the chemical reaction.

(ii) Batteries

When different cells are combined a battery is farmed.

(iii) Generator

It produces dc by converting mechanical energy into electrical energy.

(iv) Power Supplies

Power supplies also provide dc. In power supplies ac is converted to dc through rectification.

2.5.2 TYPES OF CELLS:

A cell is a device which produces direct current due to the internal chemical reactions. There are two basic types of cells.

(i) Primary cell
(ii) Secondary cell

Primary Cell

A primary cell is defined as a cell which cannot be recharged once it is discharged. The basic principle of cell is that when two dissimilar metals are called Electrodes are placed in an electrolyte; EMF is produced due to the chemical reaction. The EMF continues to remain available until the electrolyte is fully utilized and converted into some other shape. In a primary cell it is not possible to reverse the chemical action to bring the electrolyte to its original state. Examples of primary cells are Mercury Cell, Silver Oxide Cell etc.

Secondary Cell

A secondary cell is one which can be charged once it is discharged. In the secondary cell the chemical reaction which takes place between the electrolyte and electrode during the discharging can be reversed by passing a current through the cell in the opposite direction. Examples of secondary cell are Nickel Cadmium Cell, Lead Acid Batteries etc.

Comparison of Primary and Secondary Cells

Primary Cells	Secondary Cells
It cannot be recharged.	It can be recharged.
It is light in weight.	It is heavy in weight.
Its life is short.	Its life is long.
Its output is small.	It has more output voltage.
It has large internal resistance.	It has small internal resistance.
Its price is low.	Its price is high.

Table 2.8

Popular Primary Cells

1. Mercury Cell

Mercury cell is a primary cell. It is used with a high current density with a uniform discharge characteristics are required. Its internal resistance is low and remains constant.

Mercury cell consists of a cathode which is made from compressed mercuric oxide mixed with a small percentage of graphite. The anode is made from a purified zinc powder. KOH is used as electrolyte. Mercury cell is made in the shape of flat, round cylinder and small button shapes. It is shown in figure below.

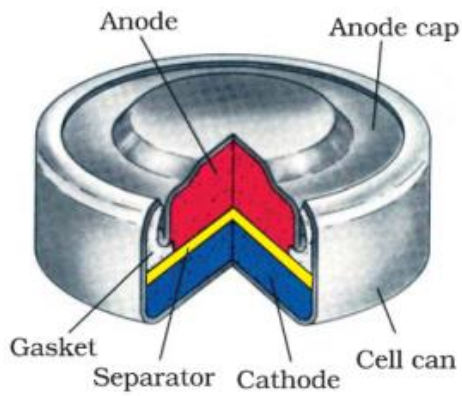


Fig.2.53 Mercury Cell

Mercury cell is used where uniform discharge characteristics are required. These are used in radios, Electric watches, Instruments, Computers and measuring devices etc. It provides output in volts 1-2 volts.

2. Silver Oxide Cell

Silver oxide cell is a primary cell. It consists of depolarizing cathode and a powdered zinc anode. KOH or NaOH is used as Electrolyte. The depolarizing cathode comprises of AgO2 and manganese dioxide MnO2.

The cathode is made depolarizing to avoid the hydrogen ions which are gathered at the silver plate during the chemical reaction. To avoid this gathering of hydrogen ions manganese dioxide is mixed with AgO2. It improves the life of the cell.

Silver oxide cells are made in the form of buttons or discs and provide few volts output 2-3 volts. Silver oxide cells are used in hearing and reference voltage sources, Electronic instruments and watches etc.

Fig.2.54 Popular Secondary Cells

3. Nickel Cadmium Cell

Nickel Cadmium is a reversible cell or a secondary cell. The open circuit voltage provided by the cell is 1.25 to 1.5 volts. It is used for high current density applications and is highly reliable for long term applications. Nickel cadmium cell is available in both sealed and non-sealed designs but the sealed constructions are common. It is shown in figure below.

Nickel cadmium cell are used in portable power tools, alarm systems, and portable radio or television equipments.

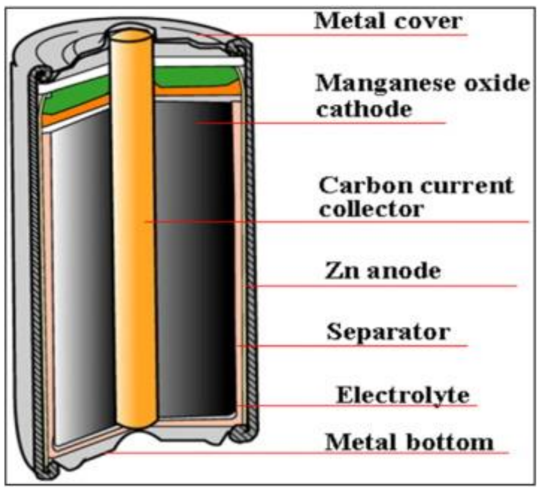


Fig.2.55 -Nickel Cadmium Cell

The positive electrode is Ni and negative electrode is Cd. KOH is used as Electrolyte.

The chemical equation for NiCd cell can be written as follows.

$$2Ni(oH)_3 + Cd \underset{\text{Discharge}}{\overset{\text{Charge}}{\rightleftarrows}} 2Ni(oH)_2 + Cd(oH)_2$$

The electrolyte KOH does not appear in the chemical reaction. The reason is that the function of this electrolyte is just to act as a conductor for the transfer of OH– ions.

NiCd cell is a true storage cell with a reversible chemical reaction for recharging that can be cycled up to 1000 times. It should be noted that a new NiCd battery may need charging before use.

2.5.3 LEAD ACID BATTERY:

Lead acid cell is used when high values of load current are necessary. The electrolyte is dilute solution of sulphuric acid H2So4. The lead acid cell is a secondary cell or storage cell which can be recharged. The charge and discharge cycle can be repeated many times to restore the output voltage as long as the cell is in good physical conditions. One cell has a nominal output of 2.1V but lead acid cells are often used in a series combination of three for a 6V battery and six far a 12 volt battery.

In lead acid battery positive and negative electrodes consists of a group of plates welded to a connecting strap. The plates are dipped in the electrolyte consisting of 8 parts of water to 3 parts of concentrated sulphuric acid. It is shown in figure 2.56. Each plate is a grid of framework, made of lead antimony alloy. This construction enables the active material, which is lead oxide to be pasted into the grid. In manufacturing of the cell, a forming charge produces the positive and negative electrodes the negative electrode is spongy lead (Pd).

The electrolyte i.e. $H2SO_4$ is a combination of hydrogen and sulphate ions. When the cell discharges, lead peroxide from the positive electrode combines with the hydrogen ions to form water and with sulphate ions to form lead sulphate. The lead sulphate is also produced by combining lead on the negative plate with sulphate ions. Therefore, the net result of discharge is to produce more water, which dilutes the electrolyte and to form lead sulfate on the plates.

As discharge continues, the sulfate fills the pores of the grids, retarding circulation of acid in the active material. Lead sulphate is the powder often seen on the outside terminals of the old batteries.

On charge the external dc source reverses the current in the battery. The reversed direction of ions flowing in the electrolyte results in a reversal of the chemical reactions. Now the lead sulphate on the positive plate reacts with the water and sulphate ions to produce lead per oxide and sulphuric acid.

This action reforms the positive plate and makes the electrolyte stronger by adding sulphuric acid. This chemical reaction for discharging and charging is shown below:

$$Pb + Pbo_2 + 2H_2So_4 \underset{\text{Discharge}}{\overset{\text{Charge}}{\rightleftarrows}} 2PbSo_4 + 2H_2O$$

The state of the discharge of a lead acid is generally checked by measuring the specific gravity of the electrolyte. Specific gravity reading is taken with a battery hydrometer.

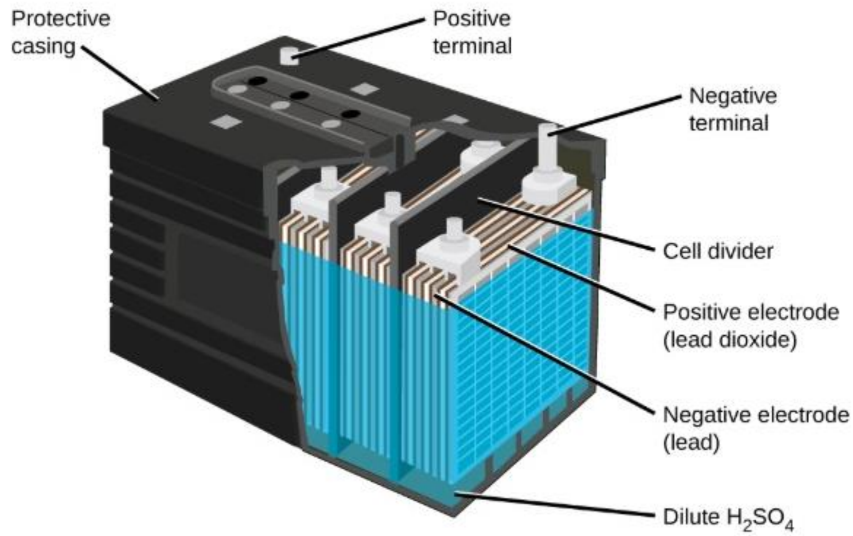


Fig.2.56 Lead Acid Cell

2.5.4 SOLAR CELL:

A solar cell works on the principle called photo voltaic effect. A solar cell consists of two layers of different materials. One layer is photo sensitive that is when light energy falls on it, emits electrons. The other layer is capable of absorbing the electrons. The layer which emits electron i.e., losses the negative charge becomes positive and acts as a positive electrode. On the other hand the layer which accepts electrons becomes negative and acts as negative electrode. In this way by these two electrodes a cell is formed which is called as Solar Cell.

A silicon solar cell is made of P-type and N-type crystals or diode which is sealed and has a glass window on the top to collect the solar light. P-type surface, the top surface of the solar cell is made very thin so that it can easily reach the PN junction. When light energy falls on the surface of the cell then electrons gains the energy and leave their parent atoms and cross the junction. In this way one side of the junction becomes positive electrode and other side becomes negative electrode. A potential difference is established and it provides output like cell.

Indium Arsenide (InAs), Cadmium Arsenide (CdAs) is the materials which are widely used in solar cells. A solar cell provides 0.26 volt. In order to get higher voltage many cells are connected in series.

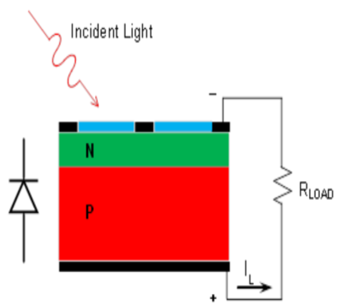


Fig.2.57 Solar Cell

2.5.5 INTERNAL RESISTANCE OF CELL:

The resistance offered by a cell is called as Internal Resistance. Expressed as "ri" Every cell has a certain internal resistance **r_i** which depends upon the construction of the cell.

A good cell should have minimum internal resistance. When load is connected to a cell voltage drop is developed across the internal resistance and this potential drop reduces the voltage across the load. The internal resistance of cell can be measured by the simple experimental arrangement shown in figure 2.58.

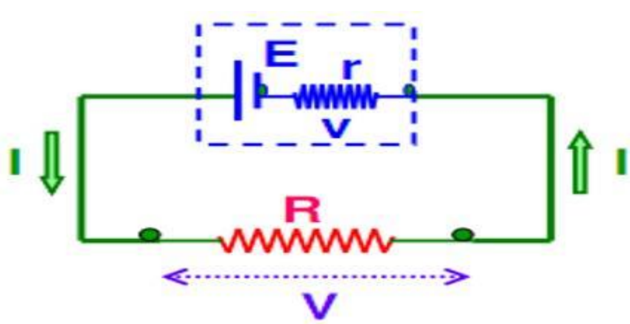


Fig.2.58 internal resistance of Cell

The cell is connected in series with the resistance R as shown in figure 2.58. Ampere meter A may be connected in series with resistance R and a voltmeter V may be connected across the two terminals of the battery.

First of all we measure the value of the voltage of the battery and say it is E. Now observe the value of the voltage at the terminal of the battery will reduce and say it is V.

The internal resistance of the cell may be obtained by the relation.

$$r_i = \frac{E - V}{I}$$

2.5.5 CONSTANT VOLTAGE AND C CURRENT SOURCE:

Parallel combination of cells as constant voltage source:

Similar cells can be combined in parallel to work as constant voltage source. In this case we can meet the higher load current demand. To achieve this combination all positive terminals are connected to each other and all negative terminals are connected to each other. One positive terminal and one negative terminal is taken out to connect to the load. In parallel combination of cells the net current is the sum of the individual currents of each and the output voltage is the same as the voltage of the individual cell.

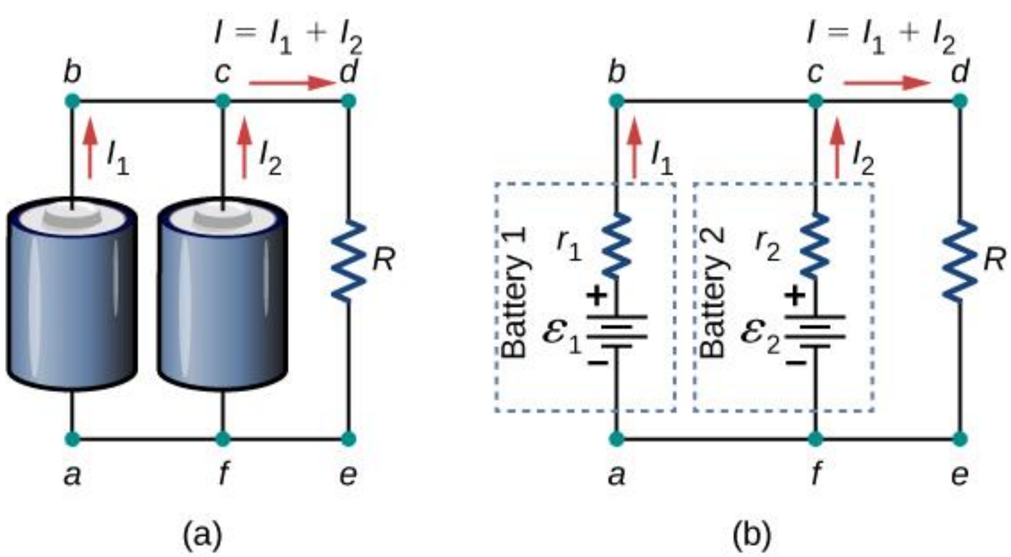


Fig.2.59 Parallel combination of Cells

Series combination of cells as constant current source:

If the load demand is higher voltage then required numbers of cells are connected in series. In series combination, the negative terminal of first cell is connected to the positive terminal of the second cell and so on. Output load is connected to the positive terminal of the first cell to the negative terminal of the last. If two cells of 2V each are connected in series then the load terminal output will be 4 volts. The current is the same in all the cells and across the load.

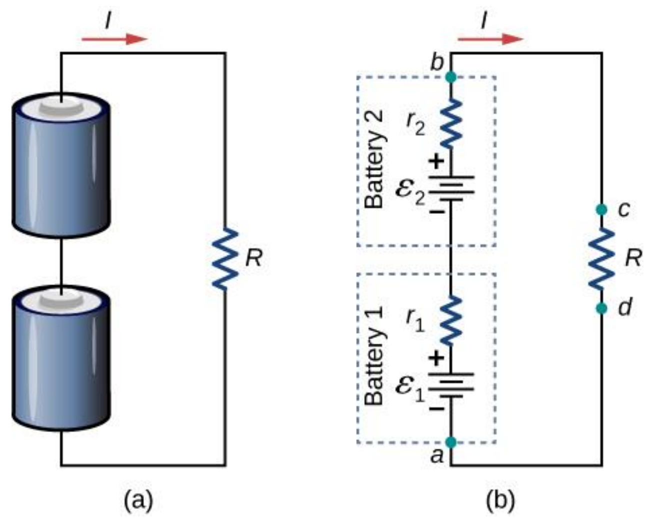


Fig.2.59 Series combination of Cells

Multiple Choice Questions

Q.1 The _______ law states that potential difference is directly proportional to current.
(a) Coulomb’s (b) Ohm's
(c) Kirchhoff's voltage (d) Lenz's

Q.2 According to Ohm's law
(a) Q = CV (b) V = IR
(c) R= ρ L / A (d) B=Ø/A

Q.3 According to Ohm's law, with the increase in potential difference current _______
(a) Increases (b) Decreases
(c) Remains constant (d) Fluctuates

Q.4 When current flows through a circuit, having 20Ω resistance, the amount of applied voltage is 100v then the current is:
(a) 4A (b) 5A
(c) 7A (d) 12A

Q.5 The resistance is directly proportional to the _______ of the conductor.
(a) Width (b) Breadth
(c)Thickness (d) Length

Q.6 Resistance is____ proportional to the cross section area of conductor.
(a) Directly (b) Inversely
(c) Not (d) Any of above

Q.7 The resistance of a conductor depends on the _______.
(a) Friction (b) Collision
(c) Colour (d) Temperature

Q.8 The Greek letter "Rho" denotes the _______
(a) Conductivity (b) Resistivity
(c) Malleability (d) Permeability

Q.9 Conductors _______ current to flow easily.
(a) Allows (b) stop
(c) Block (d) Conduct

Q.10 Conductors have _______ number of electrons in their structure.
(a) Small (b) Random
(c) Large (d) Swift

Q.11 The ability to conduct is _______.
(a) Electricity (b) Conductivity
(c) Resistivity (d) All of above

Q.12 The opposition offered to free electrons is _______.
(a) Conductance (b) Current
(c) Torque (d) Resistance

Q.13 Resistance adds up in _______.
(a) Series (b) Parallel
(c) Series parallel (d) any of above

Q.14 P.D stands for _______.
(a) Power Display (b) Power driven
(c) Potential difference (d) Proportional difference

Q.15 In series circuit of resistances, the voltage _______ in each resistor.
(a)Increases (b) Decreases
(c) Drops (d) Constant

Q.16 Current remains _______ in series circuits.
(a) Increasing (b) decreasing
(c) Constant (d) Oscillating

Q.17 Voltage remains _______ in parallel circuits.
(a) Increasing (b) decreasing
(c) Divides (d) constant

Q.18 Current _______ in parallel circuit of resistances.
(a) Increases (b) decreases
(c) Divides (d) Constant

Q.19 The rate of doing work is called _______
(a)Energy (b) Joule
(c) Voltage (d) Power

Q.20 The relationship for power is P = _______
(a) C×V (b) Q/t
(c) IR (d) VI

Q.21 1 hp = _______
(a) 742W (b) 746W
(c) 748W (d) 750W

Q.22 An amount of 100J energy is used for 5sec. Determine the power in Watts.
(a) 30W (b) 20W
(c) 40W (d) 15W

Q.23 The ability of a body to do work is called _______.
(a) Power (b) Potential
(c) Newton (d) Energy

Q.24 The algebraic sum of all voltage drops in a closed path is zero. This statement is
(a) KVL (b) KCL
(c) KBL (d) BCL

Q.25 The total current into a junction is equal to the total _______ out of that junction.
(a) Voltage (b) current
(c) Capacitance (d) inductance

Q.26 In the branch current method __ voltage and current laws are used.
(a) Lenz's (b) Ohm's
(c) Faraday's (d) Kirchhoff's

Q.27 In node voltage method _______ are founded at each node.
(a) Charges (b) Electrons
(c) Voltage (d) Currents

Q.28 Loop currents are _______ quantities.
(a) Analytical (b) Mathematical
(c) Differential (d) Positive

Q.29 There are _______ basic types of resistors.
(a) 2 (b) 4
(c) 6 (d) 8

Q.30 The _______ resistor does not change its value with applied voltage.
(a) Linear (b) Constant
(c) Non-Linear (d) Variable

Q.31 The resistor whose value cannot be changed is called a _____ resistor.
(a) Variable (b) Fixed
(c) Positive (d) Neutral

Q.32 _______ is a variable resistor.
(a) Rota meter (b) Rheostat
(c) Both a & b (d) none of above

Q.33 The thermistor is _______ device.
(a) Linear (b) Variable
(c) Non-Linear (d) Fixed

Q.34 LDR stands for _______.
(a) Light dependent resistor (b) Light-dividing resistor
(c) Light differential resistance (d) Light-doped rheostat

Q.35 DC source is basically of _______ types.
(a)Two (b) Four
(c) Six (d) Eight

Q.36 Mercury cell is _______ cell.
(a) Primary (b) Secondary
(c) Linear (d) Constant

Q.37 _______ cell cannot be recharged.
(a) Primary (b) Secondary
(c) Variable (d) Constant

Q.38 Every cell has a certain _______ resistance denoted as r_i.
(a) External (b) Internal
(c) Extrinsic (d) Intrinsic

Q.39 The combination of cells is called _______.
(a) Battery (b) Adapter
(c) Voltage level (d) Current level

Q.40 In order to provide higher currents, cells are connected in _______.
(a) Series (b) Parallel
(c) Cascaded (d) Any of above

ANSWER KEY

1.(b)	2. (b)	3.(a)	4.(b)
5.(d)	6.(b)	7.(d)	8.(b)
9.(a)	10.(c)	11.(b)	12.(d)
13.(a)	14.(c)	15.(c)	16.(c)
17.(d)	18.(c)	19.(d)	20.(d)
21.(b)	22. (b)	23.(d)	24.(a)
25.(b)	26.(d)	27.(c)	28.(b)
29.(a)	30.(a)	31.(b)	32.(b)
33.(c)	34.(a)	35.(b)	36.(a)
37.(a)	38.(b)	39.(a)	40.(b)

Short Questions

1. Define Ohm's law?
2. What is the resistance of a lamp if a current of 150mA flows through the lamp when 6 volts is applied to its terminals?
3. Describe the laws of resistance?
4. Define specific resistance?
5. Define conductor?
6. Define conductivity?
7. Define resistance?
8. Explain temperatures co-efficient of resistance?
9. Describe the resistance in series?
10. Describe the resistance in parallel?
11. What is the total resistance of four resistors connected in series if their individual values are 1MΩ, 1.5MΩ, 150KΩ and 50,000 KΩ?
12. Two resistors of 3.1Ω and 7.2Ω respectively are connected in parallel. Find the equivalent resistance?
13. Define power?
14. Define Watt?
15. Define energy?
16. Calculate the power of a 120V energy source that delivers 15A of current?
17. Calculate the voltage required to develop 10.5 KW with 5A current.
18. Define KCL?
19. Define KVL?
20. In any closed loop the algebraic sum of the EMFs applied is equals to the algebraic sum of the voltage drops in the elements?
21. List types of resistors?
22. A resistor has the following order of color codes: red, red, red, gold?
23. Describe power rating of resistor?
24. Name type of DC sources?
25. Describe series combination of cells?
26. Describe parallel combination of cells?

Long Questions

1. Describe ohm’s law and prove the equation V = IR?
2. Prove Laws of Resistances?
3. Explain the effects of temperature on resistance?
4. Explain resistances in series, in parallel and in series parallel combination?
5. Explain volt division rule and current division rule with examples?
6. Enlist the types of linear resistors and explain any one of them in detail?
7. Enlist the types of variable resistors and explain any one of them in detail?
8. Enlist the types of non-linear resistors and explain any one of them in detail?
9. How you can explain resistor color coding with examples?
10. Compare primary and secondary cells?
11. Describe the structure of mercury cell. Write down its working and its uses?
12. Describe the structure of silver oxide cell. Write down its working and its uses?
13. Describe the structure of nickel cadmium cell. Explain its working with the help of charging and discharging equation and its uses?
14. Describe the structure of lead acid battery. Explain its working with the help of charging and discharging equation and its uses?
15. How you can explain cells combination in series, parallel and series parallel?
16. How you can explain solar cell?

CHAPTER 03 ELECTROSTATICS

OBJECTIVES
After completion of this chapter students will be able to:
1. Understand Describe principle of electrostatic charges
2. Understand the effect of negative & positive charges
3. Understand the laws of electrostatics
4. Learn electrostatic induction & field strength
5. Learn about the properties of electric lines of force
6. Compare between electric lines of force and magnetic lines of Forces
7. Learn dielectric & dielectric strength/dielectric constant
8. Learn about the importance of dielectric & dielectric strength
9. Learn about capacitor, combination of capacitor and faults.
10. Learn color coding of capacitor.

3.1 ELECTROSTATIC

Electrostatic is the branch of science in which we study the behavior of the charges at rest

3.1.1 PRINCIPLE OF ELECTROSTATIC CHARGES:

Electrostatic is the branch of science in which we study the behavior of the charges at rest. There are two types of charges i.e. positive charge and negative charge. It a substance is excess of electrons, it is said to be negatively charged. If a substance has deficiency of electrons it is said to have positive charge.

When a comb is moved in dry air and is brought near small pieces of paper it attracts the pieces. It is due to fact that while combining the dry air, it is negatively charged and when it is brought near the pieces of paper, the internal distribution of the electrons and positive charge are rearranged. Positive irons come close to the negative charges of the comb and as a result, pieces of paper are attracted by the comb.

Some of the properties of the charges are as follows:

a) Similar charges repel each other
b) Opposite charges attract each other
c) Positive and negative charges are produced in its excited state. Normally the atoms of an element are electrically neutral.
d) The force of attraction or repulsion between the charges depends on the distance between them as well as the medium between them.

3.1.2 EFFECT OF POSITIVE & NEGATIVE CHARGE:

As discussed earlier a positive charge is produced when deficiency of electrons is produced and negative charge is produced due to the efficiency or excess of electrons. The distribution of electrons in the orbital rings determines the atom's electrical stability.

The number of electrons in the orbital ring farthest from the nucleus is very important. Normally electrons are filled by $2n^2$ where n is the number of their orbit. However the outermost orbit requires 8 electrons for stability or to act as filled orbit.

If the outermost orbit has 1, 2, or 3 electrons, which are called as valance electrons, in this case electrons can move from one atom to another atom easily and material is called as conductor. In general all the metals are good conductors with silver the best and copper second. Copper is used generally used for practical applications because it costs much less than silver.

If there are 4 electrons in the outermost shell, the atom can equally accept four electrons to fill the outmost shell or can lose four electrons to complete the shell. In this case we say that it will neither gain nor lose electrons but share with similar atoms. They have neither positive charge nor negative charge. Such materials are called as Semiconductors.

If the outermost electrons are more than four say 5, 6 or 7 then electrons are taken from the other atoms. When the molecules are formed by such atoms they have negative valency.

3.1.3 LAWS OF ELECTROSTATICS:

There is force of attraction or repulsion between the static charges. This force was verified by a scientist coulomb and is famous as coulomb's law of electrostatics. Similar charges repel each other and opposite charges attach each other.

Coulomb's law states that there’s a force (F) of attraction or repulsion between two point charges and this force is directly proportional to the product of charges and inversely proportional to the square of the distance between them.

Suppose two charges q1, q2 and are at a distance as shown in figure below:

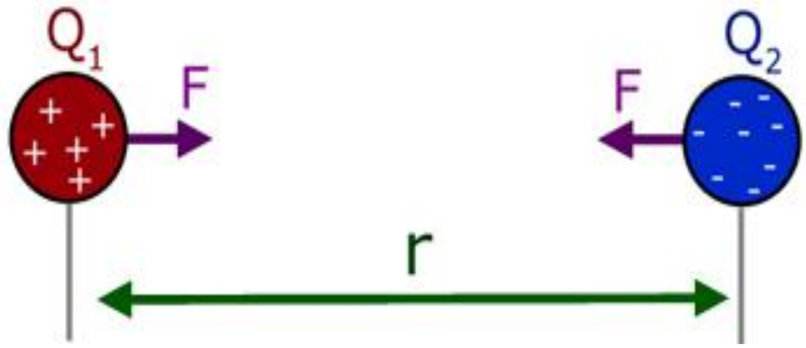


Fig.3.1 Laws of Electrostatics

According to the coulomb's law:

$$F \propto Q_1 Q_2$$

$$F \propto \frac{1}{r2}$$

$$F \propto \frac{Q1Q2}{r2}$$

$$F = k\,\frac{Q1Q2}{r2}$$

Where K is the constant of proportionality and its value depends on the medium between two charges.

It is value for free space is given as:

$$K = \frac{1}{4\pi \in_o} = 9 \times 10^9 \frac{Nm^2}{C^2}$$

ε_0 is called as permittivity of free space and its values is $8.85{\times}10^{-12} C^2/Nm^2$.So if the medium between the two point charges is free space we can write coulomb's law as.

$$F = \frac{1}{4\pi \in_o} \frac{Q_1 Q_2}{r^2}$$

If the medium between the two point charges is some other material of relative permittivity ε_r then coulomb's law can be mathematically modified as:

$$F = \frac{1}{4\pi \in_o \in_r} \frac{Q_1 Q_2}{r^2}$$

The medium between the point charges is called as Dielectric.

Problems on Coulomb's Law:

Problem No. 1

Two point charges of values +10m C and +20m C are placed at a distance of 100cm from each other in air. Find the force which they exert on each other.

Solution:

Q_1= +10µC

Q_2= +20µC

r=100cm=1m

$$F = \frac{1}{4\pi \in_o} \frac{Q_1Q_2}{r^2}$$

$$= \frac{9\times10^9 \times10\times10^{-6} \times20\times10^{-6}}{(1)^2}$$

=1.8 N

Problem No. 2 (Self-Test Problem)

Two point charges of values +6µC and –12µC are placed at a distance of 10cm on from each other. Find the force which they exert on each other when placed in air.

3.1.4 EFFECTRO SATATIC INDUCTION & FIELD STRENGTH:

Electrostatic Induction:

Electrostatic Induction is a phenomenon in which an un charged body is charged by bringing a charged body near to it.

Consider two balls of charges A & B which are attached to insulating bases. Ball A carries positive charge. Ball B is neutral. When ball A is brought near to it, the charges in the B are redistributed and negative charge comes closer side of the ball A and the positive charge contained in the ball B is repelled to the other corner.

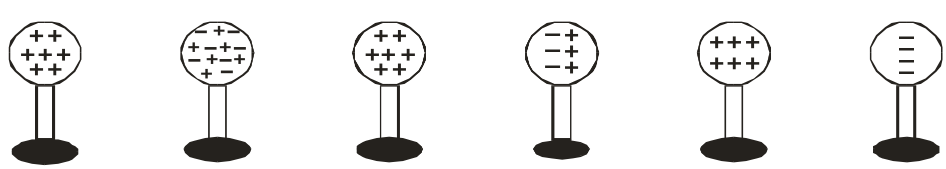


Figure (a) Figure (b) Figure (c)

Fig.3.2 Electrostatic induction

It is shown in figure (b). If we connect the ball B with ground then +ve charge will be ground. This redistribution of the charges is called as Electrostatic Induction.

Electric Field Strength:

The space around a charged body in which it can exerts a force of attraction or repulsion on a test unit charge is called as Electric Field.

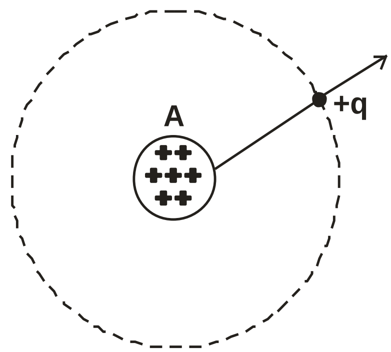


Fig.3.3 Electric Field Strength

Consider a positive charge A as shown in figure and a test unit charge q is placed near it. Due to equal nature of charge it will exert a force of repulsion F as shown in the figure. If we move away from the field charge A, then the force of repulsion will go on decreasing. There will be a certain particular point up to which this force can be experienced. If we draw a circle at this point around the charge A, the whole region will be the Electric Field.

The electric field strength at a point in an electric field is defined as the force experienced by a unit positive charge placed at that point. It is denoted by E. Mathematically,

$$E = \frac{F}{q}$$

The unit of E is Newton /Coulomb.

The direction of the electric field strength is the same as the direction of force F. The electric field strength is also called as Field Intensity.

Now F = Eq

Electric field intensity for parallel plate capacitor with potential difference V, and with distance between the plates d can also be given by:

$$E = \frac{V}{d}$$

Where V is the potential and d is the spacing of the parallel plate capacitors.

3.1.5 PROPERTIES OF ELECTRIC LINES OF FORCE:

The electric lines of force are a path around a charge along which a sample unit charge will move in the electric field. Various lines of forces are shown below:

Properties of electric lines of force are listed below.

i. The electric lines of force start from positive charge and end on a negative charge.
ii. Two lines of force do not cross at any point.
iii. The lines of force are perpendicular to the surface of a conductor.
iv. There are no lines of force inside a charge.
v. If the lines of force contract longitudinally, identifies that the charges are opposite.
vi. If the lines of force expand laterally, than it shows that the two charges are similar.

3.1.6 COMPARISION BETWEEN ELECTRIC LINES OF FORCE & MAGNETIC LINES OF FORCE:

Comparison of Electric lines of force and magnetic lines of force is as follows:

Electric Lines of Force	**Magnetic Lines of Force**
1. Electric lines of force start from the +ve charge and end at –ve charge.	1. Magnetic lines of force start from north pole and end at South pole.
2. No. two lines intersect each other.	2. No two lines intersect each other.
3. No electric lines of force are present inside the conductor.	3. No magnetic lines of force are present inside the magnet.
4. Two similar charges repel each other and opposite charges attract each other.	4. Two similar poles repel each other and opposite poles attract each other.
5.The total no. of lines of electric force present at a point is called as Electric Flux and denoted by Ø.	5. The total no. of lines of force present at a point in a magnetic field is called as Magnetic flux.

6. For similar charges, electric lines of force expand laterally.	6. For similar poles, magnetic lines of force expand laterally.

Table 3.1

3.1.7 DIELECTRIC, DIELECTRIC STRENGTH AND DIELECTRIC CONSTANT:

Dielectric:

The insulating material placed between the two charges or the two plates of a capacitor is called as Dielectric. By inserting the dielectric between the charges, the capacity of storing the charges is increased by the redistribution of charges in the Dielectric. It is called as polarization of the dielectric.

Suppose a parallel plate capacitor and a dielectric is placed between the plates of the capacitor. The surface of the dielectric adjacent to the positive plate acquires negative charge. The surface of the dielectric which is adjacent to the negative plate acquires positive charge. This redistribution of the charges inside the molecules of the dielectric is called as Polarization

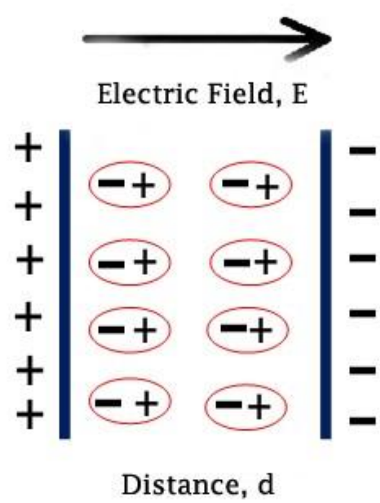


Fig 3.5 Polarization

Dielectric Strength

Dielectric strength is the maximum amount of the voltage applied to dielectric which it can withstand without breaking down.

Voltage up to less than this value is safe to use for the dielectric. Voltages more than this value applied to dielectric will cause damage to the dielectric. Dielectric strength is measured in volts/mil (1 mil=0.001 inch).

Typical values of dielectric strength for various materials are tabulated below:

Sr. No.	**Material**	**Dielectric Constant**
1	Air	75
2	Oil	380
3	Bakelite	400
4	Glass	3000
5	Mica	5000

Table 3.2

Dielectric Constant

The ability of dielectric to establish an electric field is called as its Dielectric Constant or permittivity. It is denoted by ε.

In case air is a dielectric then it is denoted by ε_0. The value of ε_0 is 8.85×10^{-12} F/m (Farad/meter). If some other material than air is used as dielectric than dielectric constant is termed as Relative Permittivity and is denoted byε_r.ε_0 and ε_r are related by the relation:

$$\varepsilon = \varepsilon_0\varepsilon_r$$

Typical values of relative permittivity of some materials are listed Table 3.3 below:

Sr. No.	**Material**	**Dielectric Constant** (ε_r)
1	Air	1
2	Oil	2.5
3	Bakelite	5.0
4	Glass	4.5
5	Mica	2.0

3.1.8 IMPORTANCE OF DIELECTRIC AND DIELECTRIC STRENGTH:

i. Dielectric is used to increase the charge storing ability of the capacitor. In case of using a dielectric, the charge storing ability of the capacitor increases due to polarization.

ii. Dielectric strength specifies the voltage rating of the capacitor for a particular design or application. If we use the capacitors of lower dielectric ratings it will be burnt out on use.

3.1.9 CAPACITOR & CAPACITANCE:

Capacitor

Capacitor is a device which is used to store electric charge. A simple capacitor consists of two parallel metal plates separated by an insulator which is called as dielectric. One plate is positively charged and other plate is negatively charged. The insulating material can be paper, mica, ceramic, plastic or glass etc. It is shown in figure below.

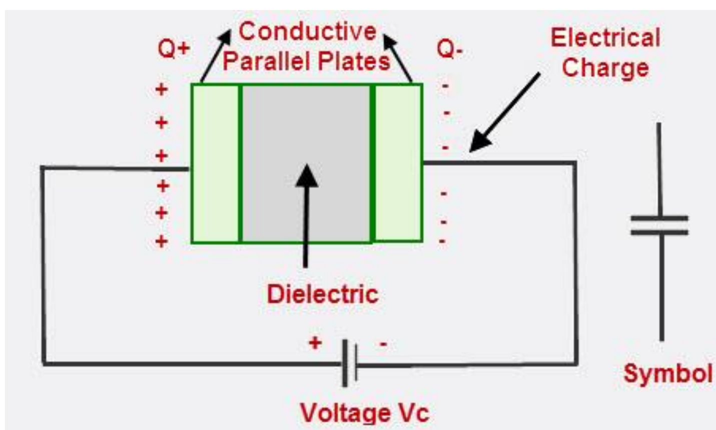


Fig.3.6 The capacitor

The plate which is connected to the positive terminal of the battery acquires positive charge and the plate which is connected to negative plate acquires negative charge. It should be noted that no current flows between the plates because of the dielectric present. Also the charges remain stored on the plates even if voltage source is removed. If we short the two terminals charge will be discharged.

Capacitance

In parallel plate capacitor if has been observed that:

$$Q \propto V$$
$$Q = \text{Cont} \times V$$
$$Q = CV$$

Where C is a constant and is called as the capacitance of the capacitor. The total capacity of strong the charge of a capacitor is called its capacity.

Since $C = \frac{Q}{V}$

So we can also define capacitance as the ratio of charge to the voltage applied. If a capacitor stores 1 coulomb of charge when the potential differance applied to its plates is 1 volts, than its capacitance will be 1 Farad.

Problems on the Formula Q = CV

Problem: 1

A capacitor stores 40mC when 20V are applied across its plates. What is its capacitance?

Solution:

$$Q = 40\mu C = 40 \times 10^{-6} \text{ Coulomb}$$
$$V = 20 \text{ volts}$$
$$Q = C\,V$$
$$C = \frac{Q}{V} = \frac{40\mu C}{20} = 20\mu F$$

Q.2: Problem (SELF TEST)

Find the voltage across a 500µF capacitor which is storing 1m C of charge.

Q.3: Problem (SELF TEST)

A 1pF capacitor is applied to 220 volt supply. Find the amount of the charge stored.

3.1.10 BREAK DOWN VOLTAGE:

The maximum value of the voltage at which a dielectric breaks down is called as break down voltage. If we apply voltage equal or greater than breakdown the dielectric will be damaged and capacitor will be damaged. In properly designed circuit and circuit implementation proper voltage should be taken into account.

3.1.11 CAPACITANCE OF PARALLEL PLATE CAPACITOR:

Consider a parallel plate capacitor as shown in figure below. It has two equal plates separated by distance d. If one plate has charge +Q than other plate has charge –Q.

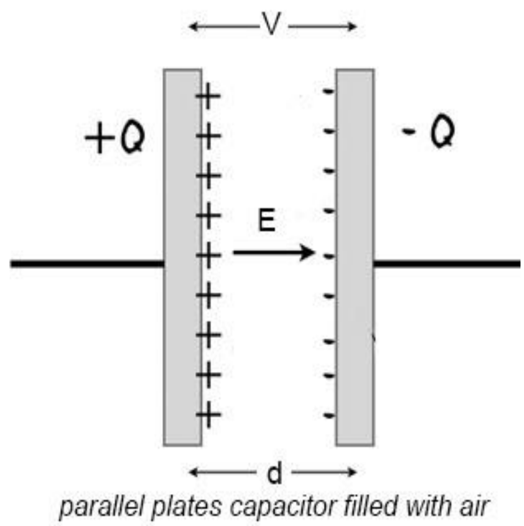


Fig.3.7Capacitance of Parallel Plate Capacitor

Suppose the dielectric between the two plates is air having permittivity ε_0. Suppose the area of one plate is A.
Then,

Charge density= $\sigma = \frac{Q}{A}$ ------ (1)

For the above capacitor we have the field strength E as

$E=\sigma/\varepsilon_0$ ------ (2)

Put σ from (1) in (2)

$E=Q/\varepsilon_0 A$ ------ (3)

For parallel plate capacitor, also

$E=\Delta V/d$ ------ (4)

Comparing (3) to (4)

$$\frac{\Delta V}{d} = \frac{Q}{\epsilon_0 A}$$

$$\Delta V = \frac{Q}{\epsilon_0 A} d \qquad \text{------ (5)}$$

Since $C = \frac{Q}{V}$

So
$$c=\frac{Q}{\Delta V}=\frac{Q}{\frac{Q}{A\in_o}\times d}$$

$$=\frac{\cancel{Q}\times A\in_o}{\cancel{Q}d}$$

$$C=\frac{A\in_o}{d}\qquad ----------\ (6)$$

This is the value of the capacitance of a parallel plate capacitor. So if we know the area of one of the plates and the distance between the plates, capacitance C can be found.

If we put some material between the plates of the capacitor as dielectric of dielectric constant ε_r then capacitance of the parallel plate capacitor is given by:

$$C'=\frac{\in_o\in_r A}{d}$$

$$C=\frac{A\in_o}{d}$$

$$C'=\frac{\in_o\in_r A}{d}$$

<u>Problem No.1</u>

Determine the capacitance of two parallel plate capacitors, having surface area 10cm^2 and separated by 0.01cm by a material of relative permittivity 12.

Solution:

A $= 10\ cm^2$

$= 10 \times (0.01)^2$ m2

d $= 0.01\ cm^2 = 0.0001\ m^2$

$\in_r = 12$

$\in_o = 8.85\times10^{-12} F/m$

$$C=\frac{\in_o\in_r}{d}A$$

$$=\frac{8.85\times10^{-12}\times12\times10^{-3}}{10^{-4}}$$

$$=106\times10^{-11}=1.06\times10^{-9}F$$

3.1.12 TYPES OF CAPACITORE:

There are two major types of capacitors

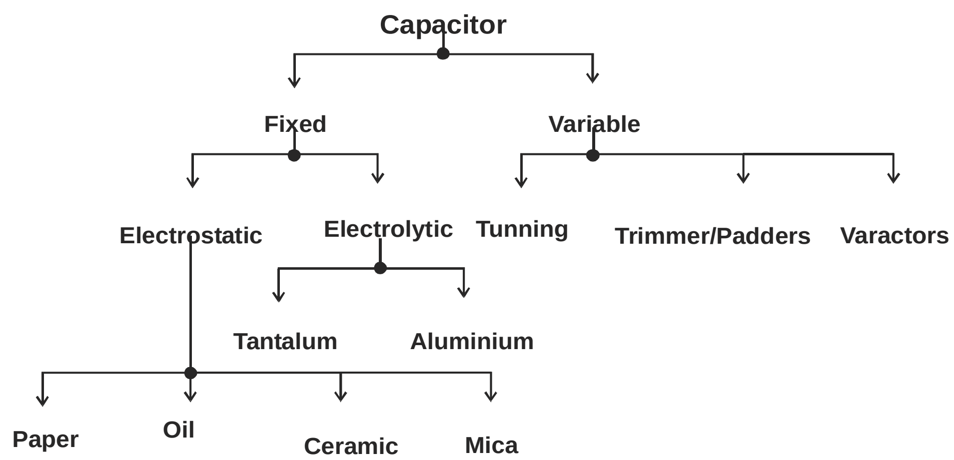
1. Fixed Capacitors
2. Variable Capacitors

Fixed Capacitors:

Fixed capacitors are defined as the capacitors whose capacitance values cannot be changed.

There are two types of fixed Capacitors.

i. Electrostatic Capacitors
ii. Electrolytic Capacitors



Electrostatic Capacitor

Electrostatic capacitors are made of two thin metal plates between which papers, mica, ceramic, oil etc. is used as dielectric. Such capacitors have no issue of polarity i.e., can be connected in the circuit in either direction. There are different types of electrostatic capacitors.

i. Paper Capacitor:

In paper capacitor two then aluminum plates are separated by dielectric which is paper or oil dipped paper. Aluminum plates are called as metal foils. These are made for the ranges of 0.001mF with voltage up to 2000V. These are made in the form of cylinders and used for high frequency application.

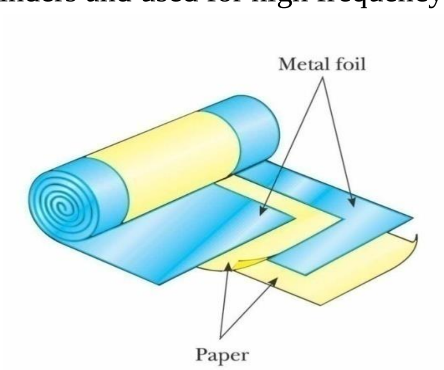


Fig.3.8 Paper capacitor

ii. Mica Capacitors:

Mica capacitors are made as stacked foil and silver-mica. These are available for the capacitance values ranging from 1pF to 0.1mF and voltage ratings up to 2500V.

Stacked Mica capacitors are made by combining two then sheets of tin or copper separated by mica and repeating this arrangement for greater values of capacitance. The final assembly is closed in an insulating material such as plastic or Bakelite. It is shown in figure below.

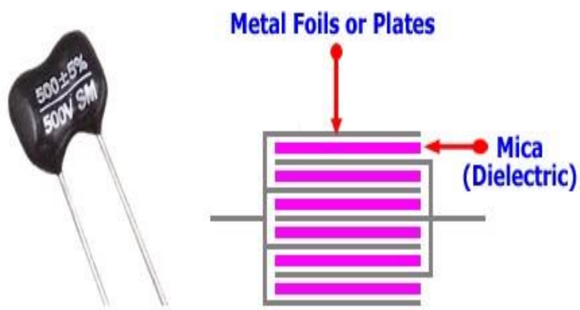


Fig.3.9 Mica capacitor

Silver mica type is same as stacked mica type, except in the silver mica capacitor, the silver film is deposited directly on the dielectric mica compared with tin or copper.

These capacitors are available n capacitance values ranging from 5pF to 10mF for 500V.

iii. Oil Capacitor

In the oil capacitor or oil filled capacitors, the dielectric used is oil filled or impregnated paper. These capacitors are used to acquire very large values of capacitances and in are used for industrial applications like filtering, arc suppression, power factor correction, start of ac motor, voltage regulation, voltage multiplications etc.

Fig.3.10 Oil capacitor

Ceramic Capacitors

In ceramic capacitors ceramic is used as dielectric material and thin film of silver is deposited on both sides of electric.

These capacitors are made in the shape of disc end tabular form as shown in figure below.

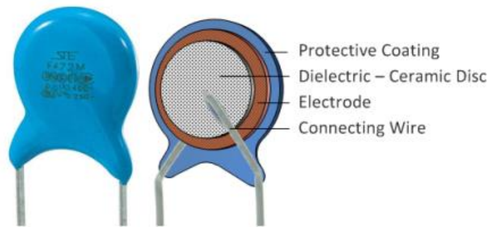


Fig. 3.11 Ceramic capacitor

Ceramic capacitors have large dielectric constant ε_r=1200. In very small size, a very large value of the capacitance can be achieved for the ceramic capacitors. Ceramic capacitors are economical and have a large capacitance in small package and can have very good high frequency response and frequently used for electronics applications.

<u>Electrolytic Capacitors</u>

Electrolytic capacitors are polarized type of capacitors. In these capacitors are plate is positive and the other plate is negative. In electrolytic capacitors we used some form of the electrolyte as dielectric. These capacitors are designed to achieve high value of capacitance i.e. up to 200,000 mF.

(i) Tantalum Capacitors
(ii) Aluminum Capacitors

These capacitors consist of two foils of aluminum or tantalum separated by a paper which is dipped with electrolyte. Frequently ammonium borate is used as electrolyte. During the manufacturing an electrochemical reaction is induced which cause an oxide layer to be produced on the inner surface of the positive plate. This oxide acts as dielectric.

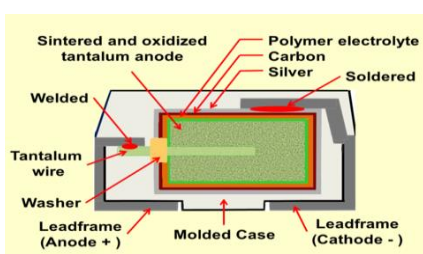


Fig.3.12 Tantalum Capacitors & Aluminum Capacitors

<u>Variable Capacitors</u>

Variable capacitors are whose values can be charged over a fixed range. In these capacitors different components can move to vary the effective area due to which capacitance varies. Dielectric materials can be air, mica or ceramic etc.

i. Tuning Capacitor (or Air Capacitor/Ganged Capacitor)

The variable capacitors using air as dielectric are called tuning or ganged or air capacitor. These capacitors consist of two sets of metal plates and air is used as dielectric. It is shown in figure below.

Fig.3.13 Tuning capacitor

In tuning capacitors, one set of plate in fixed and is called as stator while the plate is moving and is called as Rotor. Stator and rotor are separated by a very small air gap. The moving plate is rotated with the help of a knob connected to it. As the plate moves, the effective area between the plates varies, which results in the variation of the capacitance. If the two plates completely overlap, the capacitance will maximum.
When many such plates are grouped together it is called as Ganged Capacitor. These capacitors are used in tuned oscillators.

ii. Trimmer

A trimmer is a variable capacitor in which the two metal plates are separated by air or mica or ceramic slab as the dielectric. The spacing between the two plates can be charged by means of an adjustable screw attached to it. By moving the screw inward or outward with the help of a screw driver, the capacitance can be varied. Trimmers can be made from 10pF to 500pF values.

Fig.3.14 Trimmer capacitor

iii. Varactors

Varactor is a type of variable capacitor in which the capacitance is changed by changing the voltage applied to the terminals of the capacitor. Varactor is also called as voltage variable capacitor diode (VVC).
Its range is in pF and is used for automatic frequency control device. The length of the dielectric changes by the variation of voltage and resulting in the change of capacitance. It is shown in figure 5.4

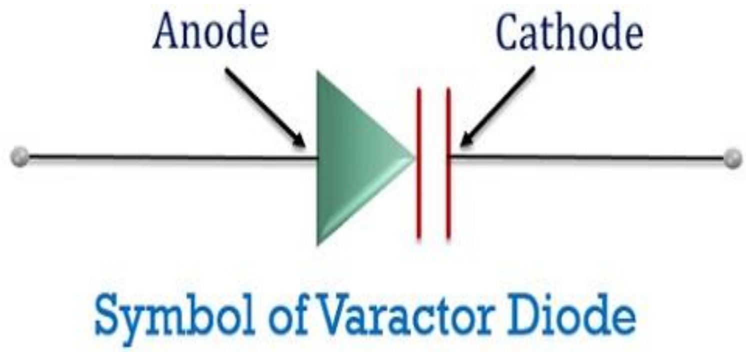


Fig.3.14 Varactor

3.1.13 USES OF CAPACITORS:

Capacitors are used to block the dc voltage and to allow pass the ac signal. If a dc is applied to a capacitor it gets charged at this value. Capacitors are used in variety of applications. Some are summarized as follows.

a) Coupling
b) By passing and filtering of ac signal.
c) Power factor improvement.
d) In resonant circuits for tuning frequencies.
e) Voltage multiplier circuits.
f) In communication systems like wireless, Radar, Transmitters and modulation etc.
g) Electronics circuits.
h) Radio, T.V sets, Computers.

3.1.14 CALCULATE THE TOTAL CAPACITANCE IN SERIES IN PARALLEL AND SERIES-PARALLEL COMBINATION:

Capacitors in Parallel

Consider three capacitors C_1, C_2 and C_3 connected in parallel across a voltage source V as shown in figure below.

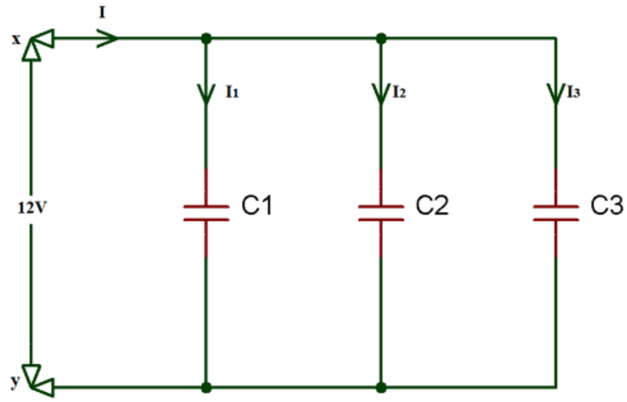


Fig.3.15 Capacitors in parallel

It is evident from the figure that one plate of each capacitor is connected to positive terminal of the battery and other plates are connected to negative terminal of the battery.

So the potential difference across the plates of the capacitor is V. Since capacitors are connected in parallel so the charges on the capacitors will be different. Let Q_1, Q_2 and Q_3 be the charges on the capacitors C_1, C_2 and C_3 respectively then.

Total charge=$Q = Q_1 + Q_2 + Q_3$

Since $Q=CV$

So $Q_1 = C_1V$

$Q_2 = C_2V$

$Q_3 = C_3V$

And $Q = C_{equ}\, V$

Therefore $Q = Q_1 + Q_2 + Q_3$

$C_{equ}\, V = C_1V + C_2V + C_3V$

$V \times C_{equ} = V \times (C_1 + C_2 + C_3)$

$C_{equ} = C_1 + C_2 + C_3$

When the capacitors are connected in parallel, the total capacitance is equal to the sum of the capacitances of individual capacitors.

Capacitors in Series

Suppose three capacitors C_1, C_2 and C_3 are connected in series to a power supply V as shown in figure below:

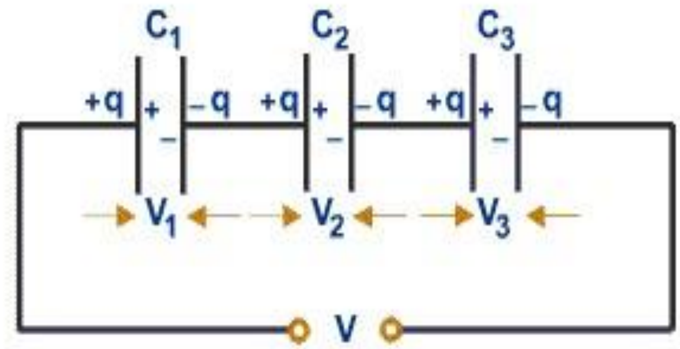


Fig.3.16 Capacitors in series

In this case there will be only one path for the current to flow through the capacitors and so the charges on the capacitors C1, C2 and C3 will be the same. However, in this case the voltage across each capacitor will be different and say it is V1, V2 and V3.

So $Q = C_1V_1$, $Q = C_2V_2$, $Q = C_3V_3$ and $Q = C_{equ}V$

According to Kirchhoff's voltage law:

$$V=V_1 + V_2 + V_3$$

$$\frac{Q}{Cequ} = \frac{Q}{C1} + \frac{Q}{C2} + \frac{Q}{C3}$$

$$\frac{1}{Cequ} = \frac{1}{C1} + \frac{1}{C2} + \frac{1}{C3}$$

So the reciprocal of the equivalent capacitance of the series combination is equal to the sum of the reciprocals of the individual capacitances connected in series.

<u>Series Parallel Combination of Capacitors</u>

If we connect some of the capacitors in series and some in parallel then it is called as series parallel combination. We apply the results of series and parallel circuits to simplify the circuit.

<u>Numerical Problems:</u>

Problem No. 1

Three capacitors 10 µF, 20 µF and 30 µF are connected in parallel to a supply of 20 Volts. Find the total capacitance.

Solution:

$C_1=10\mu F$, $C_2=20\mu F$, $C_3=30\mu F$

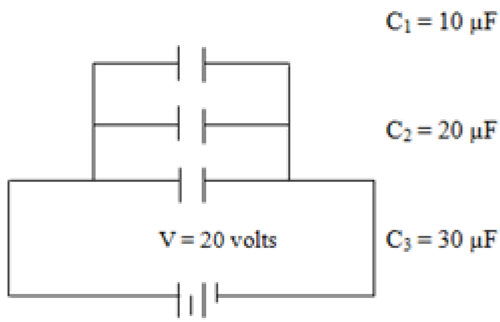


Fig: 3.17 Three Capacitors in Parallel

C_{equ}= ?

C_{equ} $=C_1 + C_2 + C_3 = 10 + 20 + 30 = 60\ \mu F$

Problem No. 2

Three capacitors of 5μF, 10μF and 15μF are connected in series to a supply of 30 volt. Find equivalent capacitance and voltage drop across each capacitor.

Solution:

C_1 =5μF

C_2 =10μF

C_3 =15μF

V =30 volts

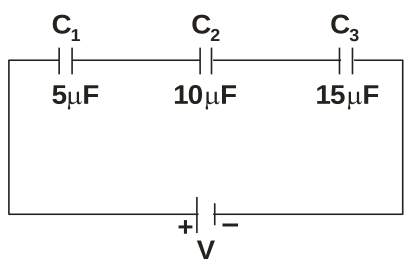


Fig.3.17 (b) circuit for problem No.2

$$\frac{1}{Ceqe} = \frac{1}{C1} + \frac{1}{C2} + \frac{1}{C3}$$

$$\frac{1}{5} + \frac{1}{10} + \frac{1}{15} = \frac{6+3+2}{30} = \frac{11}{30}$$

$C_{equ} = \frac{30}{11} = 2.73\ \mu F$

Q=CV = 2.73 × 30 = 81.90 μ Coulomb

$Q_1 = Q_2 = Q_3 = Q$ = 81.90 μ Coulomb

$V_1 = \frac{Q}{C1}$ = 81.90 μ $Coulomb/5\mu F$

=16.38 Volts

$V_2 = \frac{Q}{C2}$ = 81.90 μ $Coulomb/10\mu F$

$=8.19$ Volts

$V_2=\frac{Q}{C3}$ $= 81.90\ \mu\ Coulomb/30\mu F$

$=5.46$ Volts

Problem No. 3 (Self-Test Problem)

Two capacitors of 25mF and 50mF are connected in parallel to a voltage source of 25 volt. Find the equivalent capacitance and charge on each capacitor.

Problem No. 4

Find the equivalent capacitance of following combinations. Two capacitors C_1 = 6 µF and C_2 = 4 µF are connected in parallel, other two capacitors C_3 = 8 µF and C_4 = 12 µF are connected in parallel. These two combinations are connected in series. Calculate the total capacitance of the combination.

Solution:

C_1 = 6 µF and C_2 = 4 µF

C_3 = 8 µF and C_4 = 12 µF

Parallel Equivalent of C_1& C_2 is

$C_{equ1} = C_1 + C_2 = 6 + 4 = 10\mu F$

Parallel Equivalent of C_3& C_4 is

$C_{equ2} = C_3 + C_4 = 8 + 12 = 20\ \mu F$

These two combinations of C_{equ1}&C_{equ2} are in series

So,

$$\frac{1}{C_{equ}} = \frac{1}{C_{equ1}} + \frac{1}{C_{equ2}}$$

$$= \frac{1}{10} + \frac{1}{20}$$

$$= \frac{10+20}{10x20} \qquad = \frac{30}{200}$$

$$C_{equ} = \frac{200}{30} = 6.666\ \mu F$$

Problem No. 5 (Self-Test Problem)

Find the equivalent capacitance of following combinations.

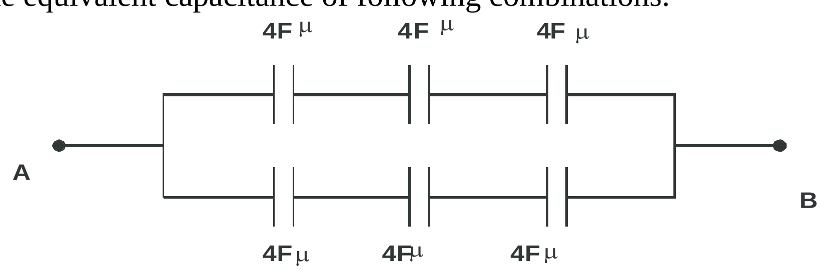


Fig.3.19 circuit for problem No.5

Problem No. 6 (Self-Test Problem)

Three capacitors are connected in a series to a 45 volts supply. The voltage across them is 10V, 20V and 15V and the charge on each capacitor is 2500mC. What is the value of the each capacitor?

3.1.15 ENERGY STORED IN CAPACITOR:

Consider a parallel plate capacitor as shown in the figure below.

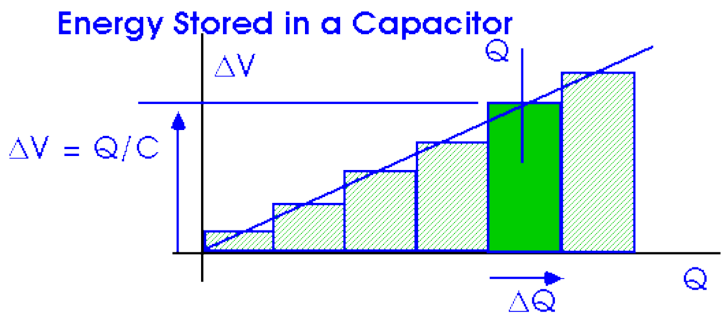


Fig.3.20 Energy stored in a Capacitor

It has two plates A & B. Let the charge on the positive plate is Q. In order to charge the capacitor, electrons are to be moved from one plate to another and as a result work will be done on the charge which will be stored in the form of energy.

If the capacitor is having capacitance C farads and current I flows for t seconds then $Q = I \times t$ coulomb will be moved or stored at one plate.

During this movement of the charge the potential difference across the capacitor will increase from 0 to V volts.

So the Average value of potential difference = $\frac{0+V}{2} = \frac{V}{2}$

The energy or work done in charging the capacitor is stored in the charged capacitor and is given by

$$\text{Energy} = W = Q \times V = Q \times \frac{V}{2} = \frac{VQ}{2}$$

Since $Q = C\,V$

$$\text{So energy} = \frac{VQ}{2} = \frac{V.\,CV}{2} = \frac{1}{2}CV^2$$

So the energy stored by the capacitor is $\frac{1}{2}CV^2$

3.1.16 COLOR CODING OF CAPACITORS:

Some capacitors have color coding on their body like resistors. The color coding procedure used for capacitors is the same as used for resistors.

Although presently the color coding of the capacitors is not a popular technique as majority of the capacitors types are marked with nominal capacitance value, tolerance, working voltage as well as the polarity for the polarized capacitors on their body.

Some of the techniques for the color coding for various capacitors are as follows:

Table3.4

CAPACITOR COLOR CODE

Color	Significant Figure	Decimal Multiplier	Tolerance	Voltage Rating(Volts)
Black	0	1		
Brown	1	10	1%	100
Red	2	100	2%	200
Orange	3	1,000	3%	300
Yellow	4	10,000	4%	400
Green	5	100,000	5%	500
Blue	6	1,000,000	6%	600
Violet	7	10,000,000	7%	700
Gray	8	100,000,000	8%	800
White	9	1,000,000,000	9%	900
Gold		0.1	5%	1000
Silver		0.01	10%	2000
No Color			20%	500

Values of 1st band combines with value of 2nd band and multiply with value of 3rd band.

3.1.17 TROUBLES IN CAPACITORS:

1. To test the capacitor with a multimeter, set the meter to read in the high ohms range, somewhere above 10k and 1m ohms. Touch the meter leads to the corresponding leads on the capacitor, red to positive and black to negative. The meter should start at zero and then moving slowly toward infinity.
2. Lightning can damage a capacitor, a compressor, the fan motor or the wires in the unit. Even a weak power surge can damage or destroy the capacitor, which can lead to compressor overload and subsequent failure. A capacitor that's leaking oil is a sure sign that it has a problem.
3. Electrolytic capacitors may become permanently damaged by excessive peak currents, which will definitely occur during short-circuit events. ... The electrolyte may vaporize along these small zones and damage to the insulating aluminum oxide layer may occur as well.
4. Electrolytic capacitor are polar by nature, and have positive and negative terminals clearly marked. If the polarity is reversed while connecting, the dielectric in the form of oxide layer is damaged. A heavy current flows, large amount of heat is generated, and capacitor is damaged.
5. One of the basic reason to explode capacitor is over voltage. ... If a high voltage greater than rated is applied across capacitor, its dielectric strength will break down and eventually capacitor will explode. # Electrolytic capacitors fail due to leakage or vaporization of the electrolyte inside.

Multiple Choice Questions

Q.1 The study of the behavior of the charges, when they are at rest is called
(a) Electricity (b) Magnetism (c) Electrostatics (d) Thermal

Q.2 The value of permittivity of free space is _______.
(a) $8.80 \times 10^{-12}\ C^2/\text{N}m^2$ (b) $8.85 \times 10^{-12}\ C^2/\text{N}m^2$
(c) $8.95 \times 10\text{-}^{12}\ C^2/\text{N}m^2$ (d) $9.0 \times 10^{-12}\ C^2/\ \text{N}m^2$

Q.3 The lines of force contract _______
(a) Longitudinally (b) Vertically
(c) Both a and b (d) None of above

Q.4 Electrolytic capacitors are also called _______ capacitors.
(a)Metal (b) Ceramic
(c) Composite (d) Polarized

Q.5 Variable capacitors are frequently used in _______ circuits.
(a) Timing (b) Radioactive
(c) Tuning (d) Transformer

Q.6 A simple parallel plate capacitor consists of _______ plates.
(a)Two (b) Three (c) Four (d) Six

Q.7 Capacitor uses a _______ material as separator.
(a) Inductor (b) Capacitance
(c) Dielectric (d) Charge

Q.8 For use at higher frequency _______ capacitor is preferable.
(a) Electrolytic (b) Ceramic (c) Polarized (d) Constant

Q.9 With the increase in distance between capacitor plates, capacitance is ___.
(a) Decreased (b) Increased
(c) Constant (d) Variable

Q.10 A capacitance of 0.01µF is large than _______
(a) 0.00001F (b) 100,000pF (c) 1000pF (d) 999F

Q.11 when the voltage across a capacitor is increased, the stored charge
(a)Increases (b) decreases
(c) Remain constant (d) none of above

Q.12 A 1µF, 2.2µF and 0.05µF capacitors are connected in series. The total capacitance is less than _______.
(A) 2.2µF (b) 0.05µF (c) 0.001µF (d) 0.002µF

Q. 13Four 0.02µF capacitors are in parallel. Total capacitance is _______.
(a) 0.02µF (b) 0.08µF (c) 0.04µF (d) 0.06µF

Q.14 which of the following capacitors can have the highest capacitance value?
(a) Mica (b) Paper
(c) Electrolytic (d) All equal

Q.15 A capacitor that stores 0.5C at 10 volts has a capacitance of ___Farads.
(a) 5 (b) 20 (c)0.05 (d)10

Q.16 A capacitance of 1000pF is smaller than _______.
(a) 0.01µF (b) 0.00000001F
(c) Both a & b (d) None of above

Q.17 The voltage rating of a capacitor is increased by _______.
(a) Increasing the plate separation (b) Both a & c
(c) Decreasing the plate separation (d) None of above

Q.18 Capacitance of a parallel plate capacitor increases with _______.
(a) Applied voltage (b) Smaller plate area
(c) Thinner dielectric (d) thicker dielectric

Q.19 The capacitance of a capacitor is not influenced by _______
(a)Plate thickness (b) Plate area
(c) Plate separation (d)All of above

Q.20 Coulomb's law is _______.
(a) F=k $\frac{Q1Q2}{d2}$ (b) F=k $\frac{Q1Q2}{d}$
(c) F=k $\frac{Q1Q2}{d3}$ (d) F=k $\frac{Q1Q2}{d4}$

Q.21 1Mil = _______ inch
(a) 0.01 (b) 0.001 (c) 0.02 (d) 0.002

Q.22 The relation C = _______.
(a) $\frac{Q}{t}$ (b) $\frac{Q}{v}$ (c) $\frac{Q}{L}$ (d) $\frac{Q}{A}$

Q.23 Which of the following is not a dielectric?
(a) Paper (b) Mica (c) Air (d) Alloy

Q.24 In capacitor color coding violet has the value ….
(a) 5 (b) 6 (c) 7 (d) 9

Q.25 No color in capacitor has _______ % tolerance.
(a) 5 (b) 10 (c) 15 (d) 20

ANSWER KEY

1.(c)	2. (b)	3.(a)	4.(d)	5.(c)	6.(a)
7.(c)	8.(b)	9.(a)	10.(c)	11.(a)	12.(b)
13.(b)	14.(c)	15.(c)	16. (c)	17. (a)	18. (c)
19.(a)	20.(a)	21.(b)	22.(b)	23.(d)	24.(c)
25.(d)					

Short Question

1. Define electrostatics?
2. State the coulomb's laws?
3. Define permittivity?
4. Define charge?
5. Describe electric field?
6. Define electric flux?
7. Describe electrostatic induction?
8. Describe electric field strength?
9. What is capacitor?
10. Describe capacitance?
11. Determine the capacitance of parallel plate capacitor having a plate area of $0.01m^2$& a plate separation of 0.02m. The dielectric is mica which has a dielectric constant of 5.0?
12. What is dielectric?
13. Describe di- electric strength?
14. Enlist types of electrostatic capacitors?
15. Define fixed capacitor?
16. Define variable capacitor?
17. What is capacitor’s tolerance?

Long Questions

1. Explain Coulomb's law of electrostatics?
2. Explain in detail the electrostatic induction and electric field strength?
3. Explain the properties of electric lines of force?
4. Compare electric and magnetic lines of force?
5. Explain capacitance of a parallel plate capacitor?
6. Enlist the types of electrostatic capacitors and explain any one of them?
7. Discuss in detail electrolytic capacitor?
8. Enlist the types of variable capacitors and explain any one of them?
9. Write down the uses of capacitors?
10. Write down the properties of capacitors connected in series?
11. Write down the properties of capacitors connected in parallel?
12. Describe capacitor color coding with examples?

Chapter 04 MAGNETISM & ELECTROMAGNETISM

OBJECTIVES
After completion of this chapter students will be able to:

1. **Learn about magnetism, magnetic line of force, flux, flux-density, permeability, Reluctance and their units**
2. **Learn Properties of magnetic lines of force & types of magnets.**
3. **Understand Magnetic properties of materials (Ferro, Para and dia-magnetic) magnetic induction.**
4. **Understand Electromagnetism.**
5. **Learn Electromagnetism, M.M.F. (AT) field intensity (H =AT/L) ampere turns/meter.**
6. **Understand & draw B-H curve and magnetic Hysteresis.**
7. **Learn Electromagnetic induction.**
8. **Understand Magnetic field around a current carrying conductor and solenoids cork screw and left hand rules.**
9. **Learn Force between two magnetic fields and motor action.**

4.1 MEGNETISM

Magnet

Magnet is a piece of metal which can attract iron or materials made with iron. When a bar magnet is freely suspended it points in the direction of North and South. The side which points towards the north is called as North Pole and the side which points towards south is called as South Pole. Two similar poles repel each other and opposite poles attract each other.
There are two types of magnet.

1. Natural Magnet 2. Artificial Magnet

Magnetism

It is the property of a magnet to attract iron or things made with iron towards itself.

Magnetic Field

The region or space around a magnet where the effects of magnetism on a test magnet or a compass needle can be detected is called a magnetic field.

4.1.1 LINES OF FORCE, FLUX, FLUX DENSITY, PERMEABILITY, RELUCTANCE AND THEIR UNITS:

Magnetic Lines of Force

The magnetic lines of forces are a path in a magnetic field along which a test magnet moves in a magnetic field.

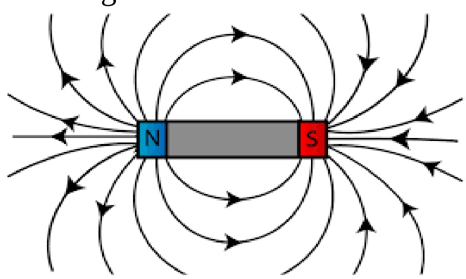


Fig.4.1 Magnetic Lines of Forces

Flux (ϕ)

Flux means magnetic flux. The total number of magnetic lines of force passing through a particular point is called as flux. It is denoted by φ.

Its unit is Weber. It is equal to 108 magnetic lines of force.

Flux Density (B)

Number of magnetic lines of force passing through per unit area is called as flux density. It is represented by B.

$$B = \frac{\varnothing}{A}$$

Its unit is Weber/m². 1 Weber/m² is also called as 1 Tesla.

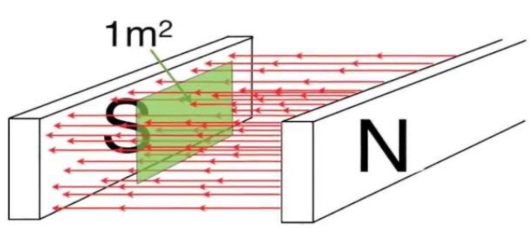


Fig.4.2 Flux Density

Permeability

The ratio of the magnetic flux density (B) to the magnetizing force (H) is called as permeability of the magnetic material and is denoted by μ.

$$\mu = \frac{B}{H}$$

The permeability of a material shows its magnetizing ability and depends on the nature of the material. The greater the value of permeability, more easily magnetic field can be produced in that material .We normally relates the permeability of a material relative to the permeability of free space. The permeability of free space is denoted by μ_o. The relative permeability is represented by μ_r

$$\mu_r = \frac{\mu}{\mu o}$$

Since μ_r is the ratio of two identical quantities so it has no units.

Reluctance ($\mathcal{R}$)

Reluctance is analog of resistance in the electric circuits. It is represented by $\boldsymbol{\mathcal{R}}$. It is opposition to the magnetic flux.

$$\mathcal{R} = \text{Reluctance} = \frac{\text{MMF}}{\varphi}$$

The unit of reluctance is ampere-turns per Weber (AT/Wb).

4.1.2 PROPERTIES OF MAGNETIC LINES OF FORCE:

i. The magnetic lines of force start from North Pole and end at South Pole.
ii. The no. of lines of force at a point represents the strength of the field. Larger no. of lines shows a strong and smaller lines corresponds a weak field.
iii. No two magnetic lines of force intersect each other.
iv. The magnetic lines of force are invisible.
v. If magnetic lines of force try to contract each other, then they start from north pole and ends at south pole i.e. they show different poles.
vi. Magnetic lines of force try to expand, they represent similar poles.

4.1.3 TYPES OF MAGNET:

Magnets are of following types:

1. Natural Magnets:

Natural magnets are found in nature in the form of stones. For example magnetite Fe_3O_4 has the magnetic properties. Our earth is also supposed to a very large magnet.

2. Permanent Magnets:

These are made from hard magnetic materials such as cobalt steel magnetized by induction in the manufacturing process. A very strong field is needed for induction in these materials. When the magnetizing field is removed residual induction makes the material a permanent magnet. A common PM material is alnico, a commercial alloy of aluminum, nickel and iron with cobalt, copper and titanium added to produce about 12 grades. The alnico V grade is often used for PM loud speakers.

Commercial permanent magnets will last indefinitely if they are not subjected to high temperatures, to physical shock, or a strong demagnetizing field. A permanent magnet does not become exhausted with use, as its magnetic properties are determined by the structure of the internal atoms and molecules.

Electromagnets:

Electromagnets are temporary magnets. If a current is passed in a wire conductor then a magnetic field is produced around the wire.

Consider a wire wrapped in the form of coil as shown in figure below, the current and its magnetic field become concentrated in a smaller space, resulting in a stronger field.

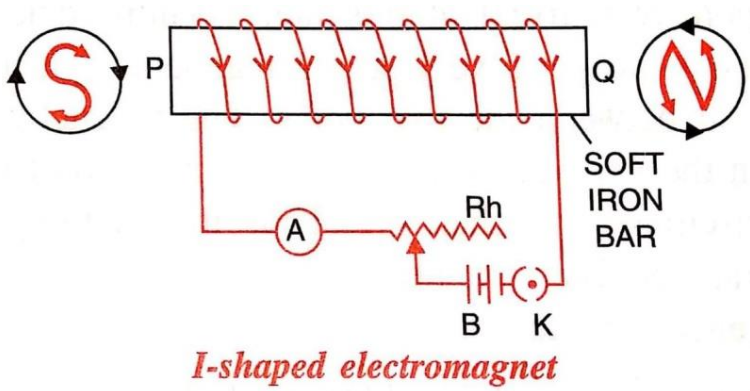


Fig.4.4arrangement for electromagnet

The direction of the north and South Pole of an electromagnet is determined by right hand rule.

Electromagnets are widely used in different application. Common applications of electromagnets are electric bell, relays, induction coils, transformers and measuring instruments.

4.1.4 MAGNETIC PROPERTIES OF MATERIALS:

Different properties of magnetic materials are as follows:

i. Two similar poles of a magnet repel each other and different poles attract each other.

ii. When a magnet is freely suspended in air it points in the direction of north and south. The side which is pointing in the direction of north is called as North Pole and the side which point in the direction of South is called as South Pole.

iii. When a magnet is broken in to pieces, at the center the separate pieces become independently.

4.1.5 TYPES OF MAGNETIC MATERIALS:

Materials can be classified as magnetic and non-magnetic Iron, Nickel and Cobalt are magnetic materials and are easily magnetized. Non-magnetic materials cannot be magnetized. Examples are air, glass, wood, paper, plastic and rubber etc.

Magnetic materials can be further divided into three types:

i. Diamagnetic material
ii. Paramagnetic materials
iii. Ferromagnetic materials

Diamagnetic Materials

These include bismuth, antimony, Copper, Zinc, and Mercury, gold and silver. The permeability is less than 1. They become weekly magnetized in the direction opposite to the magnetizing field.

The basics of all the magnetic effects are the magnetic field associated with electric charges in motion. The atoms of each substance consist of electrons which revolve around the nucleus and at the same time rotating and spinning about its own axis. These rotations and spin both give rise to magnetic field.

Since the atom consists of many electrons, so every electron will have its own magnetic field. The directions of the magnetic fields produced by these electrons are random. These fields may cancel each other or these fields can build up each other.

If the magnetic fields produced by the atoms cancel each other effect it is called as Diamagnetic Material.

Paramagnetic Materials

These materials include aluminum, platinum, manganese and chromium. The permeability is slightly more than 1.In paramagnetic materials the magnetic fields produced due to orbital motion of electrons and spin of electrons support each other. They become weekly magnetized in the same direction as the magnetizing field.

Ferromagnetic Materials

Ferromagnetic materials include iron, steel, nickel, cobalt, and commercial alloys such as alnico and Perm alloy. These materials become strongly magnetized in the same direction as the magnetizing field with high values of permeability from 50 to 5000. In ferromagnetic materials the orbital motion and spin motion produces magnetic field and this field is greatly strengthened by other atoms.

4.1.6 MAGNETIC INDUCTION:

The electrical effect of one body on another without any physical contact between them is called **Induction**. For example a permanent magnet can induce an un-magnetized iron bar to become a magnet without the two touching. The iron bar then becomes a magnet as shown in figure below.

It is due to the fact that the magnetic lines of force gathered by the permanent magnet make the internal molecular magnets in the iron bar line up in the same direction, compared with the random directions in the unmagnified iron. The magnetized iron bar then has the magnetic poles at the ends as a result of the magnetic induction.

It should be noted that the induced poles in the iron have opposite polarity from the poles of the magnet. Since opposite poles attract so the iron bar will be attracted towards the magnet. A magnet attracts any magnetic material towards itself due to Induction.

The two bars shown in above figure are not touching; even then the iron bar is in the magnetic flux of the permanent magnet. It is the invisible magnetic field that links the two magnetic fields. This idea of magnetic flux extending outward from the magnetic poles is the basis for many inductive effects in the ac circuits.

4.2 UNDERDSTAND ELECTROMAGNETISM:

When a current passes through a conductor, a magnetic field is established around the conductor. This magnetic field is surrounded along its full length. It can be verified by a simple experiment as shown below

4.2.1 ELECTROMAGNETISM:

When a current passes through a conductor, a magnetic field is established around the conductor. This magnetic field is surrounded along its full length. It can be verified by a simple experiment as shown below.

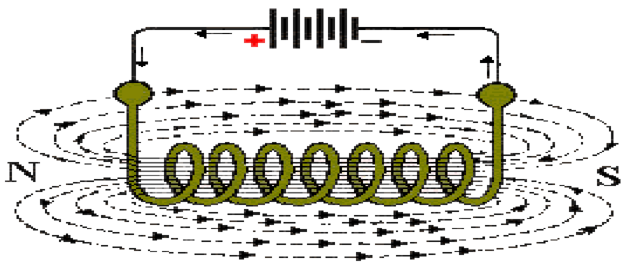


Fig.4.6 Arrangement for electromagnet

Consider a current carrying conductor wire and around this wire iron fillings are aligned in concentric rings as shown in the above figure. Since the magnetic field is invisible, however its effects can be seen easily. This effect of producing magnetic field by the current passing through the conductor is called as Electromagnetism.

4.2.2 MAGNETO- MOTIVE FORCE (M.M.F) :

The magneto motive force is analog of electromotive force for electric circuits. Magneto motive force is a force which produces magnetic flux in a magnetic circuit.

Mathematically MMF=NI

Where, I represents current and N is the number of turns.

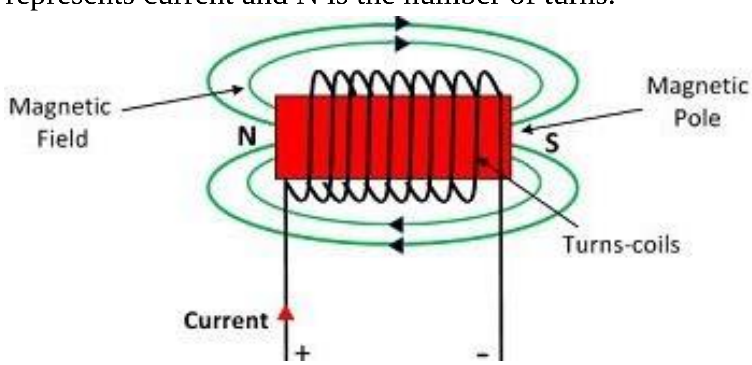


Fig.4.3 Magneto motive Force (MMF)

4.2.3 MAGNETIC FIELD INTENSITY (H=AT/L):

The magnetizing force is given by the formula

MMF=NI

Its unit is Ampere Turns.

The ampere turns or MMF specifies the magnetizing force, but the intensity of the magnetic field depends how long the coil is. At any point in the space, a specific value of the ampere turns must produce less field intensity for a long coil than for a short coil that concentrates the same NI.

The magnetic field intensity H is given by

$$H = \frac{NI(\text{Ampere Turns})}{l(\text{Meters})}$$

$$H = \frac{NI}{l}$$

This formula is for solenoid.

H= Intensity at the center of air core. With iron core H is the intensity through the entire core.

l=Length of the ends of the core or distance between poles at the ends of core.

4.2.4 MAGNETIC HYSTERSIS:

Hysteresis means a "lagging behind". In iron core of an electromagnet, the magnetic flux lags the increase or decrease in the magnetizing force. This property is called as hysteresis. The hysteresis results from the fact that the magnetic dipoles are not perfectly elastic. Once they are aligned by the external magnetizing force, the dipoles do not return exactly to their original position when the force is removed. The effect is the same as if the dipoles were forced to move against an internal friction between the molecules. Also if the magnetizing force is reversed in direction by the reversal of the current in an electromagnet, the flux produced in the opposite direction lags behind the reversed magnetizing force. It is shown in figure below.

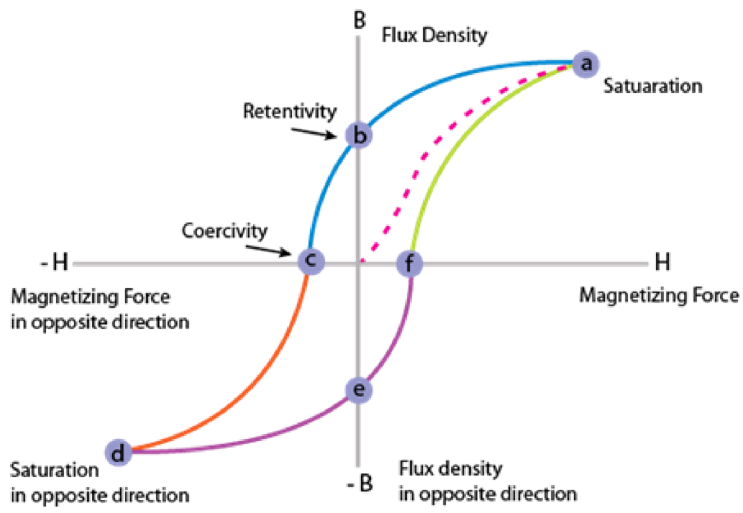


Fig.4.10 arrangement for electromagnet

The current starts from the zero at the center, when the material in unmagnified. The positive H values increases B to saturation at **+B max**. Next H decreases to zero but B drops to the value BR, instead of zero because of hysteresis. When H becomes negative B drops to zero. And continues to **$-B_{max}$** which is saturation in the opposite direction from **$+B_{max}$** because of the reversed magnetizing current. Then as the value of –H decreases, the flux density is reduced to –BR. Finally the loop is completed with positive values of H producing saturation at B_{max} again.

The curve does not return to the zero origin at the centre because of hysteresis. As the magnetizing force periodically reverses, the values of flux density are repeated to trace out the hysteresis loop.

The value of either $+B_R$ or $-B_R$ which is the flux density remaining after the magnetizing force has been reduced to zero is the residual induction of a magnetic material and also called as **retentively.**

When, the magnetizing force reverses thousands or millions of times per second as with rapidly reversing alternating current. The hysteresis can cause a considerable loss of energy. A large part of magnetizing force is then used just to overcome the internal friction of the molecular dipoles. The work done by the magnetizing force against this internal friction produces heat.

This energy wasted in heat as the molecular dipoles lag the magnetizing force is called **Hysteresis loss**.

For steel and other hard magnetic materials, the hysteresis losses are much higher than in soft magnetic materials like iron.

When the magnetizing force varies at a slow rate the hysteresis losses can be considered negligible. An example is an electromagnet with direct current that is simply turned on and off or the magnetizing force of an alternating current that reverses 60 times per second or less. The faster the magnetizing force changes, however the greater the hysteresis effect.

4.2.5 ELECTROMAGNETIC INDUCTION:

Electromagnetic induction is a technique in which current or EMF is induced in a conductor when it is moved in a magnetic field.

Suppose a conductor is moved in a magnetic field as shown in figure below. If the conductor is at rest there is no deflection in the galvanometer. Now if we move the loop conductor in one direction say from right to left at a constant speed in the magnetic field, the galvanometer indicates a deflection. Now if we reverse the direction of the movement of the conductor, then the direction of movement of the needle coil is opposite to the first case. This phenomenon of production of current or EMF is known as Electromagnetic Induction.

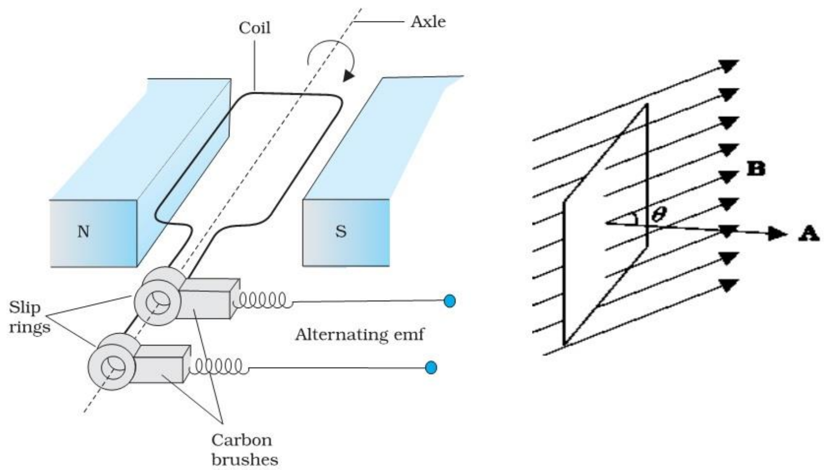


Fig.4.11 Electromagnetic induction

4.2.6 MAGNETIC FIELD AROUND A CURRENT CARRYING CONDUCTOR:

When current passes through a conductor a magnetic field is established around it. Consider a copper wire carrying a current I and is passed through a card board as shown in the figure below. Now we place a compass needle near the current carrying conductor. We move in the deflection of the needle and found circular paths along the current carrying conductor.

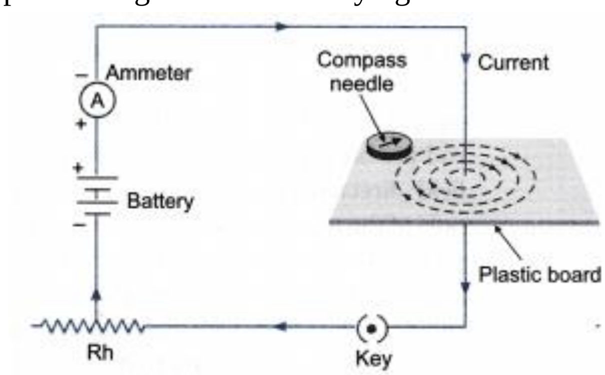


Fig.4.12 Magnetic Field around a Current Carrying Conductor

This shows that a magnetic field exists around the current carrying conductor. This field retains as long as the current continues to flow in the wire. The direction of the magnetic field can be determined by the right hand rule. This rule states that if the right hand thumb points in the direction of current and figures are allowed to curl the wire, the finger ends or tips will point in the direction of the lines of force.

4.2.7 INDUCTOR:

Inductor is a coil which can be formed by wrapping a wire on a core or without a core. It is shown in figure below. It is represented by L. the unit of inductance is Henry.

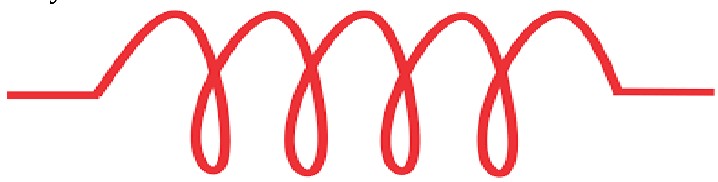


Fig. 4.13 symbol of inductor

When a current is passed through an inductor, an electromagnetic field is established around it. The inductor has the property that it maintains a steady flow of the current and it opposes an abrupt change in the current for an ac circuit, the voltage induced in the inductor is

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

The energy stored by the inductor in the magnetic field is given by

$W=\frac{1}{2} L\ I\ 2$

Inductors are of two basic type's i.e.

i. **Fixed Inductor**

The inductors whose values remain constant

ii. **Variable Inductors**

The inductors whose values can be varied

In order to improve the magnetic properties of the inductors we use core within the inductor. Different cores used are as follows

(i) Iron core (ii) Ferrite Core

Inductors are used in relays, in power supplies as filter, in frequency tuning circuits, for coupling etc.

FORMULA FOR INDUCTOR:

Consider an inductor of inductance L as shown in the figure below:

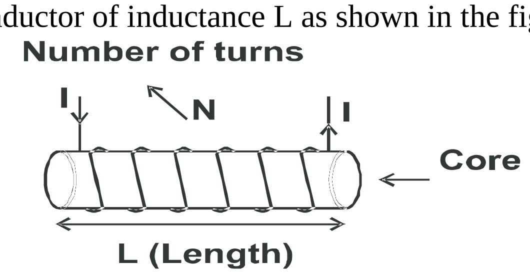


Fig.4.14 the inductor

The inductance of the material can be found by using the formula

$$L = \frac{\mu o \mu r A N^2}{\square}$$

Where A= Area of an inductor or coil core or air gap.

L= Length of core

N= No. of turns of coil

μ_r= Relative permeability of core material

μ_o= Permeability of free space.

SOLVE PROBLEMS USING THE FORMULA OF INDUCTOR:

Problem No.1

A magnetic circuit consisting of an inductor of 500 turns has air as the core 2 cm long and 10cm^2 in cross sectional areas, calculate the inductance.

Solution:

l =2cm = 2×10–2 = 0.02m

A=10cm2= 10×10–4= 0.001m2

N = 500

$\mu_r\ \mu_0 = \mu_0 = 1.26\times 01^{-6}$

$$L = \frac{\mu o \mu r A N^2}{\square}$$

$$= \frac{1.26\times10^{-6}\times0.0012\times(500)^2}{0.02}$$

L = 0.0189 Henry

Problem No. 2 (Self-Test Problem)

A magnetic circuit comprising of an inductor of 1000 turns and the length of the core is 0.01m, a cross sectional area of 0.014cm^2 and a permeability of 2200 μ Wb/ATm. Find its inductance.

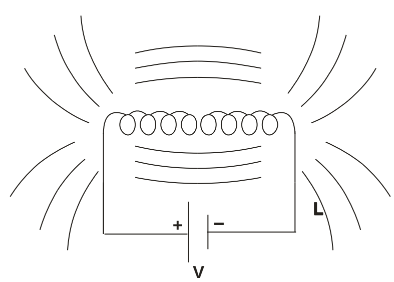


Fig.4.15 circuit for problem No.2

SOLENOIDS:

If a wire is wound round a cylindrical shaped core and is removed to make a wound coil without any core, then it is called as Solenoid. Core can be used in solenoids. When current is passed through this coil then magnetic field is produced. One end of the coil becomes North Pole and the other ends become South Pole. This magnetic field is very strong inside the solenoid and is negligibly weak outside the solenoid. The direction of the magnetic field can be found by the "Gripping Rule". If the coil is gripped in the right hand so that the fingers points in the direction of current than the thumb will point in the North direction. When a solenoid is bent into the shape of a circlet it is called a Toroid. It is shown in figure below:

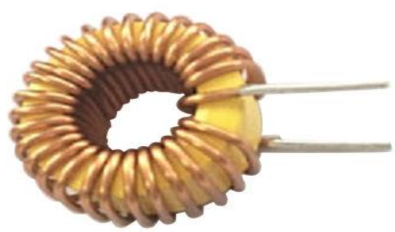


Fig.4.16 The solenoid

Solenoids are important because they can create controlled magnetic fields and are used as electromagnets. Solenoids have a variety of applications and used in transducers that convert energy into linear motion. Solenoids are used in solenoid valves in relays, hydraulic solenoid valves, electromagnets etc.

CORCK SCREW RULE AND LEFT HAND RULE:

When a current passes through a conductor coil, a magnetic field is produced around the conductor. The direction of the magnetic field can be found by following rules

Corkscrew Rule

If a corkscrew is rotated such that the direction of the screw is the same as the direction of the current flow through the conductor, the direction of the rotation indicates the direction of magnetic field i.e. magnetic line of force around the conductor.

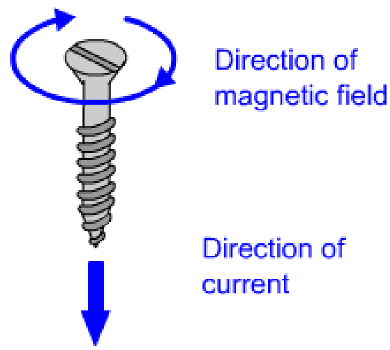
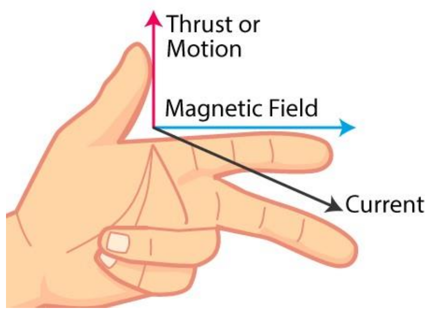


Fig.4.17 Corkscrew rule

Left Hand Role

Left hand rules states that if the left hand is stretched with the thumb pointing in the direction of flow of the current through the conductor the finger curl shows the direction of the magnetic field i.e. magnetic lines of force.



4.2.8 FORCE BETWEEN TWO MAGNETIC FIELDS AND MOTOR ACTION:

Consider a magnetic field due to the permanent magnets as shown in figure (a) below.

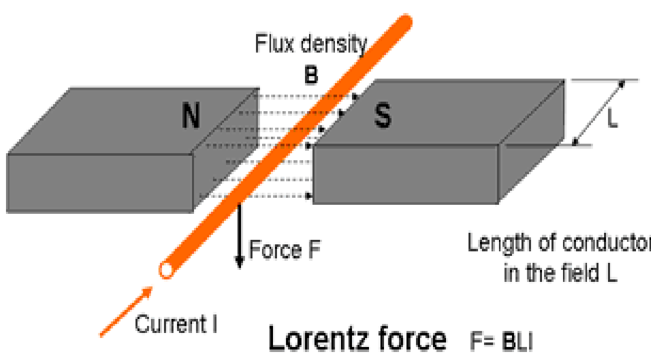


Fig4.18 (a) **Force between two Magnetic Fields and Motor action**

Magnetic lines of force start from the North Pole and end at the South Pole. It is also evident that when current passes through a conductor a magnetic field is produced around the conductor. It can be shown in figure (b).

Now if we place this current carrying conductor in the magnetic field shown in figure 4.18(c) a then the resultant field can be shown in figure (c) below:

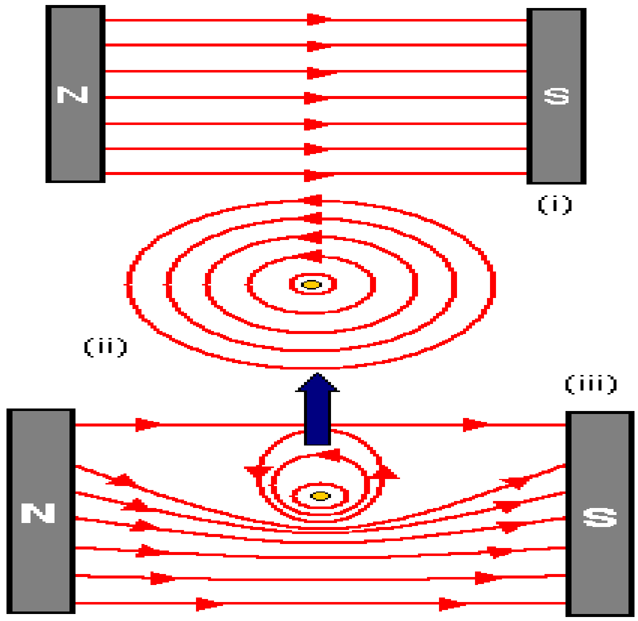


Fig.4.18 (b) line of forces   Fig.4.18 (c) conductor placed in line of forces

It is evident that the field is strengthened in the space above the conductor and weakened below it.

Now if either the current in the conductor or the direction of the magnetic field between the poles is reversed, the force acting on the conductor is also reversed and tends to move the conductor in opposite direction.

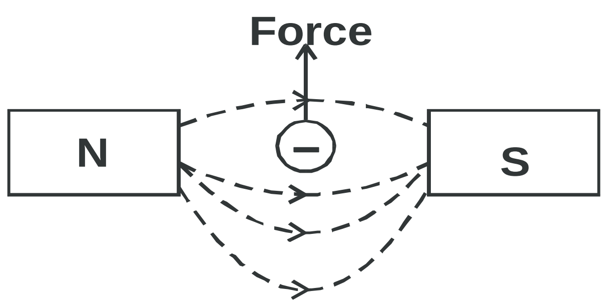


Fig.4.18 (d) line of forces

The direction of the motion of the conductor can be found from Fleming’s left hand rule. This rule state that first finger, the seemed finger and the thumb of the left hand are stretched so that they are at right angles to each other and the first finger points in the direction of magnetic field (from North to South), the second finger in the direction of the current in the conductor then the thumb of the left hand will point in the direction of motion of the conductor.

This very principle is used in the motor action. A current carrying conductor is placed in the magnetic field as shown in figure (e) below. Two conductors A & B are shown in the figure. Force on conductor A is such that to move the conductor upwards, while force on the conductor B tends to move it downward.

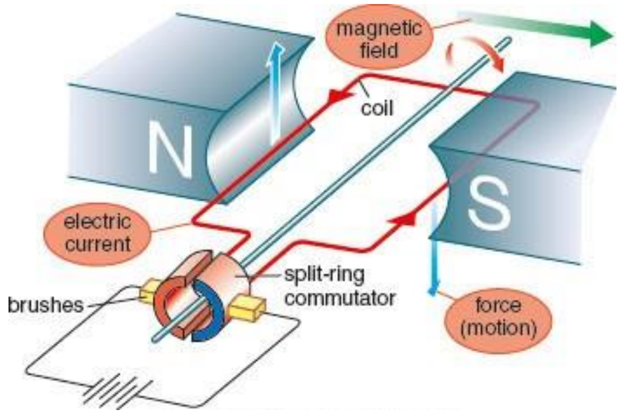


Fig.4.18 (e) motor action

Due to these forces, the loop tends to move in the clockwise direction. This is the basic motor action. When the magnetic neutral position is reached, the motor commentator reverses the connections of the supply to the loop and the current in the loop is resultantly reversed and loop continues the motion.

4.2.9 FARADAY'S LAW OF ELECTRO-MAGNETIC INDUCTION:

When a conductor is moved in a magnetic field, then the flux linked to the conductor charges at every instant. Faraday observed that this changing magnetic field induces voltage in the conductor. The magnitude of the emf can also be found by using Faraday's Laws. There are two laws.

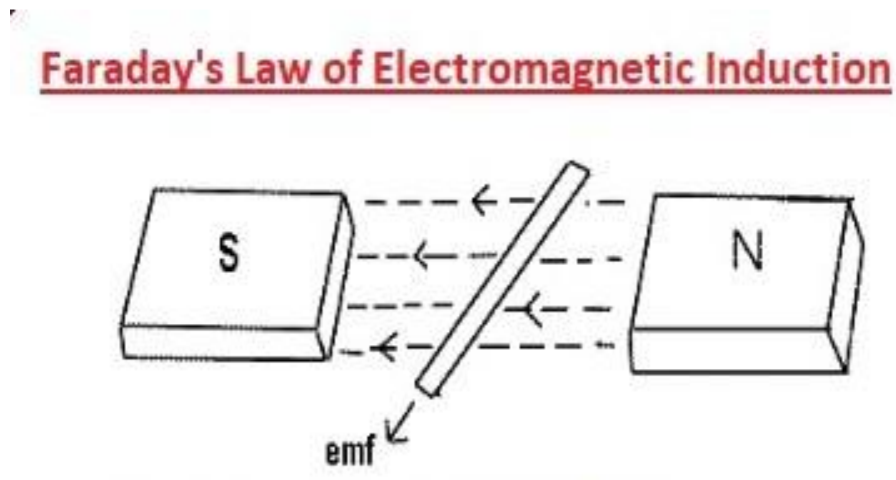


Fig.4.19Faraday's Laws of Electromagnetic Induction

Faraday's First Law:

When a charging magnetic field is linked to a conductor then an EMF is induced in the conductor. This EMF lasts only for the duration, the changing magnetic field continues.

Faraday's Second Law:

The magnitude of the induced EMF is directly proportional to the rate of change of the flux.

$$EMF \propto -\frac{\Delta \varnothing}{\Delta t}$$

$$EMF = -N\frac{\Delta \varnothing}{\Delta t}$$

$$EMF = -N\frac{d\varnothing}{dt}$$

Where, N is the No. of turns of coil in case of electromagnet. Negative sign shows that direction of the induced EMF is opposite to the applied voltage which produces the magnetic field.

4.2.16 LENZ'S LAW:

Lenz's law is used to find the direction of an induced voltage or current. Lenz's law states, the direction of the induced current be such that its own magnetic field will oppose the action that produced the induced current.

According to Faraday's Law when a conductor is rotated in a magnetic field, then EMF is induced. Due to this induced EMF another magnetic field is also produced. This field opposes the main field due to which current has been induced in the conductor.

Lenz's law can also be understood by a simple experimental arrangement shown below:

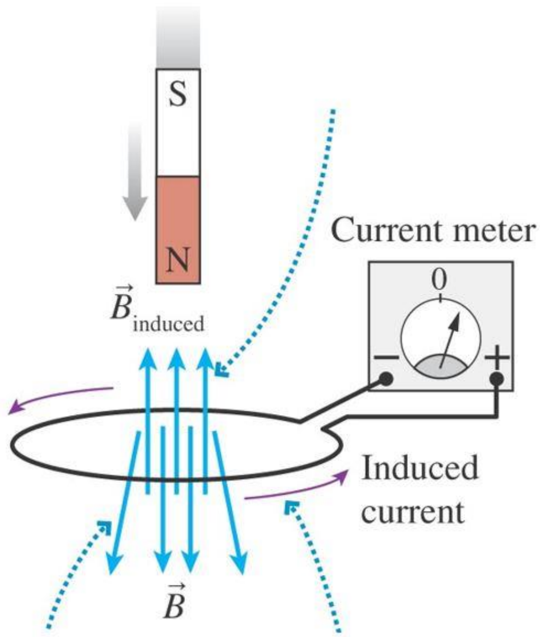


Fig.4.20 **Lenz's law**

When the magnet is moved near the coil, current is induced in the coil and can be observed on the microampere meter connected in the circuit. This induced current will also produce the magnetic field. By Lenz's law the North Pole is situated to the left of coil as shown in figure near the north pole of the magnet, which is producing the field. So the effect is always opposite to the cause which produces it.

Multiple Choice Questions

Q.1 Magnetic field is always mapped out in the form of magnetic ____
(a) Strength (b) lines of force (c) area (d) width

Q.2 Magnetic lines of force always travel from _______.
(a) Horizontal (b) axis
(c) South to North (d) North to South

Q.3 Magnetic flux is denoted by _______.
(a) φ (b) θ (c) $\in$ (d) ω

Q.4 Increased number of lines means _______ magnetic field.
(a) Wider (b) Stronger (c) Greater (d) Bigger

Q.5 A magnetic field line equals to a _______.
(a) Webber (b) Maxwell (c) Watt (d) Newton

Q.6 One Weber equals to _______ Maxwell.
(a) 1×10^{6} (b) 1×10^{7} (c) 1×10^{8} (d) 1×10^{10}

Q.7 Flux per unit area is called _______
(a) Flux density (b) Permeability
(c) Reluctance (d) Maxwell

Q.8 1KG = _______ Gauss
(a) 10^{-3} (b) 10
(c) 10^{3} (d) 10^{6}

Q.9 One Weber per square meter is called _______.
(a) Maxwell (b) Reluctance
(c) Flux density (d) Tesla

Q.10 Opposition in the production of flux is called _______.
(a)Resistance (b) Reluctance
(c) Tesla (d) Lines of force

Q.11 The magnetic lines of force become _______ where the field is strong.
(a)Thinner (b) Thicker (c) Parallel (d) Smooth

Q.12 The magnet made from iron/steel is called _______ magnet.
(a) Temporary (b) Permanent
(c) Electro (d) diamagnetic

Q.13 The magnet made up of soft iron is called _______ magnet.
(a) Soft (b) temporary
(c) Permanent (d) Electro

Q.14 When electricity is passed through a solenoid it becomes _______.
(a) Conductor (b) Magnet
(c)Inductor (d) Insulator

Q.15 Like poles of magnet _______ each other.

(a) Attracts (b) repels

(c) Both a and b (d) None of above

Q.16 Opposite poles of magnet _______ each other.

(a) Attract (b) repel

(c) Reflect (d) neglect

Q.17 Lead, Copper and Bismuth are _______ materials.

(a)Ferro magnetic (b) Diamagnetic

(c) Para Magnetic (d) Electro -magnetic

Q.18 The magnetic effect of a body on another without physical contact is called magnetic _______.

(a) Reluctance (b) Permeability

(c) Induction (d) Conduction

Q.19 1 ampere turn = _______ Gilbert

(a) 1.26 (b)1.27

(c)1.28 (d)1.29

Q.20 Magnetic field intensity is _______

(a) $\frac{mmf}{L}$ (b)$\frac{mmf}{A}$

(c)$\frac{mmf}{I}$ (d) $\frac{mmf}{G}$

Q.21 The ratio of B/H gives the absolute _______ of a material.

(a) Conduction (b) induction

(c) Reluctance (d) permeability

Q.22 Hysteresis means _______.

(a) Pushing forward (b) buffer storage

(c) Lagging behind (d) remaining constant

Q.23 _______ rule is used to determine the direction of magnetic field.

(a) Gripping (b) Faraday's

(c) Thumbwheel (d) None of above

Q.24 With the increase in turns of coil, the induced voltage _______

(a) Increases (b) decreases

(c) No change (d) any of above

Q.25 Coil formed by giving rotation to the wire is _______.

(a) Conductor (b) insulator

(c) Semi-conductor (d) inductor

ANSWER KEY

1.(b)	2. (d)	3.(a)	4.(b)
5.(b)	6.(c)	7.(a)	8.(c)
9.(c)	10.(b)	11.(b)	12.(b)
13.(b)	14.(b)	15.(b)	16.(a)
17.(b)	18.(c)	19.(a)	20.(a)
21.(d)	22.(c)	23.(a)	24.(a)
25.(d)			

Short Questions

1. Describe lines of force and magnetic field?
2. Define flux?
3. Define flux density?
4. Define relative permeability?
5. Describe reluctance and its unit?
6. List the types of magnetic material?
7. Describe the types of magnets?
8. Describe magneto motive force?
9. Explain electromagnetic induction?
10. Define Inductor?
11. State Faraday's laws of electromagnetic induction?
12. Define Lenz's law?
13. Define self-inductance?
14. What is the total inductance of 1H, a 500mH, and a 1.5H inductor when they are connected in parallel?
15. Determine the inductance of the coil in figure. The permeability of the core is 0.25×10^{-3}?

Long Questions

1. What do you mean by magnetic lines of force? Write down their characteristics?
2. Explain magnetic materials in detail?
3. What is electromagnetism? Discuss in detail?
4. Discuss in detail the magnetic hysteresis with the help of diagram?
5. Explain current carrying conductor?
6. Explain laws of electromagnetic induction?
7. Explain Lenz’s law with the help of diagram?
8. Explain Motor action in detail with the help of diagram

CHAPTER 05 AC FUNDAMENTAL

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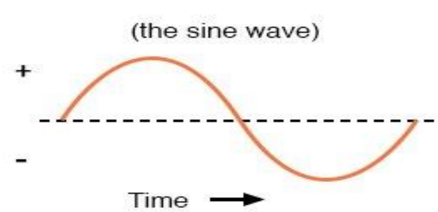
OBJECTIVES
After completion of this chapter students will be able to:

1. Basic Terminology Used for AC Circuits & Common AC Waveforms
2. Electromagnetic Waves Spectrum
3. AC through Resistors
4. Phase Lead & Lag
5. Self-Induced EMF
6. AC through RL Series & Parallel Circuits
7. AC through Capacitors, RC Series & Parallel Circuits
8. RC Time Constant
9. Series & Parallel Combinations of Inductors & Capacitors
10. AC through RLC Series & Parallel Circuits

5.1 A.C SINEWAVE:

When an alternator produces AC voltage, the voltage switches polarity over time, but does so in a very particular manner. When graphed over time, the "wave" traced by this voltage of alternating polarity from an alternator takes on a distinct shape, known as a sine wave: Figure below



Graph of AC voltage over time (the sine wave).

5.1.1 SINEWAVE:

The simplest form of an alternating current or voltage as shown below is called as Sine Wave. It is also called as Sinusoidal Wave.

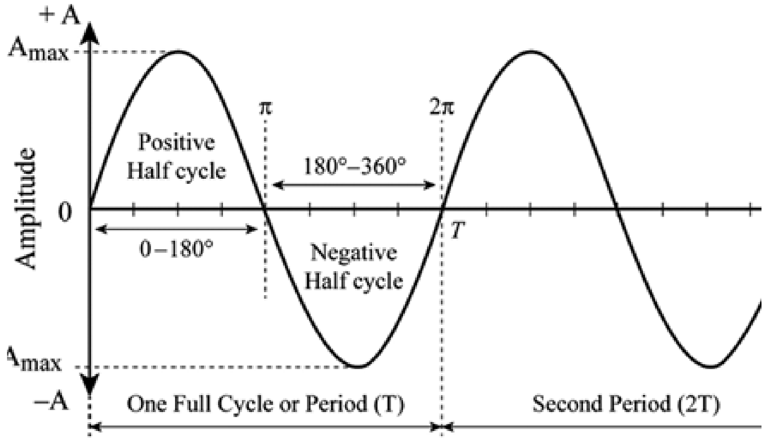


Fig.5.1 Sine wave

Sine waves can be produced by ac generator or from the signal generators. It is obvious that the sine wave periodically reverses its direction in a regular manner.

Sine wave start at zero and increases to a maximum positive value (peak value) and then returns to zero and the increases to a maximum negative value (peak value) and return to zero completing a set of values. Mathematically,

$$v = V_m \sin\theta$$

Cycle

A cycle is one complete set of positive and negative value of the alternating current or voltage. It is measured in cycles.

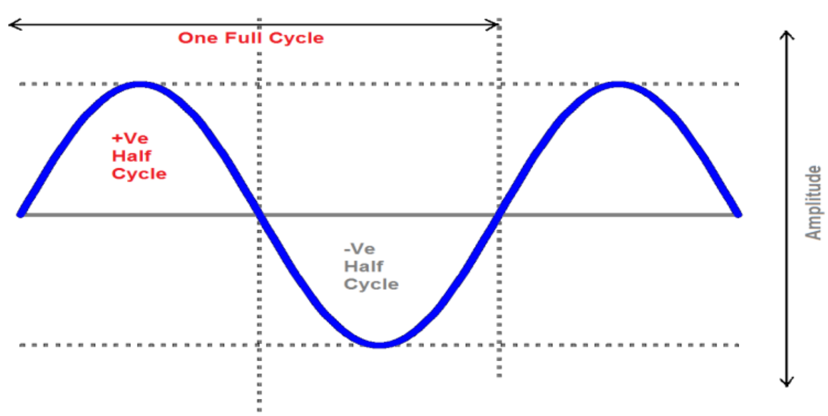


Fig.5.2 Representation of cycle

Wave Length

The distance covered by one cycle is called as wavelength. It is represented by λ.

Mathematically,

$$V = f\lambda$$

Or $\lambda = \frac{V}{f} = \frac{\text{Velocity of Wave}}{\text{Frequecy of Wave}}$

For Radio Waves f = 3×10^{10} cm/sec

$$\therefore \quad \lambda = \frac{3\times10^{10}\ \text{cm}/\text{sec}}{\text{f(Hz)}}$$

For Sound Waves f=1130 ft/sec

$$\lambda = \frac{1130\ \text{ft}/\text{sec}}{\text{f(Hz)}}$$

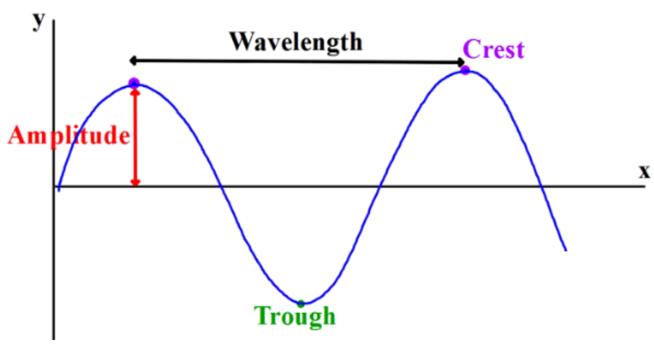


Fig.5.3 Wavelength

Period

Period is the time taken by a wave to complete one cycle. It is represented by T.

Mathematically,

$$T = \frac{1}{f}$$

Where f is the frequency of the wave in Hertz (Hz)

Higher the frequency, shorter will be the time period and vice versa. Unit of period is second and smaller units are mille seconds and micro seconds etc.

Frequency

Number of cycles per second is called as the frequency. If number of cycles completed is more, frequency will be more and if cycles completed are less then frequency will be less. It is measured in Hz (Hertz).

5.1.2 AC SINE WAVEFORM:

(i). Sine waveform

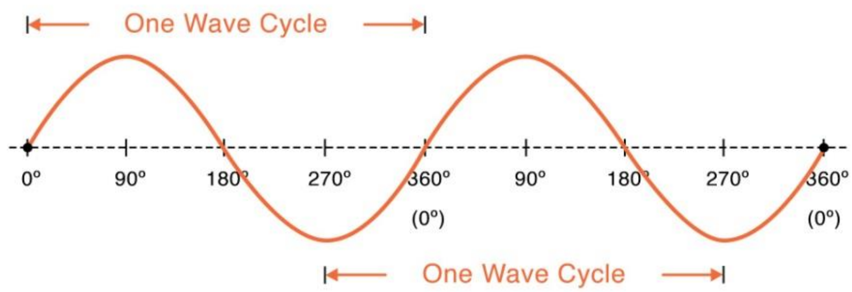


Fig.5.4 Representation of sine wave

(ii). Square Waveform

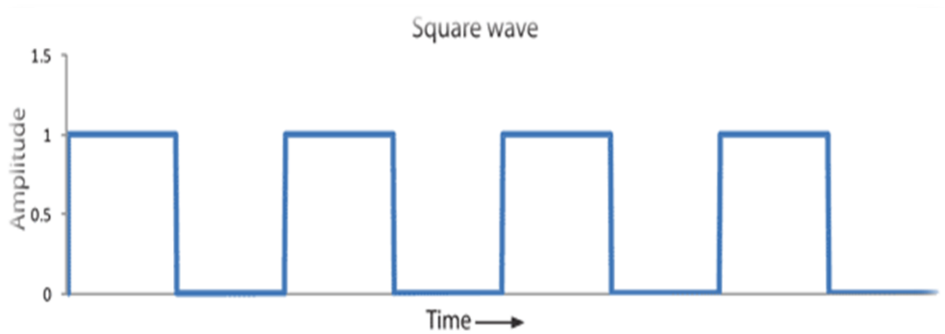


Fig.5.5 Representation of Square Waveform

(iii). Sawtooth Waveform

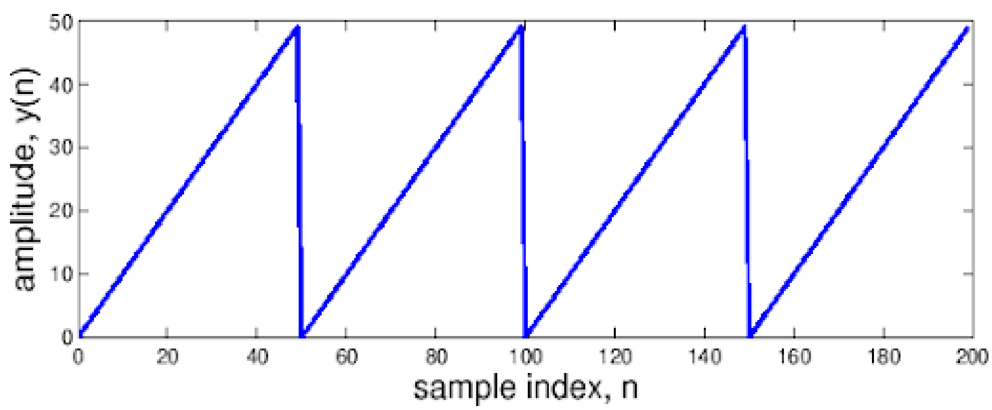


Fig.5.6 Representation of Saw tooth Waveform

(iv). Cosine Waveform

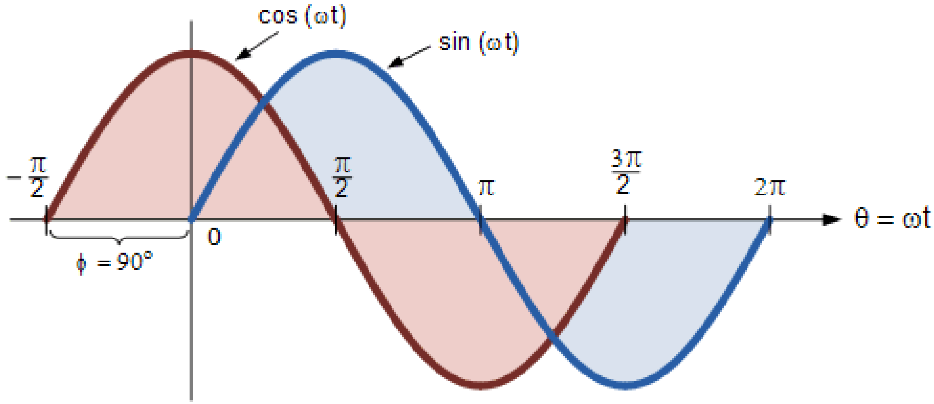


Fig.5.7 Representation of Cosine Waveform

5.1.3 INSTANTANEOUS VALUE, PEAK VALUE, AVERAGE VALUE, R.M.S VALUE EFFECTIVE VALUE AND THEIR INTER RELATION:

Instantaneous Value:

Instantaneous value of an alternating current or voltage at any instant is called as an Instantaneous Value. The instantaneous values of the current and voltage are denoted by i and v respectively and can be mathematically written as:

$V(\theta)=V_m \text{ Sin } \theta$

$i\ (\theta)=I_m \text{ Sin } \theta$

Suppose the voltage waveform as shown in figure 5.4 below with

V_m = 5Volts

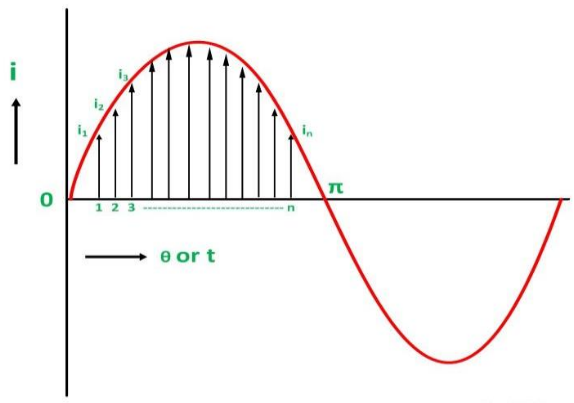


Fig.5.8 Instantaneous value of an alternating current or voltage

V (0) =5 Sin 0 = 0 volts
V (45) =5 Sin 45= (5) (0.707) =3.535 Volts
V (90) =5 Sin 90 = (5) (1) =5 Volts
V (180) =5 Sin 180= (5) (0) = 0 Volts
V (270) =5 Sin 270= (5) (-1) =-5 Volts
V (360) =5 Sin 360= (5) (0) = 0 Volts

These values are instantaneous values.

Peak Values:

Peak value is called as amplitude. The peak value of an alternating current or voltage is the highest value during the cycle.

It is represented by V_p or V_m. It is shown below:

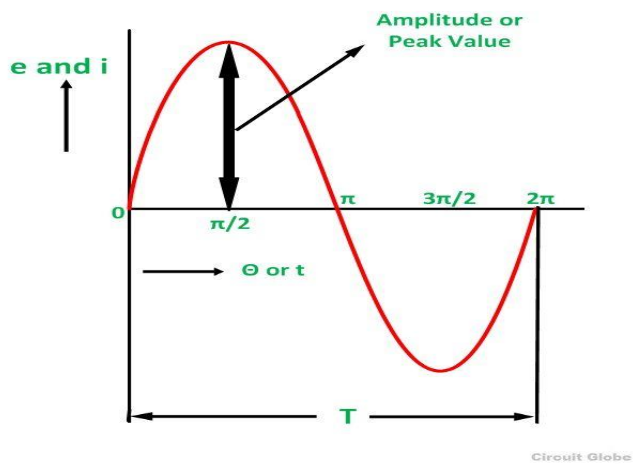


Fig.5.9 Peak Value

Peak to Peak Value:

The peak to peak value of an ac waveform is the value between positive peak to negative peak. It is represented by V_{pp} or I_{pp}.

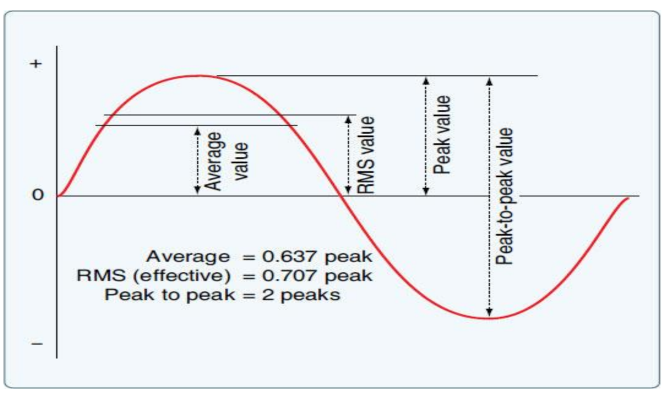


Fig 5.9 Peak to peak Value

If $V_p = V_m$ =5 Volts

Then $V_{pp} = V_{mm}$ = 10 Volts

Average Value:

The average value of an alternating current or voltage is calculated for half cycle. The average value of an alternating current or voltage is an arithmetic average of all the values for half cycle. It is represented by Vav or Iav.

The maximum value V_m and V_{avg} are related by the relation:

$$V_{avg} = 0.637\ V_{max}$$

And

$$I_{avg} = 0.637\ I_{max}$$

The average value of complete ac cycle is zero.

Effective Value (Root Mean Square):

The RMS value of an ac signal is equal to the dc value that products the same amount of heat as produced by the ac signal.

Mathematically,

$$V_{rms} = \sqrt{\text{Average value of } v^2}$$

And

$$I_{rms} = \sqrt{\text{Average value of } i^2}$$

That is the RMS or effective value of an ac signal is the square root of the average of the square values of the ac signal.

Mathematically we can find

$V_{rms} = 0.707\ V_{max}$

And $I_{rms} = 0.707\ I_{max}$

5.1.4 AUDIO AND RADIO FREQUENCIES:

Audio Frequency:

An audio frequency is the range of frequencies which can be heard by human ear. Typical value of the audio frequencies is 20 Hz to 20,000 Hz.

Wavelength of the audio frequency is:

$$= \lambda = \frac{v}{f} = \frac{1130 ft/sec}{f(Hz)}$$

Radio Frequency:

The range of radio frequency lies from 535 KHz to 1605 KHz for AM radio band and 88 MHz to 108 MHz for FM Radio band.

Wavelength of radio frequency = v=$\frac{\lambda}{f}$

$$= \frac{3\times10^{10}\ \mathrm{cm}/\mathrm{sec}}{\mathrm{F(Hz)}}$$

Wavelength of audio frequency = v=$\frac{\lambda}{f}$

$$= \frac{1130\ \mathrm{ft}/\mathrm{sec}}{\mathrm{f(Hz)}}$$

Numerical Problems :

Problem No. 1:

If 20 cycles of an ac signal are passing in 10 milli seconds, find the frequency and the time period of the ac signal.

Solution:

Frequency = f = Number of cycles/sec

$$= \frac{20}{10\mathrm{m\,sec}} = \frac{20}{10\times10^{-3}}\ \mathrm{c}/\mathrm{sec}$$

$$= \frac{20\times10^{3}}{10} = 2\mathrm{KHz.}$$

Time Period= T = $1/f = \frac{1}{2x103}$ = 0.5m sec

Problem No.2:

Find the wavelength of radio frequency wave having frequency 75 GHz. The velocity of radio wave is 3×1010 cm/sec.

Solution:

f= 75GHz = 75×10^{9}Hz.

V=3×1010 cm/sec

V = $f\lambda$

$$\lambda = \frac{v}{f} = \frac{3\times10^{10}}{75\times10^{9}} = 0.04\times10^{1} = 0.4\,\mathrm{cm.}$$

Problem No 3: (Self Test Problem)

Find the wavelength of a sound wave produced at a frequency of 60 Hz. The velocity of sound wave is ft/sec

Problem No.4:

Find the wavelength of the audio wave having frequency of 20 KHz in feet and centimeters.

Solution:

f = 20 KHz

V = Velocity of sound waves=1130 ft/sec

$$\therefore \qquad \lambda = \frac{V}{f} = \frac{1130}{20 \times 10^3} = 56.5 \times 10^{-3}\,\text{ft}$$

=0.0565 ft.

= 0.0565 × 12×2.54 cm =1.7221 cm

Problem No. 5:

An ac wave has a maximum value of 110v. Find its average and RMS values.

Solution:

V_m=V_p=110v

V_{avg} =0.637 x V_m=0.637 x 110=70 volts

V_{rms} =0.707 V_m=0.707 x 110=77.77 volts

Problem No. 6:

The length of a TV antenna is λ/4 for radio frequencies and used for =75MHz. What is the length of the antenna in cm and feet?

Solution:

Length of the antenna = λ/4

Frequency f =75MHz= 75 x 10^6Hz.

Velocity V =3 x 10^{10} cm/sec for radio frequencies.

$$\lambda = \frac{v}{f} = \frac{3 \times 10^{10}}{75 \times 10^6} = 400\,\text{cm}.$$

Length of antenna =λ /4=400/4=100 cm

Length of antenna (ft) = $\frac{100}{2.54x12}$

= 3.28 ft.

Problem No.7:

A sine wave of current has maximum value of 10 ampere. Find its value at the instant of 45°.

Solution:

$$i = I_m \sin\theta$$
$$= 10 \times \sin 45^0$$
$$= 10 \times 0.707 = 7.07 \text{ Amperes.}$$

Problem No. 8:

A wire 2 meter long vibrates in three loops with nodes at the two ends. Find the wavelength and speed of the wave in the wire if it vibrates with the frequency of 200Hz.

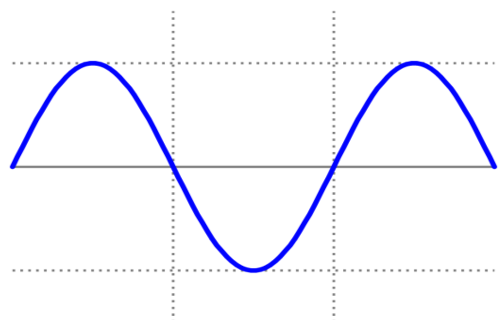


Fig.5.10 of problem No. 8

Solution:

f =200Hz.

V $= f\,\lambda$

$\lambda = \frac{v}{f}$

λ = Distance of one complete cycle

$= \frac{2}{3}$ x length $= \frac{2}{3}$ x 2 $= \frac{4}{3} = 1.33$ meters

V $= f\,\lambda$

$= 200 \times 1.33 = 266.66$ m/sec

5.1.5 ELECTROMAGNETIC WAVE SPECTRUM:

Electromagnetic waves are those waves in which there are two field components i.e. Electric field (E) and magnetic field (H). The electric field (E), Magnetic field (H) and the direction of propagation are all right angles to each other.

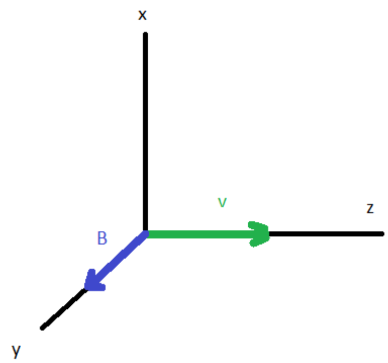


Fig.5.11 Direction of E and H field

It is obvious that changing magnetic flux produces an electric field and changing electric flux produces a magnetic field. So whenever these are a changing magnetic field or changing electric field, the other field will be available due to first. There is a vast range of electromagnetic waves and waves' travels at the speed of light i.e. 3×10^{10} cm/sec. The full range of the frequencies of the electromagnetic waves is called as Electromagnetic Wave spectrum. It is depicted in the figure below.

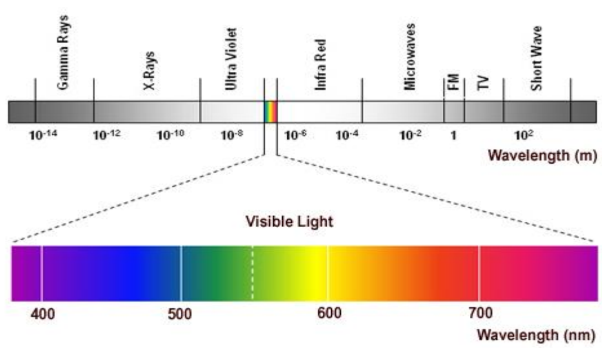


Fig.5.12Electromagnetic Wave Spectrum

5.1.6 HARMONIC AND FUNDAMENTAL WAVE:

It has been verified that a square wave or any complex wave comprises of a sine wave and its multiple frequencies. The formation of square wave is shown below:

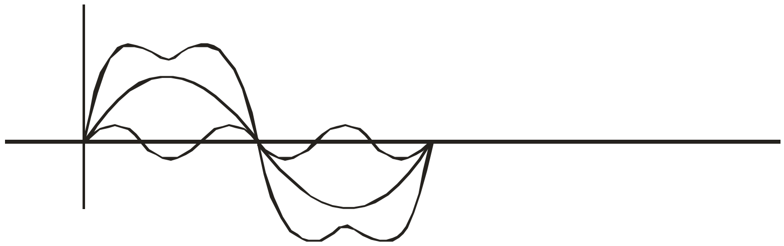


Fig.5.13Fundamental Wave & Harmonic Waves

A sine wave with the frequency f and its three times frequency i.e. 3f are combined to form a square wave as shown dotted in the above figure.

The frequency f which has the lowest frequency is called the Fundamental Wave or Fundamental Frequency. The three times of fundamental frequency is called as 3rd Harmonic.

Multiples of the principal or basic frequency is called as Harmonics like $1f$, $3f$, $5f$, $7f$ are called as odd Harmonics whereas $2f$, $4f$, $6f$, $8f$ are called as Even Harmonics.

5.2 AC CIRCUITS:

5.2.1 AC THROUGH RESISTORS:

Consider a pure resistor R and Ac supply of voltage V and frequency f are connected to the resistor as shown in figure below.

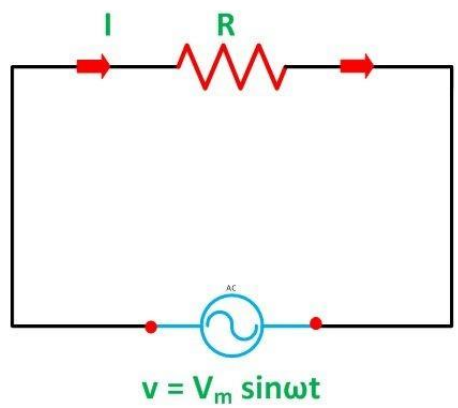


Fig.5.14 Ac through resistor

In this case the current across the resistor R and the voltage across the resistor V_R will be in phase. The phasor diagram and wave form in shown in figure below.

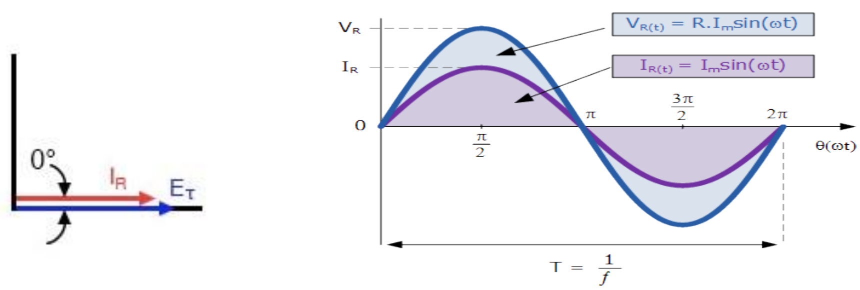


Fig.5.15 Phasor diagram

In order to find the power dissipated in the resistor

$P = V \times I$ or $Pd=V_R \times I_R$

So we can get the following figure for the power dissipation

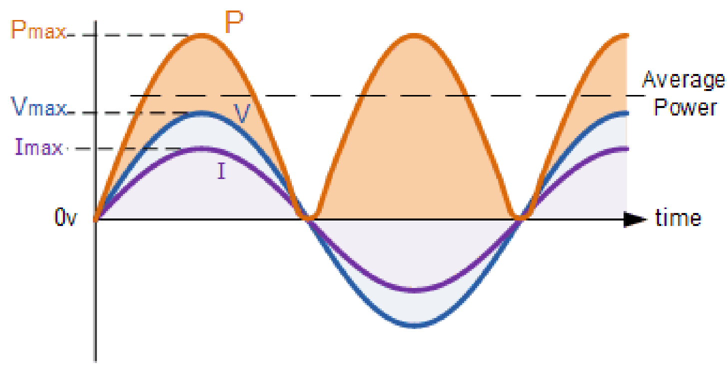


Fig.5.16 Power dissipation in Resistor

During the first half cycle the power is positive. Also during the second half cycle the power is positive because both current I_R and voltage V_R are negative. Their multiple will be positive.

5.2.2 PHASE ANGLE, IN PHASE & OUT OF PHASE:

Phase Angle:

Phase angle is defined the angular position of a wave with respect to a particular reference. Consider a wave shown in figure below.

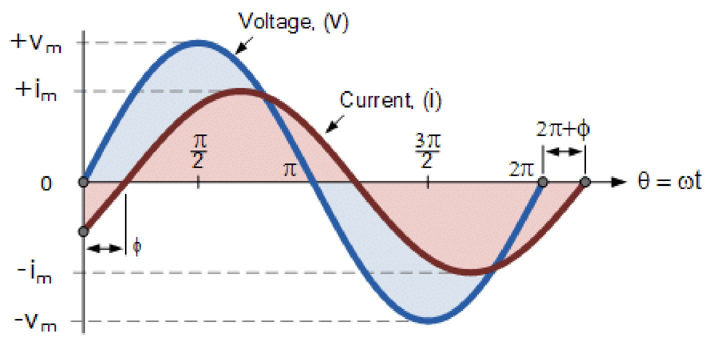


Fig.5.17 Phase angle

It is a sine wave and its position at phase angle φ is marked. The reference of the wave is considered 0°. Now consider the sine wave shown below:

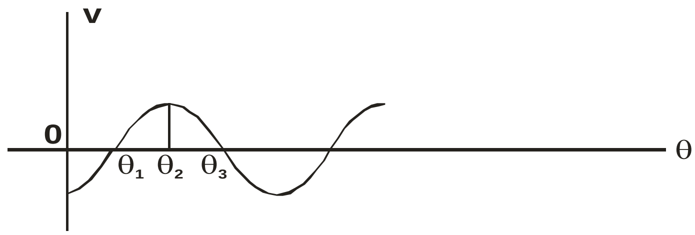


Fig.5.18Phase angle

At ϴ=0°, the wave is at its maximum negative peak,
At ϴ = $ϴ_1$, the wave is at its amplitude 0.
At ϴ = $ϴ_2$, the wave is at its amplitude maximum.
At ϴ = $ϴ_3$, the wave is at its amplitude zero.
So for a single wave, the value of the amplitude at different phase angle will be different.

In phase & out of phase:

Now if we consider two waves say V and I as shown in figure below:

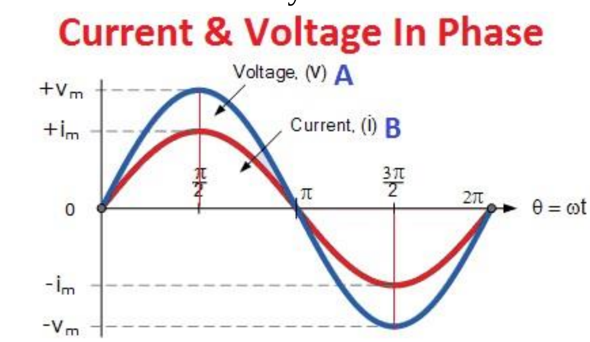


Fig.5.19 Phase angle between voltage and current

In this case V and I have the starting at the same time i.e. at ϴ =0° and reaches their maximum values at ϴ =90° and completes their half cycle at ϴ =180°. Such wave is called as In Phase.
So when two alternating quantities, having the same frequency start at the same time and reach to their maximum or minimum values at the same time, they are said to be In Phase.
In this case at every instant a 0° phase angle between the two waves is found.
However when two alternating quantities of the same frequency are such that if one quantity reaches to its maximum value, the other quantity reaches to its minimum value and vice versa are called out of phase.

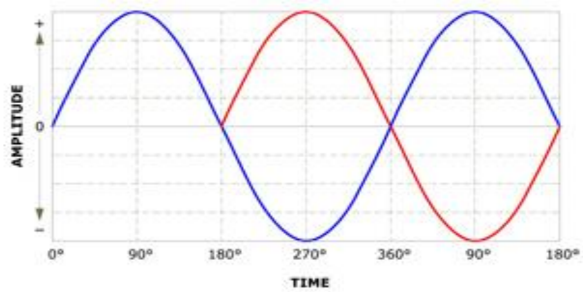


Fig.5.20 Phase angle showing out of phase relationship

5.2.3 PHASE LEAD, LAG & POWER FACTOR:

Phase Lead& Phase Lag:

Consider the following wave forms.

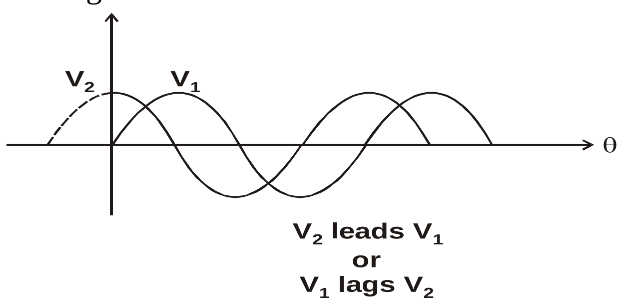


Fig.5.21 (a) V1 lads V2

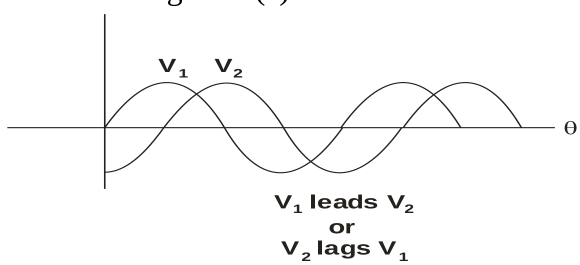


Fig.5.21 (b) V1 lags V2

In figure (a) it is quite evident that if we consider the reference as O, then V_2 reaches it maximum value at 0° compared V1. If a wave form reaches its maximum value earlier to other waveform it is said that it leads the other wave form. So in figure (b) V2 lead V_1. In other words we can say that V_1 Lags V_2. In figure (b), it is obvious that v1 reaches its maximum value earlier than V_2 so V_1 leads V_2. In other words we can say that V_2 lags V_1.

Power Factor:

The cosine of the angle (Phase angle) between voltage and current is called as Power Factor.

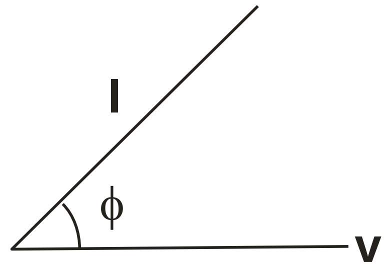


Fig.5.22 Power factor

Power Factor= PF = Cos φ

Actually power can be of following types:

i. **Apparent Power**

It is given by:

P = VI and measured in watts

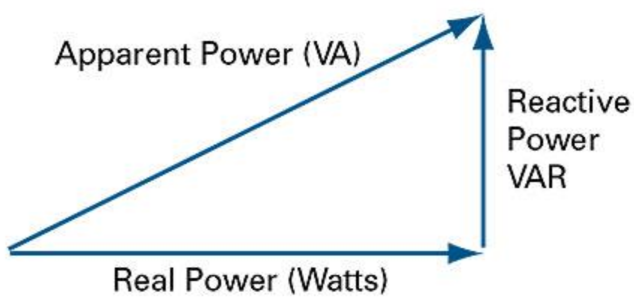


Fig.5.23 Apparent Power

ii. **True Power**

It is given by

P = VI cos φ = (I cos φ) ×V

It is also measured in watts.

iii. **Reactive Power**

P= VI Sin φ

5.2.4 CALCULATIONS OF PURE RESISTIVE CIRCUIT:

Problem. 1

A 1000W heating element is connected to a 250v AC supply voltage. Calculate the impedance (AC resistance) of the element when it is hot and the amount of current taken from the supply.

$$\text{Current}, I = \frac{P}{V} = \frac{1000W}{250V} = 4\ \text{amps}$$

$$Z = \frac{V}{I} = \frac{250}{4} = 62.5\Omega$$

Problem No. 2

Calculate the power being consumed by a 10Ω resistive element connected across a 240v supply.

Solution:

As there is only one component connected to the supply, the resistor, then $V_R = V_S$

$$Curent = I = \frac{V}{R}$$

$$I = \frac{240}{10} = 24\ Ampere$$

$$Power\ consumed = P = I^2R$$

$$\mathrm{P} = (24)^2 \times 100 = 5760\ Watt$$

5.2.5 AC THROUGH INDUCTANCE USING WAVEFORMS AND PHASOR DIAGRAM:

Consider a pure inductor L, connected to the ac supply of V volts and frequency f as shown in figure below:

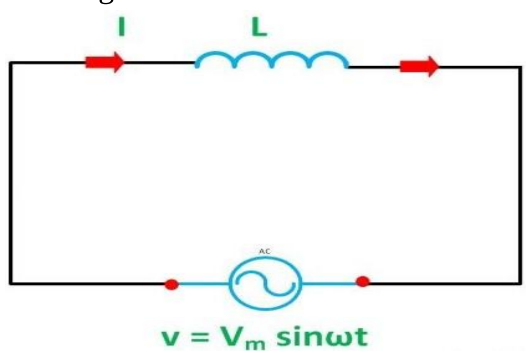


Fig.5.24 AC through Inductor

Inductor has the property that it opposes to any abrupt charge in the current passing through it and takes some time to build the current to its maximum value. However voltage can appear on the inductor immediately. Due to this property of the inductor current lags the voltage applied to the inductor. So the phasor diagram and waveform for the inductor are shown below.

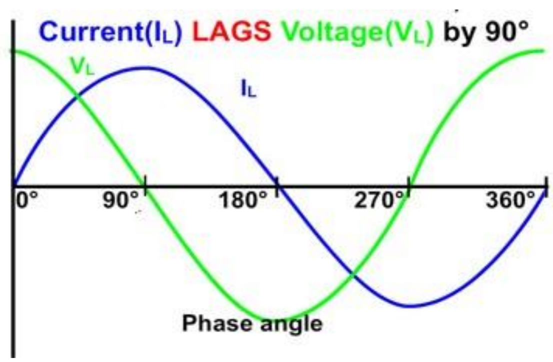


Fig.5.25 Phase angle of voltage and current in Inductive circuit

Power in pure inductive circuit can be calculated by the following diagrams.

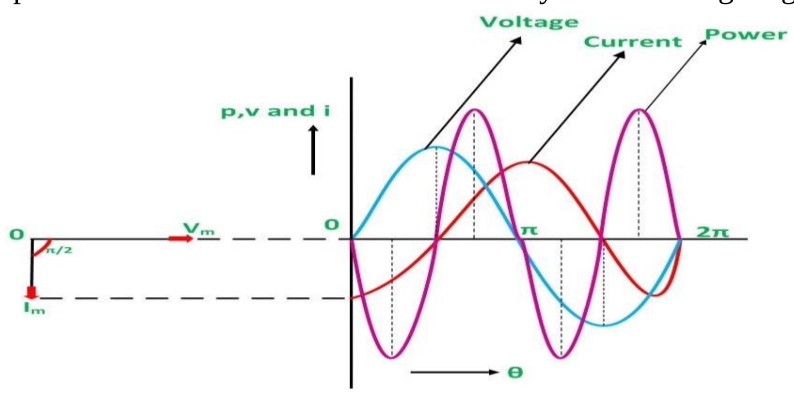


Fig.5.26 Power in pure Inductive circuit

5.2.6 SELF INDUCTANCE & SELF INDUCED VOLTAGE:

Self-Inductance:

Self-inductance or inductance is a measure of a coil's ability to establish an induced voltage as a result of a change in the current. In other words “the ability of conductor to produce induced voltage when current varies in it is called inductance or self-inductance.

It has been proved that whenever we pass a current through a conductor and electromagnetic field is established. The strength of the magnetic field depends on the amount of the current.

An increase in the current expands the magnetic field and decrease in the current reduces the magnetic field. A changing current produces, changing electromagnetic field around the inductor, a changing electromagnetic field induces a voltage across the coil and this property of the inductor is called as self-inductance. It is represented by L. For an inductor, the induced V_L is given by the formula.

$$V_L = L\frac{di}{dt} \quad \text{or} \quad L = \frac{V_L}{di/dt}$$

Its unit is Henry.

$$1\,\text{Henery} = \frac{1\text{volt}}{1\text{Amp}/\text{sec}}$$

So if the charge of current is one ampere per second in a coil induces a voltage of 1 volt then the inductance will be 1 Henry.

SELF INDUCED EMF:

The voltage which is produced by passing the ac current i.e. charging current through the inductor is called as Self-Induced voltage (EMF) and can be calculated by the formula:

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

5.2.7 INDUCTIVE REACTANCE, PHASE RELATIONSHIP BETWEEN VOLATGE AND CURRENT:

Inductive Reactance:

The opposition to the flow of the current offered of an inductor is called as Inductive Reactance (X_L). The inductive reactance (X_L) of the inductor depends upon its value of the inductance (L) and its frequency (f). If frequency is zero i.e. dc is applied to inductor its inductive reactance will be zero. If the frequency of the ac signal is increased its inductive reactance increases and vice versa.

Mathematically we can say:

$X_L \quad \infty f$

$X_L \quad \infty L$

$X_L \quad \infty f \text{ x } L$

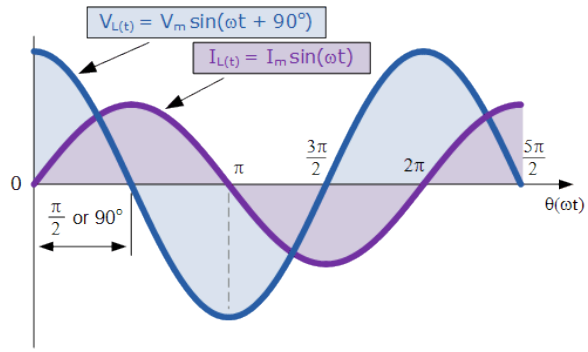
$X_L \quad = \text{Constant } (f\ L)$

$X_L \quad = 2\ \pi\ f\ L$ (Where 2π is Constant.)

The 2π radian is 360^0 mean one complete cycle. So this formula is used only for sine wave.

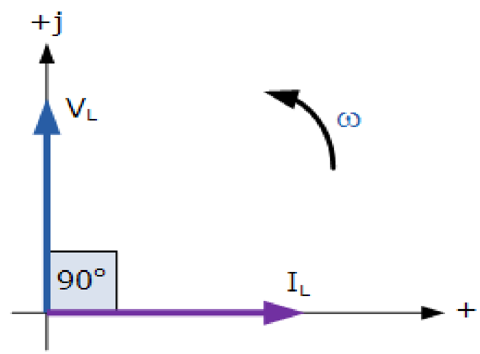
The unit of inductive reactance is Ohm. (Because of this is the opposition of current)

Phase Relationship.



This effect can also be represented by a Phasor diagram were in a purely inductive circuit the voltage "LEADS" the current by 90°. But by using the voltage as our reference, we can also say that the current "LAGS" the voltage by one quarter of a cycle or 90° as shown in the vector diagram below.

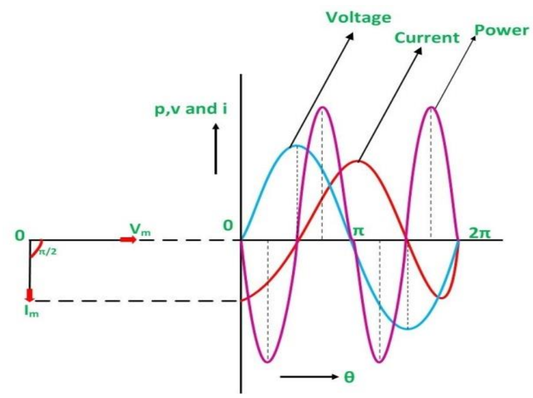
5.2.8 PHASOR DIAGRAM:



A pure loss less inductor, V_L "leads" I_L by 90°, or we can say that I_L "lags" V_L by 90°.

5.2.9 POWER OF PURE INDUCTOR:

In a pure inductive circuit, instantaneous power may be positive or negative. Because instantaneous power is the product of the instantaneous voltage and the instantaneous current, the power equals zero whenever the instantaneous current or voltage is zero.



5.2.10 A.C THROUGH RL SERIES CIRCUIT:

Consider an RL series circuit shown in figure below, connected to power supply having frequency f.

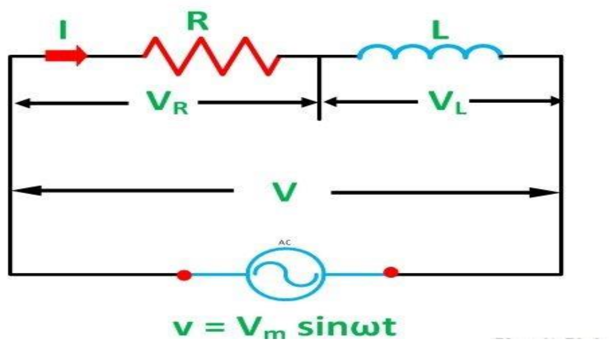


Fig.5.27 AC through RL Series Circuit

In this circuit some current I will flow and voltage applied V will be divided across the resistance and Inductance. So the voltage will be focused for the discussion of analysis of the circuit.

In the pure resistance V_R and I will be in phase whereas for inductance current I will lag the voltage induced in the inductance V_L. The waveform for the above circuit is drawn as follows:

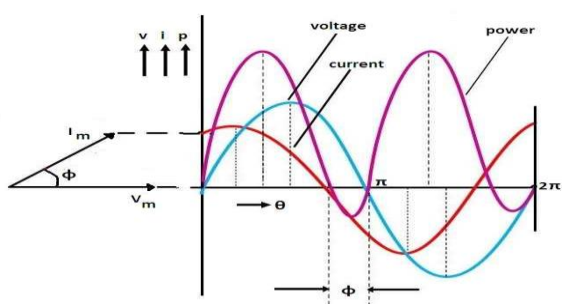


Fig.5.28 Phase relationship of voltage and current in RL Series Circuit

5.2.11 PHASOR DIAGRAM OF RL SERIES CIRCUIT:

The phasor diagram is as follows:

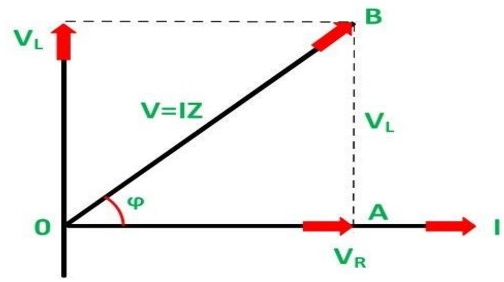


Fig.5.29 Phasor diagram of RL Series Circuit

From the phasor diagram, it is evident.

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

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

 $V_R = IR, V_L = I\,X_L$

∴ $V = \sqrt{(IR)^2 + (I\,X_L)^2}$

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

$$V = I \times Z$$

$$I = \frac{V}{Z} = \frac{V}{\sqrt{R^2 + X_L{}^2}}$$

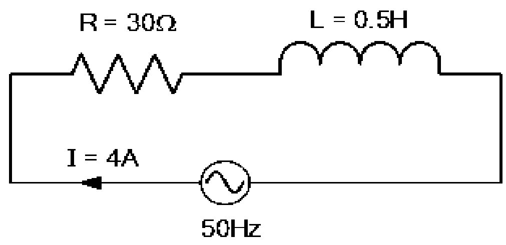
5.2.12 POWER FACTOR OF R-L CIRCUIT:

From the phasor diagram or impedance triangle we can also have:

Power Factor= Cos $\varnothing = \frac{V_R}{V} = \frac{R}{Z}$

Problem.1

A coil has a resistance of 30Ω and an inductance of 0.5H. If the current flowing through the coil is 4amps;what will be the value of the impedance, supply voltage and power if its frequency is 50Hz.



$$X_L = 2\pi f L = 2\pi \times 50 \times 0.5 = 157\Omega$$

$$Z = \sqrt{R^2 + X_L^2}$$
$$Z = \sqrt{30^2 + 157^2}$$
$$Z = 159.8\Omega$$

Then the voltage drops across each component is calculated as:

$$V_S = I.Z = 4\times159.8 = 640v$$

$$V_R = I.R = 4\times30 = 120v$$

$$V_L = I.X_L = 4\times157 = 628v$$

The phase angle between the current and supply voltage is calculated as:

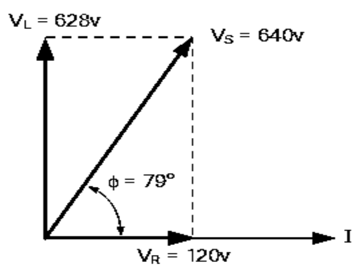
Power factor?

$$\text{Cos }\theta = \frac{R}{Z} = \frac{30}{159.8} = 0.188$$

$$\theta = \text{Cos}^{-1}\, 0.188 = 79^o$$

$$P = V\, I\, \text{Cos }\theta = 640 \times 4 \times 0.188 = 481.28\text{ W}$$

The Phasor diagram will be.



5.2.13 TIME CONSTANT OF R-L CIRCUIT:

The time constant of R_L series circuit is given by L/R. Time constant is defined as the time taken for the current I in an inductive circuit to rise to 63.2% of its maximum value. Since the inductor cannot build the current in itself instantaneously rather takes some time. Normally 5 times constant i.e. 5 L/R is the time required for the full build up of the current up to steady state value.

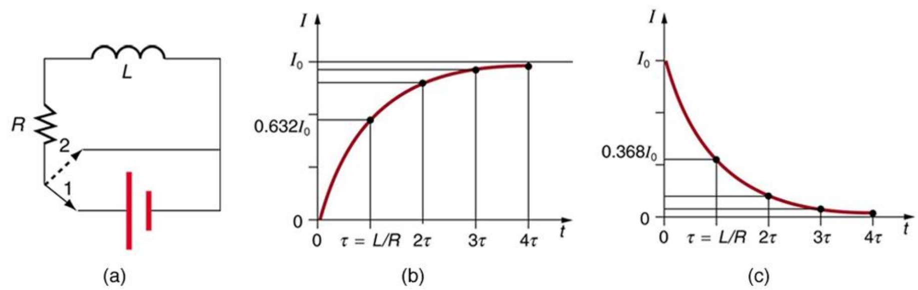


Fig.5.31 Time constant

Since

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

or $V_L = L\frac{i}{t}$

$$t = L\frac{i}{v} = \frac{L}{v/i} = \frac{L}{R}$$

$$t = \frac{L}{R} \Rightarrow \tau = \frac{L}{R}$$

5.2.14 IMPEDANCE:

Impedance (symbol Z) is a measure of the overall opposition of a circuit to current, in other words: how much the circuit impedes the flow of charge. It is like resistance, but it also takes into account the effects of capacitance and inductance. Impedance is measured in ohms (Ω).

5.2.15 IMPEDANCE TRIANGLE:

Impedance triangle is drawn as follows:

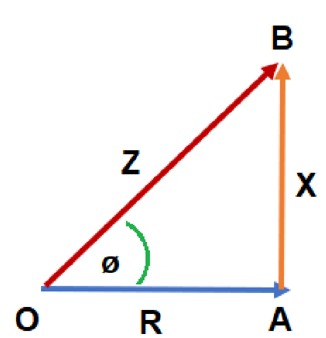


Fig.5.30 Impedance triangle of RL Series Circuit

Where Z= Impedance of the circuit. It is combination of R and X_L. In other words for a series or parallel circuit, the overall resistance offered by the circuit is called as Impedance.

5.2.16 AC THROUGH RL PARALLEL CIRCUIT:

A parallel RL circuit is shown in figure below. It is connected to ac power supply volts and having frequency f.

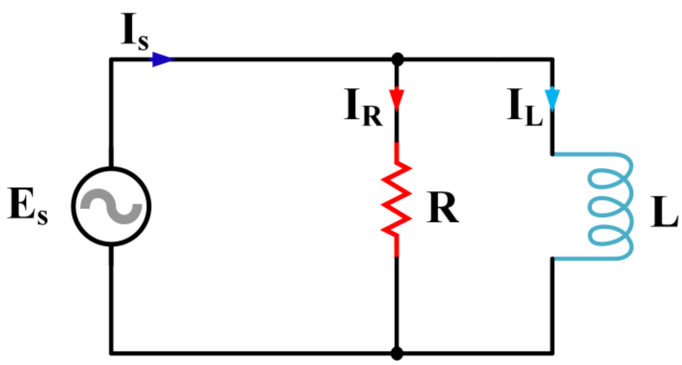


Fig.5.32 AC through RL Parallel Circuit

Now the voltage across resistance R and inductance L will be the same equal to the supply voltage V, because R and L are connected in parallel. So

$$V_R=V_L=V$$

However the currents will divide and will be as follows:

$I_R = \frac{V}{R}$

$I_L = \frac{V}{XL}$

Since the currents are divided so we will concentrate our calculations for the currents so waveform for the above circuit is as follows.

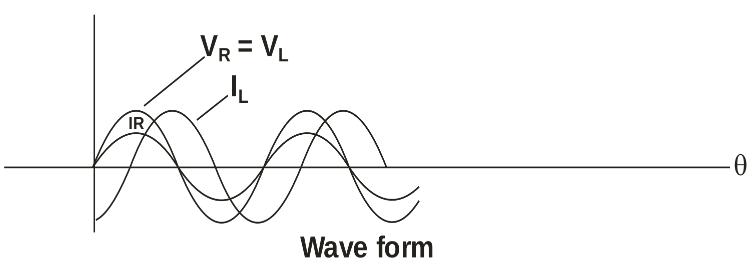


Fig.5.33 Phase relationship of voltage and current in RL Parallel Circuit

Now the phasor diagram will be as follows:

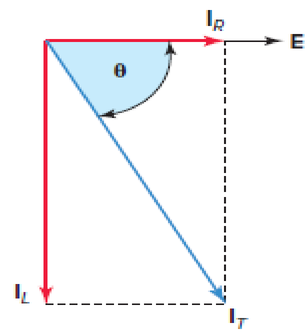


Fig.5.34 Phasor diagram

Impedance triangle is as follows:

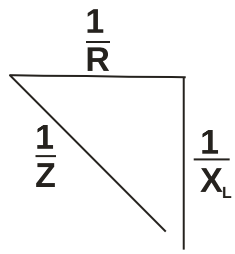


Fig.5.35Impedance triangle

From the phasor diagram for the currents we have:

$$I_T^2 = I_R^2 + I_L^2$$

$$I_T = \sqrt{I_R^2 + I_L^2} \quad \text{where} \quad I_R = \frac{V}{R}, I_L = \frac{V}{X_L}$$

$$Z = \frac{V}{I_T}$$

Phase angle and power factors are as follows:

$$PF = \cos\theta = \frac{I_R}{I_T} = \frac{\frac{V}{R}}{\frac{V}{Z}} = \frac{Z}{R}$$

It is worth nothing in impedance triangle we have taken sides as $\frac{1}{R}, \frac{1}{X_L} \& \frac{1}{Z}$ due to parallel Circuit. It is worth mention:

$\frac{1}{R}$ = G = Conductance of the circuit

$\frac{1}{X_L}$ = B = Susceptance of the circuit

$\frac{1}{Z}$ = Y = Admittance of the circuit

Also from the figure:

$$Y = \sqrt{G^2 + B^2}$$

5.2.17 CALCULATION ABOUT INDUCTIVE REACTANCE:

Problem No.1:

If a coil of 20 Henry is connected to ac supply of 220V, 50Hz find the current flowing through it.

Solution:

L = 20henry

V = 220volts

f = 50Hz.

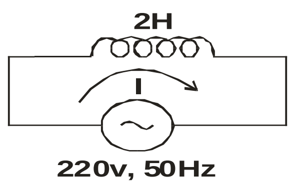


Fig.5.36 problem #1

$X_L = 2\pi fL$

$= 2\pi \times 50 \times 20$

$= 6285.71\Omega$

$I = \frac{V}{X_L} = \frac{220}{6285.71} = 0.035$ Amp

Problem No.2:

A circuit comprises of a resistance of 10Ω and an inductance of 0.5H connected in series to it. If a supply of 110V, 60Hz is applied across the combination find:

i. Inductive Reactance
ii. Impedance
iii. Total current
iv. Phase angle and power factor
v. Voltage drop across R.
vi. Voltage drop across L.

Solution:

(i) $XL = 2\pi f L$

$= 2 \times 3.1416 \times 60 \times 0.5\ \Omega$

$= 188.46\ \Omega$

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

$= \sqrt{(10)^2 + (188.46)^2}$

$= \sqrt{100 + 35517}$

$= \sqrt{35617}$

$= 188.72\ \Omega$

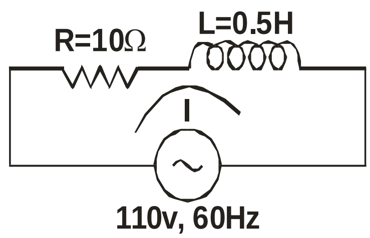


Fig.6.37 problem #2

(iii) $I = \frac{V}{Z}$

$= \frac{110}{188.72}$

$= 0.5299$ Amp

(iv) Cos φ $= \frac{R}{Z} = \frac{10}{188.72}$

$= 0.053\ \Omega$

Φ $= \text{Cos}^{-1}(0.053)$

$= 86.96$

(v) $V_R = I \times R = 0.5299 \times 10 = 5.299$ V

(vi) $V_L = I X_L = 0.5299 \times 188.46 = 9.986$ V

Problem: 3 (SELF TEST)

In a RL series circuit, the supply is 220V, 50Hz and the current taken is 3.5 amperes. The power absorbed is 250 watts, find the resistance, inductance, impedance power factor and phase angle.

Problem No. 4 (Self-Test Problem)

If a series RL circuit consisting of 25 ohm resistance and 0.5 henry inductance, takes 2 amperes of current, find the supply voltage if supply frequency is 50Hz.

Problem No. 5

If an inductive coil of 0.050 Henry takes a current of 2 amperes, when connected to a supply of 110V, 60Hz find the resistance of the coil.

Solution:

If a coil has a resistance then it comes in series with the inductance of coil and act as RL series circuit so.

L =0.50H

I = 2 Amps

V = 110 volts

f =60Hz

Z $= \frac{V}{I} = \frac{110}{2} = 55\ \Omega$

$Z^2 = R^2 + X_L^2$

$R^2 = Z^2 - X_L^2$

= 3025 – 355

= 51.67 Ω

Problem No. 6

Find the frequency of the ac supply of 110volts connected to RL series circuit of 10 Ω resistance and 0.5H inductance if it takes 5 amperes of current.

Solution:

V = 110 volts

f =?

R = 10 Ω

L = 0.5 H

I = 5 Amps

Z $= \frac{\mathrm{V}}{\mathrm{I}} = \frac{110}{5} = 22\ \Omega$

$Z^2 = R^2 + X_L^2$

$X_L^{\ 2} = Z^2 - R^2$

$= (22)^2 - (10)^2$

= 484 – 100

= 384

X_L = 19.59 Ω

$X_L = 2\ \pi\ f\ L$

$f = \frac{X_L}{2\ \pi\ L}$

$= \frac{19.59}{2\text{x}3.1416\text{x}0.5}$

= 6.236 Hz

Problem No. 7

If a parallel RL circuit consists of 20 resistance and 0.5H inductance and connected to ac supply of 110volts, 60Hz find:

(i)Total current supplied.

(ii)Impedance

(ii)Power factor and phase angle.

Solution:

i.

$$X_L = 2\pi fL = 2\pi \times 60 \times 0.5 = 188.46\Omega$$

$$I_R = \frac{V}{R} = \frac{110}{20} = 5.5 \text{ Amp}$$

$$I_L = \frac{V}{X_L} = \frac{110}{188.46} = 0.5837 \text{ Amp}$$

$$I_T^2 = I_R^2 + I_L^2$$

$$I_T = \sqrt{(5.5)^2 + (0.5837)^2}$$

$$I_T = \sqrt{30.25 + 0.3407} = \sqrt{30.59} = 5.53 \text{ Amp}$$

ii.

$$Z = \frac{V}{I} = \frac{110}{5.53} = 19.89\Omega$$

iii.

$$\text{Cos } \varnothing = ?$$

$$\text{Cos } \varnothing = \frac{Z}{R} = \frac{19.89}{20} = 0.9945$$

$$\varnothing = \frac{Z}{R} = \frac{19.89}{20} = 0.9945$$

Problem No. 8 (Self-Test Problem)

A parallel RL circuit consists of a resistance of 10KΩ and an inductor of 5mH. The combination is supplied by 20V ac having 1 KHz frequency. Find

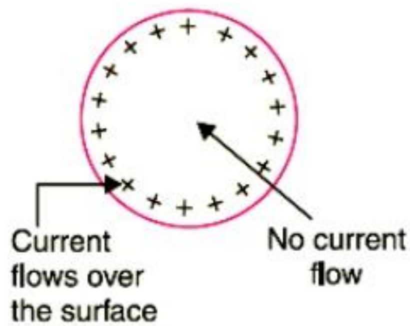
(i) Supply Current

(ii) Impedance

(iii) Power factor and phase angle

5.2.18 SKIN EFFECT:

It has been observed that at high frequencies i.e. radio frequency, current tends to flow at the surface of a conductor with a very little current at the center. This effect is called as Skin Effect. Skin effect results from the fact that current in the center of the wire faces more inductance because of the magnetic flux concentrated in the metal compared with the edges, where part of the flux is in air. Due to this reason, VHF currents are often made of hollow tubing.



The skin effect increases the effective resistance. To minimize the skin effect smaller cross sectional areas are used or the core is stranded.

5.2.18 AUDIO FREQUENCY CHOKES:

Audio frequency chokes are the inductive coils used to pass the audio signals and block the radio signals. Inductance offers more reactance at higher frequencies compared the resistance which offers same resistance at all the frequencies. This important property of the inductor is applied to the circuit shown below:

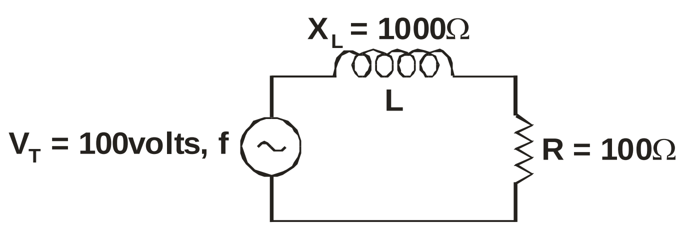


Fig.5.42 Audio Frequency Chokes

In this circuit X_L is much greater than R for the frequency of the ac source VT. This results in total voltage drop across the inductor and very little voltage drop across R. This inductor L is used as choke. So a choke is an inductor in series with an external R to prevent the ac signal voltage from developing any appreciable output across the R, at the frequency of the source. X_L is taken 10 or more times the series resistance R. Then the circuit is primarily inductive.

Now we consider the voltage drop across the X_L and R.

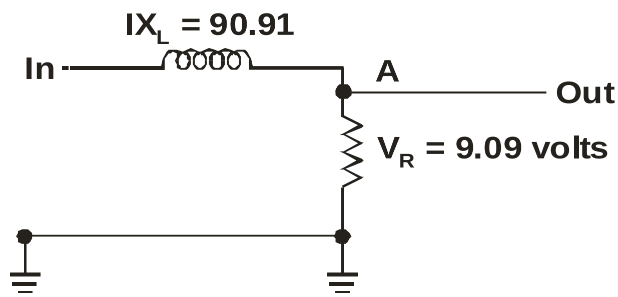
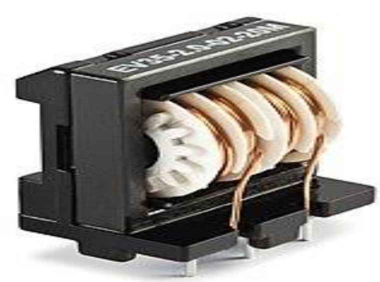


Fig.5.43 Circuit for voltage drop across the X_L and R.

Since the output is taken from the resistance, at point A with reference to ground. So for the low frequencies i.e. Audio Frequencies 16õ16000Hz the output will be across R and the high frequency component will be across XL. So idea is of passing AF signal through R while blocking RF signal as IX_L across the choke because of more X_L at the higher frequency.

5.2.20 RADIO FREQUENCY CHOKES:

Radio frequency chokes are designed to work at high frequencies or radio frequencies. Air cored inductors are normally used for this purpose. These have very high reactance at high frequencies. In this type of chokes single layer and multi-layer windings are used.



The reactance of the coil increases with the increase in the frequency. Radio frequency chokes offer a very low resistance to dc and very high resistance to ac.

5.2.21 A.C THROUGH PURE CAPACITOR:

A capacitor C is connected to an Ac supply of voltage V and frequency f as shown in figure below.

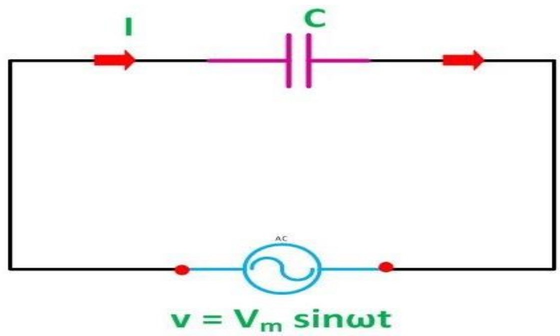


Fig.5.44 AC through capacitor

It is the property of the capacitor that it opposes to an abrupt change in the voltage through it. It maintains constant voltage across it. So initially when a capacitor is connected across a supply some time is required to charge it to the supply voltage. It has been verified that 5 times constant is time required to charge it to the supply value. However current can build across the capacitor instantly. So the voltage in a pure capacitor lags the current by 90°. It is shown in the Phasor diagram and waveform as follows.

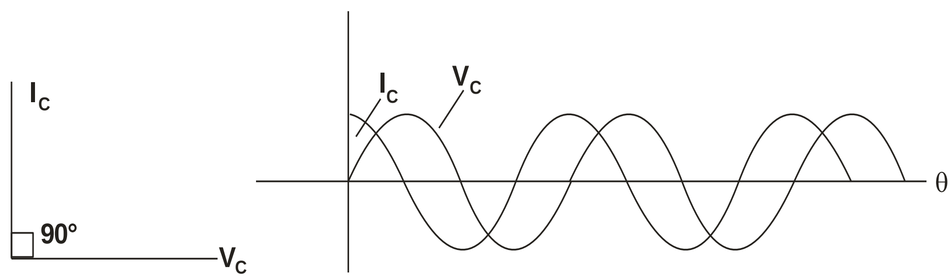


Fig.5.45 Phasor diagram and waveform of voltage in a pure capacitor lags the current by 90°.

5.2.22 PHASE RELATIONSHIP BETWEEN VOLTAGE, CURRENT, AND POWER AC THROUGH CAPACITOR:

The power across the capacitor is shown in the figure below. It is obvious from the waveforms that power consumed by the capacitor during the half cycle is opposite to the other half cycle resulting in overall zero power.

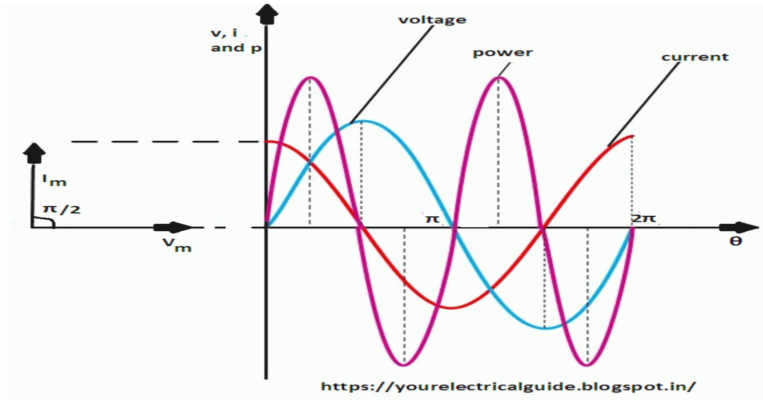


Fig.5.46 power across the capacitor

5.2.23 CAPACITIVE REACTANCE Xc:

The opposition to the flow of current offered by a capacitor is known as capacitor reactance X_C. It is verified that Xc inversely proportional to the value of the capacitance C and also inversely proportional to the supply frequency f.

So

$$X_C \propto \frac{1}{C}$$

$$X_C \propto \frac{1}{f}$$

Combining these two relations

$$X_C \propto \frac{1}{fc}$$

$$X_C \propto \frac{1}{2\pi fC}$$

$X_C = \frac{1}{2\pi f C}$ where $\frac{1}{2\pi}$ is constant of proportionality.

This relation determines the value of the capacitive reactance.

5.2.24 A.C THROUGH R-C SERIES CIRCUIT:

An RC series circuit is shown in figure below. In this circuit a resistance R is connected in series a capacitor C.

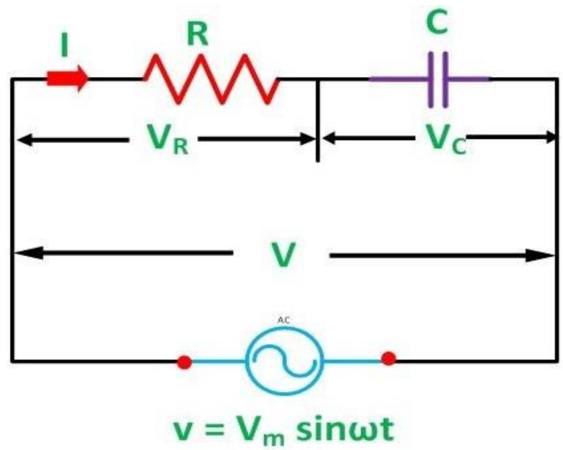


Fig.5.47 AC through RC Series Circuit

Now the voltage across the resistance and current across the resistor will be in phase. In capacitor the current will lead the voltage across the capacitor. Since R and C are connected in series so supply voltage will be divided across them and current will be the same as I. It can be shown in the phasor waveform as follows.

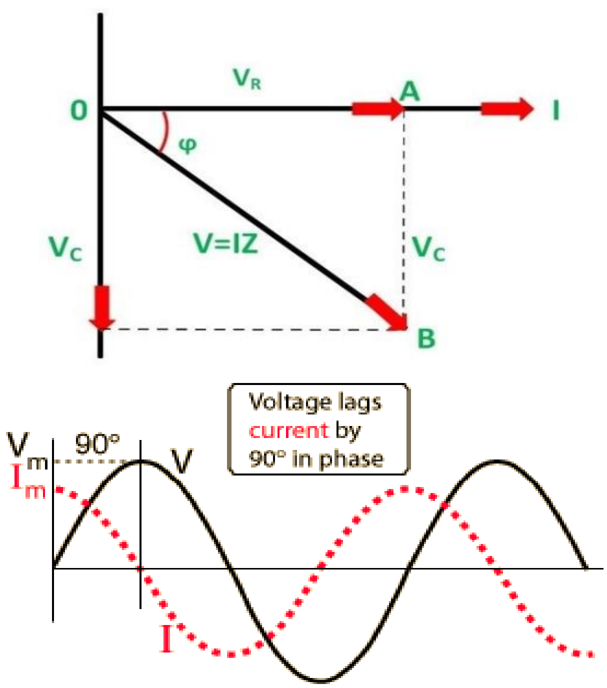
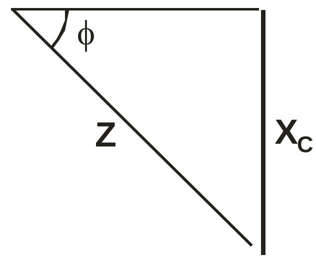


Fig.5.48 Phasor diagram and waveform of voltage in a pure capacitor lags the current by 90° (but in RC circuit angle between 0 to 90°)



Impedance triangle

Fig.5.49 Impedance triangle

From the phasor diagram it is clear that:

$$V^2 = V_R^2 + V_C^2$$

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

$$V_R = I \times R$$

$$V_C = I X_C$$

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

$$= I\sqrt{R^2 + X_c^2}$$

$$\frac{V}{I} = \sqrt{R^2 + X_c^2}$$

$$Z = \sqrt{R^2 + X_c^2}$$

$$I_T = \frac{V}{Z}$$

From the phasor diagram and impedance triangle it is clear that

$$\text{Cos}\varnothing = \frac{V_R}{V_T}$$

$$\text{Cos}\varnothing = \frac{R}{Z}$$

5.2.25 TIME CONSTANT OF RC SERIES CIRCUIT:

When a capacitor is connected to a supply certain amount of time is required to acquire the full charge. The amount of time during which it charges up to 63.2% of the full value is called as **Time Constant**. It has been verified that a capacitor charges to its full value in 5 times constant.

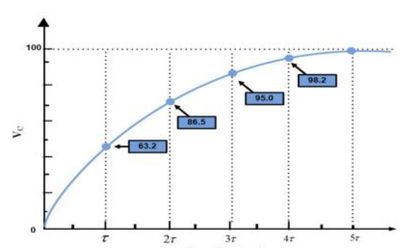


Fig.6.50 RC Time constant

The value of one time constant for RC is circuit is RC. It can be easily derived as follows.

$$Q = CV$$
$$\frac{Q}{V} = C$$
$$\frac{I \times t}{V} = C$$
$$\left(\frac{I}{V}\right) \times \tau = C$$
$$\left(\frac{I}{R}\right) \tau = C$$
$$\tau = RC$$

It is same for RC series are well as parallel circuits. It is shown in following graph.

5.2.26 A.C THROUGH R-C PARALLEL CIRCUIT:

Consider a RC parallel circuit shown in figure below. In this circuit a resistance R and a capacitor C are connected in parallel as shown in figure below.

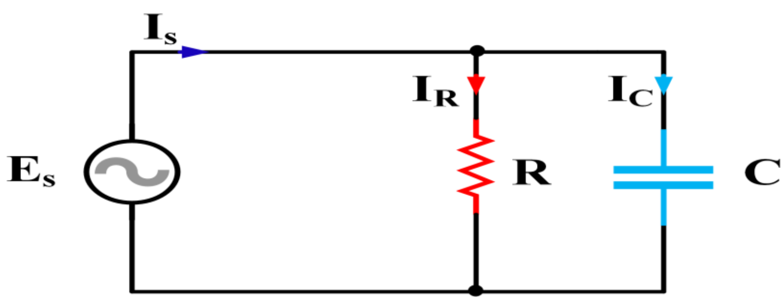


Fig.5.51AC through RC Parallel Circuit

However the current will be divided between R and C.
It is quite clear:

$$I_R = \frac{V}{R}$$
$$I_C = \frac{V}{X_C}$$

Since the currents are different so we will focus our analysis on the currents. Voltage across R and C are constant. The circuit diagram and waveform are shown below.

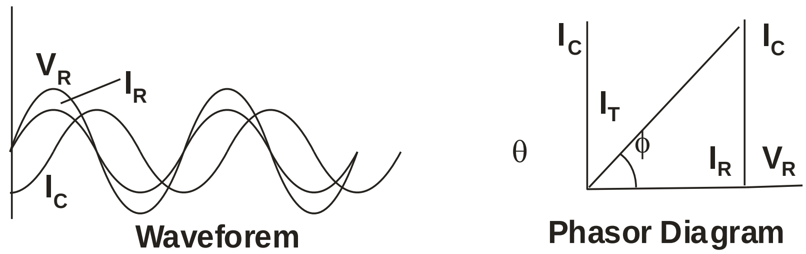


Fig.5.52 Phasor diagram and waveforms of voltage in a pure Resistor

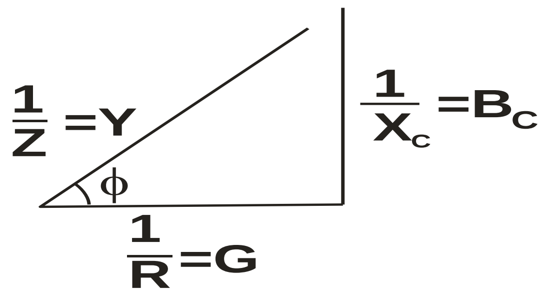


Fig.5.53 Phasor Diagram

It is evident from the phasor diagram that

$$I_T = \sqrt{I_R^2 + I_C^2}$$

$$Z = \frac{V}{I_T}$$

5.2.27 PROBLEMS ON CAPACITIVE REACTANCE Xc:

Problem.1

Find the current taken by a 20µF capacitor when connected to a 220V, 50 Hertz supply. What alteration in current will occur if the frequency is (a) Doubled (b) Halved, the supply voltage being kept constant?

Solution:

C= 20µF,

V=220V,

f=50 Hz,

I=?

$$XC = \frac{10^6}{2\,\pi\,f\,C} = \frac{10^6}{2 \times 3.142 \times 50 \times 20} = 159.134\ \Omega$$

$$I = \frac{V}{Xc}$$

$$= \frac{220}{159.134}$$

=1.382 A

(a) When frequency is doubled i.e. 100 Hz

XC = $\frac{10^6}{2\,\pi\,f\,C} = \frac{10^6}{2 \times 3.142 \times 100 \times 20}$ = 79.567 Ω

I = $\frac{V}{XC}$

$= \frac{220}{79.567}$

= 2.764 A

(b) When frequency is halved i.e. 25 Hz

XC = $\frac{10^6}{2\,\pi\,f\,C} = \frac{10^6}{2 \times 3.142 \times 25 \times 20}$ = 318.268Ω

I = $\frac{V}{XC}$

$= \frac{220}{318.268}$

= 0.690 A

5.2.28 AC THROUGH RLC SERIES CIRCUIT:

A series RLC circuit is shown in figure below. It is supplied with supply voltage V having frequency f.

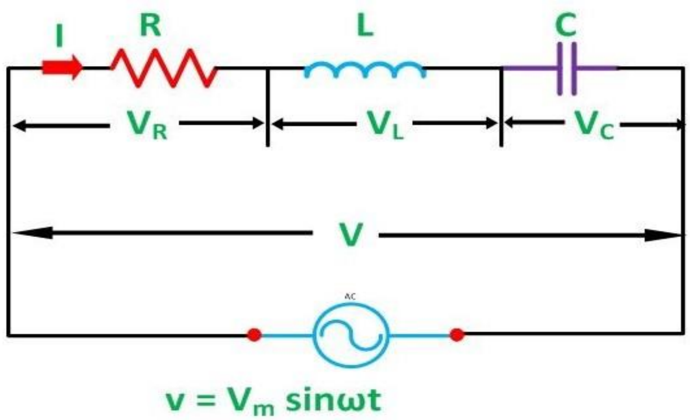
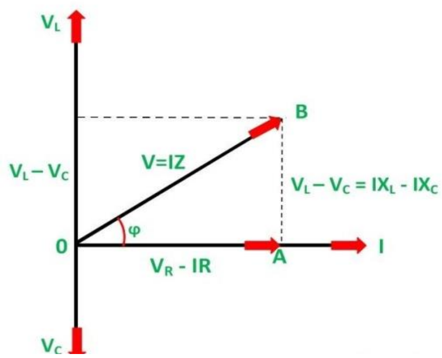


Fig 5.54 AC through Series RLC Circuit

Suppose the voltage across R is V_R, voltage across L is V_L and voltage across C is V_C. Taking voltage across the resistance as reference, we can draw the wave is the applied voltage and I_T is the total current so Z can be easily found.

Case: I When V_L>V_C

In this case we have the phasor diagram as follows.



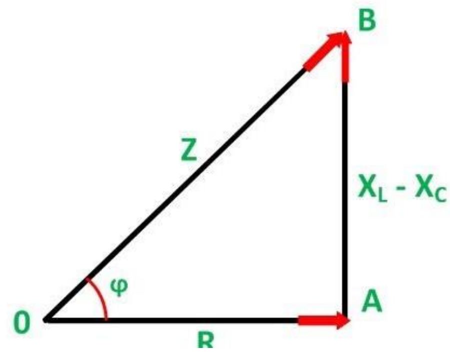
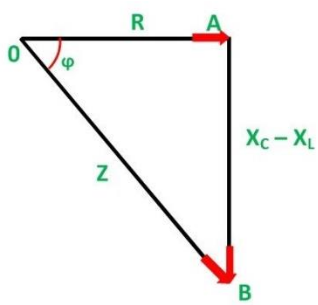


Fig 5.56 Phasor diagram shown **V_L>V_C**

$$V_T = \sqrt{V_R^2 + (V_L - V_C)^2}$$
$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$
$$I = \frac{V}{Z} = \frac{V}{\sqrt{R^2 + (X_L - X_C)^2}}$$
$$PF = \cos\varphi = \frac{R}{z} = \frac{V_R}{V_T}$$

Case: II When V_C>V_L

In this case phasor diagram and waveforms are as follows.



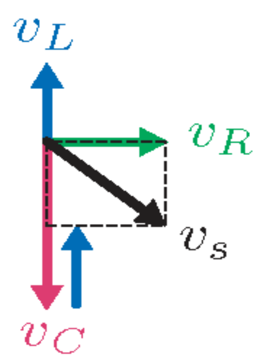


Fig 5.57 Phasor diagram shown **V_C>V_L**

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

AC through RLC Parallel Circuit:

A parallel RLC circuit is shown in figure below supplied by voltage V and frequency f.

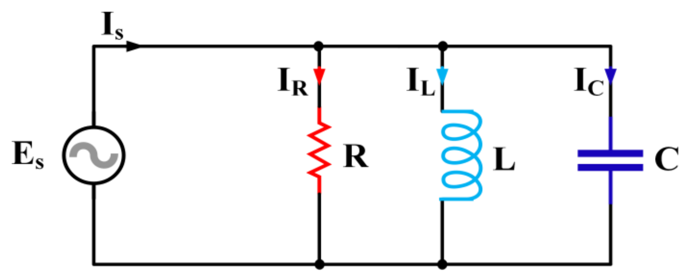


Fig 5.58 AC through RLC Parallel Circuit

In this case applied voltage will be available across R, L and C so,

$$V_R = V_L = V_C = V.$$

Current will be divided and we will focus our calculation for the currents so the waveforms are shown below.

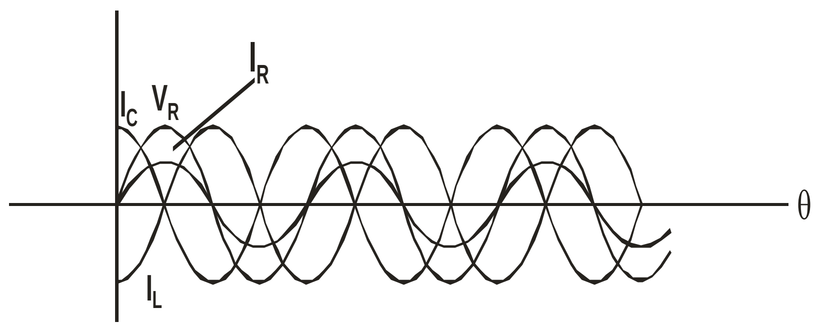


Fig 5.59 Phasor diagram and waveform

Case I: $I_L > I_C$

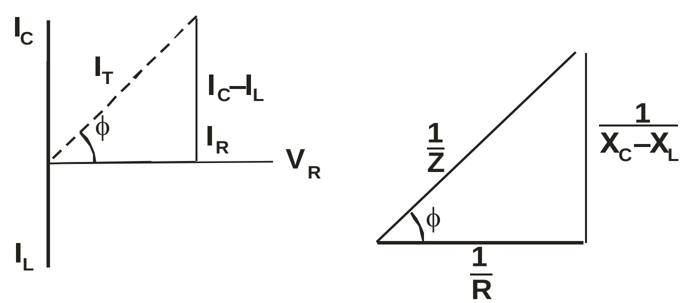


Fig 5.60 Phasor diagram of $I_L > I_C$

In this case

$$I_T = \sqrt{{I_R}^2 + (I_L - I_C)^2}$$

$$Z = \frac{V}{I_T} = \frac{V}{\sqrt{{I_R}^2 + (I_L - I_C)^2}}$$

$$\cos \varphi = \frac{I_R}{I_T}$$

Case II: If $I_C > I_L$

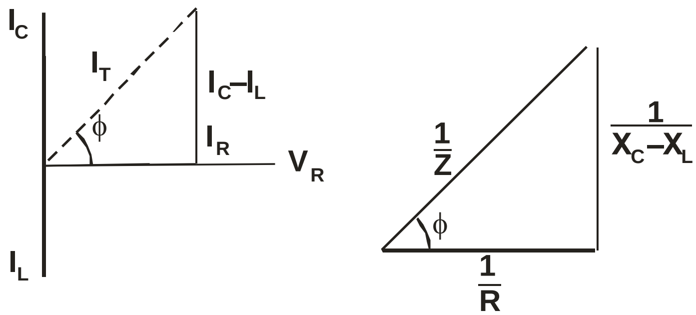


Fig 5.61 Phasor diagram of $I_C > I_L$

$$I_T = \sqrt{(I_C - I_L)^2 + {I_R}^2}$$

$$Z = \frac{V}{I_T} = \frac{V}{\sqrt{(I_C - I_L)^2 + {I_R}^2}}$$

$$\cos\varnothing = \frac{I_R}{I_T}$$

5.2.29 PHASE RELATION:

From the phasor diagram and wave form as follows

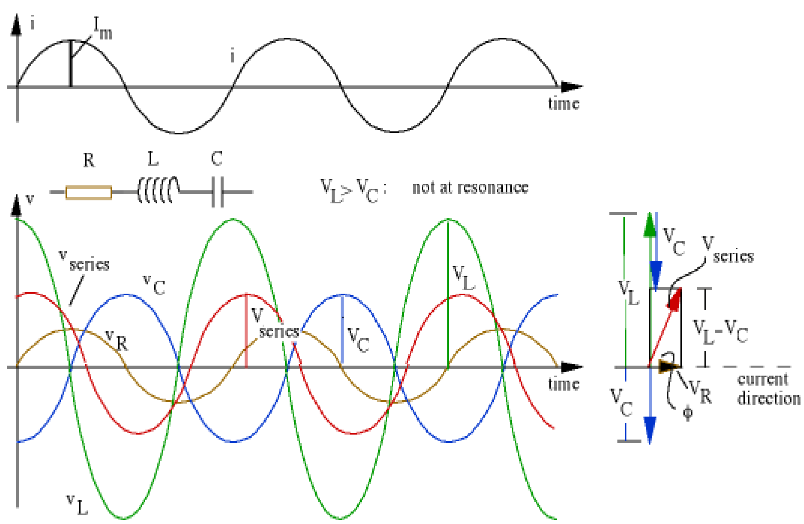


Fig 5.55 Phasor diagram and waveform

Voltage across the inductor coil lead the current I and voltage across capacitor will lag the current I. Current will be same as the components R, L and C are connected in series. Now we can draw the phasor diagram and impedance triangle as show in figure below. For the phasor diagram there are two possibilities that are as follows.

5.2.30 POWER FOR RLC SERIES CIRCUIT:

It is when an ac signal is applied to a inductor or capacitor then no power is dissipated across it or average power is zero. So the total power is dissipated across R and can be found by VI or I^2R. Consider the series RLC circuit.

Since generally,

$$P = I^2R$$

$$P = I \times I\,R$$

$$= I \times \frac{V}{Z} \times R$$

$= V\,I\,\text{Cos}\,\varphi$

Where Cos φ is called as the power factor and the factor VI is called as the apparent power.

Apparent power VI can be split into two components as shown in figure below.

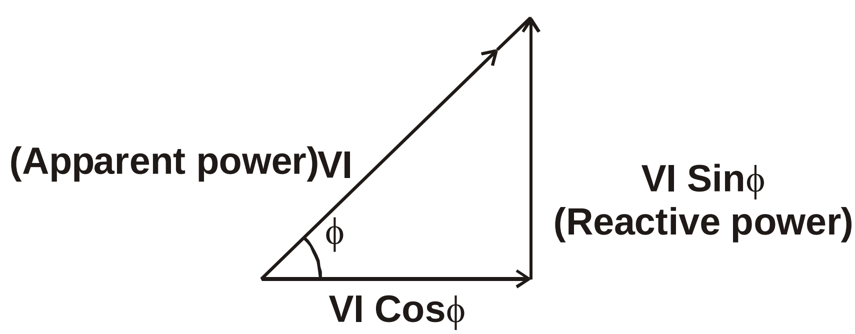


Fig.6.62 Power for RLC Circuits

So apparent power is a vector sum of two powers i.e. real power and reactive power.

Problem No. 1

In a RLC series circuit, a resister of 10Ω, a capacitor of 100mF and an inductor of 0.05H are connected in series to a supply of 100V and Hz. Find

(i) Impedance of the circuit

(ii) Current taken

(iii) Power factor

Solution:

i.

$$X_L = 2\pi fL$$
$$X_L = 2\pi \times 50 \times 0.05 = 15.7\Omega$$
$$X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi \times 50 \times 100 \times 10^{-6}} = \frac{1}{0.03141}$$
$$= 31.83\Omega$$
$$Z = \sqrt{R^2 + (X_C - X_L)^2} = \sqrt{(10)^2 + (31.83 - 15.7)^2}$$
$$= \sqrt{100 + 260.20}$$
$$Z = \sqrt{360.20} = 18.97\Omega$$

ii.

$$I = \frac{V}{Z} = \frac{100}{18.97} = 5.268\,\text{Amps}$$

iii.

$$\text{Cos}\varnothing = \frac{R}{Z} = \frac{10}{18.97} = 0.527$$

Problem No. 2 (Self-Test Problem)

A coil of 0.2H, a resistance or 20 Ohm and a capacitor of 100 mF are connected across 100 volts, 50Hz supply. Find

(i) Impedance
(ii) Line Current
(iii) Power factor (Leading/ Lagging)

Problem No. 3

A resistor of 10W, a capacitor of 120mF and an inductor of 19mH are connected in parallel across 50 volts and 60Hz supply. Find.

i. Line Current
ii. Impedance
iii. Power factor

Solution:

i.

$$I_R = \frac{V}{R} = \frac{50}{10} = 5\text{Amps}$$

$$I_L = \frac{V}{X_L} = \frac{50}{2\pi \times 60 \times 19 \times 10^{-3}} = \frac{50}{7.1628} = 6.98\text{Amp}$$

$$I_C = \frac{V}{X_C} = \frac{50}{\left(\frac{1}{2\pi \times 120 \times 10 - 3 \times 60}\right)} = \frac{50}{22}$$

$$= 2.26\text{Amps}$$

$$\therefore \qquad I_T = \sqrt{I_R{}^2 + (I_L - I_C)^2} = \sqrt{(5)^2 + (6.98 - 2.26)^2}$$

$$= \sqrt{25 + 22.27} = 6.87\text{Amps.}$$

ii.

$$Z = \frac{V}{I} = \frac{50}{6.87} = 7.27\Omega$$

iii.

$$\text{Cos}\text{Ø} = \frac{I_R}{I_T} = \frac{5}{6.87} = 0.72 \text{ Amps}$$

Problem No. 4 (Self-Test Problem)

A resistance of 10Ω, inductance of 15H and capacitor of 3.2μF are connected in parallel to a supply of 10V and 2KHz. Find

(i) Impedance
(ii) Line current
(iii) Phase angle

Problem No. 5 (Self-Test Problem)

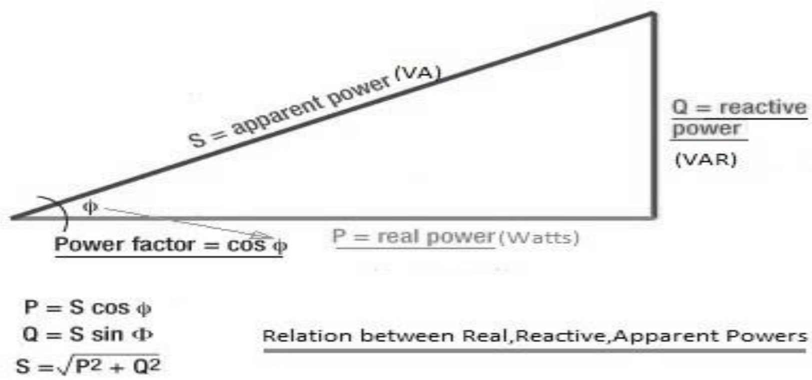
A resistance of 100Ω, inductance of 15mH and capacitor of 9.2μF are connected in parallel to a supply of 30V and 50 KHz. Find

(i) Impedance
(ii) Line current
(iii) Phase angle

5.2.31 REAL POWER, APPARENT POWER:

Real power is the power actually consumed due to the resistive load and apparent power is the power the grid must be able to withstand. The unit of real power is watt

The combination of reactive power and true power is called apparent power, and it is the product of a circuit's voltage and current, without reference to phase angle. Apparent power is measured in the unit of Volt-Amps (VA) and is symbolized by the capital letter S.



5.2.31 POWER FACTOR:

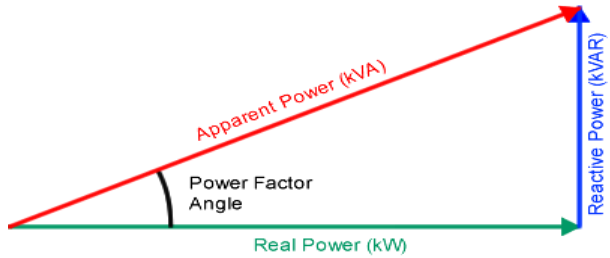
In electrical engineering, the power factor of an AC electrical power system is defined as the ratio of the *real power* absorbed by the load to the *apparent power* flowing in the circuit, and is a dimensionless number in the closed interval of −1 to 1. A power factor of less than one indicates the voltage and current are not in phase, reducing the average product of the two. Real power is the instantaneous product of voltage and current and represents the capacity of the electricity for performing work. Apparent power is the product of RMS current and voltage. Due to energy stored in the load and returned to the source, or due to a non-linear load that distorts the wave shape of the current drawn from the source, the apparent power may be greater than the real power. A negative power factor occurs when the device (which is normally the load) generates power, which then flows back towards the source.

$$Power\ factor = \frac{True\ Power}{Apparent\ Power}$$

OR

$$Power\ factor = \frac{Resistance}{Impedance}$$

$$Cos\ \varphi = \frac{R}{Z}$$



$$\text{Power Factor} = \frac{\text{Real Power (kW)}}{\text{Apparent Power (kVA)}}$$

$$= \frac{kW}{\sqrt{kW^2 + kVAR^2}}$$

In an electric power system, a load with a low power factor draws more current than a load with a high power factor for the same amount of useful power transferred. The higher currents increase the energy lost in the distribution system, and require larger wires and other equipment. Because of the costs of larger equipment and wasted energy, electrical utilities will usually charge a higher cost to industrial or commercial customers where there is a low power factor.

Multiple Choice Questions

Q.1 A sinusoidal ac voltage which undergoes 100 reversals of polarity per second has a frequency of _______ Hz.

(a) 50 (b)60 (c)70 (d)100

Q.2 The polarity of an ac waveform reverses every _______ cycle.

(a)One (b) Half (c) Three (d) Three

Q.3 The time period of a sine wave of 1 KHz is _______ millisecond.

(a) One (b) Two

(c) Both a and b (d) None of above

Q.4 Complex waveforms can be formed by adding _______ to the Fundamental frequency.

(a)Sine wave (b) RMS (c) Saw tooth (d) Harmonics

Q.5 A frequency of 1 KHz falls in the _______ frequency range.

(a) Radio (b) Audio (c) Ultra high (d) Spectrum

Q.6 The RMS value of a sinusoidal ac current is equal to its value at a angle of _______ degrees.

(a) 60 (b) 30 (c) 45 (d) 90

Q.7 A sinusoidal current has an RMS value of 7.07A. Its P-P value is ___ Amperes.

(a) 20 (b) 14.14 (c) 28.28 (d) 57.56

Q.8 The actual shape of a complex wave form is determined by _______.

(a)Number of harmonics (b) Kind of harmonics

(c)Amplitude of harmonics (d) All of the above

Q.9 In a series RL circuit, voltage _______ the current.

(a)Leads (b) Lags (c) store (d) dissipate

Q.10 Skin effect increases the resistance of a conductor at ____frequencies.

(a) Low (b) high (c) wider (d) short

Q.11 A pure inductor or capacitor dissipates _______ power.

(a) Low (b) high (c) No (d) Moderate

Q.12 In a series RLC circuit, phase difference of voltage drops across R and C is _______ degree.

(a) 30 (b) 60 (c) 120 (d) 180

Q.13 For a sine wave RMS value = _______

(a) 0.707 × max.value (b) ${}^{1}\!/\!\sqrt{2} \times \text{maximum value}$

(c) Both a & b (d) None of above

Q.14 Form factor = _______

(a) $\frac{\text{sine value}}{\text{average value}}$ (b) $\frac{\text{r.m.s value}}{\text{average value}}$

(c) $\frac{\text{average value}}{\text{volts}}$ (d) $\frac{\text{average value}}{\text{r.m.s value}}$

Q.15 The difference between AC and DC is:

(a) AC changes value DC does not

(b) AC changes direction DC does not

(c) Both a and b (d) Neither a nor b

Q.16 During each cycle, a sine wave reaches its peak value _______.

(a) One time (b) Two time

(c) Three time (d) Depending on the frequency.

Q.17 A sine wave of 12 KHz is changing faster than a sine wave of _______

(a) 20 KHz (b) 15,000 Hz (c) 10,000 Hz (d) 1.25 MHz

Q.18 A sine wave with a period of 2 ms is changing faster than a sine wave having a period of:

(a) 1ms (b) 0.0025ms (c) 1.5ms (d) 1200ms

Q.19 When a sine wave has a frequency of 60Hz, in 10 Seconds it goes through:

(a) 6 cycles (b) 10 cycles (c) 1/16 cycles (d) 600 cycles

Q.20.If the peak value of a sine wave is 10v, the P-P value is

(a) 20V (b) 5V (c) 100 (d) None of these

Q.21 If the peak value of a sine wave is 20v, then RMS value is

(a) 14.14v (b) 6.37v (c) 7.07v (d) 0.707v

Q.22 The average value of 10v peak sine wave over one complete cycle is

(a) 0 V (b) 6.37V (c) 7.07V (d) 5V

Q.23 The average half cycle value of a sine wave over one complete cycle is

(a) 0v (b) 6.37v (c) 12.74v (d) 14.14v

Q.24 A Phasor represents

(a) The magnitude of a quantity

(b) Magnitude & direction of a quantity

(c) The phase angle

(d) The length of a quantity

Q.25 The duty cycle of a square wave _______

(a)Varies with the frequency (b) both a and c

(c) Varies with the pulse width (d) is 50%

Q.26 A positive angle of 20° is equal to the negative angle of _______.

(a) –160° (b) –340° (c) –70° (d) –20°

Q.27 In a series RC circuit, the voltage across the resistor is _______.

(a) In phase with the source voltage

(b) Lagging source voltage by 90°

(c) In phase with the current
(d) Lagging the current by 90°

Q.28 In a series RC circuit, the voltage across the capacitor is _______.
(a) in phase with the source voltage
(b) Lagging source voltage by 90°
(c) in phase with the current
(d) Lagging the current by 90°

Q.29 When the frequency of the voltage applied to a series RC circuit is Increased, the Z _______.
(a) Increases (b) Decreases
(c) Remains the same (d) is Doubled

Q.30 When the frequency of the voltage to a series RC circuit is decreased, the Z _______.
(a) Increases (b) decreases
(c) Remains the same (d) becomes erratic

Q.31 In a series RC circuit when the frequency & resistance are doubled the Z
(a) Is Doubled (b) halved
(c) Gets 4 times (d) cannot be determined

Q.32 In a RC circuit, when R = Xc, the phase angle is --
(a) 0° (b) +90° (c) –90° (d) 45°

Q.33 To decrease the phase angle below 45°, the following conditions must exist.
(a)R = Xc (b)R < Xc (c)R > Xc (d)R = 10Xc

Q.34 A power factor of 1 indicates that the circuit phase angle is _______
(a) 90° (b) 45° (c) 180° (d) 0°

Q.35 In a series RL circuit initial current is _______
(a)Minimum (b) Maximum (c) Zero (d) infinite

Q.36 In a series RL circuit the rate of rise of current keeps
(a) Increasing (b) decreasing (c) constant (d) fluctuating

Q.37 In a series RL circuit current decays at a progressively _______ rate
(a) Increasing (b) decreasing (c) oscillating (d)None of these

Q.38 In an R-L circuit, current _______ the voltage
(a) Leads (b) Lags (c) both a and b (d) None of these

Q.39 Power factor is given by the ratio of circuit resistance and _______.
(a) Resistance (b) impedance (c) reluctance (d) Resonance

Q.40 In a series RL circuit, V_L ------------------------ V_R .
(a) Lags, 45 (b) Lags, 90 (c) Leads 90 (d) Leads, 45

Q.41 The power in an AC circuit is given by _______

(a) VI Cos φ (b) VI Sin φ (c) I^2Z (d) VI Sin θ

Q.42 The phase angle of a series RLC circuit is leading if

(a) XL = 0 (b) R = 0 (c) XC > XL (d) XC= XL

Q.43 Energy sources are normally rated in _______.

(a)Watts (b) Volt-ampere

(c)Volt-ampere reactive (d) None of these

Q.44 The total reactance of a series RLC circuit at resonance is _______.

(a)Zero (b) Equal to resistance

(c) Infinity (d) Capacitive

Q.45 If the resistance in parallel with a parallel resonant circuit is reduced, the band width _______

(a) Disappear (b) decreases

(c) Becomes sharper (d) increases

ANSWER KEY

1.(a)	2. (b)	3(a)	4.(d)	5.(b)
6.(c)	7.(a)	8.(d)	9.(a)	10.(b)
11.(c)	12.(d)	13.(c)	14.(b)	15.(b)
16.(b)	17.(c)	18.(b)	19.(d)	20.(a)
21.(a)	22.(a)	23.(c)	24.(b)	25.(d)
26.(b)	27.(c)	28.(b)	29.(b)	30.(a)
31.(d)	32.(d)	33.(c)	34.(d)	35.(b)
36.(c)	37.(b)	38.(b)	39.(b)	40.(c)
41.(b)	42.(c)	43.(b)	44.(a)	45.(d)

Short Questions

1. Describe alternating current?
2. Define sine wave?
3. Define cycle?
4. Describe wavelength?
5. Calculate ʎ for a radio wave with f of 30GHz?
6. Define period?
7. For the 6m band used in radio, what is the corresponding frequency?
8. Define frequency?
9. Describe amplitude?
10. Define peak to peak value?
11. The sum of positive & negative peak values is called peak to peak value?
12. Describe the average value of AC?

13. Define RMS value?
14. Define form factor?
15. Define peak factor?
16. What is Lag and lead?
17. Describe the phase difference?
18. Define impedance?
19. Define Capacitive Reactance?
20. A series RL circuit has a resistance of 1KW and an inductance of 1mH.Find the time constant.

Long Questions

1. Describe A.C through pure resistive circuit, also write down the characteristics of the resistive circuit?
2. Describe phase in, phase out, phase lag and phase lead in an A.C circuit?
3. What is difference between self-inductance and self-induced e.m.f?
4. Prove that XL = 2 π f L?
5. Prove that$Xc = \frac{1}{2\pi f C}$?
6. How you can describe electromagnetic wave spectrum with the help of diagram?
7. Discuss in detail, fundamental wave and its harmonics with the help of wave diagram?
8. Describe A.C through pure inductive circuit, also write down the characteristics of the resistive circuit?
9. Describe A.C through R-L series circuit, also write down the characteristics of the resistive circuit?
10. Describe A.C through R-L parallel circuit, also write down the characteristics of the resistive circuit?
11. Explain R- L time constant and R-C time constant?
12. Compare Audio frequency choke and radio frequency choke?
13. Explain R-C series circuit with the help of phasor and wave diagram, also describe the impedance triangle of this circuit?
14. Explain R-C parallel circuit with the help of phasor and wave diagram, also describe the impedance triangle of this circuit?
15. Explain R-L-C parallel circuit with the help of phasor and wave diagram, also describe the impedance triangle of this circuit?
16. What is difference between real power and apparent power? How can you find the power factor using real power and apparent power

CHAPTER 06 TRANSFORMER

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OBJECTIVES
After completion of this chapter students will be able to:

1. **Principle of Transformer**
2. **Mutual Induction, Coefficient of Mutual Induction**
3. **Turn Ratio of Transformer**
4. **Construction of Transformer**
5. **Types of Transformer**
6. **Auto Transformer**
7. **Star Delta Connections**
8. **Transformer Losses**

6.1 TRANSFORMER

A transformer is defined as a passive electrical device that transfers electrical energy from one circuit to another through the process of electromagnetic induction. It is most commonly used to increase (‘step up’) or decrease (‘step down’) voltage levels between circuits.

6.1.1 PRINCIPLE OF TRANSFORMER:

A transformer is a static or stationary electro-magnetic device, consisting of two magnetic fields, by means of which electric power in one circuit is transformed into electric power of the same frequency in another circuit.

A basic single phase transformer having two windings wound on a common magnetic core is shown in figure 6.1. From the principle of mutual induction, when two coils are inductively coupled and if the current in one coil is changed uniformly, an EMF (electro-magnetic force) is induced in the other coil. If a closed path is provided at the secondary circuit, this induced EMF at the secondary drives a current. As shown in figure 6.1, the transformer has two coils which are electrically separated and magnetically linked through a

common path. The basic principle of the transformer is same as the principle of mutual induction. The coils of the transformer have high mutual inductance.
In brief we can say that:
Transformer is a static device which is used for:

- Transfers electric power from one circuit to another.
- During transfer of power, there is no change of frequency.
- It uses electromagnetic induction to transfer electric power from one circuit to another circuit.
- The two electric circuits are in mutual inductive influence of each other.

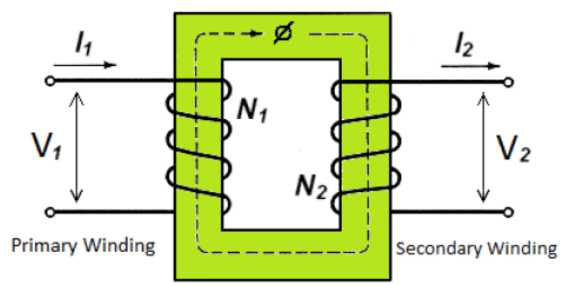


Fig.6.1 Basic Transformer

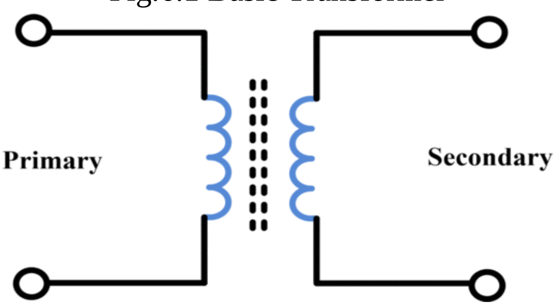
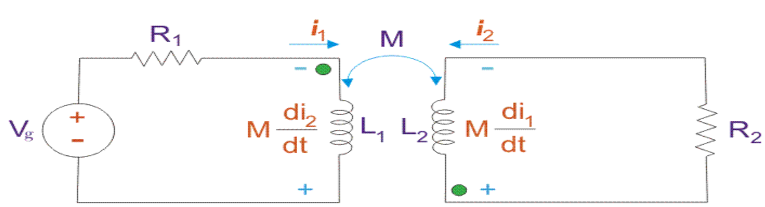


Fig.6.2 Symbolic representation of Transformer

6.1.2 MUTUAL INDUCTION:

Mutual Inductance is defined as the phenomenon of inducing emf in one coil by changing the current in another placed nearby. Two coils are named as primary and secondary coils respectively. In the primary coil, current is changed while the other coil in which e.m.f is induced is known as the secondary coil.



Consider the coils of figure 6.3 A battery is connected with the primary coil through a resistor R1 and the secondary coil is connected with the load resistor R2. When current is flowing through the primary, magnetic flux is produced across the primary. This magnetic flux is also linked with the secondary. Now, if we change the resistance in the primary circuit, the current flowing through the primary coil will also be changed. Hence the magnetic flux also changes. As the magnetic flux of primary is linked with the secondary, therefore the change in magnetic flux produces an EMF in the secondary coil.

Induced EMF in the secondary depends upon the rate of change of magnetic flux of primary, i.e.

$$(\text{emf})_{Sy} \quad \infty \quad -\left(\frac{dI}{dt}\right)_{Py} \quad \text{------------------} \quad (i)$$

$$(\text{emf})_{Sy} = -M\left(\frac{dI}{dt}\right)_{Py} \quad \text{------------------} \quad (ii)$$

Where M is the constant and known as the mutual inductance of the two coils. M depends upon the number of turns of primary & secondary, spacing between the turns and cross-sectional area.

From equation (ii) M is :

$$M = -\left(\frac{dI}{dt}\right)_{Py} / (\text{emf})_{Sy} \quad \text{-----------------------------}(iii)$$

Thus the mutual induction can be defined as the ratio of the emf induced in the secondary to the rate of change of current in the primary coil.

6.1.3 CO-EFFICIENT OF MUTUAL INDUCTION:

The ratio of flux from one coil linking with another coil is called the co-efficient of coupling (K) between the two coils.

K= Flux Linkage between L1 and L2 / Flux produced by L1

There is no unit for K because it is a ratio.

6.1.4 TURN RATIO OF TRANSFORMER:

Turn ratio is a very important transformer parameter. Following figure shows a transformer with NP turns on the primary an NS turns on the secondary winding. The voltage applied at primary is VP as shown by figure

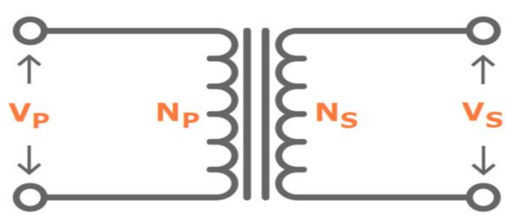


Fig 6.3 Turn ratio of transformer

$$\frac{NS}{NP} = \frac{VS}{VP} = \frac{IP}{IS}$$

The number of turns of secondary winding of a transformer is denoted by N_S and the number of primary turns is denoted by N_P. The ratio between the N_S and NP is called the Turns Ratio of the transformer. $N = \frac{Ns}{NP}$

6.1.5 CONSTRUCTION OF A TRANSFORMER:

A small power transformer comprises of the following parts.

i. Body
ii. Core
iii. Windings
iv. Tapings
v. Insulation

Body:

The body of the transformer is made up of steel normally. The body is a box like shape. The transformer body consists of magnetic core, windings and other auxiliary parts. To avoid from the corrosion, the body is painted inside and from outside. Transformer ratings is also been mentioned on the body of the transformer. For cooling purposes of transformer, there are ducts made on the transformer body. Body provides the protection to the transformer and protects the transformer from any external damaging force and from vibration as well. Some transformers especially transformers in electronic circuits are kept without the body for cooling purposes. A specific power supply transformer has been shown in figure below:

Fig 6.6 Body of Transformer

Core:

Core is used to support the transformers windings and to provide the minimum reluctance magnetic path to flux. The core used in all kind of transformers is always laminated steel made in order to provide minimum air

gap. Each stamping of laminated core is isolated from the other one. In this way the eddy currents induced in the core is reduced.
The steel used to make the laminated core is composed of high silicon contents. In order to increase the permeability sometimes the core is heat treated. In this way the hysteresis losses are reduced. Construction of core has been shown in figure below:

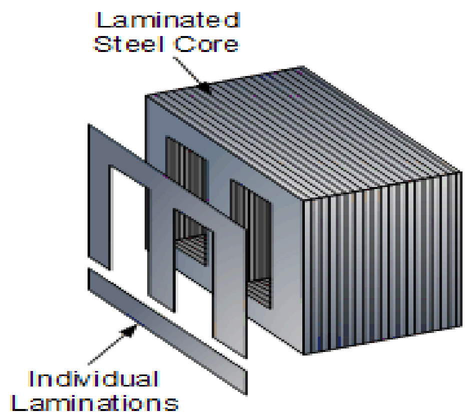


Fig 6.7 Construction of Laminated Core

Windings:

Transformers frequently used in electronics equipment's are single phase transformers which consist of a primary winding and a secondary winding. While in three phase transformers, there are three primary and three secondary windings which are connected together in star or delta. The winding which is connected with the input supply is known as the primary winding and the winding which is used for having desired output voltage is known as the secondary winding. Both windings are separated from each other and insulated from the core as well.

Tapings:

By changing the turn ratio of the transformer, we can easily control the voltage supplied to power networks by the transformer. To affect a change in the ratio of transformation, we provide tapping at different places in the windings of the transformer. Therefore, it is possible to get different turns ratio and thus different voltages at different tapings. Figure 7.9 shows the tapping used in a transformer.

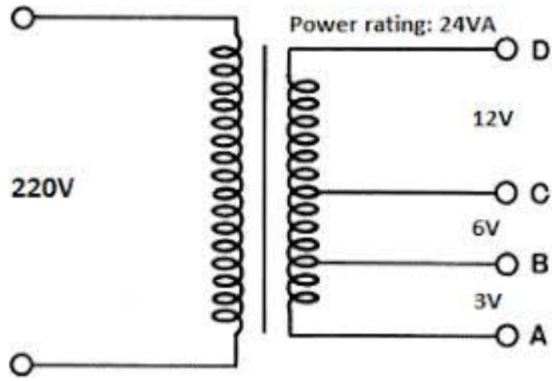


Fig.6.8 Tapped transformer

If 220 V supply is given on the high voltage side, 12 V , 6 V and 3 V are obtained on the low voltage side.

Insulation:

In any type of transformer, the insulation performs three tasks. It isolates each turn from the other turn. Insulate the coils from each other and isolate the coils from the core.

6.1.6 TYPES OF A TRANSFORMER:

There are two main types of transformer are given below.

- Step up transformer
- Step down transformer

Step Up Transformer:

If the number of turns of secondary winding are more than the number of turns of the primary winding then such a transformer is called the step up transformer. The induced voltage in the secondary coil always depends upon the turn ratio of transformer. The ratio of secondary voltage of a transformer to the primary voltage is always equal to the ratio of secondary turns to the primary turns, i.e.

$$\frac{VS}{VP} = \frac{Ns}{NP}$$

$$V_S = \frac{Ns}{NP} \times V_P$$

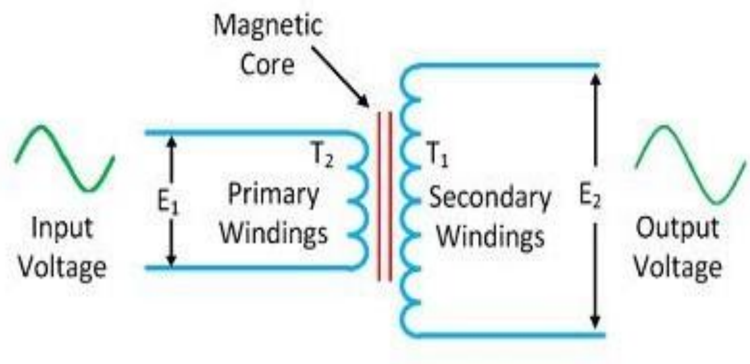


Fig 6.4 Step Up Transformer

The turn ratio of step up transformer is always more than 1.

Step Down Transformer:

If the numbers of turns in the secondary winding are less than the number of turns of the primary winding then the transformer in known as the step down transformer, the step down transformer is shown in the figure below:

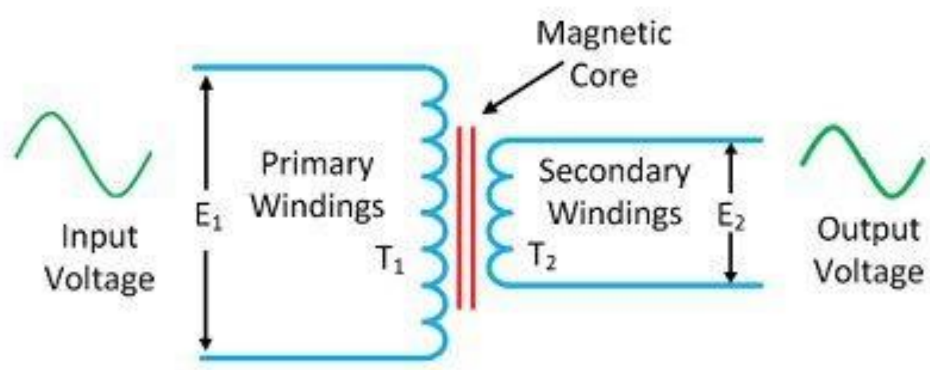


Fig 6.5 Step Down Transformer

Types of transformer with respect to core.

- Core type
- Shell type
- Berry type

Types of transformer with respect to frequency.

- Power frequency transformer.
- Audio frequency transformer.
- Radio frequency transformer.
- Video frequency transformer.

6.1.7 LIST OF CORE MATERIALS OF TRANSFORMER:

Following core materials are used in transformers.

i. Laminated Core
ii. Powdered-Iron
iii. Ferrite-Core

6.1.8 AUTO TRANSFORMER:

An auto transformer is one which is having only one winding which works as primary as well as secondary. In auto transformer, primary and secondary windings are not electrically isolated from each other as in two windings transformer. Auto transformer is only used where a low transformation ratio is required. However, its theory and operation are similar to that of a discrete winding transformer. Following Figure shows an auto-transformer in which only one winding is wound on a laminated magnetic core. Figure also a show that a single winding is used as primary and secondary and a part of winding is common is both primary and secondary. The auto transformers are also classified as step up and step down transformers because voltage can be stepped up and stopped down using these transformers. It is shown in following figure:

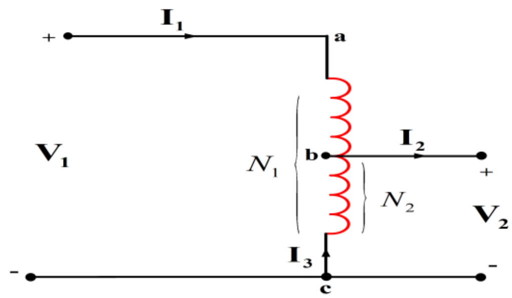


Fig.6.9 Auto transformer

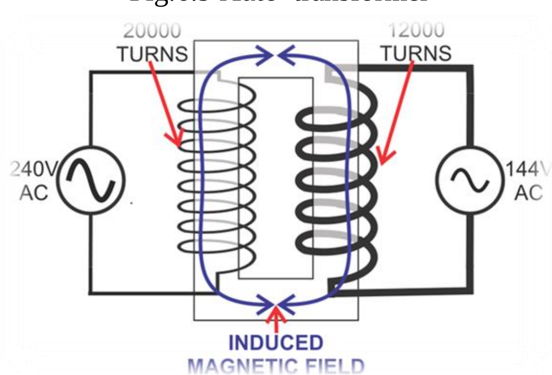


Figure (a) Two winding transformer

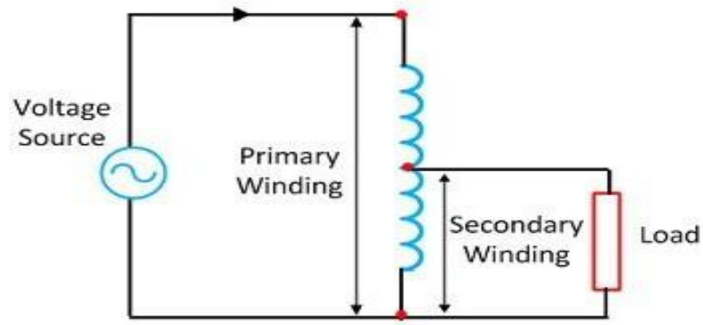
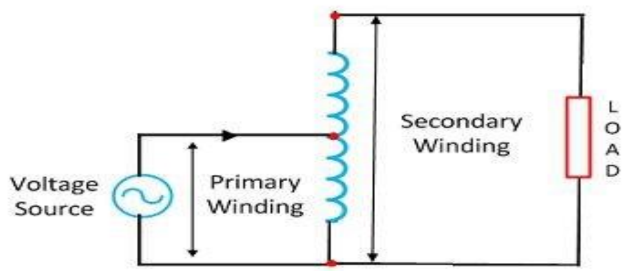


Figure (b) Step down auto transformer



Figure(c) Step up auto transformer

Fig.6.10 different transformers

Above figure (a) shows a two winding transformer figure (b) shows an auto-transformer which steps down the voltages. In step up auto transformer, the entire winding is used as a secondary winding and the part of the winding is used as a secondary winding. Figure (c) shows an auto transformer which steps up the voltage. The entire winding is used as a secondary winding.

From figure (b) and (c) it seems that an auto transformer is similar to a resistance potential divider. An auto transformer can step up and step down the voltage. An auto transformer has less voltage less whereas more less occurs in a potential divider. Therefore, the efficiency of an auto-transformer is higher than that of a potential divider.

Advantages of Auto-Transformer:

- Auto transformer has the following advantages:
- Less amount of copper is required.
- Smaller in size.
- Cost is less than two windings transformer.
- Resistance and reactance is less than two winding transformer.
- Copper loss is less
- Volt-ampere rating is more compared to two winding transformer.
- Since loss is less, efficiency is more.

- It is possible to get smooth and variation in voltages.

Disadvantages of Auto-Transformer

- There is possibility of high short circuit currents for short circuits on the secondary side.
- The full primary current will appear across the secondary causing higher voltage on secondary resulting danger of accidents.
- Risk factor appears as there is no electrical isolation between primary and secondary.
- It is economical only, if the voltage ratio is less than 2.

Applications:

(1) Is used where primary and secondary voltage have no large difference.
(2) Is used to provide neutrals to three wire lighting systems.
(3) These are used for light dimmers.
(4) These are used to get two phase supply from three phase supply.
(5) Used to control single and three phase locomotive devices.

6.1.9 APPLICATION OF TRANSFORMER IN ELECTRONICS:

i. Step down transformer:

A step down transformer is one in which output voltage is less than the input voltage. The main uses of step down transformers have been given below:

- To step down the 14KV voltage to 440V for industry applications.
- To step down 440V for house hold and other uses.
- To isolate the high primary current from the secondary current.
- To isolate the primary and secondary windings in order to avoid shorts.

ii. **Step Up Transformer:**

A step up transformer is one in which output voltage is greater than the input voltage. The main uses of step up transformer are where the voltage needs to be stepped up from low value to high value.

iii. **Impedance Matching:**

For maximum transfer of power from one circuit to another, the both of two should have equal impedances. If they do not have equal impedances, a transformer with suitable turn ratio can be used to achieve this impedance match. A certain circuit working at a high voltage but low current (hence high impedance) has some times to be coupled to another circuit which requires low voltage but high current (hence low impedance). If two such circuits are coupled directly, energy transfers will not maximum. In such cases, a transformer is used as impedance matching devices because it can do the job of increasing or decreasing the voltages and currents very efficiently.

$$T = \frac{V_S}{V_P} = \frac{I_P}{I_S}$$

$$T^2 = \frac{V_S}{V_P} \times \frac{I_P}{I_S}$$

Consider,

$$T^2 = \frac{I_S Z_S}{I_P Z_P} \times \frac{I_P}{I_S}$$

$$T^2 = \frac{Z_S}{Z_P}$$

Where Z_P=Impedance of primary
Zs = Impedance of Secondary
T = Turn ratio

Suppose a circuit of output impedance 200Ω is to be coupled to a circuit of input impedance 2π. The turn ratio Ns/Np should be such that the impedances match to each other. From the formula:

$$Z_P = \frac{Z_S}{T^2}$$

$$200 = \frac{2}{T^2}$$

$$T^2 = \frac{2}{200}$$

$$T^2 = \frac{1}{100}$$

$$T = \sqrt{\frac{1}{100}}$$

$$\frac{N_S}{N_P} = \frac{1}{10}$$

This means that the secondary turns should be one-tenth the primary turns. Often, auto transformer is also sued for impedance matching purpose.

iv. **Coupling:**

Two AC circuits are said to be coupled when they are linked in such a way that energy is transferred from one circuit to another.
When there is an existence between the coils that are in separate circuits, then they are inductively coupled. Mutual inductance makes possible the transfer of

energy from one circuit to the other by transformer action. It means that the alternating current established in the first or primary circuit produces magnetic flux which is linked with, and induces a voltage in the coupled or secondary circuit. This does not of course; apply to PC circuits since the flux must be changing for electromagnetic induction to occur.

6.1.10 TRANSFORMER LOSSES:

The various losses associated with transformer are listed below:

i. Copper Losses:

Copper losses are due to the resistance of primary and secondary windings.

ii. Core/Iron Losses

Core/Iron Losses are of following types:

(a). Magnetizing current Loss:

In the case of ideal transformer, the primary inductance will offer infinite impedance and therefore no magnetizing current will flow. Practically, the magnetizing current does flow.

(b). Eddy current Loss:

Resistive losses are caused by eddy currents induced in the core of the transformer.

(c). Hystersis Loss:

Resistive (heating) losses occure in taking the core through its magnetisation cycle.

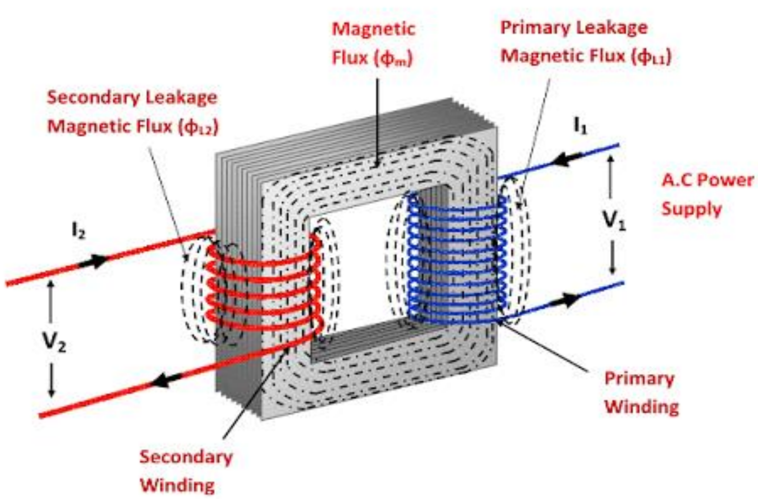


Fig.6.20 Hystersis Loss

iii. Flux leakage losses:

As all the flux of primary is not linked with the secondary, and vice versa. The leakage of flux has been shown in figure 7.20. The induced voltages are therefore smaller than those indicated by a coupling factor of unity.

6.1.11 HYSTERESIS LOSS & CORE LOSS:

Hysteresis Loss:

When iron core changes its polarity due to the passing of an A.C in every cycle, it consumes a little energy at each alternation. This loss of energy is known as the hysteresis loss. Due to the effect of hysteresis, the flux changes, loss behind the current changed producing them. Hence energy is lost due to hysteresis and appears as heat in the core. The higher the frequency of the alternating current and greater the flux density. The greater will be the hysteresis loss. As soft iron has smaller hysteresis loss than hard steel, hence the cores of the transformers are generally made of soft iron. The alloyed iron and other alloys often used for cores are stalloy, Permalloy and mumetal.

Core Losses:

There is always some loss of energy in the core material of a practical transformer. This loss is seen as a heating of ferrite and iron cores, but it does not occur in air cores. Part of this energy is consumed in the continuous reversal of the magnetic field due to the changing direction of the primary current, this energy loss is called hysteresis loss. The rest of the energy is caused by eddy currents induced in the core material by the changing magnetic flux. The eddy-current loss is greatly reduced by the use of laminated construction of iron cores. The thin layers of ferromagnetic material are insulated from each other to minimize the build-up of eddy currents by confining them to a small area and keep core losses to a minimum.

Multiple Choice Questions

Q.1 A transformer can operate from_______ dc.
(a) Fixed (b) Changing (c) Positive (d) Negative

Q.2 A _______ can operate from changing dc.
(a) Transformer (b) opto- coupler (c) source (d) Battery

Q.3 An autotransformer has only _______ winding.
(a) one (b) two (c) three (d) any of above

Q.4 An _______ transformer has only one winding.
(a) Step up (b) step down (c) tapped (d) auto

Q.5 A transformer represents an example of __inductance.
(a)Linear (b) Non-linear (c) Mutual (d) Self

Q.6 A ____ represents an example of mutual inductance.
(a) Transformer (b) Capacitor (c) Conductor (d) Insulator

Q.7 Thin sheets of silicon steel used for making transformer core are called:
(a) Windings (b) coils (c) laminations (d) Mutual

Q.8 Unit of inductance is called _______.
(a) Farad (b) Henry (c) Ampere (d) Ohm

Q.9 Unit of _______ is called Henry.
(a)Capacitance (b) Resistance
(c) Conductance (d) Inductance

Q.10 A transformer consists of _______ or more coils.
(a) Infinite (b) stepped (c) two (d) Longitudinal

Q.**11** Transformer coils are _______ coupled.
(a)Electrically (b) Magnetically(c) Horizontally (d) Vertically

Q.12 A _______ transformer has more than 1 turn ratio.
(a) Step-up (b) Step-down (c) Auto (d) Tapped

Q.13 A _______ transformer has less than 1 turn ratio.
(a)Step-up (b) Step-down (c) Auto (d) Tapped

Q.14 A transformer cannot respond to _______ source.
(a) Constant voltage (b) DC voltage
(c) Professional (d) Resonance

Q.15 _______ cannot be increased by transform.
(a)Current (b) Power (c) Resistance (d) Inductance

Q.16 Power cannot be increased by _______.
(a) Transformer (b) Capacitor
(c) Inductor (d) None of these

Q.17 Transformer working depends on _______.

(a) Self-inductance (b) magnetic flux
(c) Mutual inductance (d) any of these

Q.18 Working of _______ depends on mutual inductance.
(a) Transformer (b) Capacitor (c) Resistor (d) All of these

Q.19 Step-up transformer steps up _______.
(a)Voltage (b) Current (c) Power (d) Capacitance

Q.20 _______ transformer increases the level of voltage.
(a)Step down (b) step up (c) Auto (d) power

Q.21 A step up transformer always decreases the ______
(a)Voltage (b) Current (c) Power (d) Turn ratio

Q.22 If primary voltage is 200v with a secondary turns 100 and primary turns 500 then the output voltage at secondary will be _______.
(a) 40 (b) 60 (c) 80 (d)100

Q.23 The purpose of laminating is _______
(a) To decrease resistance
(b) To decrease eddy current loss
(c) To increase resistance
(d) To increase power

Q.24 A transformer can be used only for _______.
(a)DC voltage (b) DC Current (c) DC power (d) AC voltage

Q.25 The turn ratio to match a 50W source to 2000W load is _______.
(a) 0.10 (b) 0.5 (c) 0.20 (d) 0.17

ANSWER KEY

1.(b)	2. (a)	3.(a)	4.(d)
5.(c)	6.(a)	7.(c)	8.(b)
9.(d)	10.(c)	11(b)	12.(a)
13.(b)	14.(b)	15.(b)	16.(a)
17.(c)	18.(a)	19.(a)	20.(b)
21.(b)	22.(a)	23.(b)	24.(d)
25.(b)			

Short Questions

1. Define transformer?
2. Define mutual induction?
3. Define self-inductance?
4. Define co-efficient of mutual induction?
5. Describe the turn ratio of transformer?
6. One coil produces a magnetic flux of 50mWb while other 20mWb. Determine K?
7. **A** transformer primary has 100 turns while secondary has 400 turns. Determine turn ratio?
8. Describe the construction of transformer?
9. Enlist the types of transformer?
10. Enlist core material of transformer?
11. Describe auto transformer?
12. Describe step down transformer?
13. Describe step up transformer?
14. List the transformer losses?
15. Two 250 mH inductor has mutual inductance of 250mH. Determine K?
16. The coefficient of coupling between a coil of 2H and a coil of 0.9 His 0.7. Determine mutual inductance?
17. If Vp = 120V, f = 60Hz and turn ratio = 5 then find Vs?

Long Questions

1. What is meant by transformer? Write down its working principle?
2. Explain the construction of transformer?
3. Write a detail note on Auto transformer?
4. Explain the losses occurs in transformers?
5. Write down the applications of transformers in electronics?
6. List the advantages and disadvantages of auto transformer?
7. Explain co-efficient of coupling and co-efficient of mutual inductance?
8. Write a detail note on three phase transformer?

CHAPTER 07 RESONANCE

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OBJECTIVES
After completion of this chapter students will be able to:

1. Introduction to Resonance
2. Series Resonance & its Characteristics
3. Series RLC Impedance
4. Parallel Resonance & Characteristics
5. Comparison of Series & Parallel Resonance
6. Q of a Circuit, Selectivity
7. Application of a Resonant Circuit

7.1 RESONANCE:

The resonance effect occurs when X_L becomes equal to X_C in RLC circuits. The main application of resonance is in RF circuits for tuning an AC signal to desired frequency. All examples of tuning in radio and television, receivers, transmitters and electronic equipment in general are application of resonance. At particular frequency, in a circuit comprising of X_L and X_C, the inductive reactance is equal to the capacitive reactance i.e $X_L = X_C$ then this case of equal and opposite reactance is called resonance, and the circuit is called the **Resonant Circuit**. The frequency at which the $X_L = X_C$ is called the resonant frequency (fr).

Generally, we can say that large values of L and C provide relatively a low resonant frequency and small values of L and C provides large resonant frequency. The most common application of resonance in RF circuit is called Tuning. In this use, the LC circuit provides maximum voltage output at the resonant frequency compared with the amount of output at any other frequency either below or above resonance. This is illustrated in figure 7.1, where the LC circuit resonates at 1000KHZ. The result is maximum output at 1000 KHZ, compared with lower or higher frequencies. There are almost unlimited uses for resonance in AC circuits.

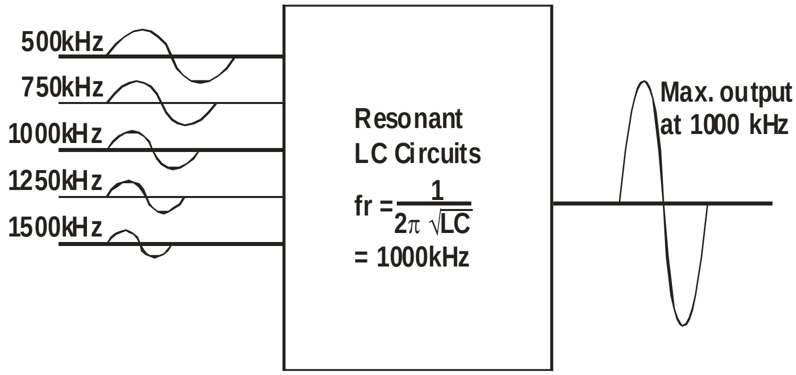


Fig.7.1 Resonant circuit

7.2 RELATION BETWEEN RESONANT FREQUENCY, INDUCTANCE AND CAPACITANCE:

We know that with the increase of frequency, the inductive reactance is increased. Therefore, the frequency and inductive reactance are directly proportional to each other. In equation form we can write this relation as:

$X_L = 2\pi f L$ ----------------- (i)

Conversely, the capacitive reactance is decreased with the increase of frequency. Thus the frequency and the capacitive reactance are inversely proportional to each other. In equation form we can write this relation as:

$X_C = \frac{1}{2\pi f C}$ ----------------- (ii)

We know that when the resonance of an ac circuit occurs then the inductive and capacitive reactance is equal, i.e.

$X_L = X_C$ ----------------------- (iii)

$$2\pi f L = \frac{1}{2\pi f C}$$

$$(f)(f) = \frac{1}{(2\pi)^2 LC}$$

$$(f)^2 = \frac{1}{(2\pi)^2 LC}$$

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

Numerical Problems

Example 7.1

What is the resonant frequency if 500mH inductance connected in series with a 2000 nF capacitor?

Solution:

As

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

So

$$f_r = \frac{1}{6.28 \times \sqrt{500 \times 10^{-3} \times 2000 \times 10^{-9}}}$$

$$= \frac{1}{6.28 \times \sqrt{10^{-6}}}$$

$$= \frac{1}{6.28 \times 10^{-3}}$$

7.3 & 7.4 SERIES RESONANT CIRCUIT:

A series resonant circuit is shown in figure below:

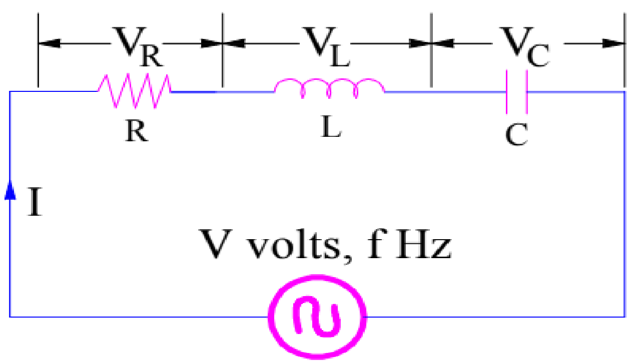


Fig.7.2 Series Resonant Circuit

In this resonant circuit, inductive and capacitive reactance are equal. The net reactance of such a circuit is zero and the impedance of the circuit is equal to the resistance(R) of the circuit.

$X_L = X_C$

So

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

$Z = R$

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

Current, is in phase with the applied voltage and power factor of such a circuit is unity. Maximum current flows through series resonant circuit. With the change of value in capacitance the resonance state is achieved. The large value of current in series resonant circuit is controlled by the resistor R. A very large voltage drop across the L and C is appeared which are equal and opposite of each other, cancel out the effect of each other. So it is also called Voltage Resonance.

7.5 CHARACTERISTICS OF SERIES RESONANT CIRCUIT:

Impedance at resonance is equal to resistance R when XL = XC. For a series RLC circuit.

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

As we know that for lower frequencies the value of inductive reactance X_L will be smaller than capacitive reactance X_C. However at higher frequencies the value of capacitive reactance will be lower than the inductive reactance. If we draw a graph between the frequency and an impedance Z, then we obtain a curve as shown in figure 7.3. The figure shows that the impedance gradually increases as the frequency separation from resonance is decreased. The main characteristic of series resonance is that, the current is maximum at resonance because the impedance is minimum and decreases both sides if the frequency separation from resonance increases.

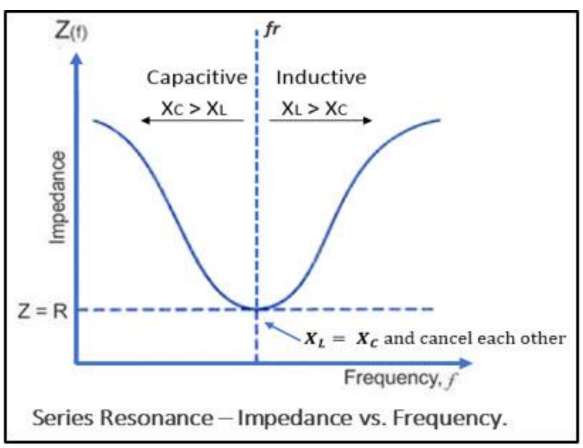


Fig.7.3 Impedance maximum on Resonance point

The relation between current and frequency is shown in figure below:

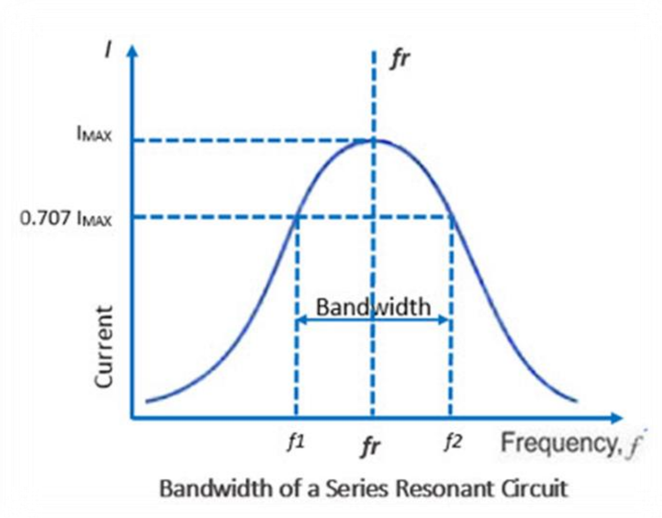


Fig 7.4 the relation between current and frequency in series resonance

The main characteristics of the series resonance circuit are listed as follows:

(1) The inductive reactance is small below the resonant frequency while the capacitive reactance has high values that limit the amount of current.

(2) Capacitive reactance is small above the resonant frequency. However the inductive reactance is having high values that limit the amount of current.

(3) Inductive reactance is equal to the capacitive reactance at the resonant frequency and they cancel out to allow maximum current.

(4) There is minimum impedance offered by the circuit i.e. Zmin=R at resonance.

(5) The voltage drops across inductor and capacitor are maximum and equal in magnitude but they cancel out each other because they are 180° out of phase with each other.

(6) The resonant frequency is given by the following formula.

$$fr = \frac{1}{2\pi\sqrt{LC}} = \frac{0.16}{\sqrt{LC}}$$

7.6 CURRENT, VOLTAGE & IMPEDANCE OF SERIES RESONANT CIRCUIT:

Series RLC Impedance:

As we know that below f_r, $X_C > X_L$. Therefore the circuit acts as capacitive. However at resonance $X_C = X_L$, the circuit is purely resistive. At frequency above the resonant $X_L > X_C$, so the circuit is inductive.
At Z=R the impedance magnitude is minimum and increases in value above and below the resonant point. The figure below shows the graph between the frequency and impedance. At zero frequency X_L is zero while X_C and Z are infinitely large, because the capacitor is behaving like an open and inductor is behaving like a short circuit. As the frequency increases X_C decreases and X_L increases. Since X_C is larger than X_L at frequencies below f_r, Z decreases along with X_C. At f_r, $X_C = X_L$ and Z=R because the impedance of simple RLC circuit is:

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

But at resonance $X_L = X_C$

$$Z = \sqrt{R^2 + (0)^2}$$

$$Z = R$$

So $$I = \frac{V}{R} (\text{at resonance})$$

and voltage drop = $V_R = I \times R$.

Current and voltage in a series RLC circuit:

The current is maximum in the series resonant circuit at resonant frequency. Because the impedance increases, above and below resonant frequency, hence the current decreases.

So I = V/R = Maximum current

The voltage of resistor, follows the current and is maximum at resonance and 0 at f = 0. On the other hand, the voltage is maximum at resonant frequency but drops off above and below f_r. The voltages across L and C at resonance are exactly equal in magnitude but 180° out of phase, so they cancel. Thus the total voltage across the L and C is zero.

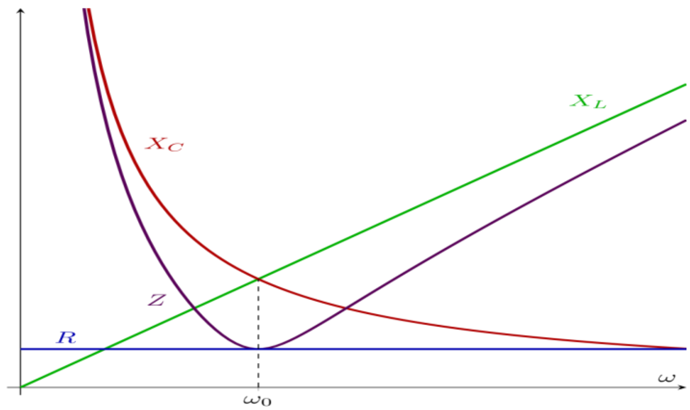


Fig.7.5 Current and voltage in a series RLC circuit

7.7 & 7.8 PARALLEL RESONANT CIRCUIT:

A parallel resonant circuit is shown in figure below:

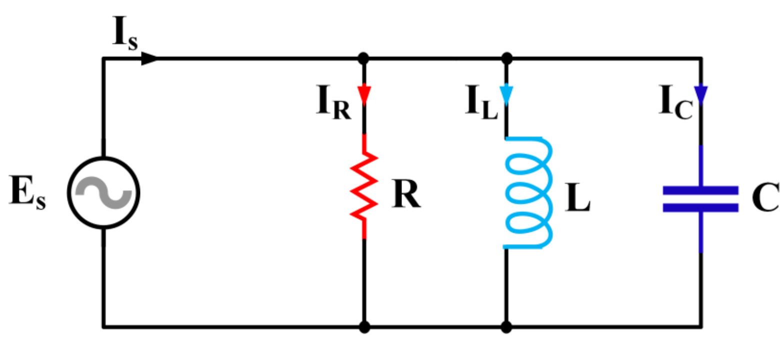


Fig.7.6 Parallel Resonant Circuit:

It consists a capacitor in parallel with a coil of negligibly small resistance, connected across an ac voltage source V having frequency f.

In such a case the coil draw lagging current while the capacitor laws of leading current. When both the inductive reactance and capacitive reactance are equal at resonant frequency, they cancel out the affect of each other because though they are equal in magnitude but opposite in direction. Hence reactive branch currents are equal and opposite at resonance. They cancel each other to produce minimum current in the main lines. Since the line current is minimum, the impedance is maximum.

7.9 CHARACTERISTICS OF PARALLEL RESONANT CIRCUIT:

The characteristics of parallel resonant circuit are exactly opposite to that of the series resonant circuit. If a graph is drawn between the changing line current with the changing frequency, then a curve as shown in figure 8.7 is obtained. As from the figure the line current is zero or minimum at resonance frequency and increases from both sides of resonance with the increase or decrease the frequency from resonant frequency. Therefore, in parallel LC circuit, the circuit impedance is infinite and line current is zero or at minimum level at resonance.

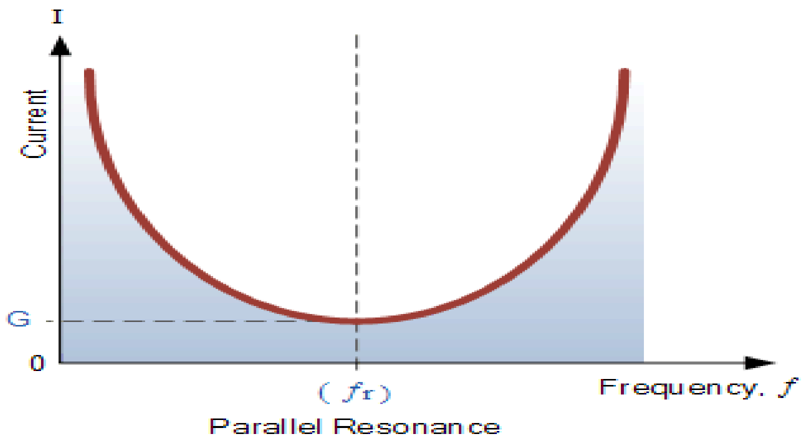


Fig 7.7 Current at resonance in parallel resonant circuit

If the graph is drawn between impedance and frequency then a curve as shown in figure below is obtained.

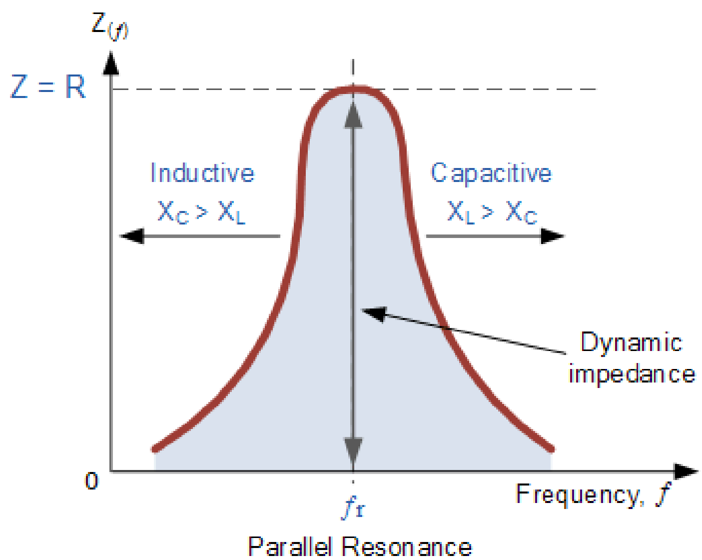


Fig 7.8 Impedance at resonance in parallel resonance circuit.

The figure shows that there is infinite impedance at resonance and reduced impedance after resonance frequency.

The main characteristics of parallel resonance circuit have been listed below:

(1) The line current is minimum at the resonant frequency.

(2) It offers maximum impedance at the resonant frequency.

(3) If the coil resistance is considered negligible then there is no DC voltage drop across it.

(4) Circuit impendence is Zmax = $\frac{L}{RC}$

(5) To find the current of this circuit

$$I_T = \frac{V}{Z_{max}} = \frac{V}{L/RC} = \frac{VRC}{L}$$

(6) The resonant frequency can be found by

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

$$f_r = \frac{0.16}{\sqrt{LC}}$$

7.10 COMPARISION OF SERIES & PARALLEL RESONANT CIRCUIT:

Series resonant circuit	**Parallel resonant circuit**
Circuit has minimum impedance	This circuit has maximum impedance
Maximum current flows through circuit	Minimum current or Zero current flows
Phase angle of circuit is zero	This circuit also 0° Phase Angle.
Power factor is unity	Power factor is unity
Maximum power is consumed	Maximum power is consumed.
Circuit current can be found by I=V/R	Circuit current can be found by

	$I = {}^{VRC}\!/\!_{L}$
Below or above resonant frequency, the current value is decreased.	Below or above resonant frequency, the current value is increased.
Resonant frequency can be found by $f_r = \frac{1}{2\pi\sqrt{LC}}$	Resonant frequency can be found by $f_r = \frac{1}{2\pi\sqrt{LC}}$
Circuits capacitive below fr and inductive above fr.	Circuit is inductive below fr and capacitive above fr.
Source is inside LC circuit	Source is outside LC circuit
This magnifies the circuit voltage	This magnifies the circuit current.

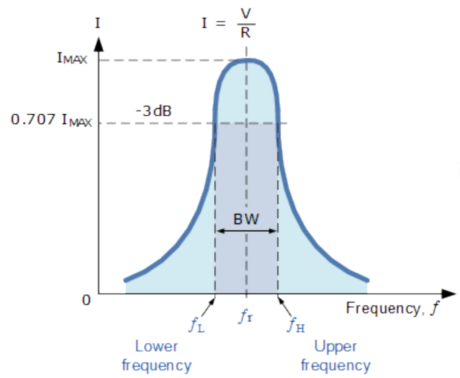
7.11 BANDWIDTH OF RESONANT CIRCUIT:

When we say that an LC circuit is resonant at one frequency, this is true for its maximum resonance effect, however other frequencies close to resonance fr, also are effective. For series resonance, frequencies just below and above fr, produce increased current, but a little less than the value of resonance. For a parallel resonance circuit, frequencies close to fr can provide high impedance, although a little less than the maximum impedance.

Therefore any resonant frequency has an associated band of frequencies that provide resonance effects. How wide the band is depends on the Q of the resonant circuit. Actually it is impossible practically to have an LC circuit with resonance effect at only one frequency. The width of the resonant band of frequencies centered on fr is called the band width of the tuned circuit.

Measurement of Bandwidth:

The group of frequencies which provides 70.7% of the output during the range of the frequencies is called as Bandwidth of the tuned circuit. It is shown in figure 7.9(b). Figure 7.9(a) shows the series circuit with input of 0 to 1000 KHz. The bandwidth is measured between two frequencies f1 and f2, producing 70.7 % of the maximum current, at fr.



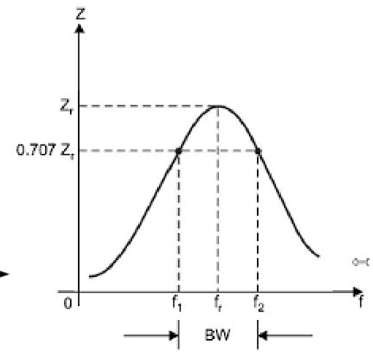


Fig 7.9 (a) Fig 7.9 (b)

For a parallel circuit the resonant response is increasing impedance. Then the bandwidth is measured between two frequencies allowing 70.7 percent of the maximum impedance at fr.

If f2 at 60KHz and f_1 at 40 KHz, both with 70.7 percent response. The bandwidth indicated on the response curve in figure (b) will be 20 KHz

Compared with the maximum current of 100mA for fr at 50 KHz, f_1 below resonance and f_1 above resonance each allow a rise to 70.7mA, or more, as the resonant response in this example.

Q OF RESONANT CIRCUIT:

The voltage across the capacitor and the inductor are many times than the supply voltage, for a series resonance. The reason is the flow of very large amount of current at resonance. We know that the value the current at resonance is maximum and is given by the relation

$$I_{max}=\frac{V}{R} \quad \text{-----------} \quad (i)$$

The voltage across inductor or capacitor is given by

$V_L=I_{max}\,X_L$ OR $V_C=I_{max}\,X_C$ ----------(ii)

The relation for supply voltage is

$V=I_{max}\,R$ ------------- (iii)

Now $$Q=\frac{I_{max}\,X_L}{I_{max}\,R} = \frac{X_L}{R} = \frac{2\pi fL}{R} \quad \text{------} \quad (iv)$$

OR $$Q=\frac{I_{max}X_C}{I_{max}R} = \frac{X_C}{R} = \frac{\frac{1}{2\pi fC}}{R} = \frac{1}{2\pi fCR} \text{-----}(v)$$

But resonance frequency is

$$f r=\frac{1}{2\pi\sqrt{LC}} \quad \text{--------------}(vi)$$

Putting the value of fr, in equation

$$\text{Q factor} = \frac{1}{R} \times \sqrt{L/C} \quad \text{--------------} \ (vii)$$

In such a case high Q factor means higher voltage amplification and higher selectivity of the tuning coil. So as to have high Q factor, the coil should have large inductance and small Ohmic resistance.

Numerical Problems:

Problem No.1

A circuit is a combination of a capacitor 5PF connected in series with a coil having a resistance of 200Ω and inductance 0.1mH. Calculate

(i) Resonant frequency (ii) Q factor (iii) Bandwidth.

Solution:

Given data is

C=5pF, R=200Ω, L=0.1mH

i. **Resonant frequency**:

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

$$= \frac{1}{2\times3.14\times\sqrt{.1\times10^{-6}\times5\times10^{-12}}}$$

$$= \frac{1}{6.28\times\sqrt{5\times10^{-18}}}$$

$$= \frac{1}{6.282\times2.23\times10^{-9}} = 71.2\text{MHz}$$

ii. Q factor:

$$Q = \frac{2\pi f_r L}{R}$$

$$= \frac{2\times3.14\times71.2\times10^{6}\times0.1\times10^{-6}}{2} = 22.36$$

iii. Bandwidth:

$$\Delta f = \frac{fr}{Q} = \frac{71.20MHz}{22.36} = 3.18\text{ MHz}$$

Problem No. 2:

Find the impedance of series RLC circuit having R=100Ω,C=0.02pf and L=20mH with a supply voltage of 10V rms at 10MHz. Calculate:

(i) Impedance (ii) Resonance frequency (iii) Voltage across L and C under the resonance condition (iv) Q of the circuit

Solution:

Given data is R=100Ω, C=0.02 μF, L=20mH, Vrms= 10V, f =10MHz

i. Impedance

ii. Resonance frequency
iii. Voltage across L and C under the resonance condition.
iv. Q of the circuit.

Solution:
Given data is R=100Ω, C= 0.02μF, L=20mH, Vrms= 10V, f =10MHz

i. Impedance:

$X_L=2\pi fL$

$= 2\pi\times10\times10^6\times20\times10^{-3}$

$=1.25\times10^6 = 1.25M\Omega$

$X_C = \dfrac{1}{2\pi\times10\times10^6\times0.02\times10^{-12}}$ $Xc = 7.95\ \times 10^5$

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

$= \sqrt{(100)^2+\left(1.25\times10^{-6}-7.95\times10^5\right)^2}$

$=\sqrt{10000+2.07\times10^{11}} = 4.54\times10^5\Omega$

ii. Resonant frequency:

$f_r = \dfrac{1}{2\pi\sqrt{LC}}$

$\dfrac{1}{2\pi\times\sqrt{20\times10^{-3}\times.02\times10^{-12}}}$

$\dfrac{1}{2\pi\times2\times10^{-8}}$

At resonance, the impedance is = $(X_L = X_C)$

And Z = R

Z = R = 100 Ω

I = $\frac{V}{R}=\frac{20}{100}=0.2\ A$

iii. Voltage across L & C under the condition of resonance:

V_L = I X_L = 0.2 × 1.25 × 106 = 250,000 volts

Voltage across capacitor C

V_C=I X_C = 0.2 × 7.95 × 10^5

= 159000 volts

iv. Q factor:

Q factor = $\frac{1}{R}\sqrt{\frac{L}{C}} = \frac{1}{100} \times \sqrt{\frac{2 \times 10^{-3}}{0.02 \times 10^{-12}}} = 3166$

Problem No. 3:

A series tuned circuit has a capacitance of 25pF. What must be inductance in order that resonance shall occur at a frequency of 200 KHz?

Solution:

Given data is:

C = 25pF, fr = 200KHz

Using the following relation:

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

Squaring on both sides

$$f_r^{\,2} = \frac{1}{4\pi^2 LC} \quad \Rightarrow \quad L = \frac{1}{4\pi^2 f_r^{\,2} C}$$

$$L = \frac{1}{4\pi^2 \times \left(200 \times 10^3\right)^2 \times 25 \times 10^{-12}} = \frac{1}{39.47} = 25mH$$

EFFECT OF LC RATIO ON SELECTIVITY:

We can obtain resonance at different frequencies by changing either L or C. A variable capacitor is connected as shown in figure 8.10 to tune the series LC circuit to resonate at any one of the three different frequencies. Each of the voltages e_1 to e_3 shows an ac input with a specific frequency.

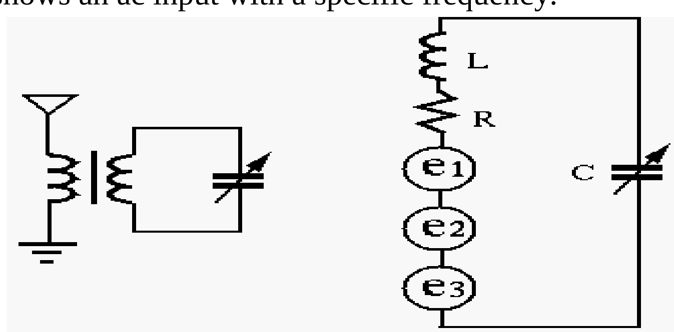


Fig.7.8 Parallel Resonant Circuit:

The value of variable capacitor can be adjusted at any values shown in table below in order to tune the LC circuit at different frequencies.

Let us suppose that we want maximum output for the ac input voltage that has the frequency of 1410 KHz. Then capacitor is adjusted at 53pF to make the LC circuit resonant 1410 KHz.

L (μ H)	C (pF)	fr (KHz)
239	106	1000
239	53	1410
239	26.5	2000

Similarly, the tuned circuit can resonant at a different frequency for each input voltage in such a way, the tuned circuit is tuned to select the desired frequency. When an LC circuit is tuned, it has been observed that the change in resonant frequency is inversely proportional to the square root of the change in L or C. By considering the above table, it has been found that when C is decreased by one fourth, from 106 to 26.5pF, the resonant frequency is doubled from 1000 to 2000 KHz or the frequency is increased by the factor$1/\sqrt{1/4}$, which is equal to 2 .If we want to tune through the whole frequency range of 500 to 2000 KHz. This will be a tuning ratio of 4:1 for the highest frequency to the lowest frequency. Then the capacitance will be varied from 424 to 26.5 pF, which is a 16:1 capacitance ratio.

7.12 USES OF RESONANT CIRCUIT:

Resonant circuits are widely used in ac circuits specifically in communication systems. The use of resonant circuits has been given below.

i. In tuned amplifiers.
ii. In the receiving antenna.
iii. As doubled tuned transformer coupling in receiver.
iv. In T.V receivers for signal reception and separation.
v. In radio tuning dials.
vi. In tuned transformers

Multiple Choice Questions

Q.1 For a series or parallel LC circuit, resonance occurs when _______.
(a) $X_L = 10X_C$ (b) $X_C = 10X_L$
(c) $X_L = X_C$ (d) the phase angle of circuit is 90°

Q.2 When either L or C is increased, the resonant frequency of the LC circuit _______.
(a) Increases (b) decreases
(c) Remains the same (d) is determined by shunt R

Q.3 The resonant frequency of an LC circuit is 1000 KHz. If L is doubled and C is reduced to 1/8th, the resonant frequency is _______.
(a) 250 KHz (b) 500KHz (c) 1000KHz (d) 2000KHz

Q.4 A coil has a 1000 Ω XL & 5 Ω Ri. Its Q equals _______.
(a) 200 (b) 5 (c) 500 (d) 1000

Q.5 In a parallel LC circuit, at the resonant frequency, the _______.
(a) Line current is maximum
(b) Inductive branch current is minimum
(c) Total impedance is minimum
(d) Total impedance is maximum

Q.6 At resonance, the phase angle equals _______.
(a) 0° (b) 90° (c) 180° (d) 270°

Q.7 In a series LC circuit, at resonant frequency, the _______.
(a) current is minimum
(b) Voltage across C is minimum
(c) Impedance is maximum (d) Current is maximum

Q.8 A series LC circuit has a Q of 100 at resonance. When 5mV is applied at resonant frequency, the voltage across C equals:
(a)5mV (b)20mV (c)100mV (d)500mV

Q.9 An LC circuit is resonant at 1000 KHz & has a Q of 100. The bandwidth b/w half power points are _______.
(a)10 KHz b/w 995 and 1005 KHz
(b) 10KHz b/w 1000 and 1010 KHz
(c)5 KHz b/w 995 and 1000 KHz
(d)200 KHz b/w 900 and 1100 KHz

Q.10 In a low Q parallel resonant circuit, when $X_L = X_C$ _______
(a)$I_L = I_C$ (b) IL< I_C (c) IL> I_C (d) the phase angle is 0°

Q.11 Resonance curve shows variation of circuit current with _______.
(a) Voltage (b) frequency (c) band width (d) all of these

Q.12 Higher the Q-factor of a circuit _______ its bandwidth.
(a)Expansion (b) Narrower (c)Increase (d)Widen

Q.13 Lower the resistance of a resonant circuit, _______ its selectivity.
(a)Decrease (b)Narrower (c)Better (d) Bad

Q.**14** Sharpness of tuning depends _______ on the Q of a coil.
(a) Minimum (b) Maximum (c) complete (d) inversely

Q.15 In parallel resonance, the line current is __ at the resonant frequency.
(a) Maximum (b) Minimum (c) complete (d) often

Q.16 Band width of a series resonant circuit depends on --
(a)R (b) L (c) C (d) All of the above

Q.17 The power factor of a resonant series circuit is ___
(a) 1 (b) 6 (c) -1 (d) 0.5

Q.18 Higher the Q factor of a series circuit _______.
(a) Greater its band width (b) Sharper its resonance curve
(c) Broader its resonance curve (d) Narrower its pass band

Q.19 As the Q factor of a circuit _______ its selectivity becomes _______.
(a)Increase, better (b) increase, worse
(c) Decrease, better (d) none of these

ANSWER KEY

1.(c)	2. (b)	3.(d)	4.(a)	5.(d)
6.(a)	7.(d)	8.(d)	9.(a)	10.(b)
11.(b)	12.(b)	13.(c)	14.(b)	15.(b)
16.(d)	17.(a)	18.(d)	19.(a)	

Short Questions (Sample)

1. Define the term resonance?
2. Describe three characteristics of a series resonance?
3. Enlist three characteristics of a parallel resonance?
4. Compare series and parallel resonance?
5. Derive the formula of resonance frequency?
6. Discuss Q of the circuit?
7. What do you mean by band width?
8. What is meant by electronic tuning?
9. Calculate f_r for series LC circuit with L=5μH and C=202.64 pF?
10. Calculate f_r for parallel LC circuit with L= 25.48μH and C=500 pF?
11. Describe Q of parallel circuit?
12. Define the rejecter circuit?
13. What is the resonant frequency of a 50mH inductance connected in series with 100 pf Capacitor?
14. List the conditions of series and parallel resonant circuits?
15. Draw series and parallel resonant circuits?
16. What value of capacitance is needed to resonate with a 300μH at 400 KHz?

Long Questions

1. Prove that $= \frac{1}{2\pi\sqrt{LC}}$?
2. Draw series resonant circuit and write down the characteristics o series resonant circuit?
3. Draw parallel resonant circuit and write down the characteristics o series resonant circuit?
4. Compare series and parallel resonant circuit?
5. Explain the bandwidth of resonant circuit?
6. Explain the Q of resonant circuit?
7. Explain the effect of the LC ratio on selectivity?

Chapter 08 Filters & Coupling circuits

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OBJECTIVES
After completion of this chapter students will be able to:

1. Filter Circuits & action of a filter Circuit
2. Types of Filter Circuits
3. K Filters & M-Derived Filters
4. Band pass & Band Stop Filters
5. Application of filter Circuits
6. Action and purpose of coupling circuits
7. Coefficient of Coupling
8. Types of Coupling
9. RL & RC Constants
8. Transformer Losses

8.1 PURPOSE AND ACTION OF FILTER CIRCUIT:

Filter Circuit:

The output of a rectifier contains dc component and some ac components which are called Ripples. The ripples comprise of an ac component and are the most undesirable part of the signal so must be removed from the output signal. This goal is achieved by a device called Filter.

The purposes of filter circuits are listed below:

1. To select the desired frequency (or band of frequency) from a complex.
2. To reject an undesired frequency or group of frequency from a complex waveform.
3. To apply the desired frequency component to the circuit where it is required.
4. To convert the pulsating dc output to steady output.
5. To change the amplitude and phase characteristics of ac input signal.

A filter circuit consists of a combination of inductors, capacitors and resistors that perform the above functions properly.

Action of a filter circuit:

The filter action of a filter depends on the following principles of ac Circuits:

i. Inductive reactance XL of an inductor increases with the increases of frequency. It offers very low reactance to dc currents but offers very high impedance to radio frequency currents and this is shown in figure below.

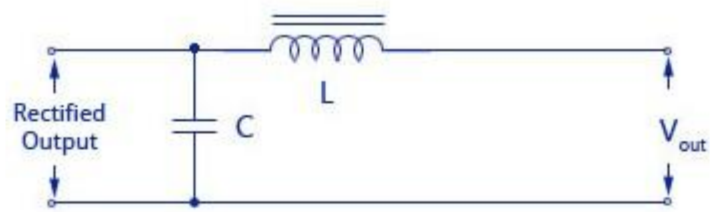


Fig. 8.1 Filter action

ii. The capacitive reactance XC of a capacitor is decreased with the increase in the frequency of input signal. A capacitor offers very high reactance to low frequency input signal while offers very low reactance to radio frequency currents. A capacitor acts as an open to DC input signal.

iii. A series circuit offers minimum impedance to that current which is having its frequency equal to its resonant frequency. But it offers very high opposition to other frequencies. It is shown by the figure 8.2.

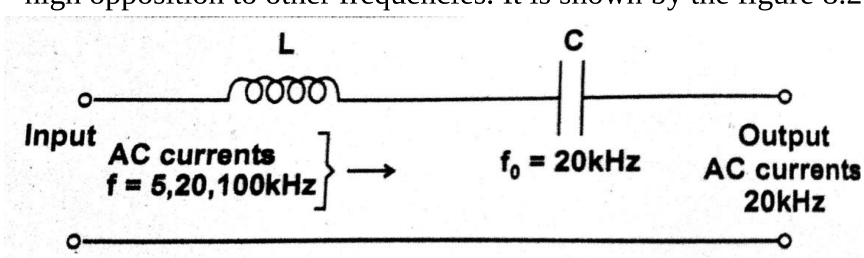


Fig. 8.2 Filter Action (Series circuit)

iv. A parallel circuit offers maximum impedance to that current which is having its frequency equal to its own resonant frequency. But it offers very low opposition to other off-resonance frequencies. As shown by figure 8.3

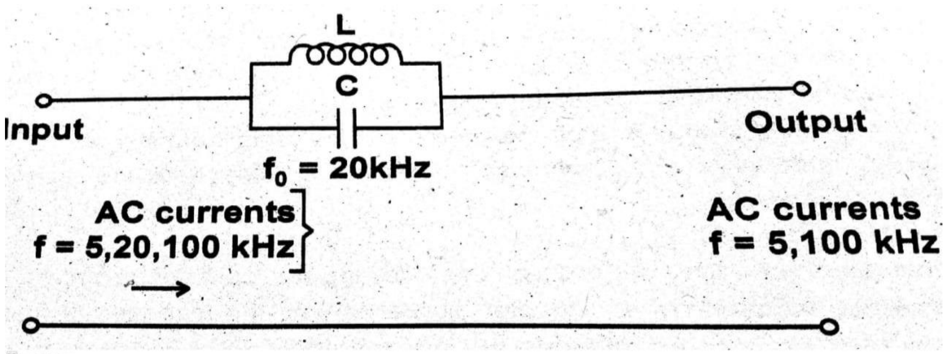


Fig. 8.3 Parallel circuit filtering action

v. Resistors do not take part in filtering action on their own but when they are used with the inductors and capacitors in the filtering circuits they increases the overall impedance, and as a result the sharpness of filter circuit is reduced.

8.2 TYPES OF FILTER CIRCUIT:

The circuits have many types which are listed below:

(i) Low pass filter
(ii) High pass filter
(iii) Band pass filter
(iv) Band stop filter

8.3 LOW PASS, HIGH PASS, K FILTER, M DERIVED FILTER:

Low pass filter:

Low pass filter is a filter which passes low frequencies through it. A simple low pass filter is shown in the block diagram and a general response curve for a low pass filter is been shown in figure 9.4 which passes 100KHz frequency and stops 1KHz through it. The frequency response of the low pass filter is shown in figure 8.5.

Low frequency = 1 K Hz

High frequency = 100 K Hz

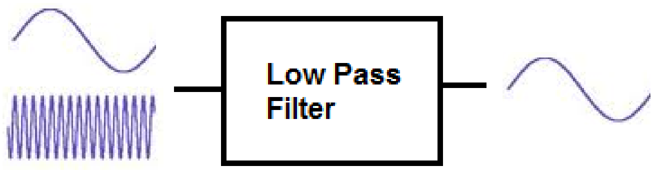


Fig 8.4 Low pass filter action

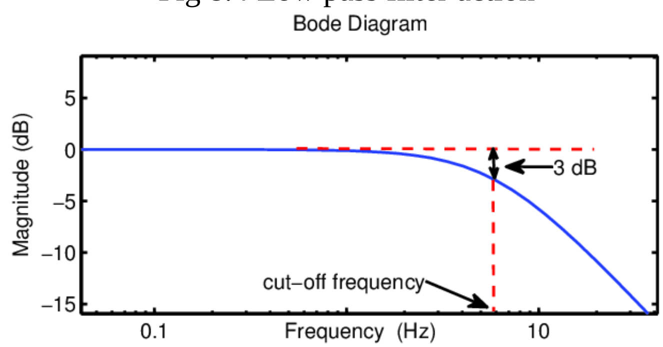
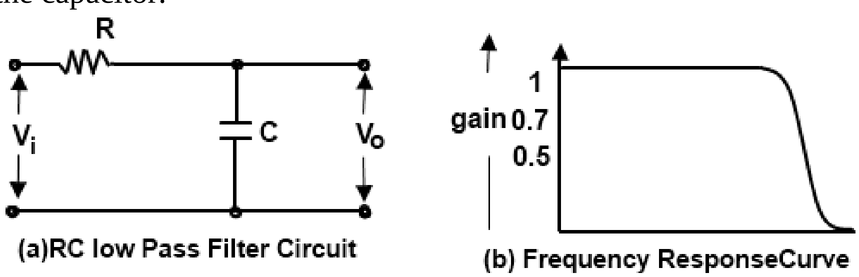


Fig 8.5 Frequency response curve of low pass filter

The maximum frequency that is passed by a low pass filter is called cut off frequency. This is also known as break frequency. The range of low frequencies passed by a low pass filter within a specified limit is called the pass band of the filter. The critical frequency (f_C) is the frequency at which the filter's output voltage is 0.707.

RC Low pas Filter:

A basic RC low pass filter is shown in figure 8.6 below. It consists of a resistance and a capacitor which is connected in series to it. The output is taken from the capacitor.



Fig, 8.6 RC Low pass filter

We know that XC and f are inversely proportional to each other. Therefore when the input is DC (0 Hz) then the Vout is equal to the Vin because XC becomes infinity at 0Hz. As soon as the frequency of the input voltage is increased, the XC decreases from infinity value and therefore output voltage is decreased. With the steady increase in the value of input voltage frequency, the point is reached where the value of XC is equal to the value of R. This specific frequency is known as the critical frequency (f_C) of filter. Thus

$X_C = R$

$$\frac{1}{2\pi f_C C} = R \quad \text{OR} \quad f_C = \frac{1}{2\pi RC}$$

The value of output voltage at critical frequency is

$$V_{out} = \left(\frac{X_C}{\sqrt{R^2 + X_C{}^2}}\right) V_{in}$$

At fc the XC = R therefore

$$V_{out} = \left(\frac{R}{\sqrt{R^2 + R^2}}\right) V_{in}$$

$$= \left(\frac{R}{\sqrt{2R^2}}\right) V_{in}$$

$$= \left(\frac{R}{R\sqrt{2}}\right) V_{in} \qquad = \left(\frac{1}{\sqrt{2}}\right) V_{in} = 0.707\, V_{in}$$

So the value of the output at critical frequency is 0.707 or its final value.

RL Low Pass Filter:

A basic RL low pass filter has been shown in figure 8.7 output voltages are taken across resistor R.

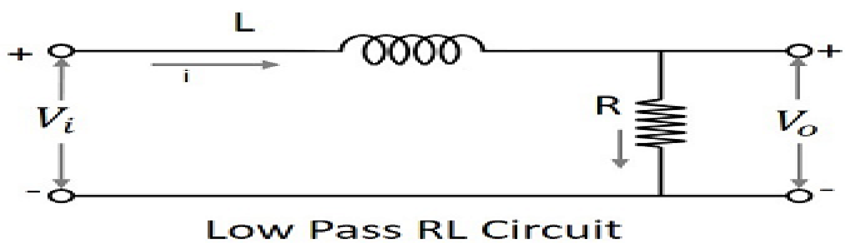


Fig 8.7 Low Pass RL Filter Circuit

As we know that X_L acts as short for DC (0 Hz), therefore when the input is DC, their output voltages (V_{out}) are equal to the input voltages (Vin). In this situation, the inductive reactance is negligible. As soon as the input frequency is increased, XL also increased. As a result output voltages are reduced. A point is reached while increasing the input voltage frequency, where XL = R. Then the frequency value is:

$$2\pi f_C L = R \quad \text{Because} \quad X_L = 2\pi f_C L$$

$$fc = \frac{R}{2\pi L} \quad \text{or} \quad \frac{1}{2\pi\left(L/R\right)}$$

The output is 0.707 Vin in RL low pass filter similarly RC low pass filter.

LC Low Pass Filter:

The output is 0.707 V_{in} in RL low pass filter similarly RC low pass filter.
LC Low Pass Filter:

The LC low pass filter with its response curve is shown in figure 8.8.

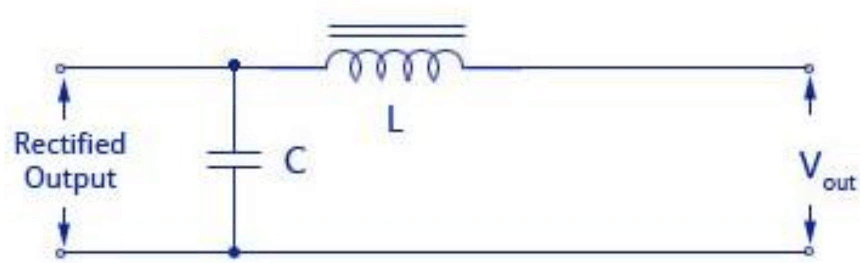


Fig .8.8 LC low pass filter

The inductor L connected in series offers a very low opposition to low frequencies and offers a high opposition to higher frequencies. Therefore only low frequencies will be passed from inductor. The high frequency currents will be returned back towards the capacitor which offers low reactance path to these high frequencies. In this way the high frequencies are passed from capacitor.

Applications of low pass filter:

a. Low pass filters are commonly used to reject the undesirable hum in electronic power supplies.
b. These are used in voice frequency circuits.
c. These are used to avoid harmonics between the transmitter and its antenna

High Pass Filters:

It is a filter which passes high frequencies and stops low frequencies. A basic block diagram and frequency response is shown in the figure 8.9 below. A high pass filter acts opposite to a low pass filter.

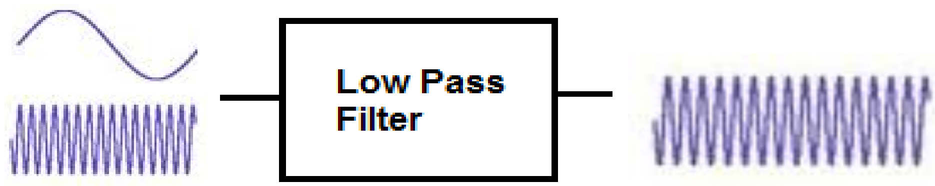


Fig 8.9 (a) Block diagram

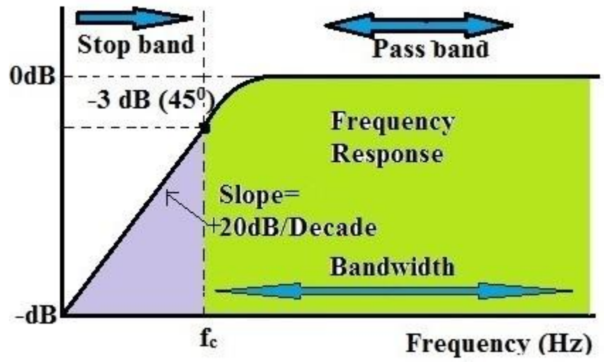


Fig 8.9 (b) Frequency response curve

RC High Pass Filter:

A basic RC high pass filter is shown in figure 8.11. The output voltage is across the resistor.

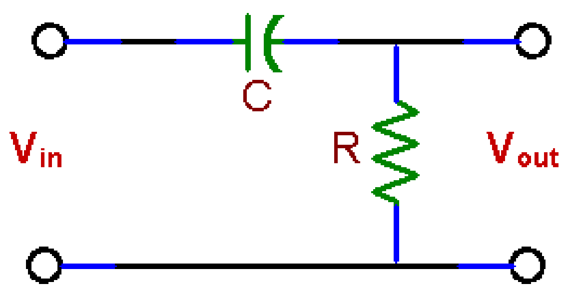


Fig 8.10 RC High pass Filter

When the input frequency is at its critical value, then similarly to low pass filter, the value of X_C is equal to the value of R. Therefore output voltage is equal to 0.707 V_{in}. As the frequency of input voltage is more than f_c, the value of X_C is decreased and the output voltages are increased. With the gradual increase in f_c, a point is reached where the $V_{out} = V_{in}$. The critical frequency of high pass filter is:

$$f_C = \frac{1}{2\pi RC}$$

The voltage across R can be found with help of voltage divider rule.

$$V_{out} = \left(\frac{R}{R + X_C}\right) V_{in}$$

RL High Pass Filter:

A basic RL high pass circuit has been shown in figure 8.11. The output voltage of this circuit is taken across the inductor.

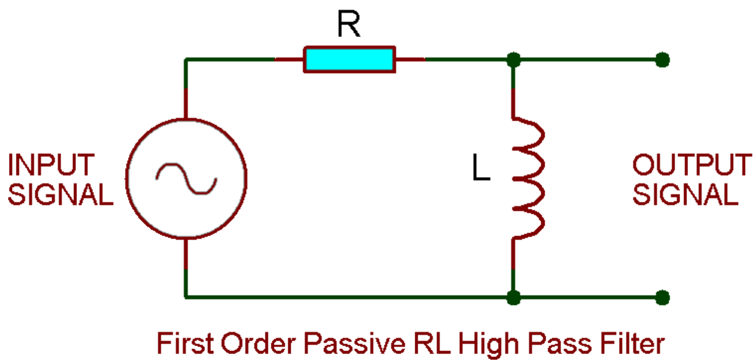


Fig 8.11 RL High pass filter

When the input frequency is at its critical value, then the value of X_L=R and the output voltage is equal to the input voltage. As the frequency is increased from fc, X_L is increased. As a result the output voltages are increased and with further increase, a point is reached where the value of output voltage is equal to the value of input voltage. For critical frequency (f_C).

$$f_C = \frac{1}{2\pi L/R}$$

Applications of High Pass Filters:

- In audio circuits.
- In TV and its antenna.

K-Filter:

It is possible to keep the product of X_L and X_C constant at all frequencies. For example, if the frequency is doubled, then the X_L is doubled and X_C is reduced to its half value but their product is constant. Such a filter, in which the product of XC and XL is kept constant, is termed as K-Filter. In this way the impedance at input and output terminals is kept constant. Constant (K) filter can be either high pass or low pass. The K filter has practically following draw backs:

i. In attention band, after the cut off frequency, the attenuation does not increase swiftly with the increase in frequency.

i. In pass band the characteristic impedance (The impedance offered by filter circuit to source) is not constant but it changes drastically from its normal value.

In an ideal K filter:

- The attenuation of the frequencies in pass band is zero.
- The attenuation of the frequencies outside the pass band is zero.
- Frequency band will be very narrow.

Additional impedances are added in series or parallel with the m-derived filter. In this way the m-derived filter has the following two types.

(a) Series m-derived filter

(b) Parallel m-derived filter

In figure 9.12 the series m-derived filter circuits has been shown while in figure 9.13 the parallel m-derived filter circuits has been shown.

8.4 BAND PASS & BAND STOP FILTER:

Band Pass Filter:

A band pass filter allows a specific band of frequencies to pass through them while attenuating/rejecting other frequencies. This pass band is known as the band width of the filter. A band pass curve is shown in figure 8.12 below.

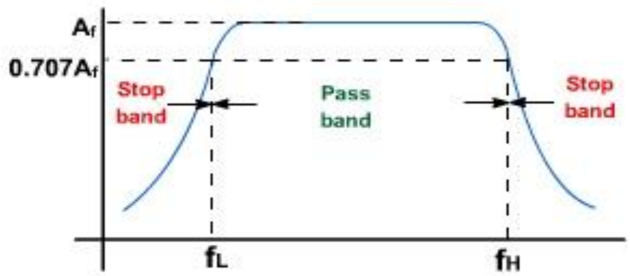


Fig 8.12 Band Pass Filter

The band pass filter passes the currents of those frequencies whose cut off value is in between f_{C1} and f_{C2} (refer to figure b). And stops the currents of all those frequencies while are more than f_{C2} or less than f_{C1}. The f_{C2} indicates the higher limit while fc1 indicates lower limit of cut off frequencies. The band pass filter does work between these frequencies.

The band pass and band stop filters are also termed as resonant filters. In figure 8.13 a filter is shown that have two resonant circuits. One circuit is in series with line and other is in parallel with line. Both circuits are turned for uniform frequency. Series resonant circuit passes such currents which are having currents of frequencies equal to resonant frequency or near to resonant frequency. It also stops all those frequencies which are having less than or greater than the band of frequencies. However this blocked frequency are grounded through the parallel resonant circuit. In order to obtain band pass characteristics,

(a) Low pass/High Pass Filter
(b) Series resonant Band pass filter
(c) Parallel resonant Band Pass Filter

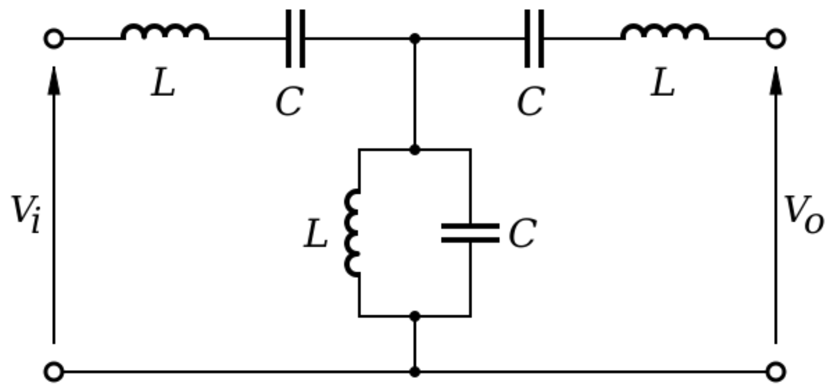


Fig 8.13 Band Pass resonant circuit

Low Pass/High Pass Filter:

Band pass filter can be obtained by connecting the one low pass and one high pass filter in cascade. Such a filter has been shown in figure 8.14.

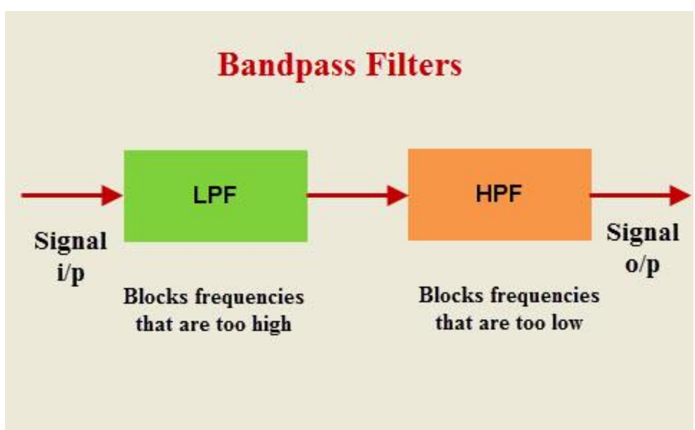


Fig 8.14 Low pass and High pass filter used to form a band pass filter

If the critical frequency of low pass band is more than the critical frequency of high pass band then the responses are overlapped. In this way, all the frequencies are eliminated except the frequencies in between f_C (h) and f_C(l). This is shown in figure 8.15.

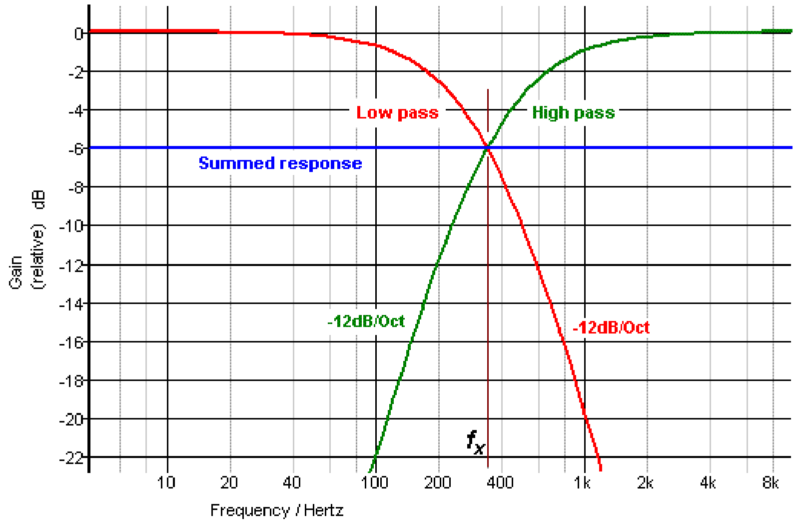
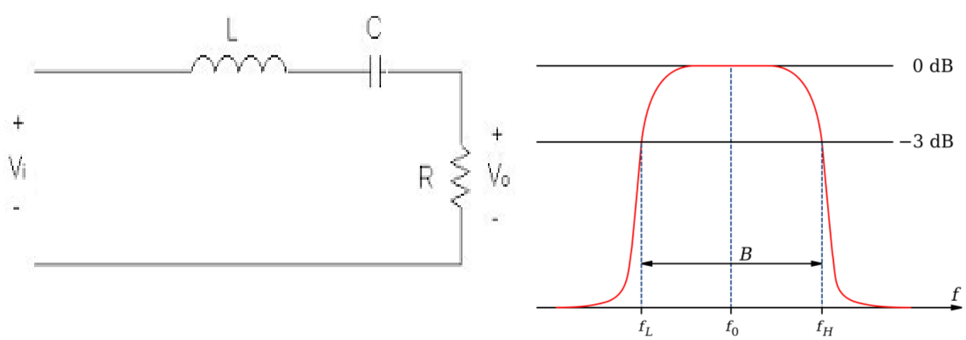


Fig 8.15 Overlapped responses of low pass & High pass filter

Series Resonant Band Pass Filter:

We know that in a series resonant circuit, the impedance is minimum at resonant frequency and the current is maximum. A series resonant band pass filter works on the very this principal. This has been shown in figure 8.18. At resonant frequency, the series resonant impedance is very less than the value of R. Therefore the output voltage is maximum at resonant frequency. In this way the maximum output across R at resonant frequency is composed of band pass characteristics.



(a) Circuit diagram (b) response curve

Fig 8.16 Series resonant band pass filter

Parallel Resonant Band Pass Filter:

In figure 8.17 the type of band pass filter is shown in which parallel resonant circuit is used. As we know that at resonance, the impedance of a parallel circuit is maximum. At resonance the impedance of parallel branches is far more than R. Therefore, maximum voltage is produced at resonance. Above or below the resonance frequency, the impedance of parallel branches is decreased therefore maximum voltages are across R. As a result the voltage across the parallel branches is decreased. Therefore this circuit is composed of band pass characteristics.

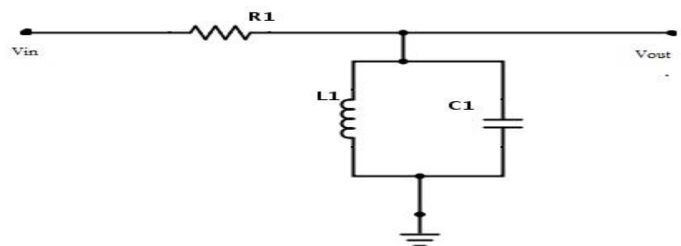
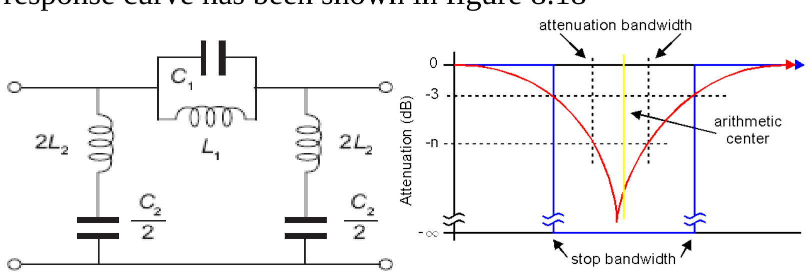


Fig 8.17 Parallel resonant band pass filter

Band Stop Filter:

When considering the responses, the band stop filter is exactly opposite to the band pass filter. Band Stop Filter allows all frequencies to pass through it except the specific frequencies which exists in particular stop band. This is also called band attenuation, band suppression filter. A band stop filter circuit with its response curve has been shown in figure 8.18



(a) Band stop filter circuit (b) Frequency Response
Fig 8.18 Band Stop Filter

A band stop filter has the following types:

- Low pass/High Pass Filter
- Series Resonant Band Stop Filter
- Parallel Resonant Band Stop Filter

Low Pass/High Stop Filter:

A band stop filter can be made by connecting a low pass and a high pass filter together in parallel as shown in figure 8.19

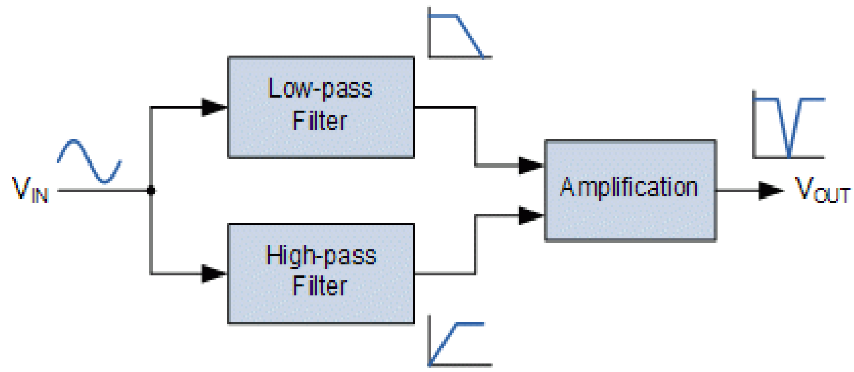
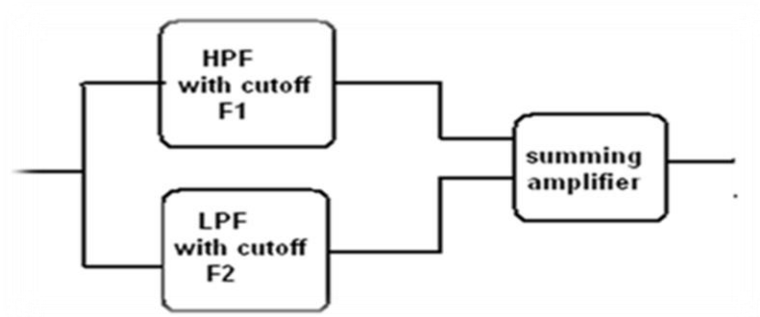


Fig 8.19 Block diagram of band stop filter

As seen from the figure 8.20, the low frequency f_1 will pass from low pass filter and high frequency f_2 will pass from the high pass filter. However any frequency which is more than low pass critical frequency and less than high pass critical frequency will be blocked. This has been shown as f_0 in figure 8.20(b). The response curve has also been shown in particular figure.



F0 blocked frequency

Fig 8.20 (a) Band pass filter action

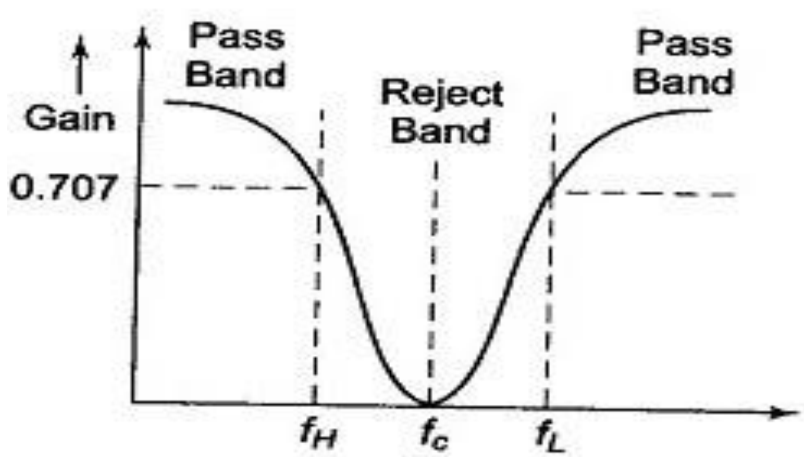
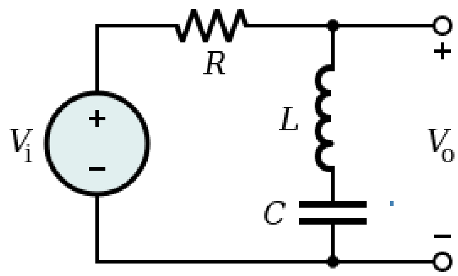
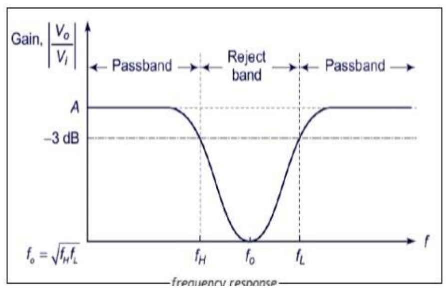


Fig 8.20 (b) Band stop characteristics

Series Resonant Band Stop Filter:

A series resonant band stop filter has been shown in figure 8.21. The working of this circuit has been explained below:





(a) Series resonant circuit (b) Frequency response

Fig 8.21 Series resonant band stop filter

At resonance the impedance is minimum, therefore the output is minimum. Most of the voltages are dropped across the R. below or above the resonance, the impedance is increased and hence output voltage is increased. This type of filter is used to reject a specific band of frequencies.

Parallel Resonant Band Stop Filter:

In this type of circuit the parallel resonant is in series with the resistor R. This circuit is shown in figure 8.22. In the parallel branches the impedance is maximum at resonant frequency. Therefore most of the voltages are across the parallel branches.

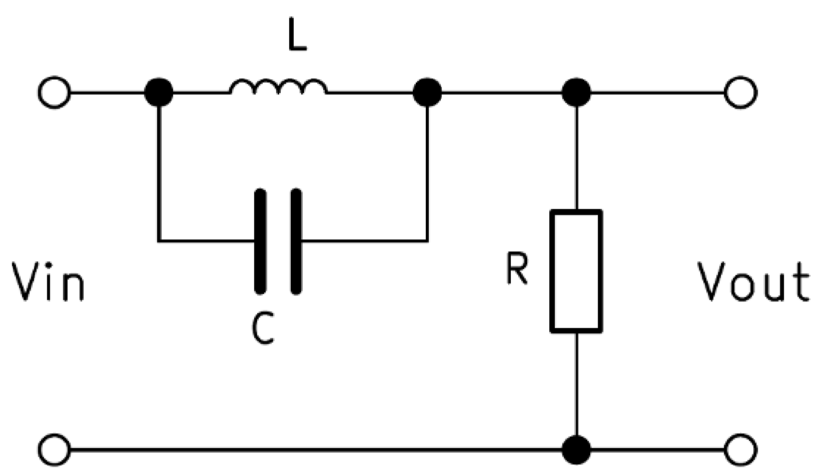


Fig 8.22 Parallel Resonant Band stop filter

As the frequency is increased or decreased from resonant frequency, the voltages are increased at output because the impedance of parallel branches is decreased.

Applications of Filters:

i. For smoothness of ripples in electronic power supplied.
ii. To select a specific side band in transmitters.
iii. To eliminate undesired signals from Radio and T.V
iv. To stop the audio frequency band pass in transmitters.
v. To eliminate undesired noise in communications.
vi. In de-coupling amplifier stages.
vii. In RF and IF stages as tune circuits.
viii. To reject the harmonic frequency in transmitters.
ix. In video amplifiers.
x. Motor, generators, transformers and in other electrical & electronics equipment in order to eliminate unnecessary frequencies.

8.5 ACTION & PURPOSE OF COUPLING CIRCUIT:

Coupling Circuits:

Coupling is a method of connecting two circuits together in which the energy is transferred between the two circuits is known as coupling. This type of circuit is called coupling circuit. For example to couple two stages of amplifier. This means than the output of one amplifier is made the input of other amplifier. In this way by coupling the different stages of amplifiers, amplification process is achieved. It is to be noted that the stages of amplifiers are coupled together only when the impedance between the two stages is common.

This common impedance is called coupling element. The energy is transferred from one stage to another due to this common impedance. This common impedance may be composed of a single resistor, capacitor or an inductor.

Purpose of coupling circuit:

The purpose of a coupling circuit is to transfer the electrical energy from one circuit to another circuit effectively. Two circuits are said to be coupled to each other if they have common impedance between them.

Action of Coupling Circuit:

1. The resistance, inductive and capacitive coupled circuits are also called direct coupled circuits. In these circuits, the coupling is achieved by having the current of the input circuit flow through the common impedance, where it produces a voltage drop. This voltage is applied to the output circuit. The output voltage is equal to the product of the current in the coupling element and its impedance. Different types of direct coupling have been given in figure 8.23

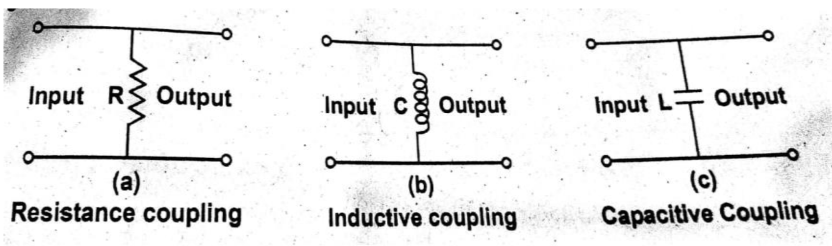


Fig 8.23 Different types of direct coupling

2. The transformer coupling is also referred to as indirect coupling, magnetic or mutual coupling. In this type of coupling, the transfer of energy is accomplished by having the alternating current of the input circuit flow through the primary winding and setting up an alternating magnetic field. The magnetic lines of this field link the turns of the secondary winding and induce the voltage that supplies the energy for output. In figure 8.24 the transformer coupling is shown.

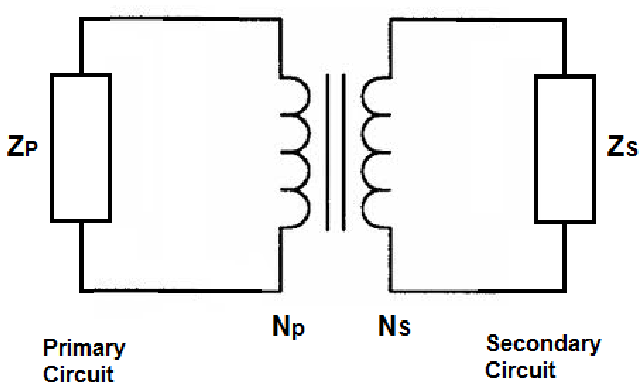
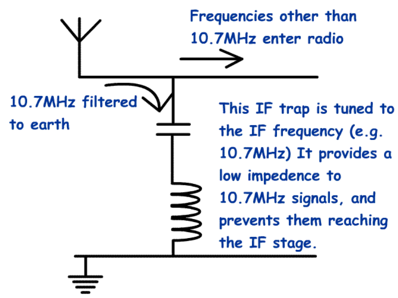
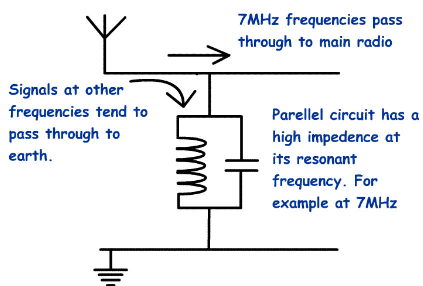


Fig 8.24 Transformer Coupling

3. Using combinations of two or more elements in the coupling unit makes it possible to obtain the various properties of energy transfer for inputs of varying frequency. For example, the coupling element of series tuned circuit as in figure 8.25(a) will have minimum impedance at its resonance frequency of the input circuit and is equal to the resonant frequency of the coupling unit. At frequencies above resonance, the proportion of energy transfer will increase and will be inductive. At frequency below resonance, the proportion of energy transfer will also increase but will be capacitive. For analysis purpose, complete coupled circuit may be represented by a simple equivalent circuit in figure 8.24



(a)



(b)

Fig 8.24 (a) Series tuned circuit (b) Parallel tuned circuit

Capacitors may be variable capacitors.

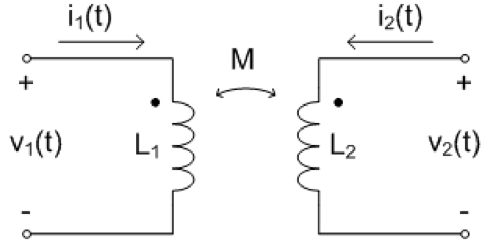


Fig 8.25 Equivalent circuit of any complex coupled circuit

Multiple Choice Questions

Q.1 A filter separates high and low _______.
(a)Voltages (b) Amplitudes (c) Frequencies (d) All of these

Q.2 A _______ pass filter provides output for the lower frequencies.
(a) High (b) Low (c) Band stop (d) Band pass

Q.3 A _______ pass filter provides output for the higher frequencies.
(a) High (b) Low (c) Band stop (d) Band pass

Q.4 __ direct current varies in amplitude but does not reverse its direction.
(a)Pulsating (b) Positive (c) Negative (d) Harmonics

Q.5 An _______ coupling circuit is effectively a high pass filter.
(a) LC (b) RC (c) RLC (d) RL

Q.6 An RC coupling is effectively a _______ pass filter.
(a) High (b) Low (c) Band (d) Any of these

Q.7 A transformer with an isolated secondary winding also effectively works as:
(a) High Pass (b) Low Pass (c) Band Pass (d) Band Stop

Q.8 A _______ capacitor in parallel with R provides a low pass filter.
(a) Coupling (b) By pass (c) Mica (d) Paper

Q.9 In _______ pass filters capacitance is in series with the load.
(a) High (b) Low (c) Band (d) All of these

Q.10 In high pass filters capacitance is in _______ with the load.
(a) Series (b) Parallel (c) Vertical (d) Shunt

Q.11 Resonant circuits are generally used for band__ and band stop filtering
(a) Pass (b) Prevent (c) Block (d) Any of these

Q.12 Which of the following is a low pass filter?
(a) L type with series C & shunt L
(b) P type with series C & shunt L
(c) T type with series C & shunt L
(d) L Type with series L & shunt C

Q.13 Combination of L, C and R can be arranged as L,T and ______filters.
(a) L – L (b) L – T (c) L – R (d) p

Q.14 RC coupling _______ dc component.
(a) Pass (b) Block (c) Both a and b (d)Neither a nor b

Q.15 A low pass filter is that circuit which stops _______ frequencies.
(a) Low (b) High (c) Pulsating (d) Smooth

Q.16 By _______ R and C low pass can be converted to high pass filter.
(a) Removing (b) Making in series (c) Interchanging (d Increasing value

Q.17 A band stop filter does the _______ of band pass filter.
(a) Equal (b) Opposite (c) Hand in hand (d) All of these

Q.18 RC coupling network consists of two _______ and one _______.
a) Resistor, Capacitor (b) Capacitor, Resistor
(c) Inductor, Resistor (d) None

Q.19 There is no need for coupling _______ in transformer coup
(a) Resistor (b) Inductor (c) By pass (d) Capacitor

Q.20 To amplify high signals direct _______ cannot be used.
(a) Current (b) Voltage (c) Signal (d) Coupling

Q.21 A high pass filter _______
(a) Pass all high frequencies (b) Stop low frequencies
(c) Stop certain lower cut-off frequencies (d) All of above

Q.22 The main function of an RC network is to _______
(a) To give flat frequency response curve
(b) Eliminate inductive effects
(c) Pass AC and block DC
(d) None of above

ANSWER KEY

1(c)	2. (b)	3.(a)	4.(a)	5.(b)	6.(a)
7.(a)	8.(b)	9.(a)	10.(a)	11.(a)	12.(d)
13.(d)	14.(b)	15.(b)	16.(c)	17.(b)	18.(a)
19.(d)	20.(d)	21.(d)	22.(c)		

Short Questions

1. Describe the purpose of filter?
2. Enlist the types of filter circuits?
3. What is band pass filter?
4. What is band stop filter?
5. Draw circuit diagrams for L-type band pass and L-type band stop filters?
6. How L-type band pass and L-type band stop filters circuit differ from each other?

7. Draw the response curve for each following filter?
   (a) low-pass cutting off at 20,000 Hz?
   (b) high-pass cutting off at 20 Hz?
8. Draw the response curve for each following filter?
   (a) Band pass for 20 to 20,000 Hz
   (b) Band pass for 450 to 460 kHz
9. Give one similarity and one difference in comparing a coupling capacitor and by pass capacitor?
10. Write down two differences between a low pass filter and high pass filter?
11. Define coupling?
12. Why do you need coupling of two stage amplifier?
13. Enlist the type of coupling?
14. Draw a circuit diagram two stage amplifier using RC coupling?
15. Draw a circuit diagram two stage amplifier using transformer coupling?
16. Draw a circuit diagram two stage amplifier direct coupling?
17. Draw a circuit diagram two stage amplifier using impedance coupling?
18. At certain frequency, the output voltage of a filter is 5V and the input is 10V. Determine the voltage ratio in decibel?
19. Determine the f_C for low pass RC filter when R=100 ohm C = 0.005µF?
20. Determine the critical frequency for the low pass RL filter when L=4.7mH, R = 2.2K ohm?

Long Questions

1. Define filter. Write down the purpose of filter circuit in detail?
2. Explain the action of filter circuit with the help of diagrams?
3. Explain low pass filter with the help of frequency response diagram. Also describe the RC low pass, RL low pass and LC low pass filter?
4. Explain high pass filter with the help of frequency response diagram. Also describe the RC high pass and RL low pass filters?
5. How you can differentiate band stop filter and band pass filter. Explain your answer with diagrams?
6. Define coupling. Write down the purpose of coupling circuit in detail?
7. Explain the action of coupling circuit with the help of diagrams?

CHAPTER 09 DIODES AND APPLICATIONS.

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OBJECTIVES

After completion of this chapter students will be able to:

1. **Semiconductors**
2. **Semiconductor Doping**
3. **Intrinsic & Extrinsic Semiconductors**
4. **Biasing the PN junction.**
5. **Depletion region, Junction barrier potential**
6. **Forward and reverse bias.**
7. **Rectifier Diode.**
8. **Half wave and full wave (Bridge) rectifier.**
9. **Ripple factor, surge current.**
10. **Rectifier filter: L, PI and T filters.**
11. **Diode as a switch.**

9.1 Understand Principles, Characteristics And Application Of Various Types Of Semiconductor Diodes.

9.1.1 TYPES OF MATERIALS:

Materials can be classified into three major types as follows:

I. CONDUCTORS

A conductor is a material that easily conducts electrical current. The best conductors are single element materials, such as copper, silver, gold, and aluminum, which are characterized by atoms with only one valence electron loosely bound to the atom. These loosely bound valence electrons can easily break away from their atoms and become free electrons. Therefore, a conductive material has many free electrons that, when moving in the same direction, make up the current.

II. INSULATORS

An insulator is a material that does not conduct electrical current under normal conditions. Most good insulators are compounds rather than single-element materials. Valence electrons are tightly bound to the atoms; therefore, there are very few free electrons in an insulator.

III. SEMICONDUCTOR

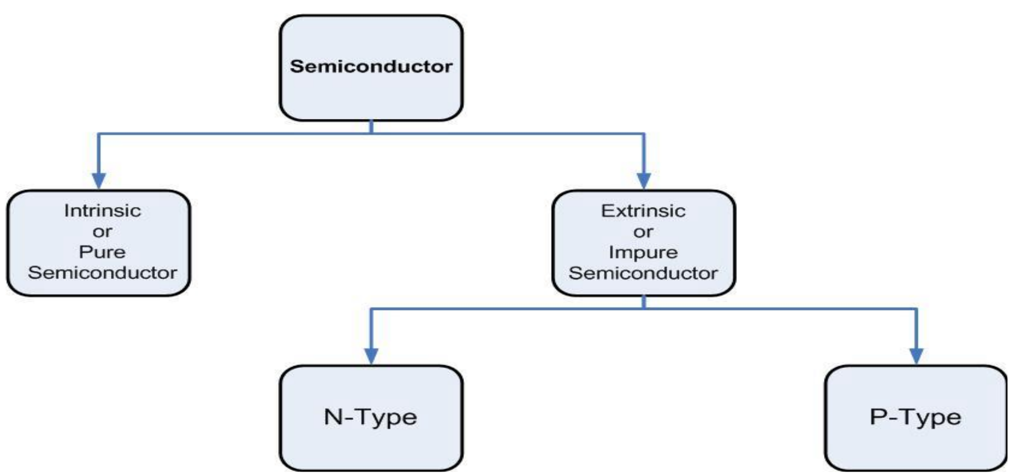
A semiconductor is a material that is between conductors and insulators in its ability to conduct the electrical current. A semiconductor in its pure state is neither a good conductor nor a good insulator. The most common single-element semiconductors are silicon, germanium and carbon. Compound semiconductors such as Gallium Arsenide are also commonly used.

9.1.2 SEMICONDUCTOR DOPING:

The conductivity of silicon and germanium can be drastically increased by the controlled addition of impurities to the intrinsic semiconductor material. This process is called **Doping**. The number of current carriers can be increased with this process. The two types of impurities are P-type and N-type.

Types of Semiconductor Materials

Semiconductor materials may be classified as under:



Types of Semiconductor

N-Type Semiconductor:

To increase the number of electrons in conduction band in intrinsic silicon, pentavalent impurity atoms are added. These are atoms with five electrons in the valance band.
As illustrated in figure 9.1 each pentavalent atom (Sb in this case) forms covalent bonds with four adjacent silicon atoms. Four of the antimony valance electrons are used to form the covalent bonds with silicon atoms leaving one extra electron. This extra electron becomes conduction electron because it is not attached to any atom. Because the pentavalent atom gives up an electron so it is called a donor atom. The number of conduction electrons can be carefully controlled by the number of impurity atoms added to the silicon. The semiconductor formed by this process is called a N-Type semiconductor because it is formed by the donor impurity. As shown in the figure that very soon after the rectifier circuit, is connected a

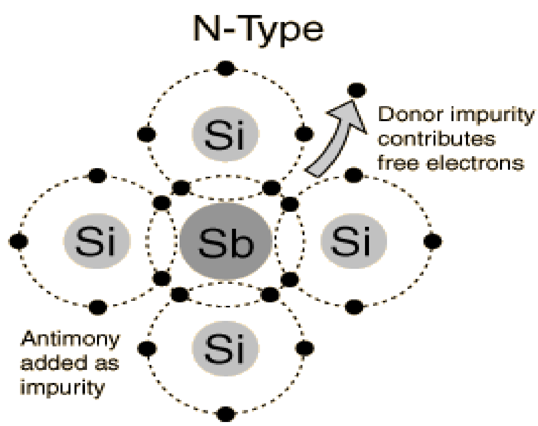


Figure 9.1

P-Type Semiconductor:

To increase the number of holes in intrinsic silicon, trivalent impurity atoms are added. These are atoms with three valance electrons such as boron, indium etc. As illustrated in figure 9.2, each trivalent atom (boron in this case) forms covalent bonds with four adjacent atoms of silicon. All three of the boron valance electrons are used in making covalent bonds with the silicon atoms and since four electrons are required, a hole results when trivalent atom is added. Because the trivalent atom can take an electron, it is often referred to as an accepter atom. The number of holes can be carefully controlled by adding the number of trivalent impurity atoms added to the silicon. The semiconductor materials formed by this process are termed as the P-Type semiconductor materials.

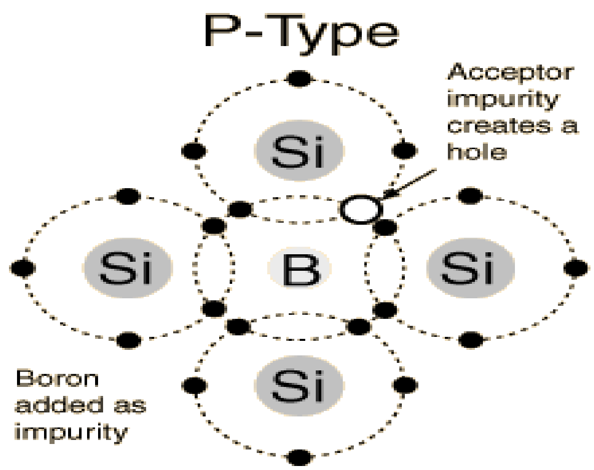


Figure 9.2

9.1.3 DONOR AND ACCEPTER MATERIALS FOR SILICON AND GERMANIUM.

Donor Materials:

Pentavalent atoms are termed as donor materials. These are:

1. Arsenic (As) 2. Bismuth(Bi) 3.Antimony (Sb)

Accepter Materials:

Trivalent atoms are termed as accepter materials. These are:

1. Boron (B) 2. Indium (In) 3. Gallium (Ga)

9.1.4 MAJORITY AND MINORITY CHARGE CARRIERS:

Majority Carriers:

The predominant carriers in a semiconductor, electrons in N type and holes in P type semiconductors are called the majority carriers.

Minority Carriers:

The less dominant carriers in a semiconductor material, electrons in P type and holes in N type semiconductor materials are called the minority carriers.

9.1.5 Effect of Temperature and Light on the Resistance of Intrinsic Semiconductors:

a. Effect of Temperature and Light on the Resistance of Intrinsic Semiconductors:

At higher temperature the resistance of an intrinsic semiconductor decreases. It happens when the material have negative temperature coefficient. The valence band of an intrinsic semiconductor material is almost full whereas the conduction band is almost empty. The energy gap is very narrow. In silicon it is 1.1eV and in germanium it is 0.72eV. With the application of energy which is in the form of heat, electrons can get sufficient energy to escape from the valence band and jump into the conduction band. Therefore the resistance of the material is decreased. The light does not have much effect on the resistance of the semiconductor material and it decreases the resistance of the material to only a small value.

b. Effect of Temperature and Light on the Resistance of Extrinsic Semiconductors:

The resistance in the extrinsic semiconductor materials also decreases with the increase in the temperature but in the extrinsic semiconductor materials the light effect very much to the resistance of the semiconductor material. With small change in the temperature a large change in the resistance of the material is produced. In other words, extrinsic semiconductor materials are more sensitive to the temperature rather than the intrinsic semiconductor materials.

The fifth electron of the antimony has an energy level just below the conduction band which is 0.01eV for germanium 0.052eV for Silicon. The energy gap is very small with respect to intrinsic semiconductor materials.

Extrinsic semiconductor materials are very sensitive to light. Their resistance decreases with the increase in light. The use of these materials is mostly in optoelectronic devices such as LDR (Light Dependent Resistor), photo diodes, phototransistors. Opto-coupler is another example of the optoelectronic devices.

9.2 PN JUNCTION:

If a piece of intrinsic silicon material is doped so that one part is N-type and the other part is P-type, a PN junction forms at the boundary between the two regions and a diode is created as shown in figure 9.3.The P region has many holes and from the impurity atoms and a few thermally generated free electrons. The N region has many free electrons from the impurity atoms and a fewer thermally generated holes.

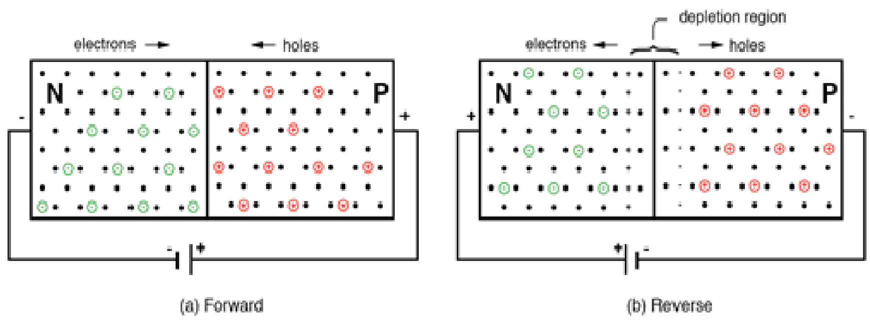


Figure 9.3

Biasing a PN Junction (Diode):

The term bias refers to the use of a dc voltage to establish certain operating conditions for an electronic device. In relation to a diode, there are two bias conditions: forward and reverse. Either of these bias conditions is established by connecting a sufficient dc voltage of the proper polarity across the PN junction.

Forward Bias:

To bias a diode, we apply dc voltage across it. Forward bias is the condition that allows current flow through the PN junction. Figure 9.5 shows a dc voltage source connected by conductive material across a diode in the direction to produce the forward bias. These external biasing voltages are referred to as V_{BIAS}. The resistor R limits the current to a value that will not damage the diode. Notice that the negative side of V_{BIAS} is connected to the N region of the diode and positive side is connected to the P region of the diode. This is first requirement for forward bias. A second requirement is that the bias voltage V_{BIAS} must be greater than barrier potential.

Because like charges repel each other, the negative side of the bias voltage source pushes the free electrons. Which are the majority carriers in the N region toward the PN junction. This flow of electron is called electron current. The negative side of the source also provides a continuous flow of electrons through the external connection and into the N region.

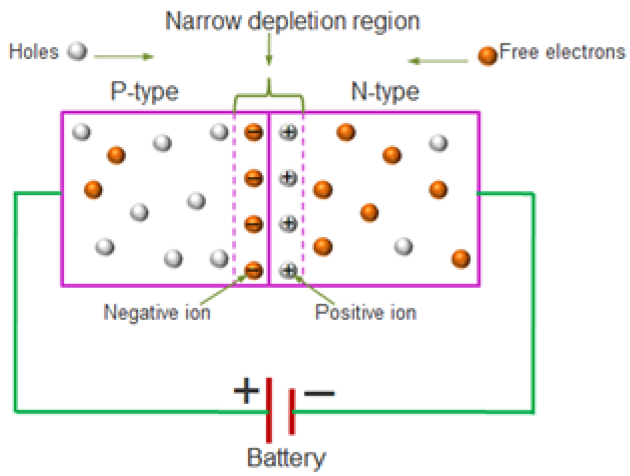


Figure 9.5 Forward Bias

Reverse Bias:

Reverse bias is the condition that prevents current through the diode. Figure 9.6 shows a dc voltage source connected across a diode in the way to produce reverse bias. This external bias voltage is designed as V_{BIAS} just as it was for forward bias. Notice that the positive side of the V_{BIAS} is connected to the N region and negative side is connected to the P region of the PN junction. Also the depletion region is much wider as shown in the figure 9.6 and the situation of a reverse diode is reverse biased is shown in figure 9.6. Because the unlike charges attract each other, the positive side of the V_{BIAS} pulls the electrons, away from the N region. As the electrons flow towards the positive side of the voltage source, additional positive ions are created. This results in a widening of the depletion region.

In the P region, electrons from the negative side of the voltage source enter as valence electrons and moves from hole to hole toward the depletion region where they create additional negative ions. This too results in widening of depletion region. The extremely small current that exists in reverse bias, is called the reverse current.

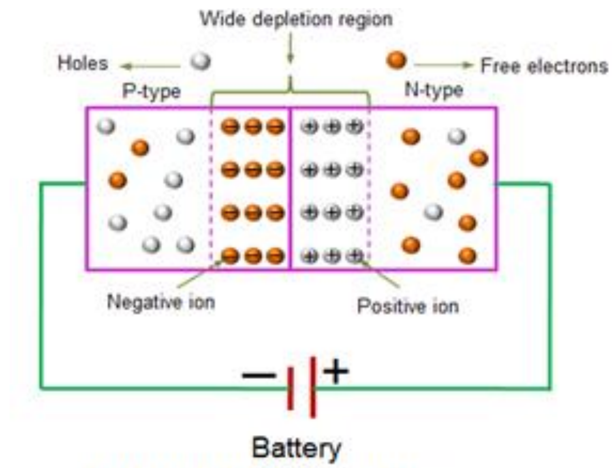


Figure 9.6 Reverse Bias

Formation of the Depletion Layer:

As we know the free electrons in the N region are randomly drifting in all directions. At the instant of PN junction formation, the free electrons near the junction in N region begin to diffuse across the junction into the P region where they combine with holes near the junction as shown in figure 9.4

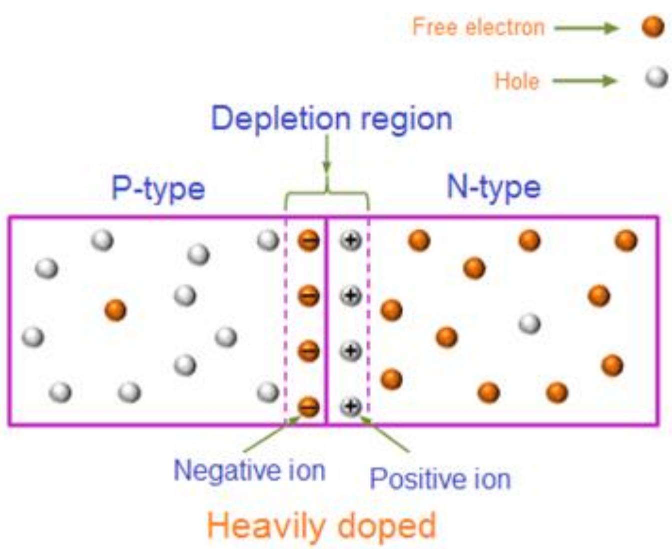


Figure 9.4

Before the junction is formed, recall that there are as many electrons as protons in the N type material, making the material neutral in terms of net charge. The same is true for the P type material. When the PN junction is formed, N region loses free electrons as they diffuse across the junction. This creates a layer of positive charges near the junction. As the electrons move across the junction, the P region loses holes as the electrons and the holes combine. This creates a layer of negative charges near the junction. These two layers of positive and negative charges forms the depletion region, as shown in figure 9.4 .The term depletion refers to fact that the region near the PN junction is depleted of charge carriers due to diffusion across the junction. Depletion region is very thin compared to P and N regions.

After the initial surge of free electrons across the PN junction, the depletion region has expanded to a point where equilibrium is established and there is no further diffusion of electrons across the junction. More and more positive charges are created near the junction as the depletion region is formed. In the end a point is reached where the total negative charges in the depletion region repels any further diffusion of electrons into the P region and the diffusion stops.

Barrier Potential:

The potential difference of the electric field across the depletion region is the amount of voltage required to move electrons through the electric field. This potential difference is called the **Barrier Potential** and is expressed in volts.

The barrier potential of a PN junction depends on several factors, including the type of semiconductor material, the amount of doping, and the temperature. The typical barrier potential is approximately 0.7 V for Silicon and 0.3V for Germanium at 25°C.

9.2.2 DEPLETION LAYER & DIFFUSION CAPACITANCE:

i. **Depletion Layer Capacitance:**

When the junction is connected in the reverse bias then there is no current flowing through the junction and the junction behaves like an insulator or a dielectric material which is essential for making a capacitor. The P and N type regions on either side have very low resistance and acts as plates. Therefore all the components necessary for making a parallel capacitor are available. This junction capacitance is termed as the depletion layer capacitance. The typical value for the depletion layer capacitance is 40 pf. With the increase in reverse bias this capacitance can be decreased. The reverse bias PN junction is used in the construction of a special purpose diode called the **Varactor Diode**.

i. Diffusion Capacitance:

When the forward bias PN junction is reverse bias suddenly, a reverse current flows which is large initially but with the passage of decreases to the level of saturation current IO. This resembles to the discharging of the capacitor therefore it is called the Diffusion Capacitance (C_D). It has a typical value of 0.02 µF.

This capacitance is very important factor where the devices are required to switch from forward to reverse bias such as switching at high frequency signals. If the C_D is large, switching at high frequency cannot be possible. This effect of C_D is also known as **Reveres Recovery Time** and the corresponding current is **Reverse Recovery Current**.

9.2.3 Voltage-Current Characteristic Curve Of PN-Junction:

The voltage and current characteristics curve of a PN junction diode is shown in figure 9.7 below

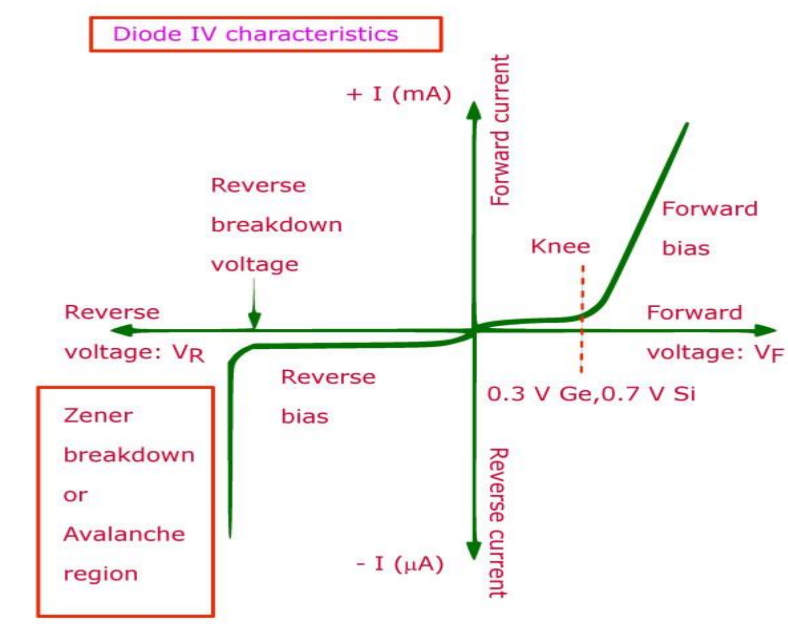


Figure 9.7

Forward Resistance:

The resistance offered by diode in forward conduction region is called Forward resistance. It is denoted by R_F.To calculate the forward resistance for the diode following relation is used.

$$R_F = V_F/I_F$$

Here V_F is forward voltage and IF is the forward current passing through the diode.

Reverse Resistance:

The resistance offered by a diode in reverse conduction region. To calculate the reverse resistance R_R for the diode following relation is;

$$R_R = V_R/I_R$$

Surge Current:

The initial rush of the current through the diode when the power is turned on is called the Surge Current.

9.2.5 TYPICAL VALUES FOR BARRIER POTENTIAL

Typical value of the barrier potential for silicon is 0.7 V and for germanium is 0.3 V at room temperature (25°C). The barrier potential is decreased with the increase in temperature.

9. 3 Understand PN Diode Applications

9.3.1 List the uses of PN diode.

The major areas of the diode applications have been listed below:

1. Diode is used as rectifier in order to convert AC into DC
2. In modulation and demodulation.
3. In Logic Circuits.
4. For voltage regulation Zener Diode is used.
5. In Light Sensitive Devices and in light meters the photo diode is used.

6. For tuning purposes the Varactor diode is used.

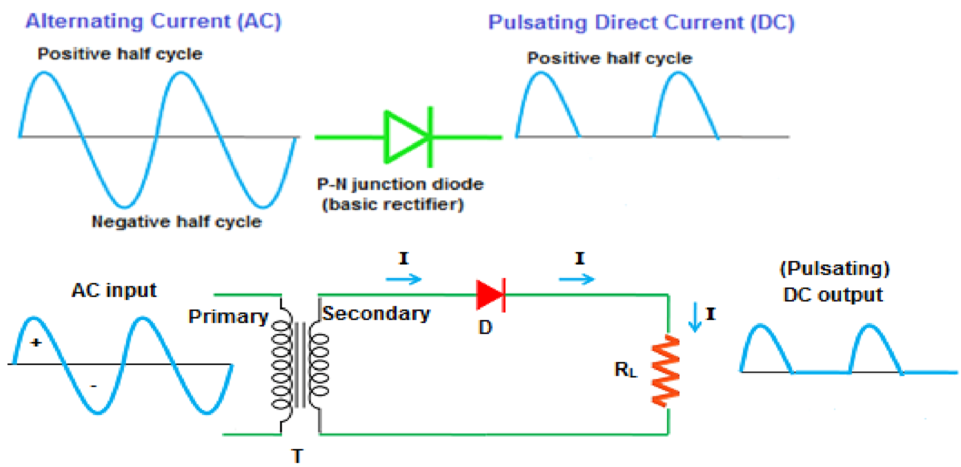
7. Schottky Diode is used in the fast Switching Applications.

9.3.2 HALF AND FULL WAVE RECTIFIER USING CIRCUIT DIAGRAM.

1. Half Wave Rectifier:

Figure 9.8 illustrates a process called the half wave rectification. A diode is connected to an AC source and to a load resistor, RL, forming a half wave rectifier. Let's examine what happens during one cycle of the input voltage using the ideal model of the diode. When the sinusoidal input voltage(Vin) goes positive, the diode is forward biased and conducts current through the load resistor, as shown in part (a). The current produces an output voltage across the load resistor R_L. The output voltage has the same shape as the positive half cycle of the input voltage.

When the input voltage goes negative during the second half of its cycle, the diode is reverse biased. There is no current, so the voltage across the load resistor is 0V, as shown on the output of figure 9.8 .The net result is that the positive half cycles of the AC input voltage appear across the load resistor. Since the output does not change its polarity, it is a pulsating DC Voltage. The frequency of the voltages is also 60 Hz.



I=Current, D=Diode, R_L = Load Resistor, T= Transformer,
+ =Positive Half Cycle, - =Negative Half Cycle

Figure 9.8 Half Wave Rectifier

Average Value of the Half Wave Output Voltage:

The average value of the half wave rectifier is the value which is measured on a DC voltmeter. Mathematically, it is determined by finding the area under the curve over a full cycle, is expressed in the equation.

$$V_{AVG} = Vp/\pi$$

Effect of Barrier Potential on Output:

When the practical diode model is used with the barrier potential of 0.7V (in case of Silicon) taken into account, during the positive half cycle, the input voltage must overcome the barrier potential, before the diode becomes forward biased. The result is a half wave rectified output with a barrier potential less than the peak value of the input. Mathematically:

$$Vout = Vp\ (in) - 0.7V$$

Peak Inverse Voltage (PIV):

The peak inverse voltage (PIV) equals the peak value of the input voltage when it is reverse biased. The diode must be capable of withstanding this amount of repetitive inverse voltage. Mathematically:

$$PIV = V_P\ (in)$$

2. **Full-Wave Rectifier:**

A full wave rectifier is one in which both cycles of the input ac appears at the load. Although half wave rectifiers have some applications, the full wave rectifier is the most commonly used in DC power supplies. The difference between the half wave and the full rectifier is that a full wave rectifier allows one way current through the load during the entire 360° of the input cycle. The frequency of the output voltage in full wave rectifier is doubled than the frequency of the half wave rectifier output voltage. The average value of the full wave rectifier is twice that of the half wave rectifier as shown in the following formula.

$$V_{AVG} = 2\ Vp/\pi$$

V_{AVG} is approximately 63.7% of Vp for a full wave rectified output.

There are two types of full wave rectifiers:

a. Center-Tapped Full-Wave Rectifier
b. Bridge Full-Wave Rectifier

Center-Tapped Full-Wave Rectifier:

A center tapped rectifier is a type of full wave rectifier that uses two diodes connected to the secondary of a center tapped transformer, as shown in the Figure 9.9 below.

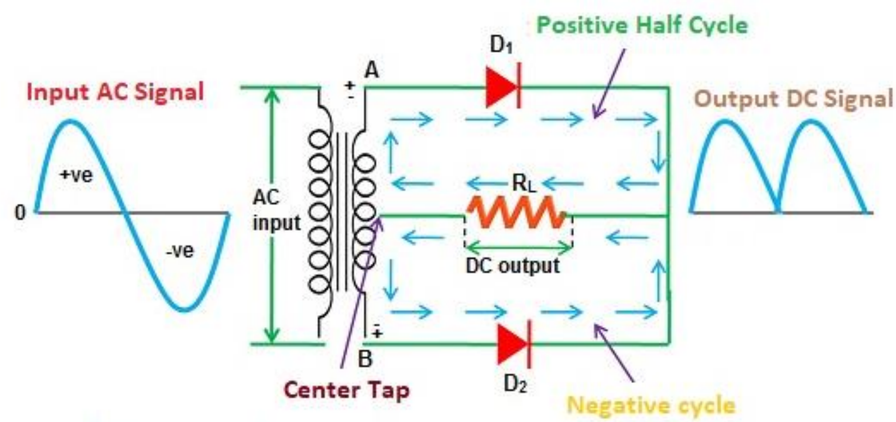


Figure 9.9

The input voltage is coupled through the transformer to the center tapped secondary. Half of the secondary voltage appears between the center tap and each end of the secondary winding as shown in figure 9.9

The polarities of the secondary voltages for a positive half of the input voltages are also shown in the figure. In this condition the diode D1 is forward biased and the diode D2 is reverse biased. The current path is through the forward biased diode D1 and through the load resistor RL, as indicated. During the negative half cycle the diode D1 is reverse biased and the diode D2 is forward biased. Therefore the current path is through the D2 and RL, as indicated. The current path both for the positive and the negative half cycle is the same through the load so the output voltage developed across the load resistor is a full wave rectified DC voltage as shown.

Bridge Full Wave Rectifier:

The modification of the conventional full wave rectifier is the bridge rectifier. The bridge rectifier uses four diodes as shown in the figure 9.10. When the input cycle is positive as in figure, D1 and D2 diodes are forward biased and current is conducted in the direction as shown. Meanwhile, the diode D3 and D4 are reverse biased and do not conduct the current. A voltage is developed across the load resistor that resembles very much to the positive half cycle of the input voltage.

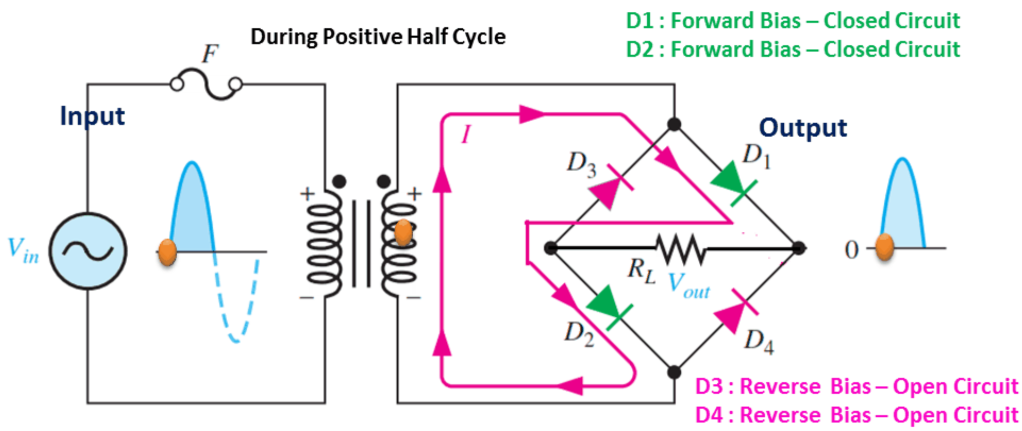


Figure 9.10

When the input cycle is negative as shown in the figure 9.10, the D1 and D2 diodes are reverse biased while the D3 and D4 are forward biased and current flows through the load resistor as shown in the figure 9.10. As a result of both the positive and the negative half cycle of the input voltage the full wave rectified output voltage appears across the load resistor RL.

Ripple Factor:

The ripple factor is the measure of the effectiveness of the filter and is defined as:

$$r = \frac{\text{ripple voltage } V_{r(pp)}}{\text{circuit dc voltage } V_{DC}}$$

Where Vr (pp) is the peak-to-peak ripple voltage and VDC the dc value of filter's output voltage.

Surge Current:

Surge current is that amount of large current which flows through the diode and it can safely take it for a very short time (up to 1 second). It is denoted as I_{FS}.

9.3.4 FILTERS:

Electronic circuits often have currents of different frequencies corresponding to the voltages of different frequencies. The reason is that a source produces current with the same frequency as the applied voltage. In such applications where the current has different frequency components, it is usually necessary either to favor or to reject one frequency or band of frequencies. For this purpose an electrical filter is used to separate higher or lower frequencies.

For most computer circuits, even a small ripple voltage can cause errors to occur in the data processed. The output of a D.C power supply should be as stable as the output of a battery. It is possible, through the use of filter circuits.

Types of Filter Circuits:

Three types of filter circuits have been listed below:

1. L-Type Filters.
2. PI-Type Filters.
3. T-Type Filters.

L-Type Filters:

The L-type filters have further two types according to the arrangement of the inductor and the capacitor.

a. Inductor Input Filter
b. Capacitor Input Filter

Inductor Input Filter

Inductor input filter is also called the choke input or LC filter. In this arrangement an inductor is connected to the circuit before the capacitor, therefore such a circuit is called as the inductor input filter. The inductor in the circuit offers a very large inductive reactance to the AC in the circuit while passes the DC without any reactance. While the capacitor offers very low reactance to the remaining AC from the inductor. In this way the ripples are bypassed by the capacitor and at output there is steady DC output.

Capacitor acts as short for AC and opens for DC while inductor acts short for DC and acts open for the AC. If the value of the L is kept small there will be more ripples and vice versa. Inductive input circuit with its waveforms has been shown in the figure 9.11 below.

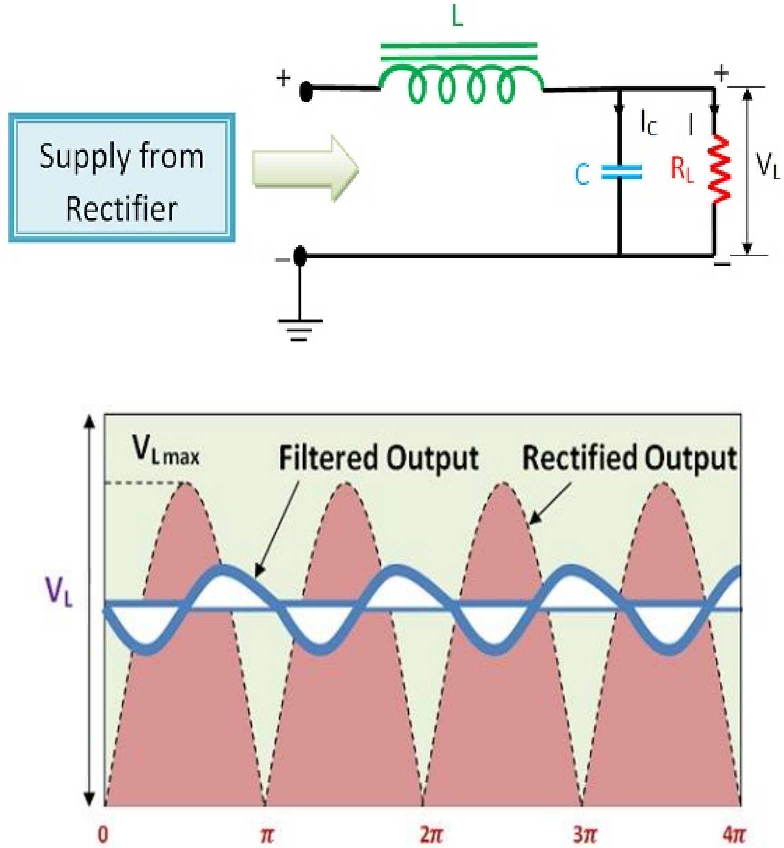


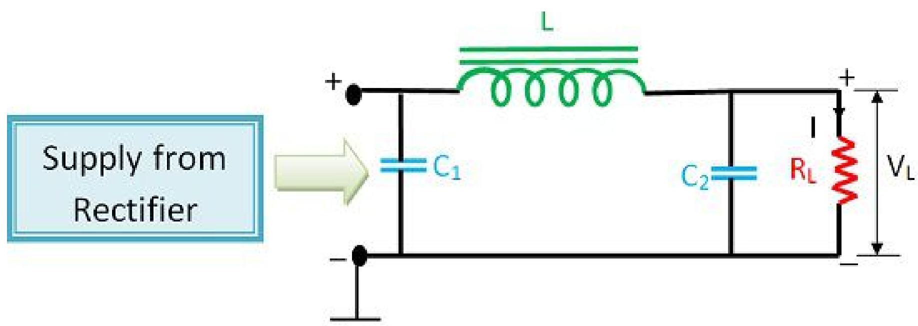
Figure 9.11

Capacitor Input Filter (PI-Filter):

The filter circuit in which the capacitor is connected first than the inductor is known as the capacitor input filter. Capacitor input circuit has been shown in the figure 9.12. As shown in the figure that very soon after the rectifier circuit, is connected a parallel capacitor and after it a series inductor with the load resistor. In this filter an inductor and two capacitors are connected in the form of the Greek letter Pi (π), is also termed as the pi filter.

Figure 2.17

We know that the capacitor acts as short for AC and open for DC. When the pulsating output from the rectifier is provided to the input of the capacitor filter; the capacitor connected at the start of the filter circuit is charged to the peak of its conducting half. Conversely, when the voltages are reduced below the peak charged value of the capacitor, it begins to discharge through the load resistor. Hence the magnitude of voltages at output is kept constant. During the next pulse the capacitor is charged again. As a result the voltages across the capacitor are such that there are very less ripples incorporating in them. After this the output of the capacitor is provided to the inductor. This inductor, due to its high reactance, by passes the remaining ripples from the capacitor. Hence the inductor connected in series of the output load resistor prevents any changes in the current. As a result AC ripples could not reach to the output and as a result at output pure DC is obtained.



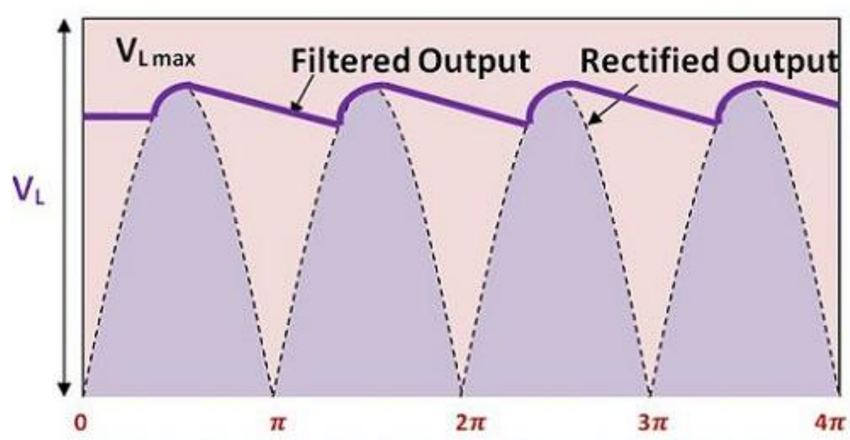
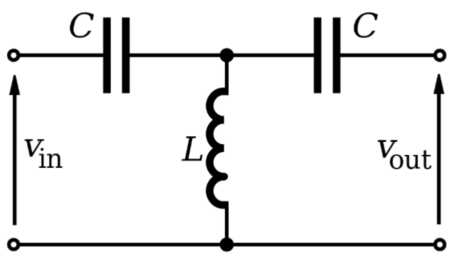


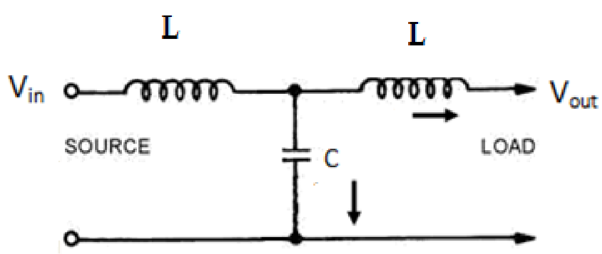
Figure 9.12

T-Type Filters:

T-type filter is comprised of two inductors and one capacitor. The two inductors and the one capacitor are connected in an arrangement that, the filter is formed in the form of T of English alphabet. In this arrangement, the capacitor is connected between the two inductors as shown in the figure 2.19.



(a). High Pass T-Filter



(b).Low Pass T-Filter

Fig 9.13

The LC filter in the start of the T filter has less voltage than that of the input peak voltage due to the voltage drop across the reactance in the circuit. The inductor L1 as shown in the figure offer very large reactance to the AC input and hence it eliminates most of the AC ripples. While the capacitor offers very less reactance to the remaining ripples and hence by passes the ripples. Hence most of the ripples are eliminated due to the LC filtering action. However if some ripples are still remaining then the second inductor L2 eliminates them due to its high reactance. As a result there is approximately pure DC is achieved at the output.

9.3.5 Use of Diode as Voltage Multiplier (Doubler):

The circuit comprising of diodes and capacitors that increases the voltages to twice, thrice or four times is termed as voltage multiplier. In fact, these are two or more than two peak rectifiers that provides output equal to the multiples of peak input voltages. Such circuits are used for high voltages or low currents e.g. in Cathode Ray Tube and T.V Receivers etc. In voltage multipliers peak rectified voltages are increased by using the clamping action without increasing the transformer input voltage ratings. The multiplication factor of voltage multipliers is usually 2, 3 or 4. The voltage multipliers commonly used has been listed below:

i. Voltage Doubler
ii. Voltage Tripler
iii. Voltage Quadrupler

9.3.6. Voltage Doubler

Voltage doublers are such multipliers that have the multiplication factor of 2. It doubles the input voltage peak at output peak so it is termed as the voltage doubler. It can be half or full wave voltage doubler. A voltage double circuit is shown in figure 9.14 below. In this circuit during the positive half cycle of the input wave the diode D1 is forward biased and the diode D2 is reverse biased. Due to this reason the capacitor C1 is charged to the peak voltage Vm.

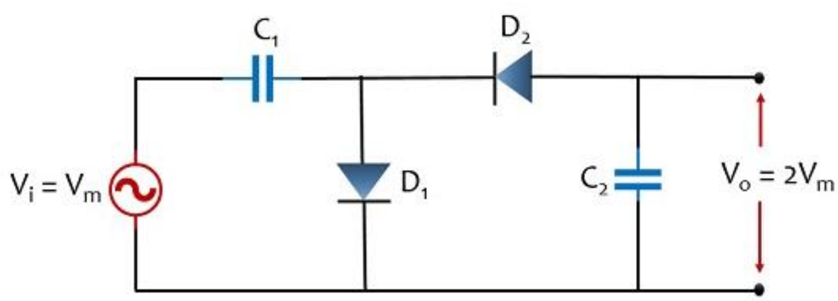


Figure 9.14

During the negative half cycle of the input wave the diode D1 is reverse biased and the diode D2 is forward biased. As the voltage source and C1 both are in series therefore C2 is charged to the 2Vm, which are the voltage of Vm+C1. In the half wave voltage doubler each diode has inverse voltage across it which are equal to 2Vm.

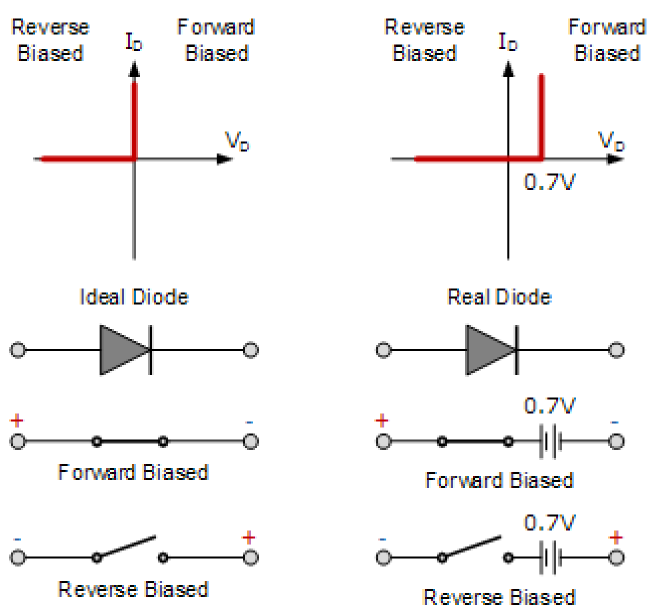
9.3.7 Applications of Voltage Multiplier Circuits:

Voltage multiplier circuits are used to obtain high value of the voltage and current. These can be used in ;

i. Cathode Ray Tubes
ii. TV Receivers
iii. Computer Displays
iv. Oscilloscopes
v. Power Supplies

9.3.8 Diode as a Switch:

An ideal diode works like a switch. When an ordinary switch is closed, the resistance between its terminals goes to zero value and when the switch is open the resistance between the contacts is infinity. Similarly when a diode is forward biased, it works like a closed switch and when it is reverse biased. It acts like an open switch. Figure 9.15 shows a diode being used as a switch.



Multiple Choice Questions

Q.1 The process by which impurities are added to a pure semiconductor is:
(a). Diffusing (b). Drift (c). Doping (d). Mixing

Q.2 A Germanium atom contains.
(a). Two electron or bits (b). Three valance electrons
(c). Four protons (d). Four valance electron

Q: 3 The type of atom bonding most common in semiconductor is
(a). Metallic (b). Ionic (c). Covalent (d). Chemical

Q.4 The reverse resistance of an ideal diode is:
(a)Low (b) Zero (c) Infinite (d) Very high

Q.5 A circuit that removes positive or negative parts of a waveform is called:
(a)Clamper (b) Clipper (c) Rectifier (d) Multiplier

Q.6 Voltage multipliers are used to produce:
(a) Low voltage and low current (b) Low Voltage and High current
(c) High voltage and low current (d) High voltage and high current

Q.7 Diode acts as a close switch when it is:
(a) Not Biased (b) Forward biased
(c) Reverse biased (d) none of above

Q.8 P region of a diode is called _______.
(a) Anode (b) Cathode (c) Any of these (d) None of these

Q. 9 The amount of energy required to produce full conduction across the PN junction is _______.
(a) Junction potential (b) Barrier potential
(c) Biased potential (d) Diode voltage

Q.10 The N region of a diode is called _______.
(a) Anode (b) Cathode
(c) Barrier potential (d) Biasing

Q.11 A semiconductor device with a single PN junction that conducts current in only one direction is ___.
(a) Diode (b) Transistor (c) SCR (d) Thyristor

Q.12 The boundary between two different types of semi conductive materials is _______.
(a) PN junction (b) Diode (c) Triode (d) Tetrode

Q.13 The condition in which a diode prevents current is _______.
(a) Forward Bias (b) Reverse Bias
(c) Conduction (d) Break down

Q.14 _______ is a semi conductive material.
(a) Silicon (b) Germanium
(c) Both a and b (d) neither a nor b

Q.15 The most widely used semi conductive material in electronic devices is
(a) Germanium (b) Carbon (c) Copper (d) Silicon

Q.16 Electron-hole pairs are produced by
(a) Recombination (b) Thermal energy (c) Ionization (d) Doping

Q.17 In an intrinsic semiconductor _______.
(a)No free electrons (b) Free electrons are thermally produced
(c) There are only holes (d) as many electrons as holes (e) b and d

Q.18 When a diode is forward biased _______.
(a) The only current is the hole current
(b) The only current is electron current
(c) The only current is produced by majority carriers
(d) The current is produced both holes & electrons

Q.19 For silicon diode, the value of the forward bias voltage typically:
(a) > 0.3v (b) > 0.7v
(c) Depends on the width of Depletion Region
(d) Depends on the Majority Carriers

Q.20 When a 60Hz sinusoidal voltage is applied to the input of a half wave rectifier, the output frequency is_______.
(a) 120Hz (b) 30Hz (c) 60Hz (d) 0Hz

ANSWER KEY

Q.1 (c)	Q.2 (d)	Q.3 (c)	Q.4 (c)
Q.5 (c)	Q.6 (b)	Q.7(c)	Q.8 (a)
Q.9 (b)	Q.10(b)	Q.11 (b)	Q.12 (a)
Q.13(a)	Q.14 (c)	Q.15 (d)	Q.16 (b)
Q.17(a)	Q.18 (d)	Q.19 (b)	Q.20 (c)

Short Questions

1. Define semiconductor. Name semiconductor materials.
2. Differentiate between intrinsic & extrinsic semiconductor.
3. Define the term doping.
4. Why pentavalent impurities called donor impurities?
5. Why trivalent impurities called accepter impurities?
6. Name pentavalent and trivalent elements.
7. What is meant by a hole?
8. What is the effect of temperature on intrinsic semiconductor?
9. Define PN junction.
10. How a diode is forward biased?
11. How a diode is reverse biased?
12. Define depletion region.
13. Define barrier potential. List the values of barrier potential for silicon and germanium diode.
14. List the application of PN junction diode.
15. Define the term rectification.
16. List the types of rectifier.
17. Define multiplier. Enlist its types.
18. In what condition, a diode is used as an open switch?
19. List the types of filters.
20. List applications of voltage multiplier circuits.

Long Questions

1. Describe the energy band structure of insulator, semiconductor & conductors.
2. Explain the difference between intrinsic and extrinsic semiconductors.
3. Compare P&N type semiconductors.
4. Explain the PN-Junction and its biasing in detail.
5. Explain the construction & working of PN junction diode.
6. Describe the V-I characteristics of PN junction diode.
7. Describe the half wave rectifier in detail.
8. Explain the full wave rectifier in detail.
9. What is a filter? Explain the types of filter.

CHAPTER 10 NUMBER SYSTEM

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OBJECTIVES
After completion of this chapter students will be able to:

1. **Conversion**
2. **Binary to Decimal.**
3. **Decimal to Binary.**
4. **Hexadecimal to Binary.**
5. **Binary to Hexadecimal.**
6. **Hexadecimal to Decimal.**
7. **Decimal to Hexadecimal.**

10.1 Number System

Definition: In digital electronics, the number system is used for representing the information. The number system has different bases and the most common of them are the decimal, binary, octal, and hexadecimal. The **base or radix** of the number system is the total number of the digit used in the number system. Suppose if the number system representing the digit from 0 – 9 then the base of the system is the 10

Types of Number Systems

Some of the important types of number system are

1. Decimal Number System
2. Binary Number System
3. Octal Number System
4. Hexadecimal Number System

These number systems are explained below in details.

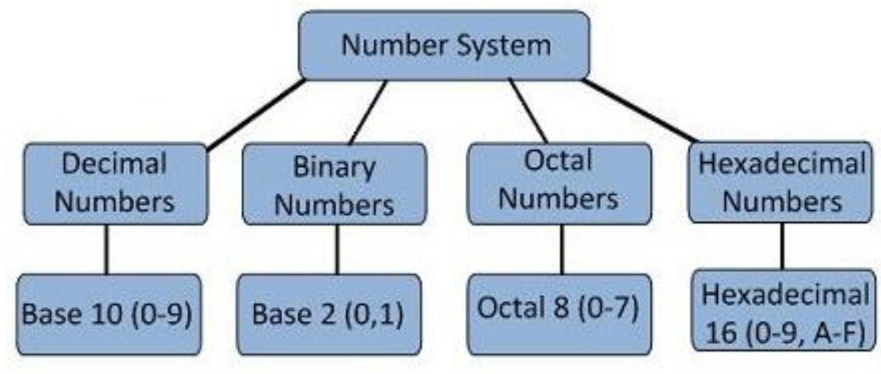

Fig 10.1 Number System

10.1.1 CONVERT BINARY NUMBERS INTO DECIMAL NUMBERS

The modern computers do not process decimal number; they work with another number system known as a binary number system which uses only two digits 0 and1.The base of binary number system is 2 because it has only two digit 0 and 1.The digital electronic equipment's are works on the binary number system and hence the decimal number system is converted into binary system.

Characteristics

Uses two digits, 0 and 1.

Each position in a binary number represents a 0 power of the base 2. Example: 2^0

Last position in a binary number represents an x power of the base 2. Example: 2^x where x represents the last position - 1.

Example

Step 1 101012 $= ((1 \times 2)^4 + (0 \times 2)^3 + (1 \times 2)^2 + (0 \times 2)^1 + (1 \times 2)^0)_{10}$

Step 2 101012 $= (16 + 0 + 4 +0 + 1)_{10}$

Step 3 101012 $=21_{10}$

Problem No.1: 001100 Binary to Decimal conversion?

$$= ((0 \times 2)^5 (0 \times 2)^4 + (1 \times 2)^3 + (1 \times 2)^2 + (0 \times 2)^1 + (0 \times 2)^0)_{10}$$

$= (0 + 0 + 8 + 4 + 0 + 0)$
$= 12_{10}$

Problem No.2: 000011 Binary to Decimal conversion?

$= ((0 \times 2)^5 (0 \times 2)^4 + (0 \times 2)^3 + (0 \times 2)^2 + (1 \times 2)^1 + (1 \times 2)^0)_{10}$
$= (0 + 0 + 0 + 0 + 2 + 1)$
$= 3_{10}$

Problem No.3: 011100 Binary to Decimal conversion?

$= ((0 \times 2)^5 (1 \times 2)^4 + (1 \times 2)^3 + (1 \times 2)^2 + (0 \times 2)^1 + (0 \times 2)^0)_{10}$
$= (0 + 16 + 8 + 4 + 0 + 0)$
$= 28_{10}$

Problem No.4 (Self-Test Problem):

Binary to Decimal conversion 111100 =?

Problem No.5 (Self-Test Problem):

Binary to Decimal conversion: 111111 =?

Problem No.6: 11100.001 Binary to Decimal conversion?

$=1 * 2^4 + 1 * 2^3 + 1 * 2^2 + 0 * 2^1 + 0 * 2^0 + 0 * 2^{-1} + 0 * 2^{-2} + 1 * 2^{-3}$
$= 16 + 8 + 4 + 0 + 0 + 0 + 0 + 0.125$
$= 28.125$

Problem No.7 110011.10011 Binary to Decimal conversion?

$=1 * 2^5 + 1 * 2^4 + 0 * 2^3 + 0 * 2^2 + 1 * 2^1 + 1 * 2^0 + 1 * 2^{-1} + 0 * 2^{-2}$
$+ 0 * 2^{-3} + 1 * 2^{-4} + 1 * 2^{-5}$
$= 32 + 16 + 0 + 0 + 2 + 1 + 0.5 + 0 + 0 + 0.0625 + 0.03125$
$= 51.59375$

Problem No.5 (Self-Test Problem):

Binary to Decimal Conversion 101010101010.1=?

10.1.2 CONVERT DECIMAL NUMBERS INTO BINARY NUMBERS:

Decimal number system has only ten (10) digits from 0 to 9. Every number (value) represents with 0,1,2,3,4,5,6, 7, 8 and 9 in this number system. The base of decimal number system is 10, because it has only 10 digits.

PROBLEMS.

Problem No.1 Decimal to Binary conversion 64 =?

Answer

A	Quotient	Remainder
64/2	32	0
32/2	16	0
16/2	8	0
8/2	4	0
4/2	2	0
2/2	1	0
1/2	0	1

$64_{10} = 1000000_2$

Problem No.2 Decimal to Binary conversion 128 =?

Answer

B	Quotient	Remainder
128/2	64	0
64/2	32	0
32/2	16	0
16/2	8	0
8/2	4	0
4/2	2	0
2/2	1	0
1/2	0	1

B, $128_{10} = 10000000_2$

Problem No.3 decimal to binary conversion 256 =?

Answer

C	Quotient	Remainder
256	128	0
128/2	64	0
64/2	32	0
32/2	16	0

16/2	8	0
8/2	4	0
4/2	2	0
2/2	1	0
1/2	0	1

C, $256_{10} = 100000000_2$

Problem No.4 decimal to binary conversion 100 =?

Answer

D,	Quotient	Remainder
100/2	50	0
50/2	25	0
25/2	12	1
12/2	6	0
6/2	3	0
3/2	1	1
1/2	0	1

D, $100_{10} = 1100100_2$

Problem No.5 decimal to binary conversion 111 =?

Answer

E,	Quotient	Remainder
111/2	55	1
55/2	27	1
27/2	13	1
13/2	6	1
6/2	3	0
3/2	1	1

E, $111_{10} = 1101111_2$

Problem No.6 (Self-Test Problem) decimal to binary conversion 145 =?

Problem No.7 (Self-Test Problem) decimal to binary conversion 255 =?

10.1.3 CONVERT HEXADECIMAL NUMBERS INTO BINARY NUMBERS.

A Hexadecimal number system has sixteen (16) alphanumeric values from 0 to 9 and A to F. Every number (value) represents with 0,1,2,3,4,5,6,7,8, 9,A,B,C,D,E and F in this number system. The base of hexadecimal number system is 16, because it has 16 alphanumeric values. Here A is 10, B is 11, C is 12, D is 14, E is 15 and F is 16.

Decimal	Binary	Hexadecimal	Decimal	Binary	Hexadecimal
0	0000	0	8	1000	8
1	0001	1	9	1001	9
2	0010	2	10	1010	A
3	0011	3	11	1011	B
4	0100	4	12	1100	C
5	0101	5	13	1101	D
6	0110	6	14	1110	E
7	0111	7	15	1111	F

How to Convert Hexadecimal to Binary Number?

To convert a hexadecimal number into its equivalent binary number, follow the steps given here:

- **Step 1:** Take given hexadecimal number
- **Step 2:** Find the number of digits in the decimal
- **Step 3:** If it has n digits, multiply each digit with 16^{n-1} where the digit is in the nth position
- **Step 4:** Add the terms after multiplication
- **Step 5:** The result is the decimal number equivalent to the given hexadecimal number. Now we have to convert this decimal to binary number.
- **Step 6:** Divide the decimal number with 2
- **Step 7:** Note the remainder
- **Step 8:** Do the above 2 steps for the quotient till the quotient is zero
- **Step 9:** Write the remainders in the reverse order.
- **Step 10:** The result is the required binary number.

Hence, from the above steps it is clear that how to convert any hexadecimal number into binary, i.e. first, we need to convert hexadecimal to decimal number and then decimal to binary.

Problem No. 1: Convert $A2B_{16}$ to an equivalent binary number.

Solution: Given hexadecimal number = $A2B_{16}$

First, convert the given hexadecimal to the equivalent decimal number.

$A2B_{16} = (A \times 16^2) + (2 \times 16^1) + (B \times 16^0)$

$= (A \times 256) + (2 \times 16) + (B \times 1)$

$= (10 \times 256) + 32 + 11$

$= 2560 + 43$

= 2603(Decimal number)

Now we have to convert 2603_{10} to binary

$A20_{16}$	**Quotient**	**Remainder**
2603/2	1301	1
1301/2	650	1
650/2	325	0
325/2	162	1
162/2	81	0
81/2	40	1
40/2	20	0
20/2	10	0
10/2	5	0
5/2	2	1
2/2	1	0

The binary number obtained is 101000101011_2

Hence, $A2B_{16} = 101000101011_2$

Problem No. 2: Convert E_{16} to an equivalent binary number.

Solution: Given, a hexadecimal number is E.

First, convert the given hexadecimal to the equivalent decimal number.

$E_{16} = E \times 16^0$

$= E \times 1$

$= E$

=14 (Decimal number)

Now we have to convert 14_{10} to binary number.

E_{16},	Quotient	Remainder
14/2	7	0
7/2	3	1
3/2	1	1

The binary number obtained is 1110_2

Hence, $E_{16} = 1110_2$

Problem No. 3: Convert 30_{16} to an equivalent binary number.

Solution: Given the hexadecimal number is 30

First, convert the given hexadecimal to the equivalent decimal number.

$$30_{16} = (3 \times 16^1) + (0 \times 16^0)$$

$$= 48 + 0$$

$$= 48(\text{Decimal number})$$

Now we have to convert 48_{10} to binary.

E,	Quotient	Remainder
48/2	24	0
24/2	12	0
12/2	6	0
6/2	3	0
3	1	1

The binary number is 110000_2

Hence, $30_{16} = 110000_2$

Problem No. 4 (Self-Test Problem):

Convert **FDA_{16}** to an equivalent binary number

Problem No. 5 (Self-Test Problem):

Convert **$98B_{16}$** to an equivalent binary number

Problem No. 6 (Self-Test Problem):

Convert **$5C_{16}$** to an equivalent binary number

Problem No. 7 (Self-Test Problem):

Convert **100_{16}** to an equivalent binary number

10.1.4 CONVERT BINARY NUMBERS INTO HEXADECIMAL NUMBERS.

You can convert binary into hexadecimal fairly easily. Since a byte is made up of 8 bits, it can be easily split into two equal sections. These two sections are known as nibbles and are made up of 4 bits.

Converting Binary to Hexadecimal is a very simple operation. The Binary string is divided into small groups of 4-bits starting from the least significant bit. Each 4-bit binary group is replaced by its Hexadecimal equivalent.

Problem No. 1 Convert Binary Numbers into Hexadecimal
11010110101110010110=?

11010110101110010110 Binary Number

1101 0110 1011 1001 0110 Dividing into groups of 4-bits
D 6 B 9 6 Replacing each group by its

Hexadecimal equivalent Thus 11010110101110010110 is represented

in Hexadecimal by D6B96

Problem No. 2 Convert Binary Numbers into Hexadecimal

1101100000110=?

Binary strings which cannot be exactly divided into a whole number of 4-bit groups are assumed to have 0's appended in the most significant bits to complete a group.

1101100000110 Binary Number
1 1011 0000 0110 Dividing into groups of 4-bits
0001 1011 0000 0110 Appending three 0s to complete the group
1 B 0 6 Replacing each group by its Hexadecimal equivalent

Problem No. 3 (Self-Test Problem):

Convert $(01001110)_2$ to an equivalent Hexadecimal number

Problem No. 4 (Self-Test Problem):

Convert $(0100101000000001)_2$ to an equivalent Hexadecimal number

10.1.5 CONVERT HEXADECIMAL NUMBERS INTO DECIMAL NUMBERS.

To convert a hexadecimal to a decimal manually, you must start by multiplying the hex number by 16. Then, you raise it to a power of 0 and increase that power by 1 each time according to the hexadecimal number equivalent.

We start from the right of the hexadecimal number and go to the left when applying the powers. Each time you multiply a number by 16, the power of 16 increases. Converting from hex to base 10 is the same process we have used before with column values, using the values 1 and 16. For example: 23 in base 16 is:

23_{16} Convert Hexadecimal Numbers into Decimal Numbers.

$=2*16^1 +3*16^0$

$=32 +3 =35_{10}$

Problem No. 1: $3C_{16}$ Convert Hexadecimal Numbers into Decimal Numbers.

$= 3*16^1 + 12*16^0$

$=3*16 + 12*1$

$= 48+12 =60_{10}$

Problem No. 2: $5F6_{16}$ Convert Hexadecimal Numbers into Decimal Numbers.

$= ((5*16)^2 + (15*16)^1 + (6*16)^0)$

$=5*256 + 15*16 + 6*1$

$=1280 + 240 +6 = 1526_{10}$

Problem No. 3 (Self-Test Problem):

Convert Hexadecimal Numbers into Decimal Numbers. 111=?

Problem No. 3 (Self-Test Problem):
Convert Hexadecimal Numbers into Decimal Numbers. DEF =?

Problem No. 3 (Self-Test Problem):
Convert Hexadecimal Numbers into Decimal Numbers. 231 =?

Problem No. 3 (Self-Test Problem):
Convert Hexadecimal Numbers into Decimal Numbers. 5DE =?

10.1.6 CONVERT DECIMAL NUMBERS INTO HEXADECIMAL NUMBERS.

To convert from decimal to hexadecimal you must divide the decimal number by 16 repeatedly. Then, write the last remainder you obtained in the hex equivalent column. If the remainder is more than nine, remember to change it to its hex letter equivalent. The answer is taken from the last remainder obtained.

How to convert from decimal numbers to hexadecimal numbers

Conversion steps:

1. Divide the number by 16.
2. Get the integer quotient for the next iteration.
3. Get the remainder for the hex digit.
4. Repeat the steps until the quotient is equal to 0.

Problem No. 1: Convert From Decimal Numbers to Hexadecimal Numbers 7562_{10}

Division by 16	Quotient (integer)	Remainder (decimal)	Remainder (hex)
7562/16	472	10	A
472/16	29	8	8
29/16	1	13	D
1/16	0	1	1

So $7562_{10} = 1D8A_{16}$\

Problem No. 2: **Convert From Decimal Numbers to Hexadecimal Numbers 540_{10}**

Division by 16	Quotient (integer)	Remainder (decimal)	Remainder (hex)
540 / 16	33	12	C
33 / 16	2	1	1
2 / 16	0	2	2

So $540_{10} = 21C_{16}$

Problem No. 3: **Convert From Decimal Numbers to Hexadecimal Numbers 35631_{10}**

Division by 16	Quotient (integer)	Remainder (decimal)	Remainder (hex)
35631/16	2226	15	F
2226/16	139	2	2
139/16	8	11	B
8/16	0	8	8

So $35631_{10} = 8B2F_{16}$

Problem No. 3 (Self-Test Problem):

Convert decimal number 600_{10} into hexadecimal number.

Problem No. 3 (Self-Test Problem):

Convert decimal number 1228_{10} into hexadecimal number.

Problem No. 3 (Self-Test Problem):

Convert decimal number 49 into hexadecimal number.

Multiple Choice Questions

Q.1: A quantity having continuous values is:

(a) A digital quantity (b) an analog quantity

(c) A binary quantity (d) a natural quantity

Q.2: The term bit means:

(a) A small amount of data (b) 0,1

(c) Binary digit (d) both answer (b) and (c)

Q.3: Decimal equivalent of (1101) is.

(a) 23 (b) 16 (c) 13 (d) 17

Q.4: The binary numbers (11011101) is equal to the decimal number:

(a) 121 (b) 221 (c) 441 (d) 256

Q.5: The decimal number 17 is equal to the binary number:

(a) 10010 (b) 11000 (c) 10001 (d) 01001

Q.6: The binary equivalent for $(A7)_{16}$ is:

(a) 10101001 (b) 10100111 (c) 11000011 (d) 11001100

Q.7: The hexadecimal equivalent the value is (10110010) is_______

(a) A2 (b) B2 (c) C2 (d) 2C

Q.8: Which of the following is a decimal no:

(a) 24 (b) C5 (c) 1010 (d) AB2

Q.9: Binary equivalent for the decimal no 373 is:

(a) 110000111000 (b) 001111110011

(c) 101001 (d) 101110101

Q.10: Binary equivalent of (47) is

(a) 100011 (b) 01101110 (c) 100111 (d) 100001

Q.11: In a binary number system the left most bit is called:

(a) LSB (b) MSB (c) Nibble (d) Byte

Q.12: A decimal number 15 may be represented by ________ binary bits:

(a) 3 (b) 4 (c) 5 (d) 6

Q.13: Digital circuit normally operates on ________

(a) Octal (b) Hexadecimal (c) Binary (d) Decimal

Q.14: A BCD No consists of _______ bits:

(a) 2 (b) 4 (c) 6 (d) 8

Q.15: The base of hexadecimal number system is_________

(a) 8 (b) 10 c) 16 (d) None

Q.16: Combination of 04 bits is called:

(a) Bit (b) Byte (c) Nibble (d) None

ANSWER KEY

Q.1 (b)	Q.2 (d)	Q.3 (c)	Q.4 (b)
Q.5 (c)	Q.6 (b)	Q.7(c)	Q.8 (a)
Q.9 (d)	Q.10(c)	Q.11 (b)	Q.12 (b)
Q.13(c)	Q.14 (b)	Q.15 (c)	Q.16 (c)

Short Questions

1. Define radix.
2. What is a decimal number system?
3. Define a binary number system?
4. What is meant by MSD & LSD?
5. Convert the binary numbers 11001101 to decimal numbers?
6. Convert the binary numbers 1101101 to decimal numbers?
7. Convert the decimal numbers 97_{10} to binary numbers $(\_\_\_\_\_\_)_2$?
8. Convert the hexadecimal numbers $CA5_{16}$ to binary numbers $(\_\_\_\_\_)_2$?
9. Convert the decimal numbers 656_{10} to hexadecimal numbers $(\_\_\_\_)_{16}$?
10. Convert the hexadecimal numbers $(17)_{16}$ to decimal numbers $(\_\_\_\_)_{10}$?

Long Questions

1. Write numbers from 1 to 30 in the following number systems:
   (i) Binary (ii) Hexadecimal
2. Convert the following binary numbers into their equivalent decimal numbers:
   (i) 1010111 (ii) 1110101 (iii) 100010011 (iv) 110010001
3. Convert the following decimal numbers into their equivalent binary numbers:
   (i) 336 (ii) 679 (iii) 5797 (iv) 4391
4. Covert the following binary numbers into their hexadecimal and decimal equivalent:
   (i) 1011101 (ii) 10101011101 (iii) 1001010111 (iv) 10111101
5. Convert the following hexadecimal number to binary.
   (i) 2BAFC (ii) 67DEF (iii) 2567C (iv) 2AB76

CHAPTER 11 LOGIC GATES

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OBJECTIVES
After completion of this chapter students will be able to:

1. **Logic Gates.**
2. **Symbols, Circuits and functions of OR, AND, NOT, NAND, NOR Gates.**
3. **Truth Table and Boolean expression of each above mentioned Gates.**
4. **Creating Multiple Input Gates.**
5. **Duality of Logic Functions.**
6. **Using NOR Gates to emulate all Logic Functions.**
7. **Using NAND Gates to emulate all Logic Functions.**
8. **The Exclusive OR and Exclusive NOR Functions.**
9. **Symbols, Circuits and functions of XOR, XNOR Gates.**
10. **Truth Table and Boolean expression of both above mentioned Gates.**

11.1 LOGIC GATES

Logic gates are used in many electronic devices, from computers to communication systems. These devices perform operations by passing data through logic gates which operate as electronic switches and react in one of the two ways of the binary code (0 or 1) to the data put into them.

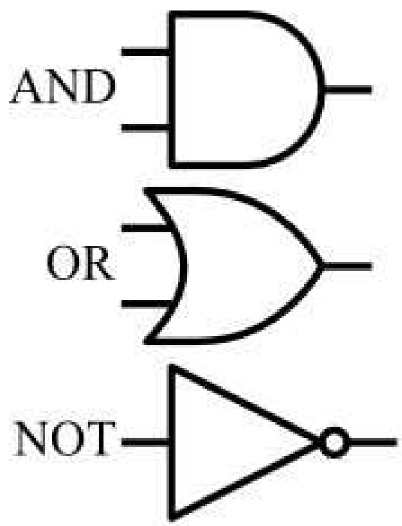
A logic gate is an elementary building block of a digital circuit. Most logic gates have two inputs and one output. The input and the output signals of a gate can be in one of the two binary conditions: low (0 or "off") or high (1 or "on"). The value of the output depends on the values of its inputs.

Logic gates allow an electronic system to make a decision based on a number on its inputs. They are digital electronic devices.

Logic gates use the principles of a mathematical system known as Boolean algebra. As well as a standard Boolean expression, the input and output information of any logic gate or circuit can be schemed into a standard table to give a visual representation of the switching function of the system.

The table used to represent the Boolean expression of a logic gate function is commonly called a Truth Table. A logic gate truth table shows each possible input combination to the gate or circuit with the resultant output depending upon the combination of these input(s). There are three basic logic gates: **AND**, **OR**, **NOT**.

The simplest possible gate is called an "***inverter***" or a **NOT gate**. It has just one input and the output is its opposite: if the input is high (1), the output is low (0) and vice versa. This could be represented by a simple lighting circuit with a push-to-break switch: if the switch is pressed then the lamp will turn off.

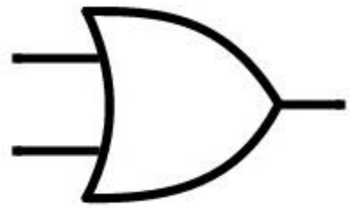


LOGIC LEVEL

In binary logic the two levels are **logical high** and **logical low**, which generally correspond to binary numbers 1 and 0 respectively. Signals with one of these two levels can be used in Boolean algebra for digital circuit design or analysis.

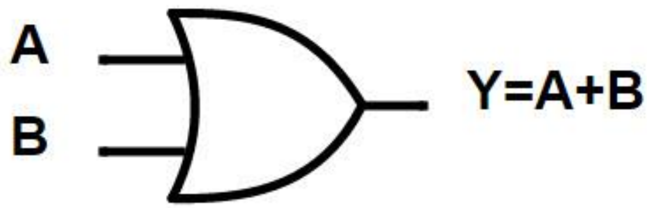
11.1.1 DRAW SYMBOLS OF OR GATE.

The symbols below can be used to represent an OR gate.



Symbols of OR Gate

11.1.2 DRAW CIRCUIT OF TWO INPUT OR GATE

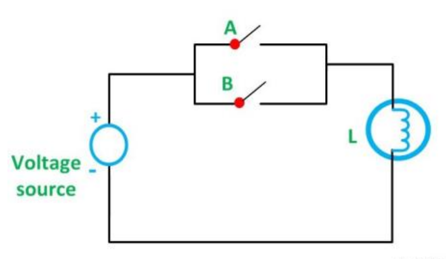


Circuit of Two Input Or Gate

11.1.3 DISCUSS FUNCTION OF OR GATE

An **OR gate** will give a high output if any of the inputs is high. An **OR gate** has two or more than two inputs and one output signal. It is called an OR gate because the output signal will be high only if any or all input signals are high.

The OR gate follows the logical operation of the input and output signals. It permits the signal to pass and stop through it. For Example:



A lamp L is connected to a voltage source. A and B are the two switches. The switching circuit illustrates that the lamp L will glow when either of the switches A or B or both A and B is closed. The lamp will go off when both the switches are in the open condition.

The output of an OR gate is HIGH only when all of its inputs are in the HIGH state. In all other cases, the output is LOW. For OR gate, **Y = A + B**

11.1.4 DESCRIBE TRUTH TABLE OF OR GATE

The Relationship between the inputs and the output can be captured in a truth table. A and B represent the inputs and Q is the output.

A	B	Q (Output)
0	0	0
0	1	1
1	0	1
1	1	1

Truth Table of OR gate

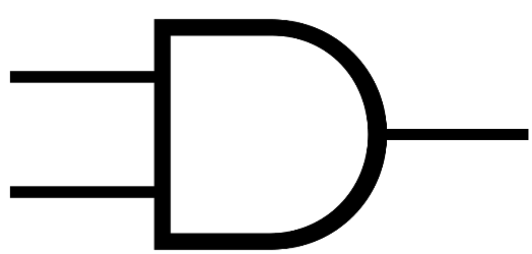
11.1.5 DESCRIBE BOOLEAN EXPRESSION FOR OR GATE

A 2-input OR gate, the output Q is true if EITHER input A “OR” input B is true, giving the Boolean Expression of: (Q = A or B).

Boolean Expression Q = A+B

11.1.6 REPEAT INSTRUCTIONAL OBJECTIVES NO. 11.1.1 TO 11.1.5 FOR AND GATE.

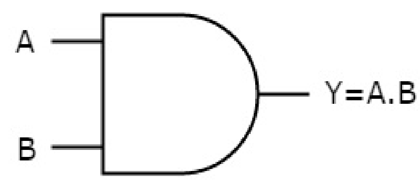
11.1.6.1 DRAW SYMBOLS OF AND GATE.



Symbols of AND gate.

11.1.6.2 DRAW CIRCUIT OF TWO INPUT AND GATE

The following figure shows the **symbol** of an AND gate, which is having two inputs A, B and one output, Y.



Two input AND gate

11.1.6.3 DISCUSS FUNCTION OF AND GATE

An AND gate is a digital circuit that has two or more inputs and produces an output, which is the logical AND of all those inputs. This AND gate produces an output Y, which is the logical AND of two inputs A, B.

Similarly, if there are 'n' inputs, then the AND gate produces an output, which is the logical AND of all those inputs. That means, the output of AND gate will be '1', when all the inputs are '1'.

11.1.6.4 DESCRIBE TRUTH TABLE OF AND GATE

A	B	Y (Output)
0	0	0
0	1	0
1	0	0
1	1	1

Truth Table of AND gate

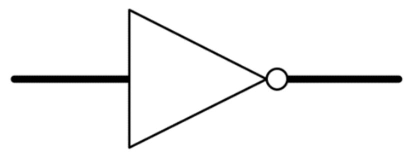
11.1.6.5 DESCRIBE BOOLEAN EXPRESSION FOR AND GATE

The AND gate with inputs A and B and output C implements the logical expression Y=A . B

Boolean Expression (A . B)

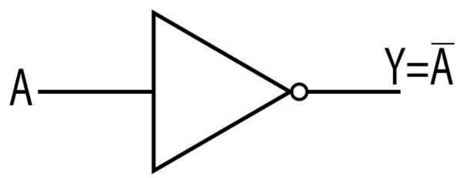
11.1.7 REPEAT INSTRUCTIONAL OBJECTIVES NO. 11.1.1 TO 11.1.5 FOR NOT CIRCUIT.

11.1.7.1 DRAW SYMBOLS OF NOT GATE.



Symbols of NOT Gate.

11.1.7.2 DRAW CIRCUIT OF INPUT NOT GATE



Circuit of Input Not Gate

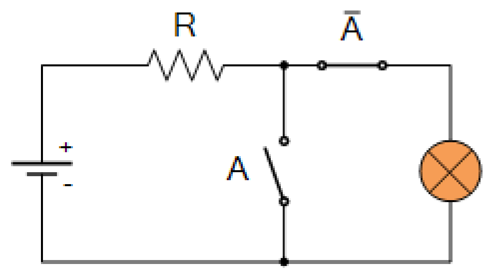
11.1.7.3 DISCUSS FUNCTION OF NOT GATE

The **Logic NOT Function** is simply a single input inverter that changes the input of a logic level "1" to an output of logic level "0" and vice versa.

The "logic NOT function" is so called because its output state is NOT the same as its input state with its Boolean Expression generally denoted by a bar or over line (‾) over its input symbol which denotes the inversion operation, (hence its name as an inverter).

As NOT gates perform the logic invert or complementation function they are more commonly known as Inverters because they invert the signal. In logic circuits this negation can be represented by a normally closed switch.

Switch Representation of the NOT Function



Switch A - Open = "0", Lamp - ON = "1"
Switch A - Closed = "1", Lamp - OFF = "0"

If A means that the switch is closed, then NOT A or simply A says that the switch is NOT closed or in other words, it is open. The logic NOT function has a single input and a single output as shown.

11.1.7.4 DESCRIBE TRUTH TABLE OF NOT GATE

A	Y (Output)
0	1
1	0

Truth Table of Not Gate

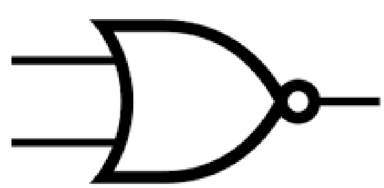
11.1.7.5 DESCRIBE BOOLEAN EXPRESSION FOR NOT GATE

For a single input **NOT gate**, the output Q is ONLY true when the input is "**NOT**" true, the output is the inverse or complement of the input giving the **Boolean Expression** of: (Y = **NOT** A).

Boolean Expression $Y = \overline{A}$

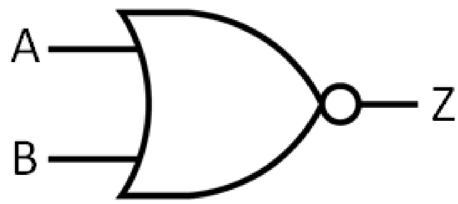
11.1.8 REPEAT INSTRUCTIONAL OBJECTIVES NO. 11.1.1 TO 11.1.5 FOR NOR GATE.

11.1.8.1 DRAW SYMBOLS OF NOR GATE.



Symbols of NOR Gate.

11.1.8.2 DRAW CIRCUIT OF TWO INPUT NOR GATE

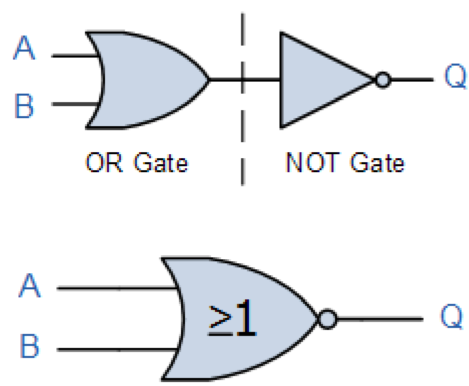


Circuit of Input NOR Gate

11.1.8.3 DISCUSS FUNCTION OF NOR GATE

The Logic NOR Function output is only true when all of its inputs are false, otherwise the output is always false. The NOR or "Not OR" gate is also a combination of two separate logic functions, Not and OR connected together to form a single logic function which is the same as the OR function except that the output is inverted.

To create a NOR gate, the OR function and the NOT function are connected together in series with its operation given by the Boolean expression as, A + B



2-input NOR Gate

The **Logic NOR Function** only produces and output when "ALL" of its inputs are not present and in Boolean algebra terms the output will be TRUE only when all of its inputs are FALSE.

11.1.8.4 DESCRIBE TRUTH TABLE OF NOR GATE

A	B	Z (Output)
0	0	1
0	1	0
1	0	0
1	1	0

Truth Table of NOR Gate

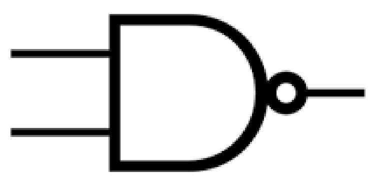
11.1.8.5 DESCRIBE BOOLEAN EXPRESSION FOR NOR GATE.

The logic or Boolean expression given for a logic NOR gate is that for *Logical Multiplication* which it performs on the *complements* of the inputs. The Boolean expression for a logic NOR gate is denoted by a plus sign, (+) with a line or *Over line*, (‾) over the expression to signify the NOT or logical negation of the NOR gate giving us the Boolean expression of: $\overline{A+B} = Q$.

Boolean Expression $Q = \overline{A+B}$

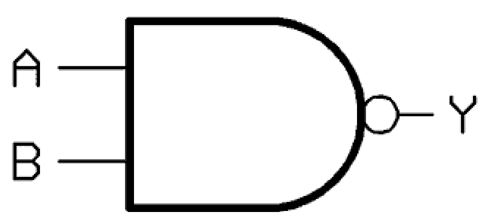
11.1.9 REPEAT INSTRUCTIONAL OBJECTIVES NO. 11.1.1 TO 11.1.5 FOR NAND GATE

11.1.9.1 DRAW SYMBOLS OF NAND GATE.



Symbols of NAND Gate

11.1.9.2 DRAW CIRCUIT OF TWO INPUT NAND GATE

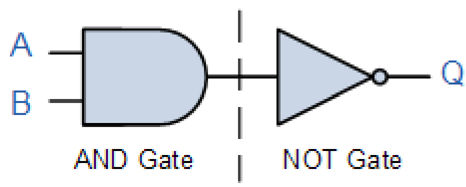


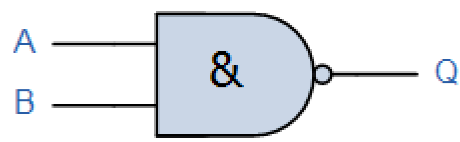
Circuit of Two Input NAND Gate

11.1.9.3 DISCUSS FUNCTION OF NAND GATE

The Logic NAND Gate is a combination of a digital logic AND gate and a NOT gate connected together in series. The Logic NAND Function output is only false when all of its inputs are true, otherwise the output is always true.

The NAND or "Not AND" function is a combination of the two separate logical functions, the AND function and the NOT function in series. The logic NAND function can be expressed by the Boolean expression of, $\overline{A . B}$





2-input NAND Gate

The **Logic NAND Function** will not produce an output when "ALL" of its inputs are present and in Boolean algebra terms the output will be FALSE only when all of its inputs are TRUE.

11.1.9.4 DESCRIBE TRUTH TABLE OF NAND GATE

A	B	Y (Output)
0	0	0
0	1	1
1	0	1
1	1	1

Truth Table of NAND Gate

11.1.9.5 DESCRIBE BOOLEAN EXPRESSION FOR NOR GATE.

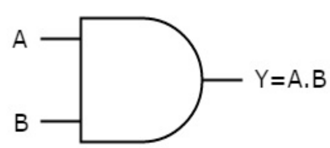
The logic or Boolean expression given for a logic NAND gate is that for *Logical Addition*, which is the opposite to the AND gate, and which it performs on the *complements* of the inputs. The Boolean expression for a logic NAND gate is denoted by a single dot or full stop symbol, (.) with a line or *Over line*, (‾) over the expression to signify the NOT or logical negation of the NAND gate giving us the Boolean expression of: A.B = Y.

Boolean Expression Y = $\overline{A.B}$

11.1.10 CREATE MULTIPLE INPUT GATES.

Two Input AND Gate

Here is an example of a two input gate as we have already seen. It is an AND gate and the truth table for this gate can be seen to the right of it.



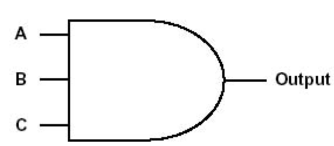
Two Input AND Gate

A	B	Y (Output)
0	0	0
0	1	0
1	0	0
1	1	1

Two Input AND Gate Truth Table

Three Input AND Gate

Here is an example of a three input AND gate. Notice that the truth table for the three input gate is similar to the truth table for the two input gate. It works on the same principle, this time all three inputs need to be high (1) to get a high output.



Three Input AND Gate

A	B	C	A.B.C Output
0	0	0	0
0	0	1	0
0	1	0	0
0	1	1	0
1	0	0	0
1	0	1	0
1	1	0	0
1	1	1	1

Three Input AND Gate Truth Table

Four Input AND Gate

Here is an example of a four input AND gate. It also works on the same principle, all four inputs need to be high (1) to get a high output. The same principles apply to 5, 6... N input gates.

Four Input AND Gate

A	B	C	D	A.B.C.D Output
0	0	0	0	0
0	0	0	1	0
0	0	1	0	0
0	0	1	1	0
0	1	0	0	0
0	1	0	1	0
0	1	1	0	0
0	1	1	1	0
1	0	0	0	0
1	0	0	1	0
1	0	1	0	0
1	0	1	1	0
1	1	0	0	0
1	1	0	1	0
1	1	1	0	0

1	1	1	1	1

Four Input AND Gate Truth Table

Problem No.1 (Self-Test Problem): To Make Multiple Input Gates.

- Five Input AND Gate
- Six Input AND Gate

Problem No.2 (Self-Test Problem): To Make Multiple Input Gates.

- 3- Input OR Gate
- 4- Input OR Gate
- 5- Input OR Gate
- 6- Input OR Gate

Problem No.3 (Self-Test Problem): To Make Multiple Input Gates.

- 3- Input NAND Gate
- 4- Input NAND Gate
- 5- Input NAND Gate
- 6- Input NAND Gate

11.2 DESCRIBE DUALITY OF LOGIC FUNCTIONS.

Universal Gates:

A universal gate is a gate which can implement any Boolean function without need to use any other gate type.

The NAND and NOR gates are universal gates.

In practice, this is advantageous since NAND and NOR gates are economical and easier to fabricate and are the basic gates used in all IC digital logic families.

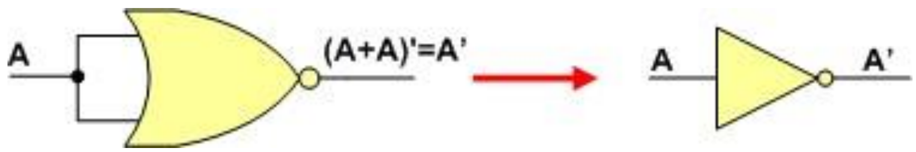
In fact, an AND gate is typically implemented as a NAND gate followed by an inverter not the other way around. Likewise, an OR gate is typically implemented as a NOR gate.

11.2.1 USE NOR GATES TO EMULATE ALL LOGIC FUNCTIONS.

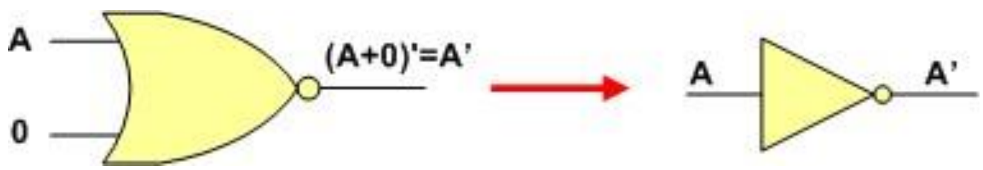
Implementing an Inverter Using only NOR Gate

The figure shows two ways in which a NOR gate can be used as an inverter (NOT gate).

1. All NOR input pins connect to the input signal A gives an output A'.

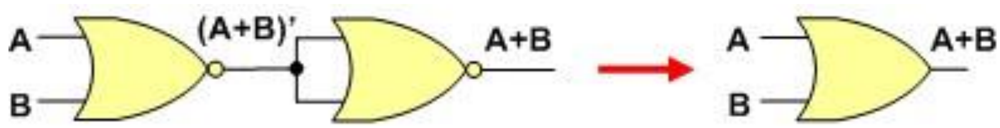


2. One NOR input pin is connected to the input signal A while all other input pins are connected to logic 0. The output will be A'.



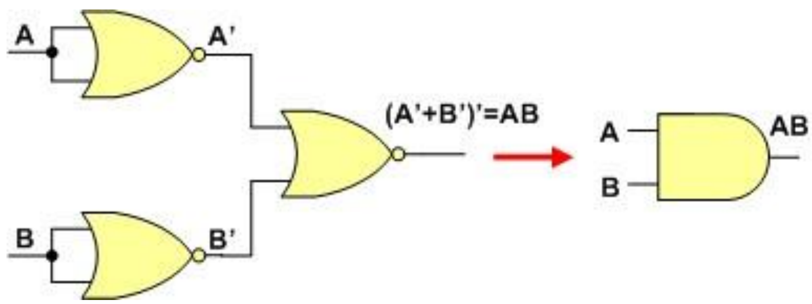
Implementing OR Using only NOR Gates

An OR gate can be replaced by NOR gates as shown in the figure (The OR is replaced by a NOR gate with its output complemented by a NOR gate inverter)



Implementing AND Using only NOR Gates

An AND gate can be replaced by NOR gates as shown in the figure (The AND gate is replaced by a NOR gate with all its inputs complemented by NOR gate inverters)



Thus, the NOR gate is a universal gate since it can implement the AND, OR and NOT functions.

11.2.2 USE NAND GATES TO EMULATE ALL LOGIC FUNCTIONS.

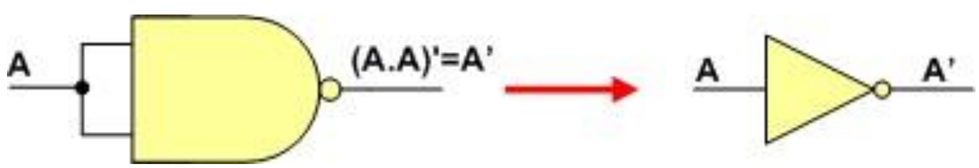
NAND Gate is a Universal Gate:

To prove that any Boolean function can be implemented using only NAND gates, we will show that the AND, OR, and NOT operations can be performed using only these gates.

Implementing an Inverter Using only NAND Gate

The figure shows two ways in which a NAND gate can be used as **an inverter (NOT gate)**.

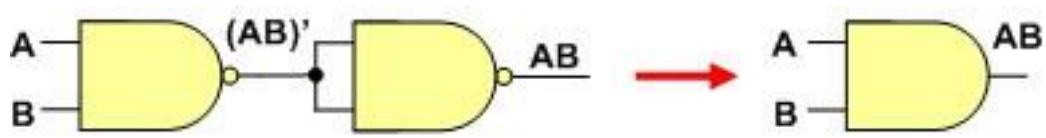
1. All NAND input pins connect to the input signal **A** gives an output **A**'.



2. One NAND input pin is connected to the input signal **A** while all other input pins are connected to logic **1**. The output will be **A'**.

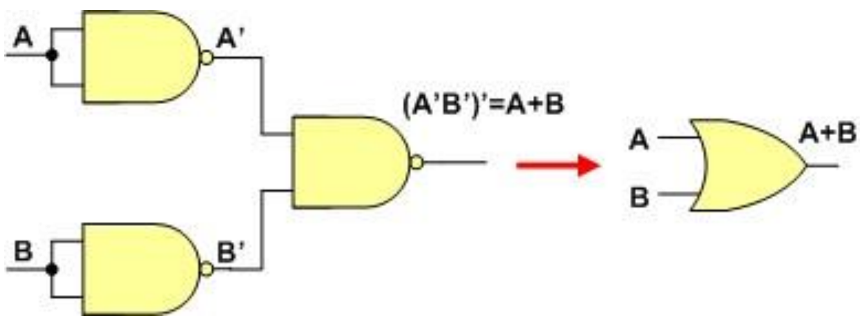
Implementing AND Using only NAND Gates

An AND gate can be replaced by NAND gates as shown in the figure (The AND is replaced by a NAND gate with its output complemented by a NAND gate inverter).



Implementing OR Using only NAND Gates

An OR gate can be replaced by NAND gates as shown in the figure (The OR gate is replaced by a NAND gate with all its inputs complemented by NAND gate inverters).

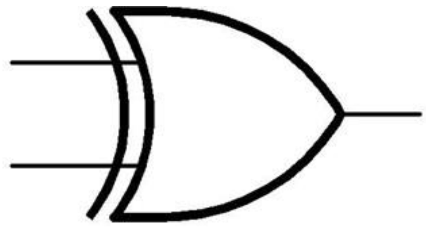


Thus, the NAND gate is a universal gate since it can implement the AND, OR and NOT functions.

11.3 UNDERSTAND EXCLUSIVE OR AND EXCLUSIVE NOR FUNCTIONS.

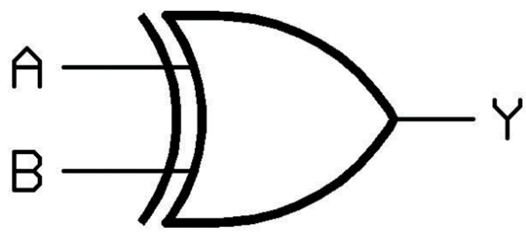
The Exclusive-NOR Gate function is a digital logic gate that is the reverse or complementary form of the Exclusive-OR function

11.3.1 DRAW SYMBOLS OF XOR GATE.



Symbols of XOR Gate

11.3.2 DRAW CIRCUIT OF TWO INPUT XOR GATE



Circuit of Two Input XOR Gate

The logic symbols ⊕, can be used to denote an XOR operation in algebraic expressions.

11.3.3 DISCUSS FUNCTION OF XOR GATE.

XOR gate is a digital logic gate that gives a true output when the number of true inputs is odd. An XOR gate implements an exclusive or; that is, a true output results if one, and only one, of the inputs to the gate is true. If both inputs are false and both are true, a false output results.

The XOR gate has many applications in electronic circuits. It is used in simple digital addition circuits which calculate the sum and carry of two (half-adder) or three (full-adder) bit numbers. XOR gates are also used to determine the parity of a binary number, i.e., if the total number of 1's in the number is odd or even. The output of the XOR function, which is 1 if the number of 1's is odd and 0 if the number of 1's is even, is referred to as a 'parity' bit.

11.3.4 DESCRIBE TRUTH TABLE OF XOR GATE

A	B	Y (Output)
0	0	0
0	1	1
1	0	1
1	1	0

Truth Table of XOR Gate

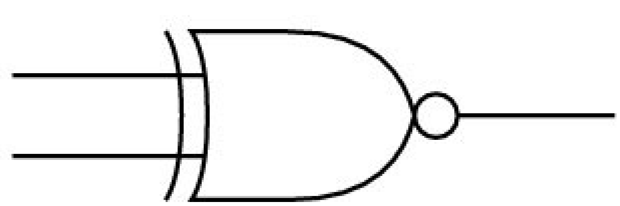
11.3.5 DESCRIBE BOOLEAN EXPRESSION FOR XOR GATE.

This ability of the Exclusive-OR gate to compare two logic levels and produce an output value dependent upon the input condition is very useful in computational logic circuits as it gives us the following Boolean expression is:

BOOLEAN EXPRESSION $Y = (A \oplus B)$

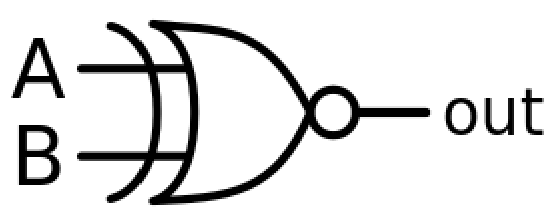
11.3.6 REPEAT INSTRUCTIONAL OBJECTIVES NO. 11.1.1 TO 11.1.5 FOR XNOR GATE.

11.3.6.1. DRAW SYMBOLS OF XNOR GATE.



Symbols of XNOR Gate.

11.3.6.2 DRAW CIRCUIT OF TWO INPUT XNOR GATE



Circuit of Two Input XNOR Gate

11.3.6.3 DISCUSS FUNCTION OF XNOR GATE.

The logic function implemented by a 2-input Ex-NOR gate is given as "when both A AND B are the SAME" will give an output at Q. In general, an Exclusive-NOR gate will give an output value of logic "1" ONLY when there are an EVEN number of 1's on the inputs to the gate (the inverse of the Ex-OR gate) except when all its inputs are "LOW".

11.3.6.4 DESCRIBE TRUTH TABLE OF XNOR GATE

A	B	OUT (Output)
0	0	1
0	1	0
1	0	0
1	1	1

Truth Table of XNOR Gate

11.3.5 DESCRIBE BOOLEAN EXPRESSION FOR XNOR GATE.

The logical XNOR operation is represented by $\odot$. That is a dot surrounded by a circle. The expression of XNOR operation between variables A and B is represented as $\overline{A \odot B}$.

Boolean Expression Q = $\overline{A \oplus B}$

Multiple Choice Questions

Q.1: Logic gates are ___________ circuits.

(a) Sequential (b) Combinational

(c) Arithmetic (d) None

Q.2: ___________ are the basic building block of digital systems.

(a) Logic is Gates (b) Flip flops

(c) ADCs (d) None

Q.3: Voltages to represent a 0 or 1 are called as ____________

(a) Logic Gates (b) Logic Operation

(c) Logic Levels (c) None

Q.4: For an inverter if input is low, output is ___________

(a)Low (b) High

(c) High Impedance (d) None

Q.5: An inverter gate perform the function which is ____________

(a) Inversion (b) Insertion

(c) Complementation (c) a & c

Q.6: A gate which results a high output for one high input is:

(a) OR Gate (b) NOT Gate

(c) AND (d) NOR

Q.7: A table which represents all the possible inputs & outputs for a logic gate is called______________

(a) Truth Table (b) Logic Table

(c) Boolean Table (d) None

Q.8: The Boolean equation of AND Gate is _____________

(a) A + B = C (b) A.B = C

(c) A $\oplus$ B = C (d) A $\oplus$ B = C

Q.9: Which of the following gate is also called as Inverter.

(a) OR (b) XOR

(c) NOT (d) XNOR

Q.10: The output of AND gate is 1 when _________

(a) Both inputs zero (b) Both inputs high

(c) Both inputs different (d) none

Q.11: A simple NOT gate can be implemented using.

(a) Diode (b) BJT

(c) FET (d) None

Q.12: The Boolean expression for XNOR gate is _______________

(a) A + B = C (b) A $\oplus$ B = C

(b) A,B = C (d) A $\odot$ B = C

Q.13: If the two inputs of a gate are low and output is high then it is _______.

(a) OR (b) NOR

(c) AND (d) NOT

Q.14: Which of the following are used as universal gate?

(a) NAND (b) OR

(c) XOR (d) XNOR

Q.15: A universal logic gate is one which can be used to generate any logic function. Which of the following is a universal logic gate?

(a) OR (b)AND
(c)XOR (d) NAND

Q.16: A logic gate having output high when inputs are different.

(a) XNOR (b) XOR

(c) AND (d) NAND

Q.17: Logical multiplication is performed by:

(a) OR (b) AND

(c) NAND (d) NOT

Q.18: A logic gate whose output is high when both inputs are similar is _____.

(a) XOR (b) XNOR

(c) NOR (d) NAND

Q.20: All logic operations can be obtained by means of __________

(a)AND and NAND operations (b) OR and NOR operations
(c) OR and NOT operations (d) NAND and NOR operations

Q.20: In a combinational circuit, the output at any time depends only

On the ______ at that time.

(a) Voltage (b) Intermediate values
(c) Input values (d) Clock pulses

ANSWER KEY

Q.1 (b)	Q.2 (a)	Q.3 (c)	Q.4 (b)	Q.5 (a)
Q.6 (a)	Q.7 (a)	Q.8 (b)	Q.9 (c)	Q.10 (b)
Q.11 (c)	Q.12 (b)	Q.13 (b)	Q.14 (a)	Q.15 (d)
Q.16 (b)	Q.1 7(b)	Q.18 (b)	Q.19 (d)	Q.20 (c)

Short Questions

1. What is Logic gates?
2. Enlist few logic gates?
3. What is a logic level?
4. Draw 2- Input AND Gate?
5. Draw the truth table of OR gate?
6. Draw the symbol & Boolean expression of AND gate?
7. What is an inverter?
8. What are the universal gates?
9. What is an exclusive OR gate?
10. Implement an OR gate using NOR gate?
11. Implement NOR gate using NAND gate?
12. Describe Boolean expression for XOR gate?
13. Describe truth table of XOR gate?

Long Questions

1. Explain OR Gate along with symbol, Circuit of two input gates, truth table, and Boolean expression?
2. Using NAND gates to emulate all logic gates.
3. Using NOR gates to emulate all logic gates.
4. Exclusive NOR along with symbol, Circuit of two input gates, truth table, and Boolean expression?
5. Draw 5- Input NOR Gate along with symbol, Circuit of two input gates, truth table, and Boolean expression?